

Power IC's Databook

- Linear Voltage Regulators
- Low Dropout Voltage Regulators
- Switching Voltage Regulators
- Motion Control
- Peripheral Drivers
- High Current Switches



POWER IC's DATABOOK

1993 Edition

Linear Voltage Regulators

Low Dropout Voltage Regulators

Switching Voltage Regulators

Motion Control

Peripheral Drivers

High Current Switches

Surface Mount

Appendices/Physical Dimensions

1

2

3

4

5

6

7

8

TRADEMARKS

Following is the most current list of National Semiconductor Corporation's trademarks and registered trademarks.

ABiCTM	FACT TM	MICROWIRE/PLUS TM	SERIES/800 TM
Abuseable TM	FACT Quiet Series TM	MOLET TM	Series 32000 [®]
Anadig TM	FAIRCAD TM	MPAT TM	Simple Switcher TM
APPST TM	Fairtech TM	MST TM	SofChek TM
ASPECT TM	FAST [®]	Naked-8 TM	SONIC TM
Auto-Chem Deflasher TM	FAST TM	National [®]	SPIRE TM
BCPT TM	Flash TM	National Semiconductor [®]	Staggered Refresh TM
BI-FET TM	GENIX TM	National Semiconductor Corp. [®]	STAR TM
BI-FET II TM	GNX TM	NAX 800 TM	Starlink TM
BI-LINE TM	GTO TM	Nitride Plus TM	STARPLEX TM
BIPLAN TM	HEX 3000 TM	Nitride Plus Oxide TM	ST-NICT TM
BLCT TM	HPC TM	NML TM	SuperATT TM
BLX TM	HyBal TM	NOBUST TM	Super-Block TM
BMAC TM	βL [®]	NSC800 TM	SuperChip TM
Brite-Lite TM	ICM TM	NSCISE TM	SuperScript TM
BSI TM	Integral ISET TM	NSX-16 TM	SYS32 TM
BSI-2 TM	Intelisplay TM	NS-XC-16 TM	TapePak [®]
CDD TM	Inter-LERIC TM	NTERCOM TM	TDS TM
CIM TM	Inter-RIC TM	NURAM TM	TeleGate TM
CIMBUST TM	ISE TM	OPAL TM	The National Anthem [®]
CLASICT TM	ISE/06 TM	OXISST TM	TLCT TM
COMBO [®]	ISE/08 TM	P ² CMOST TM	Trapezoidal TM
COMBO I TM	ISE/16 TM	Perfect Watch TM	TRI-CODE TM
COMBO II TM	ISE32 TM	PLAN TM	TRI-POLY TM
COPST TM microcontrollers	ISOPLANAR TM	PLANART TM	TRI-SAFET TM
CRD TM	ISOPLANAR-Z TM	PLAYERT TM	TRI-STATE [®]
DA4 TM	LERICT TM	Plus-2 TM	TROPIC TM
DENSPA TM	L ² CMOST TM	Polycraft TM	Tropic Pele TM
DIB TM	M ² CMOST TM	Power + Control TM	Tropic Reef TM
DISCERN TM	Macrobus TM	POWERplanar TM	TURBOTRANSCEIVER TM
DISTILL TM	Macrocomponent TM	QST TM	VIPT TM
DNR [®]	MAPL TM	QUAD3000 TM	VR32 TM
DPVM TM	MAXI-ROM [®]	QUIKLOOK TM	WATCHDOG TM
E ² CMOST TM	Microbus TM data bus	RAT TM	XMOST TM
ELSTAR TM	MICRO-DAC TM	RICT TM	XPU TM
Embedded System Processor TM	μtalker TM	RTX16 TM	Z START TM
EPT TM	Microtalker TM	SCX TM	883B/RETST TM
E-Z-LINK TM	MICROWIRE TM		883S/RETST TM

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

National Semiconductor Corporation 2900 Semiconductor Drive, P.O. Box 58090, Santa Clara, California 95052-8090 1-800-272-9959 TWX (910) 339-9240

National does not assume any responsibility for use of any circuitry described, no circuit patent licenses are implied, and National reserves the right, at any time without notice, to change said circuitry or specifications.



Product Status Definitions

Definition of Terms

Data Sheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This data sheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This data sheet contains preliminary data, and supplementary data will be published at a later date. National Semiconductor Corporation reserves the right to make changes at any time without notice in order to improve design and supply the best possible product.
No Identification Noted	Full Production	This data sheet contains final specifications. National Semiconductor Corporation reserves the right to make changes at any time without notice in order to improve design and supply the best possible product.
Obsolete	Not In Production	This data sheet contains specifications on a product that has been discontinued by National Semiconductor Corporation. The data sheet is printed for reference information only.

National Semiconductor Corporation reserves the right to make changes without further notice to any products herein to improve reliability, function or design. National does not assume any liability arising out of the application or use of any product or circuit described herein; neither does it convey any license under its patent rights, nor the rights of others.

Table of Contents

Alphanumeric Index	vii
Additional Available Linear Devices	x
Cross Reference by Part Number	xxiv
Industry Package Cross Reference Guide	xxxvi
Section 1 Linear Voltage Regulators	
Linear Voltage Regulators Definition of Terms	1-3
Linear Voltage Regulators Selection Guide	1-4
* LH0075 Positive Precision Programmable Regulator	
* LH0076 Negative Precision Programmable Regulator	
* LH7001 Positive/Negative Adjustable Regulator	
LM104/LM204/LM304 Negative Regulators	1-8
LM105/LM205/LM305/LM305A/LM376 Voltage Regulators	1-12
LM109/LM309 5-Volt Regulators	1-19
LM117/LM117A/LM317/LM317A 3-Terminal Adjustable Regulators	1-25
LM117HV/LM317HV 3-Terminal Adjustable Regulators	1-37
LM120/LM320 Series 3-Terminal Negative Regulators	1-47
LM123A/LM123/LM323A/LM323 3-Amp, 5-Volt Positive Regulators	1-56
LM125/LM325/LM325A, LM126/LM326 Voltage Regulators	1-62
LM133/LM333 3-Amp Adjustable Negative Voltage Regulators	1-70
LM137/LM337 3-Terminal Adjustable Negative Regulators	1-77
LM137HV/LM337HV 3-Terminal Adjustable Negative Regulators (High Voltage)	1-83
LM138/LM338 5-Amp Adjustable Regulators	1-89
LM140A/LM140/LM340A/LM340/LM7800/LM7800C Series 3-Terminal Positive Regulators	1-101
LM140L/LM340L Series 3-Terminal Positive Regulators	1-112
LM145/LM345 Negative 3-Amp Regulators	1-116
LM150/LM350/LM350A 3-Amp Adjustable Power Regulators	1-120
LM196/LM396 10-Amp Adjustable Voltage Regulators	1-132
LM317L 3-Terminal Adjustable Regulator	1-144
LM320L, LM79LXXAC Series 3-Terminal Negative Regulators	1-155
LM337L 3-Terminal Adjustable Regulator	1-159
LM341/LM78MXX Series 3-Terminal Positive Regulators	1-161
LM342 Series 3-Terminal Positive Regulator	1-170
LM431A Adjustable Precision Zener Shunt Regulator	1-175
LM723/LM723C Voltage Regulators	1-182
LM78G 4-Terminal Adjustable Regulator	1-191
LM78LXX Series 3-Terminal Positive Regulators	1-197
LM78MG 4-Terminal Adjustable Voltage Regulator	1-207
LM79MXX Terminal Negative Regulators	1-213
LM79XX Series 3-Terminal Negative Regulators	1-220
Section 2 Low Dropout Voltage Regulators	
Low Dropout Voltage Regulators—Definition of Terms	2-3
Low Dropout Regulators—Selection Guide	2-4
LM330 3-Terminal Positive Regulator	2-6
LM2925 Low Dropout Regulator with Delayed Reset	2-10
LM2926/LM2927 Low Dropout Regulators with Delayed Reset	2-16
LM2930 3-Terminal Positive Regulator	2-24
LM2931 Series Low Dropout Regulators	2-29
LM2935 Low Dropout Dual Regulator	2-36
LM2936 Ultra-Low Quiescent Current 5V Regulator	2-44
LM2937 500 mA Low Dropout Regulator	2-49

*See Appendix G

Table of Contents (Continued)

Section 2 Low Dropout Voltage Regulators (Continued)

LM2940/LM2940C 1A Low Dropout Regulators	2-54
LM2941/LM2941C 1A Low Dropout Adjustable Regulators	2-63
LM2984 Microprocessor Power Supply System	2-69
LM2990 Negative Low Dropout Regulator	2-82
LM2991 Negative Low Dropout Adjustable Regulator	2-89
LP2950/LP2950AC/LP2950C 5V and LP2951/LP2951AC/LP2951C Adjustable Micropower Voltage Regulators	2-95
LP2952/LP2952A/LP2953/LP2953A Adjustable Micropower Low-Dropout Voltage Regulators	2-108
LP2954/LP2954A 5V Micropower Low-Dropout Voltage Regulators	2-121

Section 3 Switching Voltage Regulators

Switching Voltage Regulators Definition of Terms	3-3
Switching Voltage Regulators Selection Guide	3-5
HS7067 7-Amp, Multimode, High Efficiency Switching Regulator	3-7
LH1605/LH1605C 5 Amp, High Efficiency Switching Regulators	3-16
LM1524D/LM2524D/LM3524D Regulating Pulse Width Modulators	3-19
LM2574/LM2574HV Series Simple Switcher 0.5A Step-Down Voltage Regulators	3-36
LM1575/LM1575HV/LM2575/LM2575HV Simple Switcher 1A Step-Down Voltage Regulators	3-54
LM2576/LM2576HV Simple Switcher 3A Step-Down Voltage Regulators	3-71
LM1577/LM2577 Simple Switcher Step-Up Voltage Regulators	3-87
LM1578A/LM2578A/LM3578A Switching Regulators	3-109
LM78S40 Universal Switching Regulator Subsystem	3-123
LMC7660 Switched Capacitor Voltage Converter	3-130

Section 4 Motion Control

Motion Control and Motor Drive Selection Guide	4-3
LM12L 80W Operational Amplifier	4-4
LM621 Brushless Motor Commutator	4-17
LM628/LM629 Precision Motion Controllers	4-28
LM18293 Four Channel Push-Pull Driver	4-49
LM18298 Dual Full-Bridge Driver	4-55
LMD18200 3A, 55VH-Bridge	4-61
LMD18201 3A, 55VH-Bridge	4-70

Section 5 Peripheral Drivers

Peripheral Drivers—Introduction	5-3
Peripheral Drivers—Selection Guide	5-4
DP7310/DP8310/DP7311/DP8311 Octal Latched Peripheral Drivers	5-5
DS1631/DS3631/DS1632/DS3632/DS1633/DS3633/DS1634/DS3634 CMOS Dual Peripheral Drivers	5-12
DS2001/DS9665/DS2002/DS9666/DS2003/DS9667/DS2004/DS9668 High Current/Voltage Darlington Drivers	5-17
DS3654 Printer Solenoid Driver	5-22
DS3658 Quad High Current Peripheral Driver	5-26
DS3668 Quad Fault Protected Peripheral Driver	5-29
DS3669 Quad High Current Peripheral Driver	5-32
DS3680 Quad Negative Voltage Relay Driver	5-35
DS55451/2/3/4, DS75450/1/2/3/4 Series Dual Peripheral Drivers	5-38

Section 6 High Current Switches

High Current Switch Selection Guide	6-3
LM1921 1 Amp Industrial Switch	6-4

*See Appendix G

Table of Contents (Continued)

Section 6 High Current Switches (Continued)

LM1950 750 mA High Side Switch	6-9
LM1951 Solid State 1 Amp Switch	6-14
LMD18400 Quad High Side Driver	6-22

Section 7 Surface Mount

Surface Mount	7-3
AN-450 Small Outline (SO) Package Surface Mounting Methods—Parameters and Their Effect on Product Reliability	7-23

Section 8 Appendices/Physical Dimensions

Appendix A General Product Marking and Code Explanation	8-3
Appendix B Device/Application Literature Cross-Reference	8-4
Appendix C Summary of Commercial Reliability Programs	8-11
Appendix D Military Aerospace Programs from National Semiconductor	8-13
Appendix E Understanding Integrated Circuit Package Power Capabilities	8-22
Appendix F How to Get the Right Information from a Datasheet	8-27
Appendix G Obsolete Product Replacement Guide	8-31
Appendix H Safe Operating Areas for Peripheral Drivers	8-33
Physical Dimensions	8-41
Bookshelf	
Distributors	

*See Appendix G

Alpha-Numeric Index

AN-450 Small Outline (SO) Package Surface Mounting Methods—Parameters and Their Effect on Product Reliability	7-23
DP7310 Octal Latched Peripheral Driver	5-5
DP7311 Octal Latched Peripheral Driver	5-5
DP8310 Octal Latched Peripheral Driver	5-5
DP8311 Octal Latched Peripheral Driver	5-5
DS1631 CMOS Dual Peripheral Driver	5-12
DS1632 CMOS Dual Peripheral Driver	5-12
DS1633 CMOS Dual Peripheral Driver	5-12
DS1634 CMOS Dual Peripheral Driver	5-12
DS2001 High Current/Voltage Darlington Driver	5-17
DS2002 High Current/Voltage Darlington Driver	5-17
DS2003 High Current/Voltage Darlington Driver	5-17
DS2004 High Current/Voltage Darlington Driver	5-17
DS3631 CMOS Dual Peripheral Driver	5-12
DS3632 CMOS Dual Peripheral Driver	5-12
DS3633 CMOS Dual Peripheral Driver	5-12
DS3634 CMOS Dual Peripheral Driver	5-12
DS3654 Printer Solenoid Driver	5-22
DS3658 Quad High Current Peripheral Driver	5-26
DS3668 Quad Fault Protected Peripheral Driver	5-29
DS3669 Quad High Current Peripheral Driver	5-32
DS3680 Quad Negative Voltage Relay Driver	5-35
DS9665 High Current/Voltage Darlington Driver	5-17
DS9666 High Current/Voltage Darlington Driver	5-17
DS9667 High Current/Voltage Darlington Driver	5-17
DS9668 High Current/Voltage Darlington Driver	5-17
DS55451 Series Dual Peripheral Drivers	5-38
DS55452 Series Dual Peripheral Drivers	5-38
DS55453 Series Dual Peripheral Drivers	5-38
DS55454 Series Dual Peripheral Drivers	5-38
DS75450 Series Dual Peripheral Drivers	5-38
DS75451 Series Dual Peripheral Drivers	5-38
DS75452 Series Dual Peripheral Drivers	5-38
DS75453 Series Dual Peripheral Drivers	5-38
DS75454 Series Dual Peripheral Drivers	5-38
HS7067 7-Amp, Multimode, High Efficiency Switching Regulator	3-7
* LH0075 Positive Precision Programmable Regulator	
* LH0076 Negative Precision Programmable Regulator	
LH1605 5 Amp, High Efficiency Switching Regulator	3-16
* LH7001 Positive/Negative Adjustable Regulator	
LM12L 80W Operational Amplifier	4-4
LM78G 4-Terminal Adjustable Regulator	1-191
LM78LXX Series 3-Terminal Positive Regulators	1-197
LM78MG 4-Terminal Adjustable Voltage Regulator	1-207
LM78MXX Series 3-Terminal Positive Regulator	1-161
LM78S40 Universal Switching Regulator Subsystem	3-123
LM79LXXAC Series 3-Terminal Negative Regulator	1-155
LM79MXX Terminal Negative Regulators	1-213
LM79XX Series 3-Terminal Negative Regulators	1-220
LM104 Negative Regulator	1-8

*See Appendix G

Alpha-Numeric Index (Continued)

LM105 Voltage Regulator	1-12
LM109 5-Volt Regulator	1-19
LM117 3-Terminal Adjustable Regulator	1-25
LM117HV 3-Terminal Adjustable Regulator	1-37
LM120 Series 3-Terminal Negative Regulator	1-47
LM123 3-Amp, 5-Volt Positive Regulator	1-56
LM125 Voltage Regulator	1-62
LM126 Voltage Regulator	1-62
LM133 3-Amp Adjustable Negative Voltage Regulator	1-70
LM137 3-Terminal Adjustable Negative Regulator	1-77
LM137HV 3-Terminal Adjustable Negative Regulator (High Voltage)	1-83
LM138 5-Amp Adjustable Regulator	1-89
LM140 Series 3-Terminal Positive Regulator	1-101
LM140L Series 3-Terminal Positive Regulator	1-112
LM145 Negative 3-Amp Regulator	1-116
LM150 3-Amp Adjustable Power Regulator	1-120
LM196 10-Amp Adjustable Voltage Regulator	1-132
LM204 Negative Regulator	1-8
LM205 Voltage Regulator	1-12
LM304 Negative Regulator	1-8
LM305 Voltage Regulator	1-12
LM309 5-Volt Regulator	1-19
LM317 3-Terminal Adjustable Regulator	1-25
LM317HV 3-Terminal Adjustable Regulator	1-37
LM317L 3-Terminal Adjustable Regulator	1-144
LM320 Series 3-Terminal Negative Regulator	1-47
LM320L Series 3-Terminal Negative Regulator	1-155
LM323 3-Amp, 5-Volt Positive Regulator	1-56
LM325 Voltage Regulator	1-62
LM326 Voltage Regulator	1-62
LM330 3-Terminal Positive Regulator	2-6
LM333 3-Amp Adjustable Negative Voltage Regulator	1-70
LM337 3-Terminal Adjustable Negative Regulator	1-77
LM337HV 3-Terminal Adjustable Negative Regulator (High Voltage)	1-83
LM337L 3-Terminal Adjustable Regulator	1-159
LM338 5-Amp Adjustable Regulator	1-89
LM340 Series 3-Terminal Positive Regulator	1-101
LM340L Series 3-Terminal Positive Regulator	1-112
LM341 Series 3-Terminal Positive Regulator	1-161
LM342 Series 3-Terminal Positive Regulator	1-170
LM345 Negative 3-Amp Regulator	1-116
LM350 3-Amp Adjustable Power Regulator	1-120
LM376 Voltage Regulator	1-12
LM396 10-Amp Adjustable Voltage Regulator	1-132
LM431A Adjustable Precision Zener Shunt Regulator	1-175
LM621 Brushless Motor Commutator	4-17
LM628 Precision Motion Controller	4-28
LM629 Precision Motion Controller	4-28
LM723 Voltage Regulator	1-182
LM1524D Regulating Pulse Width Modulator	3-19
LM1575 Simple Switcher 1A Step-Down Voltage Regulator	3-54

*See Appendix G

Alpha-Numeric Index (Continued)

LM1575HV Simple Switcher 1A Step-Down Voltage Regulator	3-54
LM1577 Simple Switcher Step-Up Voltage Regulator	3-87
LM1578A Switching Regulator	3-109
LM1921 1 Amp Industrial Switch	6-4
LM1950 750 mA High Side Switch	6-9
LM1951 Solid State 1 Amp Switch	6-14
LM2524D Regulating Pulse Width Modulator	3-19
LM2574 Simple Switcher 0.5A Step-Down Voltage Regulator	3-36
LM2574HV Simple Switcher 0.5A Step-Down Voltage Regulator	3-36
LM2575 Simple Switcher 1A Step-Down Voltage Regulator	3-54
LM2575HV Simple Switcher 1A Step-Down Voltage Regulator	3-54
LM2576 Simple Switcher 3A Step-Down Voltage Regulator	3-71
LM2576HV Simple Switcher 3A Step-Down Voltage Regulator	3-71
LM2577 Simple Switcher Step-Up Voltage Regulator	3-87
LM2578A Switching Regulator	3-109
LM2925 Low Dropout Regulator with Delayed Reset	2-10
LM2926 Low Dropout Regulator with Delayed Reset	2-16
LM2927 Low Dropout Regulator with Delayed Reset	2-16
LM2930 3-Terminal Positive Regulator	2-24
LM2931 Series Low Dropout Regulators	2-29
LM2935 Low Dropout Dual Regulator	2-36
LM2936 Ultra-Low Quiescent Current 5V Regulator	2-44
LM2937 500 mA Low Dropout Regulator	2-49
LM2940/LM2940C 1A Low Dropout Regulators	2-54
LM2941/LM2941C 1A Low Dropout Adjustable Regulators	2-63
LM2984 Microprocessor Power Supply System	2-69
LM2990 Negative Low Dropout Regulator	2-82
LM2991 Negative Low Dropout Adjustable Regulator	2-89
LM3524D Regulating Pulse Width Modulator	3-19
LM3578A Switching Regulator	3-109
LM7800 Series 3-Terminal Positive Regulator	1-101
LM18293 Four Channel Push-Pull Driver	4-49
LM18298 Dual Full-Bridge Driver	4-55
LMC7660 Switched Capacitor Voltage Converter	3-130
LMD18200 3A, 55VH-Bridge	4-61
LMD18201 3A, 55VH-Bridge	4-70
LMD18400 Quad High Side Driver	6-22
LP2950 5V Adjustable Micropower Voltage Regulator	2-95
LP2951 Adjustable Micropower Voltage Regulator	2-95
LP2952 Adjustable Micropower Low-Dropout Voltage Regulator	2-108
LP2953 Adjustable Micropower Low-Dropout Voltage Regulator	2-108
LP2954 5V Micropower Low-Dropout Voltage Regulator	2-121

*See Appendix G

Additional Available Linear Devices

54ACT715 Programmable Video Sync Generator	Section 3	App. Specific
74ACT715 Programmable Video Sync Generator	Section 3	App. Specific
ADC0800 8-Bit A/D Converter	Section 2	Data Acquisition
ADC0801 8-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC0802 8-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC0803 8-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC0804 8-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC0805 8-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC0808 8-Bit μ P Compatible A/D Converter with 8-Channel Multiplexer ..	Section 2	Data Acquisition
ADC0809 8-Bit μ P Compatible A/D Converter with 8-Channel Multiplexer ..	Section 2	Data Acquisition
ADC0811 8-Bit Serial I/O A/D Converter with 11-Channel Multiplexer	Section 2	Data Acquisition
ADC0816 8-Bit μ P Compatible A/D Converter with 16-Channel Multiplexer	Section 2	Data Acquisition
ADC0817 8-Bit μ P Compatible A/D Converter with 16-Channel Multiplexer	Section 2	Data Acquisition
ADC0819 8-Bit Serial I/O A/D Converter with 19-Channel Multiplexer	Section 2	Data Acquisition
ADC0820 8-Bit High Speed μ P Compatible A/D Converter with Track/Hold Function	Section 2	Data Acquisition
ADC0831 8-Bit Serial I/O A/D Converter with Multiplexer Options	Section 2	Data Acquisition
ADC0832 8-Bit Serial I/O A/D Converter with Multiplexer Options	Section 2	Data Acquisition
ADC0833 8-Bit Serial I/O A/D Converter with 4-Channel Multiplexer	Section 2	Data Acquisition
ADC0834 8-Bit Serial I/O A/D Converter with Multiplexer Options	Section 2	Data Acquisition
ADC0838 8-Bit Serial I/O A/D Converter with Multiplexer Options	Section 2	Data Acquisition
ADC0841 8-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC0844 8-Bit μ P Compatible A/D Converter with Multiplexer Options	Section 2	Data Acquisition
ADC0848 8-Bit μ P Compatible A/D Converter with Multiplexer Options	Section 2	Data Acquisition
ADC0851 8-Bit Analog Data Acquisition and Monitoring System	Section 1	Data Acquisition
ADC0852 Multiplexed Comparator with 8-Bit Reference Divider	Section 2	Data Acquisition
ADC0854 Multiplexed Comparator with 8-Bit Reference Divider	Section 2	Data Acquisition
ADC0858 8-Bit Analog Data Acquisition and Monitoring System	Section 1	Data Acquisition
ADC0881 8-Bit 20 MSPS Flash A/D Converter	Section 2	Data Acquisition
ADC0882 8-Bit 20 MSPS Flash A/D Converter	Section 2	Data Acquisition
ADC08031 8-Bit High-Speed Serial I/O A/D Converter with Multiplexer Options, Voltage Reference, and Track/Hold Function	Section 2	Data Acquisition
ADC08032 8-Bit High-Speed Serial I/O A/D Converter with Multiplexer Options, Voltage Reference, and Track/Hold Function	Section 2	Data Acquisition
ADC08034 8-Bit High-Speed Serial I/O A/D Converter with Multiplexer Options, Voltage Reference, and Track/Hold Function	Section 2	Data Acquisition
ADC08038 8-Bit High-Speed Serial I/O A/D Converter with Multiplexer Options, Voltage Reference, and Track/Hold Function	Section 2	Data Acquisition
ADC08061 500 ns A/D Converter with S/H Function and Input Multiplexer ..	Section 2	Data Acquisition
ADC08062 500 ns A/D Converter with S/H Function and Input Multiplexer ..	Section 2	Data Acquisition
ADC08064 500 ns A/D Converter with S/H Function and Input Multiplexer ..	Section 2	Data Acquisition
ADC08068 500 ns A/D Converter with S/H Function and Input Multiplexer ..	Section 2	Data Acquisition
ADC08131 8-Bit High-Speed Serial I/O A/D Converter with Multiplexer Options, Voltage Reference, and Track/Hold Function	Section 2	Data Acquisition
ADC08134 8-Bit High-Speed Serial I/O A/D Converter with Multiplexer Options, Voltage Reference, and Track/Hold Function	Section 2	Data Acquisition
ADC08138 8-Bit High-Speed Serial I/O A/D Converter with Multiplexer Options, Voltage Reference, and Track/Hold Function	Section 2	Data Acquisition

Additional Available Linear Devices (Continued)

ADC08161 500 ns A/D Converter with S/H Function, 2.5V Bandgap Reference, and Input Multiplexer	Section 2	Data Acquisition
ADC08164 500 ns A/D Converter with S/H Function, 2.5V Bandgap Reference, and Input Multiplexer	Section 2	Data Acquisition
ADC08168 500 ns A/D Converter with S/H Function, 2.5V Bandgap Reference, and Input Multiplexer	Section 2	Data Acquisition
ADC08231 8-Bit 2 μ s Serial I/O A/D Converter with MUX, Reference, and Track/Hold	Section 2	Data Acquisition
ADC08234 8-Bit 2 μ s Serial I/O A/D Converter with MUX, Reference, and Track/Hold	Section 2	Data Acquisition
ADC08238 8-Bit 2 μ s Serial I/O A/D Converter with MUX, Reference, and Track/Hold	Section 2	Data Acquisition
ADC1001 10-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC1005 10-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC1021 10-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC1025 10-Bit μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC1031 10-Bit Serial I/O A/D Converter with Analog Multiplexer and Track/Hold Function	Section 2	Data Acquisition
ADC1034 10-Bit Serial I/O A/D Converter with Analog Multiplexer and Track/Hold Function	Section 2	Data Acquisition
ADC1038 10-Bit Serial I/O A/D Converter with Analog Multiplexer and Track/Hold Function	Section 2	Data Acquisition
ADC1061 10-Bit High-Speed μ P-Compatible A/D Converter with Track/Hold Function	Section 2	Data Acquisition
ADC1205 12-Bit Plus Sign μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC1210 12-Bit CMOS A/D Converter	Section 2	Data Acquisition
ADC1211 12-Bit CMOS A/D Converter	Section 2	Data Acquisition
ADC1225 12-Bit Plus Sign μ P Compatible A/D Converter	Section 2	Data Acquisition
ADC1241 Self-Calibrating 12-Bit Plus Sign μ P-Compatible A/D Converter with Sample/Hold	Section 2	Data Acquisition
ADC1251 Self-Calibrating 12-Bit Plus Sign A/D Converter with Sample/Hold	Section 2	Data Acquisition
ADC3511 3 $\frac{1}{2}$ -Digit Microprocessor Compatible A/D Converter	Section 2	Data Acquisition
ADC3711 3 $\frac{3}{4}$ -Digit Microprocessor Compatible A/D Converter	Section 2	Data Acquisition
ADC10061 10-Bit 600 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition
ADC10062 10-Bit 600 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition
ADC10064 10-Bit 600 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition
ADC10154 10-Bit Plus Sign 4 μ s ADC with 4- or 8-Channel MUX, Track/Hold and Reference	Section 2	Data Acquisition
ADC10158 10-Bit Plus Sign 4 μ s ADC with 4- or 8-Channel MUX, Track/Hold and Reference	Section 2	Data Acquisition
ADC10461 10-Bit 600 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition
ADC10462 10-Bit 600 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition
ADC10464 10-Bit 600 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition

Additional Available Linear Devices (Continued)

ADC10662 10-Bit 360 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition
ADC10664 10-Bit 360 ns A/D Converter with Input Multiplexer and Sample/Hold	Section 2	Data Acquisition
ADC10731 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC10732 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC10734 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC10738 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC10831 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC10832 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC10834 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC10838 10-Bit Plus Sign Serial I/O A/D Converter with MUX, Sample/Hold and Reference	Section 2	Data Acquisition
ADC12030 Self-Calibrating 12-Bit Plus Sign Serial I/O A/D Converter with MUX and Sample/Hold	Section 2	Data Acquisition
ADC12032 Self-Calibrating 12-Bit Plus Sign Serial I/O A/D Converter with MUX and Sample/Hold	Section 2	Data Acquisition
ADC12034 Self-Calibrating 12-Bit Plus Sign Serial I/O A/D Converter with MUX and Sample/Hold	Section 2	Data Acquisition
ADC12038 Self-Calibrating 12-Bit Plus Sign Serial I/O A/D Converter with MUX and Sample/Hold	Section 2	Data Acquisition
ADC12441 Dynamically-Tested Self-Calibrating 12-Bit Plus Sign A/D Converter with Sample/Hold	Section 2	Data Acquisition
ADC12451 Dynamically-Tested Self-Calibrating 12-Bit Plus Sign A/D Converter with Sample/Hold	Section 2	Data Acquisition
ADD3501 3 $\frac{1}{2}$ -Digit DVM with Multiplexed 7-Segment Output	Section 2	Data Acquisition
ADD3701 3 $\frac{3}{4}$ -Digit DVM with Multiplexed 7-Segment Output	Section 2	Data Acquisition
AF100 Universal Active Filter	Section 7	Data Acquisition
AF151 Dual Universal Active Filter	Section 7	Data Acquisition
AH0014 Dual DPST-TTL/DTL Compatible MOS Analog Switch	Section 8	Data Acquisition
AH0015 Quad SPST Dual DPST-TTL/DTL Compatible MOS Analog Switch	Section 8	Data Acquisition
AH0019 Dual DPST-TTL/DTL Compatible MOS Analog Switch	Section 8	Data Acquisition
AH5009 Monolithic Analog Current Switch	Section 8	Data Acquisition
AH5010 Monolithic Analog Current Switch	Section 8	Data Acquisition
AH5011 Monolithic Analog Current Switch	Section 8	Data Acquisition
AH5012 Monolithic Analog Current Switch	Section 8	Data Acquisition
AH5020C Monolithic Analog Current Switch	Section 8	Data Acquisition
CD4016B Quad Bilateral Switch	Section 8	Data Acquisition
CD4051B Single 8-Channel Analog Multiplexer/Demultiplexer	Section 8	Data Acquisition
CD4052B Dual 4-Channel Analog Multiplexer/Demultiplexer	Section 8	Data Acquisition
CD4053B Triple 2-Channel Analog Multiplexer/Demultiplexer	Section 8	Data Acquisition
CD4066B Quad Bilateral Switch	Section 8	Data Acquisition
CD4529BC Dual 4-Channel or 8-Channel Analog Data Selector	Section 8	Data Acquisition

Additional Available Linear Devices (Continued)

DAC0800 8-Bit D/A Converter	Section 3	Data Acquisition
DAC0801 8-Bit D/A Converter	Section 3	Data Acquisition
DAC0802 8-Bit D/A Converter	Section 3	Data Acquisition
DAC0806 8-Bit D/A Converter	Section 3	Data Acquisition
DAC0807 8-Bit D/A Converter	Section 3	Data Acquisition
DAC0808 8-Bit D/A Converter	Section 3	Data Acquisition
DAC0830 8-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC0831 8-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC0832 8-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC0854 Quad 8-Bit Voltage-Output Serial D/A Converter with Readback ..	Section 3	Data Acquisition
DAC0890 Dual 8-Bit μ P-Compatible D/A Converter	Section 3	Data Acquisition
DAC1000 μ P Compatible, Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1001 μ P Compatible, Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1002 μ P Compatible, Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1006 μ P Compatible, Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1007 μ P Compatible, Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1008 μ P Compatible, Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1020 10-Bit Binary Multiplying D/A Converter	Section 3	Data Acquisition
DAC1021 10-Bit Binary Multiplying D/A Converter	Section 3	Data Acquisition
DAC1022 10-Bit Binary Multiplying D/A Converter	Section 3	Data Acquisition
DAC1208 12-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1209 12-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1210 12-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1218 12-Bit Multiplying D/A Converter	Section 3	Data Acquisition
DAC1219 12-Bit Multiplying D/A Converter	Section 3	Data Acquisition
DAC1220 12-Bit Binary Multiplying D/A Converter	Section 3	Data Acquisition
DAC1221 12-Bit Binary Multiplying D/A Converter	Section 3	Data Acquisition
DAC1222 12-Bit Binary Multiplying D/A Converter	Section 3	Data Acquisition
DAC1230 12-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1231 12-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1232 12-Bit μ P Compatible Double-Buffered D/A Converter	Section 3	Data Acquisition
DAC1265 Hi-Speed 12-Bit D/A Converter with Reference	Section 3	Data Acquisition
DAC1266 Hi-Speed 12-Bit D/A Converter	Section 3	Data Acquisition
DH0006 Current Driver	Section 8	App. Specific
DH0006C Current Driver	Section 8	App. Specific
DH0008 High Voltage, High Current Driver	Section 8	App. Specific
DH0011A High Voltage High Current Driver	Section 8	App. Specific
DH0034 High Speed Dual Level Translator	Section 8	App. Specific
DH0035 PIN Diode Driver	Section 8	App. Specific
DH0035C PIN Diode Driver	Section 8	App. Specific
DM2502 Successive Approximation Register	Section 2	Data Acquisition
DM2503 Successive Approximation Register	Section 2	Data Acquisition
DM2504 Successive Approximation Register	Section 2	Data Acquisition
DS0025C Two Phase MOS Clock Driver	Section 5	App. Specific
DS0026 5 MHz Two Phase MOS Clock Driver	Section 5	App. Specific
DS0056 5 MHz Two Phase MOS Clock Driver	Section 5	App. Specific
DS8187 Vacuum Fluorescent Display Driver	Section 4	App. Specific
DS8615 130 MHz Low Power Dual Modulus Prescaler	Section 6	App. Specific
DS8616 225 MHz Low Power Dual Modulus Prescaler	Section 6	App. Specific
DS8673 Low Power VHF/UHF Prescaler	Section 6	App. Specific
DS8674 Low Power VHF/UHF Prescaler	Section 6	App. Specific

Additional Available Linear Devices (Continued)

DS8908B AM/FM Digital Phase-Locked Loop Frequency Synthesizer	Section 6	App. Specific
DS8911 AM/FM/TV Sound Up-Conversion Frequency Synthesizer	Section 6	App. Specific
DS8913 AM/FM/TV Sound Up-Conversion Frequency Synthesizer	Section 6	App. Specific
DS55494 Hex Digit Driver	Section 4	App. Specific
DS75325 Memory Driver	Section 5	App. Specific
DS75361 Dual TTL-to-MOS Driver	Section 5	App. Specific
DS75365 Quad TTL-to-MOS Driver	Section 5	App. Specific
DS75491 MOS-to-LED Quad Segment Driver	Section 4	App. Specific
DS75492 MOS-to-LED Hex Digit Driver	Section 4	App. Specific
DS75494 Hex Digit Driver	Section 4	App. Specific
LF111 Voltage Comparator	Section 3	Op Amps
LF147 Wide Bandwidth Quad JFET Input Operational Amplifier	Section 1	Op Amps
LF155 Series Monolithic JFET Input Operational Amplifiers	Section 1	Op Amps
LF156 Series Monolithic JFET Input Operational Amplifiers	Section 1	Op Amps
LF157 Series Monolithic JFET Input Operational Amplifiers	Section 1	Op Amps
LF198 Monolithic Sample and Hold Circuit	Section 6	Data Acquisition
LF211 Voltage Comparator	Section 3	Op Amps
LF298 Monolithic Sample and Hold Circuit	Section 6	Data Acquisition
LF311 Voltage Comparator	Section 3	Op Amps
LF347 Wide Bandwidth Quad JFET Input Operational Amplifier	Section 1	Op Amps
LF351 Wide Bandwidth JFET Input Operational Amplifier	Section 1	Op Amps
LF353 Wide Bandwidth Dual JFET Input Operational Amplifier	Section 1	Op Amps
LF398A Monolithic Sample and Hold Circuit	Section 6	Data Acquisition
LF411 Low Offset, Low Drift JFET Input Operational Amplifier	Section 1	Op Amps
LF412 Low Offset, Low Drift Dual JFET Operational Amplifier	Section 1	Op Amps
LF441 Low Power JFET Input Operational Amplifier	Section 1	Op Amps
LF442 Dual Low Power JFET Input Operational Amplifier	Section 1	Op Amps
LF444 Quad Low Power JFET Input Operational Amplifier	Section 1	Op Amps
LF451 Wide-Bandwidth JFET Input Operational Amplifier	Section 1	Op Amps
LF453 Wide-Bandwidth Dual JFET Input Operational Amplifier	Section 1	Op Amps
LF11201 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF11202 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF11331 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF11332 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF11333 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF13006 Digital Gain Set	Section 6	Data Acquisition
LF13007 Digital Gain Set	Section 6	Data Acquisition
LF13201 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF13202 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF13331 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF13332 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF13333 Quad SPST JFET Analog Switch	Section 8	Data Acquisition
LF13508 8-Channel Analog Multiplexer	Section 8	Data Acquisition
LF13509 4-Channel Analog Multiplexer	Section 8	Data Acquisition
LH0002 Buffer	Section 2	Op Amps
LH0003 Wide Bandwidth Operational Amplifier	Section 1	Op Amps
LH0004 High Voltage Operational Amplifier	Section 1	Op Amps
* LH0020 High Gain Operational Amplifier	Section 6	Op Amps
* LH0022 High Performance FET Operational Amplifier	Section 6	Op Amps
LH0023 Sample and Hold Circuit	Section 6	Data Acquisition
LH0024 High Slew Rate Operational Amplifier	Section 1	Op Amps

*See Appendix G

Additional Available Linear Devices (Continued)

LH0032 Ultra Fast FET-Input Operational Amplifier	Section 1	Op Amps
LH0033 Fast and Ultra Fast Buffers	Section 2	Op Amps
LH0036 Instrumentation Amplifier	Section 4	Op Amps
LH0041 0.2-Amp Power Operational Amplifier	Section 1	Op Amps
LH0042 Low Cost FET Operational Amplifier	Section 1	Op Amps
LH0043 Sample and Hold Circuit	Section 6	Data Acquisition
* LH0044 Series Precision Low Noise Operational Amplifiers	Section 6	Op Amps
* LH0052 Precision FET Operational Amplifier	Section 6	Op Amps
LH0053 High Speed Sample and Hold Amplifier	Section 6	Data Acquisition
* LH0061 0.5 Amp Wide Band Operational Amplifier	Section 6	Op Amps
* LH0062 High Speed FET Operational Amplifier	Section 6	Op Amps
LH0063 Fast and Ultra Fast Buffers	Section 2	Op Amps
LH0070 Series BCD Buffered Reference	Section 4	Data Acquisition
LH0071 Series Precision Buffered Reference	Section 4	Data Acquisition
* LH0082 Optical Communication Receiver/Amplifier	Section 6	Op Amps
* LH0086 Digitally-Programmable-Gain Amplifier	Section 6	Op Amps
* LH0091 True RMS to DC Converter	Section 10	App. Specific
LH0094 Multifunction Converter	Section 8	App. Specific
LH0101 Power Operational Amplifier	Section 1	Op Amps
LH2003 100 MHz Video Line Driver	Section 2	Op Amps
LH2033 100 MHz Video Line Driver	Section 2	Op Amps
* LH2101A Dual High Performance Operational Amplifier	Section 6	Op Amps
* LH2108 Dual Super Beta Operational Amplifier	Section 6	Op Amps
* LH2110 Dual Voltage Follower	Section 6	Op Amps
LH2111 Dual Voltage Comparator	Section 3	Op Amps
* LH2201A Dual High Performance Operational Amplifier	Section 6	Op Amps
* LH2210 Dual Voltage Follower	Section 6	Op Amps
* LH2301A Dual High Performance Operational Amplifier	Section 6	Op Amps
* LH2308 Dual Super Beta Operational Amplifier	Section 6	Op Amps
* LH2310 Dual Voltage Follower	Section 6	Op Amps
LH2311 Dual Voltage Comparator	Section 3	Op Amps
LH4001 Wideband Current Buffer	Section 2	Op Amps
LH4002 Wideband Video Buffer	Section 2	Op Amps
* LH4003 Precision RF Closed Loop Buffer	Section 6	Op Amps
* LH4006 Precision RF Closed Loop Buffer	Section 6	Op Amps
* LH4008 Fast Buffer	Section 6	Op Amps
* LH4009 Fast Buffer	Section 6	Op Amps
* LH4010 Fast FET Buffer	Section 6	Op Amps
* LH4011 Fast Open Loop Buffer	Section 6	Op Amps
* LH4012 Wideband Buffer	Section 6	Op Amps
* LH4033C Fast and Ultra Fast Buffer Amplifiers	Section 6	Op Amps
* LH4063C Fast and Ultra Fast Buffer Amplifiers	Section 6	Op Amps
* LH4101 Wideband High Current Operational Amplifier	Section 6	Op Amps
LH4104 G-MIL Fast Settling High Current Operational Amplifier	Section 1	Op Amps
* LH4105 Precision Fast Settling High Current Operational Amplifier	Section 6	Op Amps
* LH4106 $\pm 5V$ High Speed Operational Amplifier	Section 6	Op Amps
* LH4117 Precision RF Amplifier	Section 6	Op Amps
LH4118 G-MIL Current Feedback Wide Band RF Amplifier	Section 1	Op Amps
* LH4124C High Slew Rate Operational Amplifier	Section 6	Op Amps
* LH4141C 0.2 Amp Power Operational Amplifier	Section 6	Op Amps
* LH4161 High Speed Operational Amplifier	Section 6	Op Amps

*See Appendix G

Additional Available Linear Devices (Continued)

* LH4162 Dual High Speed Operational Amplifier	Section 6	Op Amps
* LH4200 General Purpose GaAs FET Amplifier	Section 6	Op Amps
LH4266 SPDT RF Switch	Section 3	App. Specific
LH4860 Super Fast 12-Bit Track-Hold Amplifier	Section 6	Data Acquisition
LH7070 Series Precision BCD Buffered Reference	Section 4	Data Acquisition
LH7071 Series Precision Binary Buffered Reference	Section 4	Data Acquisition
LM10 Operational Amplifier and Voltage Reference	Section 1	Op Amps
LM11 Operational Amplifier	Section 1	Op Amps
LM12L 80W Operational Amplifier	Section 1	Op Amps
LM34 Precision Fahrenheit Temperature Sensor	Section 5	Data Acquisition
LM35 Precision Centigrade Temperature Sensor	Section 5	Data Acquisition
LM101A Operational Amplifier	Section 1	Op Amps
LM102 Voltage Follower	Section 2	Op Amps
LM106 Voltage Comparator	Section 3	Op Amps
LM107 Operational Amplifier	Section 1	Op Amps
LM108 Operational Amplifier	Section 1	Op Amps
LM110 Voltage Follower	Section 2	Op Amps
LM111 Voltage Comparator	Section 3	Op Amps
LM112 Operational Amplifier	Section 1	Op Amps
LM113 Reference Diode	Section 4	Data Acquisition
LM118 Operational Amplifier	Section 1	Op Amps
LM119 High Speed Dual Comparator	Section 3	Op Amps
LM122 Precision Timer	Section 8	App. Specific
LM124 Low Power Quad Operational Amplifier	Section 1	Op Amps
LM129 Precision Reference	Section 4	Data Acquisition
LM131 Precision Voltage-to-Frequency Converter	Section 2	Data Acquisition
LM134 3-Terminal Adjustable Current Source	Section 4	Data Acquisition
LM135 Precision Temperature Sensor	Section 5	Data Acquisition
LM136-2.5V Reference Diode	Section 4	Data Acquisition
LM136-5.0V Reference Diode	Section 4	Data Acquisition
LM139 Low Power Low Offset Voltage Quad Comparator	Section 3	Op Amps
LM143 High Voltage Operational Amplifier	Section 1	Op Amps
LM144 High Voltage, High Slew Rate Operational Amplifier	Section 1	Op Amps
LM146 Programmable Quad Operational Amplifier	Section 1	Op Amps
LM148 Quad 741 Operational Amplifier	Section 1	Op Amps
LM149 Wide Band Decompensated ($A_V(\text{MIN}) = 5$)	Section 1	Op Amps
LM158 Low Power Dual Operational Amplifier	Section 1	Op Amps
LM160 High Speed Differential Comparator	Section 3	Op Amps
LM161 High Speed Differential Comparator	Section 3	Op Amps
LM168 Precision Voltage Reference	Section 4	Data Acquisition
LM169 Precision Voltage Reference	Section 4	Data Acquisition
LM185 Adjustable Micropower Voltage Reference	Section 4	Data Acquisition
LM185-1.2 Micropower Voltage Reference Diode	Section 4	Data Acquisition
LM185-2.5 Micropower Voltage Reference Diode	Section 4	Data Acquisition
LM193 Low Power Low Offset Voltage Dual Comparator	Section 3	Op Amps
LM194 Supermatch Pair	Section 1	Op Amps
LM194 SuperMatch Pair	Section 8	App. Specific
LM195 Ultra Reliable Power Transistor	Section 8	App. Specific
LM199 Precision Reference	Section 4	Data Acquisition
LM201A Operational Amplifier	Section 1	Op Amps
LM207 Operational Amplifier	Section 1	Op Amps

*See Appendix G

Additional Available Linear Devices (Continued)

LM208 Operational Amplifier	Section 1	Op Amps
LM210 Voltage Follower	Section 2	Op Amps
LM211 Voltage Comparator	Section 3	Op Amps
LM212 Operational Amplifier	Section 1	Op Amps
LM218 Operational Amplifier	Section 1	Op Amps
LM219 High Speed Dual Comparator	Section 3	Op Amps
LM221 Precision Preamplifier	Section 4	Op Amps
LM224 Low Power Quad Operational Amplifier	Section 1	Op Amps
LM231 Precision Voltage-to-Frequency Converter	Section 2	Data Acquisition
LM234 3-Terminal Adjustable Current Source	Section 4	Data Acquisition
LM235 Precision Temperature Sensor	Section 5	Data Acquisition
LM236-2.5V Reference Diode	Section 4	Data Acquisition
LM236-5.0V Reference Diode	Section 4	Data Acquisition
LM239 Low Power Low Offset Voltage Quad Comparator	Section 3	Op Amps
LM246 Programmable Quad Operational Amplifier	Section 1	Op Amps
LM248 Quad 741 Operational Amplifier	Section 1	Op Amps
LM258 Low Power Dual Operational Amplifier	Section 1	Op Amps
LM261 High Speed Differential Comparator	Section 3	Op Amps
LM268 Precision Voltage Reference	Section 4	Data Acquisition
LM285 Adjustable Micropower Voltage Reference	Section 4	Data Acquisition
LM285-1.2 Micropower Voltage Reference Diode	Section 4	Data Acquisition
LM285-2.5 Micropower Voltage Reference Diode	Section 4	Data Acquisition
LM293 Low Power Low Offset Voltage Dual Comparator	Section 3	Op Amps
LM295 Ultra Reliable Power Transistor	Section 8	App. Specific
LM299 Precision Reference	Section 4	Data Acquisition
LM301A Operational Amplifier	Section 1	Op Amps
LM302 Voltage Follower	Section 2	Op Amps
LM306 Voltage Comparator	Section 3	Op Amps
LM307 Operational Amplifier	Section 1	Op Amps
LM308 Operational Amplifier	Section 1	Op Amps
LM310 Voltage Follower	Section 2	Op Amps
LM311 Voltage Comparator	Section 3	Op Amps
LM312 Operational Amplifier	Section 1	Op Amps
LM313 Reference Diode	Section 4	Data Acquisition
LM318 Operational Amplifier	Section 1	Op Amps
LM319 High Speed Dual Comparator	Section 3	Op Amps
LM321 Precision Preamplifier	Section 4	Op Amps
LM322 Precision Timer	Section 8	App. Specific
LM324 Low Power Quad Operational Amplifier	Section 1	Op Amps
LM329 Precision Reference	Section 4	Data Acquisition
LM331 Precision Voltage-to-Frequency Converter	Section 2	Data Acquisition
LM334 3-Terminal Adjustable Current Source	Section 4	Data Acquisition
LM335 Precision Temperature Sensor	Section 5	Data Acquisition
LM336-2.5V Reference Diode	Section 4	Data Acquisition
LM336-5.0V Reference Diode	Section 4	Data Acquisition
LM339 Low Power Low Offset Voltage Quad Comparator	Section 3	Op Amps
LM343 High Voltage Operational Amplifier	Section 1	Op Amps
LM344 High Voltage, High Slew Rate Operational Amplifier	Section 1	Op Amps
LM346 Programmable Quad Operational Amplifier	Section 1	Op Amps
LM348 Quad 741 Operational Amplifier	Section 1	Op Amps
LM349 Wide Band Decompensated ($A_V(\text{MIN}) = 5$)	Section 1	Op Amps

*See Appendix G

Additional Available Linear Devices (Continued)

LM358 Low Power Dual Operational Amplifier	Section 1	Op Amps
LM359 Dual, High Speed, Programmable Current Mode (Norton) Amplifier ..	Section 1	Op Amps
LM360 High Speed Differential Comparator	Section 3	Op Amps
LM361 High Speed Differential Comparator	Section 3	Op Amps
LM368 Precision Voltage Reference	Section 4	Data Acquisition
LM368-2.5 Precision Voltage Reference	Section 4	Data Acquisition
LM369 Precision Voltage Reference	Section 4	Data Acquisition
LM380 Audio Power Amplifier	Section 1	App. Specific
LM383 7 Watt Audio Power Amplifier	Section 1	App. Specific
LM384 5 Watt Audio Power Amplifier	Section 1	App. Specific
LM385 Adjustable Micropower Voltage Reference	Section 4	Data Acquisition
LM385-1.2 Micropower Voltage Reference Diode	Section 4	Data Acquisition
LM385-2.5 Micropower Voltage Reference Diode	Section 4	Data Acquisition
LM386 Low Voltage Audio Power Amplifier	Section 1	App. Specific
LM388 1.5-Watt Audio Power Amplifier	Section 1	App. Specific
LM389 Low Voltage Audio Power Amplifier with NPN Transistor Array	Section 1	App. Specific
LM390 1 Watt Battery Operated Audio Power Amplifier	Section 1	App. Specific
LM391 Audio Power Driver	Section 1	App. Specific
LM392 Low Power Operational Amplifier/Voltage Comparator	Section 1	Op Amps
LM393 Low Power Low Offset Voltage Dual Comparator	Section 3	Op Amps
LM394 Supermatch Pair	Section 1	Op Amps
LM394 SuperMatch Pair	Section 8	App. Specific
LM395 Ultra Reliable Power Transistor	Section 8	App. Specific
LM399 Precision Reference	Section 4	Data Acquisition
LM555 Timer	Section 8	App. Specific
LM555C Timer	Section 8	App. Specific
LM556 Dual Timer	Section 8	App. Specific
LM556C Dual Timer	Section 8	App. Specific
LM565 Phase Locked Loop	Section 8	App. Specific
LM565C Phase Locked Loop	Section 8	App. Specific
LM566C Voltage Controlled Oscillator	Section 8	App. Specific
LM567 Tone Decoder	Section 8	App. Specific
LM567C Tone Decoder	Section 8	App. Specific
LM604 4-Channel MUX-Amp	Section 1	Op Amps
LM607 Precision Operational Amplifier	Section 1	Op Amps
LM611 Operational Amplifier and Adjustable Reference	Section 1	Op Amps
LM612 Dual-Channel Comparator and Reference	Section 3	Op Amps
LM613 Dual Operational Amplifier, Dual Comparator, and Adjustable Reference	Section 3	Op Amps
LM613 Dual Operational Amplifier, Dual Comparator, and Adjustable Reference	Section 1	Op Amps
LM614 Quad Operational Amplifier and Adjustable Reference	Section 1	Op Amps
LM615 Quad Comparator and Adjustable Reference	Section 3	Op Amps
LM627 Precision Operational Amplifier	Section 1	Op Amps
LM637 Precision Operational Amplifier	Section 1	Op Amps
LM675 Power Operational Amplifier	Section 1	Op Amps
LM709 Operational Amplifier	Section 1	Op Amps
LM710 Voltage Comparator	Section 3	Op Amps
LM715 High Speed Operational Amplifier	Section 1	Op Amps
LM725 Operational Amplifier	Section 1	Op Amps
LM741 Operational Amplifier	Section 1	Op Amps

*See Appendix G

Additional Available Linear Devices (Continued)

LM747 Dual Operational Amplifier	Section 1	Op Amps
LM748 Operational Amplifier	Section 1	Op Amps
LM759 Power Operational Amplifier	Section 1	Op Amps
LM760 High Speed Differential Comparator	Section 3	Op Amps
LM831 Low Voltage Audio Power Amplifier	Section 1	App. Specific
LM832 Dynamic Noise Reduction System DNR	Section 1	App. Specific
LM833 Dual Audio Operational Amplifier	Section 1	App. Specific
LM837 Low Noise Quad Operational Amplifier	Section 1	App. Specific
LM903 Fluid Level Detector	Section 7	App. Specific
LM1035 Dual DC Operated Tone/Volume/Balance Circuit	Section 1	App. Specific
LM1036 Dual DC Operated Tone/Volume/Balance Circuit	Section 1	App. Specific
LM1037 Dual Four-Channel Analog Switch	Section 1	App. Specific
LM1040 Dual DC Operated Tone/Volume/Balance Circuit with Stereo Enhancement Facility	Section 1	App. Specific
LM1042 Fluid Level Detector	Section 7	App. Specific
LM1044 Analog Video Switch	Section 3	App. Specific
LM1131A Dual Dolby B-Type Noise Reduction Processor	Section 1	App. Specific
LM1151 Dolby B-Type Noise Reduction System	Section 1	App. Specific
LM1201 Video Amplifier System	Section 3	App. Specific
LM1201 Video Amplifier System	Section 1	Op Amps
LM1202 230 MHz Video Amplifier System	Section 1	Op Amps
LM1202 230 MHz Video Amplifier System	Section 3	App. Specific
LM1203 RGB Video Amplifier System	Section 3	App. Specific
LM1203 RGB Video Amplifier System	Section 1	Op Amps
LM1203A 150 MHz RGB Video Amplifier System	Section 1	Op Amps
LM1203A 150 MHz RGB Video Amplifier System	Section 3	App. Specific
LM1203B 100 MHz RGB Video Amplifier System	Section 3	App. Specific
LM1204 150 MHz RGB Video Amplifier System	Section 3	App. Specific
LM1211 Broadband Demodulator System	Section 2	App. Specific
LM1391 Phase-Locked Loop	Section 3	App. Specific
LM1414 Dual Differential Voltage Comparator	Section 3	Op Amps
LM1458 Dual Operational Amplifier	Section 1	Op Amps
LM1496 Balanced Modulator-Demodulator	Section 2	App. Specific
LM1558 Dual Operational Amplifier	Section 1	Op Amps
LM1596 Balanced Modulator-Demodulator	Section 2	App. Specific
LM1801 Battery Operated Power Comparator	Section 3	Op Amps
LM1815 Adaptive Sense Amplifier	Section 7	App. Specific
LM1819 Air-Core Meter Driver	Section 7	App. Specific
LM1823 Video IF Amplifier/PLL Detector System	Section 3	App. Specific
LM1830 Fluid Detector	Section 7	App. Specific
LM1851 Ground Fault Interrupter	Section 8	App. Specific
LM1865 Advanced FM IF System	Section 2	App. Specific
LM1868 AM/FM Radio System	Section 2	App. Specific
LM1875 20 Watt Power Audio Amplifier	Section 1	App. Specific
LM1875 20 Watt Power Audio Amplifier	Section 1	Op Amps
LM1877 Dual Power Audio Amplifier	Section 1	Op Amps
LM1877 Dual Power Audio Amplifier	Section 1	App. Specific
LM1881 Video Sync Separator	Section 3	App. Specific
LM1882 Programmable Video Sync Generator	Section 3	App. Specific
LM1894 Dynamic Noise Reduction System DNR	Section 1	App. Specific
LM1896 Dual Power Audio Amplifier	Section 1	App. Specific

*See Appendix G

Additional Available Linear Devices (Continued)

LM1921 1 Amp Industrial Switch	Section 7	App. Specific
LM1946 Over/Under Current Limit Diagnostic Circuit.....	Section 7	App. Specific
LM1949 Injector Drive Controller	Section 7	App. Specific
LM1950 750 mA High Side Switch	Section 7	App. Specific
LM1951 Solid State 1 Amp Switch	Section 7	App. Specific
LM1964 Sensor Interface Amplifier	Section 7	App. Specific
LM2240 Programmable Timer/Counter	Section 8	App. Specific
LM2416 Triple 50 MHz CRT Driver	Section 3	App. Specific
LM2416C Triple 50 MHz CRT Driver	Section 3	App. Specific
LM2418 Triple 30 MHz CRT Driver	Section 3	App. Specific
LM2419 Triple 65 MHz CRT Driver	Section 3	App. Specific
LM2877 Dual 4 Watt Power Audio Amplifier	Section 1	App. Specific
LM2877 Dual 4 Watt Power Audio Amplifier	Section 1	Op Amps
LM2878 Dual 5 Watt Power Audio Amplifier	Section 1	Op Amps
LM2878 Dual 5 Watt Power Audio Amplifier	Section 1	App. Specific
LM2879 Dual 8 Watt Audio Amplifier	Section 1	App. Specific
LM2879 Dual 8 Watt Audio Amplifier	Section 1	Op Amps
LM2896 Dual Power Audio Amplifier	Section 1	App. Specific
LM2900 Quad Amplifier	Section 1	Op Amps
LM2901 Low Power Low Offset Voltage Quad Comparator	Section 3	Op Amps
LM2902 Low Power Quad Operational Amplifier	Section 1	Op Amps
LM2903 Low Power Low Offset Voltage Dual Comparator	Section 3	Op Amps
LM2904 Low Power Dual Operational Amplifier	Section 1	Op Amps
LM2907 Frequency to Voltage Converter	Section 8	App. Specific
LM2917 Frequency to Voltage Converter	Section 8	App. Specific
LM2924 Low Power Operational Amplifier/Voltage Comparator	Section 1	Op Amps
LM3045 Transistor Array	Section 8	App. Specific
LM3046 Transistor Array	Section 8	App. Specific
LM3080 Operational Transconductance Amplifier	Section 1	Op Amps
LM3086 Transistor Array	Section 8	App. Specific
LM3089 FM Receiver IF System	Section 2	App. Specific
LM3146 High Voltage Transistor Array	Section 8	App. Specific
LM3189 FM IF System	Section 2	App. Specific
LM3301 Quad Amplifier	Section 1	Op Amps
LM3302 Low Power Low Offset Voltage Quad Comparator	Section 3	Op Amps
LM3303 Quad Operational Amplifier	Section 1	Op Amps
LM3361A Low Voltage/Power Narrow Band FM IF System	Section 2	App. Specific
LM3403 Quad Operational Amplifier	Section 1	Op Amps
LM3875 High Performance 40 Watt Audio Power Amplifier	Section 1	Op Amps
LM3875 High Performance 40 Watt Audio Power Amplifier	Section 1	App. Specific
LM3876 High Performance 40 Watt Audio Power Amplifier	Section 1	App. Specific
LM3900 Quad Amplifier	Section 1	Op Amps
LM3905 Precision Timer	Section 8	App. Specific
LM3909 LED Flasher/Oscillator	Section 4	App. Specific
LM3911 Temperature Controller	Section 5	Data Acquisition
LM3914 Dot/Bar Display Driver	Section 4	App. Specific
LM3915 Dot/Bar Display Driver	Section 4	App. Specific
LM3916 Dot/Bar Display Driver	Section 4	App. Specific
LM3999 Precision Reference	Section 4	Data Acquisition
LM4040 Precision Micropower Shunt Voltage Reference	Section 4	Data Acquisition
LM4041 Precision Micropower Shunt Voltage Reference	Section 4	Data Acquisition

*See Appendix G

Additional Available Linear Devices (Continued)

LM4136 Quad Operational Amplifier	Section 1	Op Amps
LM4250 Programmable Operational Amplifier	Section 1	Op Amps
LM4431 Micropower Shunt Voltage Reference	Section 4	Data Acquisition
LM6118 Fast Settling Dual Operational Amplifier	Section 1	Op Amps
LM6121 High Speed Buffer	Section 2	Op Amps
LM6125 High Speed Buffer	Section 2	Op Amps
LM6161 High Speed Operational Amplifier	Section 1	Op Amps
LM6162 High Speed Operational Amplifier	Section 1	Op Amps
LM6164 High Speed Operational Amplifier	Section 1	Op Amps
LM6165 High Speed Operational Amplifier	Section 1	Op Amps
LM6181 100 mA, 100 MHz Current Feedback Amplifier	Section 1	Op Amps
LM6218 Fast Settling Dual Operational Amplifier	Section 1	Op Amps
LM6221 High Speed Buffer	Section 2	Op Amps
LM6225 High Speed Buffer	Section 2	Op Amps
LM6261 High Speed Operational Amplifier	Section 1	Op Amps
LM6262 High Speed Operational Amplifier	Section 1	Op Amps
LM6264 High Speed Operational Amplifier	Section 1	Op Amps
LM6265 High Speed Operational Amplifier	Section 1	Op Amps
LM6313 High Speed, High Power Operational Amplifier	Section 1	Op Amps
LM6321 High Speed Buffer	Section 2	Op Amps
LM6325 High Speed Buffer	Section 2	Op Amps
LM6361 High Speed Operational Amplifier	Section 1	Op Amps
LM6362 High Speed Operational Amplifier	Section 1	Op Amps
LM6364 High Speed Operational Amplifier	Section 1	Op Amps
LM6365 High Speed Operational Amplifier	Section 1	Op Amps
LM6685 Ultra Fast Single Latched Comparator	Section 3	Op Amps
LM6687 Ultra Fast Voltage Comparator	Section 3	Op Amps
LM9140 Precision Micropower Shunt Voltage Reference	Section 4	Data Acquisition
LM12454 12-Bit + Sign Data Acquisition System with Self-Calibration	Section 1	Data Acquisition
LM12458 12-Bit + Sign Data Acquisition System with Self-Calibration	Section 1	Data Acquisition
LM13080 Programmable Power Operational Amplifier	Section 1	Op Amps
LM13600 Dual Operational Transconductance Amplifier with Linearizing Diodes and Buffers	Section 1	Op Amps
LM77000 Power Operational Amplifier	Section 1	Op Amps
LMC555 CMOS Timer	Section 8	App. Specific
LMC567 Low Power Tone Decoder	Section 8	App. Specific
LMC568 Low Power Phase-Locked Loop	Section 8	App. Specific
LMC660 CMOS Quad Operational Amplifier	Section 1	Op Amps
LMC662 CMOS Dual Operational Amplifier	Section 1	Op Amps
LMC835 Digital Controlled Graphic Equalizer	Section 1	App. Specific
LMC1982 Digitally-Controlled Stereo Tone and Volume Circuit with Two Selectable Stereo Inputs	Section 1	App. Specific
LMC1983 Digitally-Controlled Stereo Tone and Volume Circuit with Three Selectable Stereo Inputs	Section 1	App. Specific
LMC1992 Digitally-Controlled Stereo Tone and Volume Circuit with Four-Channel Input-Selector	Section 1	App. Specific
LMC6022 Micropower CMOS Dual Operational Amplifier	Section 1	Op Amps
LMC6024 Micropower CMOS Quad Operational Amplifier	Section 1	Op Amps
LMC6032 CMOS Dual Operational Amplifier	Section 1	Op Amps
LMC6034 CMOS Quad Operational Amplifier	Section 1	Op Amps
LMC6041 CMOS Single Micropower Operational Amplifier	Section 1	Op Amps

*See Appendix G

Additional Available Linear Devices (Continued)

LMC6042 CMOS Dual Micropower Operational Amplifier	Section 1	Op Amps
LMC6044 CMOS Quad Micropower Operational Amplifier	Section 1	Op Amps
LMC6061 Precision CMOS Single Micropower Operational Amplifier	Section 1	Op Amps
LMC6062 Precision CMOS Dual Micropower Operational Amplifier	Section 1	Op Amps
LMC6064 Precision CMOS Quad Micropower Operational Amplifier	Section 1	Op Amps
LMC6081 Precision CMOS Single Operational Amplifier	Section 1	Op Amps
LMC6082 Precision CMOS Dual Operational Amplifier	Section 1	Op Amps
LMC6084 Precision CMOS Quad Operational Amplifier	Section 1	Op Amps
LMC6482 CMOS Dual Rail-to-Rail Input and Output Operational Amplifier . .	Section 1	Op Amps
LMC6484 CMOS Quad Rail-to-Rail Input and Output Operational Amplifier . .	Section 1	Op Amps
LMD18400 Quad High Side Driver	Section 7	App. Specific
LMF40 High Performance 4th-Order Switched Capacitor Butterworth Low-Pass Filter	Section 7	Data Acquisition
LMF60 High Performance 6th-Order Switched Capacitor Butterworth Low-Pass Filter	Section 7	Data Acquisition
LMF90 4th-Order Elliptic Notch Filter	Section 7	Data Acquisition
LMF100 High Performance Dual Switched Capacitor Filter	Section 7	Data Acquisition
LMF120 Mask Programmable Switched Capacitor Filter	Section 7	Data Acquisition
LMF380 Triple One-Third Octave Switched Capacitor Active Filter	Section 7	Data Acquisition
LP124 Low Power Quad Operational Amplifier	Section 1	Op Amps
LP265 Micropower Programmable Quad Comparator	Section 3	Op Amps
LP311 Voltage Comparator	Section 3	Op Amps
LP324 Low Power Quad Operational Amplifier	Section 1	Op Amps
LP339 Ultra-Low Power Quad Comparator	Section 3	Op Amps
LP365 Micropower Programmable Quad Comparator	Section 3	Op Amps
LP395 Ultra Reliable Power Transistor	Section 8	App. Specific
LP2902 Low Power Quad Operational Amplifier	Section 1	Op Amps
LPC660 Low Power CMOS Quad Operational Amplifier	Section 1	Op Amps
LPC661 Low Power CMOS Operational Amplifier	Section 1	Op Amps
LPC662 Low Power CMOS Dual Operational Amplifier	Section 1	Op Amps
MF4 4th Order Switched Capacitor Butterworth Lowpass Filter	Section 7	Data Acquisition
MF5 Universal Monolithic Switched Capacitor Filter	Section 7	Data Acquisition
MF6 6th Order Switched Capacitor Butterworth Lowpass Filter	Section 7	Data Acquisition
MF8 4th Order Switched Capacitor Bandpass Filter	Section 7	Data Acquisition
MF10 Universal Monolithic Dual Switched Capacitor Filter	Section 7	Data Acquisition
* MH0007 DC Coupled MOS Clock Driver	Section 10	App. Specific
* MH0007C DC Coupled MOS Clock Driver	Section 10	App. Specific
MM54C905 12-Bit Successive Approximation Register	Section 2	Data Acquisition
MM54HC4016 Quad Analog Switch	Section 8	Data Acquisition
MM54HC4051 8-Channel Analog Multiplexer	Section 8	Data Acquisition
MM54HC4052 Dual 4-Channel Analog Multiplexer	Section 8	Data Acquisition
MM54HC4053 Triple 2-Channel Analog Multiplexer	Section 8	Data Acquisition
MM54HC4066 Quad Analog Switch	Section 8	Data Acquisition
MM54HC4316 Quad Analog Switch with Level Translator	Section 8	Data Acquisition
MM74C905 12-Bit Successive Approximation Register	Section 2	Data Acquisition
MM74HC4016 Quad Analog Switch	Section 8	Data Acquisition
MM74HC4051 8-Channel Analog Multiplexer	Section 8	Data Acquisition
MM74HC4052 Dual 4-Channel Analog Multiplexer	Section 8	Data Acquisition
MM74HC4053 Triple 2-Channel Analog Multiplexer	Section 8	Data Acquisition
MM74HC4066 Quad Analog Switch	Section 8	Data Acquisition
MM74HC4316 Quad Analog Switch with Level Translator	Section 8	Data Acquisition

*See Appendix G

Additional Available Linear Devices (Continued)

MM5368 CMOS Oscillator Divider Circuit	Section 6	App. Specific
MM5369 Series 17 Stage Oscillator/Divider	Section 6	App. Specific
MM5437 Digital Noise Source	Section 6	App. Specific
MM5450 LED Display Driver	Section 4	App. Specific
MM5451 LED Display Driver	Section 4	App. Specific
MM5452 Liquid Crystal Display Driver	Section 4	App. Specific
MM5453 Liquid Crystal Display Driver	Section 4	App. Specific
MM5480 LED Display Driver	Section 4	App. Specific
MM5481 LED Display Driver	Section 4	App. Specific
MM5483 Liquid Crystal Display Driver	Section 4	App. Specific
MM5484 16-Segment LED Display Driver	Section 4	App. Specific
MM5486 LED Display Driver	Section 4	App. Specific
MM58201 Multiplexed LCD Driver	Section 4	App. Specific
MM58241 High Voltage Display Driver	Section 4	App. Specific
MM58242 High Voltage Display Driver	Section 4	App. Specific
MM58248 High Voltage Display Driver	Section 4	App. Specific
MM58341 High Voltage Display Driver	Section 4	App. Specific
MM58342 High Voltage Display Driver	Section 4	App. Specific
MM58348 High Voltage Display Driver	Section 4	App. Specific
OP07 Low Offset, Low Drift Operational Amplifier	Section 1	Op Amps
TL081 Wide Bandwidth JFET Input Operational Amplifier	Section 1	Op Amps
TL082 Wide Bandwidth Dual JFET Input Operational Amplifier	Section 1	Op Amps

*See Appendix G



Cross Reference by Part Number

A complete interchangeability list of Linear IC's offered by most Integrated Circuit Manufacturers is listed in this section, and references the nearest National Semiconductor Corporation direct replacement or recommended replacement with either an improved or functional replacement.

The following companies are included in this cross reference:

Analog Devices	Harris (GE/RCA/Intersil)	Philips	Signetics
Burr Brown	Hitachi	Precision Monolithics Inc.	Siliconix
Cherry	Linear Technology Corp.	Raytheon	Texas Instruments
Elahtec	Maxim	Samsung	Toshiba
Fairchild (NSC)	Motorola	SGS Thompson	Unitrode

NSC			NSC			NSC		
Part Number	Part Number		Part Number	Part Number		Part Number	Part Number	
ANALOG DEVICES								
AD0042	LH0042	I	AD590	LM135	S	AD7542	DAC1210	S
AD101A	LM101A	I	AD590	LM34	S	AD7545	DAC1208	S
AD201A	LM201A	I	AD590	LM35	S	AD7545	DAC1209	S
AD301A	LM301A	I	AD611	LF441	I	AD7545	DAC1210	S
AD5035	LH0042	S	AD624	LM363	S	AD7548	DAC1230	S
AD506	LH0022	S	AD650	LM331	S	AD7548	DAC1231	S
AD509	LH0003	S	AD651	LM331	S	AD7548	DAC1232	S
AD521	LH0036	S	AD654	LM331	S	AD7552	ADC1220	S
AD521	LM363	S	AD673	ADC0841	S	AD7552	ADC1225	S
AD522	LH0038	S	AD707	LM607	I	AD7575	ADC0820	S
AD524	LM363	S	AD711	LF411	S	AD7576	ADC0820	S
AD537	LM331	S	AD712	LF412	S	AD7578	ADC1205	S
AD546	LPC660	I	AD741	LM741	D	AD7578	ADC1225	S
AD546	LPC662	I	AD746	LM6218	I	AD7820	ADC0820	D
AD548	LF441	D	AD7502	LF13509	S	AD7821	ADC08061	I
AD549	LPC660	I	AD7523	DAC0830	S	AD7824	ADC08064	I
AD549	LPC662	I	AD7523	DAC0831	S	AD7828	ADC08068	I
AD562	DAC1266	S	AD7523	DAC0832	S	AD844	LM6181	I
AD563	DAC1265	S	AD7524	DAC0830	S	AD846	LM6181	I
AD565A	DAC1265	S	AD7524	DAC0831	S	AD847	LM6161	D
AD566A	DAC1266	S	AD7524	DAC0832	S	AD848	LM6164	D
AD567	DAC1230	S	AD7533	DAC1020	D	AD849	LM6165	D
AD573	ADC1005	S	AD7533	DAC1021	D	AD96685	LM6685	I
AD581	LH0070	I	AD7533	DAC1022	D	AD96687	LM6687	I
AD582	LF398	S	AD7541	DAC1218	S	ADDAC-08	DAC0800	D
AD583	LF398	S	AD7541	DAC1219	S	ADDAC-08	DAC0801	D
AD588	LM369	S	AD7541A	DAC1218	S	ADDAC-08	DAC0802	D
AD589M	LM385	I	AD7541A	DAC1219	S	ADOP07	LM607	I
AD589U	LM185	I	AD7542	DAC1208	S	HTC-0300	LH4860	S
AD590	LM134	S	AD7542	DAC1209	S			

The following notations are appended to assist you in finding the best option.
S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC			NSC			NSC		
Part Number	Part Number		Part Number	Part Number		Part Number	Part Number	
BURR-BROWN						CHERRY		
3507	LH0003	S	OPA111	LH0052	S	CS-189	LM1819	S
3507	LM118	S	OPA121	LF441A	S	CS-2907	LM2907	D
3507	LM6361	S	OPA121	LH0022	S	CS-2917	LM2917	D
3507	LM709	S	OPA121	LH0042	S	CS-925	LM2925	S
3510	LM101	S	OPA156	LF156	S	CS-935	LM2935	S
3510	LM107	S	OPA21	LM108A	S	ELANTEC		
3510	LM112	S	OPA21	LM11	S	EHA2500	LM6161	S
3510	LM725	S	OPA2111	LF353	S	EHA2502	LM6161	S
3510	LM748	S	OPA2111	LF412A	S	EHA2505	LM6361	S
3533	LH0033	S	OPA2111	LF442A	S	EHA2510	LM6161	S
3542	LH0042	S	OPA2111	LH2011	S	EHA2512	LM6161	S
3550	LM6361	S	OPA2111	LH2101A	S	EHA2515	LM6361	S
3551	LH0024	S	OPA2111	LH2108A	S	EHA2520	LM6164	S
3551	LM6361	S	OPA2111	LM1558	S	EHA2522	LM6164	S
3553	LH0002	S	OPA2111	LM358	S	EHA2525	LM6364	S
3553	LH0063	S	OPA2111	LM2904	S	EHA2600	LM6161	S
3554	LH0032	S	OPA2111	LM747A	S	EHA2602	LM6161	S
3571	LM675	S	OPA27	LH0044	S	EHA2605	LM6361	S
3572	LH0021	S	OPA27	LM627	S	EHA2620	LM6164	S
3573	LM675	S	OPA37	LM637	S	EHA2622	LM6164	S
3580	LH0004	S	OPA404	LF444A	S	EHA2625	LM6364	S
3580	LM143	S	OPA404	LM837	S	EL2006	LM6161	S
3580	LM144	S	OPA404	LMC660	S	EL2006C	LM6261	S
3606A6	LH0084	S	OPA511	LM675	S	EL2020	LM6181	I
3606A6	LH0086	S	OPA541	LH0101	S	ELH0002	LH0002	D
3626	LH0036	S	OPA541	LM12	S	ELH0021	LH0021	D
3629	LH0038	S	OPA602	LF411	S	ELH0032	LH0032	D
ADC80	ADC1280	S	OPA605	LH0005	S	ELH0033	LH0033	D
DAC7541A	AD7521	S	OPA605	LH0032	S	ELH0041	LH0041	D
DAC7541A	AD7531	S	OPA633	LH0033	S	ELH0101	LH0101	D
DAC7541A	DAC1218	S	OPA633	LH4001	S			
DAC7541A	DAC1219	S	PGA100/102	LH0086	S			
DAC811	ADC1230	S	PGA200/201	LH0084	S			
H0S-100	LH0033	S	SHC298	LF298	D			
HI-508	LF13508	S	SHC298	LH0043	S			
HI-509	LF13509	S	SHC5320	LH0053	D			
INA101	LM163	S	SHC80	LF398	S			
INA101HP	LM363	S	SHC85	LF398	S			
INA102	LH0038	S	SHC85	LH0053	S			
INA102	LM363	S	VFC32	LM131/331	S			

The following notations are appended to assist you in finding the best option.

S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC			NSC			NSC		
Part Number	Part Number		Part Number	Part Number		Part Number	Part Number	
FAIRCHILD (NSC)								
μ A101	LM101	D	μ A5156	TP5156	D	μ A78M12	LM78M12	D
μ A105	LM105	D	μ A555	LM555	D	μ A78MXX	LM341-XX	D
μ A108	LM108	D	μ A556	LM556	D	μ A78MXX	LM78MXX	D
μ A108A	LM108A	D	μ A5800	TP3204	D	μ A78XX	LM140-XX	D
μ A110	LM110	D	μ A709	LM709	D	μ A78XX	LM340-XX	D
μ A111	LM111	D	μ A710	LM710	D	μ A78XX	LM78XX	D
μ A117	LM117	D	μ A711	LM711	D	μ A7905	LM7905	D
μ A124	LM124	D	μ A723	LM723	D	μ A7912	LM7912	D
μ A139	LM139	D	μ A725	LM725	D	μ A7915	LM7915	D
μ A1458	LM1458	D	μ A741	LM741	D	μ A79M05	LM79M05	D
μ A1489	DS1489	D	μ A747	LM747	D	μ A79M12	LM79M12	D
μ A1558	LM1558	D	μ A748	LM748	D	μ A79M15	LM79M15	D
μ A201	LM201	D	μ A75107	DS75107	D	μ A79MXX	LM320-XX	D
μ A208	LM208	D	μ A75108	DS75108	D	μ A79XX	LM320-XX	D
μ A208A	LM208A	D	μ A75150	DS75150	D	μ A79XX	LM79LXX	D
μ A2111	LH2111	D	μ A75154	DS75154	D	μ A79XX	LM79MXX	D
μ A224	LM224	D	μ A75450	DS75450	D	μ A79XX	LM79XX	D
μ A239	LM239	D	μ A75491	DS75491	D	DAC1508	MC1508	D
μ A26LS31	DS26LS31	D	μ A760	LM760	D	SH0002	LH0002	D
μ A26LS32	DS26LS32	D	μ A771	LF351	D	SH1605	LH1605	D
μ A2901	LM2901	D	μ A772	LF353	D	HARRIS (GE/RCA/Intersil)		
μ A301	LM301	D	μ A774	LF347	D	μ A748	LM748	D
μ A301A	LM301A	D	μ A7805	LM140	D	AD7520	DAC1021	D
μ A305	LM305	D	μ A7805	LM340-5	D	AD7520	DAC1022	D
μ A3052	TP3052	D	μ A7805	LM7805	D	AD7521	DAC1220	D
μ A305A	LM305A	D	μ A7806	LM7806	D	AD7521	DAC1221	D
μ A308	LM308	D	μ A7808	LM7808	D	AD7521	DAC1222	D
μ A3086	LM3086	D	μ A7812	LM140	D	AD7530	DAC1020	S
μ A30S54	TP3054	D	μ A7812	LM340-12	D	AD7530	DAC1021	S
μ A30S57	TP3057	D	μ A7812	LM7812	D	AD7530	DAC1022	S
μ A30S64	TP3064	D	μ A7815	LM140	D	AD7531	DAC1220	D
μ A30S67	TP3067	D	μ A7815	LM340-15	D	AD7531	DAC1221	D
μ A311	LM311	D	μ A7815	LM7815	D	AD7531	DAC1222	D
μ A317	LM317	D	μ A7818	LM7818	D	AD7533	DAC1020	D
μ A324	LM324	D	μ A7824	LM7824	D	AD7533	DAC1021	D
μ A3302	LM3302	D	μ A78L05	LM78L05	D	AD7533	DAC1022	D
μ A348	LM348	D	μ A78L12	LM78L12	D	AD7541	DAC1218	S
μ A3486	DS3486	D	μ A78L15	LM78L15	D	AD7541	DAC1219	S
μ A350	LM350	D	μ A78LXXA	LM78LXXA	D	ADC0801	ADC0801	D
μ A5116	TP5116	D	μ A78M05	LM78M05	D	ADC0802	ADC0802	D
						ADC0803	ADC0803	D

The following notations are appended to assist you in finding the best option.

S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC			NSC			NSC		
Part Number	Part Number		Part Number	Part Number		Part Number	Part Number	
HARRIS (GE/RCA/Intersil)								
(Continued)								
ADC0804	ADC0804	D	HA2406	LM604	S	HA5141	LM4250	S
CA081	LF411	S	HA2420	LH0023	S	HA5142	LF442	D
CA081	TL081	D	HA2420	LH0043	S	HA5144	LF444	D
CA082	LF412	S	HA2500	LM6161	S	HA5160	LF357	S
CA082	TL082	D	HA2502	LM6161	S	HA5160	LH0062	S
CA084	LF147	S	HA2505	LM6361	S	HA5162	LH0062	S
CA084	LF347	S	HA2510	LM118	S	HA5170	LF151	S
CA124	LM124	D	HA2510	LM318	S	HA5170	LF155	S
CA139	LM139	D	HA2510	LM6161	S	HA5170	LF156	S
CA139A	LM139A	D	HA2512	LM6161	S	HA5170	LF157	S
CA1458	LM1458	D	HA2515	LM6361	S	HA5170	LF355	S
CA1558	LM1558	D	HA2520	LM6164	S	HA5170	LF356	S
CA158	LM158	D	HA2520	LM6113	S	HA5180	LH0022	S
CA158A	LM158A	D	HA2522	LM6164	S	HA5180	LH0042	S
CA224	LM224	D	HA2522	LM6113	S	HA5180	LH0052	S
CA239	LM239	D	HA2525	LM6364	S	HF-10	MF10	D
CA239A	LM239A	D	HA2525	LM6313	S	HF-201	LF13201	D
CA258	LM258	D	HA2529	LM6313	S	HF-300	AH5020	S
CA258A	LM258A	D	HA2530	LH0024	S	HI-201	LF13201	D
CA301A	LM301A	D	HA2535	LH0024	S	HI-508	LF13508	S
CA307	LM307	D	HA2540	LH0032	S	HI-509	LF13509	S
CA3105	LM675	S	HA2541-2	LM6161	S	HI-5618	DAC0800	S
CA311	LM311	D	HA2541-5	LM6361	S	HI-5618	DAC0806	S
CA324	LM324	D	HA2542	LH0032	S	HI-5618	DAC0807	S
CA3290	LM393	S	HA2620	LH4104	S	HI-5618	DAC0808	S
CA339	LM339	D	HA2620	LM6164	S	HI-565A	DAC1265	D
CA339A	LM339A	D	HA2622	LM118	S	HI-5660	DAC1266	D
CA3401	LM3401	D	HA2625	LM318	S	HI-5680	DAC1280	S
CA358	LM358	D	HA2640	LH0004	S	HI-5685	DAC1200	S
CA358A	LM358A	D	HA2640	LM143	S	HI-5685	DAC1285	S
CA741	LM741	D	HA2640	LM144	S	HI-5687	DAC1201	S
CA747	LM747	D	HA2645	LM343	S	HI-5687	DAC1285	S
CA748	LM748	D	HA2645	LM344	S	HI-5690	DAC1280	S
DG201	LF13201	D	HA4741	LM348	S	HI-5695	DAC1285	S
DG211	LF13201	D	HA5002	LH0002	S	HI-5697	DAC1285	S
DG212	LF13202	D	HA5033	LH0033	S	HI-574	ADC1080	S
HA-OP07	LM607	I	HA5020	LM6181	I	HI-574	ADC1210	S
HA2400	LM604	S	HA5102	LM833	S	HI-574	ADC1211	S
HA2404	LM604	S	HA5104	LM837	S	HI-574	ADC1280	S
HA2405	LM604	S	HA5135	LM637	S	HI-674	ADC1080	S

The following notations are appended to assist you in finding the best option.
 S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC		
Part Number	Part Number	
HARRIS (GE/RCA/Intersil)		
(Continued)		
HI-674	ADC1280	S
ICH8530	LH0101	S
ICL7114	ADC1205	S
ICL7114	ADC1225	S
ICL7660	LMC7660	D
ICL8069	LM313	D
ICL8069	LM385-1.2	D
IH5009	AH5009	D
IH5010	AH5010	D
IH5011	AH5011	D
IH5012	AH5012	D
IH6106	LF13508	D
IH6206	LF13509	D
LM741	LM741	D

HITACHI

HA12012	LM833	S
HA12411	LM3089	D
HA12412	LM3189	S
HA12413	LM1868	S
HA12417	LM1863	S
HA13421A	LM18293	S
HA1374	LM2877	S
HA1389	LM384	S
HA1394	LM2879	S
HA1397	LM1875	S
HA17082	LF353	I
HA17082A	LF412	I
HA17084	LF347	I
HA17084A	LF347B	I
HA17094	LM2904	I
HA17301	LM3301	I
HA17324	LM324	I
HA17339	LM339	I
HA17358	LM358	I
HA17393	LM393	I
HA17458	LM458	I
HA17741	LM741	I
HA17747	LM747	I
HA17901	LM2901	I
HA17902	LM2902	I
HA17903	LM2903	I

NSC		
Part Number	Part Number	
LINEAR TECHNOLOGY CORP.		
LF155	LF155	D
LF155A	LF155A	D
LF156	LF156	D
LF156A	LF156A	D
LF198	LF198	D
LF198A	LF198A	D
LF355A	LF355A	D
LF356A	LF356A	D
LF398	LF398	D
LF398A	LF398A	D
LF412A	LF412A	D
LH0070	LH0070	D
LH2108	LH2108	D
LH2108A	LH2108A	D
LM10	LM10	D
LM101A	LM101A	D
LM107	LM107	D
LM108	LM108	D
LM108A	LM108A	D
LM111	LM111	D
LM117	LM117	D
LM117HV	LM117HV	D
LM118	LM118	D
LM119	LM119	D
LM123	LM123	D
LM129	LM129	D
LM129A	LM129A	D
LM134	LM134	D
LM136	LM136	D
LM137	LM137	D
LM137HV	LM137HV	D
LM138	LM138	D
LM150	LM150	D
LM185	LM185	D
LM199	LM199	D
LM234	LM234	D
LM308A	LM308A	D
LM311	LM311	D
LM317	LM317	D
LM317HV	LM317HV	D

NSC		
Part Number	Part Number	
LM318	LM318	D
LM319	LM319	D
LM323	LM323	D
LM329	LM329	D
LM329A	LM329A	D
LM334	LM334	D
LM336	LM336	D
LM337	LM337	D
LM337HV	LM337HV	D
LM338	LM338	D
LM350	LM350	D
LM385	LM385	D
LM399	LM399	D
LM399A	LM399A	D
LT1001	LH0044	D
LT1001	LM607	I
LT1003	LM123	S
LT1003	LM323	S
LT1003	LM337	D
LT1004	LM113	D
LT1004	LM185	D
LT1004	LM385	D
LT1005	LM2935	S
LT1008	LM108	D
LT1008	LM308	D
LT1009	LM136	D
LT1009	LM336	D
LT1010	LH0002	S
LT1011	LM311	D
LT1012	LM312	D
LT1013	LM358	D
LT1014	LM324	D
LT1014	LM348	D
LT1019	LM368	D
LT1020	LP2951	S
LT1021	LM369	I
LT1022	LF356	D
LT1029	LM336	D
LT1031	LH0070	D
LT1033	LM133	D

The following notations are appended to assist you in finding the best option.

S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC			NSC			NSC		
Part Number	Part Number		Part Number	Part Number		Part Number	Part Number	
LINEAR TECHNOLOGY CORP. (Continued)			MAXIM					
LT1033	LM137	S	AD565	DAC1265	D	LF444	LF444	D
LT1033	LM333	D	AD566	DAC1266	D	LM101	LM101	D
LT1034	LM385	D	AD7523	DAC0830	S	LM108	LM108	D
LT1038C	LM396	S	AD7523	DAC0831	S	LM109	LM109	D
LT1038M	LM196	S	AD7523	DAC0832	S	LM11	LM11	D
LT1055	LF355	D	AD7524	DAC0830	S	LM111	LM111	D
LT1056	LF356	D	AD7524	DAC0831	S	LM117	LM117	D
LT111	LM111	D	AD7524	DAC0832	S	LM123	LM123	D
LM317HV	LM317HV	D	AD7533	DAC1020	D	LM124	LM124	D
LT117	LM117	D	AD7533	DAC1021	D	LM137	LM137	D
LT118	LM118	D	AD7533	DAC1022	D	LM139	LM139	D
LT119	LM119	D	AD7541	DAC1218	S	LM140	LM140	D
LT123	LM123	D	AD7541	DAC1219	S	LM148	LM148	D
LT123A	LM123A	D	AD7542	DAC1208	S	LM150	LM150	D
LT1223	LM6181	I	AD7542	DAC1209	S	LM158	LM158	D
LT137	LM137	D	AD7542	DAC1210	S	LM193	LM193	D
LT150	LM150	D	AD7545	DAC1208	S	LM201	LM201	D
LT1524	LM1524D	D	AD7545	DAC1209	S	LM208	LM208	D
LT311	LM311	D	AD7545	DAC1210	S	LM209	LM109	D
LT317	LM317	D	AD7548	DAC1230	S	LM211	LM211	D
LT317A	LM317A	D	AD7548	DAC1231	S	LM217	LM117	D
LT318	LM318	D	AD7548	DAC1232	S	LM223	LM123	D
LT319	LM319	D	AD7820	ADC0820	D	LM224	LM224	D
LT323	LM323	D	ICL7642	LMC6044	S	LM237	LM137	D
LT323A	LM323A	D	MAX480	LMC6041	S	LM239	LM239	D
LT337	LM337	D	MOTOROLA			LM248	LM248	D
LT338	LM338	D	AD562	DAC1266	S	LM250	LM150	D
LT338A	LM338A	D	AD563	DAC1265	S	LM258	LM258	D
LT350A	LM350A	D	DAC-08	DAC0800	D	LM285	LM285	D
LT3524	LM3524D	D	DAC-08	DAC0801	D	LM2900	LM2900	D
LTC1059	MF5	D	DAC-08	DAC0802	D	LM2901	LM2901	D
LTC1060	MF10	D	LF347	LF347	D	LM2902	LM2902	D
LTC1099	ADC0820	D	LF351	LF351	D	LM2903	LM2903	D
REF-01	LM368	S	LF353	LF353	D	LM2904	LM2904	D
SG1524	LM1524D	I	LF355	LF355	D	LM293	LM293	D
SG3524	LM3524D	I	LF356	LF356	D	LM2931	LM2931	D
			LF357	LF357	D	LM301	LM301	D
			LF411	LF411	D	LM307	LM307	D
			LF412	LF412	D	LM308	LM308	D
			LF441	LF441	D	LM309	LM309	D
			LF442	LF442	D			

The following notations are appended to assist you in finding the best option.

S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC			NSC			NSC		
Part Number	Part Number		Part Number	Part Number		Part Number	Part Number	
MOTOROLA (Continued)								
LM311	LM311	D	MC1596	LM1596	D	MC79MXXA	LM79MXX	I
LM317	LM317	D	MC1709	LM709	D	MC79XX	LM320-XX	I
LM323	LM323	D	MC1710	LM710	D	MC79XX	LM79XX	D
LM324	LM324	D	MC1723	LM723	D	MC79XXA	LM320-XX	I
LM337	LM337	D	MC1741	LM741	D			
LM339	LM339	D	MC1747	LM747	D	PHILIPS		
LM340-XX	LM340-XX	D	MC1748	LM748	D	μA723	LM723	D
LM348	LM348	D	MC3301	LM3301	D	μA741	LM741	D
LM350	LM350	D	MC3302	LM3302	D	μA747	LM747	D
LM358	LM358	D	MC33078	LM833	S	ADC0803	ADC0803	D
LM385	LM385	D	MC33079	LM837	S	ADC0804	ADC0804	D
LM3900	LM3900	D	MC3346	LM3046	D	ADC0805	ADC0805	D
LM393	LM393	D	MC3346	LM3146	I	ADC0820	ADC0820	D
LM833	LM833	D	MC3356	LM3089	S	AM26LS30	DS3691	D
MC1391	LM1391	D	MC3356	LM3189	S	CA3089	LM3089	D
MC1408	DAC0806	D	MC3361	LM3361A	I	DAC-08	DAC0801	D
MC1408	DAC0807	D	MC34001	LF351	I	DAC-08	DAC0800	D
MC1408	DAC0808	D	MC34001	LF353	I	DAC-08	DAC0802	D
MC1414	LM1414	D	MC34001	LF411	I	ICM7555	LMC555	D
MC1436	LM343	I	MC34002	LF412	I	LF198	LF198	D
MC1437	LH2301	S	MC34004	LF347	I	LF224	LM224	D
MC14442	ADC0829	S	MC3401	LM3401	D	LF298	LF298	D
MC14444	ADC0830	S	MC3410	DAC1020	D	LF398	LF398	D
MC145040	ADC0811	S	MC3412	DAC1265	S	LM111	LM111	D
MC145041	ADC0811	D	MC3456	LM556	D	LM119	LM119	D
MC1455	LM555	D	MC35001	LF411	I	LM124	LM124	D
MC1456	LM212	S	MC35002	LF412	I	LM139	LM139	D
MC1458	LM1458	D	MC3510	DAC1020	D	LM139A	LM139A	D
MC1468	LM325	S	MC4741	LM348	D	LM158	LM158	D
MC1488	DS1488	D	MC7812	LM7812	D	LM193	LM193	D
MC1489	DS1489	D	MC7815	LM7815	D	LM193A	LM193A	D
MC1496	LM1496	D	MC7824	LM7824	D	LM211	LM211	D
MC1508	DAC0808	D	MC78LXX	LM78LXX	D	LM219	LM219	D
MC1514	LM1514	D	MC78LXXA	LM78LXXA	D	LM224	LM224	D
MC1536	LM143	I	MC78MXX	LM341-XX	D	LM239	LM239	D
MC1537	LH2101	S	MC78MXX	LM78MXX	D	LM239A	LM239A	D
MC1537	LH2201	S	MC78XX	LM78XX	D	LM258	LM258	D
MC1556	LM112	S	MC78XXA	LM340A-XX	D	LM2901	LM2901	D
MC1558	LM1558	D	MC79LXX	LM320L-XX	D	LM2903	LM2903	D
MC1568	LM125	S	MC79LXX	LM79LXXA	D	LM293	LM293	D
						LM293A	LM293A	D

The following notations are appended to assist you in finding the best option.
S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC		
Part Number	Part Number	
PHILIPS (Continued)		
LM311	LM311	D
LM319	LM319	D
LM324	LM324	D
LM324A	LM324A	D
LM339	LM339	D
LM339A	LM339A	D
LM358	LM358	D
LM393	LM393	D
LM393A	LM393A	D
MC1408	DAC0807	D
MC1408	DAC0808	D
MC1458	LM1458	D
MC1488	DS1488	D
MC1488	DS14C88	I
MC1489	DS1489	D
MC1489A	DS1489A	D
MC1489A	DS14C89A	I
MC1496	LM1496	D
MC1508	DAC0808	D
MC1596	LM1596	D
MC3302	LM3302	D
MC3403	LM3403	D
NE4558	LM833	S
NE5034	ADC0841	S
NE5118	DAC0830	S
NE5119	DAC0830	S
NE5410	DAC1020	S
NE5532	LM833	D
NE5532	LM833	D
NE555	LM555	D
NE556	LM556	D
NE565	LM565	D
NE566	LM566	D
NE567	LM567	D
SA532	LM2904	I
SA534	LM2902	I
SE529	LM161	S
SE5537	LF398	D
SE555	LM555	D
SE556	LM556	D
SE567	LM567	D
SG1532	LM1524	I

NSC		
Part Number	Part Number	
SG2524	LM2524	D
SG3524	LM3524	D
PRECISION MONOLITHICS INC.		
ADC-910	ADC1025	S
ADC-910	ADC1061	S
AMP-01	LH0038	S
AMP01	LM363	S
BUF-03	LH0033	I
BUF-03	LH0002	S
CMP-08	LM260	S
CMP-08	LM360	S
DAC-02	DAC1020	S
DAC-02	DAC1021	S
DAC-02	DAC1022	S
DAC-03	DAC1020	S
DAC-03	DAC1021	S
DAC-03	DAC1022	S
DAC-05	DAC1020	S
DAC-05	DAC1021	S
DAC-05	DAC1022	S
DAC-08	DAC0800	D
DAC-08	DAC0801	D
DAC-08	DAC0802	D
DAC-100	DAC1020	S
DAC-100	DAC1021	S
DAC-100	DAC1022	S
DAC-1408	DAC0806	S
DAC-1408	DAC0807	S
DAC-1408	DAC0808	S
DAC-312	DAC1266	D
DAC-888	DAC0830	S
DAC-888	DAC0831	S
DAC-888	DAC0832	S
MAT02	LM394	S
MAT02AH	LM194H	S
MUX-08E	LF13508	D
MUX-24E	LF13509	D
OP-05	LM607	S

NSC		
Part Number	Part Number	
OP-07	LM607	I
OP-07	OP07	D
OP-15	LF411	I
OP-215	LF412	I
OP-77	LM607	I
OP02	LM741	S
OP04	LM747	S
OP06	LM725	S
OP08	LM101	S
OP09	LM4136	S
OP11	LM324	S
OP11	LM348	S
OP14	LM1458	S
OP14	LM1558	S
OP14	LM358	S
OP15	LF351	S
OP15	LM301	S
OP15	LM310	S
OP160	LM6181	I
OP177	LM607	S
OP215	LF353	S
OP22	LM4250	S
OP221	LM2904	S
OP221	LM358	S
OP42	LH0062	S
OP42	LM318	S
OP421	LM2902	S
OP421	LM324	S
OP421	LM3303	S
OP421	L2902	S
OP421	LP324	S
OP43	LM348	S
OP43GP	LF441ACN	S
OP471	LM149	S
OP471	LM837	S
OP490	LMC6044	S
OP77	LM607	S
OP97	LM311	S
PM0820	ADC0820	D
PM1008	LM308	D

The following notations are appended to assist you in finding the best option.
S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC		
Part Number	Part Number	
PRECISION MONOLITHICS INC.		
(Continued)		
PM1012	LM312	S
PM111	LM111	D
PM119	LM119	D
PM139	LM139	D
PM139A	LM139A	D
PM148	LM148	D
PM155	LF155	D
PM155A	LF155A	D
PM156	LF156	D
PM156A	LF156A	D
PM157	LF157	D
PM157A	LF157A	D
PM208	LM208	D
PM208A	LM208A	D
PM211	LM211	D
PM219	LM219	D
PM248	LM248	D
PM308	LM308	D
PM308A	LM308A	D
PM319	LM319	D
PM339A	LM339A	D
PM355	LF355	D
PM355A	LF355A	D
PM356	LF356	D
PM356A	LF356A	D
PM357	LF357	D
PM357A	LF357A	D
PM725	LM725	D
PM741	LM741	D
PM747	LM747	D
PM7533	DAC1020	D
PM7533	DAC1021	D
PM7533	DAC1022	D
PM7541	DAC1218	S
PM7541	DAC1219	S
REF-01	LM368	S
REF-01	LM369	S
REF-02	LM368-5.0	S
REF-03	LM336	S
REF-03	LM385-2.5	S

NSC		
Part Number	Part Number	
REF-43	LM136	D
SMP10	LF398	S
SMP10	LH0043	S
SMP11	LF398	S
SMP11	LH0023	S
SSM2139	LM833	S
SSM2210	LM394	S
SW-06	LF13333	D
SW-201	LF13201	D
SW-202	LF13202	D
RAYTHEON		
DAC-08	DAC0800	S
DAC-10	DAC-1020	S
DAC-10	DAC-1021	S
DAC-6012	DAC-1220	S
DAC-6012	DAC-1221	S
LH2101A	LH2101A	D
LH2111	LH2111	D
LM101A	LM101A	D
LM111	LM111	D
LM124	LM124	D
LM139	LM139	D
LM148	LM148	D
LM2900	LM2900	D
LM301A	LM301A	D
LM324	LM324	D
LM339	LM339	D
LM348	LM348	D
LM3900	LM3900	D
LP365	LP365	D
RC1458	LM1458	D
RC1558	LM1558	D
RC4156	LM348	S
RC4157	LM348	S
RC4195	LM325	S
RC4195	LM326	S
RC714	LM607	I
RC741	LM741	D
RC747	LM747	D
REF-01	LH0070	S
REF-01	LM368	S

NSC		
Part Number	Part Number	
REF-01	LM369	I
REF-02	LM336-5.0	S
REF-02	LM368-5	S
REF-03	LM368-5	I
SAMSUNG		
KA219	LM219	D
KA2803	LM1851	S
KA2807	LM1851	S
KA301	LM301	D
KA319	LM319	D
KA331	LM331	D
KA3524	LM3524D	D
KA431	LM431	D
KA710	LM710	D
KA78S40	LM78S40	D
KF347	LF347	D
KF351	LF351	D
KF442	LF442	D
LM224A	LM224A	D
LM239	LM239	D
LM248	LM248	D
LM258A	LM258A	S
LM2901	LM2901	D
LM2902	LM2902	D
LM2903	LM2903	D
LM2904	LM2904	D
LM293	LM293	D
LM311	LM311	D
LM324	LM324	D
LM324A	LM324A	D
LM3302	LM3302	D
LM339A	LM339A	D
LM348	LM348	D
LM358A	LM358A	D
LM393	LM393	D
LM393A	LM393A	D
LM741	LM741	D
MC1458	LM1458	D
MC78LXX	LM78LXX	D
MC78MXX	LM78MXX	D

The following notations are appended to assist you in finding the best option.
 S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC			NSC			NSC		
Part Number	Part Number		Part Number	Part Number		Part Number	Part Number	
SAMSUNG (Continued)								
MC78XX	LM78XX	D	LM139	LM139	D	LM334	LM334	D
MC79MXX	LM79MXX	D	LM139A	LM139A	D	LM335	LM335	D
MC79XX	LM79XX	D	LM148	LM148	D	LM336	LM336	D
NE555	LM555	D	LM158	LM158	D	LM336B	LM336B	D
NE556	LM556	D	LM158A	LM158A	D	LM339	LM339	D
SGS THOMPSON								
μA741	LM741	D	LM1837	LM1837	D	LM339A	LM339A	D
μA748	LM748	D	LM193	LM193	D	LM346	LM346	D
L293	LM18293	D	LM193A	LM193A	D	LM348	LM348	D
L4940	LM2940	S	LM201A	LM201A	D	LM358	LM358	D
L4941	LM2940	S	LM208	LM208	D	LM358A	LM358A	D
L78MXX	LM78MXX	D	LM211	LM211	D	LM393	LM393	D
L78S05	LM323	I	LM218	LM218	D	LM393A	LM393A	D
L78XX	LM340-XX	D	LM219	LM219	D	NE555	LM555	D
L78XX	LM78XX	D	LM223	LM223	D	NE556	LM556	D
L7912	LM7912	D	LM224	LM224	D	SE555	LM555	D
L79XX	LM320-XX	D	LM224A	LM224A	D	SG556	LM556	D
L79XX	LM79XX	D	LM234	LM234	D	SG524	LM2524	D
LF198	LF198	D	LM235	LM235	D	SG3524	LM3524	D
LF255	LF255	D	LM236	LM236	D	SG3525	LM3525	D
LF256	LF256	D	LM239	LM239	D	SG3527	LM3527	D
LF257	LF257	D	LM239A	LM239A	D	TSA2040	LM1875	S
LF298	LF298	D	LM246	LM246	D	TS272	LMC662	S
LF351	LF351	D	LM248	LM249	D	TS274	LMC660	S
LF353	LF353	D	LM258	LM258	D	TS27L2	LPC662	S
LF355	LF355	D	LM2901	LM2901	D	TS27L4	LPC660	S
LF355A	LF355A	D	LM2902	LM2902	D	TS27M2	LMC662	S
LF356	LF356	D	LM2903	LM3903	D	TS27M4	LMC660	S
LF356A	LF356A	D	LM2904	LM2904	D	SIGNETICS		
LF357	LF357	D	LM293	LM293	D	μA723	LM723	D
LF357A	LF357A	D	LM2930	LM2930	D	μA741	LM741	D
LF398	LF398	D	LM2931A	LM2931A	D	μA747	LM747	D
LM101A	LM101A	D	LM301A	LM301A	D	ADC0801	ADC0801	D
LM109	LM109	D	LM308	LM308	D	ADC0802	ADC0802	D
LM117	LM117	D	LM308A	LM308A	D	ADC0803	ADC0803	D
LM123	LM123	D	LM311	LM311	D	ADC0804	ADC0804	D
LM124	LM124	D	LM318	LM318	D	ADC0805	ADC0805	D
LM124A	LM124A	D	LM319	LM319	D	ADC0820	ADC0820	D
LM134	LM134	D	LM323	LM323	D	CA3089N	LM3089	D
LM135	LM135	D	LM324	LM324	D			
LM137	LM137	D	LM324A	LM324A	D			

The following notations are appended to assist you in finding the best option.
 S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC		
Part Number	Part Number	
SIGNETICS (Continued)		
DAC-08	DAC0800	D
DAC-08	DAC0801	D
DAC-08	DAC0802	D
ICM7555	LMC555	D
LF198	LF198	D
LF298	LF298	D
LF398	LF398	D
LM2901	LM2901	D
LM2903	LM2903	D
LM311	LM311	D
LM319	LM319	D
LM324	LM324	D
LM339	LM339	D
LM358	LM358	D
LM393	LM393	D
MC1408	DAC0807	D
MC1458	LM1458	D
MC1496	LM1496	D
NE5034	ADC0841	S
NE5118	DAC0830	S
NE529	LM361	S
NE532	LM358	D
NE5410	DAC1020	S
NE5517	LM13600	D
NE5537	LF398	D
NE555	LM555	D
NE565	LM565	D
NE566	LM566	D
NE567	LM567	D
SA532	LM2904	I
SA534	LM2902	I
SE5118	DAC0830	S
SE529	LM161	S
SE532	LM158	S
SE5410	DAC1020	S
SE566	LM566	D
SE567	LM567	D
SG3524	LM3524	D

NSC		
Part Number	Part Number	
SILICONIX		
DG201	LF13201	D
DG202	LF13202	D
DG211	LF13201	D
DG212	LF13202	D
DG508	LF13508	D
DG509	LF13509	D
TEXAS INSTRUMENTS		
UA2240	LM2240	D
μA709	LM709	D
μA723	LM723	D
μA741	LM741	D
μA747	LM747	D
μA748	LM748	D
μA78LXX	LM78LXX	D
μA78MXX	LM78MXX	D
μA78XX	LM78XX	D
μA79MXX	LM79MXX	D
μA79XX	LM79XX	D
ADC0803	ADC0803	D
ADC0804	ADC0804	D
ADC0805	ADC0805	D
ADC0808	ADC0808	D
ADC0809	ADC0809	D
ADC0820	ADC0820	D
ADC0831	ADC0831	D
ADC0832	ADC0832	D
ADC0834	ADC0834	D
ADC0838	ADC0838	D
LF198	LF198	D
LF347	LF347	D
LF351	LF351	D
LF353	LF353	D
LF398	LF398	D
LF411	LF411	D
LF412	LF412	D
LM101A	LM101A	D
LM107	LM107	D
LM108	LM108	D
LM111	LM111	D
LM124	LM124	D
LM139	LM139	D
LM148	LM148	D

NSC		
Part Number	Part Number	
LM158	LM158	D
LM185	LM185	D
LM193	LM193	D
LM201	LM201	D
LM207	LM207	D
LM211	LM211	D
LM217	LM217	D
LM218	LM218	D
LM224	LM224	D
LM237	LM137	D
LM239	LM239	D
LM248	LM248	D
LM258	LM258	D
LM2900	LM2900	D
LM2901	LM2901	D
LM2902	LM2902	D
LM2903	LM2903	D
LM2904	LM2904	D
LM2907	LM2907	D
LM2917	LM2917	D
LM293	LM293	D
LM2930	LM2930	D
LM2931	LM2931	D
LM301	LM301	D
LM307	LM307	D
LM317	LM317	D
LM318	LM318	D
LM324	LM324	D
LM330	LM330	D
LM337	LM337	D
LM339	LM339	D
LM348	LM348	D
LM358	LM358	D
LM385	LM385	D
LM3900	LM3900	D
LM393	LM393	D
LP111	LP311	S
LP211	LP311	S
LP239	LP339	S
LP2901	LP339	S

The following notations are appended to assist you in finding the best option.
 S = NSC Similar Device I = NSC Improved Device D = NSC Direct Replacement

NSC		
Part Number	Part Number	
TEXAS INSTRUMENTS		
(Continued)		
LP311	LP311	D
LP339	LP339	D
LT1004	LM385	D
LT1009	LM336	D
MC1458	LM1458	D
MC155	LM1558	D
MC3303	LM3303	D
MC3403	LM3403	D
MC79LXX	LM79LXX	D
MF10	MF10	D
MF4	MF4	D
NE555	LM555	D
NE555	LM556	D
NE592	LM592	D
OP07	OP07	D
OP27	LM627	I
OP37	LM63	I
RC4136	LM4136	D
RC4558	LM833	D
SA555	LM555	D
SA556	LM556	D
SE2524	LM2524D	I
SE3524	LM3524D	I
SE555	LM555	D
SE556	LM556	D
SE592	LM592	D
TL061	LF441	I
TL062	LF442	I
TL064	LF444	I
TL071	LF351	I
TL071	LF411	I
TL072	LF353	I
TL072A	LF412	I
TL074	LF347	I
TL0808	ADC0808	D
TL0809	ADC0809	D
TL081	TL081	D
TL082	TL082	D
TL084	LF347	I
TL087	LF411	S
TL088	LF411	S
TL287	LF412	S
TL288	LF412	S
TL317	LM317	D
TL431	LM431	D
TL592	LM592	D
TLC04	MF4	D
TLC0820	ADC0820	D
TLC10	MF10	D
TLC1225	ADC1225	D

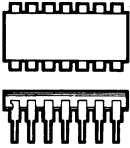
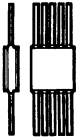

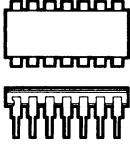
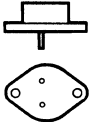
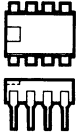
NSC		
Part Number	Part Number	
TLC14	MF4-100	D
TLC1541	ADC1031	S
TLC20	MF10	D
TLC252	LMC662	S
TLC254	LMC660	S
TLC25L2	LMC662	S
TLC25M2	LMC662	S
TLC25M4	LMC660	S
TLC27L2	LMC6042	I
TLC27L4	LMC6044	I
TLC27L7	LMC6062A	I
TLC27M2	LMC662	S
TLC27M4	LMC660	S
TLC271	LMC6041	I
TLC272	LMC6032	I
TLC274	LMC6034	I
TLC277	LMC6082A	I
TLC339	LP339	S
TLC532	ADC0829	S
TLC533	ADC0829	D
TLC540	ADC0811	S
TLC541	ADC0811	D
TLC545	ADC0819	S
TLC546	ADC0819	D
TLC549	ADC0831	S
TLC555	LMC555	D
TOSHIBA		
TA7133	LM1391	S
TA7140	LM386	S
TA7230	LM1877	S
TA7232	LM2896	S
TA7233	LM2877	S
TA7268	LM1875	S
TA7269	LM2878	S
TA7282	LM2896	S
TA7283	LM2896	S
TA7313	LM386	S
TA7336	LM390	S
TA7366	LM3914	S
TA7367	LM3914	S
TA7370	LM3361	S
TA7504	LM741	D
TA75061	LF441	I
TA75062	LF442	I
TA75064	LF444	I
TA75071	LF351	I
TA75072	LF353	I

NSC		
Part Number	Part Number	
TA75074	LF347	I
TA75092	LM2902	I
TA75092	LM324	S
TA75339	LM2901	D
TA75339	LM339	D
TA75358	LM2904	I
TA75358	LM358	D
TA75393	LM2903	I
TA75393	LM393	D
TA75458	LM1558	D
TA7555	LM555	D
TA7612	LM3914	S
TA7613	LM1868	S
TA7630	LM1036	S
TA7640	LM1868	S
TA76524	LM3624	S
TA7654	LM3914	S
TA7667	LM3915	S
TA7688	LM1896	S
TA7758	LM1868	S
TA7769	LM1896	S
TA78LXX	LM78LXX	D
TA78MXX	LM78MXX	D
TA78XXX	LM78XX	D
TA79LXXX	LM79LXX	D
TA79XXX	LM79XX	D
TA8117	LM1868	S
TA8119	LM1896	S
TA8202	LM1877	S
TA8211	LM2878	S
TC9154	LMC1982	S
UNITRODE		
L293	LM18293	D
UC117	LM117	D
UC137	LM137	D
UC150	LM150	D
UC1524	LM1524D	I
UC2524	LM2524D	I
UC317	LM317	D
UC337	LM337	D
UC350	LM350	D
UC3524	LM3524D	I
UC78XX	LM340-XX	D
UC78XX	LM78XX	D
UC79XX	LM320-XX	D
UC79XX	LM79XX	D

The following notations are appended to assist you in finding the best option.
S = NSC Similar Device **I** = NSC Improved Device **D** = NSC Direct Replacement

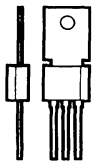
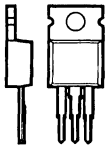
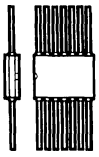

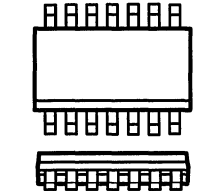
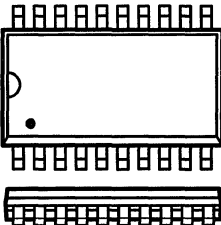
Industry Package Cross-Reference Guide

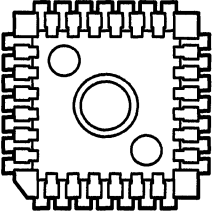
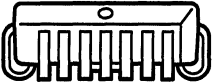
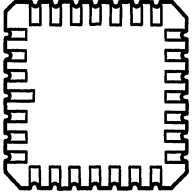



		NSC	NSC μ A	Signetics	Motorola	TI	AMD	Sprague
	4/16 Lead Glass/Metal DIP	D	D	I	L		D	R
	Glass/Metal Flat Pack	F	F	Q	F	F, S	F	
	TO-99, TO-100, TO-5	H	H	T, K, L, DB	G	L	H	
	8-, 14- and 16-Lead Low Temperature Ceramic DIP	J	R, D	F	U	J	D	H
	(Steel)	K			KS			
	(Aluminum)	KC	K	DA	K	K		
	8-, 14- and 16-Lead Plastic DIP	N	T, P	N, V	P	P, N	P	A, B, M

*With dual-in-line formed leads

**With radically formed leads

		NSC	NSC μA	Signetics	Motorola	TI	AMD	Sprague
	TO-202 (D-40, Durawatt)	P						
	TO-220 3- & 5-Lead	T	U	U		KC		
	TO-220 11-, 15- & 23-Lead	T						
	Low Temperature Glass Hermetic Flat Pack	W	F		F	W	F	
	TO-92 (Plastic)	Z	W	S	P	LP		
 	SO (Narrow Body)	M	S	S, D	D	D		L
	SO (Wide Body)	WM				DW		LW

		NSC	NSC μA	Signetics	Motorola	TI	AMD	Sprague
 <p>PCC</p>		V	Q	A	FN	FN	L	EP
								
 <p>LCC Leadless Ceramic Chip Carrier</p>		E	L1	G	U	FK/ FG/FH	L	EK
								



Section 1
**Linear Voltage
Regulators**



Section 1 Contents

Linear Voltage Regulators Definition of Terms	1-3
Linear Voltage Regulators Selection Guide	1-4
LM104/LM204/LM304 Negative Regulators	1-8
LM105/LM205/LM305/LM305A/LM376 Voltage Regulators	1-12
LM109/LM309 5-Volt Regulators	1-19
LM117/LM117A/LM317/LM317A 3-Terminal Adjustable Regulators	1-25
LM117HV/LM317HV 3-Terminal Adjustable Regulators	1-37
LM120/LM320 Series 3-Terminal Negative Regulators	1-47
LM123A/LM123/LM323A/LM323 3-Amp, 5-Volt Positive Regulators	1-56
LM125/LM325/LM325A, LM126/LM326 Voltage Regulators	1-62
LM133/LM333 3-Amp Adjustable Negative Voltage Regulators	1-70
LM137/LM337 3-Terminal Adjustable Negative Regulators	1-77
LM137HV/LM337HV 3-Terminal Adjustable Negative Regulators (High Voltage)	1-83
LM138/LM338 5-Amp Adjustable Regulators	1-89
LM140A/LM140/LM340A/LM340/LM7800/LM7800C Series 3-Terminal Positive Regulators	1-101
LM140L/LM340L Series 3-Terminal Positive Regulators	1-112
LM145/LM345 Negative 3-Amp Regulators	1-116
LM150/LM350/LM350A 3-Amp Adjustable Power Regulators	1-120
LM196/LM396 10-Amp Adjustable Voltage Regulators	1-132
LM317L 3-Terminal Adjustable Regulator	1-144
LM320L, LM79LXXAC Series 3-Terminal Negative Regulators	1-155
LM337L 3-Terminal Adjustable Regulator	1-159
LM341/LM78MXX Series 3-Terminal Positive Regulators	1-161
LM342 Series 3-Terminal Positive Regulator	1-170
LM431A Adjustable Precision Zener Shunt Regulator	1-175
LM723/LM723C Voltage Regulators	1-182
LM78G 4-Terminal Adjustable Regulator	1-191
LM78LXX Series 3-Terminal Positive Regulators	1-197
LM78MG 4-Terminal Adjustable Voltage Regulator	1-207
LM79MXX Terminal Negative Regulators	1-213
LM79XX Series 3-Terminal Negative Regulators	1-220

Voltage Regulators Definition of Terms

Current-Limit Sense Voltage: The voltage across the current limit terminals required to cause the regulator to current-limit with a short circuited output. This voltage is used to determine the value of the external current-limit resistor when external booster transistors are used.

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reductions in input voltage.

Feedback Sense Voltage: The voltage, referred to ground, on the feedback terminal of the regulator while it is operating in regulation.

Input Voltage Range: The range of dc input voltages over which the regulator will operate within specifications.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions at 125°C with maximum rated voltages and power dissipation for 1000 hours.

Maximum Power Dissipation: The maximum total device dissipation for which the regulator will operate within specifications.

Output-Input Voltage Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate within specifications.

Output Noise Voltage: The RMS ac voltage at the output with constant load and no input ripple, measured over a specified frequency range.

Output Voltage Range: The range of regulated output voltages over which the specifications apply.

Output Voltage Scale Factor: The output voltage obtained for a unit value of resistance between the adjustment terminal and ground.

Quiescent Current: That part of input current to the regulator that is not delivered to the load.

Ripple Rejection: The line regulation for ac input signals at or above a given frequency with a specified value of bypass capacitor on the reference bypass terminal.

Standby Current Drain: That part of the operating current of the regulator which does not contribute to the load current. (See Quiescent Current)

Temperature Stability: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Thermal Regulation: Percentage change in output voltage for a given change in power dissipation over a specified time period.



Linear Voltage Regulators Selection Guide

Adjustable Positive Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Input Voltage (V) ^a	Operating Temperature (T _J)	Package Availability ^{**}	Page No.
10.0	LM196	1.25 to 15	Diff. ≤ 20	-55°C to +150°C	K2	1-132
	LM396	1.25 to 15	Diff. ≤ 20	0°C to +125°C	K2	1-132
5.0	LM138	1.2 to 32	Diff. ≤ 40	-55°C to +150°C	K2	1-89
	LM338	1.2 to 32	Diff. ≤ 40	0°C to +125°C	K2, T3	1-89
3.0	LM150	1.2 to 32	Diff. ≤ 35	-55°C to +150°C	K2	1-120
	LM350	1.2 to 32	Diff. ≤ 35	0°C to +125°C	K2, T3	1-120
	LM350A	1.2 to 32	Diff. ≤ 35	-40°C to +125°C	K2, T3	1-120
1.5	LM117	1.2 to 37	Diff. ≤ 40	-55°C to +150°C	K2	1-25
	LM117A	1.2 to 37	Diff. ≤ 40	-55°C to +150°C	K2 ^{***}	1-25
	LM117HV	1.2 to 57	Diff. ≤ 60	-55°C to +150°C	K2	1-37
	LM317	1.2 to 37	Diff. ≤ 40	0°C to +125°C	K2, T3	1-25
	LM317A	1.2 to 37	Diff. ≤ 40	-40°C to +125°C	K2, T3	1-25
	LM317HV	1.2 to 57	Diff. ≤ 60	0°C to +125°C	K2, T3	1-37
1.0	LM78GC	5 to 30	7.5 to 40	0°C to +150°C	P4	1-191
0.5	LM117	1.2 to 37	Diff. ≤ 40	-55°C to +150°C	H3, E20 ^{***}	1-25
	LM117A	1.2 to 37	Diff. ≤ 40	-55°C to +150°C	H3 ^{***}	1-25
	LM117HV	1.2 to 57	Diff. ≤ 60	-55°C to +150°C	H3	1-37
	LM317	1.2 to 37	Diff. ≤ 40	0°C to +125°C	H3	1-25
	LM317M	1.2 to 37	Diff. ≤ 40	0°C to +125°C	P3	1-25
	LM317A	1.2 to 37	Diff. ≤ 40	-40°C to +125°C	H3	1-25
	LM317AM	1.2 to 37	Diff. ≤ 40	-40°C to +125°C	P3	1-25
	LM317HV	1.2 to 57	Diff. ≤ 60	0°C to +125°C	H3	1-37
0.1	LM78MGC	5 to 30	7.5 to 40	0°C to +150°C	P4	1-207
	LM317L	1.2 to 37	Diff. ≤ 40	-40°C to +125°C	M8, Z3	1-25

^aIn cases where the regulator is "floating" the maximum input-to-output voltage differential is listed.

^{**}Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the indicated package. For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.

- E: Leadless Ceramic Chip Carrier
- H: Metal Can (TO-39, TO-99)
- K: Metal Can (TO-9)
- M: Small Outline Molded Package (Surface Mount)
- P: TO-202
- T: TO-220
- Z: TO-92

^{***}Available in indicated package only as a military specified device.

Adjustable Negative Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Input Voltage (V)*	Operating Temperature (T _J)	Package Availability**	Page No.
3.0	LM133	-1.2 to -32	Diff. ≤ 35	-55°C to +150°C	K2	1-70
	LM333	-1.2 to -32	Diff. ≤ 35	-40°C to +125°C	K2, T3	1-70
1.5	LM137	-1.2 to -37	Diff. ≤ 40	-55°C to +150°C	K2	1-77
	LM137A	-1.2 to -37	Diff. ≤ 40	-55°C to +150°C	K2***	1-77
	LM137HV	-1.2 to -47	Diff. ≤ 50	-55°C to +150°C	K2	1-83
	LM337	-1.2 to -37	Diff. ≤ 40	0°C to +125°C	K2, T3	1-77
	LM337HV	-1.2 to -47	Diff. ≤ 50	0°C to +125°C	K2	1-83
0.5	LM137	-1.2 to -37	Diff. ≤ 40	-55°C to +150°C	H3	1-77
	LM137A	-1.2 to -37	Diff. ≤ 40	-55°C to +150°C	H3***	1-77
	LM137HV	-1.2 to -47	Diff. ≤ 50	-55°C to +150°C	H3	1-83
	LM337	-1.2 to -37	Diff. ≤ 40	0°C to +125°C	H3	1-77
	LM337M	-1.2 to -37	Diff. ≤ 40	0°C to +125°C	P3	1-77
	LM337HV	-1.2 to -47	Diff. ≤ 50	0°C to +125°C	H3	1-83
0.1	LM337L	-1.2 to -37	Diff. ≤ 40	-25°C to +125°C	M8, Z3	1-77

Building Block Adjustable Positive and Negative Voltage Regulators

Output Current (mA)	Device	Output Voltage (V)	Input Voltage (V)	Operating Temperature (T _J)	Package Availability**	Page No.
150	LM723	2 to 37	9.5 to 40	-55°C to +150°C	H10, J14, E20***	1-182
	LM723C	2 to 37	9.5 to 40	0°C to +150°C	H10, J14, M14, N14	1-182
45	LM105	4.5 to 40	8.5 to 50	-55°C to +150°C	H8	1-12
	LM205	4.5 to 40	8.5 to 50	-25°C to +100°C	H8	1-12
	LM305	4.5 to 40	8.5 to 50	0°C to +85°C	H8	1-12
	LM305A	4.5 to 40	8.5 to 50	0°C to +150°C	H8	1-12
	LM376	5 to 37	9 to 40	0°C to +100°C	N8	1-12
	25	LM104	-0.015 to -40	-8 to -50	-55°C to +150°C	H10
LM204		-0.015 to -40	-8 to -50	-25°C to +125°C	H10	1-8
LM304		-0.035 to -30	-8 to -40	0°C to +100°C	H10	1-8

*In cases where the regulator is "floating" the maximum input-to-output voltage differential is listed.

**Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the indicated package. For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.

E: Leadless Ceramic Chip Carrier

H: Metal Can (TO-99, TO-99, TO-100)

J: Ceramic Dual-In-Line Package

K: Metal Can (TO-3)

M: Small Outline Molded Package (Surface Mount)

N: Molded Dual-In-Line Package

P: TO-202

T: TO-220

Z: TO-92

***Available in indicated package only as a military specified device.

Fixed Positive Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Max Input Voltage (V)	Operating Temperature (T _J)	Package Availability*	Page No.
3.0	LM123	5	20	-55°C to +150°C	K2	1-56
	LM123A	5	20	-55°C to +150°C	K2	1-56
	LM323	5	20	0°C to +125°C	K2	1-56
	LM323A	5	20	-40°C to +125°C	K2	1-56
1.5	LM140	5, 12, 15	35	-55°C to +150°C	K2	1-101
	LM140A	5, 12, 15	35	-55°C to +150°C	K2	1-101
	LM340	5, 12, 15	35	0°C to +150°C	K2, T3	1-101
	LM340A	5, 12, 15	35	0°C to +150°C	K2, T3	1-101
	LM78XX	5, 8, 12, 15, 18, 24	35	-55°C to +150°C	K2	1-101
	LM78XXC	5, 6, 8, 12, 15, 18, 24	35	0°C to +150°C	K2, T3	1-101
1.0	LM109	5	35	-55°C to +150°C	K2	1-19
	LM309	5	35	0°C to +125°C	K2	1-19
0.5	LM140	5, 6, 8, 12, 15, 24	35	-55°C to +150°C	H3**	
	LM140A	15	35	-55°C to +150°C	H3**	
	LM341	5, 12, 15	35	-40°C to +125°C	P3, T3	1-161
	LM78MXXC	5, 6, 8, 12, 15	35	-40°C to +125°C	H3, T3	1-161
		24	40	-40°C to +125°C	T3	1-161
0.2	LM109	5	35	-55°C to +150°C	H3	1-19
	LM309	5	35	0°C to +125°C	H3	1-19
	LM342	5	30	0°C to +150°C	P3	1-170
		12, 15	35	0°C to +150°C	P3	1-170
0.1	LM140LA	5, 12, 15	35	-55°C to +150°C	H3	1-112
	LM340LA	5, 12, 15	35	0°C to +150°C	H3, Z3	1-112
	LM78LXXAC	5, 12, 15	35	0°C to +125°C	H3, M8	1-197
		5, 6.2, 8.2, 9, 12, 15	35	0°C to +125°C	Z3	1-197

*Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the indicated package. For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.

H: Metal Can (TO-39)

K: Metal Can (TO-3)

M: Small Outline Molded Package (Surface Mount)

P: TO-202

T: TO-220

Z: TO-92

** Available in indicated package only as a military specified device. The specifications for the LM140H and LM140AH are not contained in the LM140 datasheet. If specifications for these devices are required, contact your local National Semiconductor sales office or authorized Distributor. For the pin-out of the LM140H and LM140AH look to the LM140 datasheet.

Fixed Negative Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Min Input Voltage (V)	Operating Temperature (T _J)	Package Availability*	Page No.
3.0	LM145	-5, -5.2	-20	-55°C to +150°C	K2	1-116
	LM345	-5, -5.2	-20	0°C to +125°C	K2	1-116
1.5	LM120	-5	-25	-55°C to +150°C	K2	1-47
		-12, -15	-35	-55°C to +150°C	K2	1-47
	LM320	-5	-25	0°C to +125°C	K2, T3	1-47
		-12, -15	-35	0°C to +125°C	K2, T3	1-47
	LM79XXC	-5	-35	0°C to +125°C	K2, T3	1-220
		-8, -12, -15	-40	0°C to +125°C	K2, T3	1-220
0.5	LM120	-5	-25	-55°C to +150°C	H3	1-47
	LM320	-5	-25	0°C to +125°C	H3	1-47
	LM320M	-5	-25	0°C to +125°C	P3	1-47
		-12, -15	-35	0°C to +125°C	P3	1-47
	LM79MXXC	-5	-25	0°C to +125°C	H3, P3, T3	1-213
		-8	-30	0°C to +125°C	H3, T3	1-213
0.2	LM120	-12, -15	-35	-55°C to +150°C	H3	1-47
	LM320	-12, -15	-35	0°C to +125°C	H3	1-47
0.1	LM320L	-5, -12, -15	-35	0°C to +125°C	Z3	1-155
	LM79LXXAC	-5, -12, -15	-35	0°C to +125°C	M8, Z3	1-155

Shunt Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Max Input Voltage (V)	Operating Temperature (T _J)	Package Availability*	Page No.
0.15	LM431AI	2.5 to 36	37	-40°C to +150°C	Z3	1-175
	LM431AC	2.5 to 36	37	0°C to +150°C	M8, Z3	1-175

*Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the indicated package. For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.

H: Metal Can (TO-39)

K: Metal Can (TO-3)

M: Small Outline Molded Package (Surface Mount)

P: TO-202

T: TO-220

Z: TO-92



LM104/LM204/LM304 Negative Regulator

General Description

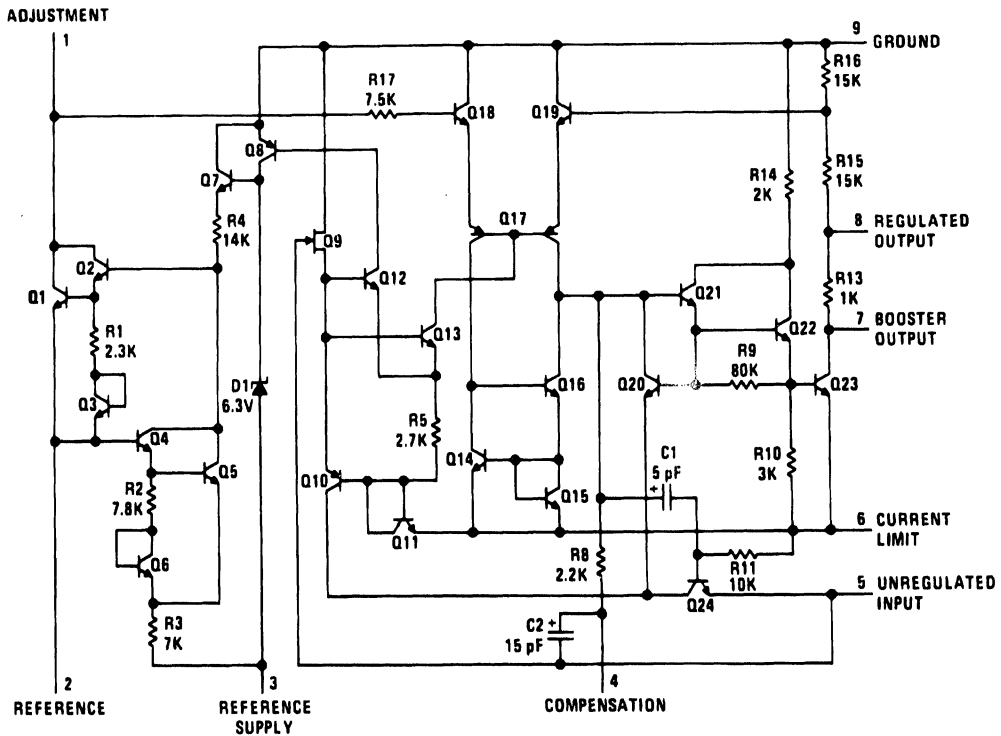
The LM104 series are precision voltage regulators which can be programmed by a single external resistor to supply any voltage from 40V down to zero while operating from a single unregulated supply. They can also provide 0.01-percent regulation in circuits using a separate, floating bias supply, where the output voltage is limited only by the breakdown of external pass transistors. Although designed primarily as linear, series regulators, the circuits can be used as switching regulators, current regulators or in a number of other control applications. Typical performance characteristics are:

- Subsurface zener reference
- 1 mV regulation no load to full load
- 0.01%/V line regulation
- 0.2 mV/V ripple rejection
- 0.3% temperature stability over military temperature range

The LM104 series is the complement of the LM105 positive regulator, intended for systems requiring regulated negative voltages which have a common ground with the unregulated supply. By themselves, they can deliver output currents to 25 mA, but external transistors can be added to get any desired current. The output voltage is set by external resistors, and either constant or foldback current limiting is made available.

The LM104 is specified for operation over the -55°C to $+125^{\circ}\text{C}$ military temperature range. The LM204 is specified for operation over the -25°C to $+85^{\circ}\text{C}$ temperature range. The LM304 is specified for operation from 0°C to $+70^{\circ}\text{C}$.

Schematic Diagram



TL/H/7754-1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 6)

	LM104/LM204	LM304
Input Voltage	50V	40V
Input-Output Voltage Differential	50V	40V
Power Dissipation (Note 1)	500 mW	500 mW
Operating Temperature Range		
LM104	-55°C to +125°C	
LM204	-25°C to +85°C	
LM304		0°C to +70°C
Storage Temperature Range	-65°C to +150°C	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C for plastic	300°C for hermetic

Electrical Characteristics

Parameter	Conditions	LM104/LM204			LM304			Units
		Min	Typ	Max	Min	Typ	Max	
Input Voltage Range		-50		-8	-40		-8	V
Output Voltage Range		-40		-0.015	-30		-0.035	V
Output-Input Voltage Differential (Note 3)	$I_O = 20 \text{ mA}$	2.0		50	2.0		40	V
	$I_O = 5 \text{ mA}$	0.5		50	0.5		40	V
Load Regulation (Note 4)	$0 \leq I_O \leq 20 \text{ mA}$							
	$R_{SC} = 15\Omega$		1	5		1	5	mV
Line Regulation (Note 5)	$V_{OUT} \leq -5V$							
	$\Delta V_{IN} = 0.1 V_{IN}$		0.056	0.1		0.056	0.1	%
Ripple Rejection	$C_{19} = 10 \mu\text{F}$, $f = 120 \text{ Hz}$ $V_{IN} < -15V$ $-7V \geq V_{IN} \geq -15V$							
			0.2	0.5	0.2	0.5	mV/V	
			0.5	1.0	0.5	1.0	mV/V	
Output Voltage Scale Factor	$R_{2-3} = 2.4k$	1.8	2.0	2.2	1.8	2.0	2.2	V/k Ω
Temperature Stability	$V_O \leq -1V$		0.3	1.0		0.3	1.0	%
Output Noise Voltage	$10 \text{ Hz} \leq f \leq 10 \text{ kHz}$ $V_O \leq -5V$, $C_{1-9} = 0$ $C_{1-9} = 10 \mu\text{F}$		0.007			0.007		%
			15			15		μV
Standby Current Drain	$I_L = 5 \text{ mA}$, $V_O = 0$ $V_O = -30V$ $V_O = -40V$		1.7	2.5		1.7	2.5	mA
			3.6	5.0		3.6	5.0	mA
Long Term Stability	$V_O \leq -1V$		0.01	1.0		0.01	1.0	%

Note 1: The maximum junction temperature of the LM104 is 150°C, while that of the LM204 is 125°C and LM304 is 100°C. For operating at elevated temperatures, devices in the H10C package must be derated based on a thermal resistance of 150°C/W, junction to ambient, or 45°C/W, junction to case.

Note 2: These specifications apply for junction temperatures between -55°C and 150°C (between -25°C and 100°C for the LM204 and 0°C to +85°C for the LM304) and for input and output voltages within the ranges given, unless otherwise specified. The load and line regulation specifications are for constant junction temperature. Temperature drift effects must be taken into account separately when the unit is operating under conditions of high dissipation.

Note 3: When external booster transistors are used, the minimum output-input voltage differential is increased, in the worst case, by approximately 1V.

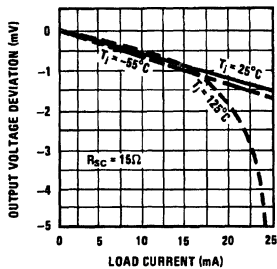
Note 4: The output currents given, as well as the load regulation, can be increased by the addition of external transistors. The improvement factor will be roughly equal to the composite current gain of the added transistors.

Note 5: With zero output, the dc line regulation is determined from the ripple rejection. Hence, with output voltages between 0V and -5V, a dc output variation, determined from the ripple rejection, must be added to find the worst-case line regulation.

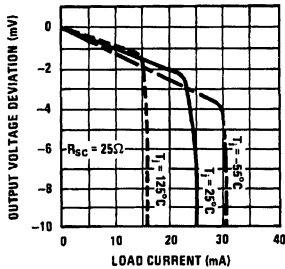
Note 6: Refer to RETS104X drawing for military specifications for the LM104.

Typical Performance Characteristics

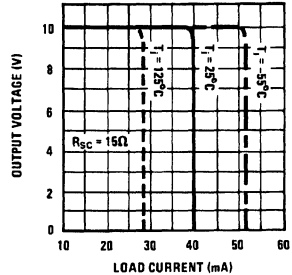
Load Regulation



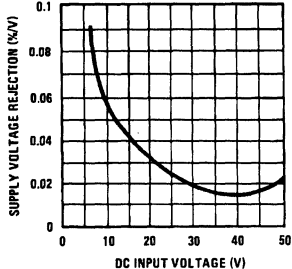
Load Regulation



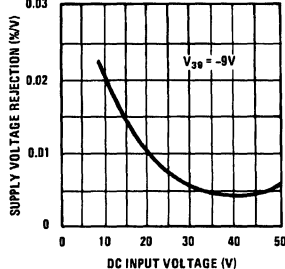
Current Limiting



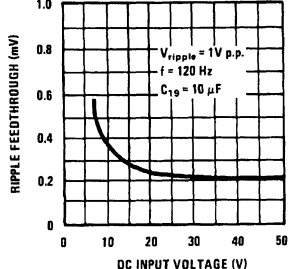
Supply Voltage Rejection



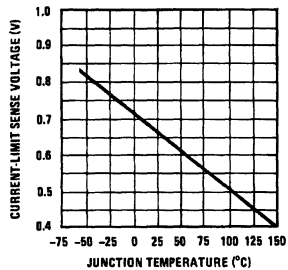
Supply Voltage Rejection With Preregulated Reference Supply



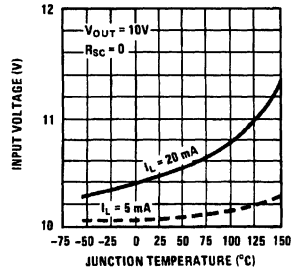
Ripple Rejection



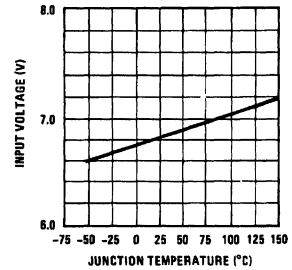
Current Limit Sense Voltage



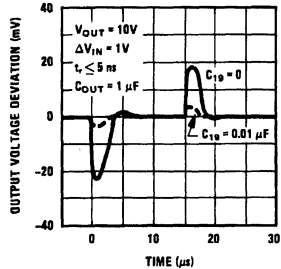
Regulator Dropout Voltage



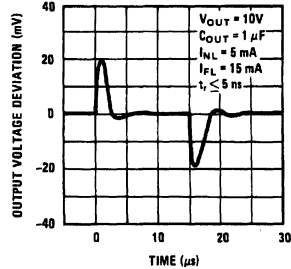
Minimum Input Voltage



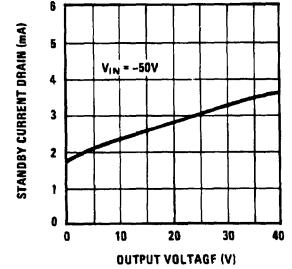
Line Transient Response



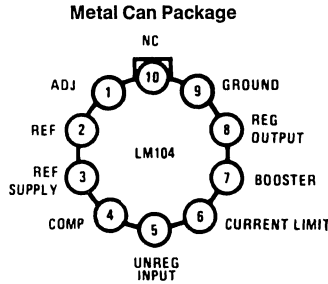
Load Transient Response



Standby Current Drain



Connection Diagram



Note: Pin 5 connected to case.

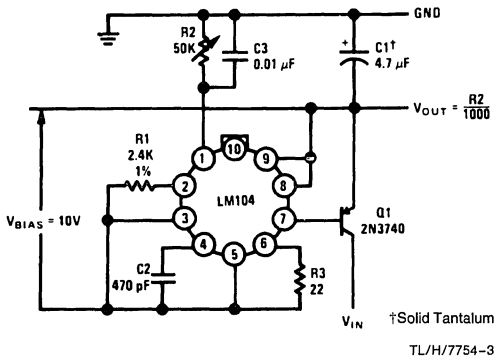
TL/H/7754-2

Top View

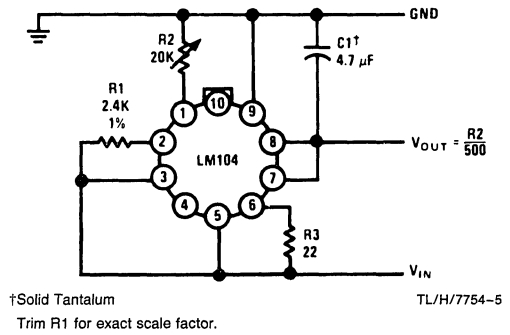
Order Number LM104H, LM204H or LM304H
See NS Package H10C

Typical Applications

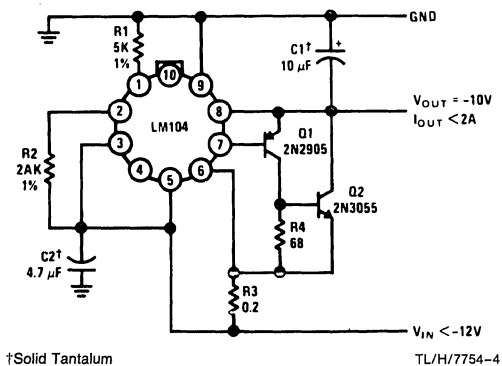
Operating with Separate Bias Supply



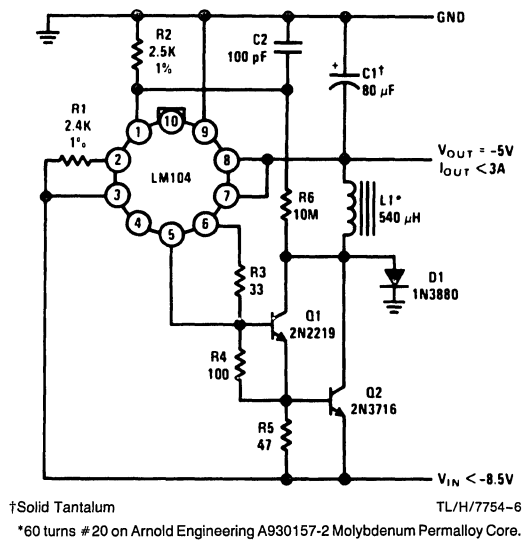
Basic Regulator Circuit



High Current Regulator



Switching Regulator





LM105/LM205/LM305/LM305A, LM376 Voltage Regulators

General Description

The LM105 series are positive voltage regulators similar to the LM100, except that an extra gain stage has been added for improved regulation. A redesign of the biasing circuitry removes any minimum load current requirement and at the same time reduces standby current drain, permitting higher voltage operation. They are direct, plug-in replacements for the LM100 in both linear and switching regulator circuits with output voltages greater than 4.5V. Important characteristics of the circuits are:

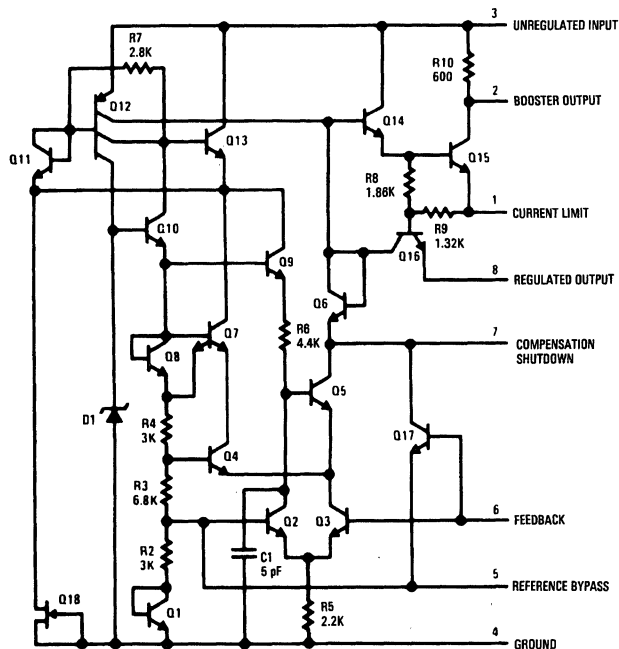
- Output voltage adjustable from 4.5V to 40V
- Output currents in excess of 10A possible by adding external transistors
- Load regulation better than 0.1%, full load with current limiting

- DC line regulation guaranteed at 0.03%/V
- Ripple rejection on 0.01%V
- 45 mA output current without external pass transistor (LM305A)

Like the LM100, they also feature fast response to both load and line transients, freedom from oscillations with varying resistive and reactive loads and the ability to start reliably on any load within rating. The circuits are built on a single silicon chip and are supplied in either a TO-99 metal can or an 8-lead dual-in-line package (as LM376N).

The LM105 is specified for operation for $-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$, the LM205 is specified for $-25^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$, and the LM305/LM305A, LM376 is specified for $0^{\circ}\text{C} \leq T_A \leq +70^{\circ}\text{C}$.

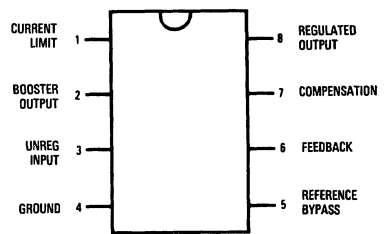
Schematic and Connection Diagrams



TL/H/7755-1

Pin connections shown are for metal can.

Dual-In-Line Package

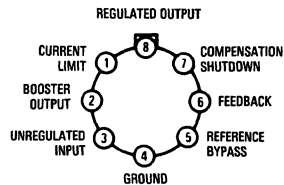


TL/H/7755-2

Top View

Order Number LM376N
See NS Package Number N08E

Metal Can Package



TL/H/7755-3

Top View

Order Number LM105H,
LM205H, LM305H or LM305AH
See NS Package Number H08C

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.
(Note 5)

	LM105	LM205	LM305	LM305A	LM376
Input Voltage	50V	50V	40V	50V	40V
Input-Output Differential	40V	40V	40V	40V	40V
Power Dissipation (Note 1)	800 mW	800 mW	800 mW	800 mW	400 mW
Operating Temperature Range	-55°C to +125°C	-25°C to +85°C	-0°C to +70°C	0°C to +70°C	0°C to +70°C
Storage Temperature Range	-65°C to +150°C	-65°C to +150°C	-65°C to +150°C	-65°C to +150°C	-65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C	300°C	300°C	300°C	260°C

Electrical Characteristics (Note 2)

Parameter	Conditions	LM105			LM205			LM305			LM305A			LM376			Units	
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max		
Input Voltage Range		8.5		50	8.5		50	8.5		40	8.5		50	9.0		40	V	
Output Voltage Range		4.5		40	4.5		40	4.5		30	4.5		40	5.0		37	V	
Input-Output Voltage Differential		3.0		30	3.0		30	3.0		30	3.0		30	3.0		30	V	
Load Regulation (Note 3)	$R_{SC} = 10\Omega, T_A = 25^\circ\text{C}$		0.02	0.05		0.02	0.05		0.02	0.05							%	
	$R_{SC} = 10\Omega, T_A = T_{A(\text{MAX})}$		0.03	0.1		0.03	0.1		0.03	0.1							%	
	$R_{SC} = 10\Omega, T_A = T_{A(\text{MIN})}$		0.03	0.1		0.03	0.1		0.03	0.1							%	
			$0 \leq I_O \leq 12 \text{ mA}$			$0 \leq I_O \leq 12 \text{ mA}$			$0 \leq I_O \leq 12 \text{ mA}$									
		$R_{SC} = 0\Omega, T_A = 25^\circ\text{C}$											0.02	0.2			0.2	%
		$R_{SC} = 0\Omega, T_A = 70^\circ\text{C}$											0.03	0.4			0.5	%
		$R_{SC} = 0\Omega, T_A = 0^\circ\text{C}$											0.03	0.4			0.5	%
Line Regulation														$0 \leq I_O \leq 45 \text{ mA}$		$0 \leq I_O \leq 25 \text{ mA}$		
	$T_A = 25^\circ\text{C}$															0.03	%/V	
	$0^\circ\text{C} \leq T_A \leq +70^\circ\text{C}$															0.1	%/V	
	$V_{IN} - V_{OUT} \leq 5\text{V}, T_A = 25^\circ\text{C}$		0.025	0.06		0.025	0.06		0.025	0.06		0.025	0.06					%/V
	$V_{IN} - V_{OUT} \geq 5\text{V}, T_A = 25^\circ\text{C}$		0.015	0.03		0.015	0.03		0.015	0.03		0.015	0.03					%/V
Temperature Stability	$T_{A(\text{MIN})} \leq T_A \leq T_{A(\text{MAX})}$		0.3	1.0		0.3	1.0		0.3	1.0		0.3	1.0					%

Electrical Characteristics (Note 2) (Continued)

Parameter	Conditions	LM105			LM205			LM305			LM305A			LM376			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Feedback Sense Voltage		1.63	1.7	1.81	1.63	1.7	1.81	1.63	1.7	1.81	1.55	1.7	1.85	1.60	1.72	1.80	V
Output Noise Voltage	$10 \text{ Hz} \leq f \leq 10 \text{ kHz}$																
	$C_{REF} = 0$		0.005			0.005			0.005			0.005					%
	$C_{REF} = 0.1 \mu\text{F}$		0.002			0.002			0.002			0.002					%
Standby Current Drain	$V_{IN} = 30\text{V}, T_A = 25^\circ\text{C}$															2.5	mA
	$V_{IN} = 40\text{V}$								0.8	2.0							mA
	$V_{IN} = 50\text{V}$		0.8	2.0		0.8	2.0					0.8	2.0				mA
Current Limit Sense Voltage	$T_A = 25^\circ\text{C}, R_{SC} = 10\Omega, V_{OUT} = 0\text{V},$ (Note 4)	225	300	375	225	300	375	225	300	375	225	300	375		300		mV
Long Term Stability			0.1			0.1			0.1			0.1					%
Ripple Rejection θ_{JA}	$C_{REF} = 10 \mu\text{F}, f = 120 \text{ Hz}$ Epoxy Dual-In-Line Package		0.003			0.003			0.003			0.003			140		%/V °C/W
θ_{JA}	TO-5 Board Mount in Still Air		230			230			230			230					°C/W
θ_{JA}	TO-5 Board Mount in 400 LF/Min Air Flow		92			92			92			92					°C/W
θ_{JC}	TO-5		25			25			25			25					°C/W

Note 1: The maximum junction temperature of the LM105 and LM305A is 150°C, the LM205 and LM376 is 100°C, and the LM305 is 85°C. For operation at elevated temperatures, devices in the H08C package must be derated based on a thermal resistance of 168°C/W junction to ambient, or 25°C/W junction to case. For the epoxy dual-in-line package, derating is based on a thermal resistance of 138°C/W junction to ambient. Peak dissipations to 1W are allowable providing the dissipation rating is not exceeded with the power average over a five second interval for the LM105 and LM205, and averaged over a two second interval for the LM305.

Note 2: Unless otherwise specified, these specifications apply for temperatures within the operating temperature range, for input and output voltages within the range given, and for a divider impedance seen by the feedback terminal of 2 kΩ. Load and line regulation specifications are for a constant junction temperature. Temperature drift effects must be taken into account separately when the unit is operating under conditions of high dissipation.

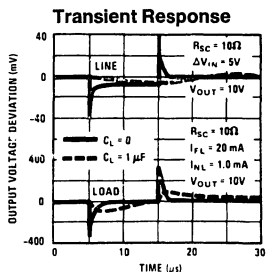
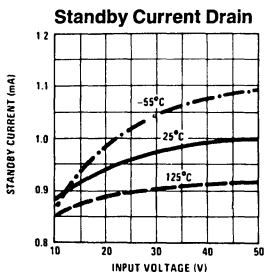
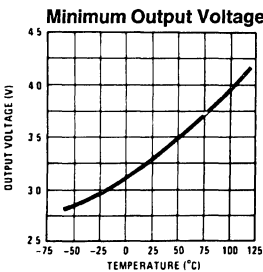
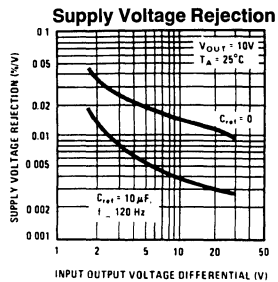
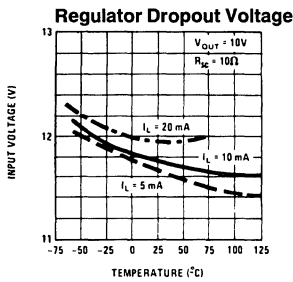
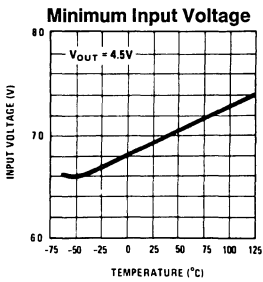
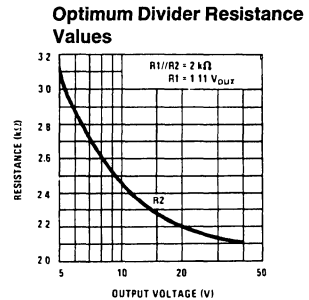
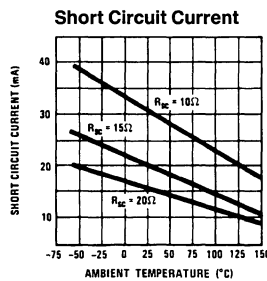
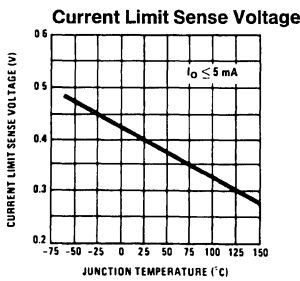
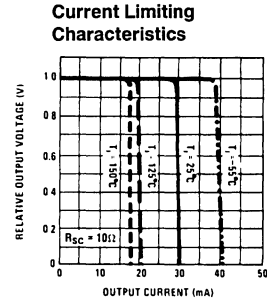
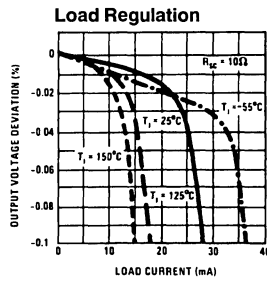
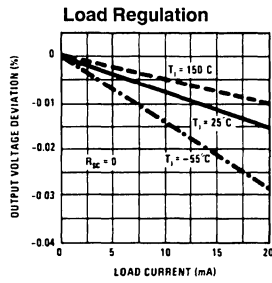
Note 3: The output currents given, as well as the load regulation, can be increased by the addition of external transistors. The improvement factor will be roughly equal to the composite current gain of the added transistors.

Note 4: With no external pass transistor.

Note 5: Refer to RETS105X Drawing for military specifications for the LM105.

Typical Performance Characteristics LM105/LM205/LM305/LM305A

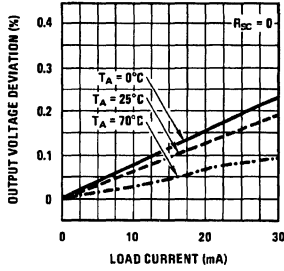
LM105/LM205/LM305/LM305A/LM376



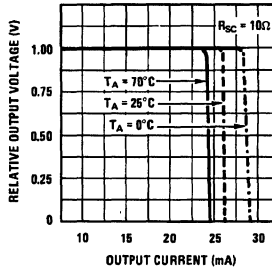
1

Typical Performance Characteristics LM376

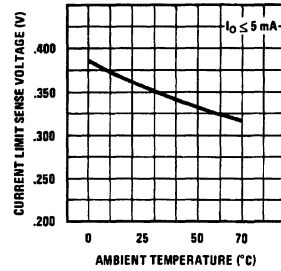
Load Regulation



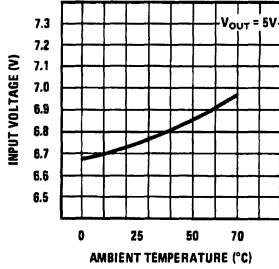
Current Limiting Characteristics



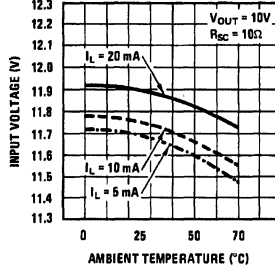
Current Limiting Sense Voltage



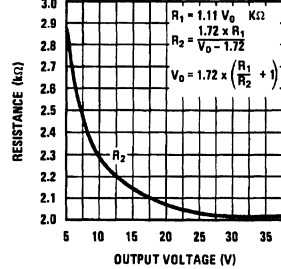
Minimum Input Voltage



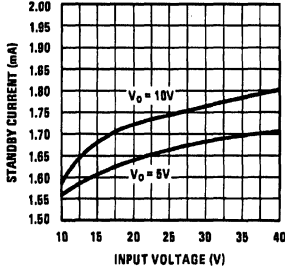
Regulator Dropout Voltage



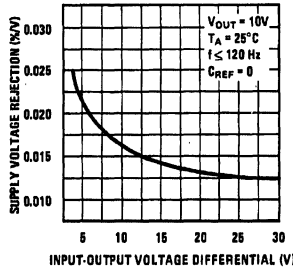
Optimum Divider Resistance



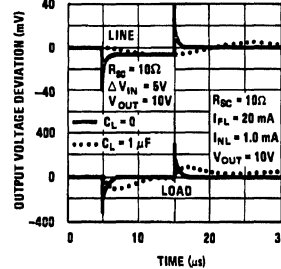
Standby Current Drain
 $T_A = 25^\circ\text{C}$



Supply Voltage Rejection



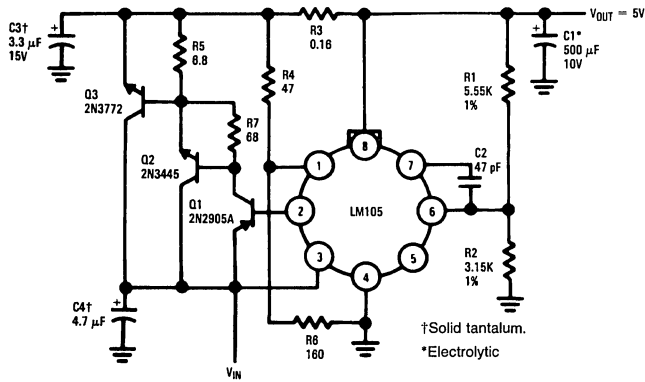
Transient Response



TL/H/7755-7

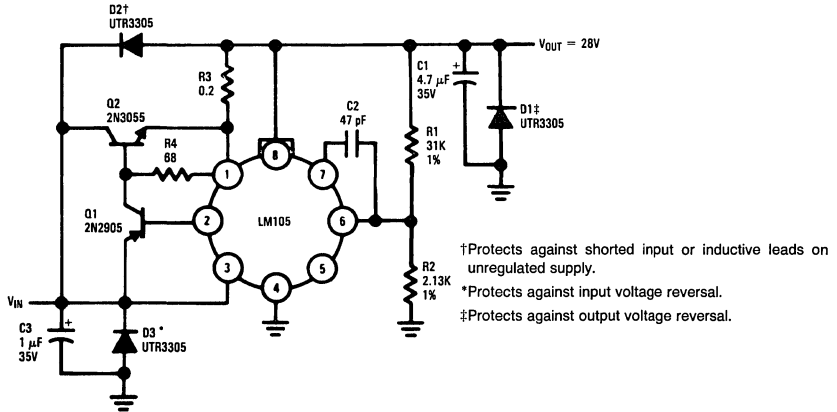
Typical Applications

10A Regulator with Foldback Current Limiting



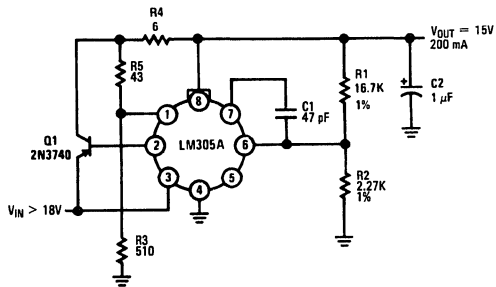
TL/H/7755-4

1.0A Regulator with Protective Diodes



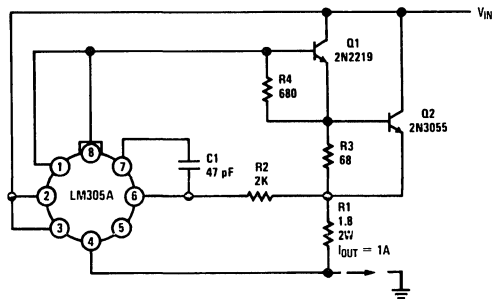
TL/H/7755-5

Linear Regulator with Foldback Current Limiting



TL/H/7755-8

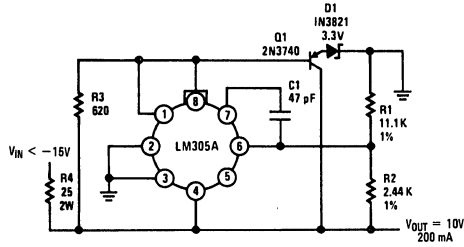
Current Regulator



TL/H/7755-9

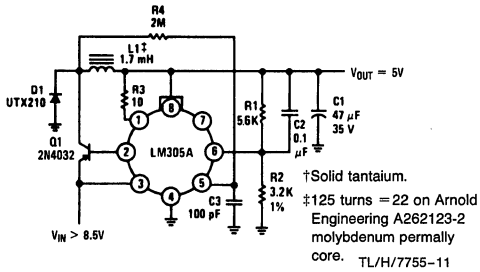
Typical Applications (Continued)

Shunt Regulator



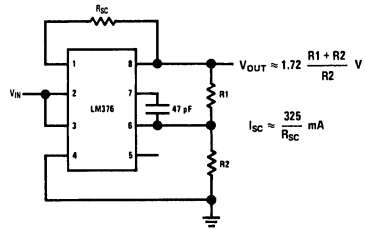
TL/H/7755-10

Switching Regulator



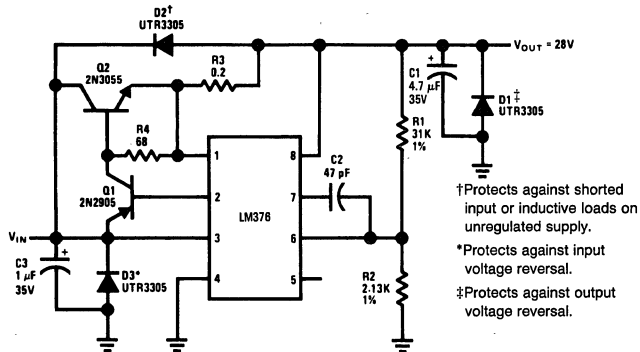
TL/H/7755-11

Basic Positive Regulator with Current Limiting



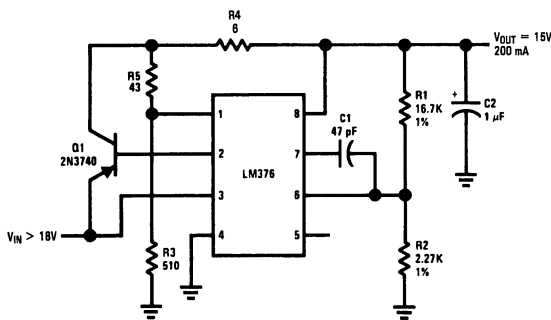
TL/H/7755-12

1.0A Regulator with Protective Diodes



TL/H/7755-13

Linear Regulator with Foldback Current Limiting



TL/H/7755-14

LM109/LM309 5-Volt Regulator

General Description

The LM109 series are complete 5V regulators fabricated on a single silicon chip. They are designed for local regulation on digital logic cards, eliminating the distribution problems association with single-point regulation. The devices are available in two standard transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1A.

The regulators are essentially blowout proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating.

Considerable effort was expended to make these devices easy to use and to minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response somewhat. Input bypassing is needed, however, if the regulator is located very

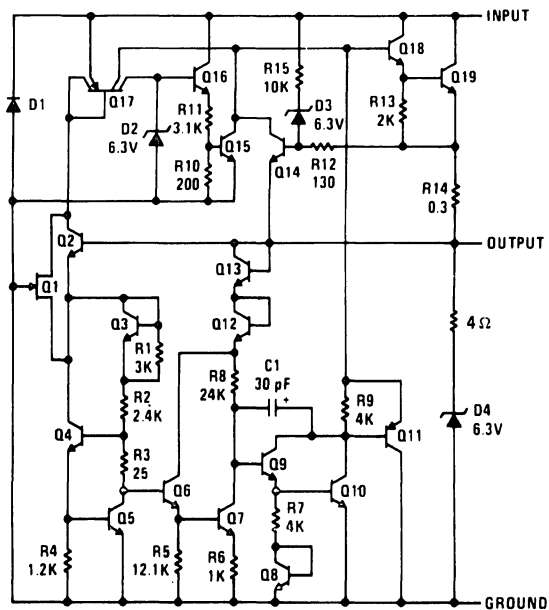
far from the filter capacitor of the power supply. Stability is also achieved by methods that provide very good rejection of load or line transients as are usually seen with TTL logic.

Although designed primarily as a fixed-voltage regulator, the output of the LM109 series can be set to voltages above 5V, as shown. It is also possible to use the circuits as the control element in precision regulators, taking advantage of the good current-handling capability and the thermal overload protection.

Features

- Specified to be compatible, worst case, with TTL and DTL
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required

Schematic Diagram



TL/H/7138-1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 3)

Input Voltage 35V
Power Dissipation Internally Limited

Operating Junction Temperature Range

LM109 -55°C to +150°C

LM309 0°C to +125°C

Storage Temperature Range

-65°C to +150°C

Lead Temperature (Soldering, 10 sec.)

300°C

Electrical Characteristics (Note 1)

Parameter	Conditions	LM109			LM309			Units
		Min	Typ	Max	Min	Typ	Max	
Output Voltage	$T_j = 25^\circ\text{C}$	4.7	5.05	5.3	4.8	5.05	5.2	V
Line Regulation	$T_j = 25^\circ\text{C}$ $7.10\text{V} \leq V_{\text{IN}} \leq 25\text{V}$		4.0	50		4.0	50	mV
Load Regulation	$T_j = 25^\circ\text{C}$ $5\text{mA} \leq I_{\text{OUT}} \leq 0.5\text{A}$ TO-39 Package $5\text{mA} \leq I_{\text{OUT}} \leq 1.5\text{A}$ TO-3 Package		15	50		15	50	mV
			15	100		15	100	mV
Output Voltage	$7.40\text{V} \leq V_{\text{IN}} \leq 25\text{V}$, $5\text{mA} \leq I_{\text{OUT}} \leq I_{\text{MAX}}$, $P < P_{\text{MAX}}$	4.6		5.4	4.75		5.25	V
Quiescent Current	$7.40\text{V} \leq V_{\text{IN}} \leq 25\text{V}$		5.2	10		5.2	10	mA
Quiescent Current Change	$7.40\text{V} \leq V_{\text{IN}} \leq 25\text{V}$ $5\text{mA} \leq I_{\text{OUT}} \leq I_{\text{MAX}}$			0.5			0.5	mA
				0.8			0.8	mA
Output Noise Voltage	$T_A = 25^\circ\text{C}$ $10\text{Hz} \leq f \leq 100\text{kHz}$		40			40		μV
Long Term Stability			10			20		mV
Ripple Rejection	$T_j = 25^\circ\text{C}$	50			50			dB
Thermal Resistance, Junction to Case	(Note 2)							
			15			15		$^\circ\text{C}/\text{W}$
			2.5			2.5		$^\circ\text{C}/\text{W}$

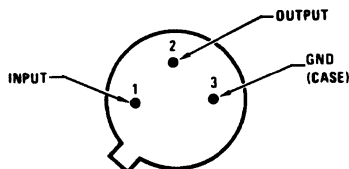
Note 1: Unless otherwise specified, these specifications apply $-55^\circ\text{C} \leq T_j \leq +150^\circ\text{C}$ for the LM109 and $0^\circ\text{C} \leq T_j \leq +125^\circ\text{C}$ for the LM309; $V_{\text{IN}} = 10\text{V}$; and $I_{\text{OUT}} = 0.1\text{A}$ for the TO-39 package or $I_{\text{OUT}} = 0.5\text{A}$ for the TO-3 package. For the TO-39 package, $I_{\text{MAX}} = 0.2\text{A}$ and $P_{\text{MAX}} = 2.0\text{W}$. For the TO-3 package, $I_{\text{MAX}} = 1.0\text{A}$ and $P_{\text{MAX}} = 20\text{W}$.

Note 2: Without a heat sink, the thermal resistance of the TO-39 package is about $150^\circ\text{C}/\text{W}$, while that of the TO-3 package is approximately $35^\circ\text{C}/\text{W}$. With a heat sink, the effective thermal resistance can only approach the values specified, depending on the efficiency of the sink.

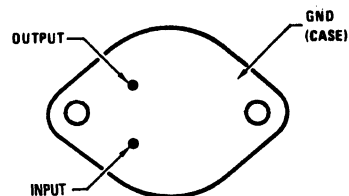
Note 3: Refer to RETS109H drawing for LM109H or RETS109K drawing for LM109K military specifications.

Connection Diagrams

Metal Can Packages



Order Number LM109H or LM309H
See NS Package Number H03A



Order Number LM109K STEEL or LM309K STEEL
See NS Package Number K02A

For Aluminum Package
Order Number LM309K
See NS Package Number KC02A

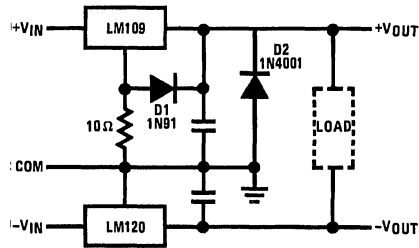
TL/H/7138-3

Application Hints

- Bypass the input** of the LM109 to ground with $\geq 0.2 \mu\text{F}$ ceramic or solid tantalum capacitor if main filter capacitor is more than 4 inches away.
- Use steel package** instead of aluminum if more than 5,000 thermal cycles are expected. ($\Delta T \geq 50^\circ\text{C}$)
- Avoid insertion of regulator into "live" socket** if input voltage is greater than 10V. The output will rise to within 2V of the unregulated input if the ground pin does not make contact, possibly damaging the load. The LM109 may also be damaged if a large output capacitor is charged up, then discharged through the internal clamp zener when the ground pin makes contact.
- The output clamp zener** is designed to absorb transients only. It will not clamp the output effectively if a failure occurs in the internal power transistor structure. Zener dynamic impedance is $\approx 4\Omega$. Continuous RMS current into the zener should not exceed 0.5A.
- Paralleling of LM109s** for higher output current is not recommended. Current sharing will be almost nonexistent, leading to a current limit mode operation for devices with the highest initial output voltage. The current limit devices may also heat up to the thermal shutdown point ($\approx 175^\circ\text{C}$). Long term reliability cannot be guaranteed under these conditions.

f. Preventing latchoff for loads connected to negative voltage:

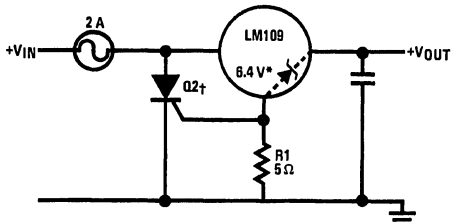
If the output of the LM109 is pulled negative by a high current supply so that the output pin is more than 0.5V negative with respect to the ground pin, the LM109 can latch off. This can be prevented by clamping the ground pin to the output pin with a germanium or Schottky diode as shown. A silicon diode (1N4001) at the output is also needed to keep the positive output from being pulled too far negative. The 10Ω resistor will raise $+V_{\text{OUT}}$ by $\approx 0.05\text{V}$.



TL/H/7138-7

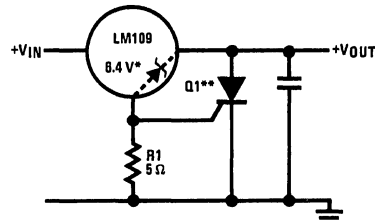
Crowbar Overvoltage Protection

Input Crowbar



TL/H/7138-8

Output Crowbar



TL/H/7138-9

*Zener is internal to LM109.

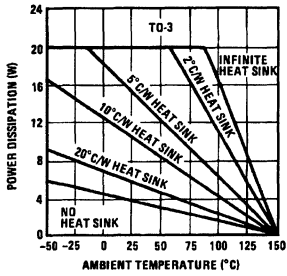
**Q1 must be able to withstand 7A continuous current if fusing is not used at regulator input. LM109 bond wires will fuse at currents above 7A.

†Q2 is selected for surge capability. Consideration must be given to filter capacitor size, transformer impedance, and fuse blowing time.

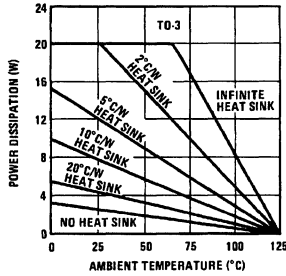
††Trip point is $\approx 7.5\text{V}$.

Typical Performance Characteristics

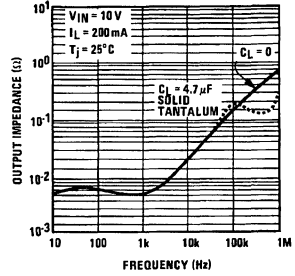
Maximum Average Power Dissipation (LM109K)



Maximum Average Power Dissipation (LM309K)

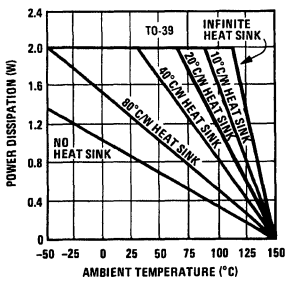


Output Impedance

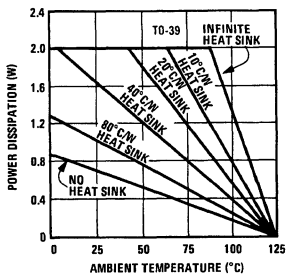


TL/H/7138-10

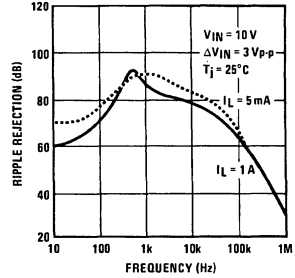
Maximum Average Power Dissipation (LM109H)



Maximum Average Power Dissipation (LM309H)

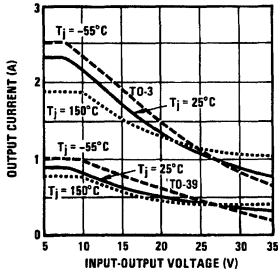


Ripple Rejection

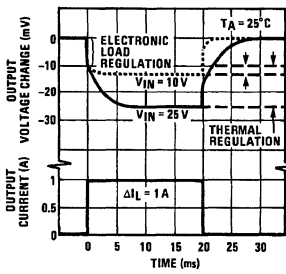


TL/H/7138-11

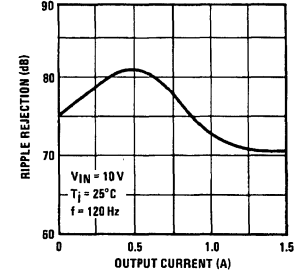
Current Limit Characteristics (Note 1)



Thermally Induced Output Voltage Variation



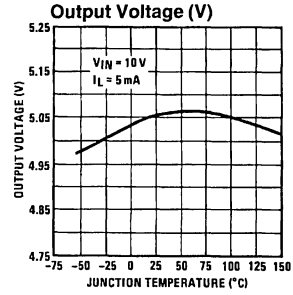
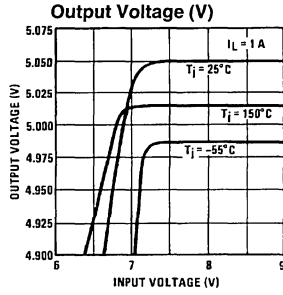
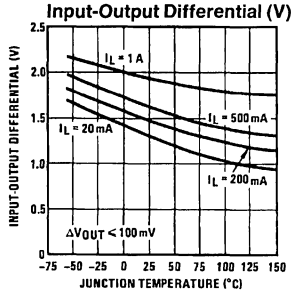
Ripple Rejection



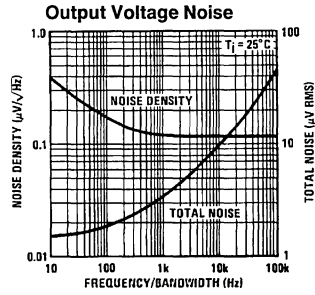
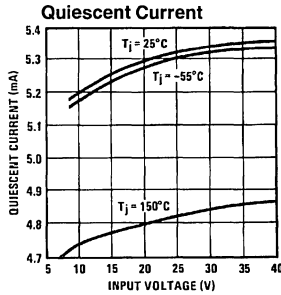
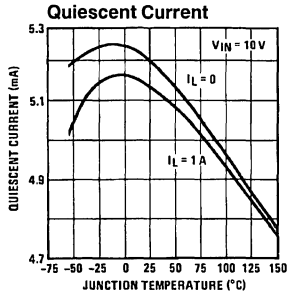
TL/H/7138-12

Note 1: Current limiting foldback characteristics are determined by input output differential, not by output voltage.

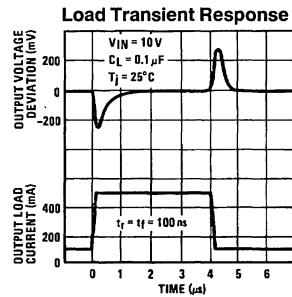
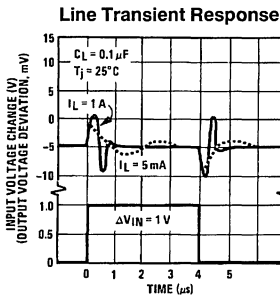
Typical Performance Characteristics (Continued)



TL/H/7138-13



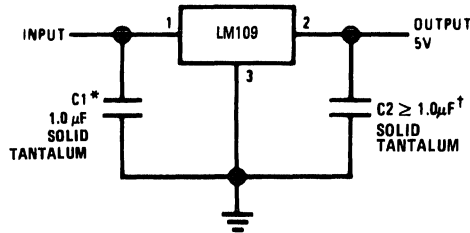
TL/H/7138-14



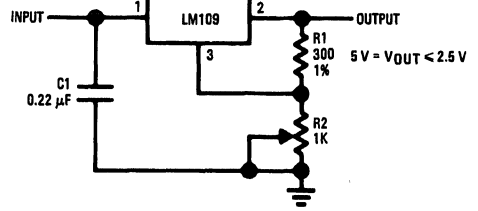
TL/H/7138-15

Typical Applications

Fixed 5V Regulator



Adjustable Output Regulator



TL/H/7138-2

TL/H/7138-4

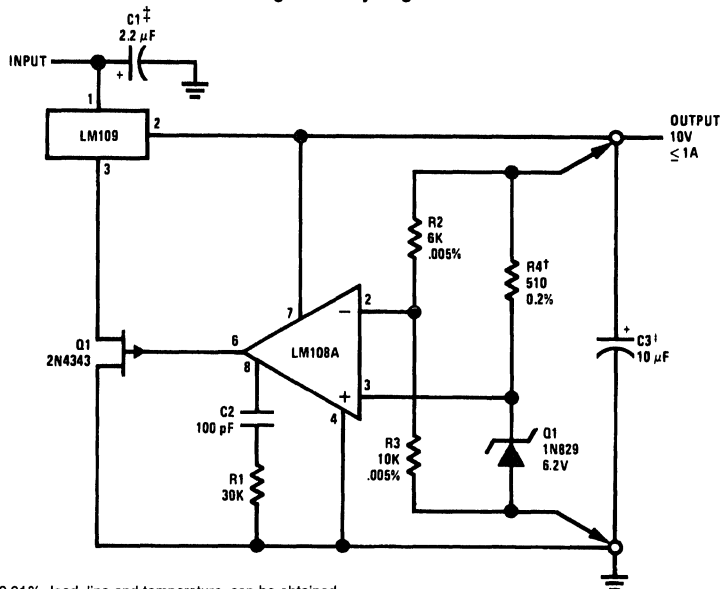
*Required if regulator is located more than 4" from power supply filter capacitor.

†Although no output capacitor is needed for stability, it does improve transient response.

C2 should be used whenever long wires are used to connect to the load, or when transient response is critical.

Note: Pin 3 electrically connected to case.

High Stability Regulator*



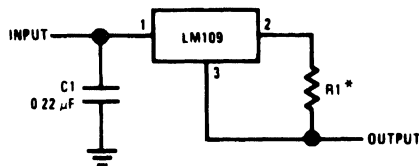
*Regulation better than 0.01%, load, line and temperature, can be obtained.

†Determines zener current. May be adjusted to minimize thermal drift.

‡Solid tantalum.

TL/H/7138-5

Current Regulator



*Determines output current. If wirewound resistor is used, bypass with 0.1 μF.

TL/H/7138-6

LM117A/LM117/LM317A/LM317

3-Terminal Adjustable Regulator

General Description

The LM117 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 1.5A over a 1.2V to 37V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM117 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., avoid short-circuiting the output.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment pin and output, the LM117 can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping

the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

For applications requiring greater output current, see LM150 series (3A) and LM138 series (5A) data sheets. For the negative complement, see LM137 series data sheet.

LM117 Series Packages and Power Capability

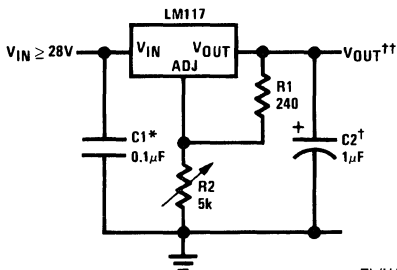
Part Number Suffix	Package	Rated Power Dissipation	Design Load Current
K	TO-3	20W	1.5A
H	TO-39	2W	0.5A
T	TO-220	20W	1.5A
MP	TO-202	2W	0.5A
E	LCC	2W	0.5A

Features

- Guaranteed 1% output voltage tolerance (LM117A, LM317A)
- Guaranteed max. 0.01%/V line regulation (LM117A, LM317A)
- Guaranteed max. 0.3% load regulation (LM117A, LM117)
- Guaranteed 1.5A output current
- Adjustable output down to 1.2V
- Current limit constant with temperature
- P+ Product Enhancement tested
- 80 dB ripple rejection
- Output is short-circuit protected

Typical Applications

1.2V-25V Adjustable Regulator



TL/H/9063-1

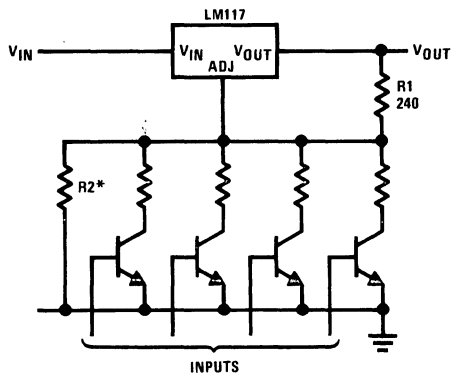
Full output current not available at high input-output voltages

*Needed if device is more than 6 inches from filter capacitors.

†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

$$\dagger\dagger V_{OUT} = 1.25V \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ}(R_2)$$

Digitally Selected Outputs



TL/H/9063-2

*Sets maximum V_{OUT}

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 2)

Power Dissipation	Internally Limited
Input-Output Voltage Differential	+40V, -0.3V
Storage Temperature	-65°C to +150°C
Lead Temperature	
Metal Package (Soldering, 10 seconds)	300°C
Plastic Package (Soldering, 4 seconds)	260°C
ESD Tolerance (Note 5)	3 kV

Operating Temperature Range

LM117A/LM117	-55°C ≤ T _J ≤ +150°C
LM317A	-40°C ≤ T _J ≤ +125°C
LM317	0°C ≤ T _J ≤ +125°C

Preconditioning

Thermal Limit Burn-In All Devices 100%

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, V_{IN} - V_{OUT} = 5V, and I_{OUT} = 10 mA. (Note 3)

Parameter	Conditions	LM117A (Note 2)			LM117 (Note 2)			Units	
		Min	Typ	Max	Min	Typ	Max		
Reference Voltage		1.238	1.250	1.262				V	
	3V ≤ (V _{IN} - V _{OUT}) ≤ 40V, 10 mA ≤ I _{OUT} ≤ I _{MAX} , P ≤ P _{MAX}	1.225	1.250	1.270	1.20	1.25	1.30	V	
Line Regulation	3V ≤ (V _{IN} - V _{OUT}) ≤ 40V (Note 4)		0.005	0.01		0.01	0.02	%/V	
			0.01	0.02		0.02	0.05	%/V	
Load Regulation	10 mA ≤ I _{OUT} ≤ I _{MAX} (Note 4)		0.1	0.3		0.1	0.3	%	
			0.3	1		0.3	1	%	
Thermal Regulation	20 ms Pulse		0.03	0.07		0.03	0.07	%/W	
Adjustment Pin Current			50	100		50	100	μA	
Adjustment Pin Current Change	10 mA ≤ I _{OUT} ≤ I _{MAX} 3V ≤ (V _{IN} - V _{OUT}) ≤ 40V		0.2	5		0.2	5	μA	
Temperature Stability	T _{MIN} ≤ T _J ≤ T _{MAX}		1			1		%	
Minimum Load Current	(V _{IN} - V _{OUT}) = 40V		3.5	5		3.5	5	mA	
Current Limit	(V _{IN} - V _{OUT}) ≤ 15V	K Package	1.5	2.2	3.4	1.5	2.2	3.4	A
		H, K Packages	0.5	0.8	1.8	0.5	0.8	1.8	A
	(V _{IN} - V _{OUT}) = 40V	K Package	0.3	0.4		0.3	0.4		A
		H, K Packages	0.15	0.2		0.15	0.2		A
RMS Output Noise, % of V _{OUT}	10 Hz ≤ f ≤ 10 kHz		0.003			0.003		%	
Ripple Rejection Ratio	V _{OUT} = 10V, f = 120 Hz, C _{ADJ} = 0 μF		65			65		dB	
	V _{OUT} = 10V, f = 120 Hz, C _{ADJ} = 10 μF		66	80		66	80	dB	
Long-Term Stability	T _J = 125°C, 1000 hrs		0.3	1		0.3	1	%	
Thermal Resistance, Junction-to-Case	K Package		2.3	3		2.3	3	°C/W	
	H Package		12	15		12	15	°C/W	
	E Package		5					°C/W	
Thermal Resistance, Junction-to-Ambient (No Heat Sink)	K Package		35			35		°C/W	
	H Package		140			140		°C/W	
	E Package		88					°C/W	

Electrical Characteristics (Continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, $V_{IN} - V_{OUT} = 5\text{V}$, and $I_{OUT} = 10\text{mA}$. (Note 3)

Parameter	Conditions	LM317A			LM317			Units
		Min	Typ	Max	Min	Typ	Max	
Reference Voltage		1.238	1.250	1.262				V
	$3\text{V} \leq (V_{IN} - V_{OUT}) \leq 40\text{V}$, $10\text{mA} \leq I_{OUT} \leq I_{MAX}$, $P \leq P_{MAX}$	1.225	1.250	1.270	1.20	1.25	1.30	V
Line Regulation	$3\text{V} \leq (V_{IN} - V_{OUT}) \leq 40\text{V}$ (Note 4)		0.005	0.01		0.01	0.04	%/V
			0.01	0.02		0.02	0.07	%/V
Load Regulation	$10\text{mA} \leq I_{OUT} \leq I_{MAX}$ (Note 4)		0.1	0.5		0.1	0.5	%
			0.3	1		0.3	1.5	%
Thermal Regulation	20 ms Pulse		0.04	0.07		0.04	0.07	%/W
Adjustment Pin Current			50	100		50	100	μA
Adjustment Pin Current Change	$10\text{mA} \leq I_{OUT} \leq I_{MAX}$ $3\text{V} \leq (V_{IN} - V_{OUT}) \leq 40\text{V}$		0.2	5		0.2	5	μA
Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		1			1		%
Minimum Load Current	$(V_{IN} - V_{OUT}) = 40\text{V}$		3.5	10		3.5	10	mA
Current Limit	$(V_{IN} - V_{OUT}) \leq 15\text{V}$ K, T Packages		1.5	2.2		1.5	2.2	A
	H, P Packages		0.5	0.8		0.5	0.8	A
	$(V_{IN} - V_{OUT}) = 40\text{V}$ K, T Packages	0.15	0.4		0.15	0.4		A
	H, P Packages	0.075	0.2		0.075	0.2		A
RMS Output Noise, % of V_{OUT}	$10\text{Hz} \leq f \leq 10\text{kHz}$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = 10\text{V}$, $f = 120\text{Hz}$, $C_{ADJ} = 0\mu\text{F}$		65			65		dB
	$V_{OUT} = 10\text{V}$, $f = 120\text{Hz}$, $C_{ADJ} = 10\mu\text{F}$	66	80		66	80		dB
Long-Term Stability	$T_J = 125^\circ\text{C}$, 1000 hrs		0.3	1		0.3	1	%
Thermal Resistance, Junction-to-Case	K Package		2.3	3		2.3	3	$^\circ\text{C/W}$
	H Package		12	15		12	15	$^\circ\text{C/W}$
	T Package		4	5		4		$^\circ\text{C/W}$
	P Package		7			7		$^\circ\text{C/W}$
Thermal Resistance, Junction-to-Ambient (No Heat Sink)	K Package		35			35		$^\circ\text{C/W}$
	H Package		140			140		$^\circ\text{C/W}$
	T Package		50			50		$^\circ\text{C/W}$
	P Package		80			80		$^\circ\text{C/W}$

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed.

Note 2: Refer to RETS117AH drawing for the LM117AH, the RETS117H drawing for the LM117H, the RETS117AK drawing for the LM117AK, or the RETS117K for the LM117K military specifications.

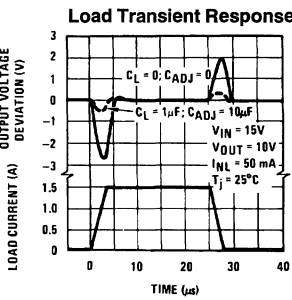
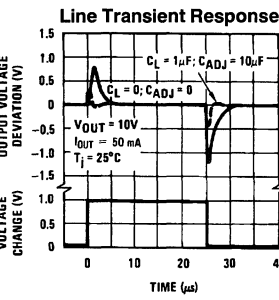
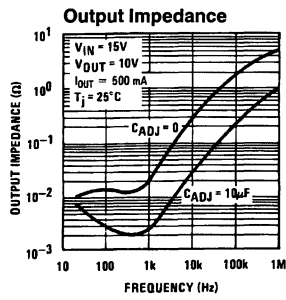
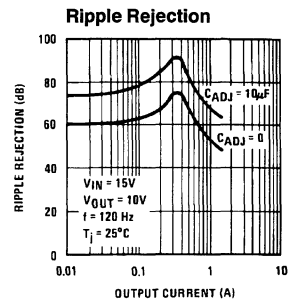
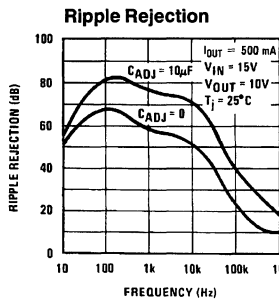
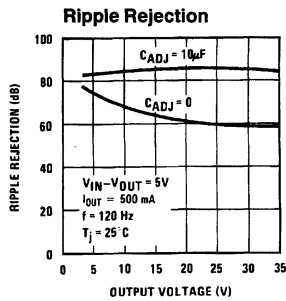
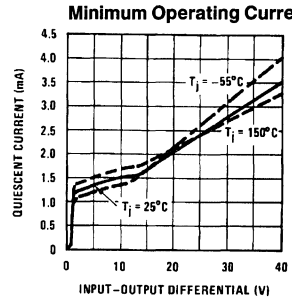
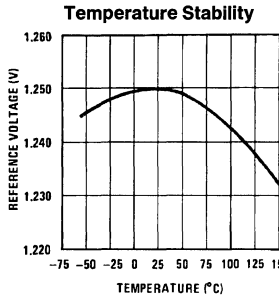
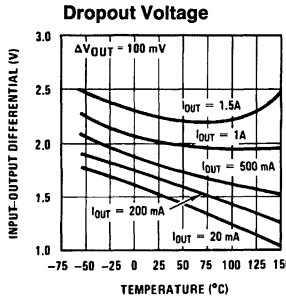
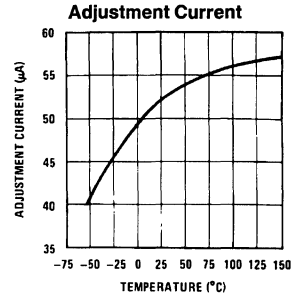
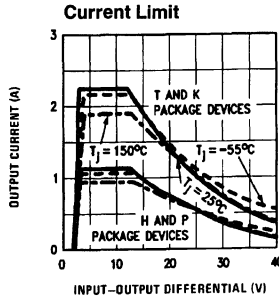
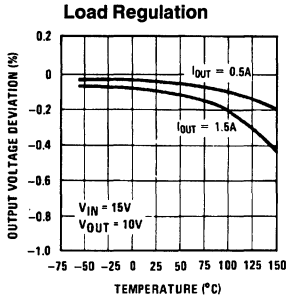
Note 3: Although power dissipation is internally limited, these specifications are applicable for maximum power dissipations of 2W for the TO-39 and TO-202, and 20W for the TO-3 and TO-220. I_{MAX} is 1.5A for the TO-3 and TO-220 packages and 0.5A for the TO-39 and TO-202 packages. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 4: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

Note 5: Human body model, 100 pF discharged through a 1.5 k Ω resistor.

Typical Performance Characteristics

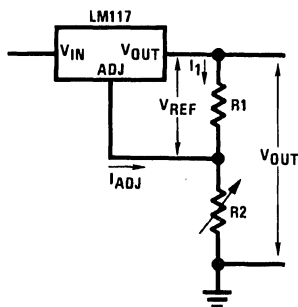
Output Capacitor = 0 μ F unless otherwise noted



Application Hints

In operation, the LM117 develops a nominal 1.25V reference voltage, V_{REF} , between the output and adjustment terminal. The reference voltage is impressed across program resistor R_1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R_2 , giving an output voltage of

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ} R_2$$



TL/H/9063-5

FIGURE 1

Since the 100 μ A current from the adjustment terminal represents an error term, the LM117 was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

External Capacitors

An input bypass capacitor is recommended. A 0.1 μ F disc or 1 μ F solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM117 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μ F bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10 μ F do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

In general, the best type of capacitors to use is solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μ F in aluminum electrolytic to equal 1 μ F solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μ F disc may seem to work better than a 0.1 μ F disc as a bypass.

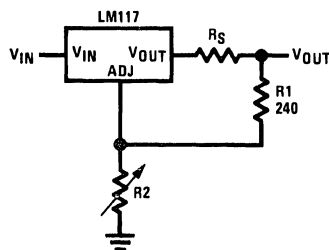
Although the LM117 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values be-

tween 500 pF and 5000 pF. A 1 μ F solid tantalum (or 25 μ F aluminum electrolytic) on the output swamps this effect and insures stability. Any increase of the load capacitance larger than 10 μ F will merely improve the loop stability and output impedance.

Load Regulation

The LM117 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240 Ω) should be tied directly to the output (case) of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05 Ω resistance between the regulator and load will have a load regulation due to line resistance of $0.05\Omega \times I_L$. If the set resistor is connected near the load the effective line resistance will be 0.05 Ω (1 + R_2/R_1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240 Ω set resistor.



TL/H/9063-6

FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. However, with the TO-5 package, care should be taken to minimize the wire length of the output lead. The ground of R_2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

Protection Diodes

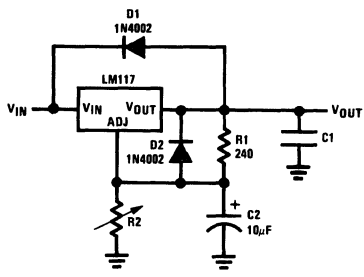
When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10 μ F capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN} . In the LM117, this discharge path is through a large junction that is able to sustain 15A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μ F or less, there is no need to use diodes.

Application Hints (Continued)

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM117 is a 50Ω resistor which limits the peak discharge

current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM117 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.



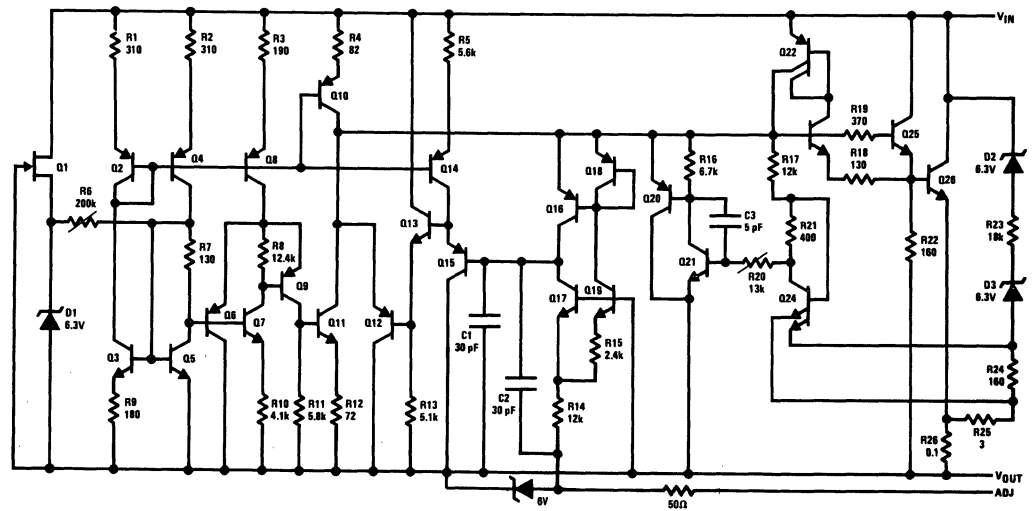
$$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1} \right) + I_{ADJ}R2$$

- D1 protects against C1
- D2 protects against C2

TL/H/9063-7

FIGURE 3. Regulator with Protection Diodes

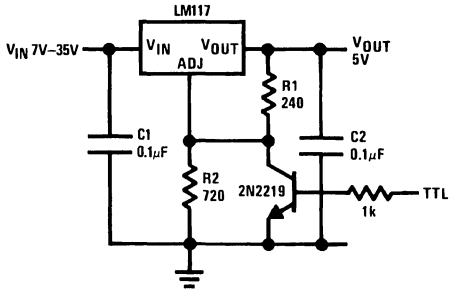
Schematic Diagram



TL/H/9063-8

Typical Applications (Continued)

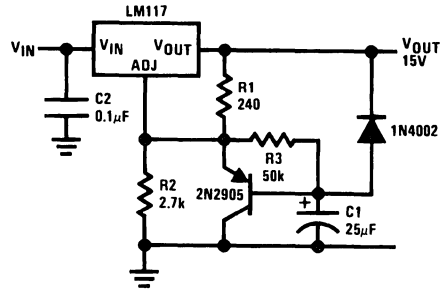
5V Logic Regulator with Electronic Shutdown*



*Min. output $\approx 1.2V$

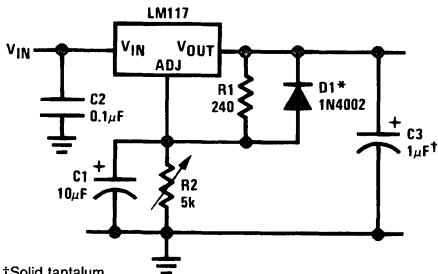
TL/H/9063-3

Slow Turn-On 15V Regulator



TL/H/9063-9

Adjustable Regulator with Improved Ripple Rejection

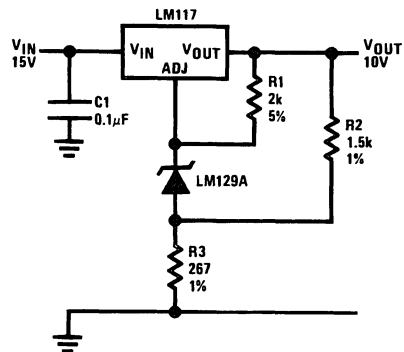


†Solid tantalum

*Discharges C1 if output is shorted to ground

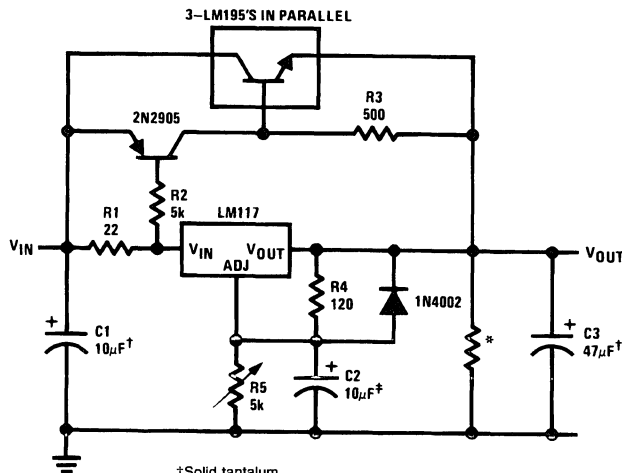
TL/H/9063-10

High Stability 10V Regulator



TL/H/9063-11

High Current Adjustable Regulator



†Solid tantalum

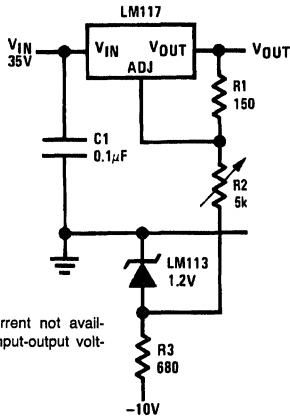
*Minimum load current = 30 mA

‡Optional—improves ripple rejection

TL/H/9063-12

Typical Applications (Continued)

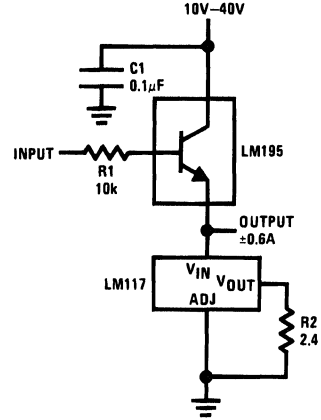
0 to 30V Regulator



Full output current not available at high input-output voltages

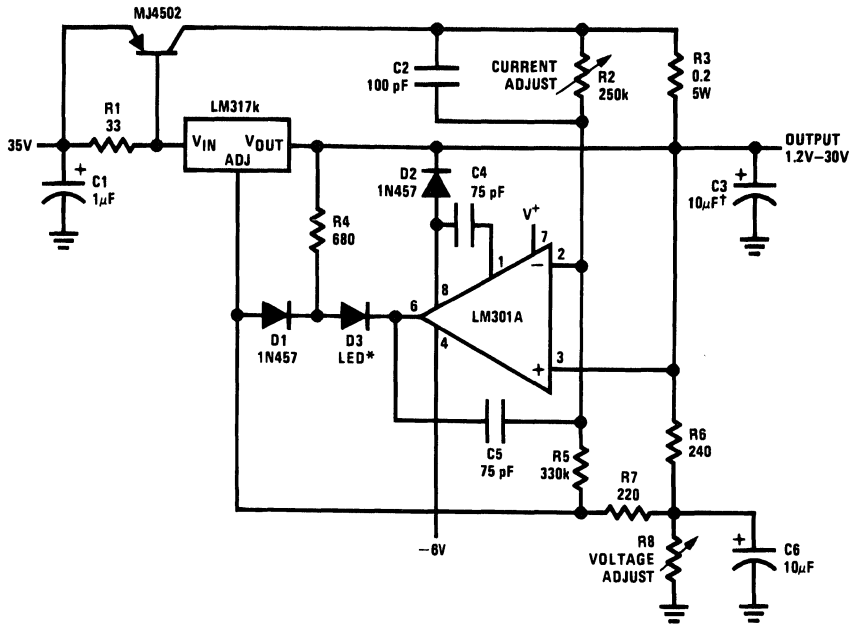
TL/H/9063-13

Power Follower



TL/H/9063-14

5A Constant Voltage/Constant Current Regulator



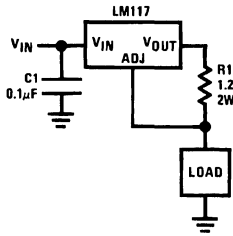
†Solid tantalum

*Lights in constant current mode

TL/H/9063-15

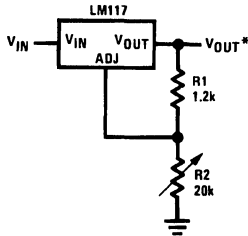
Typical Applications (Continued)

1A Current Regulator



TL/H/9063-16

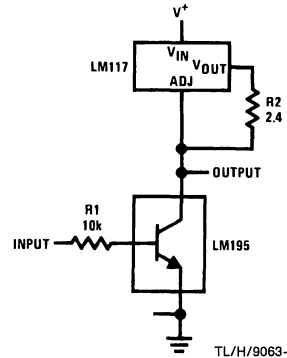
1.2V-20V Regulator with Minimum Program Current



TL/H/9063-17

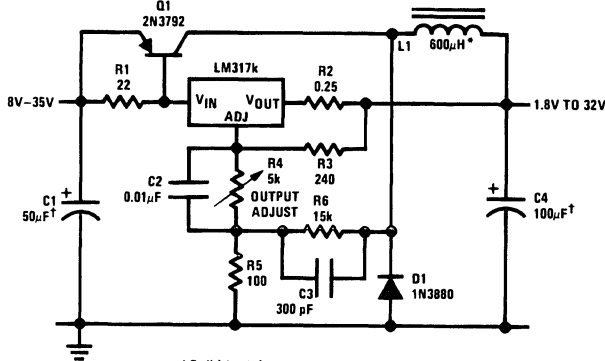
*Minimum load current ≈ 4 mA

High Gain Amplifier



TL/H/9063-18

Low Cost 3A Switching Regulator

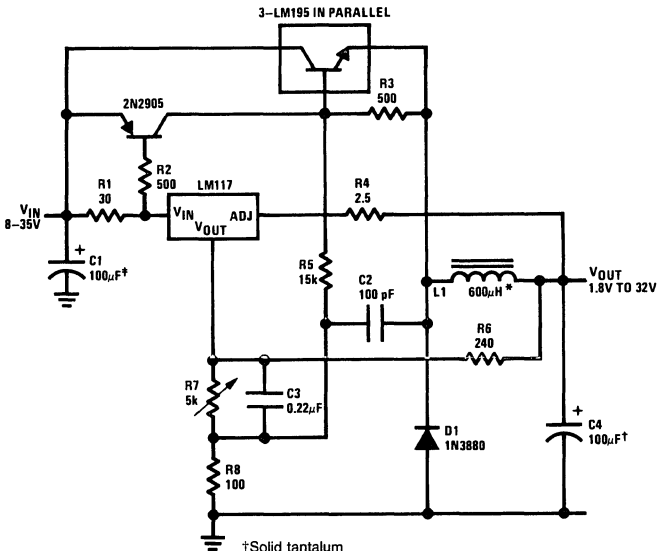


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9063-19

4A Switching Regulator with Overload Protection

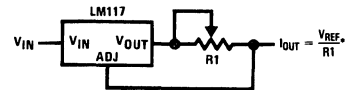


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9063-20

Precision Current Limiter

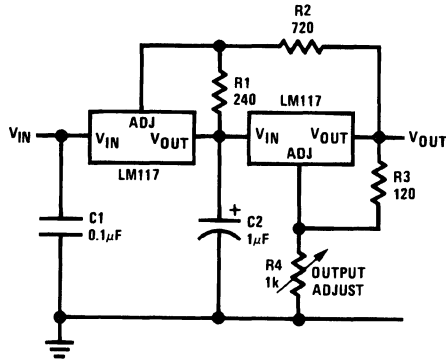


* $0.8\Omega \leq R1 \leq 120\Omega$

TL/H/9063-21

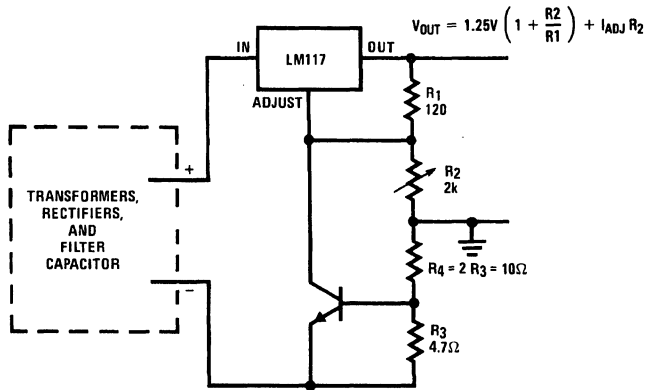
Typical Applications (Continued)

Tracking Preregulator



TL/H/9063-22

Current Limited Voltage Regulator



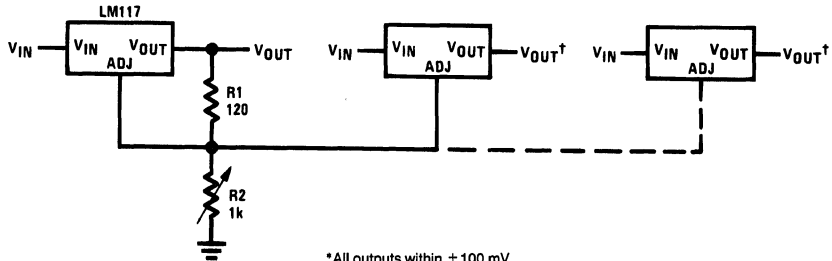
- Short circuit current is approximately $\frac{600 \text{ mV}}{R_3}$, or 120 mA

(Compared to LM117's higher current limit)

- At 50 mA output only 3/4 volt of drop occurs in R₃ and R₄

TL/H/9063-23

Adjusting Multiple On-Card Regulators with Single Control*



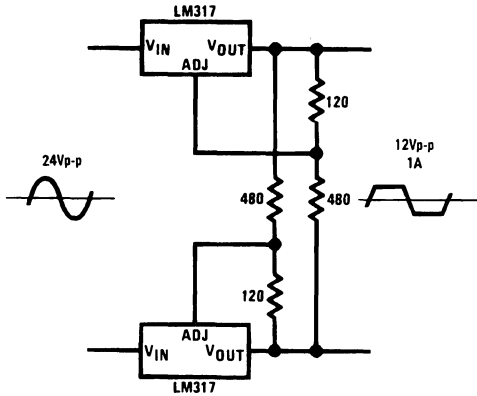
*All outputs within ± 100 mV

†Minimum load—10 mA

TL/H/9063-24

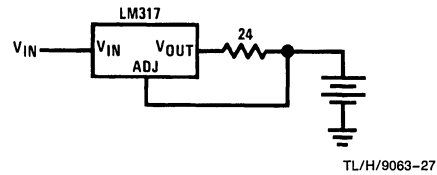
Typical Applications (Continued)

AC Voltage Regulator



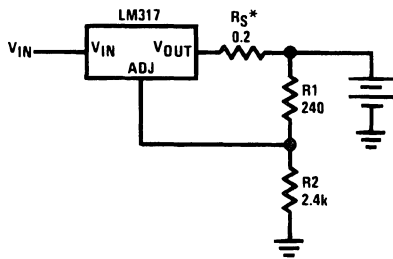
TL/H/9063-25

50 mA Constant Current Battery Charger



TL/H/9063-27

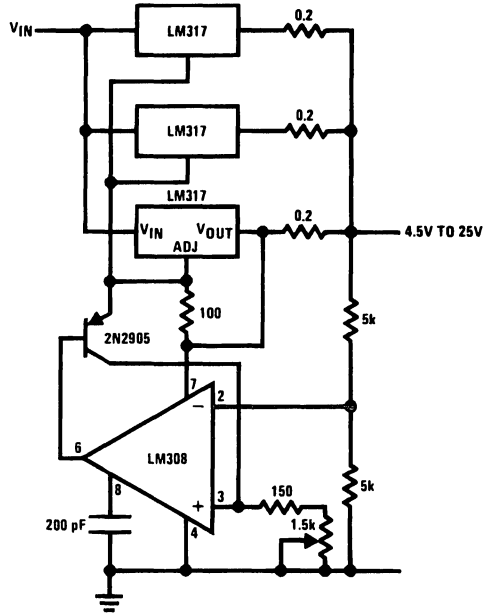
12V Battery Charger



TL/H/9063-26

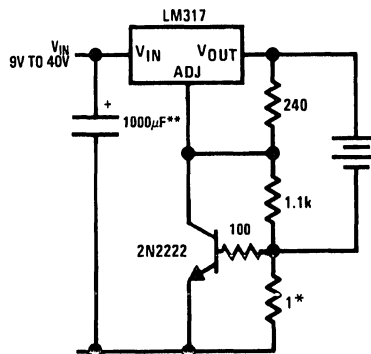
* R_S —sets output impedance of charger: $Z_{OUT} = R_S \left(1 + \frac{R_2}{R_1} \right)$
 Use of R_S allows low charging rates with fully charged battery.

Adjustable 4A Regulator



TL/H/9063-28

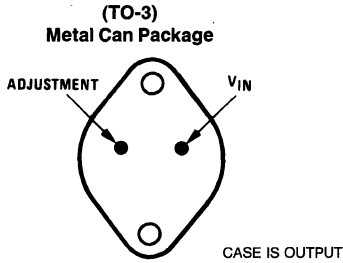
Current Limited 6V Charger



TL/H/9063-29

*Sets peak current (0.6A for 1Ω)
 **The 1000 μF is recommended to filter out input transients

Connection Diagrams



TL/H/9063-30

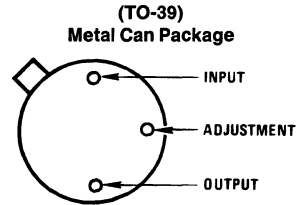
Bottom View

Steel Package

Order Number LM117AK STEEL, LM117AK/883,
LM117K STEEL, LM117K STEEL/883,
LM317AK STEEL or LM317K STEEL
See NS Package Number K02A

Aluminum Package

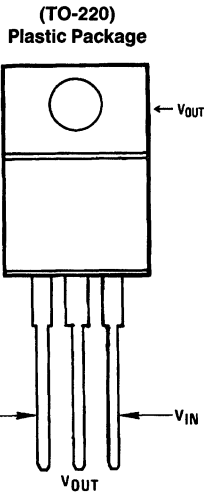
Order Number LM317KC
See NS Package Number KC02A



TL/H/9063-31

Bottom View

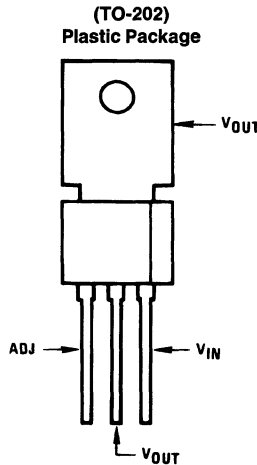
Order Number LM117AH, LM117AH/883, LM117H,
LM117H/883, LM317AH or LM317H
See NS Package Number H03A



TL/H/9063-32

Front View

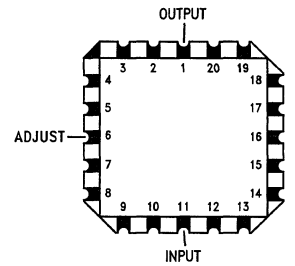
Order Number LM317AT or LM317T
See NS Package Number T03B



TL/H/9063-33

Front View

Order Number
LM317AMP or LM317MP
See NS Package Number P03A



TL/H/9063-34

Top View

Order Number LM117E/883
See NS Package Number E20A

LM117HV/LM317HV 3-Terminal Adjustable Regulator

General Description

The LM117HV/LM317HV are adjustable 3-terminal positive voltage regulators capable of supplying in excess of 1.5A over a 1.2V to 57V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117HV is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117HV series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejections ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM117HV is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e. do not short the output to ground.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM117HV can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

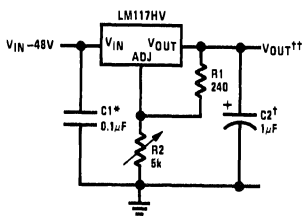
The LM117HVK STEEL and LM317HVK STEEL are packaged in standard TO-3 transistor packages, while the LM117HVH and LM317HVH are packaged in a solid Kovar base TO-39 transistor package. The LM317HVT uses a TO-220 plastic package. The LM117HV is rated for operation from -55°C to $+150^{\circ}\text{C}$, and the LM317HV from 0°C to $+125^{\circ}\text{C}$.

Features

- Adjustable output down to 1.2V
- Guaranteed 1.5A output current
- Line regulation typically 0.01%/V
- Load regulation typically 0.1%
- Current limit constant with temperature
- 100% electrical burn-in
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Output is short-circuit protected
- P+ Product Enhancement tested

Typical Applications

1.2V-45V Adjustable Regulator



TL/H/9082-1

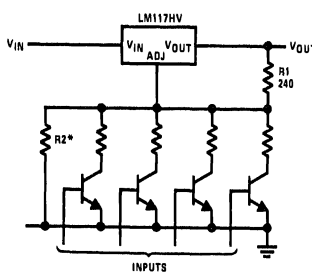
Full output current not available at high input-output voltages

†Optional—Improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is more than 6 inches from filter capacitors.

$$\dagger\dagger V_{\text{OUT}} = 1.25\text{V} \left(1 + \frac{R_2}{R_1} \right) + I_{\text{ADJ}} R_2$$

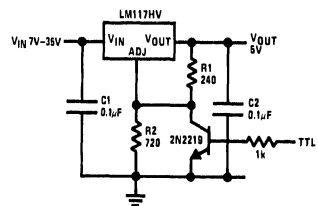
Digitally Selected Outputs



TL/H/9082-2

*Sets maximum V_{OUT}

5V Logic Regulator with Electronic Shutdown*



TL/H/9082-3

*Min. output $\approx 1.2\text{V}$

1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 3)

Power Dissipation Internally limited
Input—Output Voltage Differential +60V, -0.3V

Operating Junction Temperature Range

LM117HV -55°C to +150°C
LM317HV 0°C to +125°C

Storage Temperature -65°C to +150°C

Lead Temperature (Soldering, 10 sec.) 300°C

ESD Tolerance (Note 4) 2000V

Electrical Characteristics (Note 1)

Parameter	Conditions	LM117HV			LM317HV			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	$T_J = 25^\circ\text{C}$, $3\text{V} \leq V_{IN} - V_{OUT} \leq 60\text{V}$ (Note 2) $I_L = 10\text{mA}$		0.01	0.02		0.01	0.04	%/V
Load Regulation	$T_J = 25^\circ\text{C}$, $10\text{mA} \leq I_{OUT} \leq I_{MAX}$		0.1	0.3		0.1	0.5	%
Thermal Regulation	$T_J = 25^\circ\text{C}$, 20 ms Pulse		0.03	0.07		0.04	0.07	%/W
Adjustment Pin Current			50	100		50	100	μA
Adjustment Pin Current Change	$10\text{mA} \leq I_L \leq I_{MAX}$ $3.0\text{V} \leq (V_{IN} - V_{OUT}) \leq 60\text{V}$		0.2	5		0.2	5	μA
Reference Voltage	$3.0\text{V} \leq (V_{IN} - V_{OUT}) \leq 60\text{V}$, (Note 3) $10\text{mA} \leq I_{OUT} \leq I_{MAX}$, $P \leq P_{MAX}$	1.20	1.25	1.30	1.20	1.25	1.30	V
Line Regulation	$3.0\text{V} \leq (V_{IN} - V_{OUT}) \leq 60\text{V}$, $I_L = 10\text{mA}$, (Note 2)		0.02	0.05		0.02	0.07	%/V
Load Regulation	$10\text{mA} \leq I_{OUT} \leq I_{MAX}$ (Note 2)		0.3	1		0.3	1.5	%
Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		1			1		%
Minimum Load Current	$(V_{IN} - V_{OUT}) = 60\text{V}$		3.5	7		3.5	12	mA
Current Limit	$(V_{IN} - V_{OUT}) \leq 15\text{V}$ K, T Packages H Package $(V_{IN} - V_{OUT}) \leq 60\text{V}$ K, T Packages H Package	1.5	2.2	3.5	1.5	2.2	3.7	A
		0.5	0.8	1.8	0.5	0.8	1.9	A
			0.3			0.3		A
			0.03			0.03		A
RMS Output Noise, % of V_{OUT}	$T_J = 25^\circ\text{C}$, $10\text{Hz} \leq f \leq 10\text{kHz}$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = 10\text{V}$, $f = 120\text{Hz}$ $C_{ADJ} = 10\mu\text{F}$	66	65 80		66	65 80		dB dB
Long-Term Stability	$T_J = 125^\circ\text{C}$		0.3	1		0.3	1	%
Thermal Resistance, Junction to Case	H Package		12	15		12	15	$^\circ\text{C}/\text{W}$
	T Package					4	5	$^\circ\text{C}/\text{W}$
	K Package		2.3	3		2.3	3	$^\circ\text{C}/\text{W}$
Thermal Resistance, Junction to Ambient (no heat sink)	H Package		140			140		$^\circ\text{C}/\text{W}$
	T Package					50		$^\circ\text{C}/\text{W}$
	K Package		35			35		$^\circ\text{C}/\text{W}$

Note 1: Unless otherwise specified, these specifications apply: $-55^\circ\text{C} \leq T_J \leq +150^\circ\text{C}$ for the LM117HV, and $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ for the LM317HV; $V_{IN} - V_{OUT} = 5\text{V}$ and $I_{OUT} = 0.1\text{A}$ for the TO-39 package and $I_{OUT} = 0.5\text{A}$ for the TO-3 and TO-220 packages. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-39 and 20W for the TO-3 and TO-220. I_{MAX} is 1.5A for the TO-3 and TO-220 and 0.5A for the TO-39 package.

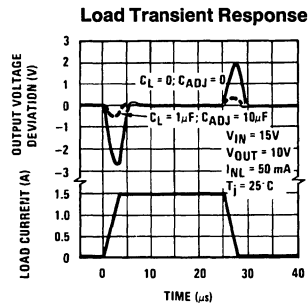
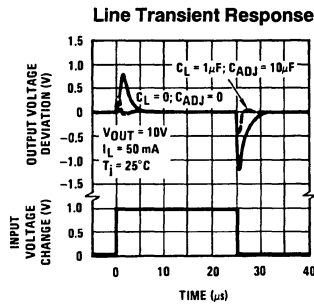
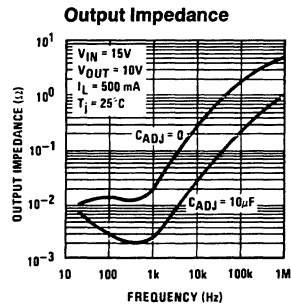
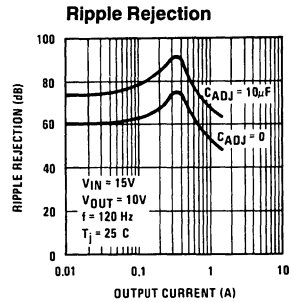
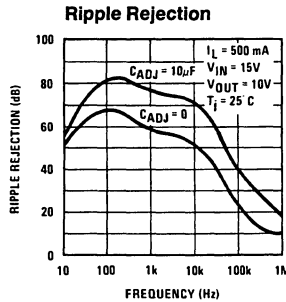
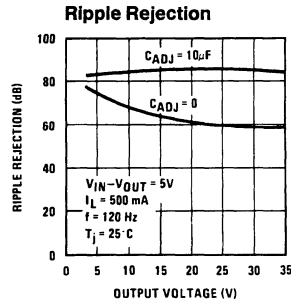
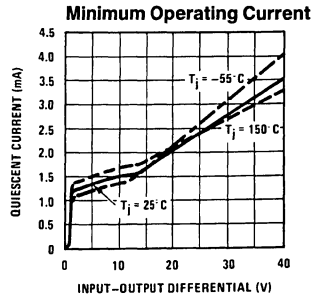
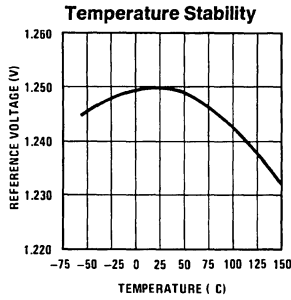
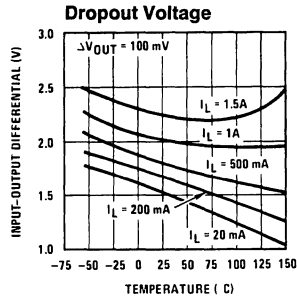
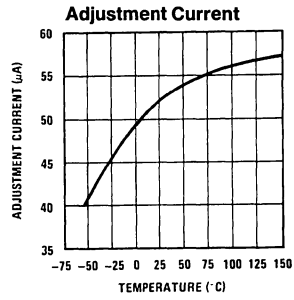
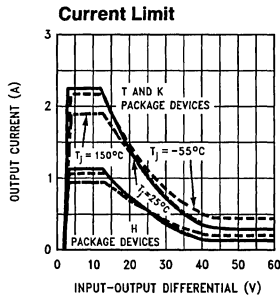
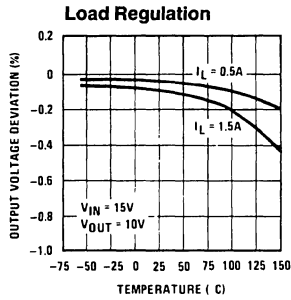
Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Note 3: Refer to RETS117HVH for LM117HVH or RETS117HVK for LM117HVK military specifications.

Note 4: Human body model, 1.5 k Ω in series with 100 pF.

Typical Performance Characteristics

Output capacitor = 0 μ F unless otherwise noted.



TL/H/9062-4

Application Hints

In operation, the LM117HV develops a nominal 1.25V reference voltage, V_{REF} , between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ} R_2$$

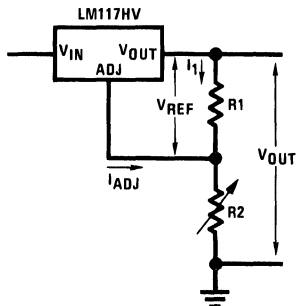


FIGURE 1

TL/H/9062-5

Since the 100 μ A current from the adjustment terminal represents an error term, the LM117HV was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

External Capacitors

An input bypass capacitor is recommended. A 0.1 μ F disc or 1 μ F solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM117HV to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μ F bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10 μ F do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

In general, the best type of capacitors to use are solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μ F in aluminum electrolytic to equal 1 μ F solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μ F disc may seem to work better than a 0.1 μ F disc as a bypass.

Although the LM117HV is stable with no output capacitors, like any feedback circuit, certain values of external capaci-

tance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μ F solid tantalum (or 25 μ F aluminum electrolytic) on the output swamps this effect and insures stability. Any increase of load capacitance larger than 10 μ F will merely improve the loop stability and output impedance.

Load Regulation

The LM117HV is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240 Ω) should be tied directly to the output of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05 Ω resistance between the regulator and load will have a load regulation due to line resistance of $0.05\Omega \times I_L$. If the set resistor is connected near the load the effective line resistance will be 0.05 Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240 Ω set resistor.

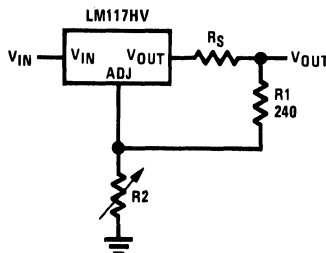


FIGURE 2. Regulator with Line Resistance in Output Lead

TL/H/9062-6

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. However, with the TO-5 package, care should be taken to minimize the wire length of the output lead. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

Protection Diodes

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10 μ F capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

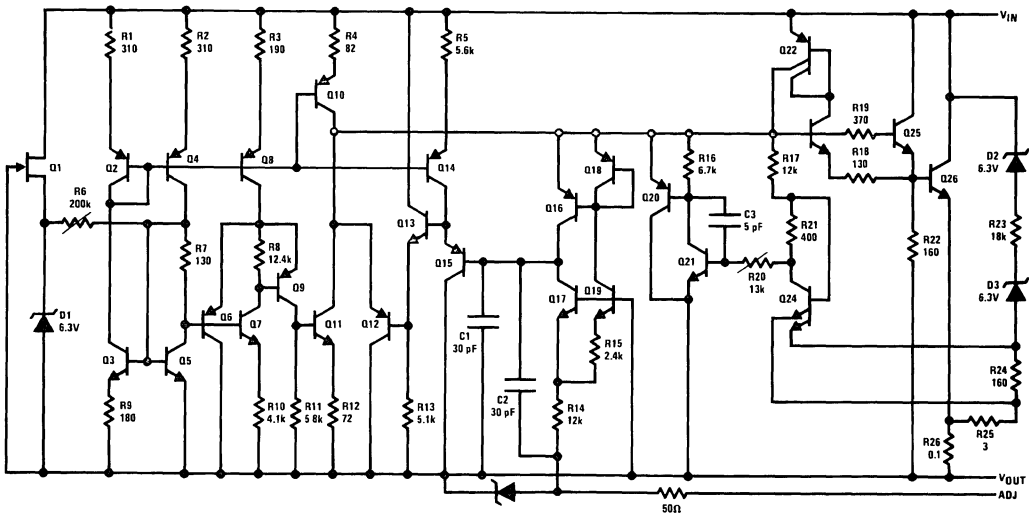
When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN} . In the LM117HV, this discharge path is through a large junction that is able to sustain 15A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μ F or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM117HV is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM117HV with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

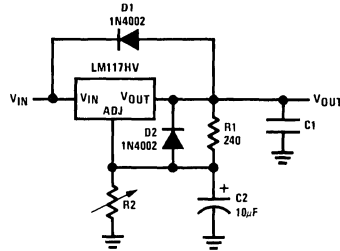
Current Limit

Internal current limit will be activated whenever the output current exceeds the limit indicated in the Typical Performance Characteristics. However, if during a short circuit condition the regulator's differential voltage exceeds the Absolute Maximum Rating of 60V (e.g. $V_{IN} \geq 60V$, $V_{OUT} = 0V$), internal junctions in the regulator may break down and the device may be damaged or fail. Failure modes range from an apparent open or short from input to output of the regulator, to a destroyed package (most common with the TO-220 package). To protect the regulator, the user is advised to be aware of voltages that may be applied to the regulator during fault conditions, and to avoid violating the Absolute Maximum Ratings.

Schematic Diagram



TL/H/9062-8



TL/H/9062-7

FIGURE 3. Regulator with Protection Diodes

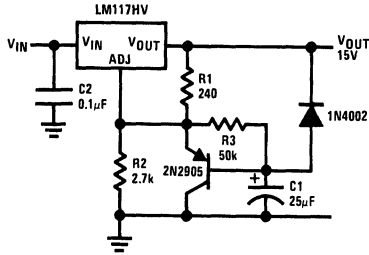
$$V_{OUT} = 1.25V \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ}R_2$$

D1 protects against C1

D2 protects against C2

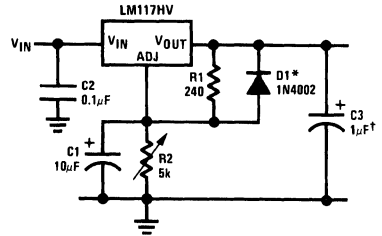
Typical Applications (Continued)

Slow Turn-On 15V Regulator



TL/H/9062-9

Adjustable Regulator with Improved Ripple Rejection

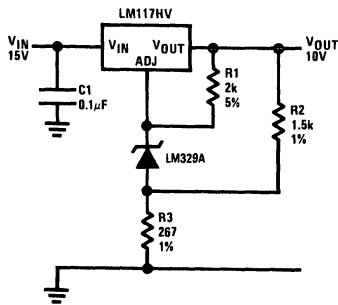


TL/H/9062-10

†Solid tantalum

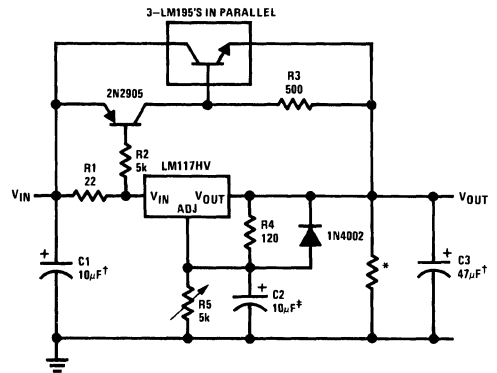
*Discharges C1 if output is shorted to ground

High Stability 10V Regulator



TL/H/9062-11

High Current Adjustable Regulator



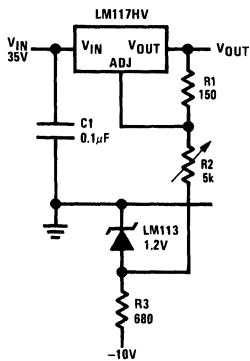
TL/H/9062-12

†Solid tantalum

*Minimum load current = 30 mA

‡Optional—improves ripple rejection

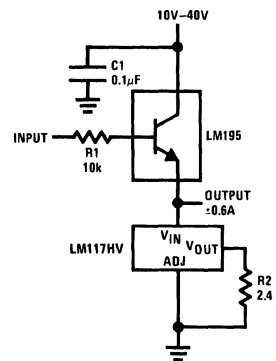
0 to 30V Regulator



TL/H/9062-13

Full output current not available at high input-output voltages

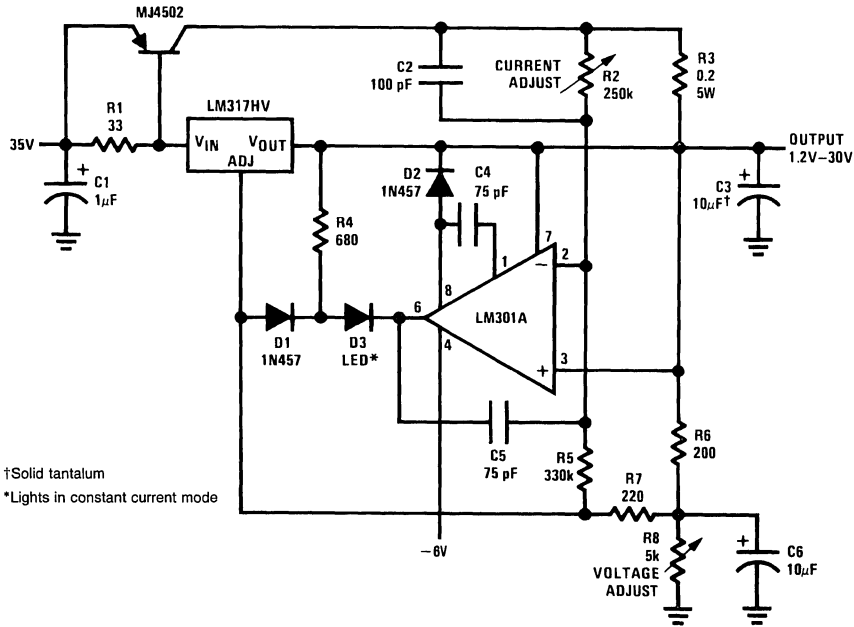
Power Follower



TL/H/9062-14

Typical Applications (Continued)

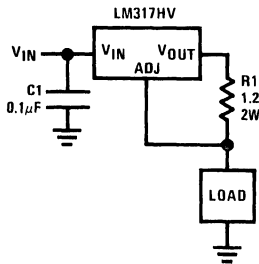
5A Constant Voltage/Constant Current Regulator



†Solid tantalum
*Lights in constant current mode

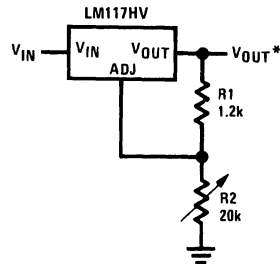
TL/H/9062-15

1A Current Regulator



TL/H/9062-16

1.2V-20V Regulator with Minimum Program Current



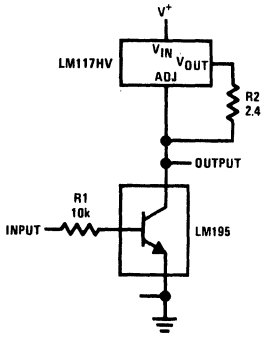
*Minimum load current ≈ 4 mA

TL/H/9062-17

1

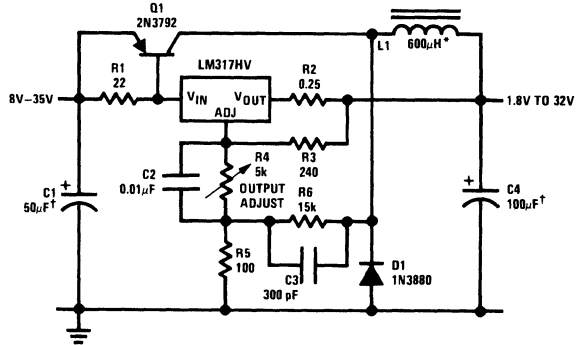
Typical Applications (Continued)

High Gain Amplifier



TL/H/9062-18

Low Cost 3A Switching Regulator

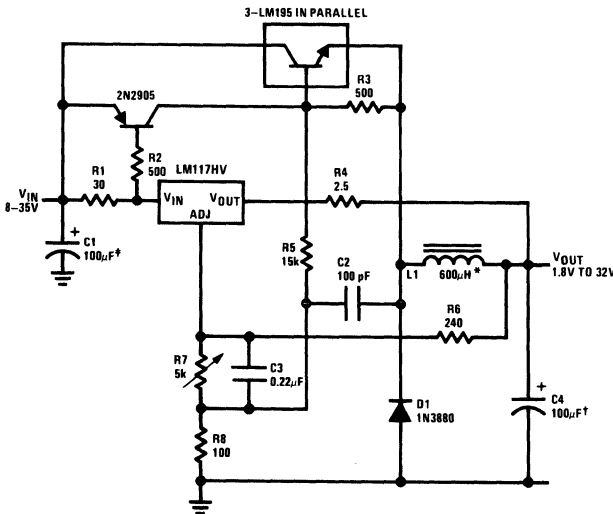


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9062-19

4A Switching Regulator with Overload Protection

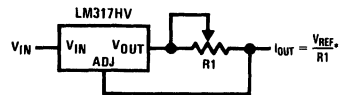


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9062-20

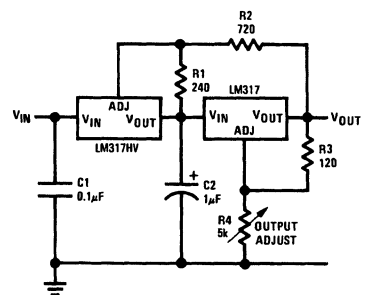
Precision Current Limiter



* $0.8\Omega \leq R1 \leq 120\Omega$

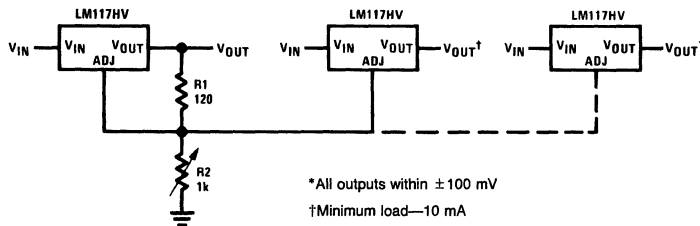
TL/H/9062-21

Tracking Preregulator



TL/H/9062-22

Adjustable Multiple On-Card Regulators with Single Control*



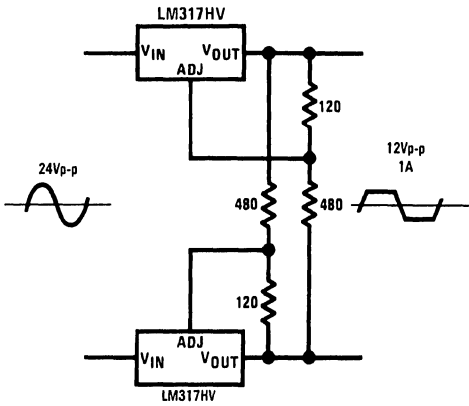
*All outputs within ± 100 mV

†Minimum load—10 mA

TL/H/9062-23

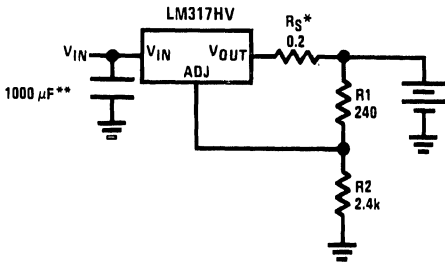
Typical Applications (Continued)

AC Voltage Regulator



TL/H/9082-24

12V Battery Charger



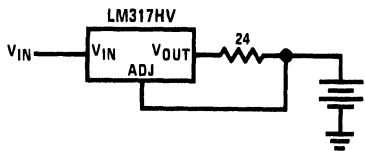
TL/H/9082-25

* R_S —sets output impedance of charger $Z_{OUT} = R_S \left(1 + \frac{R_2}{R_1} \right)$

Use of R_S allows low charging rates with fully charged battery.

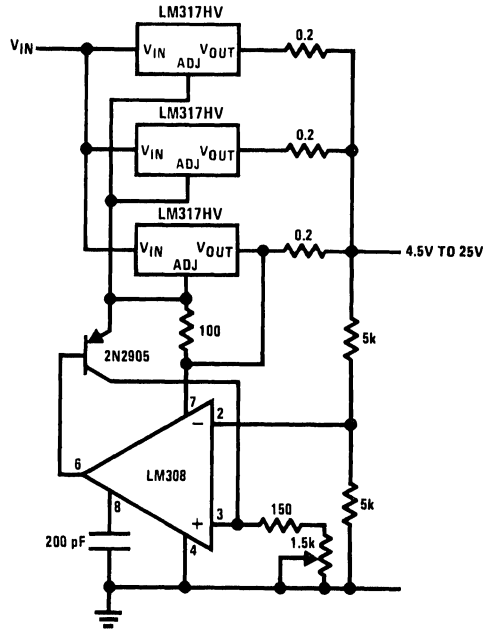
**The 1000 μF is recommended to filter out input transients

50 mA Constant Current Battery Charger



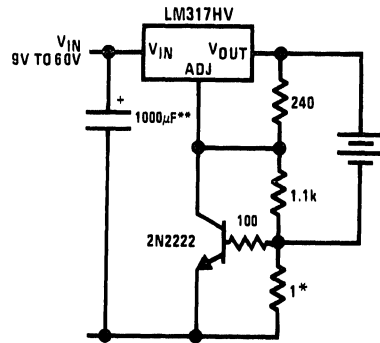
TL/H/9082-26

Adjustable 4A Regulator



TL/H/9082-27

Current Limited 6V Charger



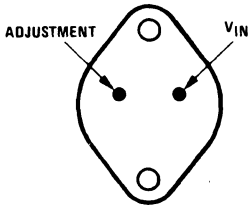
TL/H/9082-28

*Sets peak current (0.8A for 1 Ω)

**The 1000 μF is recommended to filter out input transients

Connection Diagrams (See Physical Dimension section for further information)

**(TO-3 Steel)
Metal Can Package**

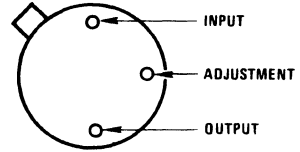


**Case is Output
Bottom View**

**Order Number LM117HVK STEEL,
LM317HVK STEEL
See NS Package Number K02A**

TL/H/9062-29

**(TO-39)
Metal Can Package**

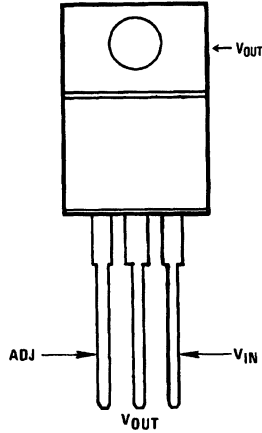


**Case is Output
Bottom View**

**Order Number LM117HVH,
or LM317HVH
See NS Package Number H03A**

TL/H/9062-30

**(TO-220)
Plastic Package**



Front View

**Order Number LM317HVT
See NS Package Number T03B**

TL/H/9062-31

LM120/LM320 Series 3-Terminal Negative Regulators

General Description

The LM120 series are three-terminal negative regulators with a fixed output voltage of $-5V$, $-12V$, and $-15V$, and up to 1.5A load current capability. Where other voltages are required, the LM137 and LM137HV series provide an output voltage range of $-1.2V$ to $-47V$.

The LM120 need only one external component—a compensation capacitor at the output, making them easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM120 Series immune to overload conditions. The regulators have current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shut-down prevents junction temperatures from exceeding safe limits during prolonged overloads.

Although primarily intended for fixed output voltage applications, the LM120 Series may be programmed for higher output voltages with a simple resistive divider. The low quiescent drain current of the devices allows this technique to be used with good regulation.

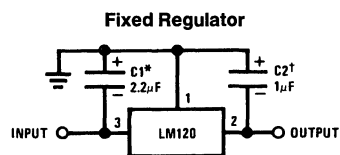
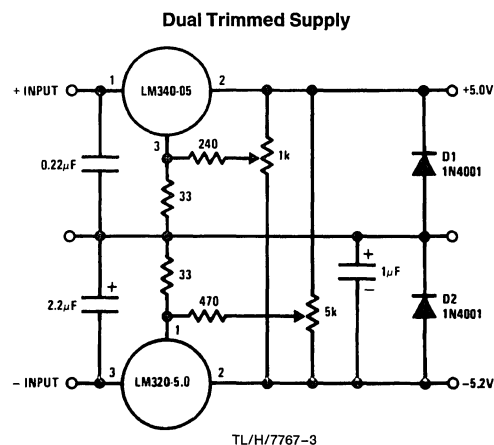
Features

- Preset output voltage error less than $\pm 3\%$
- Preset current limit
- Internal thermal shutdown
- Operates with input-output voltage differential down to 1V
- Excellent ripple rejection
- Low temperature drift
- Easily adjustable to higher output voltage

LM120 Series Packages and Power Capability

Device	Package	Rated Power Dissipation	Design Load Current
LM120/LM320	TO-3 (K)	20W	1.5A
	TO-39 (H)	2W	0.5A
LM320	TO-220 (T)	15W	1.5A
LM320M	TO-202 (P)	7.5W	0.5A

Typical Applications



*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may substituted. Values given may be increased without limit.

For output capacitance in excess of 100 μF , a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

— 5 Volt Regulators (Note 3)

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

Power Dissipation Internally Limited
Input Voltage -25V

Input-Output Voltage Differential 25V
Junction Temperatures See Note 1
Storage Temperature Range -65°C to +150°C
Lead Temperature (Soldering, 10 sec.) 300°C
Plastic 260°C

Electrical Characteristics

Order Numbers		Metal Can Package											Power Plastic Package						Units
		LM120K-5.0 (TO-3)			LM320K-5.0 (TO-3)			LM120H-5.0 (TO-39)			LM320H-5.0 (TO-39)		LM320T-5.0 (TO-220)			LM320MP-5.0 (TO-202)			
Design Output Current (I _D) Device Dissipation (P _D)		1.5A 20W			1.5A 20W			0.5A 2W			0.5A 2W		1.5A 15W			0.5A 7.5W			
Parameter	Conditions (Note 1)	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
Output Voltage	T _J = 25°C, V _{IN} = 10V, I _{LOAD} = 5 mA	-5.1	5	-4.9	-5.2	5	-4.8	-5.1	5	-4.9	-5.2	5	-4.8	-5.2	5	-4.8	-5.2	5	-4.8
Line Regulation	T _J = 25°C, I _{LOAD} = 5 mA, V _{MIN} ≤ V _{IN} ≤ V _{MAX}		10	25		10	40		10	25		10	40		10	40		10	40
Input Voltage		-25		-7	-25		-7	-25		-7	-25		-7	-25		-7.5	-25		-7.5
Ripple Rejection	f = 120 Hz	54	64		54	64		54	64		54	64		54	64		54	64	
Load Regulation, (Note 2)	T _J = 25°C, V _{IN} = 10V, 5 mA ≤ I _{LOAD} ≤ I _D		50	75		60	100		30	50		30	50		50	100		40	100
Output Voltage, (Note 1)	-7.5V ≤ V _{IN} ≤ V _{MAX} , 5 mA ≤ I _{LOAD} ≤ I _D , P ≤ P _D	-5.20		-4.80	-5.25		-4.75	-5.20		-4.80	-5.25		-4.75	-5.25		-4.75	-5.25		-4.75
Quiescent Current	V _{MIN} ≤ V _{IN} ≤ V _{MAX}		1	2		1	2		1	2		1	2		1	2		1	2
Quiescent Current Change	T _J = 25°C V _{MIN} ≤ V _{IN} ≤ V _{MAX} 5 mA ≤ I _{LOAD} ≤ I _D		0.1	0.4		0.1	0.4		0.05	0.4		0.05	0.4		0.1	0.4		0.05	0.3
Output Noise Voltage	T _A = 25°C, C _L = 1 μF, I _L = 5 mA, V _{IN} = 10V, 10 Hz ≤ f ≤ 100 kHz		150		150		150		150		150		150		150		150		150
Long Term Stability			5	50		5	50		5	50		5	50		10			10	
Thermal Resistance Junction to Case Junction to Ambient				3			3			Note 4			Note 4		4			12	
				35			35			Note 4			Note 4		50			70	

Note 1: This specification applies over -55°C ≤ T_J ≤ +150°C for the LM120 and 0°C ≤ T_J ≤ +125°C for the LM320.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to P_D.

Note 3: For -5V 3 amp regulators, see LM145 data sheet.

Note 4: Thermal resistance of typically 85°C/W (in 400 linear feet air flow), 224°C/W (in static air) junction to ambient, of typically 21°C/W junction to case.

Note 5: Refer to RETS120-5H drawing for LM120H-5.0 or RETS120-5K drawing for LM120-5K military specifications.

– 12 Volt Regulators

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Power Dissipation Internally Limited
Input Voltage –35V

Input-Output Voltage Differential 30V
Junction Temperatures See Note 1
Storage Temperature Range –65°C to +150°C
Lead Temperature (Soldering, 10 sec.) 300°C

Electrical Characteristics

Order Numbers		Metal Can Package											Power Plastic Package						Units		
		LM120K-12 (TO-3)			LM320K-12 (TO-3)			LM120H-12 (TO-39)			LM320H-12 (TO-39)			LM320T-12 (TO-220)			LM320MP-12 (TO-202)				
Design Output Current (I _D) Device Dissipation (P _D)		1A 20W			1A 20W			0.2A 2W			0.2A 2W			1A 15W			0.5A 7.5W				
Parameter	Conditions (Note 1)	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max		
Output Voltage	T _J = 25°C, V _{IN} = 17V, I _{LOAD} = 5 mA	-12.3	-12	-11.7	-12.4	-12	-11.6	-12.3	-12	-11.7	-12.4	-12	-11.6	-12.4	-12	-11.6	-12.5	-12	-11.5	V	
Line Regulation	T _J = 25°C, I _{LOAD} = 5 mA, V _{MIN} ≤ V _{IN} ≤ V _{MAX}		4	10		4	20		4	10		4	20		4	20		4	24	mV	
Input Voltage		-32		-14	-32		-14	-32		-14	-32		-14	-32		-14.5	-32		-14.5	V	
Ripple Rejection	f = 120 Hz	56	80		56	80		56	80		56	80		56	80		56	80		80	dB
Load Regulation, (Note 2)	T _J = 25°C, V _{IN} = 17V, 5 mA ≤ I _{LOAD} ≤ I _D		30	80		30	80		10	25		10	40		30	80		40	100	mV	
Output Voltage, (Note 1)	14.5V ≤ V _{IN} ≤ V _{MAX} , 5 mA ≤ I _{LOAD} ≤ I _D , P ≤ P _D	-12.5		-11.5	-12.6		-11.4	-12.5		-11.5	-12.6		-11.4	-12.6		-11.4	-12.6		-11.4	V	
Quiescent Current	V _{MIN} ≤ V _{IN} ≤ V _{MAX}		2	4		2	4		2	4		2	4		2	4		2	4	mA	
Quiescent Current Change	T _J = 25°C V _{MIN} ≤ V _{IN} ≤ V _{MAX} 5 mA ≤ I _{LOAD} ≤ I _D		0.1 0.1	0.4 0.4		0.1 0.1	0.4 0.4		0.05 0.03	0.4 0.4		0.05 0.03	0.4 0.4		0.1 0.1	0.4 0.4		0.05 0.04	0.3 0.25	mA mA	
Output Noise Voltage	T _A = 25°C, C _L = 1 μF, I _L = 5 mA, V _{IN} = 17V, 10 Hz ≤ f ≤ 100 kHz		400		400				400			400			400			400		μV	
Long Term Stability			12	120		12	120		12	120		12	120		24			24		mV	
Thermal Resistance Junction to Case Junction to Ambient				3 35			3 35			Note 3 Note 3			Note 3 Note 3		4 50			12 70		°C/W °C/W	

Note 1: This specification applies over –55°C ≤ T_J ≤ +150°C for the LM120 and 0°C ≤ T_J ≤ +125°C for the LM320.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to P_D.

Note 3: Thermal resistance of typically 85°C/W (in 400 linear feet/min air flow), 224°C/W (in static air) junction to ambient, of typically 21°C/W junction to case.

Note 4: Refer to RETS120H-12 drawing for LM120H-12 or RETS120-12K drawing for LM120K-12 military specifications.

— 15 Volt Regulators

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Power Dissipation Internally Limited

Input Voltage

LM120/LM320 -40V

LM320T/LM320MP -35V

Input-Output Voltage Differential 30V

Junction Temperatures See Note 1

Storage Temperature Range -65°C to +150°C

Lead Temperature (Soldering, 10 sec.) 300°C

Electrical Characteristics

Order Numbers		Metal Can Package										Power Plastic Package						Units	
		LM120K-15 (TO-3)			LM320K-15 (TO-3)			LM120H-15 (TO-39)			LM320H-15 (TO-39)			LM320T-15 (TO-220)			LM320MP-15 (TO-202)		
Design Output Current (I _D) Device Dissipation (P _D)		1A 20W			1A 20W			0.2A 2W			0.2A 2W			1A 15W			0.5A 7.5W		
Parameter	Conditions (Note 1)	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
Output Voltage	T _J = 25°C, V _{IN} = 20V, I _{LOAD} = 5 mA	-15.3	-15	-14.7	-15.4	-15	-14.6	-15.3	-15	-14.7	-15.4	-15	-14.6	-15.5	-15	-14.5	-15.6	-15	-14.4
Line Regulation	T _J = 25°C, I _{LOAD} = 5 mA, V _{MIN} ≤ V _{IN} ≤ V _{MAX}		5	10		5	20		5	10		5	20		5	20		5	30
Input Voltage		-35		-17	-35		-17	-35		-17	-35		-17	-35		-17.5	-35		-17.5
Ripple Rejection	f = 120 Hz	56	80		56	80		56	80		56	80		56	80		56	80	
Load Regulation, (Note 2)	T _J = 25°C, V _{IN} = 20V, 5 mA ≤ I _{LOAD} ≤ I _D		30	80		30	80		10	25		10	40		30	80		40	100
Output Voltage, (Note 1)	17.5V ≤ V _{IN} ≤ V _{MAX} , 5 mA ≤ I _{LOAD} ≤ I _D , P ≤ P _D	-15.5		-14.5	-15.6		-14.4	-15.5		-14.5	-15.6		-14.4	-15.7		-14.3	-15.7		-14.3
Quiescent Current	V _{MIN} ≤ V _{IN} ≤ V _{MAX}		2	4		2	4		2	4		2	4		2	4		2	4
Quiescent Current Change	T _J = 25°C V _{MIN} ≤ V _{IN} ≤ V _{MAX} 5 mA ≤ I _{LOAD} ≤ I _D		0.1	0.4		0.1	0.4		0.05	0.4		0.05	0.4		0.1	0.4		0.05	0.3
Output Noise Voltage	T _A = 25°C, C _L = 1 μF, I _L = 5 mA, V _{IN} = 20V, 10 Hz ≤ f ≤ 100 kHz		400		400				400		400			400			400		
Long Term Stability			15	150		15	150		15	150		15	150		30			30	
Thermal Resistance Junction to Case Junction to Ambient				3 35			3 35			Note 3 Note 3			Note 3 Note 3		4 50			12 70	

Note 1: This specification applies over -55°C ≤ T_J ≤ +150°C for the LM120 and 0°C ≤ T_J ≤ +125°C for the LM320.

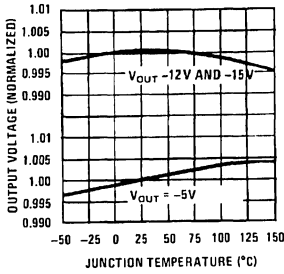
Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to P_D.

Note 3: Thermal resistance of typically 85°C/W (in 400 linear feet/min air flow), 224°C/W (in static air) junction to ambient, of typically 21°C/W junction to case.

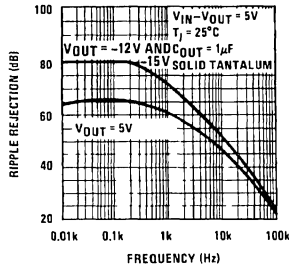
Note 4: Refer to RETS120-15H drawing for LM120H-15 or RETS120-15K drawing for LM120K-15 military specifications.

Typical Performance Characteristics

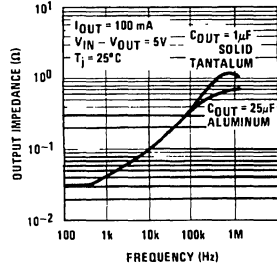
Output Voltage vs Temperature



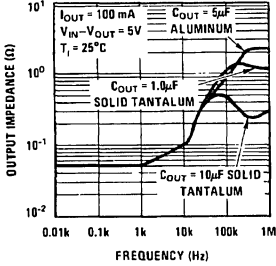
Ripple Rejection (All Types)



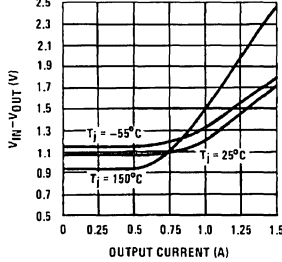
Output Impedance TO-3 and TO-220 Packages



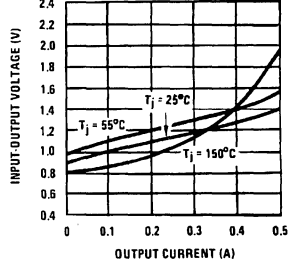
Output Impedance TO-5 and TO-202 Packages



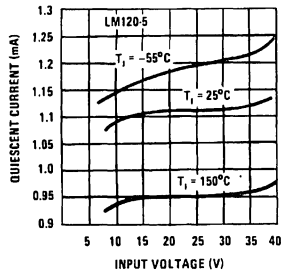
Minimum Input-Output Differential TO-3 and TO-220 Packages



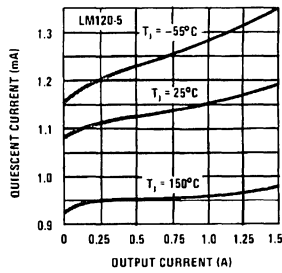
Minimum Input-Output Differential TO-5 and TO-202 Packages



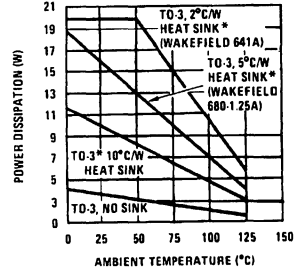
Quiescent Current vs Input Voltage



Quiescent Current vs Load Current



Maximum Average Power Dissipation (TO-3)

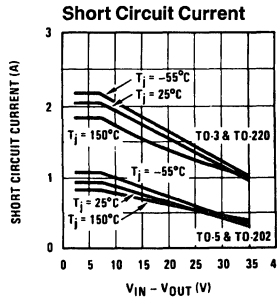
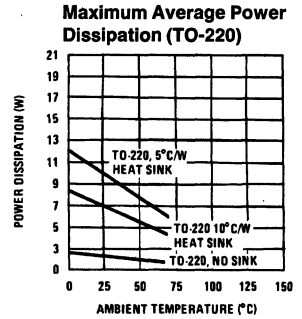
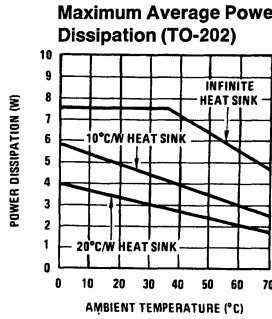
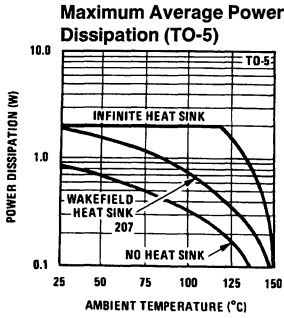


*These curves for LM120. Derate 25°C further for LM320.

TL/H/7767-4



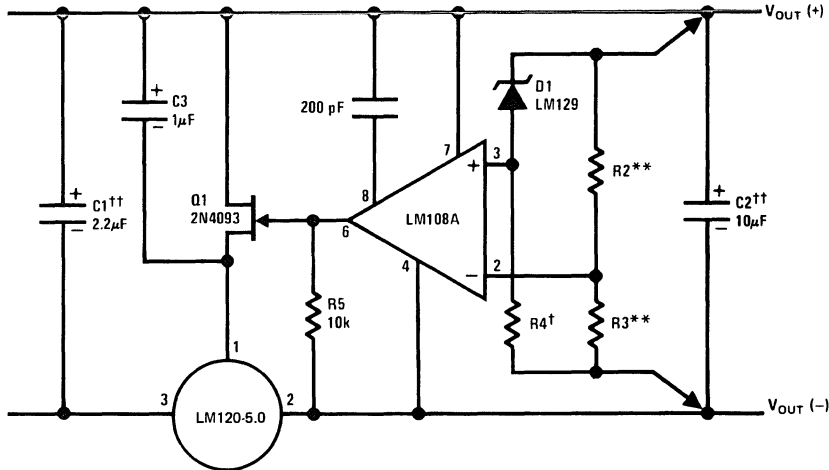
Typical Performance Characteristics (Continued)



TL/H/7767-5

Typical Applications (Continued)

High Stability 1 Amp Regulator



TL/H/7767-6

Lead and line regulation — 0.01% temperature stability — 0.2%

†Determines Zener current.

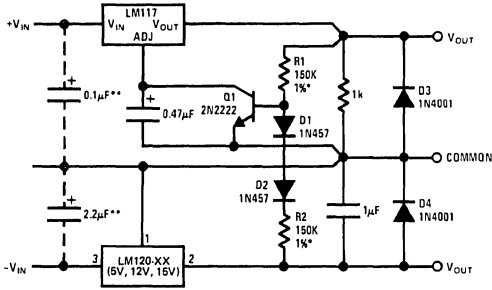
††Solid tantalum.

An LM120-12 or LM120-15 may be used to permit higher input voltages, but the regulated output voltage must be at least -15V when using the LM120-12 and -18V for the LM120-15.

**Select resistors to set output voltage. 2 ppm/°C tracking suggested.

Typical Applications (Continued)

Wide Range Tracking Regulator

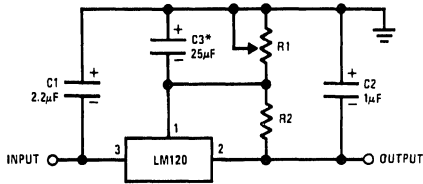


TL/H/7767-7

*Resistor tolerance of R1 and R2 determine matching of (+) and (-) inputs.

**Necessary only if raw supply capacitors are more than 3" from regulators. An LM3086N array may substitute for Q1, D1 and D2 for better stability and tracking. In the array diode transistors Q5 and Q4 (in parallel) make up D2; similarly, Q1 and Q2 become D1 and Q3 replaces the 2N2222.

Variable Output



TL/H/7767-9

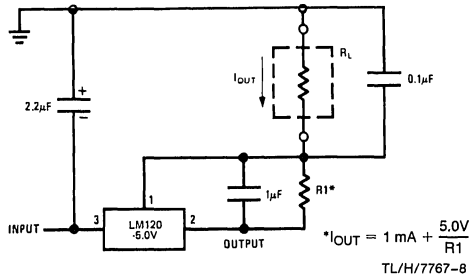
*Optional. Improves transient response and ripple rejection.

$$V_{OUT} = V_{SET} \frac{R1 + R2}{R2}$$

SELECT R2 AS FOLLOWS:

- LM120-5 - 300Ω
- LM120-12 - 750Ω
- LM120-15 - 1k

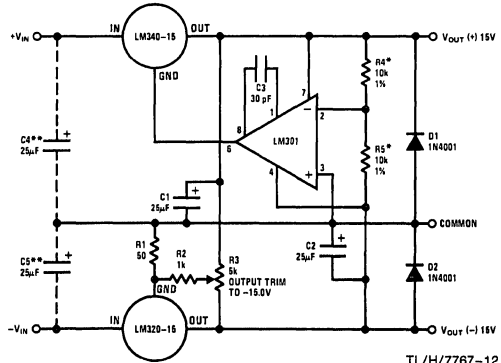
Current Source



$$*I_{OUT} = 1 \text{ mA} + \frac{5.0\text{V}}{R1}$$

TL/H/7767-8

± 15V, 1 Amp Tracking Regulators



TL/H/7767-12

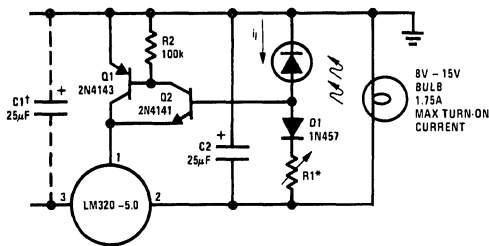
Performance (Typical)

Load Regulation at $\Delta I_L = 1 \text{ A}$	10 mV	1 mV
Output Ripple, $C_{IN} = 3000 \mu\text{F}$, $I_L = 1 \text{ A}$	100 μVrms	100 μVrms
Temperature Stability	+50 mV	+50 mV
Output Noise 10 Hz $\leq f \leq 10 \text{ kHz}$	150 μVrms	150 μVrms

*Resistor tolerance of R4 and R5 determine matching of (+) and (-) outputs.

**Necessary only if raw supply filter capacitors are more than 2" from regulators.

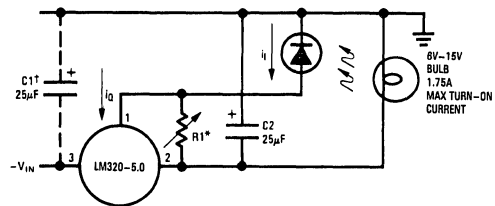
Light Controllers Using Silicon Photo Cells



TL/H/7767-10

*Lamp brightness increases until $i_L = 5\text{V}/R1$ (i_L can be set as low as 1 μA).

†Necessary only if raw supply filter capacitor is more than 2" from LM320MP.

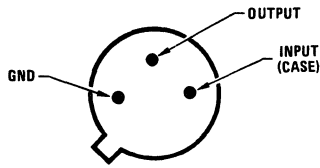


TL/H/7767-11

*Lamp brightness increases until $i_L = i_Q (1 \text{ mA}) + 5\text{V}/R1$.

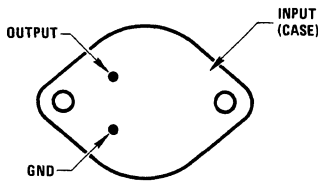
†Necessary only if raw supply filter capacitor is more than 2" from LM320.

Connection Diagrams



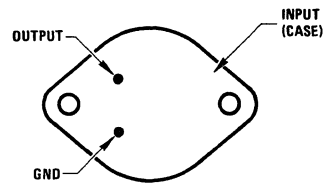
TL/H/7767-13

Metal Can Package TO-39 (H)
 Order Number LM120H-5.0,
 LM120H-12, LM120H-15, LM320H-
 5.0, LM320H-12 or LM320H-15
 See NS Package Number H03A



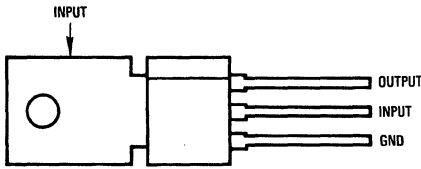
TL/H/7767-14

Steel Metal Can Package TO-3 (K)
 Order Number LM120K-5.0,
 LM120K-12, LM120K-15, LM320K-
 5.0, LM320K-12 or LM320K-15
 See NS Package Number K02A



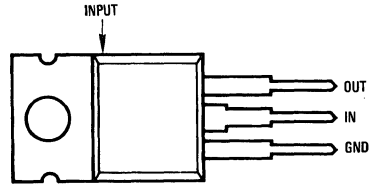
TL/H/7767-15

Aluminum Metal Can Package TO-3 (KC)
 Order Number LM320KC-5.0,
 LM320KC-12 or LM320KC-15
 See NS Package Number KC02A



TL/H/7767-16

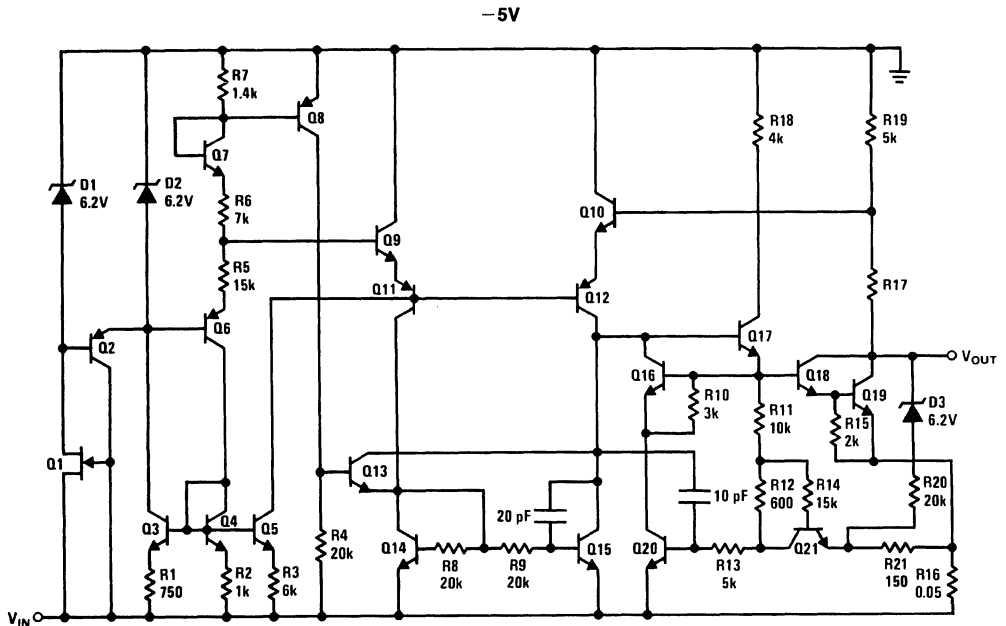
Power Package TO-202 (P)
 Order Number LM320MP-5.0,
 LM320MP-12 or LM320MP-15
 See NS Package Number P03A



TL/H/7767-17

Power Package TO-220 (T)
 Order Number LM320T-5.0, LM320T-12 or LM320T-15
 See NS Package Number T03B

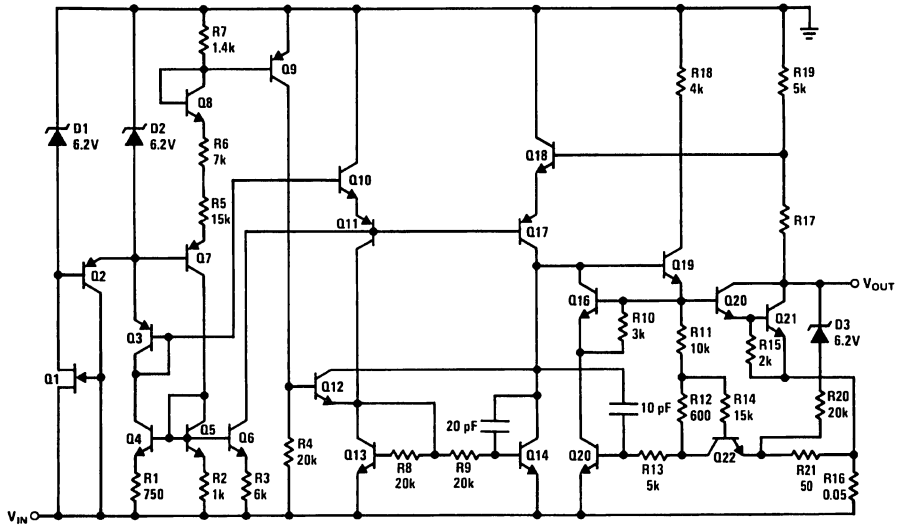
Schematic Diagrams



TL/H/7767-18

Schematic Diagrams (Continued)

-12V and -15V



TL/H/7767-19



LM123A/LM123/LM323A/LM323 3-Amp, 5-Volt Positive Regulator

General Description

The LM123 is a three-terminal positive regulator with a pre-set 5V output and a load driving capability of 3 amps. New circuit design and processing techniques are used to provide the high output current without sacrificing the regulation characteristics of lower current devices.

The LM123A and LM323A offer improved precision over the standard LM123 and LM323. Parameters with tightened specifications include output voltage tolerance, line regulation, and load regulation.

The 3 amp regulator is virtually blowout proof. Current limiting, power limiting, and thermal shutdown provide the same high level of reliability obtained with these techniques in the LM109 1 amp regulator.

No external components are required for operation of the LM123. If the device is more than 4 inches from the filter capacitor, however, a 1 μ F solid tantalum capacitor should be used on the input. A 0.1 μ F or larger capacitor may be used on the output to reduce load transient spikes created by fast switching digital logic, or to swamp out stray load capacitance.

An overall worst case specification for the combined effects of input voltage, load currents, ambient temperature, and

power dissipation ensure that the LM123 will perform satisfactorily as a system element.

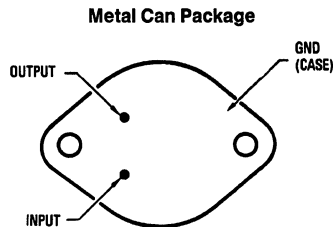
For applications requiring other voltages, see LM150 series adjustable regulator data sheet.

Operation is guaranteed over the junction temperature range -55°C to $+150^{\circ}\text{C}$ for LM123A/LM123, -40°C to $+125^{\circ}\text{C}$ for LM323A, and 0°C to $+125^{\circ}\text{C}$ for LM323. A hermetic TO-3 package is used for high reliability and low thermal resistance.

Features

- Guaranteed 1% initial accuracy (A version)
- 3 amp output current
- Internal current and thermal limiting
- 0.01 Ω typical output impedance
- 7.5V minimum input voltage
- 30W power dissipation
- P+ Product Enhancement tested

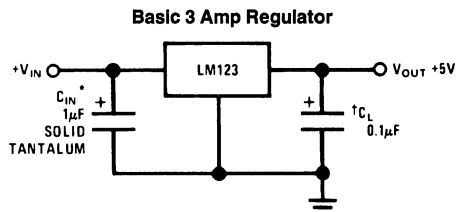
Connection Diagram



TL/H/7771-2

Order Number LM123AK STEEL, LM123K STEEL, LM323AK STEEL or LM323K STEEL
See NS Package Number K02A

Typical Applications



TL/H/7771-3

*Required if LM123 is more than 4" from filter capacitor.

†Regulator is stable with no load capacitor into resistive loads.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Input Voltage 20V
Power Dissipation Internally Limited

Operating Junction Temperature Range

LM123A, LM123 -55°C to +150°C
LM323A -40°C to +125°C
LM323 0°C to +125°C

Storage Temperature Range

-65°C to +150°C
Lead Temperature (Soldering, 10 sec.) 300°C
ESD Tolerance (Note 5) 2000V

LM123A/LM123 Electrical Characteristics (Note 1)

Parameter	Conditions	LM123A			LM123			Units
		Min	Typ	Max	Min	Typ	Max	
Output Voltage	$T_j = 25^\circ\text{C}$ $V_{IN} = 7.5\text{V}, I_{OUT} = 0\text{A}$	4.95	5	5.05	4.7	5	5.3	V
	$7.5\text{V} \leq V_{IN} \leq 15\text{V}$ $0\text{A} \leq I_{OUT} \leq 3\text{A}, P \leq 30\text{W}$	4.85		5.15	4.6		5.4	V
Line Regulation (Note 3)	$T_j = 25^\circ\text{C}$ $7.5\text{V} \leq V_{IN} \leq 15\text{V}$		5	10		5	25	mV
Load Regulation (Note 3)	$T_j = 25^\circ\text{C}, V_{IN} = 7.5\text{V},$ $0\text{A} \leq I_{OUT} \leq 3\text{A}$		25	50		25	100	mV
Quiescent Current	$7.5\text{V} \leq V_{IN} \leq 15\text{V},$ $0\text{A} \leq I_{OUT} \leq 3\text{A}$		12	20		12	20	mA
Output Noise Voltage	$T_j = 25^\circ\text{C}$ $10\text{ Hz} \leq f \leq 100\text{ kHz}$		40			40		μVrms
Short Circuit Current Limit	$T_j = 25^\circ\text{C}$ $V_{IN} = 15\text{V}$		3	4.5		3	4.5	A
	$V_{IN} = 7.5\text{V}$		4	6		4	5	A
Long Term Stability				35			35	mV
Thermal Resistance Junction to Case (Note 2)			2			2		$^\circ\text{C/W}$

LM323A/LM323 Electrical Characteristics (Note 1)

Parameter	Conditions	LM323A			LM323			Units
		Min	Typ	Max	Min	Typ	Max	
Output Voltage	$T_j = 25^\circ\text{C}$ $V_{IN} = 7.5\text{V}, I_{OUT} = 0\text{A}$	4.95	5	5.05	4.8	5	5.2	V
	$7.5\text{V} \leq V_{IN} \leq 15\text{V}$ $0\text{A} \leq I_{OUT} \leq 3\text{A}, P \leq 30\text{W}$	4.85		5.15	4.75		5.25	V
Line Regulation (Note 3)	$T_j = 25^\circ\text{C}$ $7.5\text{V} \leq V_{IN} \leq 15\text{V}$		5	10		5	25	mV
Load Regulation (Note 3)	$T_j = 25^\circ\text{C}, V_{IN} = 7.5\text{V},$ $0\text{A} \leq I_{OUT} \leq 3\text{A}$		25	50		25	100	mV
Quiescent Current	$7.5\text{V} \leq V_{IN} \leq 15\text{V},$ $0\text{A} \leq I_{OUT} \leq 3\text{A}$		12	20		12	20	mA
Output Noise Voltage	$T_j = 25^\circ\text{C}$ $10\text{ Hz} \leq f \leq 100\text{ kHz}$		40			40		μVrms
Short Circuit Current Limit	$T_j = 25^\circ\text{C}$ $V_{IN} = 15\text{V}$		3	4.5		3	4.5	A
	$V_{IN} = 7.5\text{V}$		4	6		4	5	A
Long Term Stability				35			35	mV
Thermal Resistance Junction to Case (Note 2)			2			2		$^\circ\text{C/W}$

Note 1: Unless otherwise noted, specifications apply for $-55^\circ\text{C} \leq T_j \leq +150^\circ\text{C}$ for the LM123A and LM123, $-40^\circ\text{C} \leq T_j \leq +125^\circ\text{C}$ for the LM323A, and $0^\circ\text{C} \leq T_j \leq +125^\circ\text{C}$ for the LM323. Although power dissipation is internally limited, specifications apply only for $P \leq 30\text{W}$.

Note 2: Without a heat sink, the thermal resistance of the TO-3 package is about 35°C/W . With a heat sink, the effective thermal resistance can only approach the specified values of 2°C/W , depending on the efficiency of the heat sink.

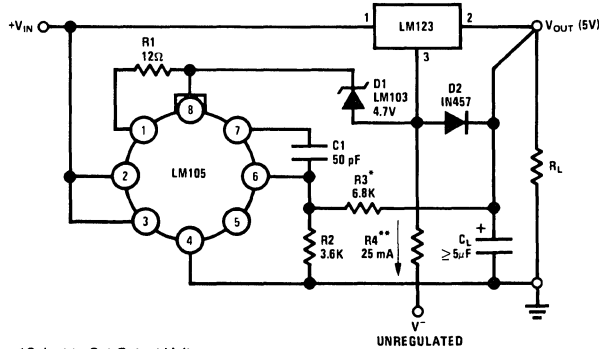
Note 3: Load and line regulation are specified at constant junction temperature. Pulse testing is required with a pulse width $\leq 1\text{ ms}$ and a duty cycle $\leq 5\%$.

Note 4: Refer to RETS123K drawing for LM123K, and to RETS123AK for LM123AK military specifications.

Note 5: Human body model, $1.5\text{ k}\Omega$ in series with 100 pF .

Typical Applications (Continued)

Adjustable Output 5V–10V 0.1% Regulation



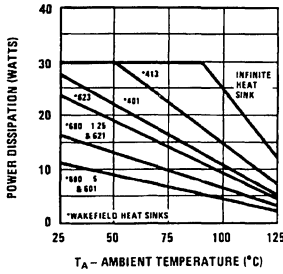
*Select to Set Output Voltage

**Select to Draw 25 mA from V₋

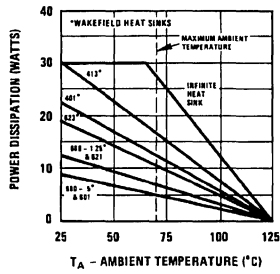
TL/H/7771-4

Typical Performance Characteristics

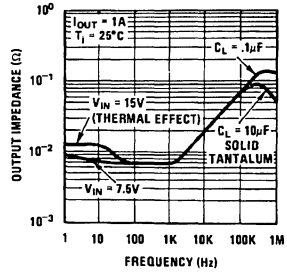
Maximum Average Power Dissipation for LM123A, LM123



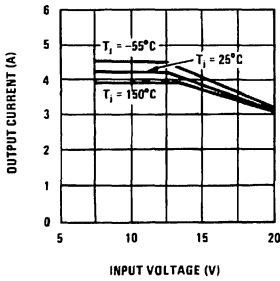
Maximum Average Power Dissipation for LM323A, LM323



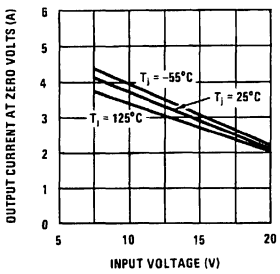
Output Impedance



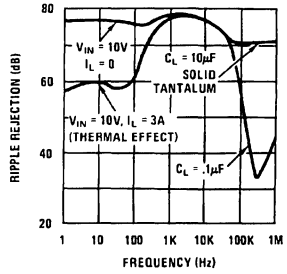
Peak Available Output Current



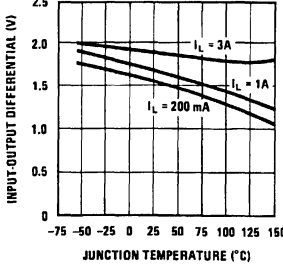
Short Circuit Current



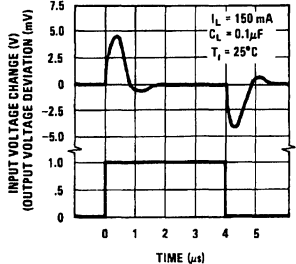
Ripple Rejection



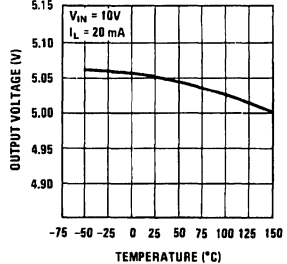
Dropout Voltage



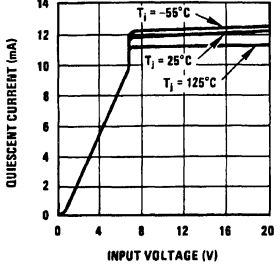
Line Transient Response



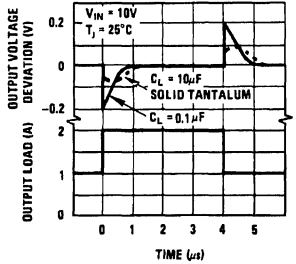
Output Voltage



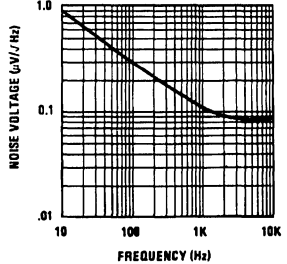
Quiescent Current



Load Transient Response



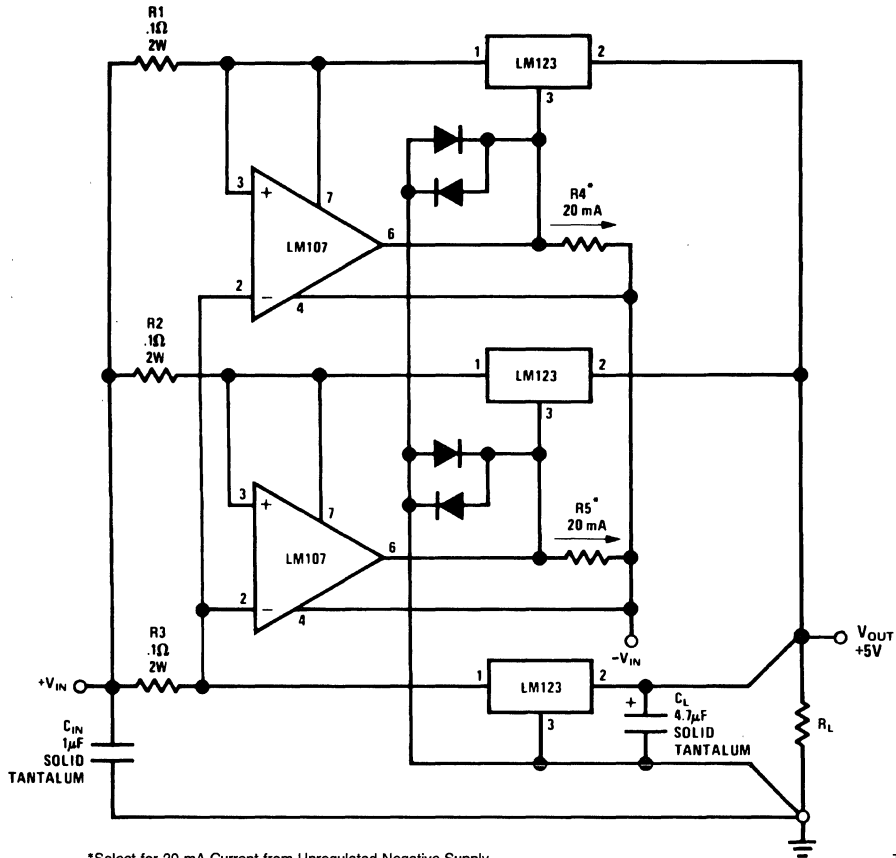
Output Noise Voltage



1

Typical Applications (Continued)

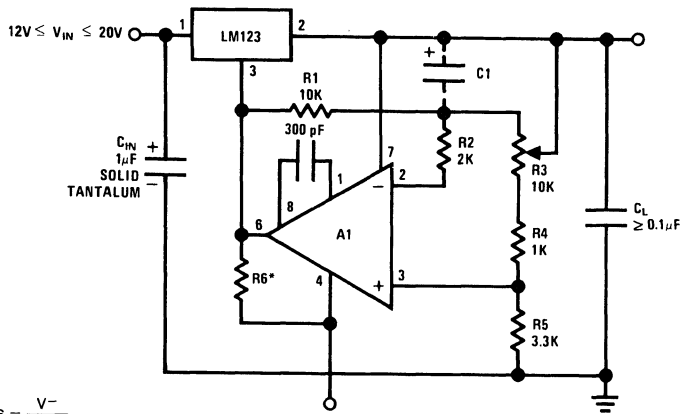
10 Amp Regulator with Complete Overload Protection



*Select for 20 mA Current from Unregulated Negative Supply

TL/H/7771-6

Adjustable Regulator 0V-10V @ 3A



$$*R6 = \frac{V^-}{12 \text{ mA}}$$

A₁—LM101A

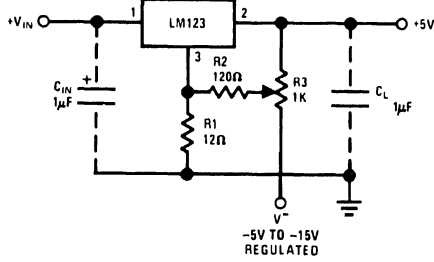
C₁—2 µF Optional—Improves Ripple Rejection, Noise, and Transient Response

V⁻ (-10V TO 20V)
NEED NOT BE REGULATED

TL/H/7771-7

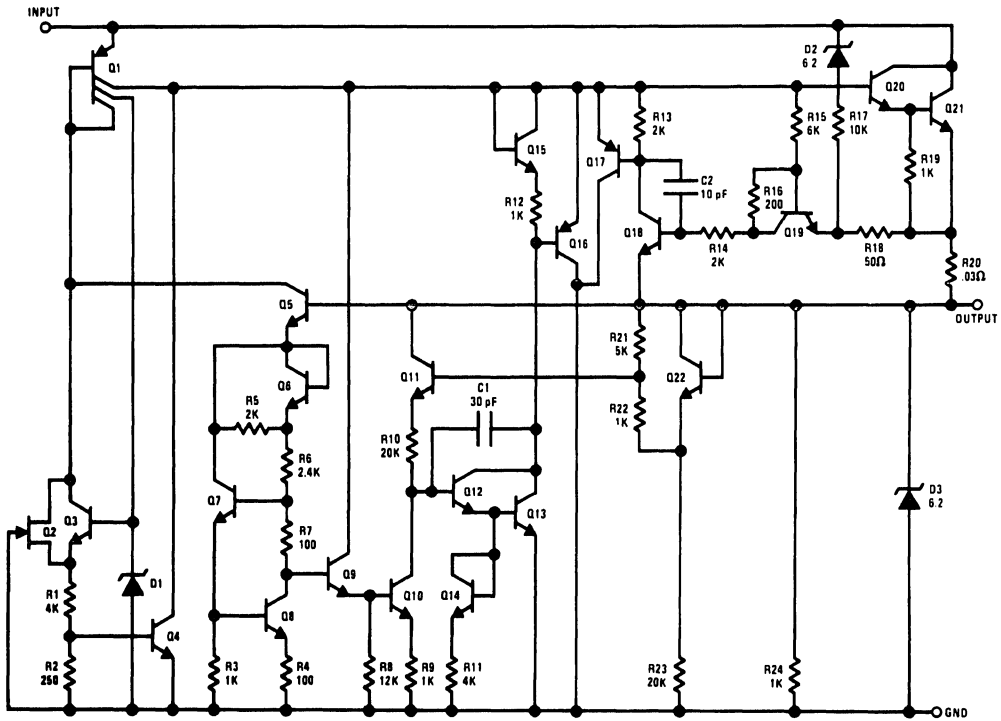
Typical Applications (Continued)

Trimming Output to 5V



TL/H/7771-8

Schematic Diagram



TL/H/7771-1



LM125/LM325/LM325A, LM126/LM326 Voltage Regulators

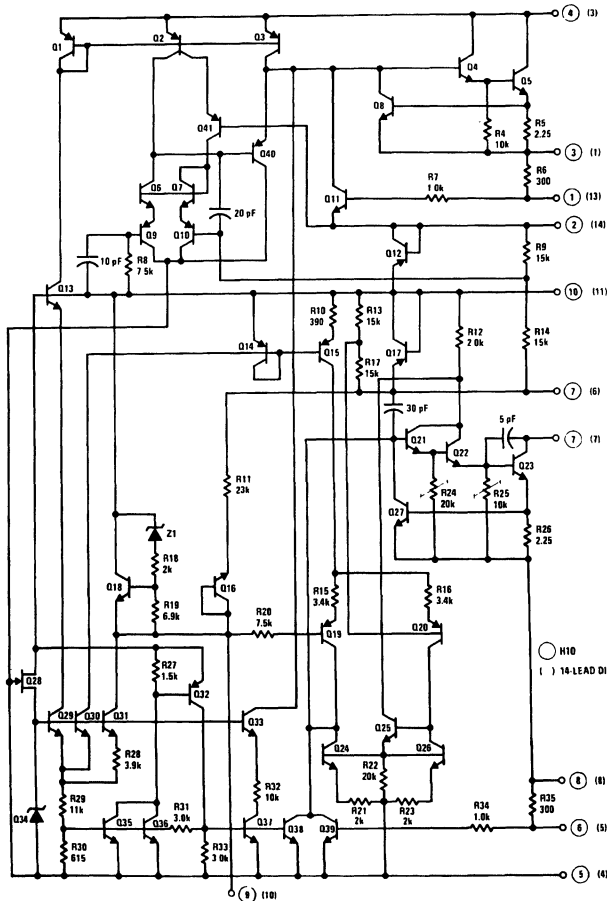
General Description

These are dual polarity tracking regulators designed to provide balanced positive and negative output voltages at current up to 100 mA, the devices are set for $\pm 15V$ and $\pm 12V$ outputs respectively. Input voltages up to $\pm 30V$ can be used and there is provision for adjustable current limiting. These devices are available in two package types to accommodate various power requirements and temperature ranges.

Features

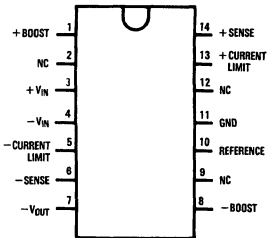
- $\pm 15V$ and $\pm 12V$ tracking outputs
- Output current to 100 mA
- Output voltage balanced to within 1% (LM125, LM126, LM325A)
- Line and load regulation of 0.06%
- Internal thermal overload protection
- Standby current drain of 3 mA
- Externally adjustable current limit
- Internal current limit

Schematic and Connection Diagrams



TL/H/7776-1

Dual-In-Line Package

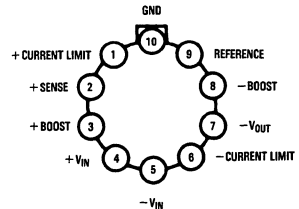


TL/H/7776-2

Top View

Order Number LM325AN,
LM325N or LM326N
See NS Package Number N14A

Metal Can Package



Case connected to $-V_{IN}$ TL/H/7776-3

Top View

Order Number LM125H,
LM325H, LM126H or LM326H
See NS Package Number H10C

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

Input Voltage	±30V
Forced V_{O+} (Min) (Note 1)	-0.5V
Forced V_{O-} (Max) (Note 1)	+0.5V
Power Dissipation (Note 2)	P_{MAX}
Output Short-Circuit Duration (Note 3)	Continuous

Operating Conditions

Operating Free Temperature Range	-55°C to +125°C
LM125	0°C to +70°C
LM325, LM325A	
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics LM125/LM325/LM325A (Note 2)

Parameter	Conditions	Min	Typ	Max	Units
Output Voltage LM125/LM325A LM325	$T_j = 25^\circ\text{C}$	14.8 14.5	15 15	15.2 15.5	V V
Input-Output Differential		2.0			V
Line Regulation	$V_{IN} = 18\text{V to }30\text{V}$, $I_L = 20\text{ mA}$, $T_j = 25^\circ\text{C}$		2.0	10	mV
Line Regulation Over Temperature Range	$V_{IN} = 18\text{V to }30\text{V}$, $I_L = 20\text{ mA}$,		2.0	20	mV
Load Regulation V_{O+} V_{O-}	$I_L = 0\text{ to }50\text{ mA}$, $V_{IN} = \pm 30\text{V}$, $T_j = 25^\circ\text{C}$		3.0 5.0	10 10	mV mV
Load Regulation Over Temperature Range V_{O+} V_{O-}	$I_L = 0\text{ to }50\text{ mA}$, $V_{IN} = \pm 30\text{V}$		4.0 7.0	20 20	mV mV
Output Voltage Balance LM125, LM325A LM325	$T_j = 25^\circ\text{C}$			±150 ±300	mV mV
Output Voltage Over Temperature Range LM125, LM325A LM325	$P \leq P_{MAX}$, $0 \leq I_O \leq 50\text{ mA}$, $18\text{V} \leq V_{IN} \leq 30$	14.65 14.27		15.35 15.73	V V
Temperature Stability of V_O			±0.3		%
Short Circuit Current Limit	$T_j = 25^\circ\text{C}$		260		mA
Output Noise Voltage	$T_j = 25^\circ\text{C}$, BW = 100 – 10 kHz		150		μVrms
Positive Standby Current	$T_j = 25^\circ\text{C}$		1.75	3.0	mA
Negative Standby Current	$T_j = 25^\circ\text{C}$		3.1	5.0	mA
Long Term Stability			0.2		%/kHr
Thermal Resistance Junction to Case (Note 4) LM125H, LM325H Junction to Ambient Junction to Ambient	(Still Air) (400 Lf/min Air Flow)		20 215 82		°C/W °C/W °C/W
Junction to Ambient LM325AN, LM325N	(Still Air)		90		°C/W

Note 1: That voltage to which the output may be forced without damage to the device.

Note 2: Unless otherwise specified these specifications apply for $T_j = 55^\circ\text{C}$ to $+150^\circ\text{C}$ on LM125, $T_j = 0^\circ\text{C}$ to $+125^\circ\text{C}$ on LM325A, $T_j = 0^\circ\text{C}$ to $+125^\circ\text{C}$ on LM325, $V_{IN} = \pm 20\text{V}$, $I_L = 0\text{ mA}$, $I_{MAX} = 100\text{ mA}$, $P_{MAX} = 2.0\text{W}$ for the H10 Package. $I_{MAX} = 100\text{ mA}$, $I_{MAX} = 100\text{ mA}$, $P_{MAX} = 1.0\text{W}$ for the DIP N Package.

Note 3: If the junction temperature exceeds 150°C , the output short circuit duration is 60 seconds.

Note 4: Without a heat sink, the thermal resistance junction to ambient of the H10 Package is about 155°C/W . With a heat sink, the effective thermal resistance can only approach the junction to case values specified, depending on the efficiency of the sink.

Note 5: Refer to RETS125X drawing for military specification of LM125.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

Input Voltage	±30V
Forced V_{O+} (Min) (Note 1)	-0.5V
Forced V_{O-} (Max) (Note 1)	+0.5V
Power Dissipation (Note 2)	Internally Limited
Output Short-Circuit Duration (Note 3)	Continuous

Operating Conditions

Operating Free Temperature Range	-55°C to +125°C
LM126	0°C to +70°C
LM326	
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics LM126/LM326 (Note 2)

Parameter	Conditions	Min	Typ	Max	Units
Output Voltage LM126/LM326	$T_j = 25^\circ\text{C}$	11.8 11.5	12	12.2 12.5	V V
Input-Output Differential		2.0			V
Line Regulation	$V_{IN} = 15\text{V to }30\text{V}$ $I_L = 20\text{ mA}, T_j = 25^\circ\text{C}$		2.0	10	mV
Line Regulation Over Temperature Range	$V_{IN} = 15\text{V to }30\text{V}, I_L = 20\text{ mA}$		2.0	20	mV
Load Regulation V_{O+} V_{O-}	$I_L = 0\text{ to }50\text{ mA}, V_{IN} = \pm 30\text{V},$ $T_j = 25^\circ\text{C}$		3.0 5.0	10 10	mV mV
Load Regulation Over Temperature Range V_{O+} V_{O-}	$I_L = 0\text{ to }50\text{ mA}, V_{IN} = \pm 30\text{V}$		4.0 7.0	20 20	mV mV
Output Voltage Balance LM126, LM326	$T_j = 25^\circ\text{C}$			±125 ±250	mV mV
Output Voltage Over Temperature Range LM126 LM326	$P \leq P_{MAX}, 0 \leq I_O \leq 50\text{ mA},$ $15\text{V} \leq V_{IN} \leq 30$	11.68 11.32		12.32 12.68	V V
Temperature Stability of V_O			±0.3		%
Short Circuit Current Limit	$T_j = 25^\circ\text{C}$		260		mA
Output Noise Voltage	$T_j = 25^\circ\text{C}, \text{BW} = 100 - 10\text{ kHz}$		100		μVrms
Positive Standby Current	$T_j = 25^\circ\text{C}, I_L = 0$		1.75	3.0	mA
Negative Standby Current	$T_j = 25^\circ\text{C}, I_L = 0$		3.1	5.0	mA
Long Term Stability			0.2		%/kHr
Thermal Resistance Junction to Case (Note 4) LM126H, LM326H			20		$^\circ\text{C/W}$
Junction to Ambient	(Still Air)		155		$^\circ\text{C/W}$
Junction to Ambient	(400 Lf/min Air Flow)		62		$^\circ\text{C/W}$
Junction to Ambient LM326N			150		$^\circ\text{C/W}$

Note 1: That voltage to which the output may be forced without damage to the device.

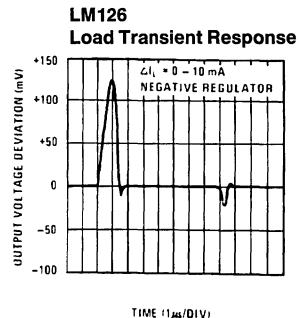
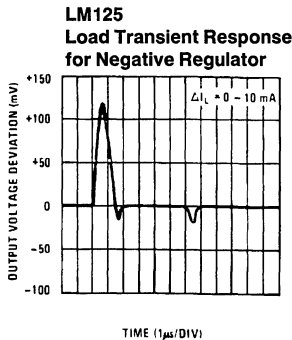
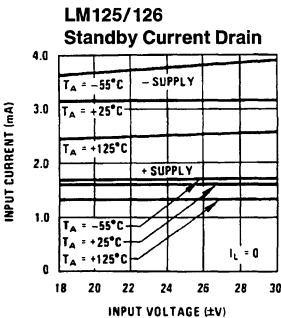
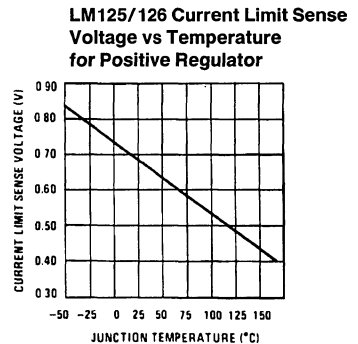
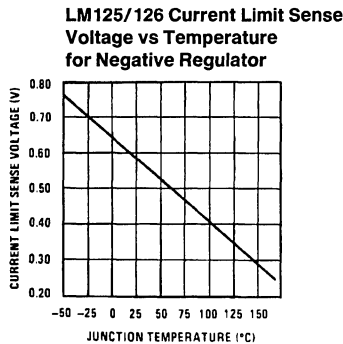
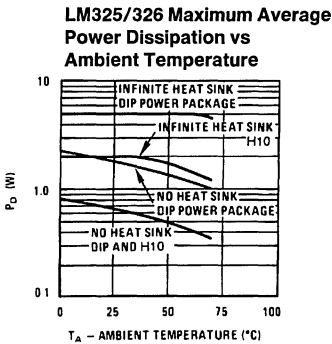
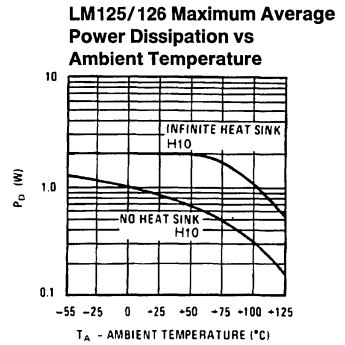
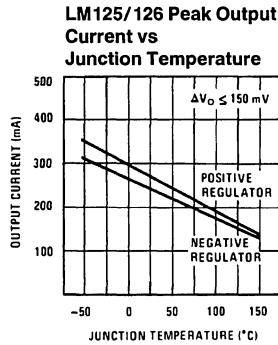
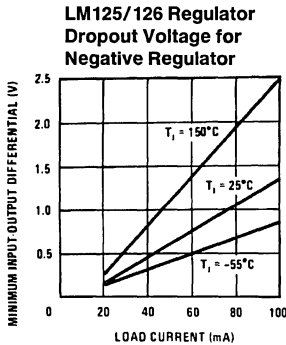
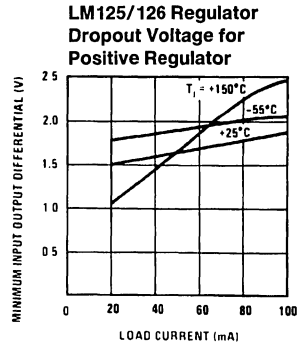
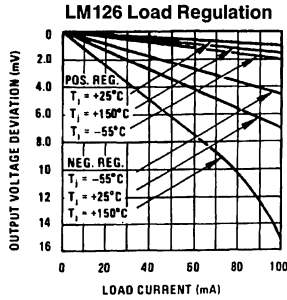
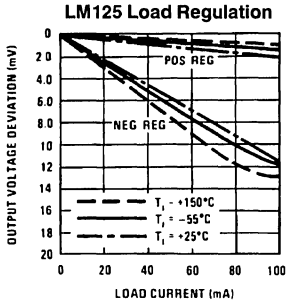
Note 2: Unless otherwise specified these specifications apply for $T_j = 55^\circ\text{C}$ to $+150^\circ\text{C}$ on LM126, $T_j = 0^\circ\text{C}$ to $+125^\circ\text{C}$ on LM326, $V_{IN} = \pm 20\text{V}$, $I_L = 0\text{ mA}$, $I_{MAX} = 100\text{ mA}$, $P_{MAX} = 2.0\text{W}$ for the H10 Package. $I_{MAX} = 100\text{ mA}$, $P_{MAX} = 1.0\text{W}$ for the DIP N Package.

Note 3: If the junction temperature exceeds 150°C , the output short circuit duration is 60 seconds.

Note 4: Without a heat sink, the thermal resistance junction to ambient of the H10 Package is about 155°C/W . With a heat sink, the effective thermal resistance can only approach the junction to case values specified, depending on the efficiency of the sink.

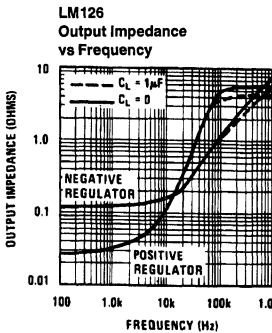
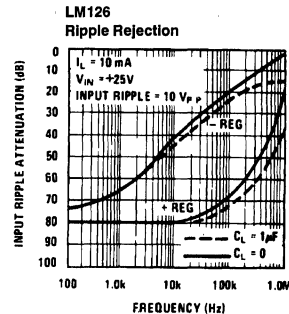
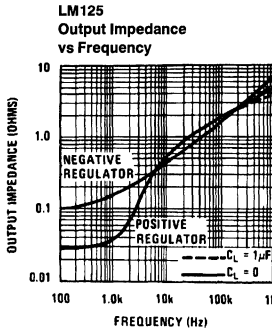
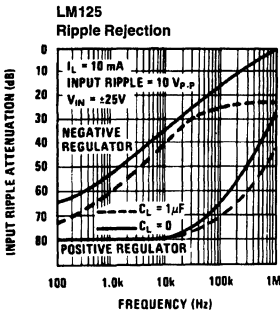
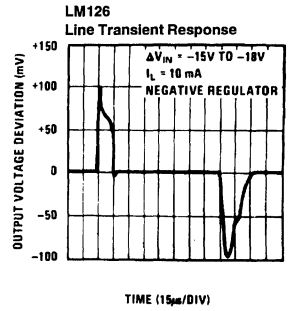
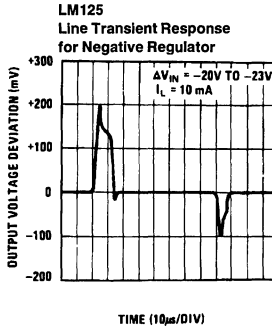
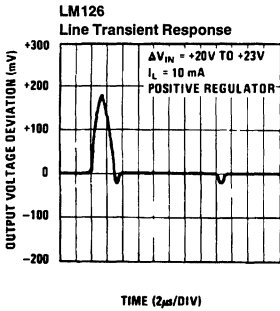
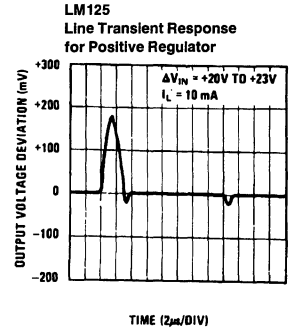
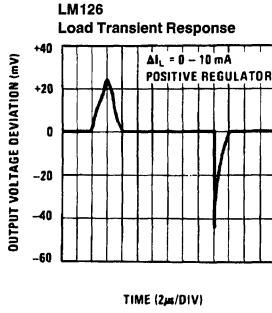
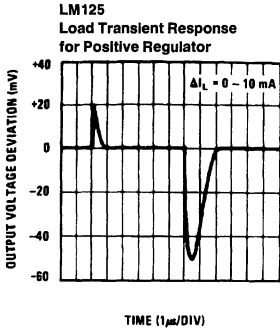
Note 5: Refer to RETS126X drawing for military specification of LM126.

Typical Performance Characteristics



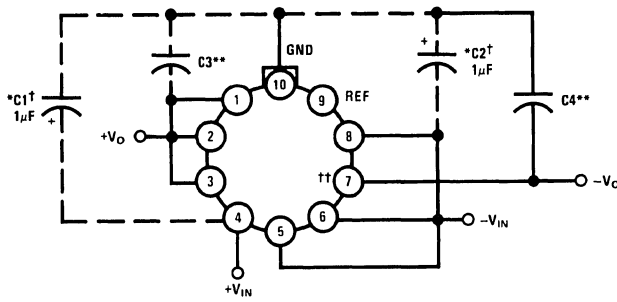
1

Typical Performance Characteristics (Continued)



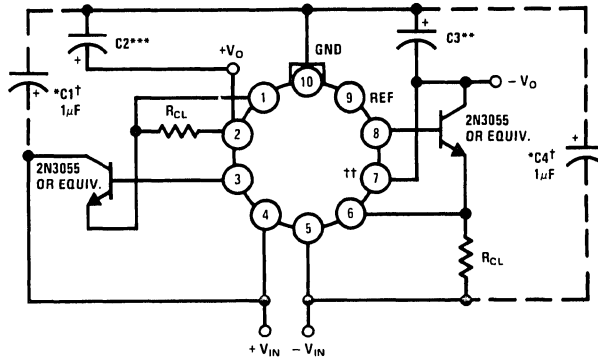
Typical Applications

Basic Regulator†††



TL/H/7776-6

2.0 Amp Boosted Regulator With Current Limit



TL/H/7776-7

Note: Metal can (H) packages shown.

$$I_{CL} = \frac{\text{Current Limit Sense Voltage (See Curve)}}{R_{CL}}$$

†Solid tantalum

††Short pins 6 and 7 on dip

†††R_{CL} can be added to the basic regulator between pins 6 and 5, 1 and 2 to reduce current limit.

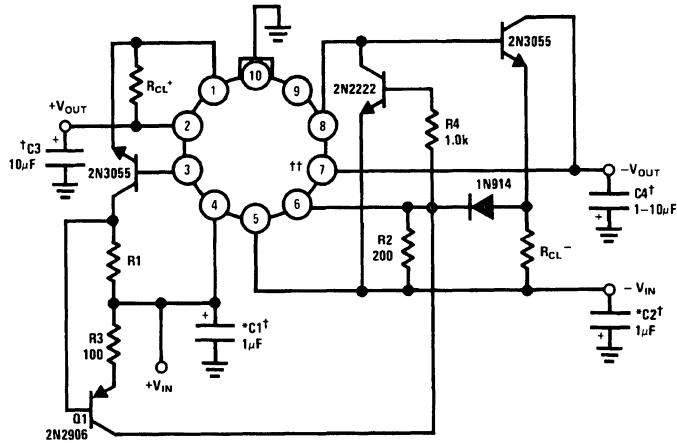
*Required if regulator is located an appreciable distance from power supply filter.

**Although no capacitor is needed for stability, it does help transient response. (If needed use 1 µF electrolytic).

***Although no capacitor is needed for stability, it does help transient response. (If needed use 10 µF electrolytic).

Typical Applications (Continued)

Positive Current Dependent Simultaneous Current Limiting



TL/H/7776-8

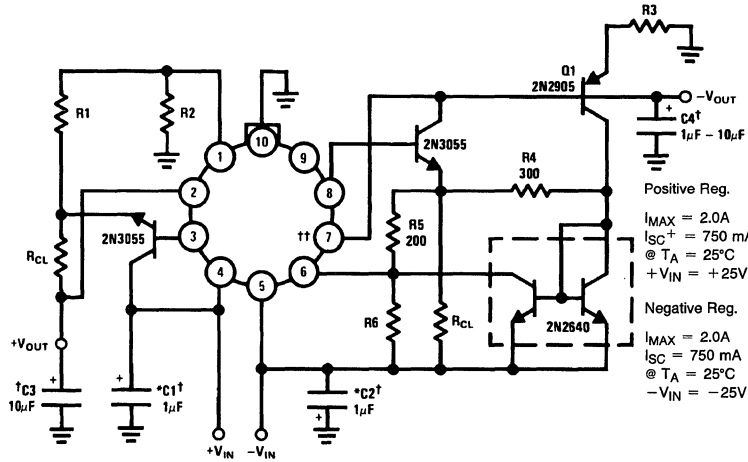
$$I_{CL}^+ = \frac{\frac{V_{SENSE\ NEG}}{2} + V_{BEQ1}}{R1}$$

$$I_{CL}^+ = \frac{V_{SENSE\ NEG} + V_{DIODE}}{R_{CL}^-}$$

I_{CL}^+ Controls Both Sides of the Regulator.

$$R_{CL}^+ = \frac{V_{SENSE}^+}{1.1 I_{CL}^+}$$

Boosted Regulator With Foldback Current Limit



Resistor Values

	125	126
R1	18	20
R2	310	180
R3	2.4k	1.35k
R6	300	290
RCL	0.7	0.9

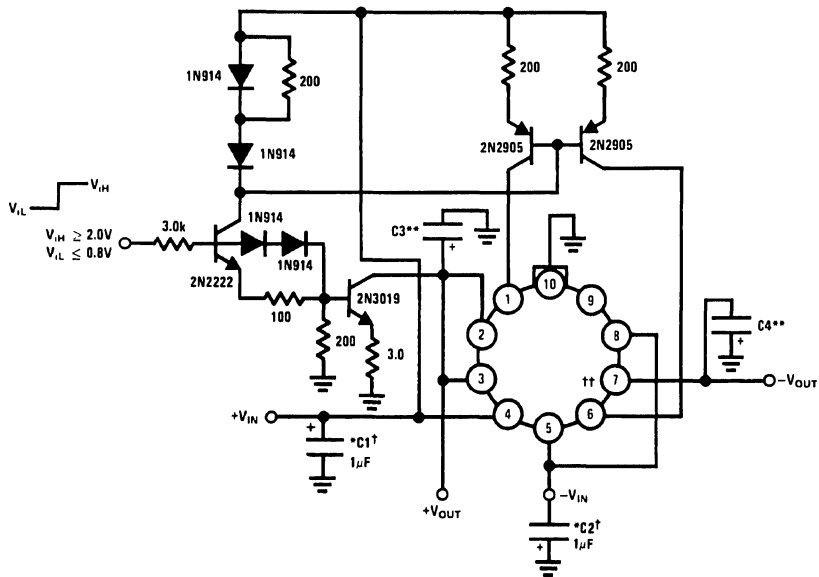
Positive Reg.
 $I_{MAX} = 2.0A$
 $I_{SC}^+ = 750\ mA$
 @ $T_A = 25^\circ C$
 $+V_{IN} = +25V$

Negative Reg.
 $I_{MAX} = 2.0A$
 $I_{SC}^- = 750\ mA$
 @ $T_A = 25^\circ C$
 $-V_{IN} = -25V$

TL/H/7776-9

Typical Applications (Continued)

Electric Shutdown



†Solid tantalum

††Short pins 6 and 7 on dip

*Required if regulator is located an appreciable distance from power supply filter.

**Although no capacitor is needed for stability, it does help transient response. (If needed use 1 μF electrolytic).

TL/H/7776-10



LM133/LM333 3-Ampere Adjustable Negative Regulators

General Description

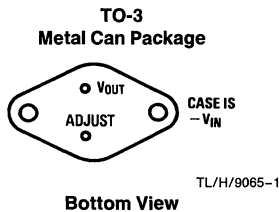
The LM133/LM333 are adjustable 3-terminal negative voltage regulators capable of supplying in excess of $-3.0A$ over an output voltage range of $-1.2V$ to $-32V$. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM133 series features internal current limiting, thermal shutdown and safe-area compensation, making them substantially immune to failure from overloads.

The LM133/LM333 serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM133/LM333 are ideal complements to the LM150/LM350 adjustable positive regulators.

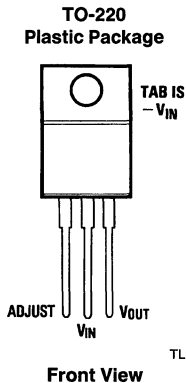
Features

- Output voltage adjustable from $-1.2V$ to $-32V$
- $3.0A$ output current guaranteed, $-55^{\circ}C$ to $+150^{\circ}C$
- Line regulation typically $0.01\%/V$
- Load regulation typically 0.2%
- Excellent rejection of thermal transients
- 50 ppm/ $^{\circ}C$ temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- P+ Product Enhancement tested
- Standard 3-lead transistor package
- Output is short circuit protected

Connection Diagrams

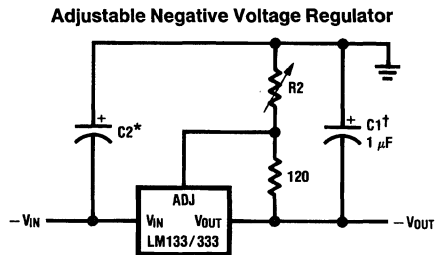


**Steel TO-3 Metal Can Package
(K STEEL)**
Order Number LM133K STEEL or
LM333K STEEL
See NS Package Number K02A



3-Lead TO-220 Plastic Package (T)
Order Number LM333T
See NS Package Number T03B

Typical Applications



$$-V_{OUT} = -1.25V \left(1 + \frac{R2}{120\Omega} \right) + (-I_{ADJ} \times R2)$$

†C1 = $1 \mu F$ solid tantalum or $10 \mu F$ aluminum electrolytic required for stability.

*C2 = $1 \mu F$ solid tantalum is required only if regulator is more than 4" from power supply filter capacitor.

Output capacitors in the range of $1 \mu F$ to $1000 \mu F$ of aluminum or tantalum electrolytic are commonly used to provide lower output impedance and improved transient response.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Input-Output Voltage Differential	35V
Operating Junction Temperature Range	T_{MIN} to T_{MAX}
LM133	-55°C to +150°C
LM333	-40°C to +125°C

Storage Temperature	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package	300°C
TO-220 Package	260°C
ESD Susceptibility	TBD

Electrical Characteristics LM133 Specifications with standard typeface are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over the full operating temperature range. (Note 3)

Parameter	Conditions	Typical	Min (Note 2)	Max (Note 2)	Units
Reference Voltage	$I_L = 10\text{ mA}$	-1.250	-1.238	-1.262	V
	$3\text{V} \leq V_{IN} - V_{OUT} \leq 35\text{V}$ $10\text{ mA} \leq I_L \leq 3\text{A}$, $P \leq P_{MAX}$	-1.250	-1.225	-1.275	V
Line Regulation	$3\text{V} \leq V_{IN} - V_{OUT} \leq 35\text{V}$ $I_{OUT} = 50\text{ mA}$ (Note 4)	0.01 0.02		0.02 0.05	% /V
Load Regulation	$10\text{ mA} \leq I_{OUT} \leq 3\text{A}$, $P \leq P_{MAX}$ (Notes 4, 5)	0.2 0.4		0.5 1.0	%
Thermal Regulation	10 ms Pulse	0.002		0.01	% /W
Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$	0.4			%
Long Term Stability	$T_J = 125^\circ\text{C}$, 1000 Hours	0.15			%
Adjust Pin Current		65 70		90 100	μA
Adjust Pin Current Change	$10\text{ mA} \leq I_L \leq 3\text{A}$ $3.0\text{V} \leq V_{IN} - V_{OUT} \leq 35\text{V}$	2		6	μA
Minimum Load Current	$ V_{IN} - V_{OUT} \leq 35\text{V}$	2.5		5.0	mA
	$ V_{IN} - V_{OUT} \leq 10\text{V}$	1.2		2.5	
Current Limit (Note 5)	$3\text{V} \leq V_{IN} - V_{OUT} \leq 10\text{V}$	3.9	3.0		A
	$ V_{IN} - V_{OUT} = 20\text{V}$	2.4	1.25		
	$ V_{IN} - V_{OUT} = 30\text{V}$	0.4	0.3		
Output Noise (% of V_{OUT})	10 Hz to 10 kHz	0.003			% (rms)
Ripple Rejection	$V_{OUT} = 10\text{V}$, $f = 120\text{ Hz}$ $C_{ADJ} = 0\ \mu\text{F}$ $C_{ADJ} = 10\ \mu\text{F}$	60 77			dB
Thermal Resistance Junction-to-Case	TO-3 Package (K STEEL)	1.2		1.8	$^\circ\text{C}/\text{W}$
Thermal Shutdown Temperature		163	150	190	$^\circ\text{C}$

Electrical Characteristics LM333

Specifications with standard typeface are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over the full operating temperature range. (Note 3)

Parameter	Conditions	Typical	Min (Note 2)	Max (Note 2)	Units
Reference Voltage	$I_L = 10\text{ mA}$	-1.250	-1.225	-1.275	V
	$3\text{V} \leq V_{IN} - V_{OUT} \leq 35\text{V}$ $10\text{ mA} \leq I_L \leq 3\text{A}$, $P \leq P_{MAX}$	-1.250	-1.213	-1.287	
Line Regulation	$3\text{V} \leq V_{IN} - V_{OUT} \leq 35\text{V}$ $I_{OUT} = 50\text{ mA}$ (Note 4)	0.01 0.02		0.04 0.07	% /V
Load Regulation	$10\text{ mA} \leq I_L \leq 3\text{A}$, $P \leq P_{MAX}$ (Notes 4 and 5)	0.2 0.4		1.0 1.5	%
Thermal Regulation	10 ms Pulse	0.002		0.02	% /W
Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$	0.5			%
Long Term Stability	$T_J = 125^\circ\text{C}$, 1000 Hours	0.2			%
Adjust Pin Current		65 70		95 100	μA
Adjust Pin Current Change	$10\text{ mA} \leq I_L \leq 3\text{A}$ $3.0\text{V} \leq V_{IN} - V_{OUT} \leq 35\text{V}$	2.5		8	μA
Minimum Load Current	$ V_{IN} - V_{OUT} \leq 35\text{V}$	2.5		10	mA
	$ V_{IN} - V_{OUT} \leq 10\text{V}$	1.5		5.0	
Current Limit (Note 5)	$3\text{V} \leq V_{IN} - V_{OUT} \leq 10\text{V}$	3.9	3.0		A
	$ V_{IN} - V_{OUT} = 20\text{V}$	2.4	1.0		
	$ V_{IN} - V_{OUT} = 30\text{V}$	0.4	0.20		
Output Noise (% of V_{OUT})	10 Hz to 10 kHz	0.003			% (rms)
Ripple Rejection	$V_{OUT} = 10\text{V}$, $f = 120\text{ Hz}$ $C_{ADJ} = 0\ \mu\text{F}$ $C_{ADJ} = 10\ \mu\text{F}$	60 77			dB
Thermal Resistance Junction to Case	TO-3 Package (K STEEL)	1.2		1.8	$^\circ\text{C}/\text{W}$
	TO-220 Package (T)	3		4	
Thermal Shutdown Temperature		163			$^\circ\text{C}$
Thermal Resistance Junction to Ambient (No Heatsink)	K Package	35			$^\circ\text{C}/\text{W}$
	T Package	50			

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device outside of its stated operating conditions.

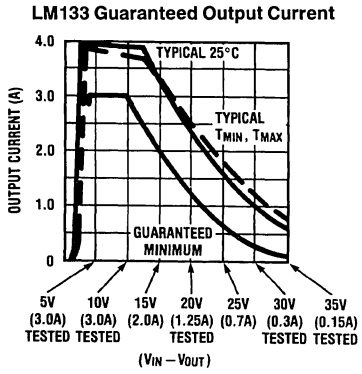
Note 2: All limits are guaranteed at either room temperature (standard type face) or at **temperature extremes (bold typeface)** by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods.

Note 3: Unless otherwise specified: $|V_{IN} - V_{OUT}| = 5\text{V}$, $I_{OUT} = 0.5\text{A}$, $P_{DISS} \leq 30\text{W}$.

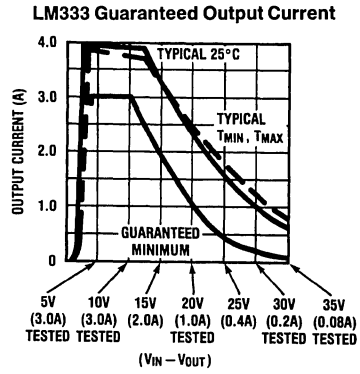
Note 4: Load and line regulation are measured at constant junction temperature, using low duty cycle pulse testing (output voltage changes due to heating effects are covered by the Thermal Regulation specification). For the TO-3 package, load regulation is measured on the output pin, $\frac{1}{8}$ " below the base of the package.

Note 5: The output current of the LM333 is guaranteed to be $\geq 3\text{A}$ in the range $3\text{V} \leq |V_{IN} - V_{OUT}| \leq 10\text{V}$. For the range $10\text{V} \leq |V_{IN} - V_{OUT}| \leq 15\text{V}$, the guaranteed minimum output current is equal to: $30 / (V_{IN} - V_{OUT})$. Refer to graphs for guaranteed output currents at other voltages.

Guaranteed Performance Characteristics



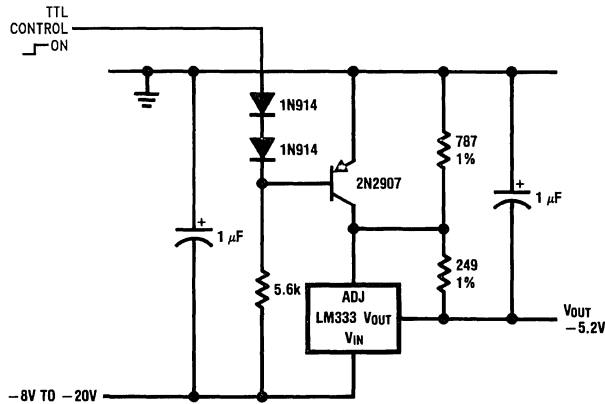
TL/H/9065-4



TL/H/9065-5

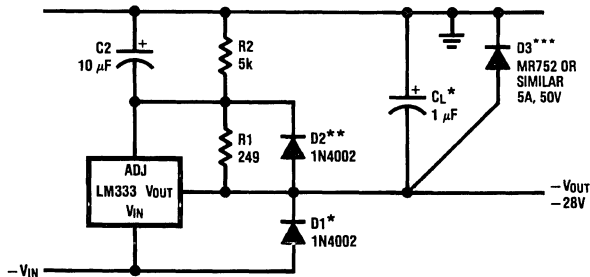
Typical Applications (Continued)

-5.2V Regulator with Electronic Shutdown



TL/H/9065-6

Negative Regulator with Protection Diodes



TL/H/9065-7

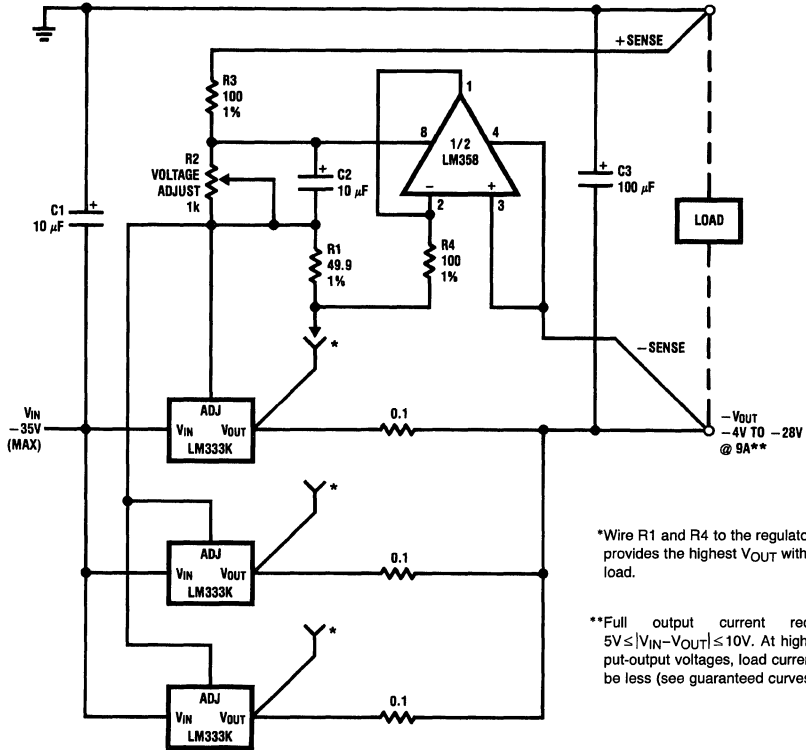
*When C_L is larger than 20 µF, D1 protects the LM133 in case the input supply is shorted.

**When C2 is larger than 10 µF and $-V_{OUT}$ is larger than -25V, D2 protects the LM133 in case the output is shorted.

***In case V_{OUT} is shorted to a positive supply, D3 protects the LM133 from overvoltage, and protects the load from reversed voltage.

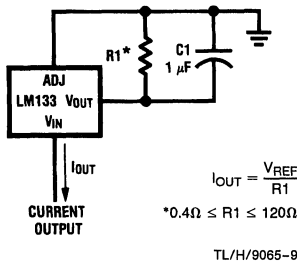
Typical Applications (Continued)

High-Performance 9-Ampere Adjustable Regulator

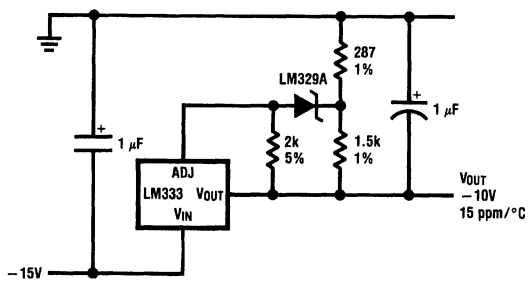


TL/H/9065-8

Current Regulator

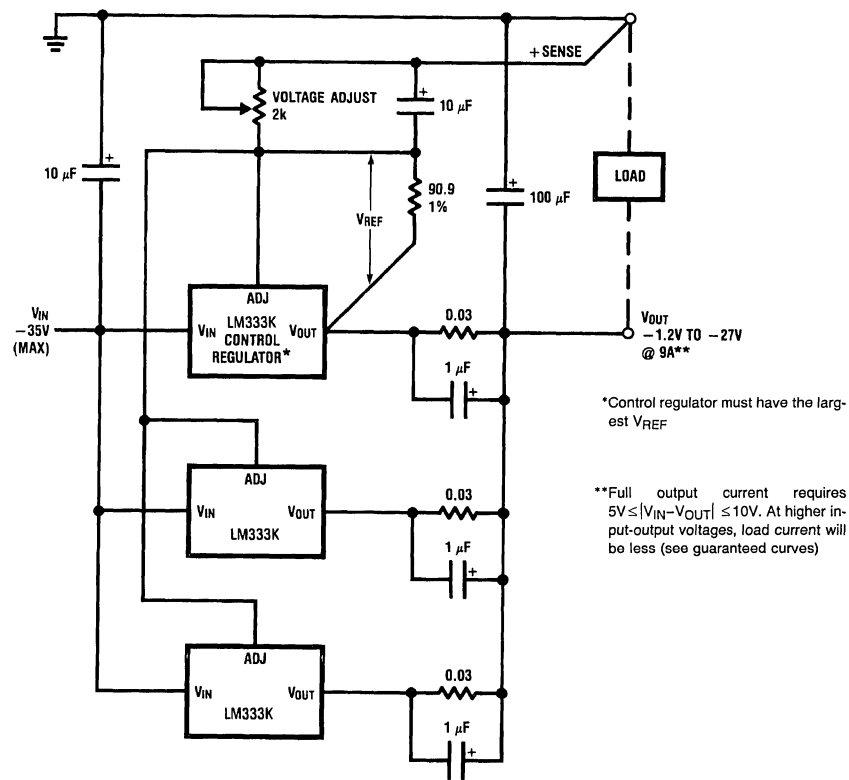


High Stability 10V Regulator

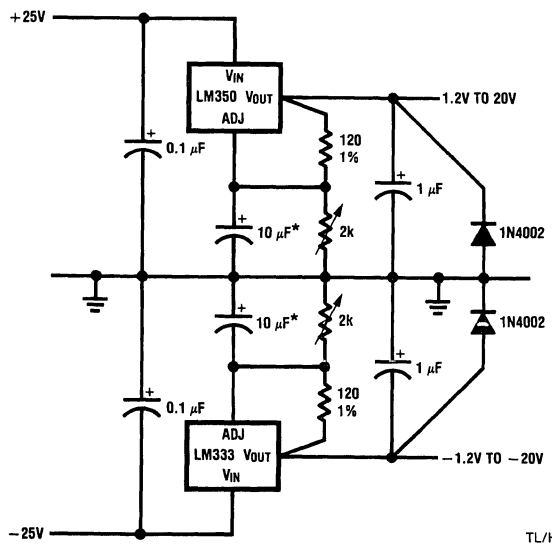


Typical Applications (Continued)

High-Current Adjustable Regulator

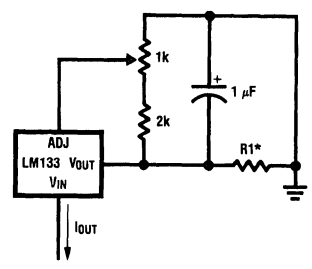


Adjustable Lab Voltage Regulator



*The 10 µF capacitors are optional to improve ripple rejection.

Adjustable Current Regulator



$I_{OUT} = \left(\frac{1.5V}{R1} \right) \pm 15\% \text{ adjustable}$

$0.5\Omega \leq R1 \leq 24\Omega$

TL/H/9065-12

TL/H/9065-11

TL/H/9065-13

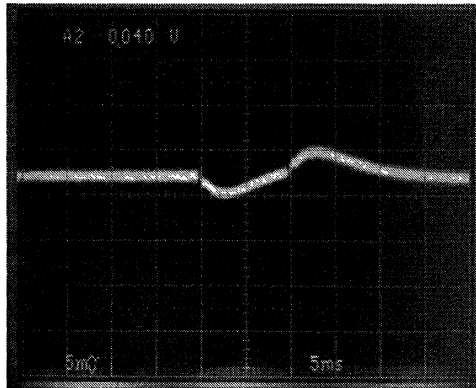
Typical Applications (Continued)

THERMAL REGULATION

When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since the power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT} ,

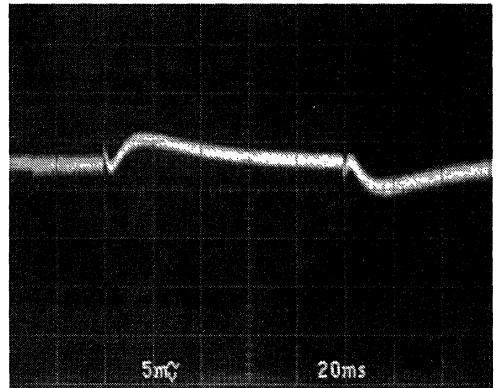
per watt, within the first 10 ms after a step of power is applied. The LM133's specification is 0.01%/W, max.

In *Figure 1*, a typical LM133's output drifts only 2 mV (or 0.02% of $V_{OUT} = -10V$) when a 20W pulse is applied for 10 ms. This performance is thus well inside the specification limit of $0.01\%/W \times 20W = 0.2\%$ max. When the 20W pulse is ended, the thermal regulation again shows a 2 mV step as the LM133 chip cools off. Note that the load regulation error of about 1 mV (0.01%) is additional to the thermal regulation error. In *Figure 2*, when the 20W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).



TL/H/9065-14

FIGURE 1



TL/H/9065-15

FIGURE 2

LM137/LM337

3-Terminal Adjustable Negative Regulators

General Description

The LM137/LM337 are adjustable 3-terminal negative voltage regulators capable of supplying in excess of $-1.5A$ over an output voltage range of $-1.2V$ to $-37V$. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM137 series features internal current limiting, thermal shutdown and safe-area compensation, making them virtually blowout-proof against overloads.

The LM137/LM337 serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM137/LM337 are ideal complements to the LM117/LM317 adjustable positive regulators.

Features

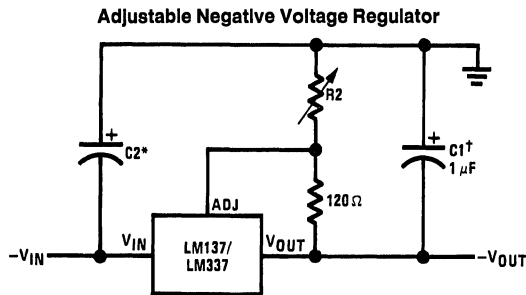
- Output voltage adjustable from $-1.2V$ to $-37V$
- $1.5A$ output current guaranteed, $-55^{\circ}C$ to $+150^{\circ}C$
- Line regulation typically $0.01\%/V$
- Load regulation typically 0.3%
- Excellent thermal regulation, $0.002\%/W$

- 77 dB ripple rejection
- Excellent rejection of thermal transients
- 50 ppm/ $^{\circ}C$ temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- P+ Product Enhancement tested
- Standard 3-lead transistor package
- Output is short circuit protected

LM137 Series Packages and Power Capability

Device	Package	Rated Power Dissipation	Design Load Current
LM137/337	TO-3 (K)	20W	1.5A
	TO-39 (H)	2W	0.5A
LM337	TO-220 (T)	15W	1.5A
LM337M	TO-202 (P)	7.5W	0.5A

Typical Applications



TL/H/9087-1

Full output current not available at high input-output voltages

$$-V_{OUT} = -1.25V \left(1 + \frac{R_2}{120\Omega} \right) + (-I_{ADJ} \times R_2)$$

†C1 = $1 \mu F$ solid tantalum or $10 \mu F$ aluminum electrolytic required for stability

*C2 = $1 \mu F$ solid tantalum is required only if regulator is more than $4''$ from power-supply filter capacitor

Output capacitors in the range of $1 \mu F$ to $1000 \mu F$ of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 4)

Power Dissipation	Internally Limited
Input-Output Voltage Differential	40V

Operating Junction Temperature Range

LM137	-55°C to +150°C
LM337	0°C to +125°C

Storage Temperature

-65°C to +150°C

Lead Temperature (Soldering, 10 sec.)

300°C

Plastic Package (Soldering, 4 sec.)

260°C

ESD Rating

2k Volts

Electrical Characteristics (Note 1)

Parameter	Conditions	LM137			LM337			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	$T_j = 25^\circ\text{C}$, $3\text{V} \leq V_{IN} - V_{OUT} \leq 40\text{V}$ (Note 2) $I_L = 10\text{ mA}$		0.01	0.02		0.01	0.04	%/V
Load Regulation	$T_j = 25^\circ\text{C}$, $10\text{ mA} \leq I_{OUT} \leq I_{MAX}$		0.3	0.5		0.3	1.0	%
Thermal Regulation	$T_j = 25^\circ\text{C}$, 10 ms Pulse		0.002	0.02		0.003	0.04	%/W
Adjustment Pin Current			65	100		65	100	μA
Adjustment Pin Current Charge	$10\text{ mA} \leq I_L \leq I_{MAX}$ $3.0\text{V} \leq V_{IN} - V_{OUT} \leq 40\text{V}$, $T_A = 25^\circ\text{C}$		2	5		2	5	μA
Reference Voltage	$T_j = 25^\circ\text{C}$ (Note 3) $3\text{V} \leq V_{IN} - V_{OUT} \leq 40\text{V}$, (Note 3) $10\text{ mA} \leq I_{OUT} \leq I_{MAX}$, $P \leq P_{MAX}$	-1.225 -1.200	-1.250 -1.250	-1.275 -1.300	-1.213 -1.200	-1.250 -1.250	-1.287 -1.300	V V
Line Regulation	$3\text{V} \leq V_{IN} - V_{OUT} \leq 40\text{V}$, (Note 2)		0.02	0.05		0.02	0.07	%/V
Load Regulation	$10\text{ mA} \leq I_{OUT} \leq I_{MAX}$, (Note 2)		0.3	1		0.3	1.5	%
Temperature Stability	$T_{MIN} \leq T_j \leq T_{MAX}$		0.6			0.6		%
Minimum Load Current	$ V_{IN} - V_{OUT} \leq 40\text{V}$ $ V_{IN} - V_{OUT} \leq 10\text{V}$		2.5 1.2	5 3		2.5 1.5	10 6	mA mA
Current Limit	$ V_{IN} - V_{OUT} \leq 15\text{V}$ K and T Package H and P Package $ V_{IN} - V_{OUT} = 40\text{V}$, $T_j = 25^\circ\text{C}$ K and T Package H and P Package	1.5 0.5	2.2 0.8	3.5 1.8	1.5 0.5	2.2 0.8	3.7 1.9	A A
RMS Output Noise, % of V_{OUT}	$T_j = 25^\circ\text{C}$, $10\text{ Hz} \leq f \leq 10\text{ kHz}$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = -10\text{V}$, $f = 120\text{ Hz}$ $C_{ADJ} = 10\text{ }\mu\text{F}$	66	77		66	77		dB dB
Long-Term Stability	$T_j = 125^\circ\text{C}$, 1000 Hours		0.3	1		0.3	1	%
Thermal Resistance, Junction to Case	H Package K Package T Package P Package		12 2.3	15 3		12 2.3 4 7	15 3	$^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$
Thermal Resistance, Junction to Ambient (No Heat Sink)	H Package K Package T Package P Package		140 35			140 35 50 80		$^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$ $^\circ\text{C}/\text{W}$

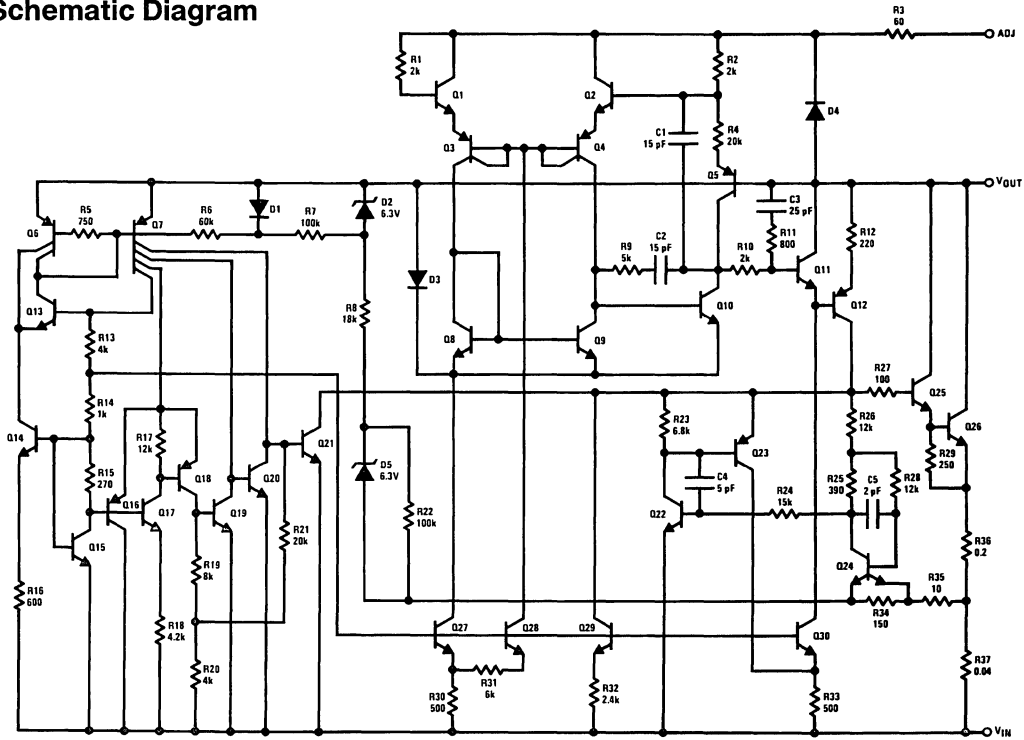
Note 1: Unless otherwise specified, these specifications apply $-55^\circ\text{C} \leq T_j \leq +150^\circ\text{C}$ for the LM137, $0^\circ\text{C} \leq T_j \leq +125^\circ\text{C}$ for the LM337; $V_{IN} - V_{OUT} = 5\text{V}$; and $I_{OUT} = 0.1\text{A}$ for the TO-39 and TO-202 packages and $I_{OUT} = 0.5\text{A}$ for the TO-3 and TO-220 packages. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-39 and TO-202 and 20W for the TO-3 and TO-220. I_{MAX} is 1.5A for the TO-3 and TO-220 packages, and 0.5A for the TO-202 package and 0.2A for the TO-39 package.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation. Load regulation is measured on the output pin at a point $1/8"$ below the base of the TO-3 and TO-39 packages.

Note 3: Selected devices with tightened tolerance reference voltage available.

Note 4: Refer to RETS137H drawing for LM137H or RETS137K drawing for LM137K military specifications.

Schematic Diagram

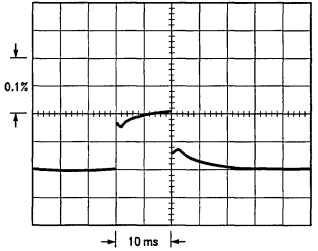


TL/H/9067-2

Thermal Regulation

When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per Watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT} , per Watt, within the first 10 ms after a step of power is applied. The LM137's specification is 0.02%/W, max.

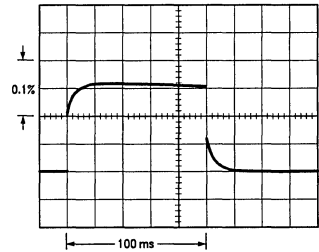
In Figure 1, a typical LM137's output drifts only 3 mV (or 0.03% of $V_{OUT} = -10V$) when a 10W pulse is applied for 10 ms. This performance is thus well inside the specification limit of 0.02%/W \times 10W = 0.2% max. When the 10W pulse is ended, the thermal regulation again shows a 3 mV step at the LM137 chip cools off. Note that the load regulation error of about 8 mV (0.08%) is additional to the thermal regulation error. In Figure 2, when the 10W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).



LM137, $V_{OUT} = -10V$
 $V_{IN} - V_{OUT} = -40V$
 $I_L = 0A \rightarrow 0.25A \rightarrow 0A$
 Vertical sensitivity, 5 mV/div

TL/H/9067-3

FIGURE 1

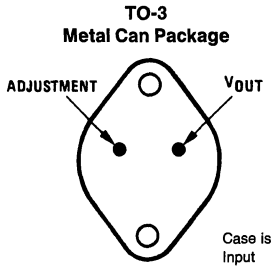


LM137, $V_{OUT} = -10V$
 $V_{IN} - V_{OUT} = -40V$
 $I_L = 0A \rightarrow 0.25A \rightarrow 0A$
 Horizontal sensitivity, 20 ms/div

TL/H/9067-4

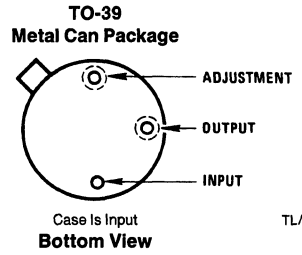
FIGURE 2

Connection Diagrams



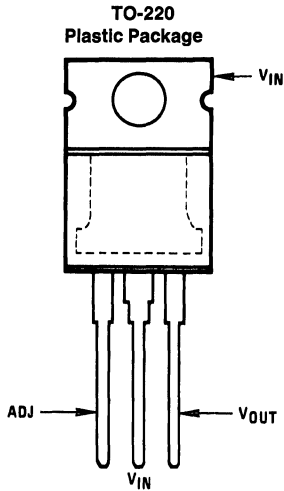
TL/H/9067-5

Bottom View
Order Number LM137K STEEL or LM337K STEEL
See NS Package Number K02A



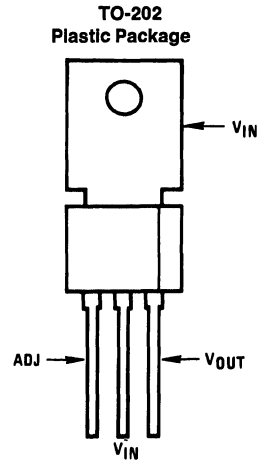
TL/H/9067-6

Bottom View
Order Number LM137H or LM337H
See NS Package Number H03A



TL/H/9067-7

Front View
Order Number LM337T
See NS Package Number T03B

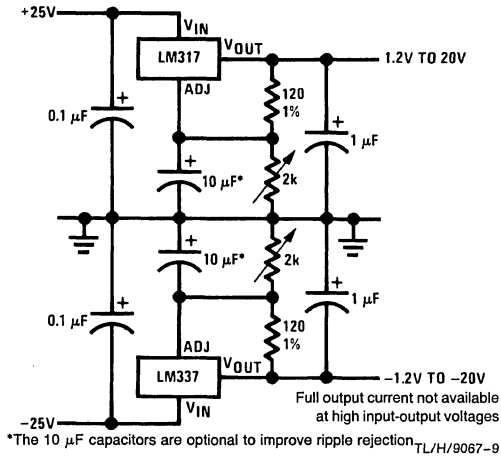


TL/H/9067-8

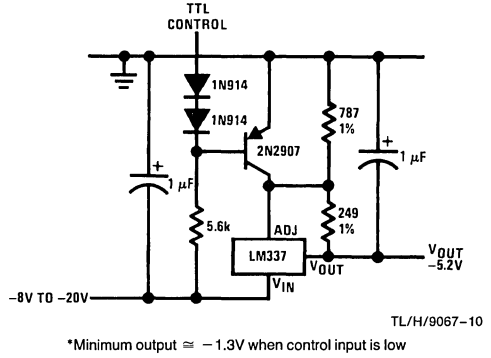
Front View
Order Number LM337MP
See NS Package Number P03A

Typical Applications (Continued)

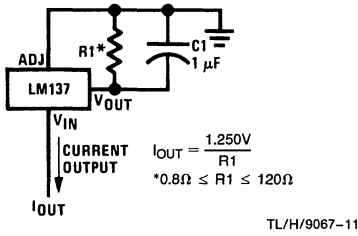
Adjustable Lab Voltage Regulator



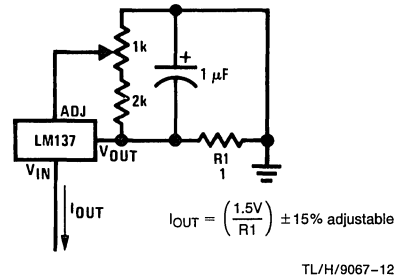
-5.2V Regulator with Electronic Shutdown*



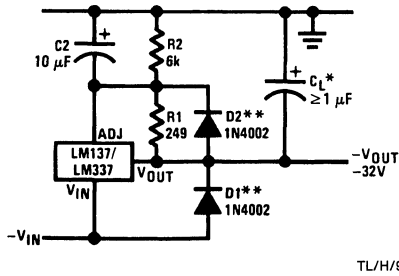
Current Regulator



Adjustable Current Regulator



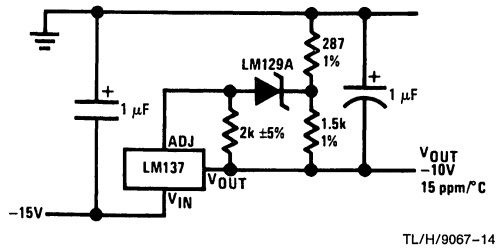
Negative Regulator with Protection Diodes



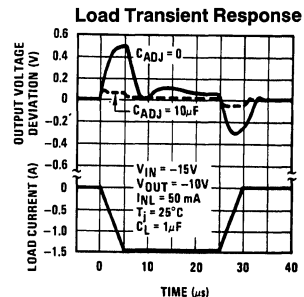
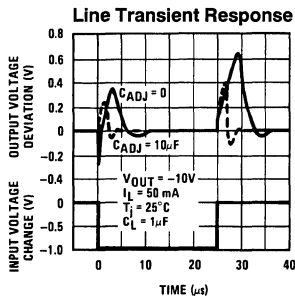
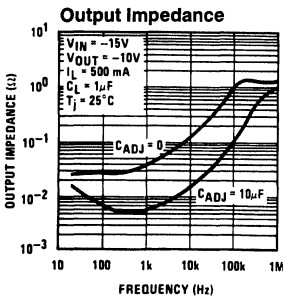
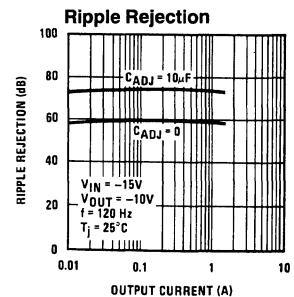
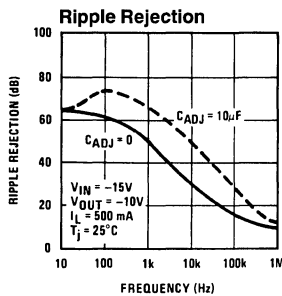
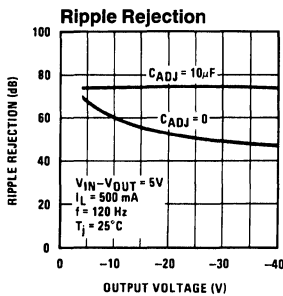
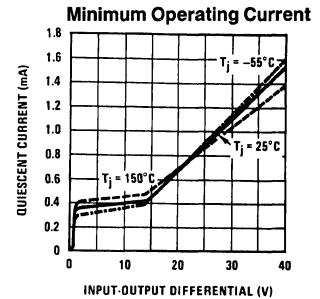
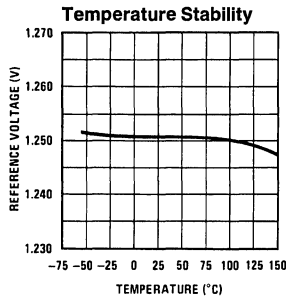
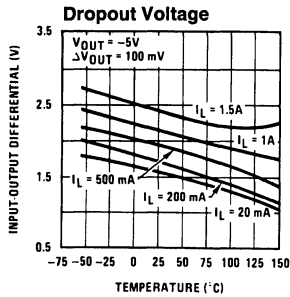
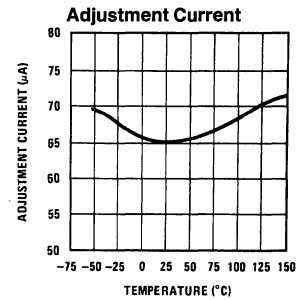
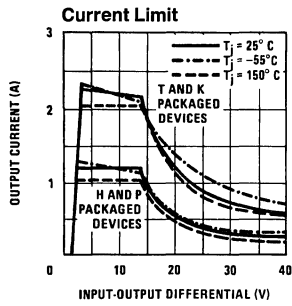
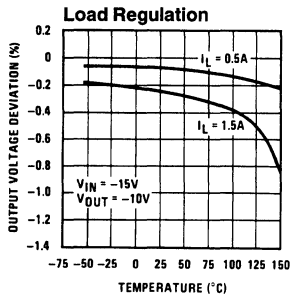
*When C₁ is larger than 20 μF, D1 protects the LM137 in case the input supply is shorted

**When C₂ is larger than 10 μF and -V_{OUT} is larger than -25V, D2 protects the LM137 in case the output is shorted

High Stability -10V Regulator



Typical Performance Characteristics (K Steel and T Packages)



LM137HV/LM337HV 3-Terminal Adjustable Negative Regulators (High Voltage)

General Description

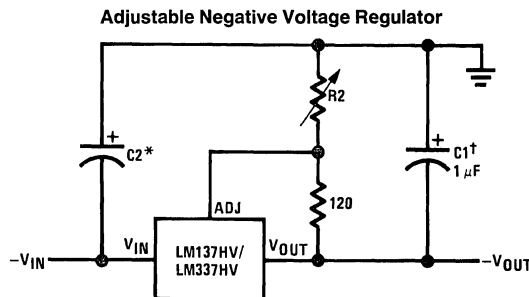
The LM137HV/LM337HV are adjustable 3-terminal negative voltage regulators capable of supplying in excess of $-1.5A$ over an output voltage range of $-1.2V$ to $-47V$. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM137HV series features internal current limiting, thermal shutdown and safe-area compensation, making them virtually blowout-proof against overloads.

The LM137HV/LM337HV serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM137HV/LM337HV are ideal complements to the LM117HV/LM317HV adjustable positive regulators.

Features

- Output voltage adjustable from $-1.2V$ to $-47V$
- $1.5A$ output current guaranteed, $-55^{\circ}C$ to $+150^{\circ}C$
- Line regulation typically $0.01\%/V$
- Load regulation typically 0.3%
- Excellent thermal regulation, $0.002\%/W$
- 77 dB ripple rejection
- Excellent rejection of thermal transients
- 50 ppm/ $^{\circ}C$ temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- P+ Product Enhancement tested
- Standard 3-lead transistor package
- Output short circuit protected

Typical Applications



TL/H/9066-1

$$-V_{OUT} = -1.25V \left(1 + \frac{R2}{120\Omega} \right) + \left[-I_{Adj}(R2) \right]$$

†C1 = $1 \mu F$ solid tantalum or $10 \mu F$ aluminum electrolytic required for stability. Output capacitors in the range of $1 \mu F$ to $1000 \mu F$ of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*C2 = $1 \mu F$ solid tantalum is required only if regulator is more than $4''$ from power-supply filter capacitor.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 3)

Power Dissipation Internally limited
Input—Output Voltage Differential 50V

Operating Junction Temperature Range

LM137HV -55°C to +150°C
LM337HV 0°C to +125°C

Storage Temperature

-65°C to +150°C

Lead Temperature (Soldering, 10 sec.)

300°

ESD rating is to be determined.

Electrical Characteristics (Note 1)

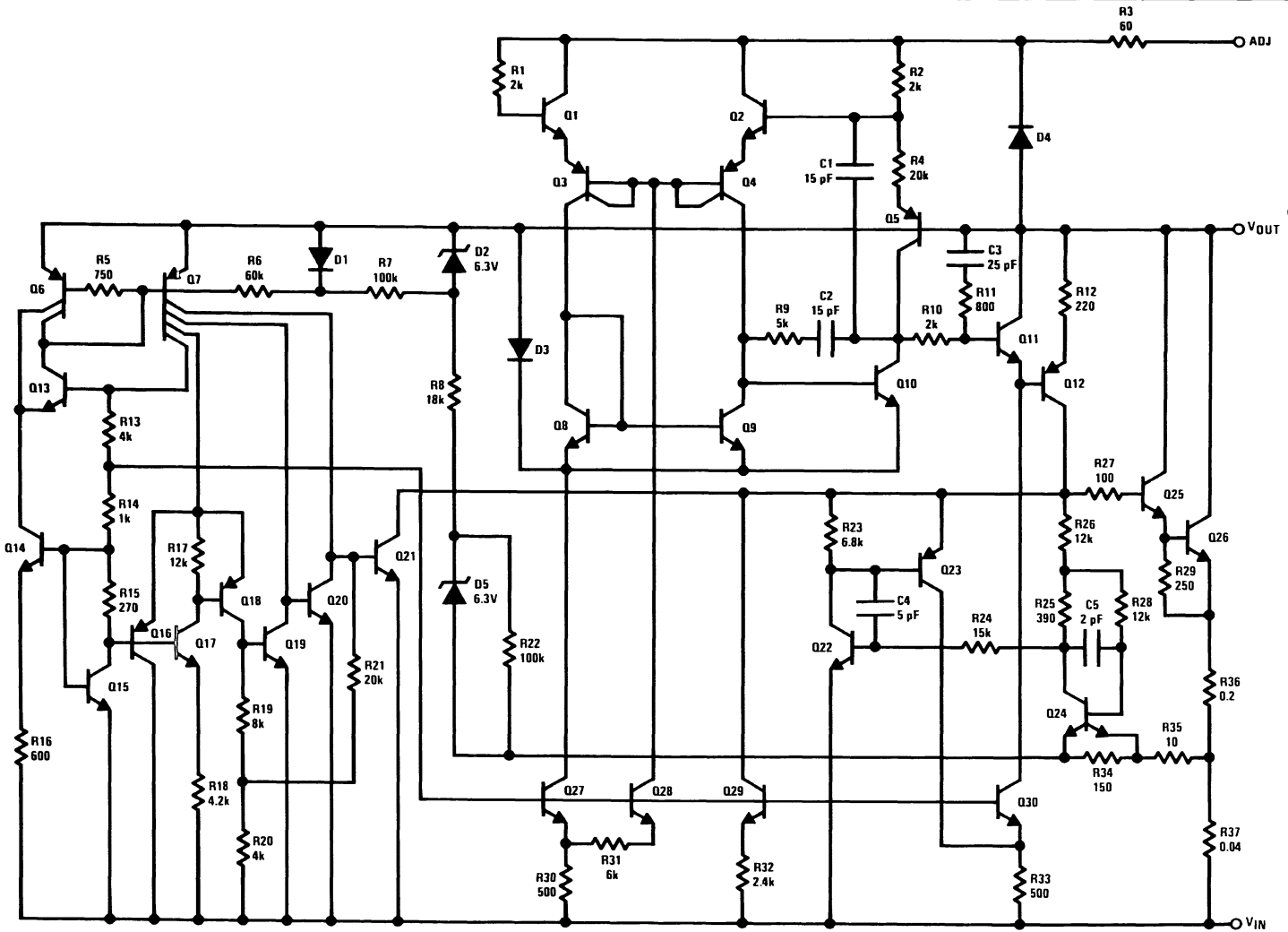
Parameter	Conditions	LM137HV			LM337HV			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	$T_J = 25^\circ\text{C}$, $3\text{V} \leq V_{IN} - V_{OUT} \leq 50\text{V}$, (Note 2) $I_L = 10\text{ mA}$		0.01	0.02		0.01	0.04	%/V
Load Regulation	$T_J = 25^\circ\text{C}$, $10\text{ mA} \leq I_{OUT} \leq I_{MAX}$		0.3	0.5		0.3	1.0	%
Thermal Regulation	$T_J = 25^\circ\text{C}$, 10 ms Pulse		0.002	0.02		0.003	0.04	%/W
Adjustment Pin Current			65	100		65	100	μA
Adjustment Pin Current Change	$10\text{ mA} \leq I_L \leq I_{MAX}$ $3.0\text{V} \leq V_{IN} - V_{OUT} \leq 50\text{V}$, $T_J = 25^\circ$		2	5		2	5	μA
			4	6		3	6	μA
Reference Voltage	$T_J = 25^\circ\text{C}$, (Note 3) $3\text{V} \leq V_{IN} - V_{OUT} \leq 50\text{V}$, (Note 3) $10\text{ mA} \leq I_{OUT} \leq I_{MAX}$, $P \leq P_{MAX}$	-1.225	-1.250	-1.275	-1.213	-1.250	-1.287	V
		-1.200	-1.250	-1.300	-1.200	-1.250	-1.300	V
Line Regulation	$3\text{V} \leq V_{IN} - V_{OUT} \leq 50\text{V}$, (Note 2) $I_L = 10\text{ mA}$		0.02	0.05		0.02	0.07	%/V
Load Regulation	$10\text{ mA} \leq I_{OUT} \leq I_{MAX}$, (Note 2)		0.3	1		0.3	1.5	%
Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		0.6			0.6		%
Minimum Load Current	$ V_{IN} - V_{OUT} \leq 50\text{V}$ $ V_{IN} - V_{OUT} \leq 10\text{V}$		2.5	5		2.5	10	mA
			1.2	3		1.5	6	mA
Current Limit	$ V_{IN} - V_{OUT} \leq 13\text{V}$ K Package H Package $ V_{IN} - V_{OUT} = 50\text{V}$ K Package H Package	1.5	2.2	3.2	1.5	2.2	3.5	A
		0.5	0.8	1.6	0.5	0.8	1.8	A
		0.2	0.4	0.8	0.1	0.4	0.8	A
		0.1	0.17	0.5	0.050	0.17	0.5	A
RMS Output Noise, % of V_{OUT}	$T_J = 25^\circ\text{C}$, $10\text{ Hz} \leq f \leq 10\text{ kHz}$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = -10\text{V}$, $f = 120\text{ Hz}$ $C_{ADJ} = 10\text{ }\mu\text{F}$	66	60		66	60		dB
			77			77		dB
Long-Term Stability	$T_A = 125^\circ\text{C}$, 1000 Hours		0.3	1		0.3	1	%
Thermal Resistance, Junction to Case	H Package		12	15		12	15	$^\circ\text{C}/\text{W}$
	K Package		2.3	3		2.3	3	$^\circ\text{C}/\text{W}$
Thermal Resistance, Junction to Ambient	H Package		140			140		$^\circ\text{C}/\text{W}$
	K Package		35			35		$^\circ\text{C}/\text{W}$

Note 1: Unless otherwise specified, these specifications apply: $-55^\circ\text{C} \leq T_J \leq +150^\circ\text{C}$ for the LM137HV, $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ for the LM337HV; $V_{IN} - V_{OUT} = 5\text{V}$; and $I_{OUT} = 0.1\text{A}$ for the TO-39 package and $I_{OUT} = 0.5\text{A}$ for the TO-3 package. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-39 and 20W for the TO-3. I_{MAX} is 1.5A for the TO-3 package and 0.2A for the TO-39 package.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulations. Load regulation is measured on the output pin at a point $1/8"$ below the base of the TO-3 and TO-39 packages.

Note 3: Refer to RETS137HVH drawing for LM137HVH or RETS137HVK for LM137HVK military specifications.

Schematic Diagram



1-85

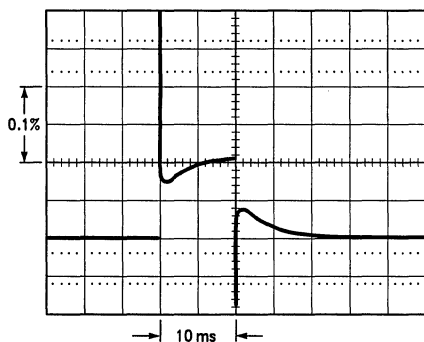
TL/H/9066-2

LM137HV/LM337HV

Thermal Regulation

When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per Watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT} , per Watt, within the first 10 ms after a step of power is applied. The LM137HV's specification is 0.02%/W, max.

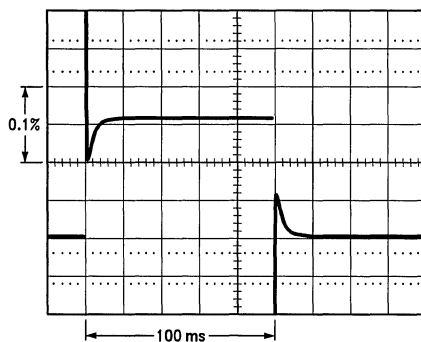
In *Figure 1*, a typical LM137HV's output drifts only 3 mV (or 0.03% of $V_{OUT} = -10V$) when a 10W pulse is applied for 10 ms. This performance is thus well inside the specification limit of $0.02\%/W \times 10W = 0.2\%$ max. When the 10W pulse is ended, the thermal regulation again shows a 3 mV step as the LM137HV chip cools off. Note that the load regulation error of about 8 mV (0.08%) is additional to the thermal regulation error. In *Figure 2*, when the 10W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).



TL/H/9066-3

LM137HV, $V_{OUT} = -10V$
 $V_{IN} - V_{OUT} = -40V$
 $I_L = 0A \rightarrow 0.25A \rightarrow 0A$
 Vertical sensitivity, 5 mV/div

FIGURE 1

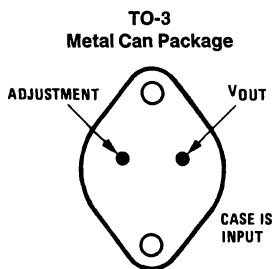


TL/H/9066-4

LM137HV, $V_{OUT} = -10V$
 $V_{IN} - V_{OUT} = -40V$
 $I_L = 0A \rightarrow 0.25A \rightarrow 0A$
 Horizontal sensitivity, 20 ms/div

FIGURE 2

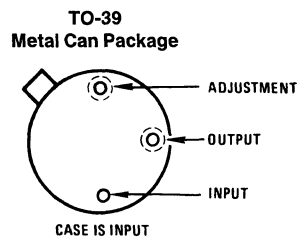
Connection Diagram (See Physical Dimensions section for further information)



Bottom View

Order Number LM137HVK Steel or LM337HVK Steel
 See NS Package Number K02A

TL/H/9066-5



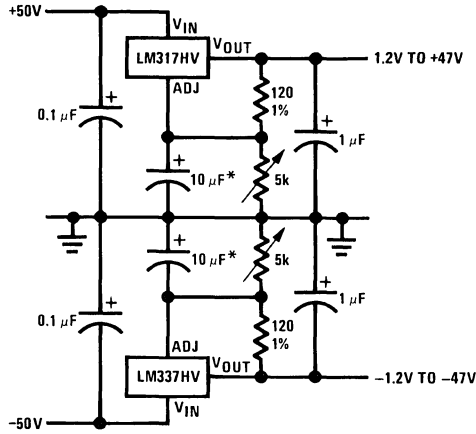
Bottom View

Order Number LM137HVH or LML337HVH
 See NS Package Number H03A

TL/H/9066-6

Typical Applications (Continued)

Adjustable High Voltage Regulator

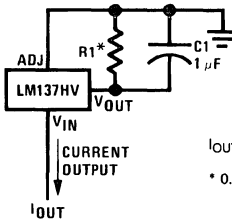


TL/H/9066-7

Full output current not available at high input-output voltages

*The 10 μF capacitors are optional to improve ripple rejection

Current Regulator

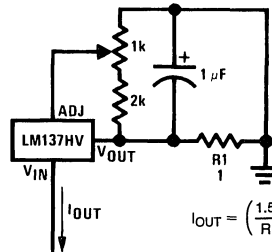


$$I_{OUT} = \frac{V_{REF}}{R_1}$$

* 0.8Ω ≤ R1 ≤ 120Ω

TL/H/9066-8

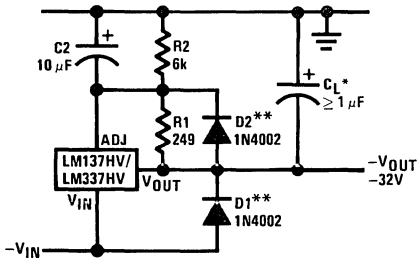
Adjustable Current Regulator



$$I_{OUT} = \left(\frac{1.5V}{R_1} \right) \pm 15\% \text{ adjustable}$$

TL/H/9066-9

Negative Regulator with Protection Diodes

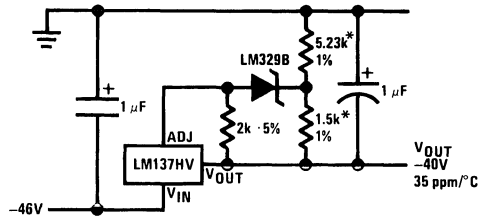


TL/H/9066-10

*When CL is larger than 20 μF, D1 protects the LM137HV in case the input supply is shorted

**When C2 is larger than 10 μF and -VOUT is larger than -25V, D2 protects the LM137HV in case the output is shorted

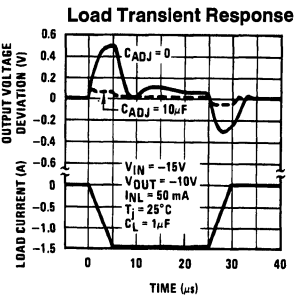
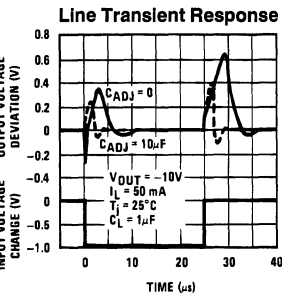
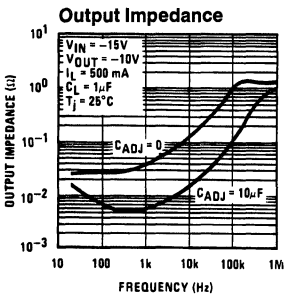
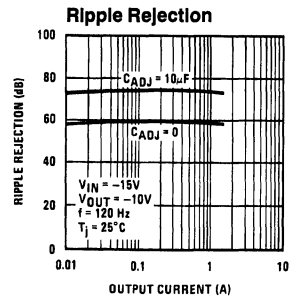
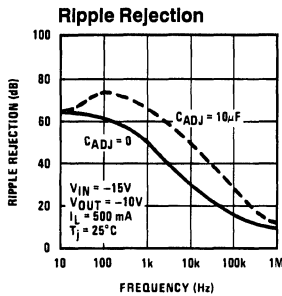
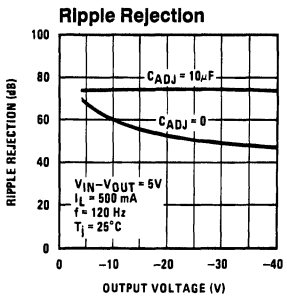
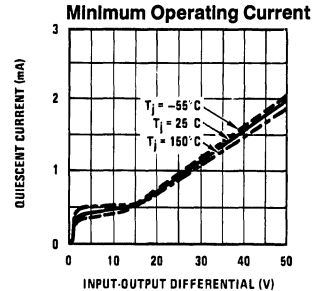
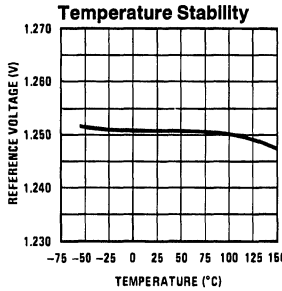
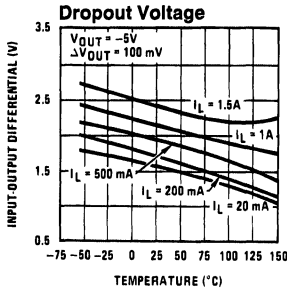
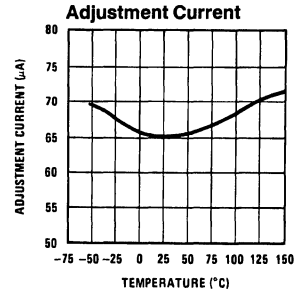
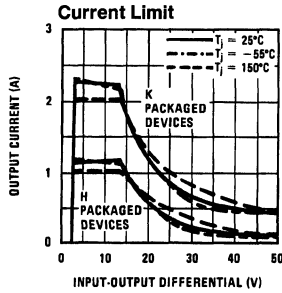
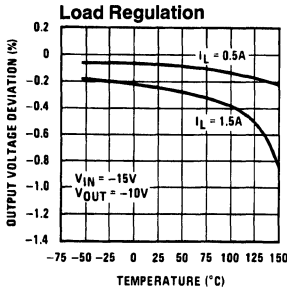
High Stability -40V Regulator



TL/H/9066-11

* Use resistors with good tracking TC < 25 ppm/°C

Typical Performance Characteristics (H and K-STEEL Package)



LM138, LM338

5-Amp Adjustable Regulators

General Description

The LM138 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 5A over a 1.2V to 32V output range. They are exceptionally easy to use and require only 2 resistors to set the output voltage. Careful circuit design has resulted in outstanding load and line regulation—comparable to many commercial power supplies. The LM138 family is supplied in a standard 3-lead transistor package.

A unique feature of the LM138 family is time-dependent current limiting. The current limit circuitry allows peak currents of up to 12A to be drawn from the regulator for short periods of time. This allows the LM138 to be used with heavy transient loads and speeds start-up under full-load conditions. Under sustained loading conditions, the current limit decreases to a safe value protecting the regulator. Also included on the chip are thermal overload protection and safe area protection for the power transistor. Overload protection remains functional even if the adjustment pin is accidentally disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An output capacitor can be added to improve transient response, while bypassing the adjustment pin will increase the regulator's ripple rejection.

Besides replacing fixed regulators or discrete designs, the LM138 is useful in a wide variety of other applications. Since

the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., do not short-circuit output to ground. The part numbers in the LM138 series which have a K suffix are packaged in a standard Steel TO-3 package, while those with a T suffix are packaged in a TO-220 plastic package. The LM138 is rated for $-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$, and the LM338 is rated for $0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$.

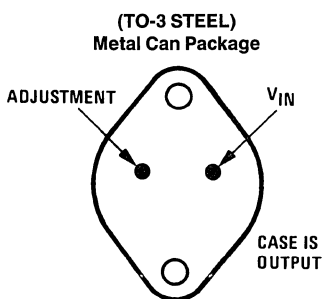
Features

- Guaranteed 7A peak output current
- Guaranteed 5A output current
- Adjustable output down to 1.2V
- Guaranteed thermal regulation
- Current limit constant with temperature
- P+ Product Enhancement tested
- Output is short-circuit protected

Applications

- Adjustable power supplies
- Constant current regulators
- Battery chargers

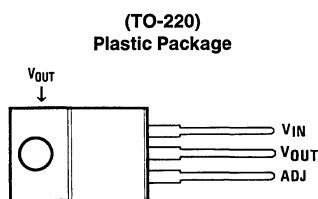
Connection Diagrams (See Physical Dimension section for further information)



Bottom View

Order Number LM138K STEEL or LM338K STEEL
See NS Package Number K02A

TL/H/9060-30



Front View

Order Number LM338T
See NS Package Number T03B

TL/H/9060-31

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 4)

Power Dissipation	Internally limited
Input/Output Voltage Differential	+40V, -0.3V
Storage Temperature	-65°C to +150°C

Lead Temperature

Metal Package (Soldering, 10 seconds)

300°C

Plastic Package (Soldering, 4 seconds)

260°C

ESD Tolerance

TBD

Operating Temperature Range

LM138

-55°C ≤ T_J ≤ +150°C

LM338

0°C ≤ T_J ≤ +125°C

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, V_{IN} - V_{OUT} = 5V; and I_{OUT} = 10 mA. (Note 2)

Symbol	Parameter	Conditions	LM138			Units
			Min	Typ	Max	
V _{REF}	Reference Voltage	I _{OUT} = 10 mA, T _J = 25°C				V
		3V ≤ (V _{IN} - V _{OUT}) ≤ 35V, 10 mA ≤ I _{OUT} ≤ 5A, P ≤ 50W	1.19	1.24	1.29	V
V _{RLINE}	Line Regulation	3V ≤ (V _{IN} - V _{OUT}) ≤ 35V (Note 3)		0.005	0.01	%/V
				0.02	0.04	%/V
V _{RLOAD}	Load Regulation	10 mA ≤ I _{OUT} ≤ 5V (Note 3)		0.1	0.3	%
				0.3	0.6	%
	Thermal Regulation	20 ms Pulse		0.002	0.01	%/W
I _{ADJ}	Adjustment Pin Current			45	100	μA
ΔI _{ADJ}	Adjustment Pin Current Change	10 mA ≤ I _{OUT} ≤ 5A, 3V ≤ (V _{IN} - V _{OUT}) ≤ 35V		0.2	5	μA
ΔV _{R/T}	Temperature Stability	T _{MIN} ≤ T _J ≤ T _{MAX}		1		%
I _{LOAD(Min)}	Minimum Load Current	V _{IN} - V _{OUT} = 35V		3.5	5	mA
I _{CL}	Current Limit	V _{IN} - V _{OUT} ≤ 10V DC	5	8		A
		0.5 ms Peak	7	12		A
		V _{IN} - V _{OUT} = 30V		1	1	A
V _N	RMS Output Noise, % of V _{OUT}	10 Hz ≤ f ≤ 10 kHz		0.003		%
$\frac{\Delta V_R}{\Delta V_{IN}}$	Ripple Rejection Ratio	V _{OUT} = 10V, f = 120 Hz, C _{ADJ} = 0 μF		60		dB
		V _{OUT} = 10V, f = 120 Hz, C _{ADJ} = 10 μF		75		dB
	Long-Term Stability	T _J = 125°C, 1000 Hrs		0.3	1	%
θ _{JC}	Thermal Resistance, Junction to Case	K Package			1	°C/W
θ _{JA}	Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35		°C/W

Electrical Characteristics (Continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, $V_{IN} - V_{OUT} = 5\text{V}$; and $I_{OUT} = 10\text{ mA}$. (Note 2)

Symbol	Parameter	Conditions	LM338			Units
			Min	Typ	Max	
V_{REF}	Reference Voltage	$I_{OUT} = 10\text{ mA}$, $T_J = 25^\circ\text{C}$				V
		$3\text{V} \leq (V_{IN} - V_{OUT}) \leq 35\text{V}$, $10\text{ mA} \leq I_{OUT} \leq 5\text{A}$, $P \leq 50\text{W}$	1.19	1.24	1.29	V
V_{RLINE}	Line Regulation	$3\text{V} \leq (V_{IN} - V_{OUT}) \leq 35\text{V}$ (Note 3)		0.005	0.03	%/V
				0.02	0.06	%/V
V_{RLOAD}	Load Regulation	$10\text{ mA} \leq I_{OUT} \leq 5\text{V}$ (Note 3)		0.1	0.5	%
				0.3	1	%
	Thermal Regulation	20 ms Pulse		0.002	0.02	%/W
I_{ADJ}	Adjustment Pin Current			45	100	μA
ΔI_{ADJ}	Adjustment Pin Current Change	$10\text{ mA} \leq I_{OUT} \leq 5\text{A}$, $3\text{V} \leq (V_{IN} - V_{OUT}) \leq 35\text{V}$		0.2	5	μA
$\Delta V_{R/T}$	Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		1		%
$I_{LOAD(\text{Min})}$	Minimum Load Current	$V_{IN} - V_{OUT} = 35\text{V}$		3.5	10	mA
I_{CL}	Current Limit	$V_{IN} - V_{OUT} \leq 10\text{V}$ DC	5	8		A
		0.5 ms Peak	7	12		A
		$V_{IN} - V_{OUT} = 30\text{V}$			1	A
V_N	RMS Output Noise, % of V_{OUT}	$10\text{ Hz} \leq f \leq 10\text{ kHz}$		0.003		%
$\frac{\Delta V_R}{\Delta V_{IN}}$	Ripple Rejection Ratio	$V_{OUT} = 10\text{V}$, $f = 120\text{ Hz}$, $C_{ADJ} = 0\ \mu\text{F}$		60		dB
		$V_{OUT} = 10\text{V}$, $f = 120\text{ Hz}$, $C_{ADJ} = 10\ \mu\text{F}$	60	75		dB
	Long-Term Stability	$T_J = 125^\circ\text{C}$, 1000 hrs		0.3	1	%
θ_{JC}	Thermal Resistance Junction to Case	K Package			1	$^\circ\text{C/W}$
		T Package			4	$^\circ\text{C/W}$
θ_{JA}	Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35		$^\circ\text{C/W}$
		T Package		50		$^\circ\text{C/W}$

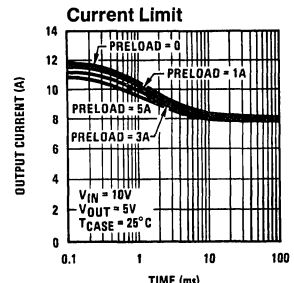
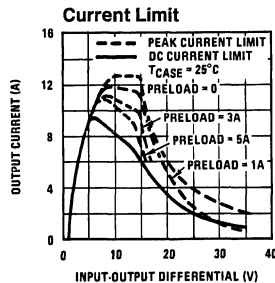
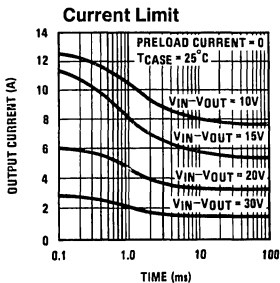
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: These specifications are applicable for power dissipations up to 50W for the TO-3 (K) package and 25W for the TO-220 (T) package. Power dissipation is guaranteed at these values up to 15V input-output differential. Above 15V differential, power dissipation will be limited by internal protection circuitry. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 3: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

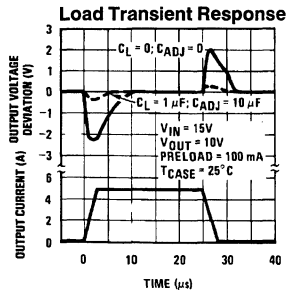
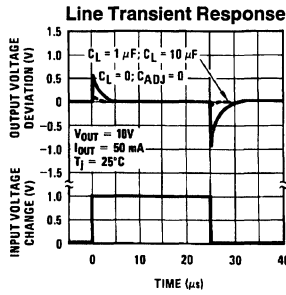
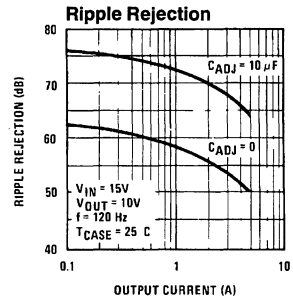
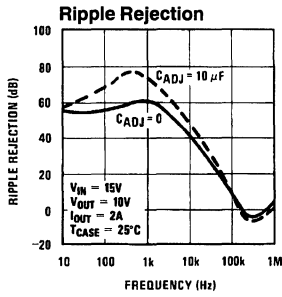
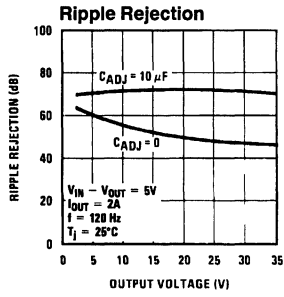
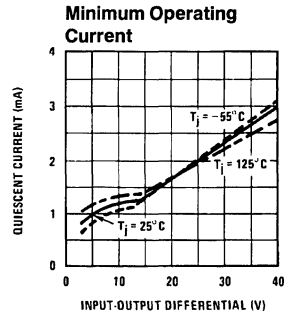
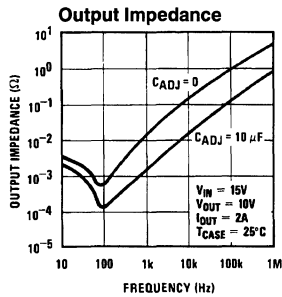
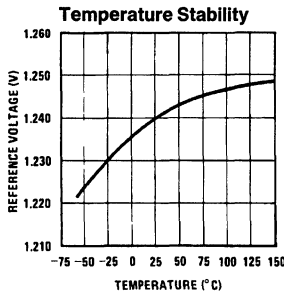
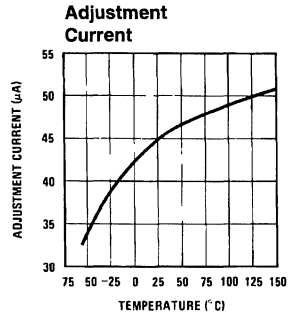
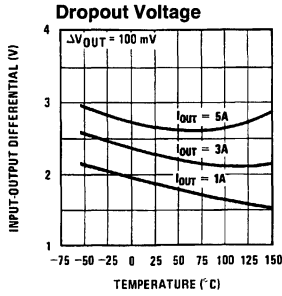
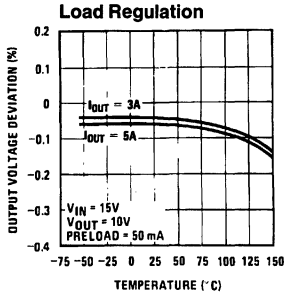
Note 4: Refer to RETS138K drawing for military specifications of LM138K.

Typical Performance Characteristics



TL/H/9060-4

Typical Performance Characteristics (Continued)



Application Hints

In operation, the LM138 develops a nominal 1.25V reference voltage, V_{REF} , between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ}R_2.$$

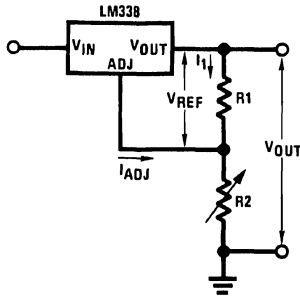


FIGURE 1

TL/H/9060-6

Since the 50 μ A current from the adjustment terminal represents an error term, the LM138 was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

External Capacitors

An input bypass capacitor is recommended. A 0.1 μ F disc or 1 μ F solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM138 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μ F bypass capacitor 75 dB ripple rejection is obtainable at any output level. Increases over 20 μ F do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

In general, the best type of capacitors to use are solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μ F in aluminum electrolytic to equal 1 μ F solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μ F disc may seem to work better than a 0.1 μ F disc as a bypass.

Although the LM138 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μ F solid tantalum (or 25 μ F aluminum electrolytic) on the output swamps this effect and insures stability.

Load Regulation

The LM138 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240 Ω) should be tied directly to the output of the regulator (case) rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05 Ω resistance between the regulator and load will have a load regulation due to line resistance of $0.05\Omega \times I_L$. If the set resistor is connected near the load the effective line resistance will be 0.05 Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240 Ω set resistor.

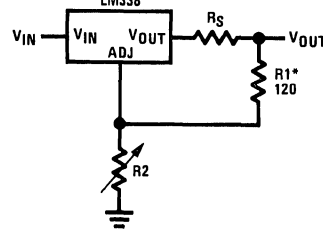


FIGURE 2. Regulator with Line Resistance in Output Lead

TL/H/9060-7

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using 2 separate leads to the case. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

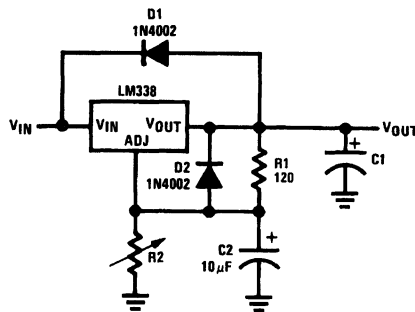
Protection Diodes

When external capacitors are used with any IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 20 μ F capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN} . In the LM138 this discharge path is through a large junction that is able to sustain 25A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 100 μ F or less at output of 15V or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when either the input or output is shorted. Internal to the LM138 is a 50 Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μ F capacitance. Figure 3 shows an LM138 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

Application Hints (Continued)



TL/H/9060-8

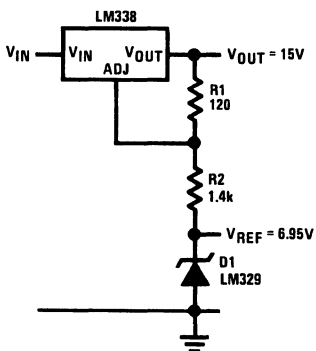
D1 protects against C1
D2 protects against C2

$$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1} \right) + I_{ADJ}R2$$

FIGURE 3. Regulator with Protection Diodes

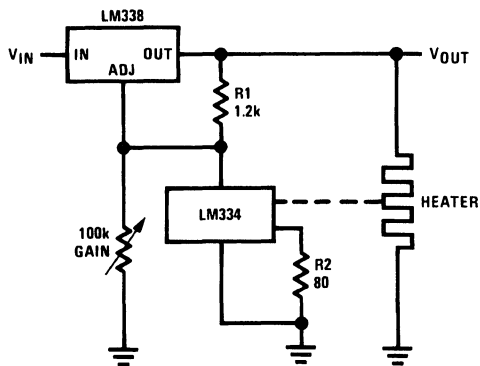
Typical Applications

Regulator and Voltage Reference



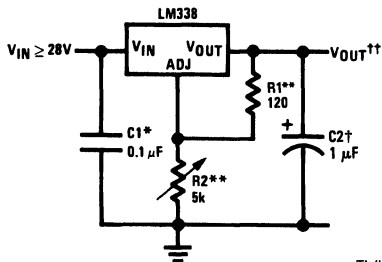
TL/H/9060-3

Temperature Controller



TL/H/9060-10

1.2V-25V Adjustable Regulator



TL/H/9060-1

Full output current not available
at high input-output voltages

†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is more than 6 inches from filter capacitors.

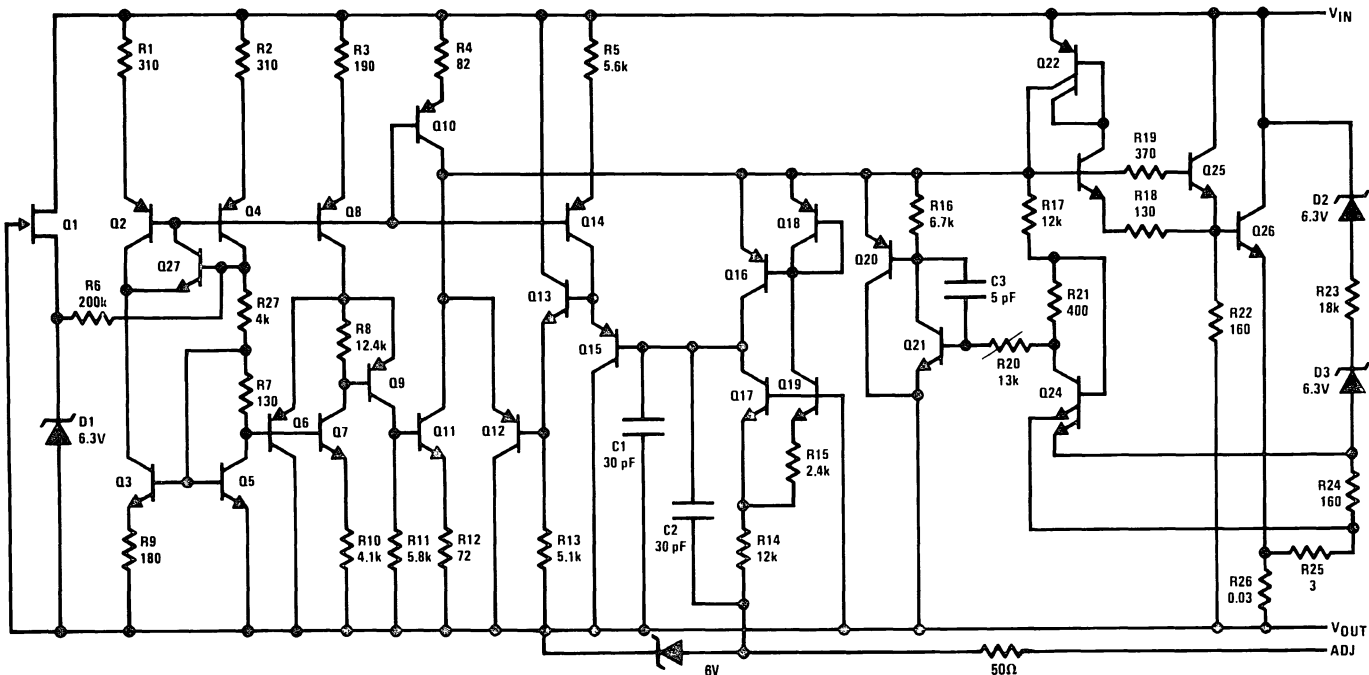
$$\dagger\dagger V_{OUT} = 1.25V \left(1 + \frac{R2}{R1} \right) + I_{ADJ} (R2)$$

**R1 = 240Ω for LM138. R1, R2 as an assembly can be ordered from Bourns:

MIL part no. 7105A-AT2-502

COMM part no. 7105A-AT7-502

Schematic Diagram



1-95

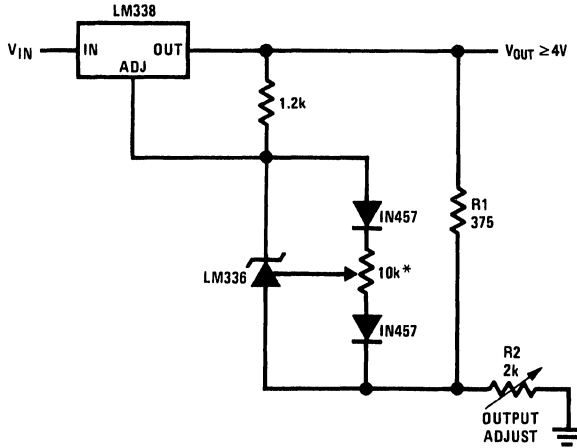
TL/H/9060-9

LM138/LM338



Typical Applications (Continued)

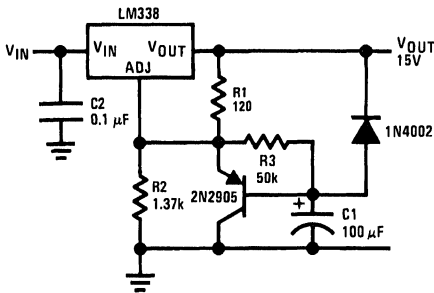
Precision Power Regulator with Low Temperature Coefficient



*Adjust for 3.75 across R1

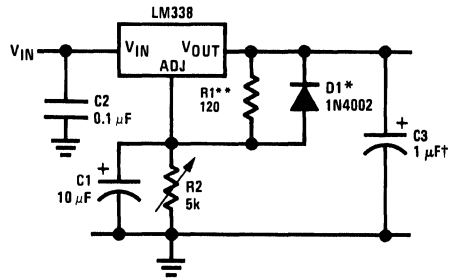
TL/H/9060-12

Slow Turn-On 15V Regulator



TL/H/9060-13

Adjustable Regulator with Improved Ripple Rejection



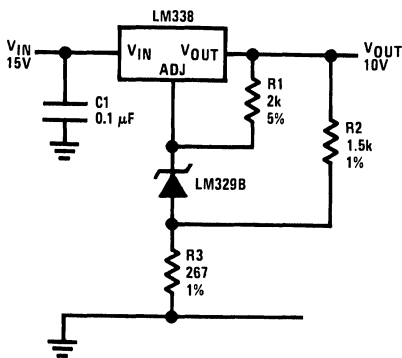
TL/H/9060-14

†Solid tantalum

*Discharges C1 if output is shorted to ground

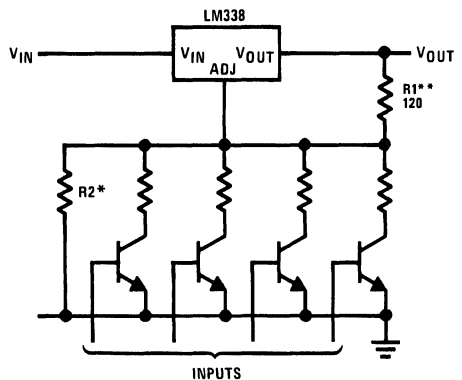
**R1 = 240Ω for LM138

High Stability 10V Regulator



TL/H/9060-15

Digitally Selected Outputs

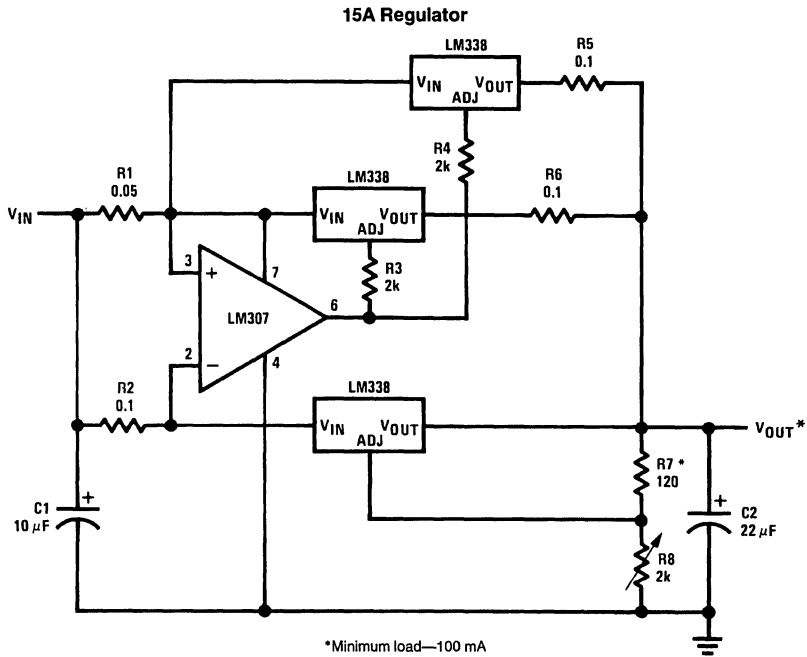


TL/H/9060-16

*Sets maximum VOUT

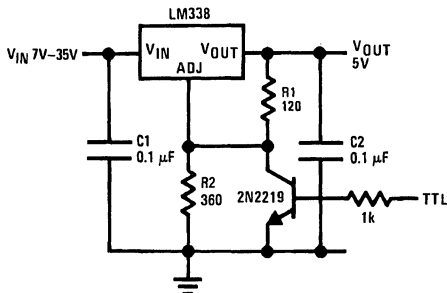
**R1 = 240Ω for LM138

Typical Applications (Continued)



TL/H/9060-17

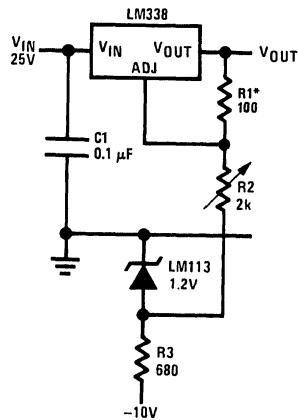
5V Logic Regulator with Electronic Shutdown**



**Minimum output ≈ 1.2V

TL/H/9060-18

0 to 22V Regulator

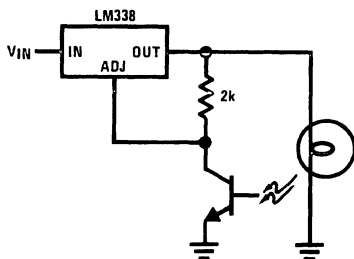


*R1 = 240Ω, R2 = 5k for LM138

Full output current not available at high input-output voltages

TL/H/9060-19

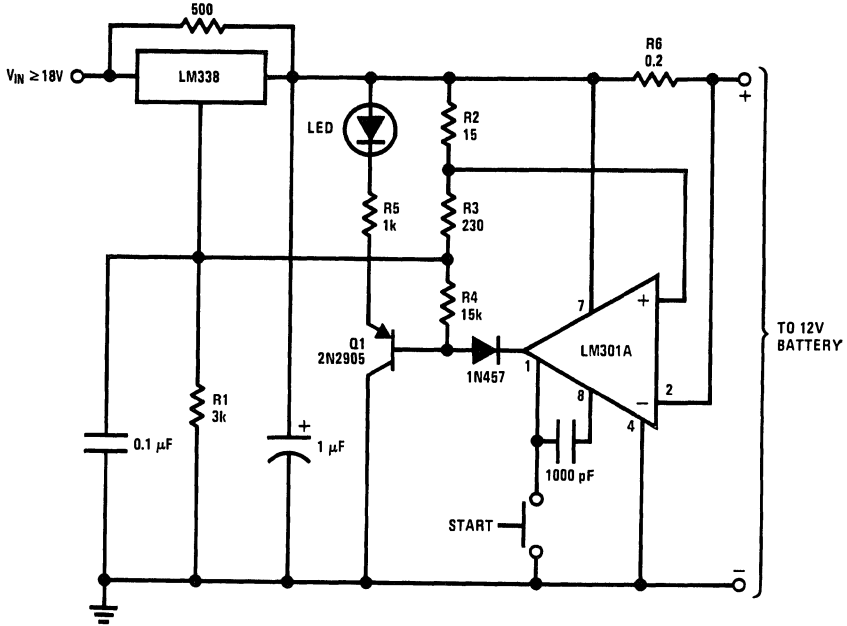
Light Controller



TL/H/9060-11

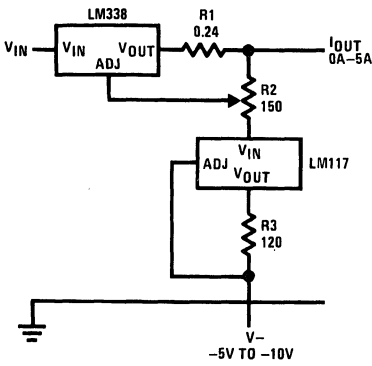
Typical Applications (Continued)

12V Battery Charger



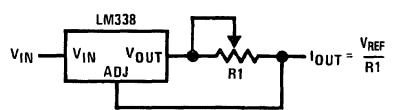
TL/H/9060-20

Adjustable Current Regulator



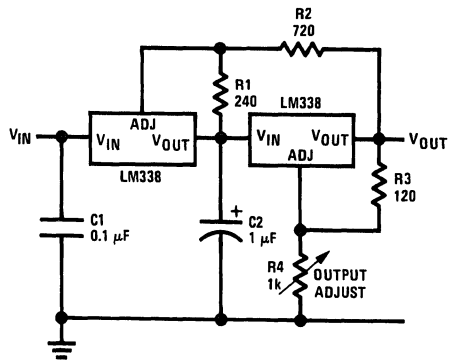
TL/H/9060-21

Precision Current Limiter



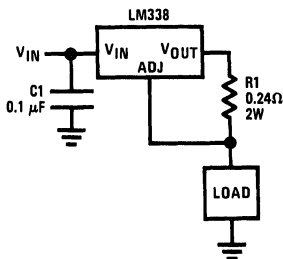
TL/H/9060-22

Tracking Preregulator



TL/H/9060-24

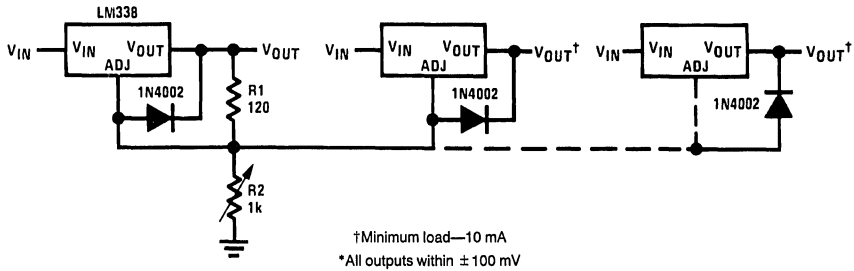
5A Current Regulator



TL/H/9060-23

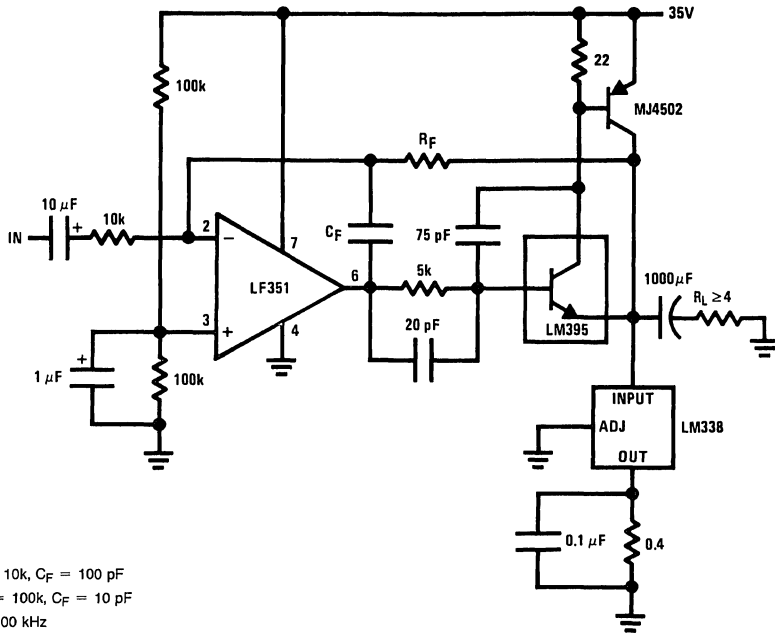
Typical Applications (Continued)

Adjusting Multiple On-Card Regulators with Single Control*



TL/H/9060-25

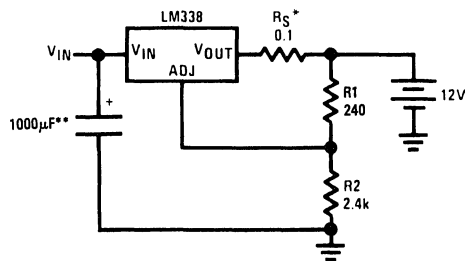
Power Amplifier



$A_V = 1, R_F = 10k, C_F = 100 \text{ pF}$
 $A_V = 10, R_F = 100k, C_F = 10 \text{ pF}$
 Bandwidth $\geq 100 \text{ kHz}$
 Distortion $\leq 0.1\%$

TL/H/9060-27

Simple 12V Battery Charger



TL/H/9060-28

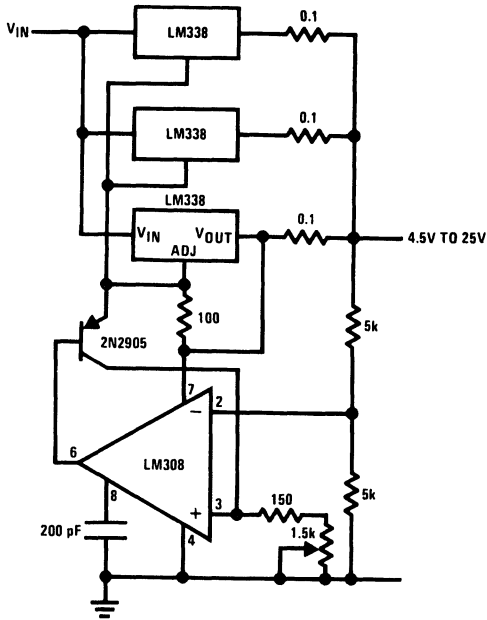
* R_S —sets output impedance of charger $Z_{OUT} = R_S \left(1 + \frac{R_2}{R_1} \right)$

Use of R_S allows low charging rates with fully charged battery.

**The 1000 μF is recommended to filter out input transients

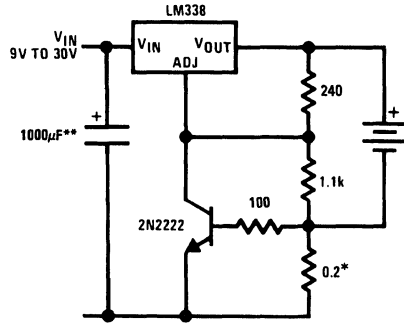
Typical Applications (Continued)

Adjustable 15A Regulator



TL/H/9060-26

Current Limited 6V Charger

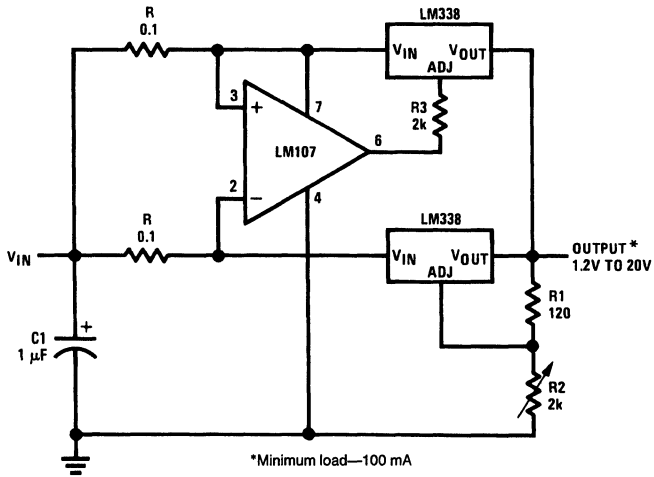


TL/H/9060-29

*Set max charge current to 3A

**The 1000 μ F is recommended to filter out input transients.

10A Regulator



*Minimum load—100 mA

TL/H/9060-2

LM140A/LM140/LM340A/LM340/LM7800/LM7800C

Series 3-Terminal Positive Regulators

General Description

The LM140A/LM140/LM340A/LM340/LM7800/LM7800C monolithic 3-terminal positive voltage regulators employ internal current-limiting, thermal shutdown and safe-area compensation, making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.0A output current. They are intended as fixed voltage regulators in a wide range of applications including local (on-card) regulation for elimination of noise and distribution problems associated with single-point regulation. In addition to use as fixed voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents.

Considerable effort was expended to make the entire series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

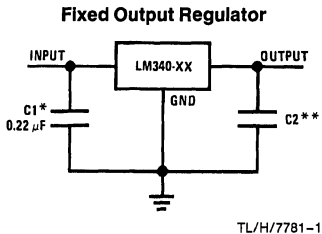
The entire series of regulators is available in the steel TO-3 power package. The LM340A/LM340/LM7800/LM7800C series is also available in the TO-220 plastic power package.

Features

- Complete specifications at 1A load
- Output voltage tolerances of $\pm 2\%$ at $T_j = 25^\circ\text{C}$ and $\pm 4\%$ over the temperature range (LM140A/LM340A)
- Line regulation of 0.01% of V_{OUT}/V of ΔV_{IN} at 1A load (LM140A/LM340A)
- Load regulation of 0.3% of V_{OUT}/A (LM140A/LM340A)
- Internal thermal overload protection
- Internal short-circuit current limit
- Output transistor safe area protection
- P+ Product Enhancement tested

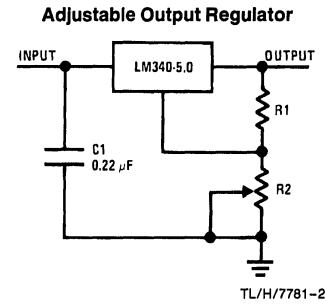
Device	Output Voltages	Packages
LM140A/LM140	5, 12, 15	TO-3 (K)
LM340A/LM340	5, 12, 15	TO-3 (K), TO-220 (T)
LM7800	8, 18, 24	TO-3 (K), TO-220 (T)
LM7800C	5, 6, 8, 12, 15, 18, 24	TO-3 (K), TO-220 (T)

Typical Applications

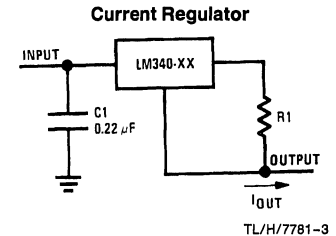


*Required if the regulator is located far from the power supply filter.

**Although no output capacitor is needed for stability, it does help transient response. (If needed, use 0.1 μF , ceramic disc).



$V_{OUT} = 5V + (5V/R1 + I_Q) R2$
 $R2 \geq 5V/R1 + 3 I_Q$
 load regulation (L_r) $\approx [(R1 + R2)/R1] (L_r \text{ of LM340-5})$



$$I_{OUT} = \frac{V_{2-3}}{R1} + I_Q$$

$\Delta I_Q = 1.3 \text{ mA}$ over line and load changes.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

DC Input Voltage	
All Devices except LM7824/LM7824C	35V
LM7824/LM7824C	40V
Internal Power Dissipation (Note 2)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package (K, KC)	300°C
TO-220 Package (T)	230°C
ESD Susceptibility (Note 3)	2 kV

Operating Conditions (Note 1)Temperature Range (T_A) (Note 2)

LM140A, LM140, LM7808, LM7818, LM7824	-55°C to +125°C
LM340A, LM340, LM7805C, LM7812C, LM7815C	0°C to +70°C
LM7806C, LM7808C, LM7818C, LM7824C	0°C to +125°C

LM140A/LM340A**Electrical Characteristics**
 $I_{OUT} = 1A$, $-55^\circ\text{C} \leq T_J \leq +150^\circ\text{C}$ (LM140A), or $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ (LM340A) unless otherwise specified (Note 4)

Symbol	Output Voltage		5V			12V			15V			Units
	Input Voltage (unless otherwise noted)		10V			19V			23V			
	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	$T_J = 25^\circ\text{C}$	4.9	5	5.1	11.75	12	12.25	14.7	15	15.3	V
		$P_D \leq 15\text{W}$, $5\text{ mA} \leq I_O \leq 1\text{ A}$	4.8		5.2	11.5		12.5	14.4		15.6	V
		$V_{MIN} \leq V_{IN} \leq V_{MAX}$	(7.5 $\leq V_{IN} \leq 20$)			(14.8 $\leq V_{IN} \leq 27$)			(17.9 $\leq V_{IN} \leq 30$)			V
ΔV_O	Line Regulation	$I_O = 500\text{ mA}$			10			18			22	mV
		ΔV_{IN}	(7.5 $\leq V_{IN} \leq 20$)			(14.8 $\leq V_{IN} \leq 27$)			(17.9 $\leq V_{IN} \leq 30$)			V
		$T_J = 25^\circ\text{C}$		3	10		4	18		4	22	mV
		ΔV_{IN}	(7.5 $\leq V_{IN} \leq 20$)			(14.5 $\leq V_{IN} \leq 27$)			(17.5 $\leq V_{IN} \leq 30$)			V
ΔV_O	Load Regulation	$T_J = 25^\circ\text{C}$		4			9			10	mV	
		Over Temperature		12		30		30		30	mV	
		ΔV_{IN}	(8 $\leq V_{IN} \leq 12$)			(16 $\leq V_{IN} \leq 22$)			(20 $\leq V_{IN} \leq 26$)			V
ΔV_O	Load Regulation	$T_J = 25^\circ\text{C}$	10	25		12	32		12	35	mV	
		$5\text{ mA} \leq I_O \leq 1.5\text{ A}$ $250\text{ mA} \leq I_O \leq 750\text{ mA}$		15			19			21	mV	
I_Q	Quiescent Current	$T_J = 25^\circ\text{C}$		6			6			6	mA	
		Over Temperature		6.5			6.5			6.5	mA	
ΔI_Q	Quiescent Current Change	$5\text{ mA} \leq I_O \leq 1\text{ A}$		0.5			0.5			0.5	mA	
		$T_J = 25^\circ\text{C}$, $I_O = 1\text{ A}$		0.8			0.8			0.8	mA	
		$V_{MIN} \leq V_{IN} \leq V_{MAX}$	(7.5 $\leq V_{IN} \leq 20$)			(14.8 $\leq V_{IN} \leq 27$)			(17.9 $\leq V_{IN} \leq 30$)			V
V_N	Output Noise Voltage	$T_A = 25^\circ\text{C}$, $10\text{ Hz} \leq f \leq 100\text{ kHz}$		40			75			90	μV	
		$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$T_J = 25^\circ\text{C}$, $f = 120\text{ Hz}$, $I_O = 1\text{ A}$ or $f = 120\text{ Hz}$, $I_O = 500\text{ mA}$, Over Temperature, $V_{MIN} \leq V_{IN} \leq V_{MAX}$	68	80		61	72		60	70
R_O	Dropout Voltage Output Resistance Short-Circuit Current Peak Output Current Average TC of V_O	$T_J = 25^\circ\text{C}$, $I_O = 1\text{ A}$		2.0			2.0			2.0	V	
		$f = 1\text{ kHz}$		8			18			19	m Ω	
		$T_J = 25^\circ\text{C}$		2.1			1.5			1.2	A	
		$T_J = 25^\circ\text{C}$		2.4			2.4			2.4	A	
		Min, $T_J = 0^\circ\text{C}$, $I_O = 5\text{ mA}$		-0.6			-1.5			-1.8	mV/ $^\circ\text{C}$	
V_{IN}	Input Voltage Required to Maintain Line Regulation	$T_J = 25^\circ\text{C}$		7.5			14.5			17.5	V	

LM140

Electrical Characteristics (Note 4) $-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ unless otherwise specified

Symbol	Output Voltage		5V			12V			15V			Units	
	Input Voltage (unless otherwise noted)		10V			19V			23V				
	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max		
V_O	Output Voltage	$T_J = 25^{\circ}\text{C}, 5 \text{ mA} \leq I_O \leq 1 \text{ A}$	4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V	
		$P_D \leq 15\text{W}, 5 \text{ mA} \leq I_O \leq 1 \text{ A}$	4.75		5.25	11.4		12.6	14.25		15.75	V	
		$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$			($8 \leq V_{\text{IN}} \leq 20$)			($15.5 \leq V_{\text{IN}} \leq 27$)			($18.5 \leq V_{\text{IN}} \leq 30$)	V	
ΔV_O	Line Regulation	$I_O = 500 \text{ mA}$	$T_J = 25^{\circ}\text{C}$	3	50	4	120	4	150			mV	
			ΔV_{IN}		($7 \leq V_{\text{IN}} \leq 25$)		($14.5 \leq V_{\text{IN}} \leq 30$)		($17.5 \leq V_{\text{IN}} \leq 30$)			V	
			$-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$		50		120		150			mV	
		$I_O \leq 1 \text{ A}$	ΔV_{IN}		($8 \leq V_{\text{IN}} \leq 20$)		($15 \leq V_{\text{IN}} \leq 27$)		($18.5 \leq V_{\text{IN}} \leq 30$)			V	
			$T_J = 25^{\circ}\text{C}$		50		120		150			mV	
			ΔV_{IN}		($7.5 \leq V_{\text{IN}} \leq 20$)		($14.6 \leq V_{\text{IN}} \leq 27$)		($17.7 \leq V_{\text{IN}} \leq 30$)			V	
ΔV_O	Load Regulation	$T_J = 25^{\circ}\text{C}$	$5 \text{ mA} \leq I_O \leq 1.5 \text{ A}$	10	50	12	120	12	150			mV	
			$250 \text{ mA} \leq I_P \leq 750 \text{ mA}$		25		60		75			mV	
			$-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}, 5 \text{ mA} \leq I_O \leq 1 \text{ A}$		50		120		150			mV	
I_Q	Quiescent Current	$I_O \leq 1 \text{ A}$	$T_J = 25^{\circ}\text{C}$		6		6		6			mA	
			$-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$		7		7		7			mA	
ΔI_Q	Quiescent Current Change	$5 \text{ mA} \leq I_O \leq 1 \text{ A}$			0.5		0.5		0.5			mA	
			$T_J = 25^{\circ}\text{C}, I_O \leq 1 \text{ A}$		0.8		0.8		0.8			mA	
			$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$		($8 \leq V_{\text{IN}} \leq 20$)		($15 \leq V_{\text{IN}} \leq 27$)		($18.5 \leq V_{\text{IN}} \leq 30$)			V	
			$I_O = 500 \text{ mA}, -55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$		0.8		0.8		0.8			mA	
V_N	Output Noise Voltage	$T_A = 25^{\circ}\text{C}, 10 \text{ Hz} \leq f \leq 100 \text{ kHz}$		40		75		90				μV	
			$\frac{\Delta V_{\text{IN}}}{\Delta V_{\text{OUT}}}$	Ripple Rejection	$f = 120 \text{ Hz}$	$\left\{ \begin{array}{l} I_O \leq 1 \text{ A}, T_J = 25^{\circ}\text{C} \text{ or} \\ I_O \leq 500 \text{ mA}, \\ -55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C} \end{array} \right.$	68	80	61	72	60	70	dB
			$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$					($8 \leq V_{\text{IN}} \leq 18$)		($15 \leq V_{\text{IN}} \leq 25$)		($18.5 \leq V_{\text{IN}} \leq 28.5$)	
R_O	Dropout Voltage	$T_J = 25^{\circ}\text{C}, I_O = 1 \text{ A}$		2.0		2.0		2.0				V	
			Output Resistance		8		18		19			m Ω	
			Short-Circuit Current		2.1		1.5		1.2			A	
			Peak Output Current		2.4		2.4		2.4			A	
			Average TC of V_{OUT}		$0^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}, I_O = 5 \text{ mA}$	-0.6		-1.5		-1.8			mV/ $^{\circ}\text{C}$
V_{IN}	Input Voltage Required to Maintain Line Regulation	$T_J = 25^{\circ}\text{C}, I_O \leq 1 \text{ A}$	7.5		14.6		17.7				V		

LM340/LM7800C

Electrical Characteristics (Note 4) $0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$ unless otherwise specified

Symbol	Output Voltage		5V			12V			15V			Units	
	Input Voltage (unless otherwise noted)		10V			19V			23V				
	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max		
V_O	Output Voltage	$T_J = 25^{\circ}\text{C}, 5\text{ mA} \leq I_O \leq 1\text{ A}$	4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V	
		$P_D \leq 15\text{ W}, 5\text{ mA} \leq I_O \leq 1\text{ A}$	4.75		5.25	11.4		12.6	14.25		15.75	V	
		$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$	(7.5 $\leq V_{\text{IN}} \leq 20$)				(14.5 $\leq V_{\text{IN}} \leq 27$)			(17.5 $\leq V_{\text{IN}} \leq 30$)		V	
ΔV_O	Line Regulation	$I_O = 500\text{ mA}$	$T_J = 25^{\circ}\text{C}$	3	50	4	120	4	150	4	150	mV V	
			ΔV_{IN}	(7 $\leq V_{\text{IN}} \leq 25$)			(14.5 $\leq V_{\text{IN}} \leq 30$)			(17.5 $\leq V_{\text{IN}} \leq 30$)		V	
		$0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$	ΔV_{IN}	50		120			150			mV V	
			ΔV_{IN}	(8 $\leq V_{\text{IN}} \leq 20$)			(15 $\leq V_{\text{IN}} \leq 27$)			(18.5 $\leq V_{\text{IN}} \leq 30$)		V	
		$I_O \leq 1\text{ A}$	$T_J = 25^{\circ}\text{C}$	50		120			150			mV V	
			ΔV_{IN}	(7.5 $\leq V_{\text{IN}} \leq 20$)			(14.6 $\leq V_{\text{IN}} \leq 27$)			(17.7 $\leq V_{\text{IN}} \leq 30$)		V	
ΔV_O	Load Regulation	$T_J = 25^{\circ}\text{C}$	$5\text{ mA} \leq I_O \leq 1.5\text{ A}$	10	50	12	120	12	150		mV mV		
			$250\text{ mA} \leq I_O \leq 750\text{ mA}$		25		60		75				
		$5\text{ mA} \leq I_O \leq 1\text{ A}, 0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$		50		120		150			mV		
I_Q	Quiescent Current	$I_O \leq 1\text{ A}$	$T_J = 25^{\circ}\text{C}$		8		8		8		8	mA	
			$0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$		8.5		8.5		8.5		8.5	mA	
ΔI_Q	Quiescent Current Change	$5\text{ mA} \leq I_O \leq 1\text{ A}$	$T_J = 25^{\circ}\text{C}, I_O \leq 1\text{ A}$		0.5		0.5		0.5		0.5	mA	
			$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$	(7.5 $\leq V_{\text{IN}} \leq 20$)		1.0		1.0		1.0		1.0	mA V
			$I_O \leq 500\text{ mA}, 0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$	$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$	(7 $\leq V_{\text{IN}} \leq 25$)		1.0		1.0		1.0		1.0
V_N	Output Noise Voltage	$T_A = 25^{\circ}\text{C}, 10\text{ Hz} \leq f \leq 100\text{ kHz}$	40			75			90		μV		
$\frac{\Delta V_{\text{IN}}}{\Delta V_{\text{OUT}}}$	Ripple Rejection	$f = 120\text{ Hz}$	$I_O \leq 1\text{ A}, T_J = 25^{\circ}\text{C}$	62	80	55	72	54	70			dB	
			or $I_O \leq 500\text{ mA}, 0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$	62		55		54				dB	
			$V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$	(8 $\leq V_{\text{IN}} \leq 18$)			(15 $\leq V_{\text{IN}} \leq 25$)			(18.5 $\leq V_{\text{IN}} \leq 28.5$)		V	
R_O	Dropout Voltage	$T_J = 25^{\circ}\text{C}, I_O = 1\text{ A}$	2.0		2.0		2.0		2.0		V		
	Output Resistance	$f = 1\text{ kHz}$	8		18		19				m Ω		
	Short-Circuit Current	$T_J = 25^{\circ}\text{C}$	2.1		1.5		1.2				A		
	Peak Output Current	$T_J = 25^{\circ}\text{C}$	2.4		2.4		2.4				A		
	Average TC of V_{OUT}	$0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}, I_O = 5\text{ mA}$	-0.6		-1.5		-1.8				mV/ $^{\circ}\text{C}$		
V_{IN}	Input Voltage Required to Maintain Line Regulation	$T_J = 25^{\circ}\text{C}, I_O \leq 1\text{ A}$	7.5		14.6		17.7				V		

Note 1: Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Conditions are conditions under which the device functions but the specifications might not be guaranteed. For guaranteed specifications and test conditions see the Electrical Characteristics.

Note 2: The maximum allowable power dissipation at any ambient temperature is a function of the maximum junction temperature for operation ($T_{\text{JMAX}} = 125^{\circ}\text{C}$ or 150°C), the junction-to-ambient thermal resistance (θ_{JA}), and the ambient temperature (T_A). $P_{\text{DMAX}} = (T_{\text{JMAX}} - T_A)/\theta_{\text{JA}}$. If this dissipation is exceeded, the die temperature will rise above T_{JMAX} and the electrical specifications do not apply. If the die temperature rises above 150°C , the device will go into thermal shutdown. For the TO-3 package (K, KC), the junction-to-ambient thermal resistance (θ_{JA}) is $39^{\circ}\text{C}/\text{W}$. When using a heatsink, θ_{JA} is the sum of the $4^{\circ}\text{C}/\text{W}$ junction-to-case thermal resistance (θ_{JC}) of the TO-3 package and the case-to-ambient thermal resistance of the heatsink. For the TO-220 package (T), θ_{JA} is $54^{\circ}\text{C}/\text{W}$ and θ_{JC} is $4^{\circ}\text{C}/\text{W}$.

Note 3: ESD rating is based on the human body model, 100 pF discharged through 1.5 k Ω .

Note 4: All characteristics are measured with a 0.22 μF capacitor from input to ground and a 0.1 μF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \leq 10\text{ ms}$, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 5: A military RETS specification is available on request. At the time of printing, the military RETS specifications for the LM140AK-5.0/883, LM140AK-12/883, and LM140AK-15/883 complied with the min and max limits for the respective versions of the LM140A. At the time of printing, the military RETS specifications for the LM140K-5.0/883, LM140K-12/883, and LM140K-15/883 complied with the min and max limits for the respective versions of the LM140. The LM140H/883, LM140K/883, and LM140AK/883 may also be procured as a Standard Military Drawing.

LM7806C**Electrical Characteristics**
 $0^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$, $V_I = 11\text{V}$, $I_O = 500\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$, unless otherwise specified

Symbol	Parameter	Conditions (Note 4)	Min	Typ	Max	Units
V_O	Output Voltage	$T_J = 25^{\circ}\text{C}$	5.75	6.0	6.25	V
ΔV_O	Line Regulation	$T_J = 25^{\circ}\text{C}$		5.0	120	mV
		$8.0\text{V} \leq V_I \leq 25\text{V}$		1.5	60	
ΔV_O	Load Regulation	$T_J = 25^{\circ}\text{C}$		14	120	mV
		$5.0\text{ mA} \leq I_O \leq 1.5\text{A}$		4.0	60	
V_O	Output Voltage	$8.0\text{V} \leq V_I \leq 21\text{V}$, $5.0\text{ mA} \leq I_O \leq 1.0\text{A}$, $P \leq 15\text{W}$	5.7		6.3	V
I_Q	Quiescent Current	$T_J = 25^{\circ}\text{C}$		4.3	8.0	mA
ΔI_Q	Quiescent Current Change	With Line	$8.0\text{V} \leq V_I \leq 25\text{V}$		1.3	mA
		With Load	$5.0\text{ mA} \leq I_O \leq 1.0\text{A}$		0.5	
V_N	Noise	$T_A = 25^{\circ}\text{C}$, $10\text{ Hz} \leq f \leq 100\text{ kHz}$		45		μV
$\Delta V_I/\Delta V_O$	Ripple Rejection	$f = 120\text{ Hz}$, $I_O = 350\text{ mA}$, $T_J = 25^{\circ}\text{C}$	59	75		dB
V_{DO}	Dropout Voltage	$I_O = 1.0\text{A}$, $T_J = 25^{\circ}\text{C}$		2.0		V
R_O	Output Resistance	$f = 1.0\text{ kHz}$		9		$\text{m}\Omega$
I_{OS}	Output Short Circuit Current	$T_J = 25^{\circ}\text{C}$, $V_I = 35\text{V}$		550		mA
I_{PK}	Peak Output Current	$T_J = 25^{\circ}\text{C}$		2.2		A
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage	$I_O = 5.0\text{ mA}$, $0^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$		0.8		$\text{mV}/^{\circ}\text{C}$

LM7808/LM7808C**Electrical Characteristics**
 $-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ (LM7808) or $0^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ (LM7808C), $V_I = 14\text{V}$, $I_O = 500\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$, unless otherwise specified

Symbol	Parameter	Conditions (Note 4)	LM7808			LM7808C			Units	
			Min	Typ	Max	Min	Typ	Max		
V_O	Output Voltage	$T_J = 25^{\circ}\text{C}$	7.7	8.0	8.3	7.7	8.0	8.3	V	
ΔV_O	Line Regulation	$T_J = 25^{\circ}\text{C}$	$10.5\text{V} \leq V_I \leq 25\text{V}$		6.0	80	6.0		160	mV
			$11.0\text{V} \leq V_I \leq 17\text{V}$		2.0	40	2.0		80	
ΔV_O	Load Regulation	$T_J = 25^{\circ}\text{C}$	$5.0\text{ mA} \leq I_O \leq 1.5\text{A}$		12	100	12		160	mV
			$250\text{ mA} \leq I_O \leq 750\text{ mA}$		4.0	40	4.0		80	
V_O	Output Voltage	$11.5\text{V} \leq V_I \leq 23\text{V}$, $5.0\text{ mA} \leq I_O \leq 1.0\text{A}$, $P \leq 15\text{W}$	7.6		8.4	7.6		8.4	V	
I_Q	Quiescent Current	$T_J = 25^{\circ}\text{C}$		4.3	6.0		4.3	8.0	mA	
ΔI_Q	Quiescent Current Change	With Line	$11.5\text{V} \leq V_I \leq 25\text{V}$			0.8			1.0	mA
		With Load	$5.0\text{ mA} \leq I_O \leq 1.0\text{A}$			0.5			0.5	
V_N	Noise	$T_A = 25^{\circ}\text{C}$, $10\text{ Hz} \leq f \leq 100\text{ kHz}$		64	320		52		μV	
$\Delta V_I/\Delta V_O$	Ripple Rejection	$f = 120\text{ Hz}$, $I_O = 350\text{ mA}$, $T_J = 25^{\circ}\text{C}$	62	72		56	72		dB	
V_{DO}	Dropout Voltage	$I_O = 1.0\text{A}$, $T_J = 25^{\circ}\text{C}$		2.0	2.5		2.0		V	
R_O	Output Resistance	$f = 1.0\text{ kHz}$		16			16		$\text{m}\Omega$	
I_{OS}	Output Short Circuit Current	$T_J = 25^{\circ}\text{C}$, $V_I = 35\text{V}$		0.75	1.2		0.45		A	
I_{PK}	Peak Output Current	$T_J = 25^{\circ}\text{C}$	1.3	2.2	3.3		2.2		A	
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage	$I_O = 5.0\text{ mA}$	LM7808	$-55^{\circ}\text{C} \leq T_A \leq +25^{\circ}\text{C}$			0.4			$\text{mV}/^{\circ}\text{C}/V_O$
			LM7808	$+25^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$			0.3			
			LM7808C					0.8		

Note 4: All characteristics are measured with a $0.22\ \mu\text{F}$ capacitor from input to ground and a $0.1\ \mu\text{F}$ capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \leq 10\text{ ms}$, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

LM7818/LM7818C**Electrical Characteristics**

$-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ (LM7818) or $0^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ (LM7818C), $V_I = 27\text{V}$,
 $I_O = 500\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$, unless otherwise specified

Symbol	Parameter	Conditions (Note 4)	LM7818			LM7818C			Units	
			Min	Typ	Max	Min	Typ	Max		
V_O	Output Voltage	$T_J = 25^{\circ}\text{C}$	17.3	18.0	18.7	17.3	18.0	18.7	V	
ΔV_O	Line Regulation	$T_J = 25^{\circ}\text{C}$	$21\text{V} \leq V_I \leq 33\text{V}$			15	180	15	360	mV
			$24\text{V} \leq V_I \leq 30\text{V}$			5.0	90	5.0	180	
ΔV_O	Load Regulation	$T_J = 25^{\circ}\text{C}$	$5.0\text{ mA} \leq I_O \leq 1.5\text{ A}$			12	180	12	360	mV
			$250\text{ mA} \leq I_O \leq 750\text{ mA}$			4.0	90	4.0	180	
V_O	Output Voltage	$22\text{V} \leq V_I \leq 33\text{V}$, $5.0\text{ mA} \leq I_O \leq 1.0\text{ A}$, $P \leq 15\text{ W}$	17.1		18.9	17.1		18.9	V	
I_Q	Quiescent Current	$T_J = 25^{\circ}\text{C}$		4.5	6.0		4.5	8.0	mA	
ΔI_Q	Quiescent Current Change	With Line	$22\text{V} \leq V_I \leq 33\text{V}$				0.8		1.0	mA
		With Load	$5.0\text{ mA} \leq I_O \leq 1.0\text{ A}$				0.5		0.5	
V_N	Noise	$T_A = 25^{\circ}\text{C}$, $10\text{ Hz} \leq f \leq 100\text{ kHz}$		144	720		110		μV	
$\Delta V_I/\Delta V_O$	Ripple Rejection	$f = 120\text{ Hz}$, $I_O = 350\text{ mA}$, $T_J = 25^{\circ}\text{C}$	59	69		53	69		dB	
V_{DO}	Dropout Voltage	$I_O = 1.0\text{ A}$, $T_J = 25^{\circ}\text{C}$		2.0			2.0		V	
R_O	Output Resistance	$f = 1.0\text{ kHz}$		22			22		$\text{m}\Omega$	
I_{OS}	Output Short Circuit Current	$T_J = 25^{\circ}\text{C}$, $V_I = 35\text{V}$		0.75			0.20		A	
I_{PK}	Peak Output Current	$T_J = 25^{\circ}\text{C}$	1.3	2.2	3.3		2.1		A	
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage	$I_O = 5.0\text{ mA}$	LM7818	$-55^{\circ}\text{C} \leq T_A \leq +25^{\circ}\text{C}$				0.4		$\text{mV}/^{\circ}\text{C}/V_O$
			LM7818	$+25^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$				0.3		
			LM7818C						1.0	

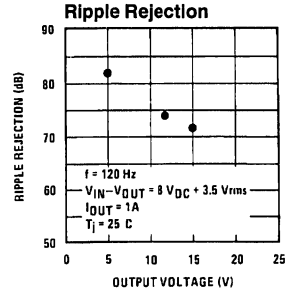
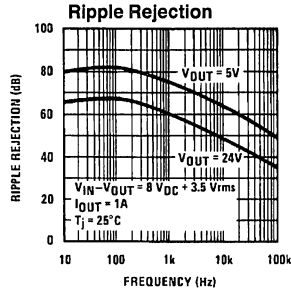
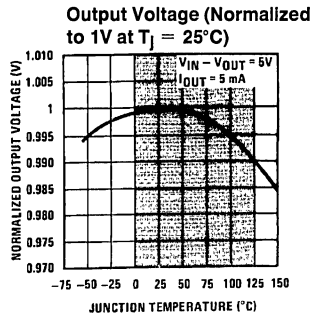
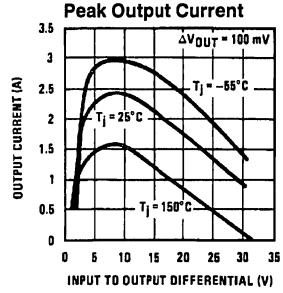
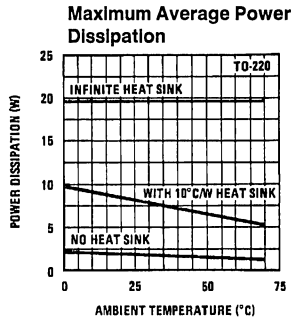
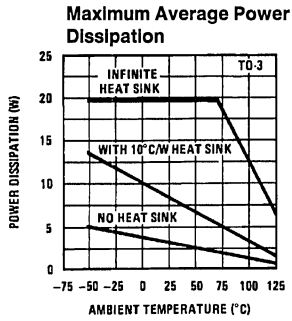
LM7824/LM7824C**Electrical Characteristics**

$-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ (LM7824) or $0^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ (LM7824C), $V_I = 33\text{V}$,
 $I_O = 500\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$, unless otherwise specified

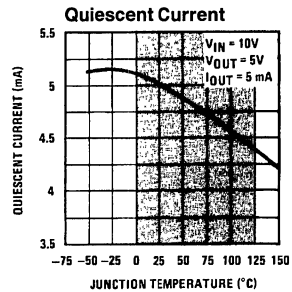
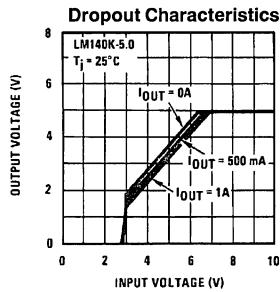
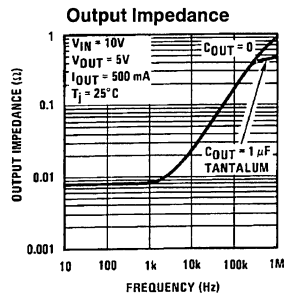
Symbol	Parameter	Conditions (Note 4)	LM7824			LM7824C			Units	
			Min	Typ	Max	Min	Typ	Max		
V_O	Output Voltage	$T_J = 25^{\circ}\text{C}$	23.0	24.0	25.0	23.0	24.0	25.0	V	
ΔV_O	Line Regulation	$T_J = 25^{\circ}\text{C}$	$27\text{V} \leq V_I \leq 38\text{V}$			18	240	18	480	mV
			$30\text{V} \leq V_I \leq 36\text{V}$			6.0	120	6.0	240	
ΔV_O	Load Regulation	$T_J = 25^{\circ}\text{C}$	$5.0\text{ mA} \leq I_O \leq 1.5\text{ A}$			12	240	12	480	mV
			$250\text{ mA} \leq I_O \leq 750\text{ mA}$			4.0	120	4.0	240	
V_O	Output Voltage	$28\text{V} \leq V_I \leq 38\text{V}$, $5.0\text{ mA} \leq I_O \leq 1.0\text{ A}$, $P \leq 15\text{ W}$	22.8		25.2	22.8		25.2	V	
I_Q	Quiescent Current	$T_J = 25^{\circ}\text{C}$		4.6	6.0		4.6	8.0	mA	
ΔI_Q	Quiescent Current Change	With Line	$28\text{V} \leq V_I \leq 38\text{V}$				0.8		1.0	mA
		With Load	$5.0\text{ mA} \leq I_O \leq 1.0\text{ A}$				0.5		0.5	
V_N	Noise	$T_A = 25^{\circ}\text{C}$, $10\text{ Hz} \leq f \leq 100\text{ kHz}$		192	960		170		μV	
$\Delta V_I/\Delta V_O$	Ripple Rejection	$f = 120\text{ Hz}$, $I_O = 350\text{ mA}$, $T_J = 25^{\circ}\text{C}$	56	66		50	66		dB	
V_{DO}	Dropout Voltage	$I_O = 1.0\text{ A}$, $T_J = 25^{\circ}\text{C}$		2.0	2.5		2.0		V	
R_O	Output Resistance	$f = 1.0\text{ kHz}$		28			28		$\text{m}\Omega$	
I_{OS}	Output Short Circuit Current	$T_J = 25^{\circ}\text{C}$, $V_I = 35\text{V}$		0.75	1.2		0.15		A	
I_{PK}	Peak Output Current	$T_J = 25^{\circ}\text{C}$	1.3	2.2	3.3		2.1		A	
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage	$I_O = 5.0\text{ mA}$	LM7824	$-55^{\circ}\text{C} \leq T_A \leq +25^{\circ}\text{C}$				0.4		$\text{mV}/^{\circ}\text{C}/V_O$
			LM7824	$+25^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$				0.3		
			LM7824C						1.5	

Note 4: All characteristics are measured with a $0.22\ \mu\text{F}$ capacitor from input to ground and a $0.1\ \mu\text{F}$ capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \leq 10\text{ ms}$, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

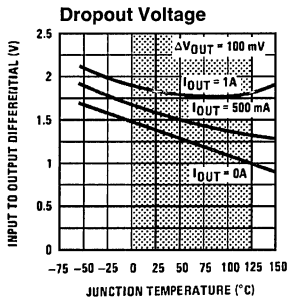
Typical Performance Characteristics



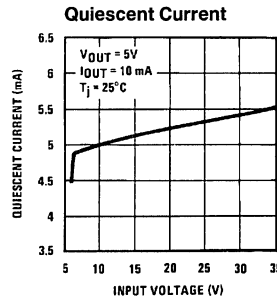
Note: Shaded area refers to LM340A/LM340, LM7805C, LM7812C and LM7815C.



Note: Shaded area refers to LM340A/LM340, LM7805C, LM7812C and LM7815C.

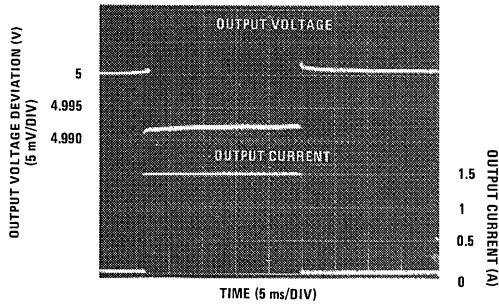


Note: Shaded area refers to LM340A/LM340, LM7805C, LM7812C and LM7815C.



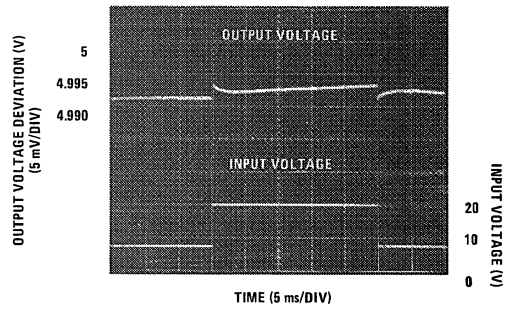
Typical Performance Characteristics (Continued)

Load Regulation
 140AK-5.0, $V_{IN} = 10V$, $T_A = 25^\circ C$



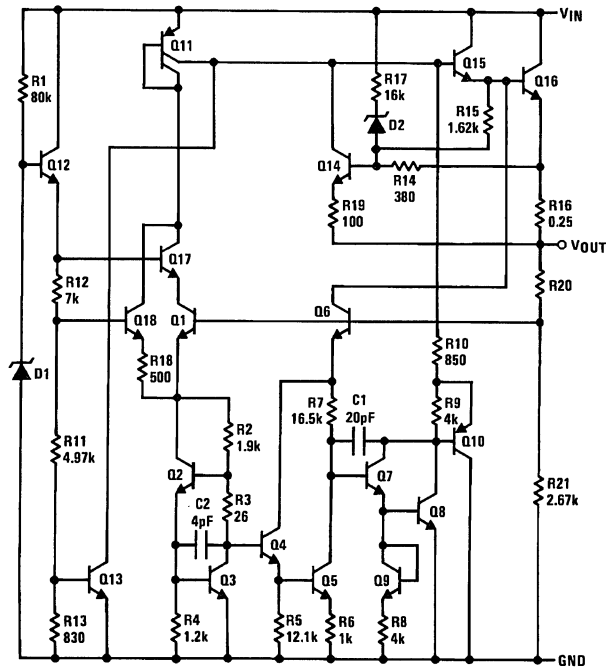
TL/H/7781-5

Line Regulation
 140AK-5.0, $I_{OUT} = 1A$, $T_A = 25^\circ C$



TL/H/7781-6

Equivalent Schematic



TL/H/7781-7

Application Hints

The LM340/LM78XX series is designed with thermal protection, output short-circuit protection and output transistor safe area protection. However, as with *any* IC regulator, it becomes necessary to take precautions to assure that the regulator is not inadvertently damaged. The following describes possible misapplications and methods to prevent damage to the regulator.

Shorting the Regulator Input: When using large capacitors at the output of these regulators, a protection diode connected input to output (*Figure 1*) may be required if the input is shorted to ground. Without the protection diode, an input short will cause the input to rapidly approach ground potential, while the output remains near the initial V_{OUT} because of the stored charge in the large output capacitor. The capacitor will then discharge through a large internal input to output diode and parasitic transistors. If the energy released by the capacitor is large enough, this diode, low current metal and the regulator will be destroyed. The fast diode in *Figure 1* will shunt most of the capacitors discharge current around the regulator. Generally no protection diode is required for values of output capacitance $\leq 10 \mu\text{F}$.

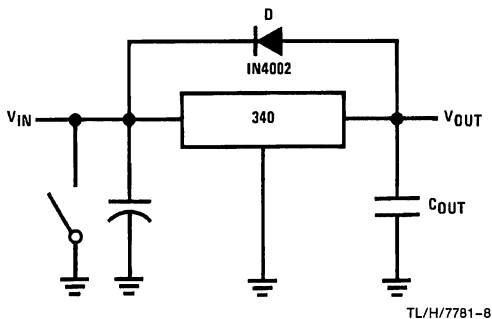


FIGURE 1. Input Short

Raising the Output Voltage above the Input Voltage: Since the output of the device does not sink current, forcing the output high can cause damage to internal low current paths in a manner similar to that just described in the "Shorting the Regulator Input" section.

Regulator Floating Ground (*Figure 2*): When the ground pin alone becomes disconnected, the output approaches the unregulated input, causing possible damage to other circuits connected to V_{OUT} . If ground is reconnected with power "ON", damage may also occur to the regulator. This fault is most likely to occur when plugging in regulators or modules with on card regulators into powered up sockets. Power should be turned off first, thermal limit ceases operating, or ground should be connected first if power must be left on.

Transient Voltages: If transients exceed the maximum rated input voltage of the device, or reach more than 0.8V below ground and have sufficient energy, they will damage the regulator. The solution is to use a large input capacitor, a series input breakdown diode, a choke, a transient suppressor or a combination of these.

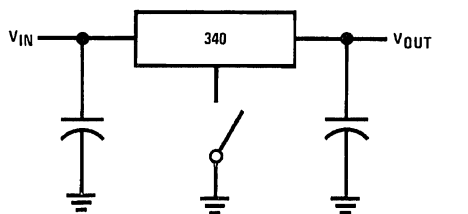


FIGURE 2. Regulator Floating Ground

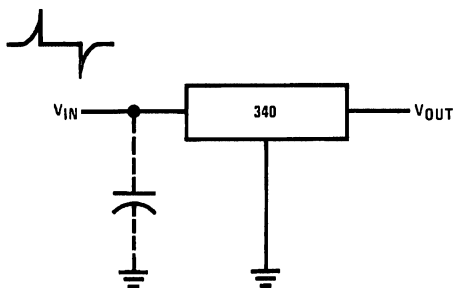
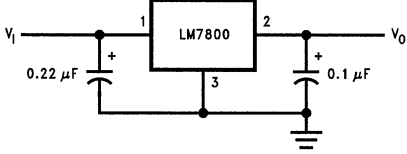


FIGURE 3. Transients

Typical Applications

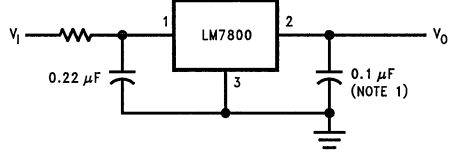
Fixed Output Regulator



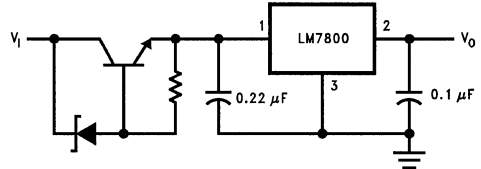
TL/H/7781-13

Note 1: Bypass capacitors are recommended for optimum stability and transient response, and should be located as close as possible to the regulator.

High Input Voltage Circuits

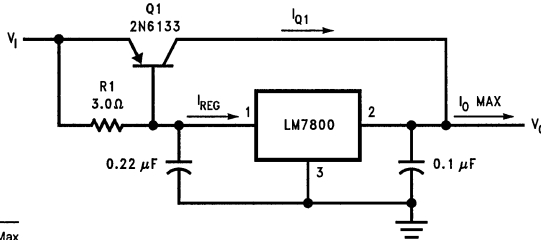


TL/H/7781-14



TL/H/7781-15

High Current Voltage Regulator

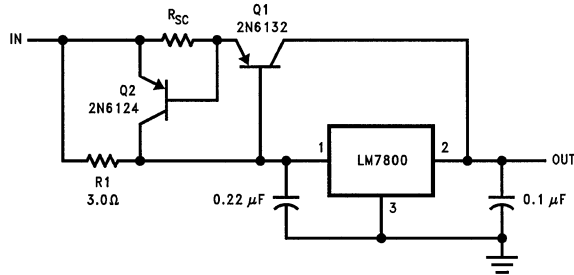


$$\beta(Q1) \geq \frac{I_{O \text{ Max}}}{I_{\text{REG Max}}}$$

$$R1 = \frac{0.9}{I_{\text{REG}}} = \frac{\beta(Q1) V_{BE}(Q1)}{I_{\text{REG Max}} (\beta + 1) - I_{O \text{ Max}}}$$

TL/H/7781-16

High Output Current, Short Circuit Protected

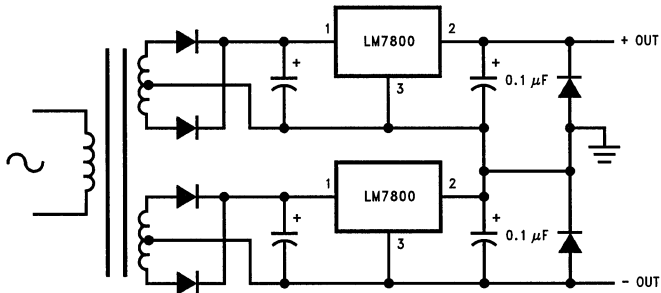


$$R_{SC} = \frac{0.8}{I_{SC}}$$

$$R1 = \frac{\beta V_{BE}(Q1)}{I_{\text{REG Max}} (\beta + 1) - I_{O \text{ Max}}}$$

TL/H/7781-17

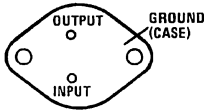
Positive and Negative Regulator



TL/H/7781-18

Connection Diagrams and Ordering Information

TO-3 Metal Can Package (K and KC)



Bottom View

TL/H/7781-11

Steel Package Order Numbers:

LM140AK-5.0	LM140AK-12	LM140AK-15
LM140K-5.0	LM140K-12	LM140K-15
LM140AK-5.0/883	LM140AK-12/883	LM140AK-15/883
LM140K-5.0/883	LM140K-12/883	LM140K-15/883
LM340AK-5.0	LM340AK-12	LM340AK-15
LM340K-5.0	LM340K-12	LM340K-15
LM7806CK	LM7808CK	LM7808K
LM7818CK	LM7818K	LM7824CK
	LM7824K	

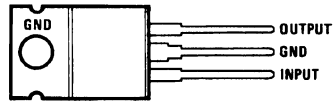
See Package Number K02A

Aluminum Package Order Numbers:

LM340KC-5.0
LM340KC-12
LM340KC-15
LM7805CK
LM7812CK
LM7815CK

See Package Number KC02A

TO-220 Power Package (T)



Top View

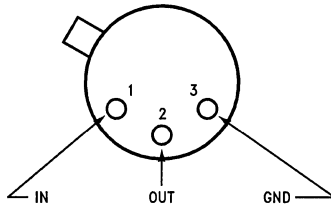
TL/H/7781-12

Plastic Package Order Numbers:

LM340AT-5.0	LM340T-5.0
LM340AT-12	LM340T-12
LM340AT-15	LM340T-15
LM7805CT	LM7812CT
LM7815CT	LM7806CT
LM7808CT	LM7818CT
	LM7824CT

See Package Number T03B

TO-39 Metal Can Package (H)



Top View

TL/H/7781-19

Metal Can Order Numbers†:

LM140H-5.0/883	LM140H-6.0/883
LM140H-8.0/883	LM140H-12/883
LM140H-15/883	LM140H-24/883

See Package Number H03A

†The specifications for the LM140H/883 devices are not contained in this datasheet. If specifications for these devices are required, contact the National Semiconductor Sales Office/Distributors.



LM140L/LM340L Series 3-Terminal Positive Regulators

General Description

The LM140L series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. The LM140LA is an improved version of the LM78LXX series with a tighter output voltage tolerance (specified over the full military temperature range), higher ripple rejection, better regulation and lower quiescent current. The LM140LA regulators have $\pm 2\%$ V_{OUT} specification, 0.04%/V line regulation, and 0.01%/mA load regulation. When used as a zener diode/resistor combination replacement, the LM140LA usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM140LA to be used in logic systems, instrumentation, Hi-Fi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

The LM140LA/LM340LA are available in the low profile metal three lead TO-39 (H) and the LM340LA are also available in the plastic TO-92 (Z). With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation

becomes too high for the heat sinking provided, the thermal shut-down circuit takes over, preventing the IC from overheating.

For applications requiring other voltages, see LM117L Data Sheet.

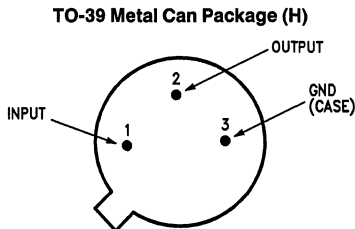
Features

- Line regulation of 0.04%/V
- Load regulation of 0.01%/mA
- Output voltage tolerances of $\pm 2\%$ at $T_j = 25^\circ\text{C}$ and $\pm 4\%$ over the temperature range (LM140LA) $\pm 3\%$ over the temperature range (LM340LA)
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection
- Internal short circuit current limit
- Available in metal TO-39 low profile package (LM140LA/LM340LA) and plastic TO-92 (LM340LA)

Output Voltage Options

LM140LA-5.0	5V	LM340LA-5.0	5V
LM140LA-12	12V	LM340LA-12	12V
LM140LA-15	15V	LM340LA-15	15V

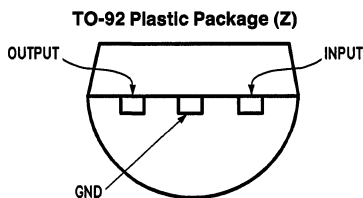
Connection Diagrams



TL/H/7782-2

Bottom View

Order Number LM140LAH-5.0, LM140LAH-5.0/883, LM140LAH-12,
LM140LAH-12/883, LM140LAH-15, LM140LAH-15/883, LM340LAH-5.0, LM340LAH-12 or LM340LAH-15
See NS Package Number H03A



TL/H/7782-3

Bottom View

Order Number LM340LAZ-5.0, LM340LAZ-12 or LM340LAZ-15
See NS Package Number Z03A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Input Voltage 35V
Internal Power Dissipation (Note 1) Internally Limited

Operating Temperature Range
LM140LA -55°C to +125°C
LM340LA 0°C to +70°C
Maximum Junction Temperature +150°C
Storage Temperature Range
Metal Can (H package) -65°C to +150°C
Molded TO-92 -55°C to +150°C
Lead Temperature (Soldering, 10 sec.)
Metal Can +300°C
Plastic TO-92 +230°C

Electrical Characteristics

Test conditions unless otherwise specified. $T_A = -55^\circ\text{C}$ to $+125^\circ\text{C}$ (LM140LA), $T_A = 0^\circ\text{C}$ to $+70^\circ\text{C}$ (LM340LA), $I_O = 40\text{ mA}$, $C_{IN} = 0.33\ \mu\text{F}$, $C_O = 0.01\ \mu\text{F}$.

Output Voltage Option			5.0V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	$T_j = 25^\circ\text{C}$	4.9	5	5.1	11.75	12	12.25	14.7	15	15.3	V
	Output Voltage Over Temp. (Note 3)	LM140LA $I_O = 1 - 100\text{ mA}$	4.8	5.2		11.5		12.5	14.4		15.6	
		LM340LA $I_O = 1 - 100\text{ mA}$ or $I_O = 1 - 40\text{ mA}$ and $V_{IN} = ()\text{V}$	4.85	5.15		11.65		12.35	14.55		15.45	
ΔV_O	Line Regulation	$T_j = 25^\circ\text{C}$ $I_O = 40\text{ mA}$ $V_{IN} = ()\text{V}$	18	30		30	65		37	70		mV
		$I_O = 100\text{ mA}$ $V_{IN} = ()\text{V}$	18	30		30	65		37	70		
			(7-25)		(14.2-30)		(17.3-30)					
	Load Regulation	$T_j = 25^\circ\text{C}$ $I_O = 1 - 40\text{ mA}$ $I_O = 1 - 100\text{ mA}$	5	20		10	40		12	50		mV 1000 hrs
	Long Term Stability		12		24		30					
I_O	Quiescent Current	$T_j = 25^\circ\text{C}$	3	4.5		3	4.5		3.1	4.5		mA
		$T_j = 125^\circ\text{C}$		4.2			4.2			4.2		
ΔI_O	Quiescent Current Change	$T_j = 25^\circ\text{C}$ $\Delta\text{Load } I_O = 1 - 40\text{ mA}$		0.1		0.1		0.1		0.1		mA
		ΔLine $V_{IN} = ()\text{V}$		0.5		0.5		0.5		0.5		
			(7.5-25)		(14.3-30)		(17.5-30)					
V_N	Output Noise Voltage	$T_j = 25^\circ\text{C}$ (Note 2) $f = 10\text{ Hz} - 10\text{ kHz}$	40			80			90			μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\text{ Hz}$, $V_{IN} = ()\text{V}$	55	62		47	54		45	52		dB
			(7.5-18)		(14.5-25)		(17.5-28.5)					
	Input Voltage Required to Maintain Line Regulation	$T_j = 25^\circ\text{C}$, $I_O = 40\text{ mA}$	7			14.2			17.3			V

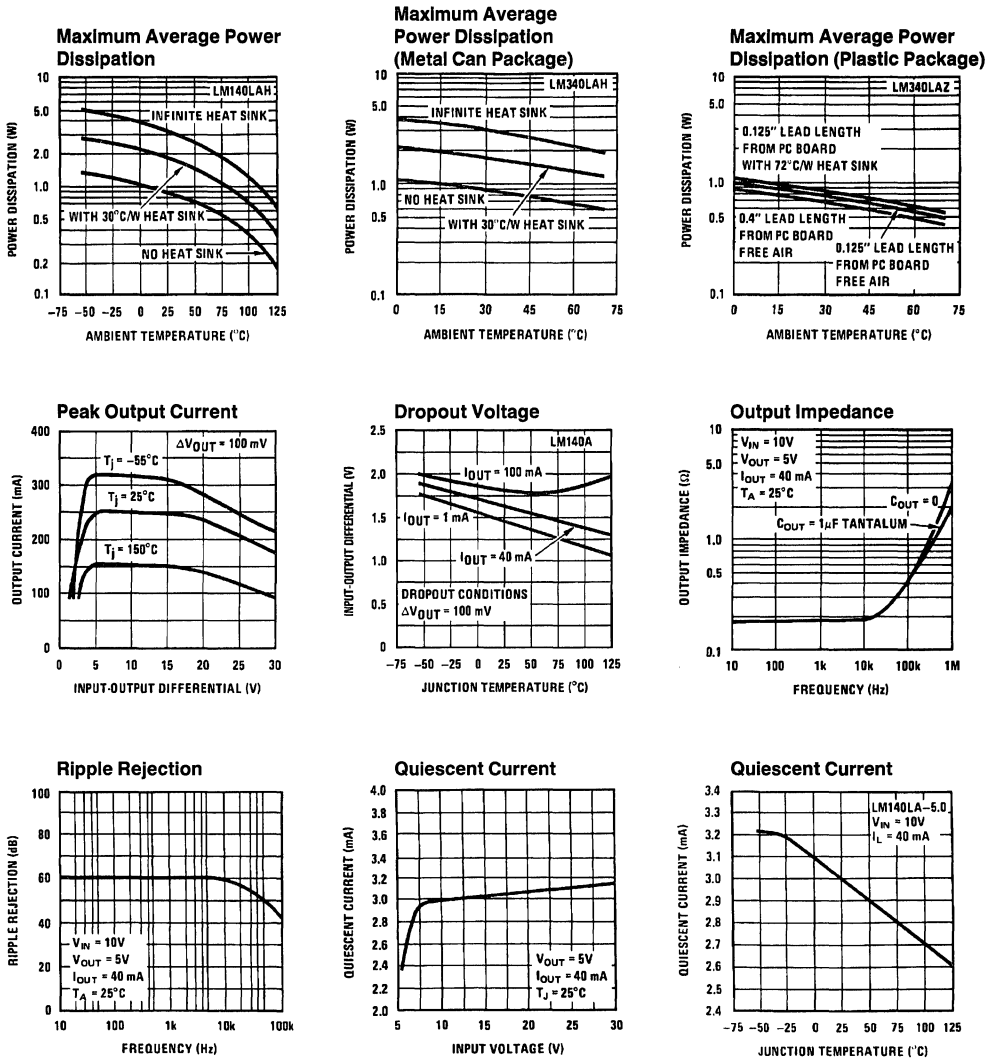
Note 1: Thermal resistance of H-package is typically $26^\circ\text{C}/\text{W } \theta_{jC}$, $250^\circ\text{C}/\text{W } \theta_{jA}$ still air, and $94^\circ\text{C}/\text{W } \theta_{jA}$ 400 l/min of air. For the Z-package is $60^\circ\text{C}/\text{W } \theta_{jC}$, $232^\circ\text{C}/\text{W } \theta_{jA}$ still air, and $88^\circ\text{C}/\text{W } \theta_{jA}$ at 400 l/min of air. The maximum junction temperature shall not exceed 125°C on electrical parameters.

Note 2: It is recommended that a minimum load capacitor of $0.01\ \mu\text{F}$ be used to limit the high frequency noise bandwidth.

Note 3: The temperature coefficient of V_{OUT} is typically within $0.01\% V_O/^\circ\text{C}$.

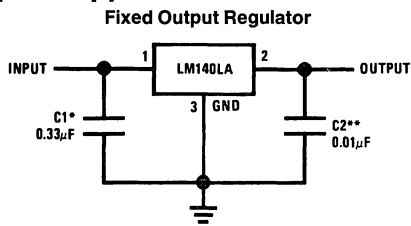
Note 4: A military RETS specification is available upon request. At the time of printing, the LM140LA-5.0, -12, and -15 RETS specifications complied with the Min and Max limits in this table. The LM140LAH-5.0, LM140LAH-12, and LM140LAH-15 may also be procured as Standard Military Drawings.

Typical Performance Characteristics

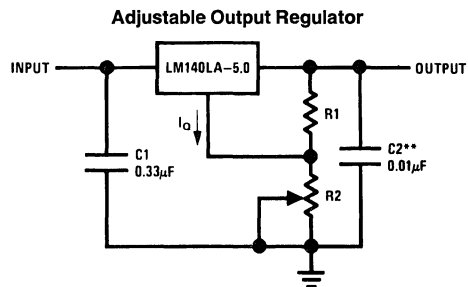


TL/H/7782-4

Typical Applications



TL/H/7782-5



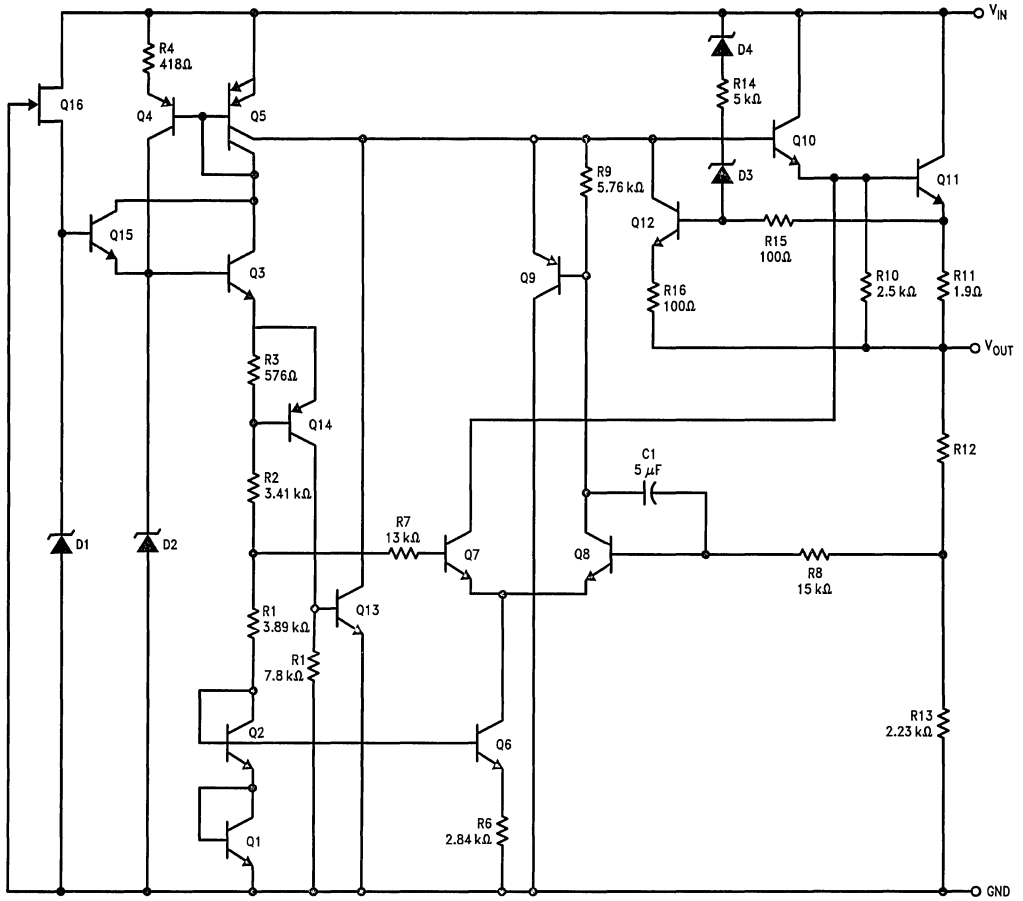
TL/H/7782-6

*Required if the regulator is located far from the power supply filter.
 **See note 3 in the electrical characteristics table.

$$V_{OUT} = 5V + (5V/R1 + I_O) R2$$

$$5V/R1 = 3 I_O \text{ load regulation (L)} \left[(R1 + R2)/R1 \right] \text{ (L, of LM140LA-5.0)}$$

Equivalent Circuit



TL/H/7782-1





LM145/LM345 Negative Three Amp Regulator

General Description

The LM145 is a three-terminal negative regulator with a fixed output voltage of $-5V$ or $-5.2V$, and up to 3A load current capability. This device needs only one external component—a compensation capacitor at the output, making it easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM145 immune to overload conditions. The regulator has current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shutdown prevents junction temperatures from exceeding safe limits during prolonged overloads.

Although primarily intended for fixed output voltage applications, the LM145 may be programmed for higher output voltages with a simple resistive divider. The low quiescent drain

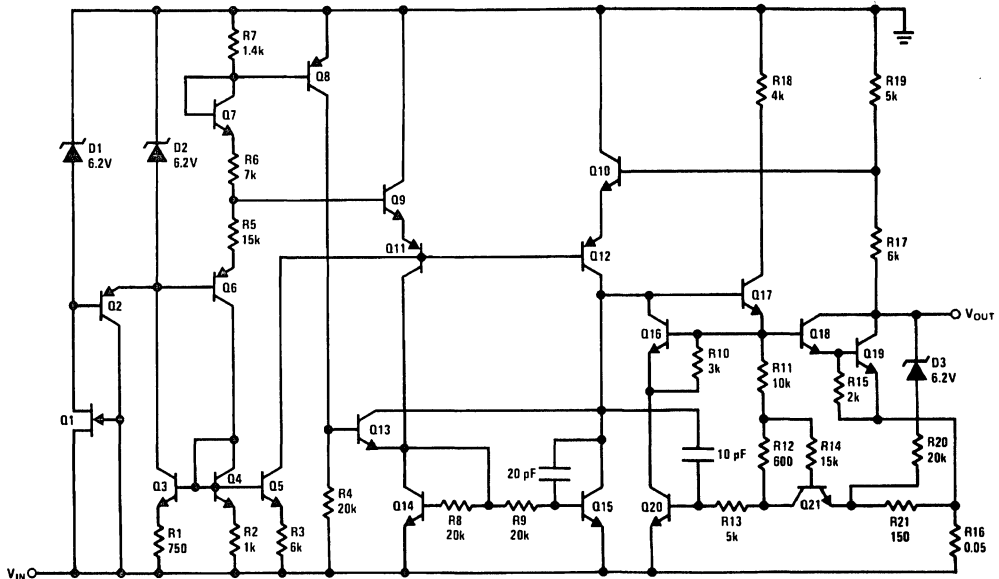
current of the device allows this technique to be used with good regulation.

The LM145 comes in a hermetic TO-3 package rated at 25W. A reduced temperature range part LM345 is also available.

Features

- Output voltage accurate to better than $\pm 2\%$
- Current limit constant with temperature
- Internal thermal shutdown protection
- Operates with input-output voltage differential of 2.8V at full rated load over full temperature range
- Regulation guaranteed with 25W power dissipation
- 3A output current guaranteed
- Only one external component needed
- P+ Product Enhancement tested

Schematic Diagram



TL/H/7785-1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 3)

Input Voltage	20V
Input-Output Differential	20V

Power Dissipation	Internally Limited
Operating Junction Temperature Range	
LM145	-55°C to +150°C
LM345	0°C to +125°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics (-5V & -5.2V) (Note 1)

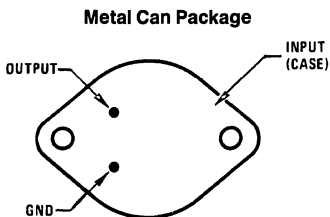
Parameter	Conditions	Limits						Units
		LM145			LM345			
		Min	Typ	Max	Min	Typ	Max	
Output Voltage 5.0V 5.2V	$T_j = 25^\circ\text{C}$, $I_{OUT} = 5\text{ mA}$, $V_{IN} = -7.5$	-5.1 -5.3	-5.0 -5.2	-4.9 -5.1	-5.2 -5.4	-5.0 -5.2	-4.8 -5.0	V
Line Regulation (Note 2)	$T_j = 25^\circ\text{C}$ $-20\text{V} \leq V_{IN} \leq -7.5\text{V}$		5	15		5	25	mV
Load Regulation (Note 2)	$T_j = 25^\circ\text{C}$, $V_{IN} = -7.5\text{V}$ $5\text{ mA} \leq I_{OUT} \leq 3\text{A}$		30	75		30	100	mV
Output Voltage 5.0V 5.2V	$-20\text{V} \leq V_{IN} \leq -7.8\text{V}$ $5\text{ mA} \leq I_{OUT} \leq 3\text{A}$ $P \leq 25\text{W}$ $T_{MIN} \leq T_j \leq T_{MAX}$	-5.20 -5.40		-4.80 -5.00	-5.25 -5.45		-4.75 -4.95	V
Quiescent Current	$-20\text{V} \leq V_{IN} \leq -7.5\text{V}$ $5\text{ mA} \leq I_{OUT} \leq 3\text{A}$		1.0	3.0		1.0	3.0	mA
Short Circuit Current	$V_{IN} = -7.5\text{V}$, $T_j = +25^\circ\text{C}$ $V_{IN} = -20\text{V}$, $T_j = +25^\circ\text{C}$		4 2	5.5 3.5		4 2	5.5 3.5	A
Output Noise Voltage	$T_A = 25^\circ\text{C}$, $C_L = 4.7\ \mu\text{F}$ $10\text{ Hz} \leq f \leq 100\text{ kHz}$		150			150		μV
Long Term Stability			5	50		5	50	mV
Thermal Resistance Junction to Case			2			2		$^\circ\text{C/W}$

Note 1: Unless otherwise specified, these specifications apply: $-55^\circ\text{C} \leq T_j \leq +150^\circ\text{C}$ for the LM145 and $0^\circ\text{C} \leq T_j \leq +125^\circ\text{C}$ for the LM345. $V_{IN} = 7.5\text{V}$ and $I_{OUT} = 5\text{ mA}$. Although power dissipation is internally limited, electrical specifications apply only for power levels up to 25W. For calculations of junction temperature rise due to power dissipation, use a thermal resistance of 35°C/W for the TO-3 with no heat sink. With a heat sink, use 2°C/W for junction to case thermal resistance.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, pulse testing with a low duty cycle is used.

Note 3: Refer to RETS145K-5.2V for LM145K-5.2V or RETS145K-5V for LM145K-5.0 military specifications.

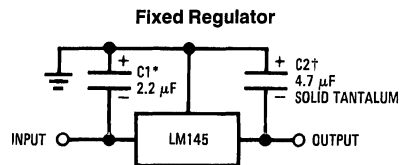
Connection Diagram



Bottom View
Order Number LM145K-5.0,
LM345K-5.0, LM145K-5.2,
or LM345K-5.2
See NS Package Number K02A

TL/H/7785-2

Typical Applications

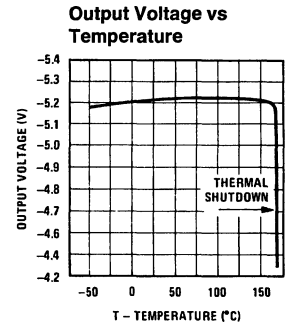
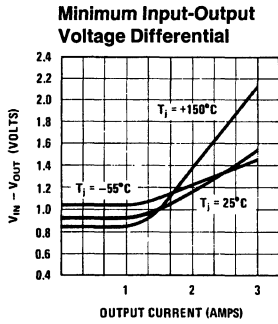
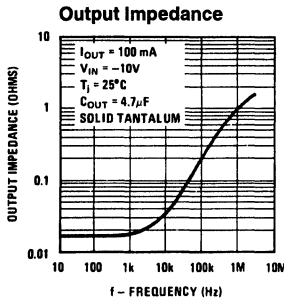
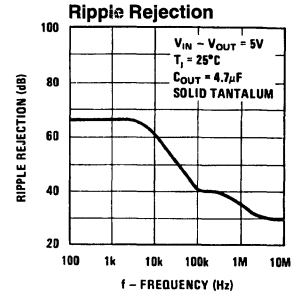
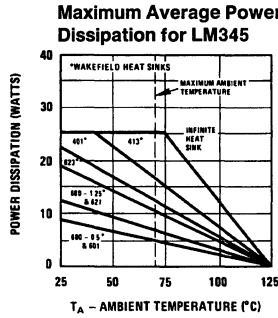
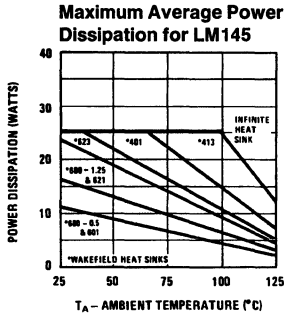


TL/H/7785-3

*Required for stability. For value given, capacitor must be solid tantalum. 50 μF aluminum electrolytic may be substituted. Values given may be increased without limit.

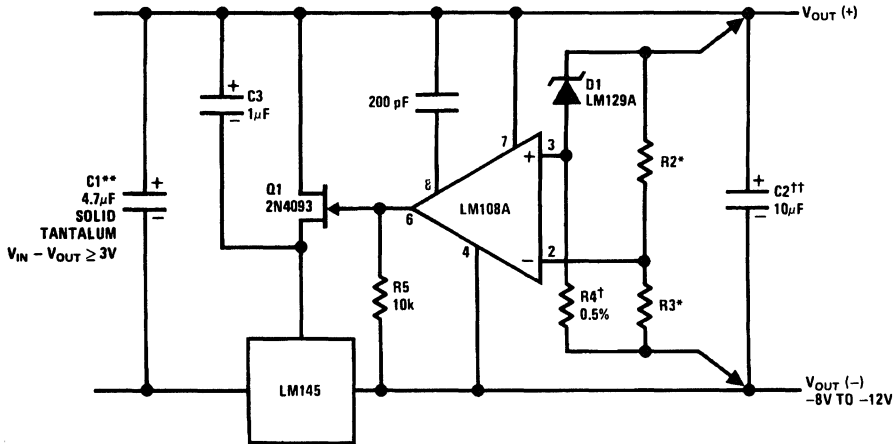
†Required if regulator is separated from filter capacitor. For value given, capacitor must be solid tantalum. 50 μF aluminum electrolytic may be substituted.

Typical Performance Characteristics



TL/H/7785-4

Typical Applications (Continued)



TL/H/7785-5

*Select resistors to set output voltage. 1 ppm/C tracking suggested.

**C1 is not needed if power supply filter capacitor is within 3" of regulator.

†Determines zener current. May be adjusted to minimize temperature drift.

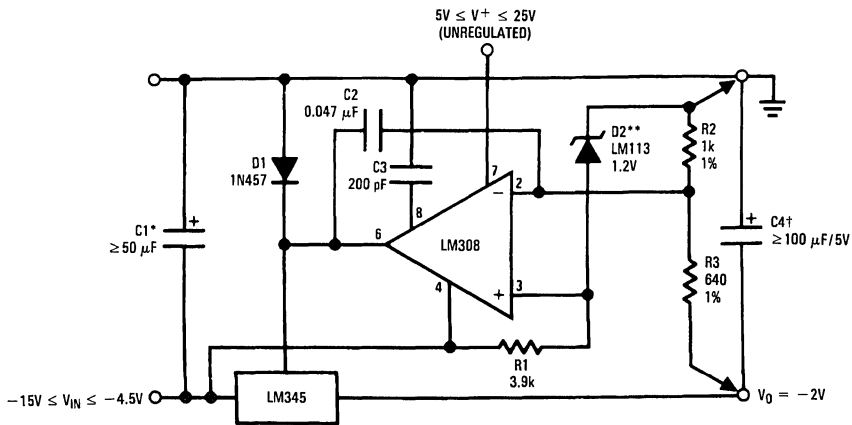
††Solid tantalum.

Load and line regulation < 0.01%

Temperature drift < 0.001%/C

Typical Applications (Continued)

High Stability Regulator



TL/H/7785-6

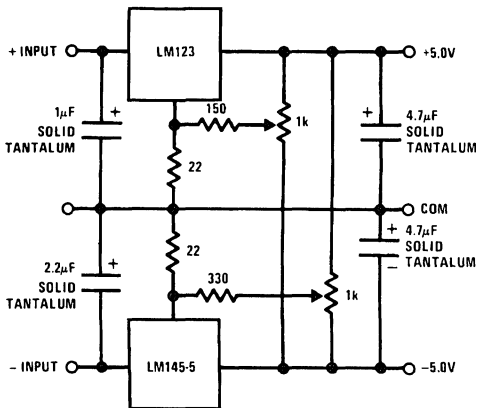
**C1 is not needed if power supply filter capacitor is within 3" of regulator.

†Keep C4 within 2" of LM345.

**D2 sets initial output voltage accuracy. The LM113 is available in -5, -2, and -1% tolerance.

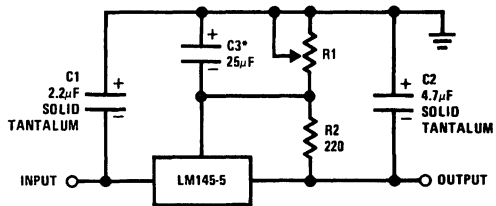
-2V ECL Termination Regulator

Dual 3 Amp Trimmed Supply



TL/H/7785-7

Variable Output (-5.0V to -15V)



TL/H/7785-8

*Optional. Improves transient response and ripple rejection.

$$V_{OUT} = -5V \left(\frac{R1 + R2}{R2} \right)$$



LM150, LM350A/LM350 3-Amp Adjustable Regulators

General Description

The LM150 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 3A over a 1.2V to 33V output range. They are exceptionally easy to use and require only 2 external resistors to set the output voltage. Further, both line and load regulation are comparable to discrete designs. Also, the LM150 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM150 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is accidentally disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An output capacitor can be added to improve transient response, while bypassing the adjustment pin will increase the regulator's ripple rejection.

Besides replacing fixed regulators or discrete designs, the LM150 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., avoid short-circuiting the output.

By connecting a fixed resistor between the adjustment pin and output, the LM150 can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground

which programs the output to 1.2V where most loads draw little current.

The part numbers in the LM150 series which have a K suffix are packaged in a standard Steel TO-3 package, while those with a T suffix are packaged in a TO-220 plastic package. The LM150 is rated for $-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$, while the LM350A is rated for $-40^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$, and the LM350 is rated for $0^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$.

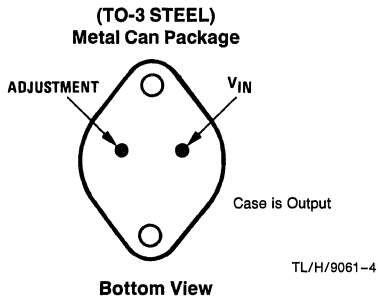
Features

- Adjustable output down to 1.2V
- Guaranteed 3A output current
- Guaranteed thermal regulation
- Output is short circuit protected
- Current limit constant with temperature
- P+ Product Enhancement tested
- 86 dB ripple rejection
- Guaranteed 1% output voltage tolerance (LM350A)
- Guaranteed max. 0.01%/V line regulation (LM350A)
- Guaranteed max. 0.3% load regulation (LM350A)

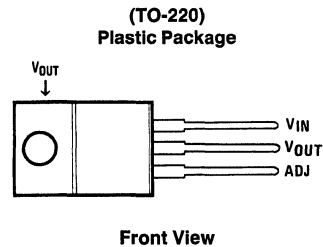
Applications

- Adjustable power supplies
- Constant current regulators
- Battery chargers

Connection Diagrams



Order Number LM150K STEEL,
LM350AK STEEL or LM350K STEEL
See NS Package Number K02A



Order Number LM350AT or LM350T
See NS Package Number T03B

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 4)

Power Dissipation	Internally Limited
Input-Output Voltage Differential	+35V
Storage Temperature	-65°C to +150°C

Lead Temperature		
Metal Package (Soldering, 10 sec.)		300°C
Plastic Package (Soldering, 4 sec.)		260°C
ESD Tolerance		TBD
Operating Temperature Range		
LM150		-55°C ≤ T _J ≤ +150°C
LM350A		-40°C ≤ T _J ≤ +125°C
LM350		0°C ≤ T _J ≤ +125°C

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, V_{IN} - V_{OUT} = 5V, and I_{OUT} = 10 mA. (Note 2)

Parameter	Conditions	LM150			Units
		Min	Typ	Max	
Reference Voltage	3V ≤ (V _{IN} - V _{OUT}) ≤ 35V, 10 mA ≤ I _{OUT} ≤ 3A, P ≤ 30W	1.20	1.25	1.30	V
Line Regulation	3V ≤ (V _{IN} - V _{OUT}) ≤ 35V (Note 3)		0.005	0.01	%/V
			0.02	0.05	%/V
Load Regulation	10 mA ≤ I _{OUT} ≤ 3A (Note 3)		0.1	0.3	%
			0.3	1	%
Thermal Regulation	20 ms Pulse		0.002	0.01	%/W
Adjustment Pin Current			50	100	μA
Adjustment Pin Current Change	10 mA ≤ I _{OUT} ≤ 3A, 3V ≤ (V _{IN} - V _{OUT}) ≤ 35V		0.2	5	μA
Temperature Stability	T _{MIN} ≤ T _J ≤ T _{MAX}		1		%
Minimum Load Current	V _{IN} - V _{OUT} = 35V		3.5	5	mA
Current Limit	V _{IN} - V _{OUT} ≤ 10V V _{IN} - V _{OUT} = 30V	3.0	4.5		A
		0.3	1		A
RMS Output Noise, % of V _{OUT}	10 Hz ≤ f ≤ 10 kHz		0.001		%
Ripple Rejection Ratio	V _{OUT} = 10V, f = 120 Hz, C _{ADJ} = 0 μF		65		dB
	V _{OUT} = 10V, f = 120 Hz, C _{ADJ} = 10 μF	66	86		dB
Long-Term Stability	T _J = 125°C, 1000 hrs		0.3	1	%
Thermal Resistance, Junction to Case	K Package		1.2	1.5	°C/W
Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35		°C/W

Electrical Characteristics (Continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT} = 5\text{V}$, and $I_{OUT} = 10\text{ mA}$. (Note 2) (Continued)

Parameter	Conditions	LM350A			LM350			Units
		Min	Typ	Max	Min	Typ	Max	
Reference Voltage	$I_{OUT} = 10\text{ mA}$, $T_J = 25^\circ\text{C}$	1.238	1.250	1.262				V
	$3\text{V} \leq (V_{IN} - V_{OUT}) \leq 35\text{V}$, $10\text{ mA} \leq I_{OUT} \leq 3\text{A}$, $P \leq 30\text{W}$	1.225	1.250	1.270	1.20	1.25	1.30	V
Line Regulation	$3\text{V} \leq (V_{IN} - V_{OUT}) \leq 35\text{V}$ (Note 3)		0.005	0.01		0.005	0.03	%/V
			0.02	0.05		0.02	0.07	%/V
Load Regulation	$10\text{ mA} \leq I_{OUT} \leq 3\text{A}$ (Note 3)		0.1	0.3		0.1	0.5	%
			0.3	1		0.3	1.5	%
Thermal Regulation	20 ms Pulse		0.002	0.01		0.002	0.03	%/W
Adjustment Pin Current			50	100		50	100	μA
Adjustment Pin Current Change	$10\text{ mA} \leq I_{OUT} \leq 3\text{A}$, $3\text{V} \leq (V_{IN} - V_{OUT}) \leq 35\text{V}$		0.2	5		0.2	5	μA
Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		1			1		%
Minimum Load Current	$V_{IN} - V_{OUT} = 35\text{V}$		3.5	10		3.5	10	mA
Current Limit	$V_{IN} - V_{OUT} \leq 10\text{V}$	3.0	4.5		3.0	4.5		A
	$V_{IN} - V_{OUT} = 30\text{V}$	0.3	1		0.25	1		A
RMS Output Noise, % of V_{OUT}	$10\text{ Hz} \leq f \leq 10\text{ kHz}$		0.001			0.001		%
Ripple Rejection Ratio	$V_{OUT} = 10\text{V}$, $f = 120\text{ Hz}$, $C_{ADJ} = 0\ \mu\text{F}$		65			65		dB
	$V_{OUT} = 10\text{V}$, $f = 120\text{ Hz}$, $C_{ADJ} = 10\ \mu\text{F}$	66	86		66	86		dB
Long-Term Stability	$T_J = 125^\circ\text{C}$, 1000 hrs		0.25	1		0.25	1	%
Thermal Resistance, Junction to Case	K Package		1.2	1.5		1.2	1.5	$^\circ\text{C}/\text{W}$
	T Package		3	4		3	4	$^\circ\text{C}/\text{W}$
Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35			35		$^\circ\text{C}/\text{W}$
	T Package		50			50		$^\circ\text{C}/\text{W}$

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

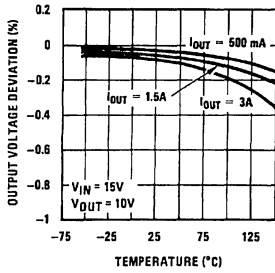
Note 2: These specifications are applicable for power dissipations up to 30W for the TO-3 (K) package and 25W for the TO-220 (T) package. Power dissipation is guaranteed at these values up to 15V input-output differential. Above 15V differential, power dissipation will be limited by internal protection circuitry. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 3: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

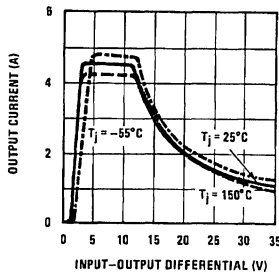
Note 4: Refer to RETS150K drawing for military specifications of the LM150K.

Typical Performance Characteristics

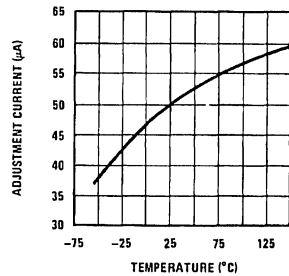
Load Regulation



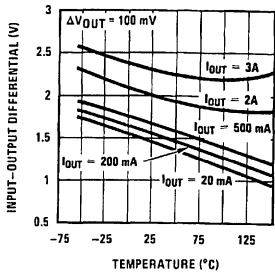
Current Limit



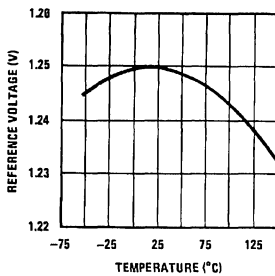
Adjustment Current



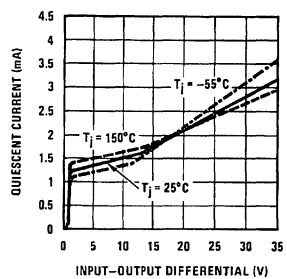
Dropout Voltage



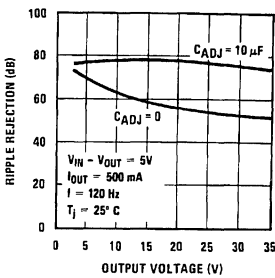
Temperature Stability



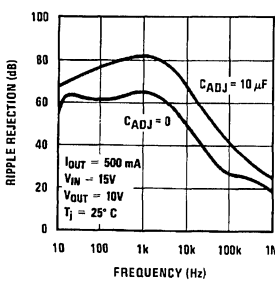
Minimum Operating Current



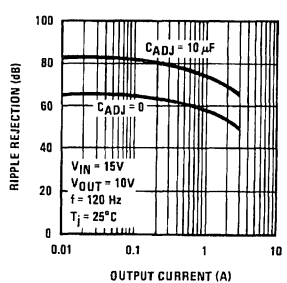
Ripple Rejection



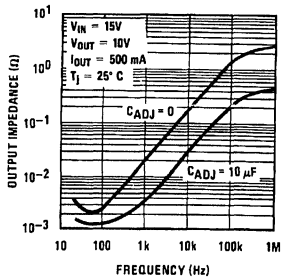
Ripple Rejection



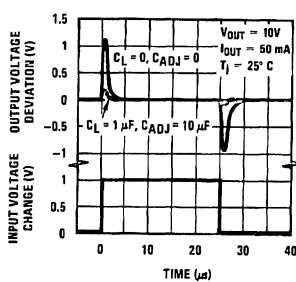
Ripple Rejection



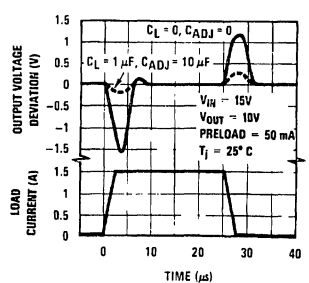
Output Impedance



Line Transient Response



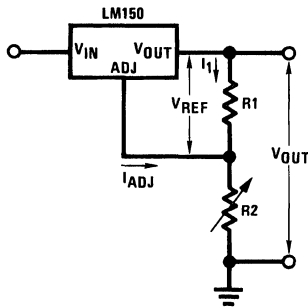
Load Transient Response



Application Hints

In operation, the LM150 develops a nominal 1.25V reference voltage, V_{REF} , between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ} R_2.$$



TL/H/9061-7

FIGURE 1

Since the 50 μ A current from the adjustment terminal represents an error term, the LM150 was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

EXTERNAL CAPACITORS

An input bypass capacitor is recommended. A 0.1 μ F disc or 1 μ F solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM150 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μ F bypass capacitor 86 dB ripple rejection is obtainable at any output level. Increases over 10 μ F do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

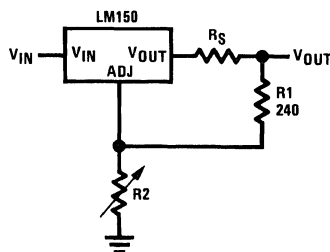
In general, the best type of capacitors to use is solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μ F in aluminum electrolytic to equal 1 μ F solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies, but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μ F disc may seem to work better than a 0.1 μ F disc as a bypass.

Although the LM150 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μ F solid tantalum (or 25 μ F aluminum electrolytic) on the output swamps this effect and insures stability.

LOAD REGULATION

The LM150 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240 Ω) should be tied directly to the output (case) of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05 Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05 Ω \times I_{OUT} . If the set resistor is connected near the load the effective line resistance will be 0.05 Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240 Ω set resistor.



TL/H/9061-8

FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

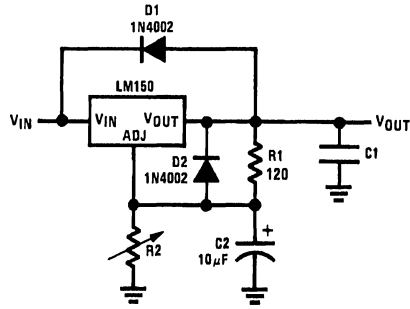
PROTECTION DIODES

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10 μ F capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN} . In the LM150, this discharge path is through a large junction that is able to sustain 25A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μ F or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM150 is a 50 Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μ F capacitance. Figure 3 shows an LM150 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

Application Hints (Continued)



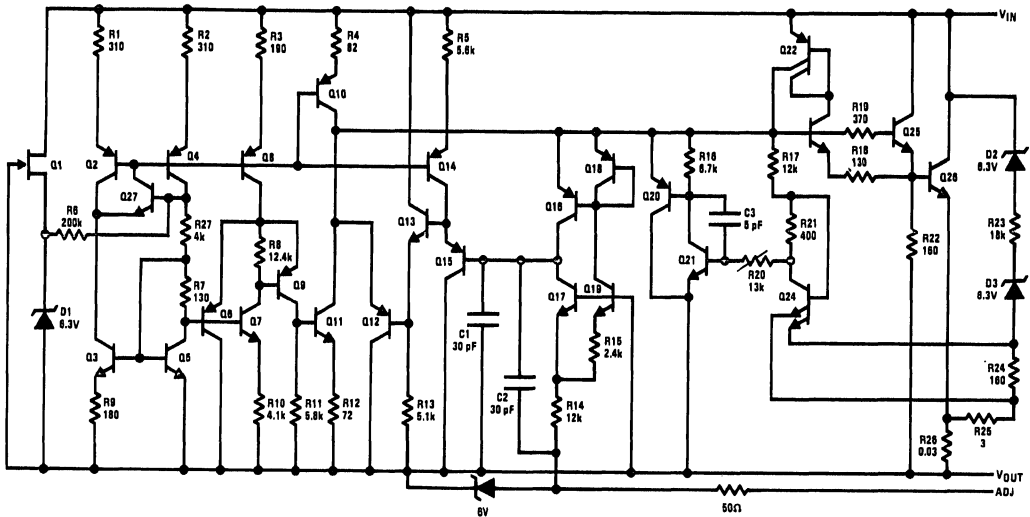
D1 protects against C1
D2 protects against C2

$$V_{OUT} = 1.25V \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ}R_2$$

TL/H/9081-9

FIGURE 3. Regulator with Protection Diodes

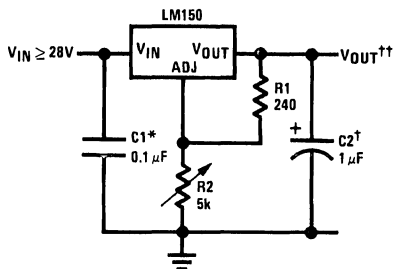
Schematic Diagram



TL/H/9081-10

Typical Applications

1.2V—25V Adjustable Regulator



TL/H/9061-1

Full output current not available at high input-output voltages.

†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

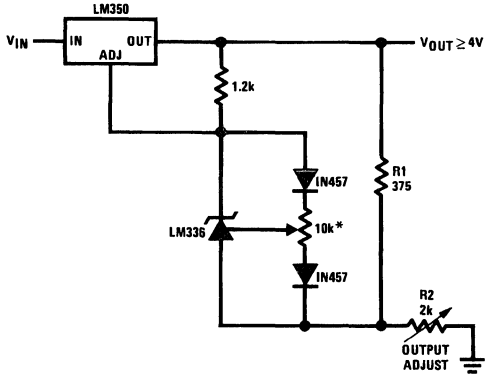
*Needed if device is more than 6 inches from filter capacitors.

$$\dagger\dagger V_{OUT} = 1.25V \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ} (R_2)$$

Note: Usually R1 = 240Ω for LM150 and R1 = 120Ω for LM350.

Typical Applications (Continued)

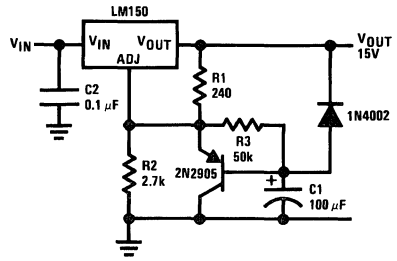
Precision Power Regulator with Low Temperature Coefficient



*Adjust for 3.75V across R1

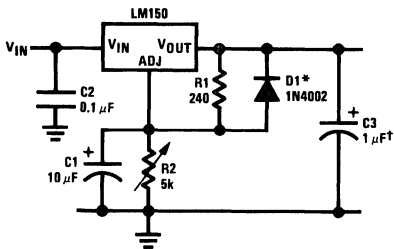
TL/H/9061-13

Slow Turn-ON 15V Regulator



TL/H/9061-14

Adjustable Regulator with Improved Ripple Rejection

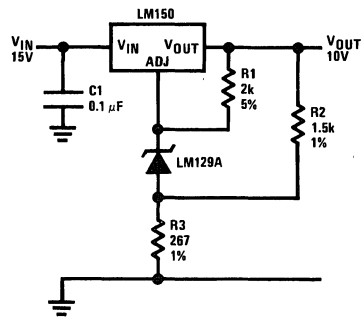


†Solid tantalum

*Discharges C1 if output is shorted to ground

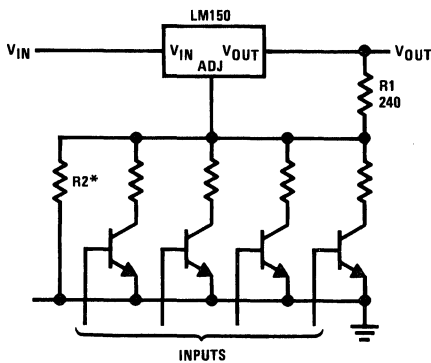
TL/H/9061-15

High Stability 10V Regulator



TL/H/9061-16

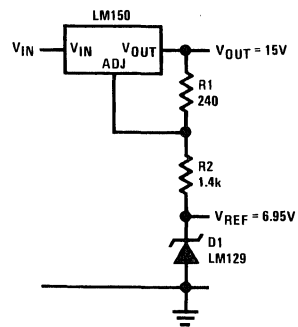
Digitally Selected Outputs



*Sets maximum V_{OUT}

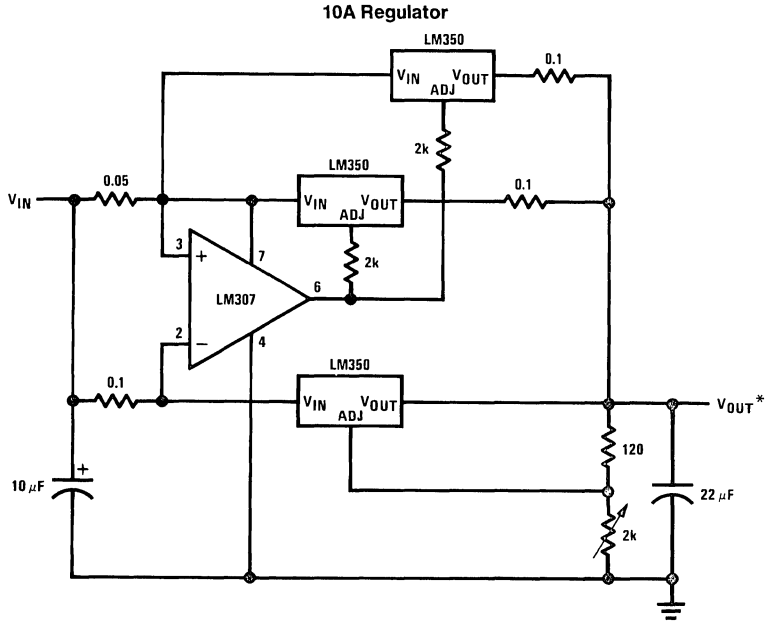
TL/H/9061-17

Regulator and Voltage Reference

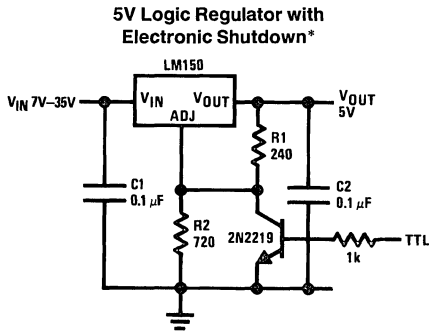


TL/H/9061-3

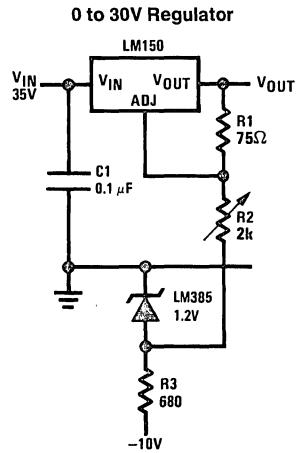
Typical Applications (Continued)



TL/H/9061-18



TL/H/9061-19

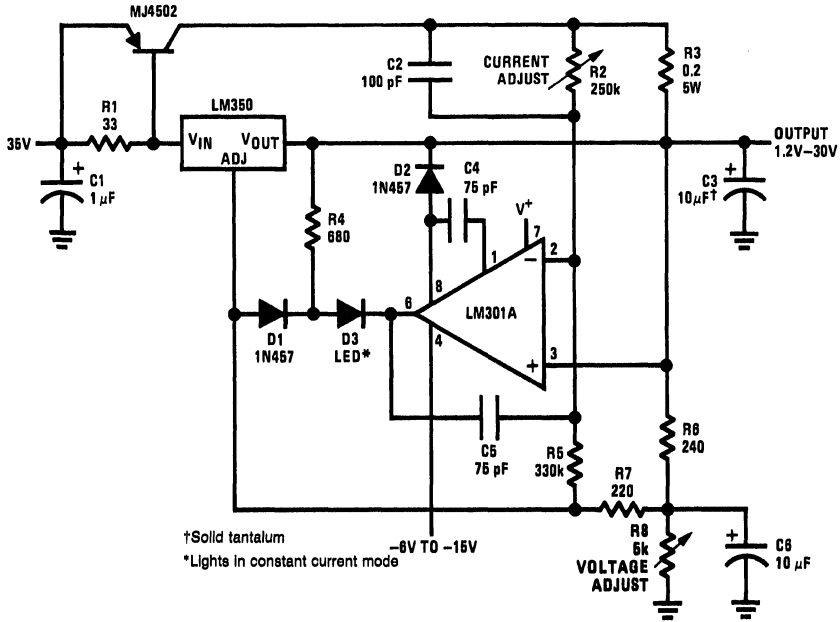


TL/H/9061-20

Full output current not available at high input-output voltages

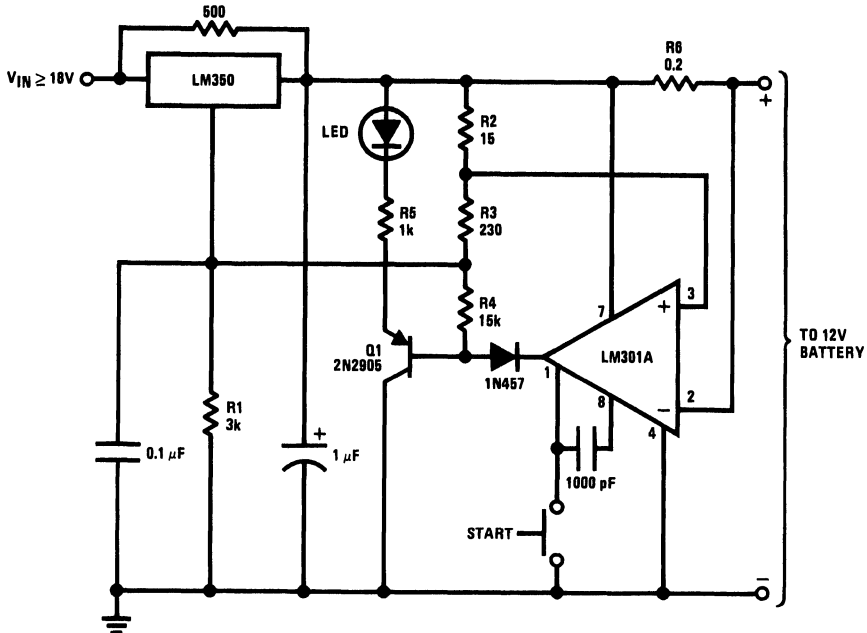
Typical Applications (Continued)

5A Constant Voltage/Constant Current Regulator



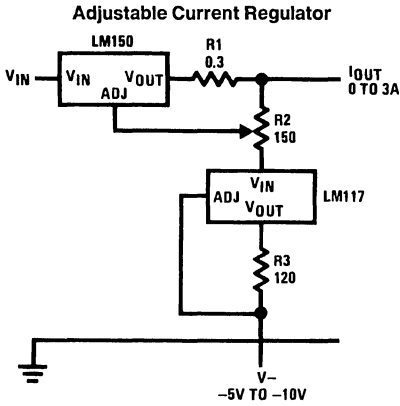
TL/H/9061-21

12V Battery Charger

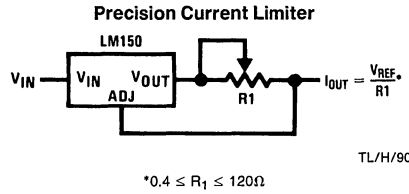


TL/H/9061-22

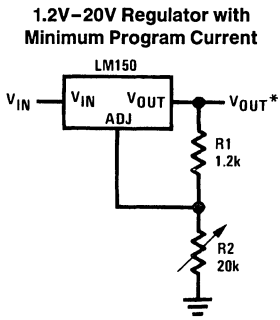
Typical Applications (Continued)



TL/H/9061-23

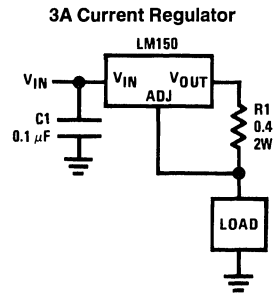


TL/H/9061-24

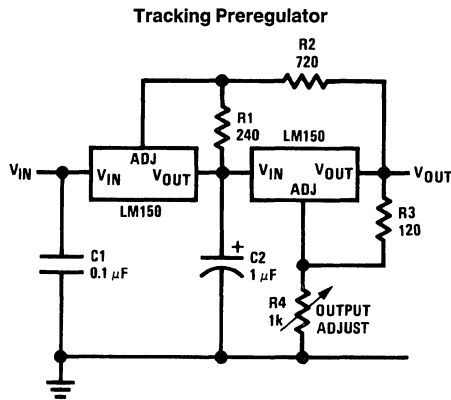


TL/H/9061-25

*Minimum output current ≈ 4 mA



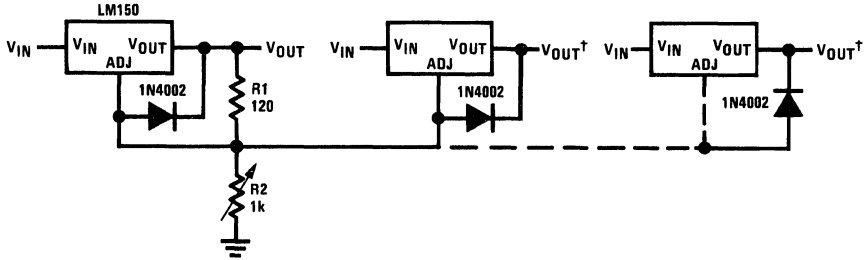
TL/H/9061-26



TL/H/9061-27

Typical Applications (Continued)

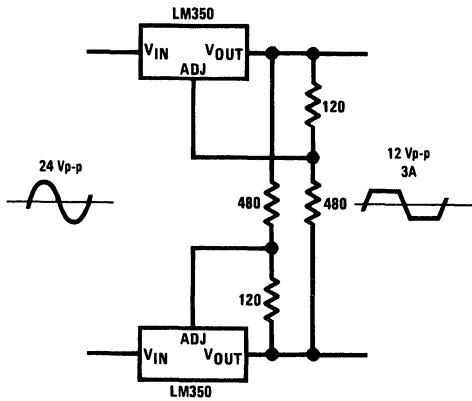
Adjusting Multiple On-Card Regulators with Single Control*



†Minimum load—10 mA
 *All outputs within ±100 mV

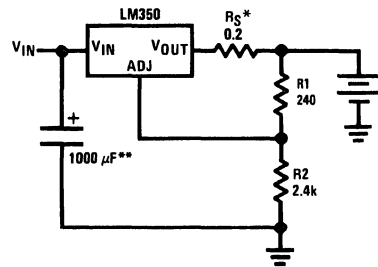
TL/H/9061-28

AC Voltage Regulator



TL/H/9061-29

Simple 12V Battery Charger



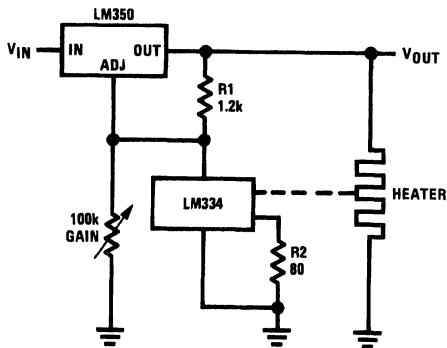
*RS—sets output impedance of charger: $Z_{OUT} = R_S \left(1 + \frac{R_2}{R_1} \right)$

Use of RS allows low charging rates with fully charged battery.

**1000 μF is recommended to filter out any input transients

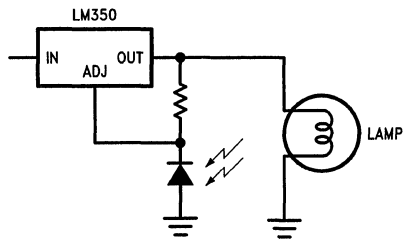
TL/H/9061-30

Temperature Controller



TL/H/9061-11

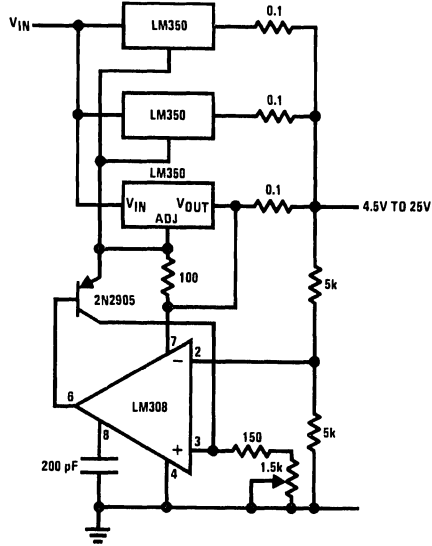
Light Controller



TL/H/9061-12

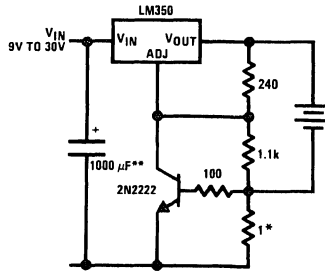
Typical Applications (Continued)

Adjustable 10A Regulator



TL/H/9061-31

Current Limited 6V Charger

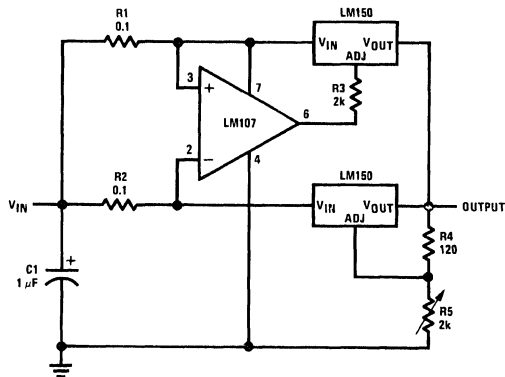


TL/H/9061-32

*Sets peak current (2A for 0.3Ω)

**1000 μF is recommended to filter out any input transients.

6A Regulator



TL/H/9061-2



LM196/LM396 10 Amp Adjustable Voltage Regulator

General Description

The LM196 is a 10 amp regulator, adjustable from 1.25V to 15V, which uses a revolutionary new IC fabrication structure to combine high power discrete transistor technology with modern monolithic linear IC processing. This combination yields a high-performance single-chip regulator capable of supplying in excess of 10 amps and operating at power levels up to 70 watts. The regulators feature on-chip trimming of reference voltage to $\pm 0.8\%$ and simultaneous trimming of reference temperature drift to 30 ppm/ $^{\circ}\text{C}$ typical. Thermal interaction between control circuitry and the pass transistor which affects the output voltage has been reduced to extremely low levels by strict attention to isothermal layout. This interaction, called thermal regulation, is 100% tested.

These new regulators have all the protection features of popular lower power adjustable regulators such as LM117 and LM138, including current limiting and thermal limiting. The combination of these features makes the LM196 immune to blowout from output overloads or shorts, even if the adjustment pin is accidentally disconnected. All devices are "burned-in" in thermal shutdown to guarantee proper operation of these protective features under actual overload conditions.

Output voltage is continuously adjustable from 1.25V to 15V. Higher output voltages are possible if the maximum input-output voltage differential specification is not exceeded. Full load current of 10A is available at all output voltages, subject only to the maximum power limit of 70W and of course, maximum junction temperature.

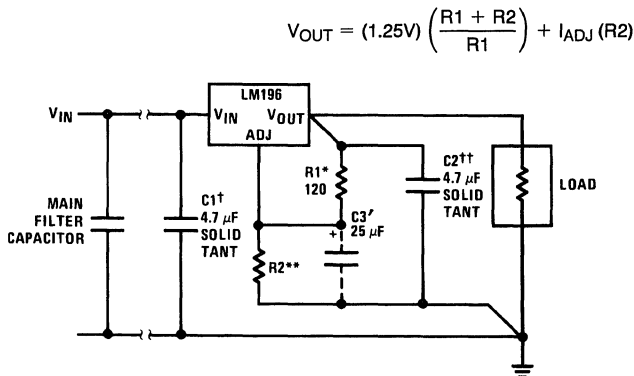
The LM196 is exceptionally easy to use. Only two external resistors are used to set output voltage. On-chip adjustment of the reference voltage allows a much tighter specification of output voltage, eliminating any need for trimming in most cases. The regulator will tolerate an extremely wide range of reactive loads, and does not depend on external capacitors for frequency stabilization. Heat sink requirements are much less stringent, because overload situations do not have to be accounted for—only worst-case full load conditions.

The LM196 is in a TO-3 package with oversized (0.060") leads to provide best possible load regulation. Operating junction temperature range is -55°C to $+150^{\circ}\text{C}$. The LM396 is specified for a 0°C to $+125^{\circ}\text{C}$ junction temperature range.

Features

- Output pre-trimmed to $\pm 0.8\%$
- 10A guaranteed output current
- P+ Product Enhancement tested
- 70W maximum power dissipation
- Adjustable output—1.25V to 15V
- Internal current and power limiting
- Guaranteed thermal resistance
- Output voltage guaranteed under worst-case conditions
- Output is short circuit protected

Typical Applications



TL/H/9059-1
FIGURE 1. Basic 1.25V to 15V Regulator

*For best TC of V_{OUT} , R1 should be wirewound or metal film, 1% or better.

**R2 should be same type as R1, with TC tracking of 30 ppm/ $^{\circ}\text{C}$ or better.

†C1 is necessary only if main filter capacitor is more than 6" away, assuming #18 or larger leads.

††C2 is not absolutely necessary, but is suggested to lower high frequency output impedance. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

‡C3 improves ripple rejection, output impedance, and noise. C2 should be 1 μF or larger close to the regulator if C3 is used.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Input-Output Voltage Differential	20V
Operating Junction Temperature Range	
LM196 Control Section	-55°C to +150°C
Power Transistor	-55°C to +200°C
LM396 Control Section	0°C to +125°C
Power Transistor	0°C to +175°C

Storage Temperature	-65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C
ESD rating to be determined	

Electrical Characteristics (Note 1)

Parameter	Conditions	LM196			LM396			Units
		Min	Typ	Max	Min	Typ	Max	
Reference Voltage	$I_{OUT} = 10 \text{ mA}$	1.24	1.25	1.26	1.23	1.25	1.27	V
Reference Voltage (Note 2)	$V_{MIN} \leq (V_{IN} - V_{OUT}) \leq 20V$ $10 \text{ mA} \leq I_{OUT} \leq 10A, P \leq P_{MAX}$ Full Temperature Range	1.22	1.25	1.28	1.21	1.25	1.29	V
Line Regulation (Note 3)	$V_{MIN} \leq (V_{IN} - V_{OUT}) \leq 20V$ Full Temperature Range		0.005	0.01 0.05		0.005	0.02 0.05	%/V %/V
Load Regulation LM196/LM396 (Note 4)	$10 \text{ mA} \leq I_{OUT} \leq 10A$ $V_{MIN} \leq V_{IN} - V_{OUT} \leq 10V, P \leq P_{MAX}$ Full Temperature Range			0.1 0.15			0.1 0.15	%/A %/A
Ripple Rejection (Note 5)	$C_{ADJ} = 25 \mu\text{F}, f = 120 \text{ Hz}$ Full Temperature Range	60 54	74		66 54	74		dB dB
Thermal Regulation (Note 6)	$V_{IN} - V_{OUT} = 5V, I_{OUT} = 10A$		0.003	0.005		0.003	0.015	%/W
Average Output Voltage Temperature Coefficient	$T_{jMIN} \leq T_j \leq T_{jMAX}$ (See Curves for Limits)		0.003			0.003		%/°C
Adjustment Pin Current			50	100		50	100	μA
Adjustment Pin Current Change (Note 7)	$10 \text{ mA} \leq I_{OUT} \leq 10A$ $3V \leq V_{IN} - V_{OUT} \leq 20V$ $P \leq P_{MAX}$, Full Temperature Range			3			3	μA
Minimum Load Current (Note 9)	$2.5V \leq (V_{IN} - V_{OUT}) \leq 20V$ Full Temperature Range			10			10	mA
Current Limit (Note 8)	$2.5 \leq (V_{IN} - V_{OUT}) \leq 7V$ $V_{IN} - V_{OUT} = 20V$	10 1.5	14 3	20 8	10 1.5	14 3	20 8	A A
Rms Output Noise	$10 \text{ Hz} \leq f \leq 10 \text{ kHz}$		0.001			0.001		% V_{OUT}
Long Term Stability	$T_j = 125^\circ\text{C}, t = 1000 \text{ Hours}$		0.3	1.0		0.3	1.0	%
Thermal Resistance Junction to Case (Note 10)	Control Circuitry Power Transistor		0.3 1.0	0.5 1.2		0.3 1.0	0.5 1.2	°C/W °C/W

Electrical Characteristics (Note 1) (Continued)

Parameter	Conditions	LM196			LM396			Units
		Min	Typ	Max	Min	Typ	Max	
Power Dissipation (P_{MAX}) (Note 11)	$7.0V \leq V_{IN} - V_{OUT} \leq 12V$	70	100		70	100		W
	$V_{IN} - V_{OUT} = 15V$	50			50			W
	$V_{IN} - V_{OUT} = 18V$	36			36			W
Drop-Out Voltage LM196/LM396	$I_{OUT} = 10A$, Full Temperature Range		2.1	2.5		2.1	2.5	V
				2.75			2.75	

Note 1: Unless otherwise stated, these specifications apply for $T_j = 25^\circ C$, $V_{IN} - V_{OUT} = 5V$, $I_{OUT} = 10 mA$ to 10A.

Note 2: This is a worst-case specification which includes all effects due to input voltage, output current, temperature, and power dissipation. Maximum power (P_{MAX}) is specified under Electrical Characteristics.

Note 3: Line regulation is measured on a short-pulse, low-duty-cycle basis to maintain constant junction temperature. Changes in output voltage due to thermal gradients or temperature changes must be taken into account separately. See discussion of Line Regulation under Application Hints.

Note 4: Load regulation on the 2-pin package is determined primarily by the voltage drop along the output pin. Specifications apply for an external Kelvin sense connection at a point on the output pin $1/4"$ from the bottom of the package. Testing is done on a short-pulse-width, low-duty-cycle basis to maintain constant junction temperature. Changes in output voltage due to thermal gradients or temperature changes must be taken into account separately. See discussion of Load Regulation under Application Hints.

Note 5: Ripple rejection is measured with the adjustment pin bypassed with 25 μF capacitor, and is therefore independent of output voltage. With no load or bypass capacitor, ripple rejection is determined by line regulation and may be calculated from: $RR = 20 \log_{10} [100/(K \times V_{OUT})]$ where K is line regulation expressed in %/V. At frequencies below 100 Hz, ripple rejection may be limited by thermal effects, if load current is above 1A.

Note 6: Thermal regulation is defined as the change in output voltage during the time period of 0.2 ms to 20 ms after a change in power dissipation in the regulator, due to either a change in input voltage or output current. See graphs and discussion of thermal effects under Application Hints.

Note 7: Adjustment pin current change is specified for the worst-case combination of input voltage, output current, and power dissipation. Changes due to temperature must be taken into account separately. See graph of adjustment pin current vs temperature.

Note 8: Current limit is measured 10 ms after a short is applied to the output. DC measurements may differ slightly due to the rapidly changing junction temperature, tending to drop slightly as temperature increases. A minimum available load current of 10A is guaranteed over the full temperature range as long as power dissipation does not exceed 70W, and $V_{IN} - V_{OUT}$ is less than 7.0V.

Note 9: Minimum load current of 10 mA is normally satisfied by the resistor divider which sets up output voltage.

Note 10: Total thermal resistance, junction-to-ambient, will include junction-to-case thermal resistance plus interface resistance and heat sink resistance. See discussion of Heat Sinking under Application Hints.

Note 11: Although power dissipation is internally limited, electrical specifications apply only for power dissipation up to the limits shown. Derating with temperature is a function of both power transistor temperature and control area temperature, which are specified differently. See discussion of Heat Sinking under Application Hints. For $V_{IN} - V_{OUT}$ less than 7V, power dissipation is limited by current limit of 10A.

Note 12: Dropout voltage is input-output voltage differential measured at a forced reference voltage of 1.15V, with a 10A load, and is a measurement of the minimum input/output differential at full load.

Application Hints

Further improvements in efficiency can be obtained by using Schottky diodes or high efficiency diodes with lower forward voltage, combined with larger filter capacitors to reduce ripple. However, this reduces the voltage difference between input and drive pins and may not allow sufficient voltage to fully saturate the pass transistor. Special transformers are available from Signal Transformer that have a 1V tap on the output winding to provide the extra voltage for the drive pin. The transformers are available as standard items for 5V applications at 5A, 10A and 20A. Other voltages are available on special request.

Heat Sinking

Because of its extremely high power dissipation capability, the major limitation in the load driving capability of the LM196 is *heat sinking*. Previous regulators such as LM109, LM340, LM117, etc., had internal power limiting circuitry which limited power dissipation to about 30W. The LM196

is guaranteed to dissipate up to 70W continuously, as long as the maximum junction temperature limit is not exceeded. This requires careful attention to all sources of thermal resistance from junction-to-ambient, including junction-to-case resistance, case-to-heat sink interface resistance (0.1–1.0°C/W), and heat sink resistance itself. A good thermal joint compound such as Wakefield type 120 or Thermalloy Thermocote must be used when mounting the LM196, especially if an electrical insulator is used to isolate the regulator from the heat sink. Interface resistance without this compound will be no better than 0.5°C/W, and probably much worse. With the compound, and no insulator, interface resistance will be 0.2°C/W or less, assuming 0.005" or less combined flatness run-out of TO-3 and heat sink. Proper torquing of the mounting bolts is important to achieve minimum thermal resistance. Four to six inch pounds is recommended. Keep in mind that good electrical, as well as thermal, contact must be made to the case.

Application Hints (Continued)

The actual heat sink chosen for the LM196 will be determined by the worst-case continuous full load current, input voltage and maximum ambient temperature. Overload or short circuit output conditions do not normally have to be considered when selecting a heat sink because the thermal shutdown built into the LM196 will protect it under these conditions. An exception to this is in situations where the regulator must recover very quickly from overload. The LM196 may take some time to recover to within specified output tolerance following an extended overload, if the regulator is cooling from thermal shutdown temperature (approximately 175°C) to specified operating temperature (125°C or 150°C). The procedure for heat sink selection is as follows:

Calculate worst-case *continuous* average power dissipation in the regulator from $P = (V_{IN} - V_{OUT}) \times (I_{OUT})$. To do this, you must know the raw power supply voltage/current characteristics fairly accurately. For example, consider a 10V output with 15V nominal input voltage. At full load of 10A, the regulator will dissipate $P = (15 - 10) \times (10) = 50W$. If input voltage rises by 10%, power dissipation will increase to $(16.5 - 10) \times (10) = 65W$, a 30% increase. It is strongly suggested that a raw supply be assembled and tested to determine its average DC output voltage *under full load with maximum line voltage*. Do not over-design by using unloaded voltage as a worst-case, since the regulator will not be dissipating any power under no load conditions. Worst-case regulator dissipation normally occurs under full load conditions except when the effective DC resistance of the raw supply ($\Delta V/\Delta I$) is larger than $(V_{IN}^* - V_{OUT})/2I_{FL}$, where V_{IN}^* is the lightly-loaded raw supply voltage and I_{FL} is full load current. For $(V_{IN}^* - V_{OUT}) = 5V - 8V$, and $I_{FL} = 5A-10A$, this gives a resistance of 0.25Ω to 0.8Ω. If raw supply resistance is higher than this, the regulator power dissipation may be less at full load current, then at some intermediate current, due to the large drop in input voltage. Fortunately, most well designed raw supplies have low enough output resistance that regulator dissipation does maximize at full load current, or very close to it, so tedious testing is not usually required to find worst-case power dissipation.

A very important consideration is the size of the filter capacitor in the raw supply. At these high current levels, capacitor size is usually dictated by ripple current ratings rather than just obtaining a certain ripple voltage. Capacitor ripple current (rms) is 2–3 times the DC output current of the filter. If the capacitor has just 0.05Ω DC resistance, this can cause 30W internal power dissipation at 10A output current. Capacitor life is very sensitive to operating temperature, decreasing by a factor of two for each 15°C rise in internal temperature. Since capacitor life is not all that great to start with, it is obvious that a small capacitor with a large internal temperature rise is inviting very short mean-time-to-failure. A second consideration is the loss of usable input voltage to the regulator. If the capacitor is small, the large dips in the input voltage may cause the LM196 to drop out of regulation. 2000 μF per ampere of load current is the *minimum* recommended value, yielding about 2 Vp-p ripple of 120 Hz. Larger values will have longer life and the reduced ripple will allow lower DC input voltage to the regulator, with subse-

quent cost savings in the transformer and heat sink. Sometimes several capacitors in parallel are better to decrease series resistance and increase heat dissipating area.

After the raw supply characteristics have been determined, and worst-case power dissipation in the LM196 is known, the heat sink thermal resistance can be found from the graphs titled Maximum Heat Sink Thermal Resistance. These curves indicate the minimum size heat sink required as a function of ambient temperature. They are derived from a case-to-control area thermal resistance of 0.5°C/W and a case-to-power transistor thermal resistance of 1.2°C/W. 0.2°C/W is assumed for interface resistance. A maximum control area temperature of 150°C is used for the LM196 and 125°C for the LM396. Maximum power transistor temperature is 200°C for the LM196 and 175°C for the LM396. For conservative designs, it is suggested that when using these curves, you assume an ambient temperature 25°C–50°C higher than is actually anticipated, to avoid running the regulator right at its design limits of operating temperature.

A quick look at the curves show that heat sink resistance (θ_{SA}) will normally fall into the range of 0.2°C/W–1.5°C/W. These are *not* small heat sinks. A model 441, for instance, which is sold by several manufacturers, has a θ_{SA} of 0.6°C/W with natural convection and is about five inches on a side. Smaller sinks are more volumetrically efficient, and larger sinks, less so. A rough formula for estimating the volume of heat sink required is: $V = 50/\theta_{SA}^{1.5}$ CU. IN. This holds for natural convection only. If the heat sink is inside a small sealed enclosure, θ_{SA} will increase substantially because the air is not free to form natural convection currents. Fan-forced convection can reduce θ_{SA} by a factor of two at 200 FPM air velocity, and by four at 1000 FPM.

Ripple Rejection

Ripple rejection at the normal ripple frequency of 120 Hz is a function of both electrical and thermal effects in the LM196. If the adjustment pin is not bypassed with a capacitor, it is also dependent on output voltage. A 25 μF capacitor from the adjustment pin to ground will make ripple rejection independent of output voltage for frequencies above 100 Hz. If lower ripple frequencies are encountered, the capacitor should be increased proportionally.

To keep in mind that the bypass capacitor on the adjustment pin will limit the turn-on time of the regulator. A 25 μF capacitor, combined with the output divider resistance, will give an extended output voltage settling time following the application of input power.

Load Regulation (LM196/LM396)

Because the LM196 is a three-terminal device, it is not possible to provide true remote load sensing. Load regulation will be limited by the resistance of the output pin and the wire connecting the regulator to the load. For the data sheet specification, regulation is measured 1/4" from the bottom of the package on the output pin. Negative side sensing is a true Kelvin connection, with the bottom of the output divider returned to the negative side of the load.

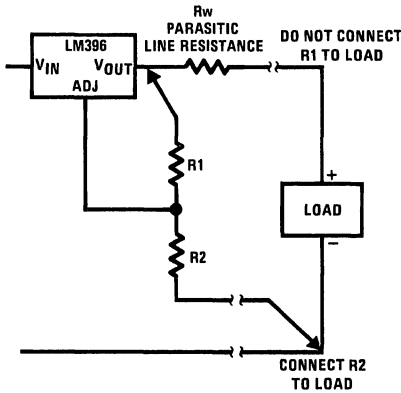
Application Hints (Continued)

Although it may not be immediately obvious, best load regulation is obtained when the top of the divider is connected *directly* to the output pin, *not to the load*. This is illustrated in *Figure 2*. If R1 were connected to the load, the effective resistance between the regulator and the load would be

$$(R_w) \times \left(\frac{R_2 + R_1}{R_1} \right)$$

R_w = Line Resistance

Connected as shown, R_w is not multiplied by the divider ratio. R_w is about 0.004Ω per foot using 16 gauge wire. This translates to 40 mV/ft at 10A load current, so it is important to keep the positive lead between regulator and load as short as possible.



TL/H/9059-2

FIGURE 2. Proper Divider Connection

The input resistance of the sense pin is typically $6\text{ k}\Omega$, modeled as a resistor between the sense pin and the output pin. Load regulation will start to degrade if a resistance higher than 10Ω is inserted in series with the sense. This assumes a worst-case condition of 0.5V between output and sense pins. Lower differential voltage will allow higher sense series resistance.

Thermal Load Regulation

Thermal, as well as electrical, load regulation must be considered with IC regulators. Electrical load regulation occurs in microseconds, thermal regulation due to die thermal gradients occurs in the 0.2 ms - 20 ms time frame, and regulation due to overall temperature changes in the die occurs over a 20 ms to 20 minute period, depending on the time constant of the heat sink used. Gradient induced load regulation is calculated from

$$\Delta V_{\text{OUT}} = (V_{\text{IN}} - V_{\text{OUT}}) \times (\Delta I_{\text{OUT}}) \times (\beta)$$

β = Thermal regulation specified on data sheet.

For $V_{\text{IN}} = 9\text{V}$, $V_{\text{OUT}} = 5\text{V}$, $\Delta I_{\text{OUT}} = 10\text{A}$, and $\beta = 0.005\%/W$, this yields a 0.2% change in output voltage. Changes in output voltage due to overall temperature rise are calculated from

$$V_{\text{OUT}} = (V_{\text{IN}} - V_{\text{OUT}}) \times (\Delta I_{\text{OUT}}) \times (\text{TC}) \times (\theta_{\text{JA}})$$

TC = Temperature coefficient of output voltage.

θ_{JA} = Thermal resistance from junction to ambient. θ_{JA} is approximately $0.5^\circ\text{C}/W + \theta$ of heat sink.

For the same conditions as before, with $\text{TC} = 0.003\%/^\circ\text{C}$, and $\theta_{\text{JA}} = 1.5^\circ\text{C}/W$, the change in output voltage will be 0.18% . Because these two thermal terms can have either polarity, they may subtract from, or add to, electrical load regulation. For worst-case analysis, they must be assumed to add. If the output of the regulator is trimmed under load, only that portion of the load that changes need be used in the previous calculations, significantly improving output accuracy.

Line Regulation

Electrical line regulation is very good on the LM196—typically less than 0.005% change in output voltage for a 1V change in input. This level of regulation is achieved only for very low load currents, however, because of thermal effects. Even with a thermal regulation of $0.002\%/W$, and a temperature coefficient of $0.003\%/^\circ\text{C}$, DC line regulation will be dominated by thermal effects as shown by the following example:

Assume $V_{\text{OUT}} = 5\text{V}$, $V_{\text{IN}} = 9\text{V}$, $I_{\text{OUT}} = 8\text{A}$

Following a 10% change in input voltage (0.9), the output will change quickly ($\leq 100\ \mu\text{s}$), due to electrical effects, by $(0.005\%/V) \times (0.9\text{V}) = 0.0045\%$. In the next 20 ms , the output will change an additional $(0.002\%/W) \times (8\text{A}) \times (0.9\text{V}) = 0.0144\%$ due to thermal gradients across the die. After a much longer time, determined by the time constant of the heat sink, the output will change an additional $(0.003\%/^\circ\text{C}) \times (8\text{A}) \times (0.9\text{V}) \times (2^\circ\text{C}/W) = 0.043\%$ due to the temperature coefficient of output voltage and the thermal resistance from die to ambient. ($2^\circ\text{C}/W$ was chosen for this calculation). The sign of these last two terms varies from part to part, so no assumptions can be made about any cancelling effects. All three terms must be added for a proper analysis. This yields $0.0045 + 0.0144 + 0.043 = 0.062\%$ using *typical* values for thermal regulation and temperature coefficient. For worst-case analysis, the maximum data sheet specifications for thermal regulation and temperature coefficient should be used, along with the *actual* thermal resistance of the heat sink being used.

Paralleling Regulators

Direct paralleling of regulators is not normally recommended because they do not share currents equally. The regulator with the highest reference voltage will supply all the current to the load until it current limits. With an 18A load, for instance, one regulator might be operating in current limit at 16A while the second device is only carrying 2A . Power dissipation in the high current regulator is extremely high with attendant high junction temperatures. Long term reliability cannot be guaranteed under these conditions.

Quasi-paralleling may be accomplished if load regulation is not critical. The connection shown in *Figure 5a* will typically share to within 1A , with a worst-case of about 3A . Load regulation is degraded by 150 mV at 20A loads. An external op amp may be used as in *Figure 5b* to improve load regulation and provide remote sensing.

Application Hints (Continued)

Input and Output Capacitors

The LM196 will tolerate a wide range of input and output capacitance, but long wire runs or small values of output capacitance can sometimes cause problems. If an output capacitor is used, it should be $1\ \mu\text{F}$ or larger. We suggest $10\ \mu\text{F}$ solid tantalum if significant improvements in high frequency output impedance are needed (see output impedance graph). This capacitor should be as close to the regulator as possible, with short leads, to reduce the effects of lead inductance. No input capacitor is needed if the regulator is within 6 inches of the power supply filter capacitor, using 18 gauge stranded wire. For longer wire runs, the LM196 input should be bypassed locally with a $4.7\ \mu\text{F}$ (or larger) solid tantalum capacitor, or a $100\ \mu\text{F}$ (or larger) aluminum electrolytic capacitor.

Correcting for Output Wire Losses (LM196/LM396)

Three-terminal regulators can only provide partial Kelvin load sensing (see Load Regulation). Full remote sensing can be added by using an external op amp to cancel the effect of voltage drops in the unsensed positive output lead. In *Figure 7*, the LM301A op amp forces the voltage loss across the unsensed output lead to appear across R3. The current through R3 then flows out the V^- pin of the op amp through R4. The voltage drop across R4 will raise the output voltage by an amount equal to the line loss, just cancelling the line loss itself. A small ($\approx 40\ \text{mV}$) initial output voltage error is created by the quiescent current of the op amp. Cancellation range is limited by the maximum output current of the op amp, about $300\ \text{mV}$ as shown. This can be raised by increasing R3 or R4 at the expense of more initial output error.

Transformers and Diodes

Proper transformer ratings are very important in a high current supply because of the conflicting requirements of efficiency and tolerance to low-line conditions. A transformer with a high secondary voltage will waste power and cause unnecessary heating in the regulator. Too low a secondary voltage will cause loss of regulation under low-line conditions. The following formulas may be used to calculate the required secondary voltage and current ratings using a full-wave center tap:

$$V_{\text{rms}} = \left(\frac{V_{\text{OUT}} + V_{\text{REG}} + V_{\text{RECT}} + V_{\text{RIPPLE}}}{\sqrt{2}} \right)$$

$$\left(\frac{V_{\text{NOM}}}{V_{\text{LOW}}} \right) \left((1.1)^* \right)$$

$$I_{\text{rms}} = (I_{\text{OUT}}) (1.2) \quad \text{(Full-wave center tap)}$$

where:

V_{OUT} = DC regulated output voltage

V_{REG} = Minimum input-output voltage of regulator

V_{RECT} = Rectifier forward voltage drop at three times DC output current

V_{RIPPLE} = 1/2 peak-to-peak capacitor ripple voltage

$$= \frac{(5.3 \times 10^{-3}) (I_{\text{OUT}})}{2C}$$

*The factor of 1.1 is only an approximate factor accounting for load regulation of the transformer.

V_{NOM} = Nominal line voltage AC rms

V_{LOW} = Low line voltage AC rms

I_{OUT} = DC output current

Example: $I_{\text{OUT}} = 10\text{A}$, $V_{\text{OUT}} = 5\text{V}$

Assume: $V_{\text{REG}} = 2.2\text{V}$, $V_{\text{RECT}} = 1.2\text{V}$

$V_{\text{RIPPLE}} = 2\text{Vp-p}$, $V_{\text{NOM}} = 115\text{V}$,

$V_{\text{LOW}} = 105\text{V}$

$$V_{\text{rms}} = \left(\frac{5 + 2.2 + 1.2 + 1}{\sqrt{2}} \right) \left(\frac{115}{105} \right) 1.1$$

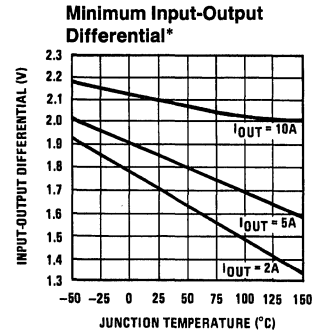
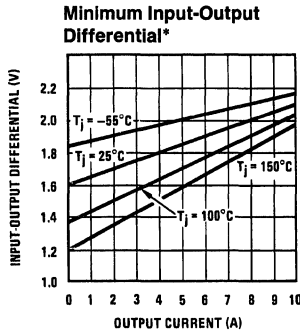
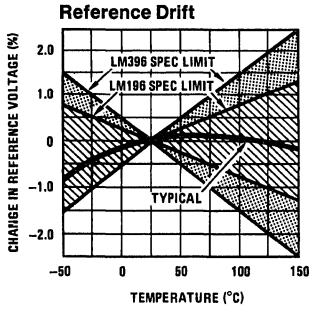
$$= 8.01\ V_{\text{rms}}$$

$$\text{Capacitor } C = \frac{(5.3 \times 10^{-3}) (I_{\text{OUT}})}{2 \times V_{\text{RIPPLE}}}$$

$$= \frac{(5.3 \times 10^{-3}) (10)}{2} = 26,500\ \mu\text{F}$$

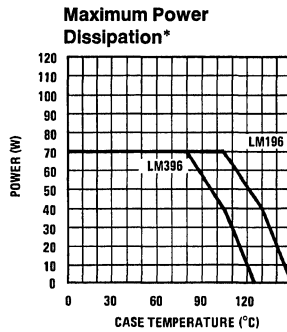
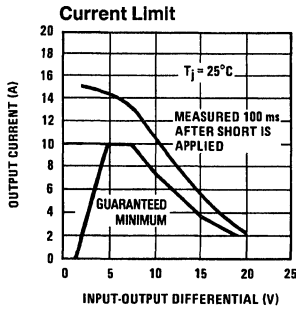
The diodes used in a full-wave rectified capacitor input supply must have a DC current rating considerably higher than the average current flowing through them. In a 10A supply, for instance, the average current through each diode is only 5A, but the diodes should have a rating of 10A–15A. There are many reasons for this, both thermal and electrical. The diodes conduct current in pulses about 3.5 ms wide with a peak value of 5–8 times the average value, and an rms value 1.5–2.0 times the average value. This results in long term diode heating roughly equivalent to 10A DC current. The most demanding condition however, may be the one cycle surge through the diode during power turn on. The peak value of the surge is about 10–20 times the DC output current of the supply, or 100A–200A for a 10A supply. The diodes must have a one cycle non-repetitive surge rating of 200A or more, and this is usually not found in a diode with less than 10A average current rating. Keep in mind that even though the LM196 may be used at current levels below 10A, the diodes may still have to survive shorted output conditions where average current could rise to 12A–15A. Smaller transformers and filter capacitors used in lower current supplies will reduce surge currents, but unless specific information is available on worst-case surges, it is best not to economize on diodes. Stud-mounted devices in a DO-4 package are recommended. Cathode-to-case types may be bolted directly to the same heat sink as the LM196 because the case of the regulator is its power input. Part numbers to consider are the 1N1200 series rated at 12A average current in a DO-4 stud package. Additional types include common cathode diodes in a TO-3 package, both standard and Schottky, and various diodes in plastic filled assemblies. Schottky diodes will improve efficiency, especially in low voltage applications. In a 5V supply for instance, Schottky diodes will decrease wasted power by up to 6W, or alternatively provide an additional 5% "drop out" margin for low-line conditions. Several manufacturers are producing "high efficiency" diodes with a forward voltage drop nearly as good as Schottkys at high current levels. These devices do not have the low breakdown voltages of Schottkys, so are much less prone to reverse breakdown induced failures.

Typical Performance Characteristics

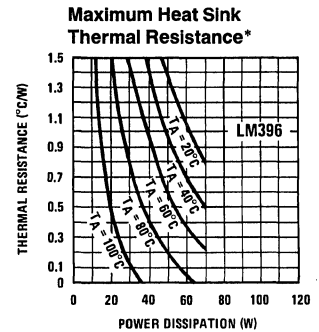


* V_{IN} is reduced until output drops 2%

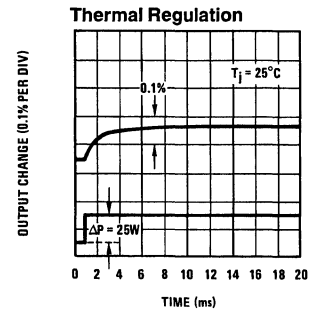
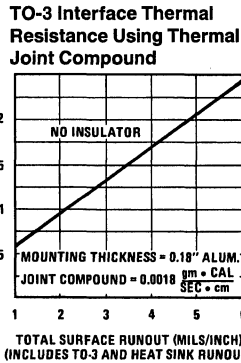
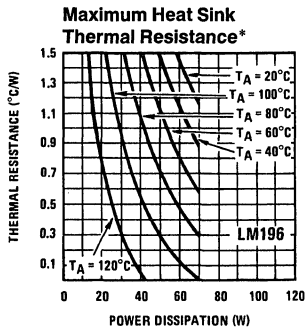
TL/H/9059-3
* V_{IN} is reduced until output drops 2%



*As limited by maximum junction temperature.



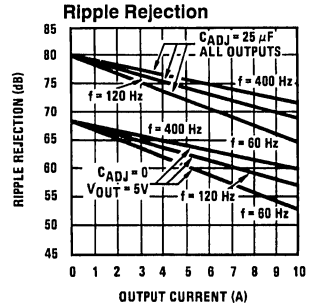
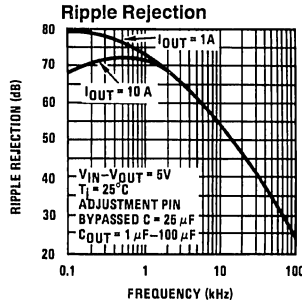
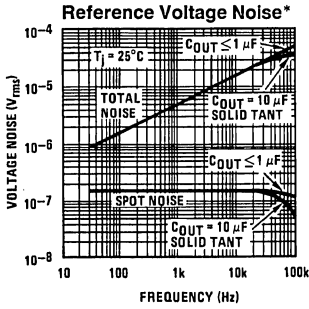
TL/H/9059-4
*See "Heat Sinking" under Applications Hints.



*See "Heat Sinking" under Application Hints.

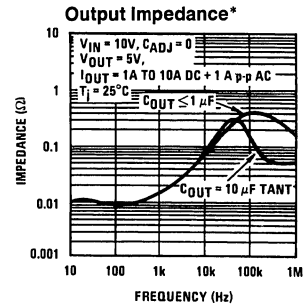
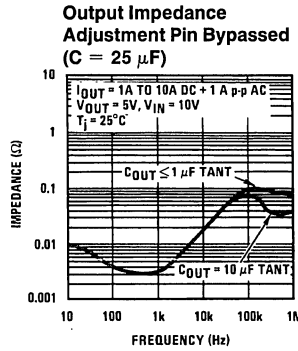
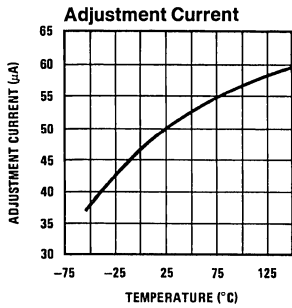
TL/H/9059-5

Typical Performance Characteristics (Continued)



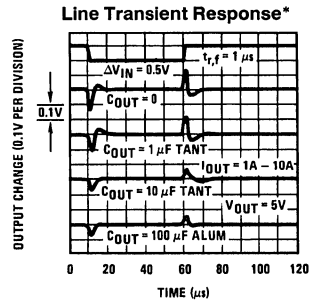
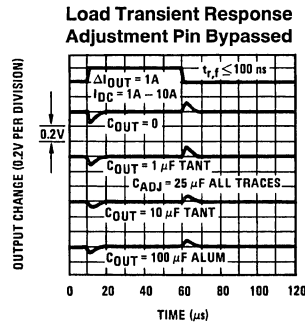
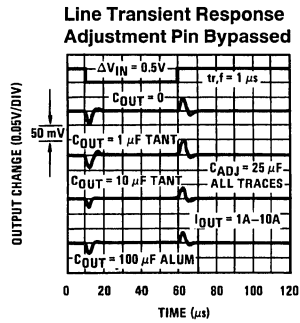
TL/H/9059-6

*To obtain output noise, multiply by $V_{OUT}/1.25$ if adjustment pin is not bypassed.



TL/H/9059-7

*For output voltages other than 5V, multiply vertical scale readings by $V_{OUT}/5$.

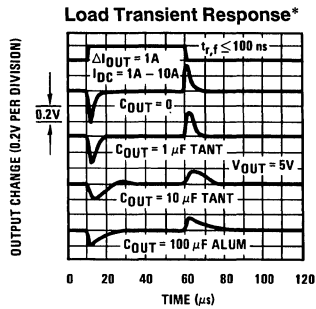


TL/H/9059-8

*With no adjustment pin bypass. For output voltages other than 5V, multiply vertical scale by $V_{OUT}/5$.



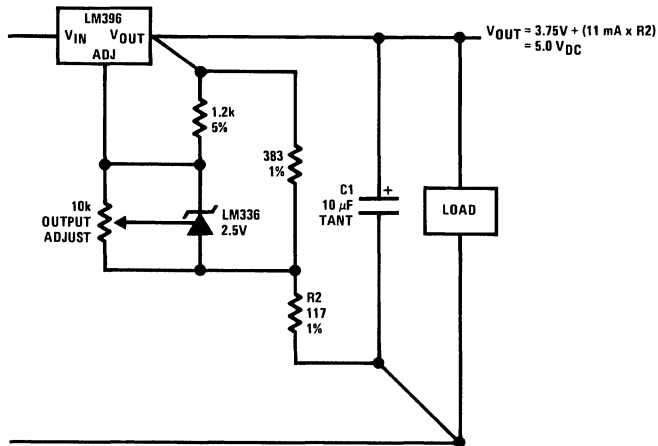
Typical Performance Characteristics (Continued)



TL/H/9059-9

*With no adjustment pin bypass. For output voltages other than 5V, multiply vertical scale by $V_{OUT}/5$.

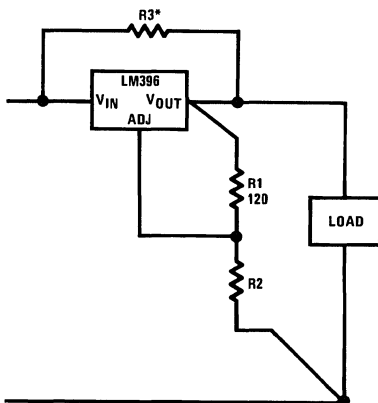
Typical Applications (Continued)



TL/H/9059-10

*Regulation can be improved by adding an LM336 reference diode to increase the effective reference voltage to 3.75V. Load and line regulation are improved by 3:1, including thermal effects.

FIGURE 3. Improving Regulation*



TL/H/9059-11

*R3 is selected to supply partial load current. Therefore, a minimum load must always be maintained to prevent the regulated output from rising uncontrolled. R3 must be greater than $(V_{MAX} - V_{OUT})/I_{MIN}$, where V_{MAX} is worst-case high input voltage, and I_{MIN} is the minimum load current. R3 must be rated for at least $(V_{IN} - V_{OUT})^2/R3$ watts. Regulator power dissipation will be reduced by a factor of 2-3 in a typical situation where minimum load current is 1/2 full load current. Regulator dissipation will peak at:

$$V_{IN} = \frac{(R3)(I_{OUT})}{2} + V_{OUT}$$

and will be equal to:

$$P_{MAX} = \frac{(R3)(I_{OUT})^2}{4} \text{ Assuming: } (R3)(I_{OUT}) \leq V_{MAX} - V_{OUT}$$

A few words of caution; (1) R3 power rating must be increased to $(V_{MAX})^2/R3$ if continuous output shorts are possible. (2) Under normal load conditions, system power dissipation is not changed, but under short circuit conditions *system* power dissipation increases by $(V_{IN})^2/R3$ watts over the already high power of a shorted regulator. The LM196 will not be harmed and neither will R3 if it is rated properly, but the raw supply components must be able to withstand the overload also. Thermal shutdown of the LM196 will probably occur for sustained shorts, somewhat alleviating the problem.

FIGURE 4. Reducing Regulator Power Dissipation

Typical Applications (Continued)

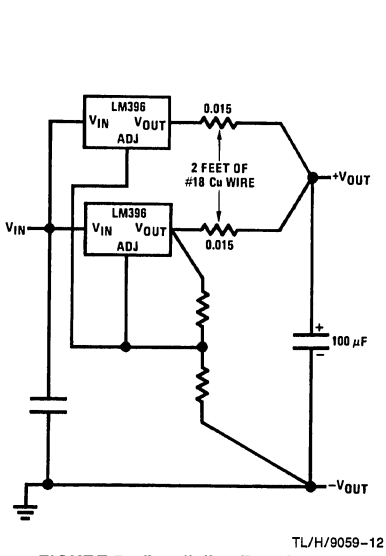
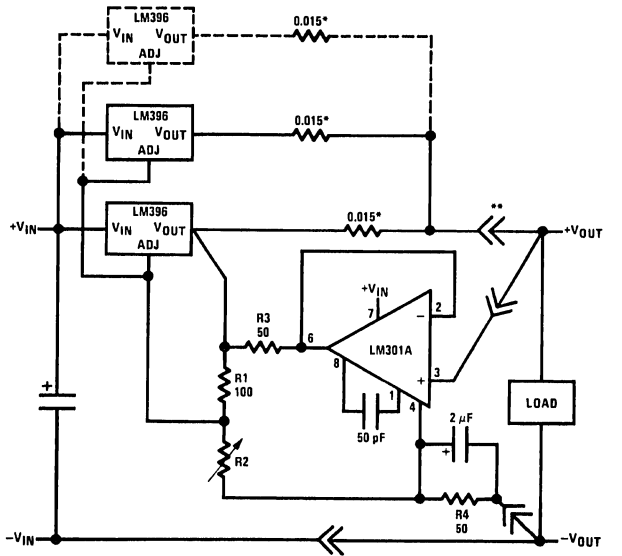


FIGURE 5a. Paralleling Regulators

TL/H/9059-12

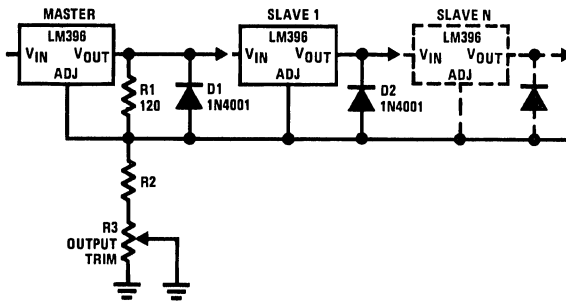


TL/H/9059-13

*2 feet of #18 CU wire

**Total voltage drop across output wire and connector should not exceed 0.3V

FIGURE 5b

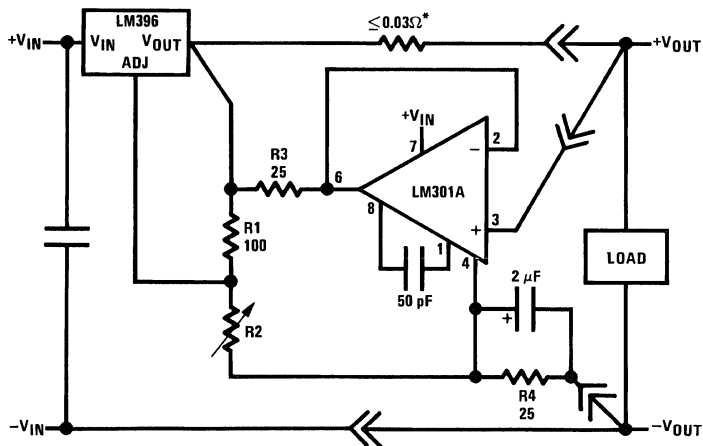


TL/H/9059-14

Output will be within ± 20 mV at 25°C, no load. Regulation of tracking units is improved by $V_{OUT}/1.25$ compared to a normal connection. Regulation of master unit is unchanged. Load or input voltage changes on slave units do not affect other units, but all units will be affected by changes on master. A short on any output will cause all other outputs to drop to approximately 2V.

FIGURE 6. Tracking Regulators

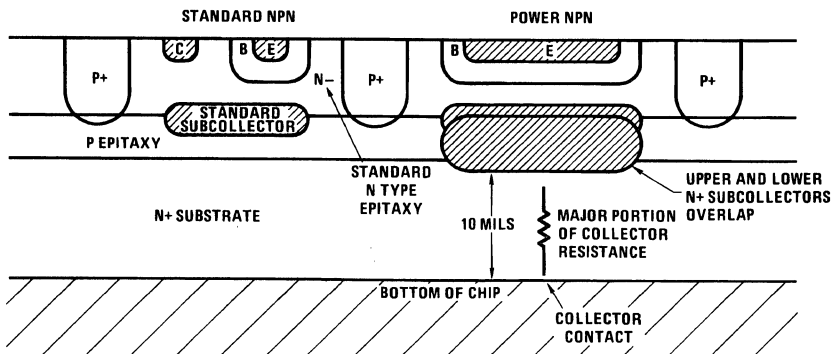
Typical Applications (Continued)



TL/H/9059-15

*Parasitic line resistance created by wiring connectors, or parallel ballasting.

FIGURE 7. Correcting for Line Losses

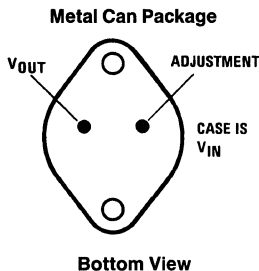


TL/H/9059-16

Power NPNs have low collector resistance, and do not require collector bond wires. Collectors are all common to substrate. Standard NPNs are still isolated.

FIGURE 8. Process Technology

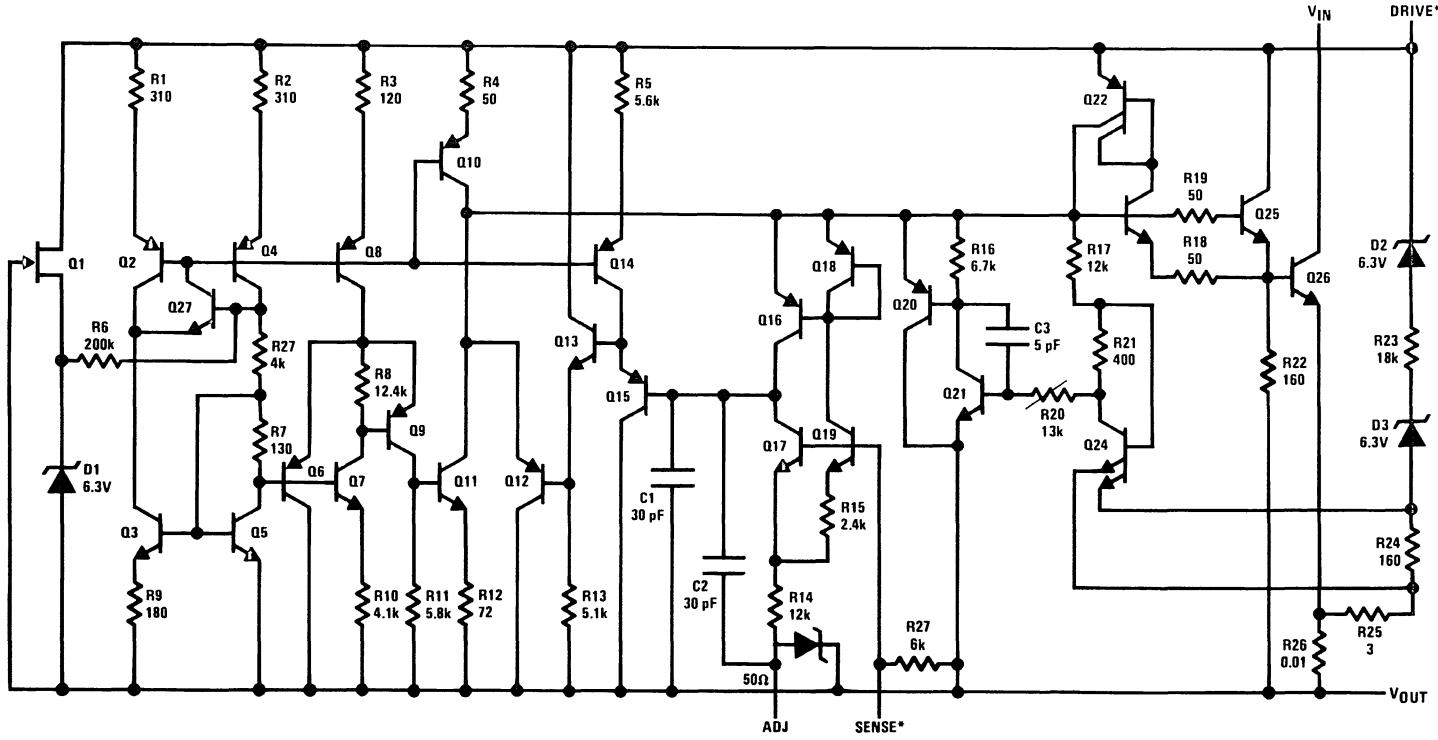
Connection Diagram



TL/H/9059-18

Order Number LM196K STEEL or LM396K STEEL
See NS Package Number K02B

Schematic Diagram*



*Drive is tied to V_{IN} and sense is tied to V_{OUT} on LM196 and LM396.

TL/H/9059-17

1-143





LM317L 3-Terminal Adjustable Regulator

General Description

The LM317L is an adjustable 3-terminal positive voltage regulator capable of supplying 100 mA over a 1.2V to 37V output range. It is exceptionally easy to use and requires only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM317L is available packaged in a standard TO-92 transistor package which is easy to use.

In addition to higher performance than fixed regulators, the LM317L offers full overload protection. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Features

- Adjustable output down to 1.2V
- Guaranteed 100 mA output current
- Line regulation typically 0.01%V
- Load regulation typically 0.1%
- Current limit constant with temperature
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Output is short circuit protected

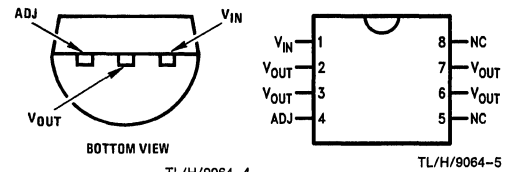
Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM317L is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input-to-output differential is not exceeded.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM317L can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

The LM317L is available in a standard TO-92 transistor package and the SO-8 package. The LM317L is rated for operation over a -25°C to 125°C range.

Connection Diagram

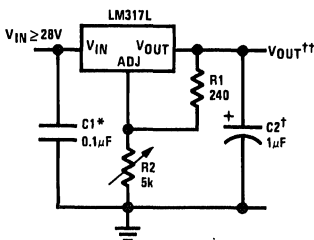


Order Number **LM317LZ**
See NS Package
Number **Z03A**

Order Number **LM317LM**
See NS Package
Number **M08A**

Typical Applications

1.2V–25V Adjustable Regulator



TL/H/9064-1

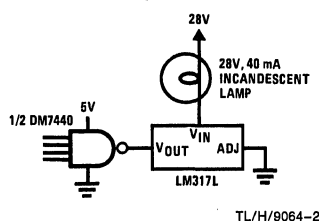
Full output current not available at high input-output voltages

†Optional—improves transient response

*Needed if device is more than 6 inches from filter capacitors

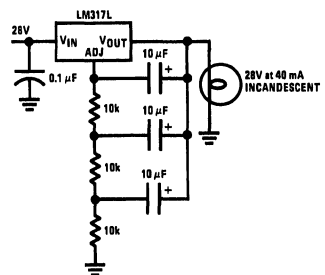
$$\dagger\dagger V_{OUT} = 1.25V \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ}(R_2)$$

Fully Protected (Bulletproof) Lamp Driver



TL/H/9064-2

Lamp Flasher



TL/H/9064-3

Output rate—4 flashes per second at 10% duty cycle

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation Internally Limited
 Input-Output Voltage Differential 40V
 Operating Junction Temperature Range -40°C to $+125^{\circ}\text{C}$

Storage Temperature -55°C to $+150^{\circ}\text{C}$
 Lead Temperature (Soldering, 4 seconds) 260°C
 Output is Short Circuit Protected
 ESD rating to be determined.

Electrical Characteristics (Note 1)

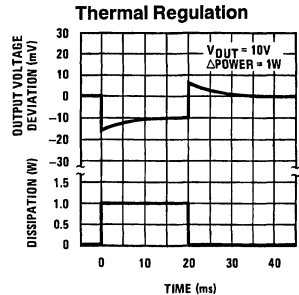
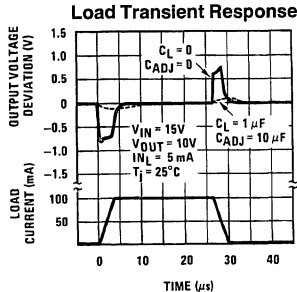
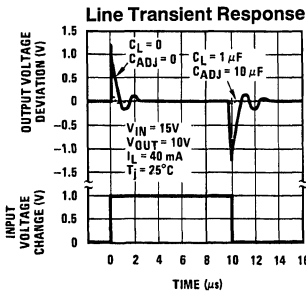
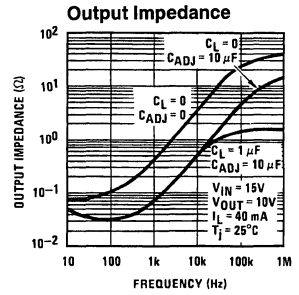
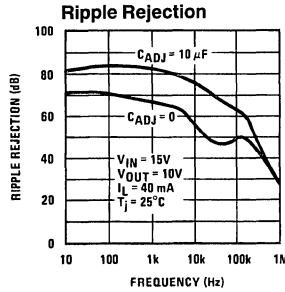
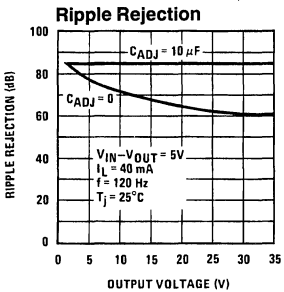
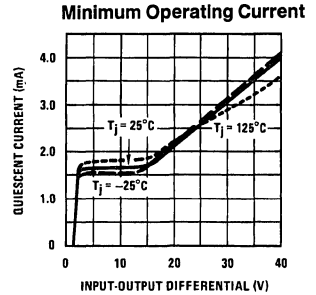
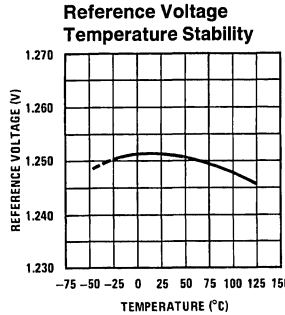
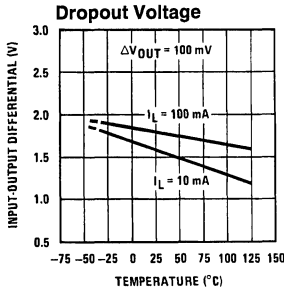
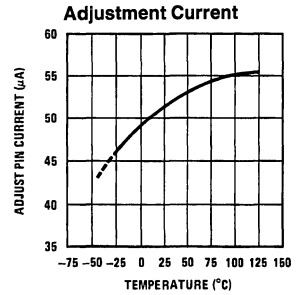
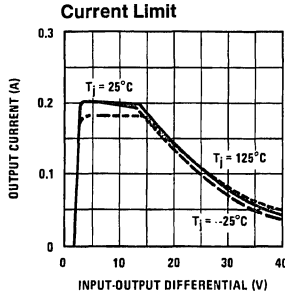
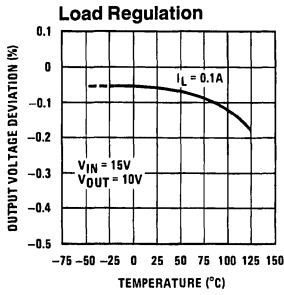
Parameter	Conditions	Min	Typ	Max	Units
Line Regulation	$T_j = 25^{\circ}\text{C}$, $3\text{V} \leq (V_{\text{IN}} - V_{\text{OUT}}) \leq 40\text{V}$, $I_L \leq 20\text{ mA}$ (Note 2)		0.01	0.04	%/V
Load Regulation	$T_j = 25^{\circ}\text{C}$, $5\text{ mA} \leq I_{\text{OUT}} \leq I_{\text{MAX}}$ (Note 2)		0.1	0.5	%
Thermal Regulation	$T_j = 25^{\circ}\text{C}$, 10 ms Pulse		0.04	0.2	%/W
Adjustment Pin Current			50	100	μA
Adjustment Pin Current Change	$5\text{ mA} \leq I_L \leq 100\text{ mA}$ $3\text{V} \leq (V_{\text{IN}} - V_{\text{OUT}}) \leq 40\text{V}$, $P \leq 625\text{ mW}$		0.2	5	μA
Reference Voltage	$3\text{V} \leq (V_{\text{IN}} - V_{\text{OUT}}) \leq 40\text{V}$, (Note 3) $5\text{ mA} \leq I_{\text{OUT}} \leq 100\text{ mA}$, $P \leq 625\text{ mW}$	1.20	1.25	1.30	V
Line Regulation	$3\text{V} \leq (V_{\text{IN}} - V_{\text{OUT}}) \leq 40\text{V}$, $I_L \leq 20\text{ mA}$ (Note 2)		0.02	0.07	%/V
Load Regulation	$5\text{ mA} \leq I_{\text{OUT}} \leq 100\text{ mA}$, (Note 2)		0.3	1.5	%
Temperature Stability	$T_{\text{MIN}} \leq T_j \leq T_{\text{MAX}}$		0.65		%
Minimum Load Current	$(V_{\text{IN}} - V_{\text{OUT}}) \leq 40\text{V}$ $3\text{V} \leq (V_{\text{IN}} - V_{\text{OUT}}) \leq 15\text{V}$		3.5 1.5	5 2.5	mA
Current Limit	$3\text{V} \leq (V_{\text{IN}} - V_{\text{OUT}}) \leq 13\text{V}$ $(V_{\text{IN}} - V_{\text{OUT}}) = 40\text{V}$	100 25	200 50	300 150	mA mA
Rms Output Noise, % of V_{OUT}	$T_j = 25^{\circ}\text{C}$, $10\text{ Hz} \leq f \leq 10\text{ kHz}$		0.003		%
Ripple Rejection Ratio	$V_{\text{OUT}} = 10\text{V}$, $f = 120\text{ Hz}$, $C_{\text{ADJ}} = 0$ $C_{\text{ADJ}} = 10\ \mu\text{F}$	66	65 80		dB dB
Long-Term Stability	$T_j = 125^{\circ}\text{C}$, 1000 Hours		0.3	1	%
Thermal Resistance Junction to Ambient	Z Package 0.4" Leads Z Package 0.125 Leads SO-8 Package		180 160 165		$^{\circ}\text{C}/\text{W}$ $^{\circ}\text{C}/\text{W}$ $^{\circ}\text{C}/\text{W}$
Thermal Rating of SO Package			165		$^{\circ}\text{C}/\text{W}$

Note 1: Unless otherwise noted, these specifications apply: $-25^{\circ}\text{C} \leq T_j \leq 125^{\circ}\text{C}$ for the LM317L; $V_{\text{IN}} - V_{\text{OUT}} = 5\text{V}$ and $I_{\text{OUT}} = 40\text{ mA}$. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 625 mW. I_{MAX} is 100 mA.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

Note 3: Thermal resistance of the TO-92 package is $180^{\circ}\text{C}/\text{W}$ junction to ambient with 0.4" leads from a PC board and $160^{\circ}\text{C}/\text{W}$ junction to ambient with 0.125" lead length to PC board.

Typical Performance Characteristics (Output capacitor = 0 μ F unless otherwise noted.)



Application Hints

In operation, the LM317L develops a nominal 1.25V reference voltage, V_{REF} , between the output and adjustment terminal. The reference voltage is impressed across program resistor $R1$ and, since the voltage is constant, a constant current I_1 then flows through the output set resistor $R2$, giving an output voltage of

$$V_{OUT} = V_{REF} \left(1 + \frac{R2}{R1} \right) + I_{ADJ}(R2)$$

Since the 100 μ A current from the adjustment terminal represents an error term, the LM317L was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

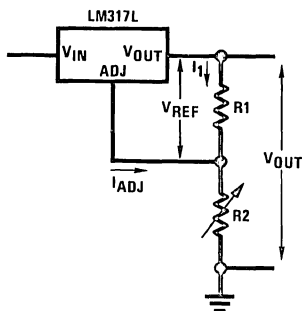


FIGURE 1

TL/H/9064-7

External Capacitors

An input bypass capacitor is recommended in case the regulator is more than 6 inches away from the usual large filter capacitor. A 0.1 μ F disc or 1 μ F solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used, but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM317L to improve ripple rejection and noise. This bypass capacitor prevents ripple and noise from being amplified as the output voltage is increased. With a 10 μ F bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10 μ F do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

In general, the best type of capacitors to use is solid tantalum. *Solid tantalum capacitors have low impedance even at high frequencies.* Depending upon capacitor construction, it takes about 25 μ F in aluminum electrolytic to equal 1 μ F solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, a 0.01 μ F disc may seem to work better than a 0.1 μ F disc as a bypass.

Although the LM317L is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μ F solid tantalum (or 25 μ F aluminum electrolytic) on the output swamps this effect and insures stability.

Load Regulation

The LM317L is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240 Ω) should be tied directly to the output of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05 Ω resistance between the regulator and load will have a load regulation due to line resistance of $0.05\Omega \times I_L$. If the set resistor is connected near the load the effective line resistance will be $0.05\Omega (1 + R2/R1)$ or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240 Ω set resistor.

With the TO-92 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the output pin. The ground of $R2$ can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

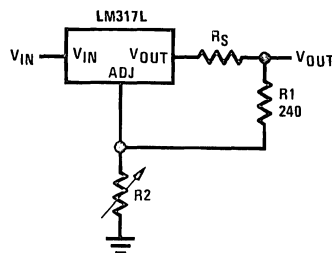


FIGURE 2. Regulator with Line Resistance in Output Lead

TL/H/9064-8

Application Hints (Continued)

Thermal Regulation

When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT} , per watt, within the first 10 ms after a step of power is applied. The LM317L specification is 0.2%/W, maximum.

In the Thermal Regulation curve at the bottom of the Typical Performance Characteristics page, a typical LM317L's output changes only 7 mV (or 0.07% of $V_{OUT} = -10V$) when a 1W pulse is applied for 10 ms. This performance is thus well inside the specification limit of $0.2\%/W \times 1W = 0.2\%$ maximum. When the 1W pulse is ended, the thermal regulation again shows a 7 mV change as the gradients across the LM317L chip die out. Note that the load regulation error of about 14 mV (0.14%) is additional to the thermal regulation error.

Protection Diodes

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to pre-

vent the capacitors from discharging through low current points into the regulator. Most 10 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN} . In the LM317L, this discharge path is through a large junction that is able to sustain a 2A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μF or less, the LM317L's ballast resistors and output structure limit the peak current to a low enough level so that there is no need to use a protection diode.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM317L is a 50 Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM317L with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

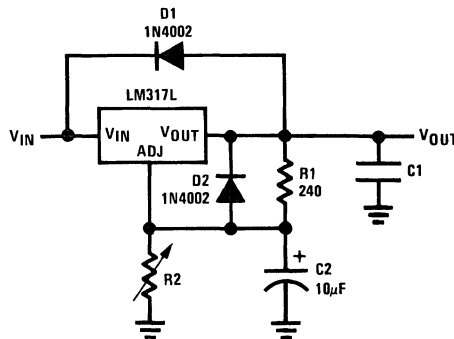


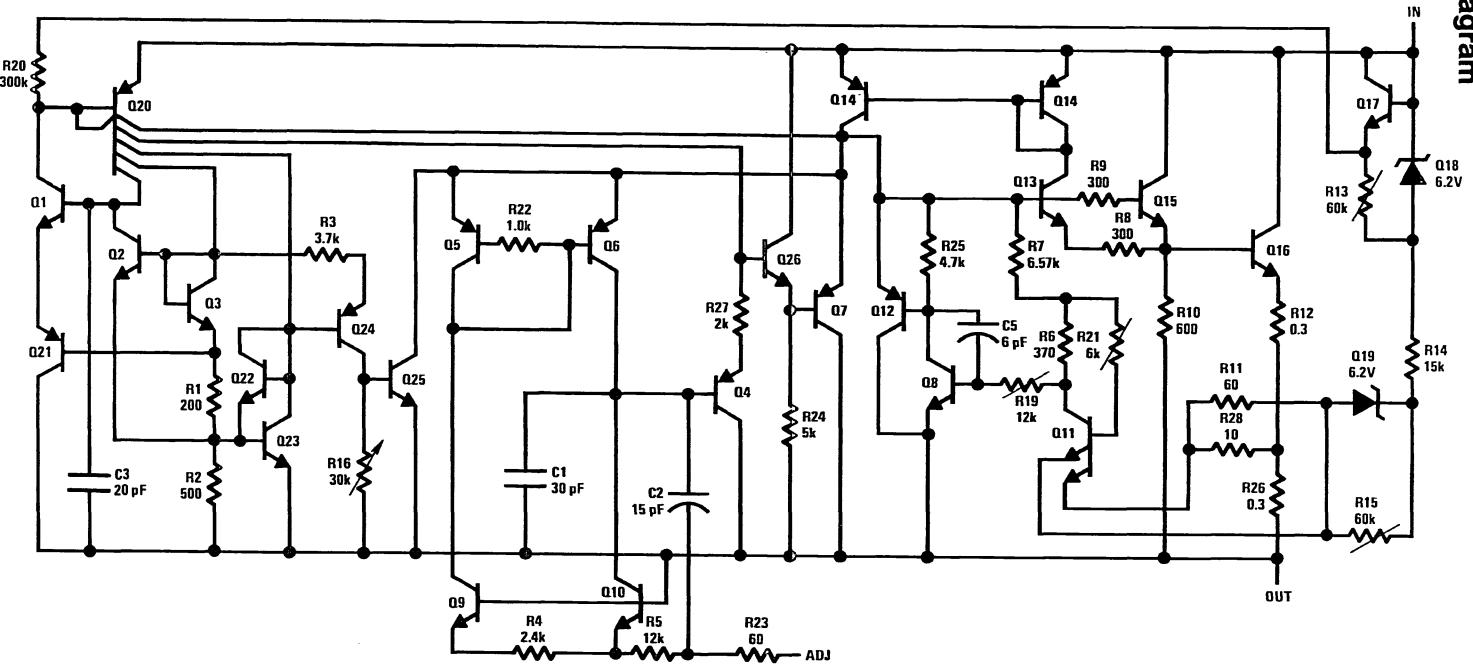
FIGURE 3. Regulator with Protection Diodes

$$V_{OUT} = 1.25V \left(1 + \frac{R_2}{R_1} \right) I_{ADJ} R_2$$

D1 protects against C1

D2 protects against C2

Schematic Diagram



1-149

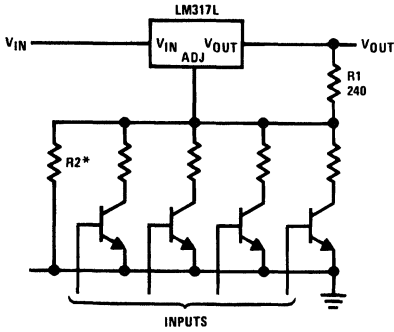
TL/H/9064-10

LM317L



Typical Applications (Continued)

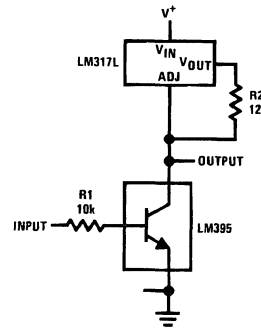
Digitally Selected Outputs



TL/H/9064-11

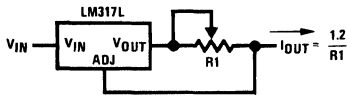
*Sets maximum V_{OUT}

High Gain Amplifier



TL/H/9064-12

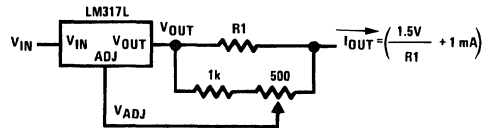
Adjustable Current Limiter



TL/H/9064-13

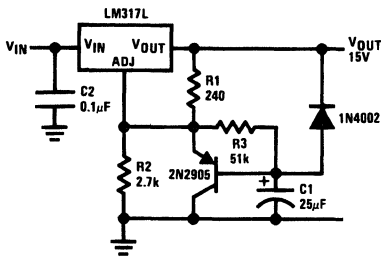
12 ≤ R1 ≤ 240

Precision Current Limiter



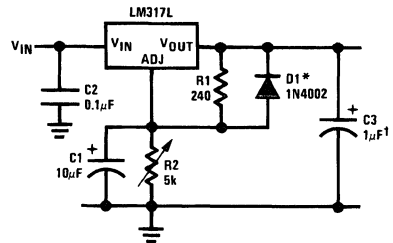
TL/H/9064-14

Slow Turn-On 15V Regulator



TL/H/9064-15

Adjustable Regulator with Improved Ripple Rejection

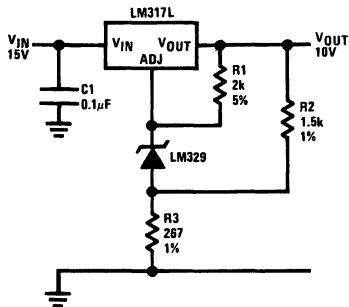


TL/H/9064-16

†Solid tantalum

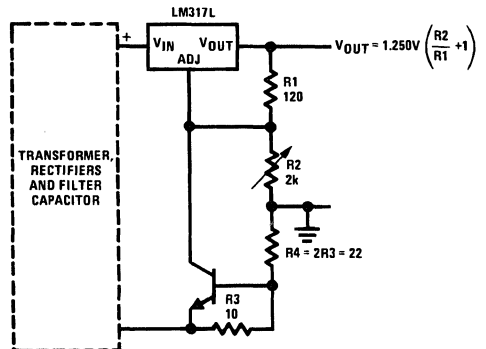
*Discharges C1 if output is shorted to ground

High Stability 10V Regulator



TL/H/9064-17

Adjustable Regulator with Current Limiter



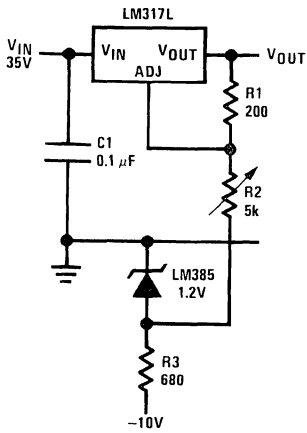
TL/H/9064-18

Short circuit current is approximately 600 mV/R3, or 60 mA (compared to LM317LZ's 200 mA current limit).

At 25 mA output only 3/4V of drop occurs in R3 and R4.

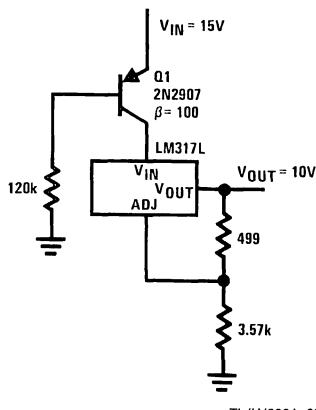
Typical Applications (Continued)

0V–30V Regulator



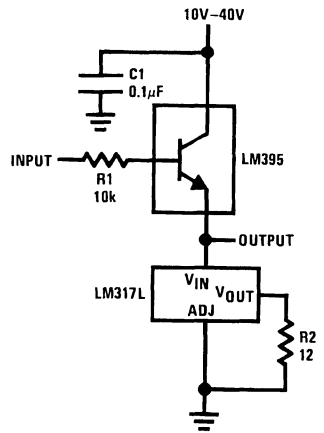
TL/H/9064–19

Regulator With 15 mA Short Circuit Current



TL/H/9064–20

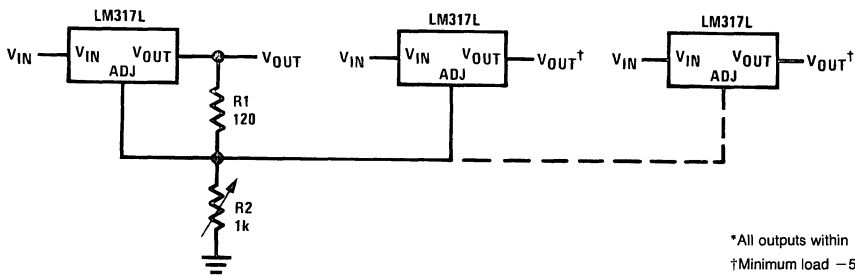
Power Follower



TL/H/9064–21

Full output current not available at high input-output voltages

Adjusting Multiple On-Card Regulators with Single Control*

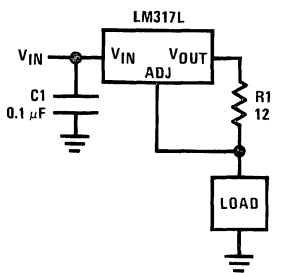


*All outputs within ± 100 mV

†Minimum load -5 mA

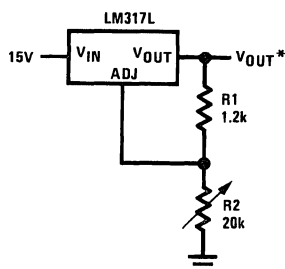
TL/H/9064–22

100 mA Current Regulator



TL/H/9064–23

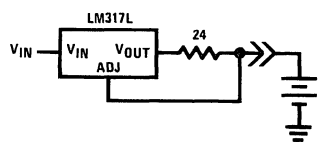
1.2V–12V Regulator with Minimum Program Current



*Minimum load current ≈ 2 mA

TL/H/9064–24

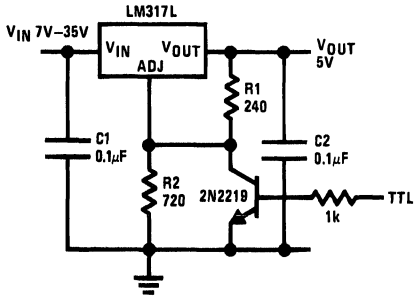
50 mA Constant Current Battery Charger for Nickel-Cadmium Batteries



TL/H/9064–25

Typical Applications (Continued)

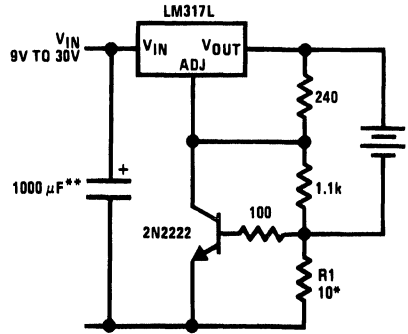
5V Logic Regulator with Electronic Shutdown*



TL/H/9064-26

*Minimum output $\approx 1.2V$

Current Limited 6V Charger

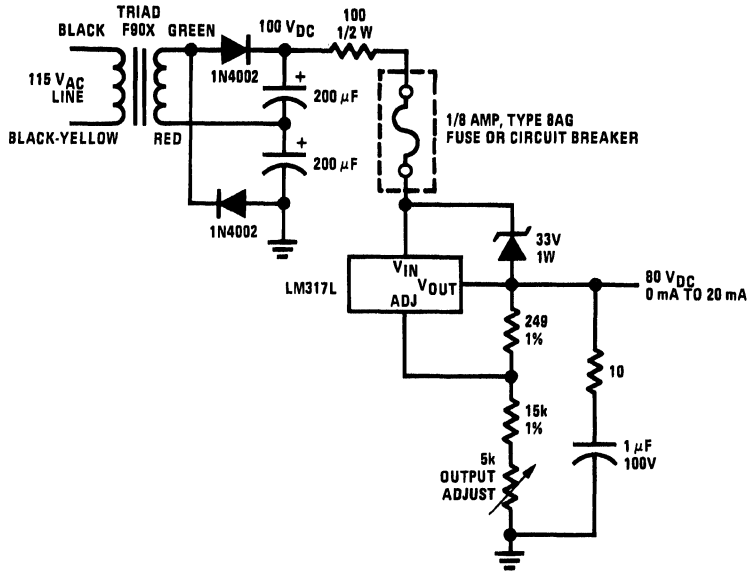


TL/H/9064-27

*Sets peak current, $I_{PEAK} = 0.6V/R1$

**1000 μF is recommended to filter out any input transients.

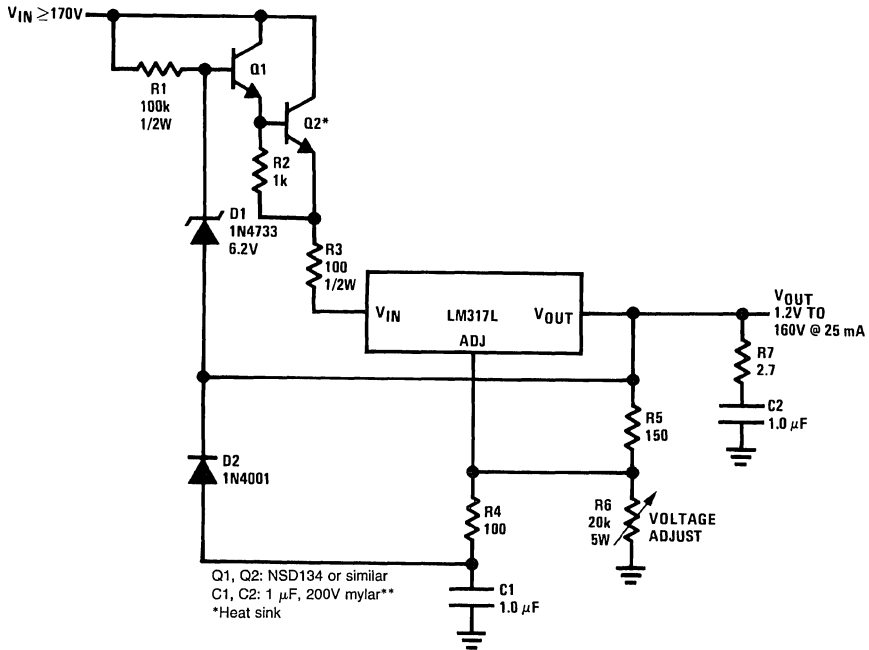
Short Circuit Protected 80V Supply



TL/H/9064-28

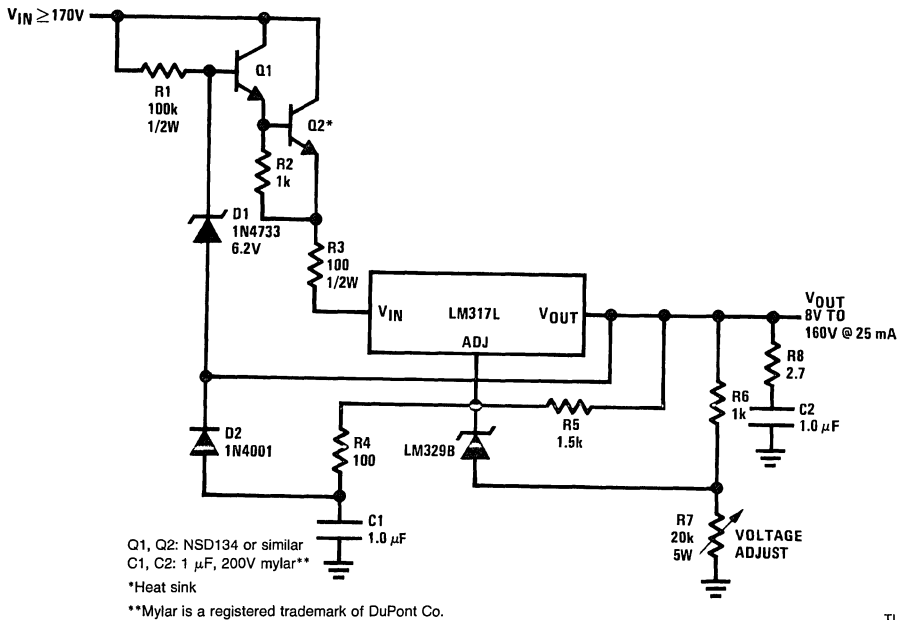
Typical Applications (Continued)

Basic High Voltage Regulator



TL/H/9064-29

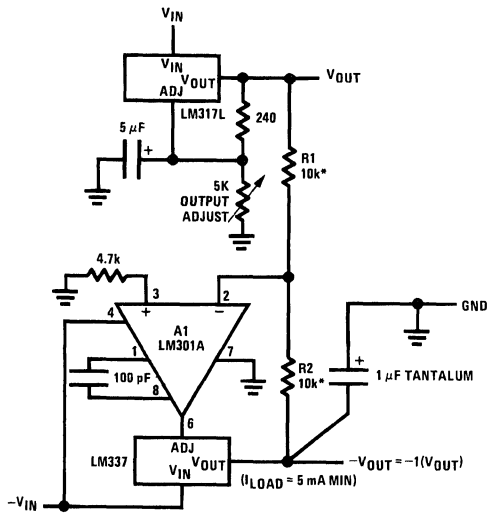
Precision High Voltage Regulator



TL/H/9064-30

Typical Applications (Continued)

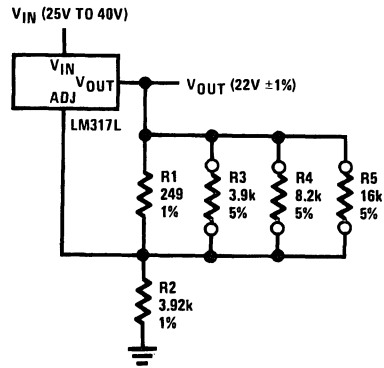
Tracking Regulator



TL/H/9064-31

A1 = LM301A, LM307, or LF13741 only
 R1, R2 = matched resistors with good TC tracking

Regulator With Trimmable Output Voltage



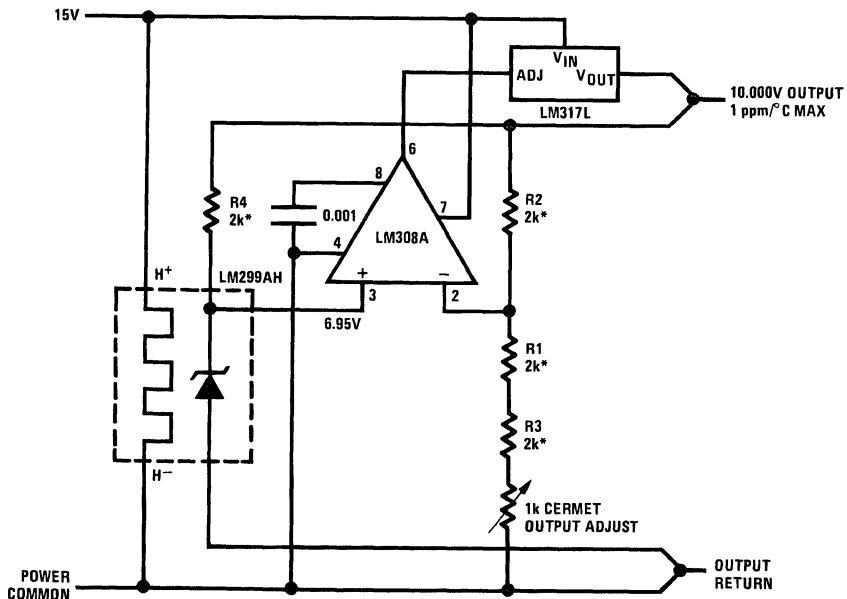
TL/H/9064-32

Trim Procedure:

- If V_{OUT} is 23.08V or higher, cut out R3 (if lower, don't cut it out).
- Then if V_{OUT} is 22.47V or higher, cut out R4 (if lower, don't).
- Then if V_{OUT} is 22.16V or higher, cut out R5 (if lower, don't).

This will trim the output to well within $\pm 1\%$ of 22.00 V_{DC} , without any of the expense or uncertainty of a trim pot (see LB-46). Of course, this technique can be used at any output voltage level.

Precision Reference with Short-Circuit Proof Output



*R1-R4 from thin-film network, Beckman 694-3-R2K-D or similar

TL/H/9064-33

LM320L, LM79LXXAC Series 3-Terminal Negative Regulators

General Description

The LM320L/LM79LXXAC series of 3-terminal negative voltage regulators features fixed output voltages of $-5V$, $-12V$, and $-15V$ with output current capabilities in excess of 100 mA. These devices were designed using the latest computer techniques for optimizing the packaged IC thermal/electrical performance. The LM79LXXAC series, even when combined with a minimum output compensation capacitor of $0.1 \mu F$, exhibits an excellent transient response, a maximum line regulation of $0.07\% V_{O}/V$, and a maximum load regulation of $0.01\% V_{O}/mA$.

The LM320L/LM79LXXAC series also includes, as self-protection circuitry: safe operating area circuitry for output transistor power dissipation limiting, a temperature independent short circuit current limit for peak output current limiting, and a thermal shutdown circuit to prevent excessive junction temperature. Although designed primarily as fixed voltage regulators, these devices may be combined with simple external circuitry for boosted and/or adjustable voltages and currents. The LM79LXXAC series is available in the 3-lead TO-92 package, and SO-8; 8 lead package. The LM320L series is available in the 3-lead TO-92 package.

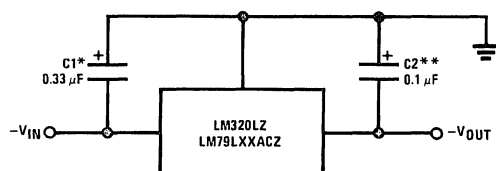
For output voltage other than $-5V$, $-12V$ and $-15V$ the LM137L series provides an output voltage range from 1.2V to 47V.

Features

- Preset output voltage error is less than $\pm 5\%$ overload, line and temperature
- Specified at an output current of 100 mA
- Easily compensated with a small $0.1 \mu F$ output capacitor
- Internal short-circuit, thermal and safe operating area protection
- Easily adjustable to higher output voltages
- Maximum line regulation less than $0.07\% V_{O}/V$
- Maximum load regulation less than $0.01\% V_{O}/mA$

Typical Applications

Fixed Output Regulator

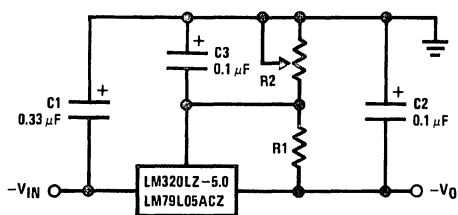


TL/H/7748-1

*Required if the regulator is located far from the power supply filter. A $1 \mu F$ aluminum electrolytic may be substituted.

**Required for stability. A $1 \mu F$ aluminum electrolytic may be substituted.

Adjustable Output Regulator



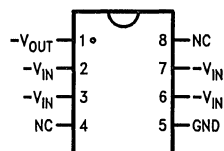
TL/H/7748-3

$$-V_O = -5V - (5V/R1 + I_O) \cdot R2,$$

$$5V/R1 > 3I_O$$

Connection Diagrams

SO-8 Plastic (Narrow Body)

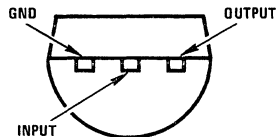


TL/H/7748-4

Top View

Order Number LM79L05ACM,
LM79L12ACM or LM79L15ACM
See NS Package Number M08A

TO-92 Plastic Package (Z)



TL/H/7748-2

Bottom View

Order Number LM320LZ-5.0, LM79L05ACZ,
LM320LZ-12, LM79L12ACZ, LM320LZ-15 or
LM79L15ACZ
See NS Package Number Z03A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage
 $V_O = -5V, -12V, -15V$ -35V
 Internal Power Dissipation (Note 1) Internally Limited

Operating Temperature Range 0°C to +70°C
 Maximum Junction Temperature +125°C
 Storage Temperature Range -55°C to +150°C
 Lead Temperature (Soldering, 10 sec.) 260°C

Electrical Characteristics (Note 2) $T_A = 0^\circ\text{C}$ to $+70^\circ\text{C}$ unless otherwise noted.

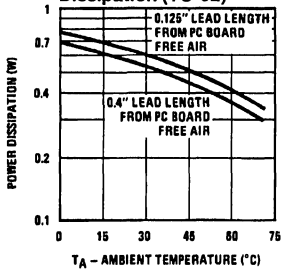
Output Voltage		-5V			-12V			-15V			Units				
Input Voltage (unless otherwise noted)		-10V			-17V			-20V							
Symbol	Parameter	Conditions			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max		
V_O	Output Voltage	$T_j = 25^\circ\text{C}, I_O = 100\text{ mA}$			-5.2	-5	-4.8	-12.5	-12	-11.5	-15.6	-15	-14.4	V	
		$1\text{ mA} \leq I_O \leq 100\text{ mA}$			-5.25		-4.75	-12.6		-11.4	-15.75		-14.25		
		$V_{MIN} \leq V_{IN} \leq V_{MAX}$			(-20 $\leq V_{IN} \leq -7.5$)			(-27 $\leq V_{IN} \leq -14.8$)			(-30 $\leq V_{IN} \leq -18$)				
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			-5.25		-4.75	-12.6	-11.4	-15.75		-14.25			
$V_{MIN} \leq V_{IN} \leq V_{MAX}$			(-20 $\leq V_{IN} \leq -7$)			(-27 $\leq V_{IN} \leq -14.5$)			(-30 $\leq V_{IN} \leq -17.5$)						
ΔV_O	Line Regulation	$T_j = 25^\circ\text{C}, I_O = 100\text{ mA}$					60			45			45	mV	
		$V_{MIN} \leq V_{IN} \leq V_{MAX}$			(-20 $\leq V_{IN} \leq -7.3$)			(-27 $\leq V_{IN} \leq -14.6$)			(-30 $\leq V_{IN} \leq -17.7$)			V	
ΔV_O	Load Regulation	$T_j = 25^\circ\text{C}$					60			45			45	mV	
		$1\text{ mA} \leq I_O \leq 100\text{ mA}$			(-20 $\leq V_{IN} \leq -7$)			(-27 $\leq V_{IN} \leq -14.5$)			(-30 $\leq V_{IN} \leq -17.5$)			V	
ΔV_O	Long Term Stability	$I_O = 100\text{ mA}$					20			48			60	mV/khrs	
I_Q	Quiescent Current	$I_O = 100\text{ mA}$					2			6			2	6	mA
ΔI_Q	Quiescent Current Change	$1\text{ mA} \leq I_O \leq 100\text{ mA}$					0.3			0.3			0.3	mA	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$					0.1			0.1			0.1		
		$I_O = 100\text{ mA}$					0.25			0.25			0.25	mA	
		$V_{MIN} \leq V_{IN} \leq V_{MAX}$			(-20 $\leq V_{IN} \leq -7.5$)			(-27 $\leq V_{IN} \leq -14.8$)			(-30 $\leq V_{IN} \leq -18$)			V	
V_n	Output Noise Voltage	$T_j = 25^\circ\text{C}, I_O = 100\text{ mA}$ $f = 10\text{ Hz} - 10\text{ kHz}$					40			96			120	μV	
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	$T_j = 25^\circ\text{C}, I_O = 100\text{ mA}$ $f = 120\text{ Hz}$					50			52			50	dB	
	Input Voltage Required to Maintain Line Regulation	$T_j = 25^\circ\text{C}, I_O = 100\text{ mA}$					-7.3			-14.6			-17.7	V	
		$I_O = 40\text{ mA}$					-7.0			-14.5			-17.5	V	

Note 1: Thermal resistance of Z package is 60°C/W θ_{JC} , 232°C/W θ_{JA} at still air, and 88°C/W at 400 ft/min of air. The M package θ_{JA} is 180°C/W in still air. The maximum junction temperature shall not exceed 125°C on electrical parameters.

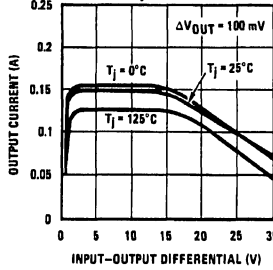
Note 2: To ensure constant junction temperature, low duty cycle pulse testing is used.

Typical Performance Characteristics

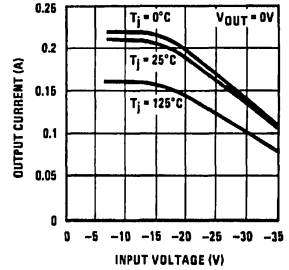
Maximum Average Power Dissipation (TO-92)



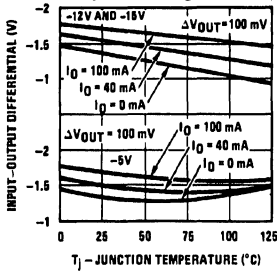
Peak Output Current



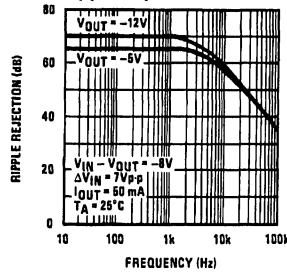
Short Circuit Output Current



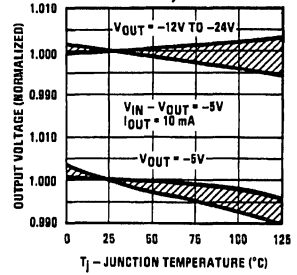
Dropout Voltage



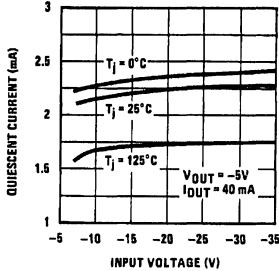
Ripple Rejection



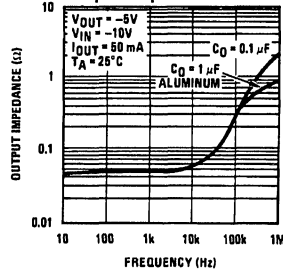
Output Voltage vs. Temperature (Normalized to 1V @ 25°C)



Quiescent Current



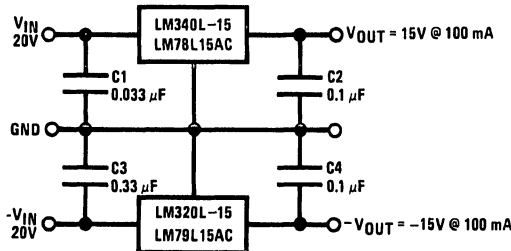
Output Impedance



TL/H/7748-5

Typical Applications (Continued)

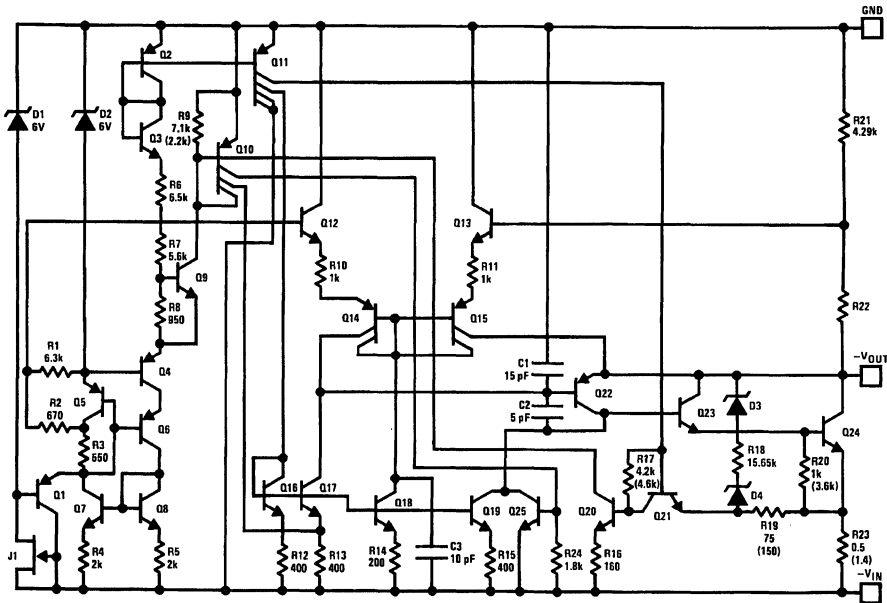
± 15V, 100 mA Dual Power Supply



TL/H/7748-6

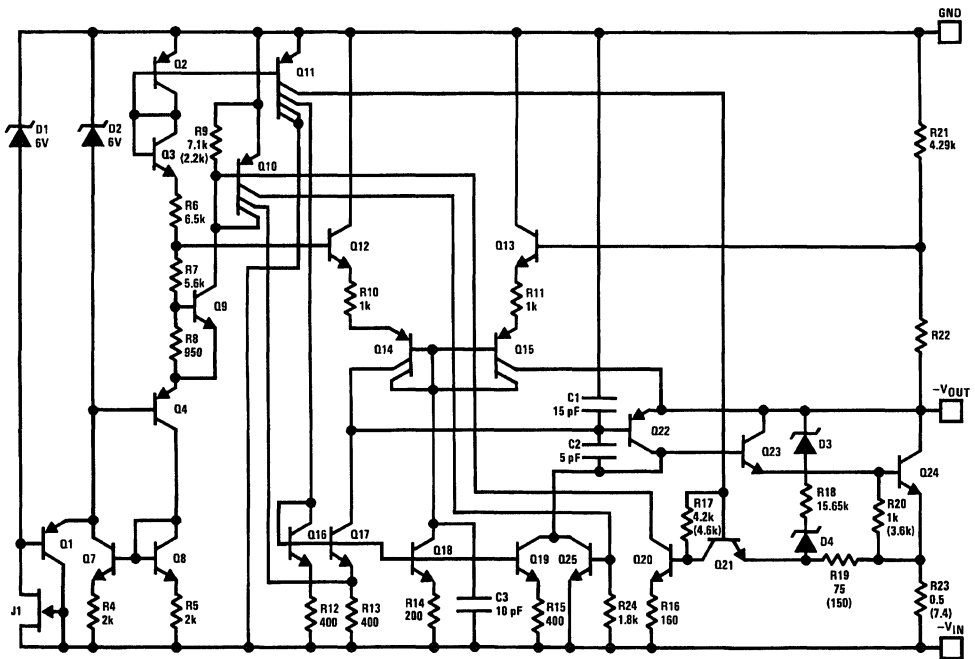
Schematic Diagrams

-5V



TL/H/7748-9

-12V and -15V



TL/H/7748-10

LM337L 3-Terminal Adjustable Regulator

General Description

The LM337L is an adjustable 3-terminal negative voltage regulator capable of supplying 100 mA over a 1.2V to 37V output range. It is exceptionally easy to use and requires only two external resistors to set the output voltage. Furthermore, both line and load regulation are better than standard fixed regulators. Also, the LM337L is packaged in a standard TO-92 transistor package which is easy to use.

In addition to higher performance than fixed regulators, the LM337L offers full overload protection. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, only a single 1 μ F solid tantalum output capacitor is needed unless the device is situated more than 6 inches from the input filter capacitors, in which case an input bypass is needed. A larger output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM337L is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input-to-output differential is not exceeded.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM337L can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

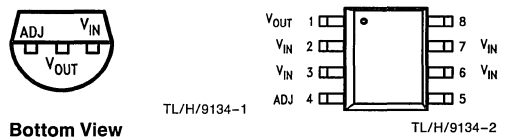
The LM337L is available in a standard TO-92 transistor package and a SO-8 surface mount package. The LM337L is rated for operation over a -25°C to $+125^{\circ}\text{C}$ range.

For applications requiring greater output current in excess of 0.5A and 1.5A, see LM137 series data sheets. For the positive complement, see series LM117 and LM317L data sheets.

Features

- Adjustable output down to 1.2V
- Guaranteed 100 mA output current
- Line regulation typically 0.01%/V
- Load regulation typically 0.1%
- Current limit constant with temperature
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Output is short circuit protected

Connection Diagram



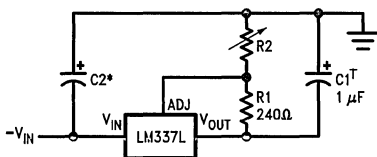
Bottom View

Top View

Order Number LM337LM or LM337LZ
See NS Package Number M08A or Z03A

Typical Applications

1.2V-25V Adjustable Regulator



TL/H/9134-3

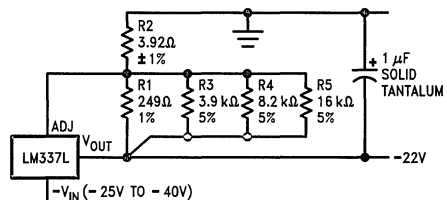
Full output current not available at high input-output voltages

$$-V_{OUT} = -1.25V \left(1 + \frac{R2}{240\Omega} \right)$$

†C1 = 1 μ F solid tantalum or 10 μ F aluminum electrolytic required for stability

*C2 = 1 μ F solid tantalum is required only if regulator is more than 4" from power supply filter capacitor

Regulator with Trimmable Output Voltage



TL/H/9134-4

Trim Procedure:

- If V_{OUT} is -23.08V or bigger, cut out R3 (if smaller, don't cut it out).
- Then if V_{OUT} is -22.47V or bigger, cut out R4 (if smaller, don't).
- Then if V_{OUT} is -22.16V or bigger, cut out R5 (if smaller, don't).

This will trim the output to well within 1% of -22.00V_{DC} , without any of the expense or trouble of a trim pot (see LB-46). Of course, this technique can be used at any output voltage level.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation Internally Limited
Input–Output Voltage Differential 40V

Operating Junction Temperature Range -25°C to $+125^{\circ}\text{C}$
Storage Temperature -55°C to $+150^{\circ}\text{C}$
Lead Temperature (Soldering, 10 sec.) 300°C
Plastic Package (Soldering 4 sec.) 260°C
ESD rating to be determined.

Electrical Characteristics (Note 1)

Parameter	Conditions	Min	Typ	Max	Units
Line Regulation	$T_A = 25^{\circ}\text{C}$, $3\text{V} \leq V_{\text{IN}} - V_{\text{OUT}} \leq 40\text{V}$, (Note 2)		0.01	0.04	%/V
Load Regulation	$T_A = 25^{\circ}\text{C}$, $5\text{ mA} \leq I_{\text{OUT}} \leq I_{\text{MAX}}$, (Note 2)		0.1	0.5	%
Thermal Regulation	$T_A = 25^{\circ}\text{C}$, 10 ms Pulse		0.04	0.2	%/W
Adjustment Pin Current			50	100	μA
Adjustment Pin Current Change	$5\text{ mA} \leq I_L \leq 100\text{ mA}$ $3\text{V} \leq V_{\text{IN}} - V_{\text{OUT}} \leq 40\text{V}$		0.2	5	μA
Reference Voltage	$3\text{V} \leq V_{\text{IN}} - V_{\text{OUT}} \leq 40\text{V}$, (Note 3) $10\text{ mA} \leq I_{\text{OUT}} \leq 100\text{ mA}$, $P \leq 625\text{ mW}$	1.20	1.25	1.30	V
Line Regulation	$3\text{V} \leq V_{\text{IN}} - V_{\text{OUT}} \leq 40\text{V}$, (Note 2)		0.02	0.07	%/V
Load Regulation	$5\text{ mA} \leq I_{\text{OUT}} \leq 100\text{ mA}$, (Note 2)		0.3	1.5	%
Temperature Stability	$T_{\text{MIN}} \leq T_J \leq T_{\text{MAX}}$		0.65		%
Minimum Load Current	$ V_{\text{IN}} - V_{\text{OUT}} \leq 40\text{V}$ $3\text{V} \leq V_{\text{IN}} - V_{\text{OUT}} \leq 15\text{V}$		3.5 2.2	5 3.5	 mA mA
Current Limit	$3\text{V} \leq V_{\text{IN}} - V_{\text{OUT}} \leq 13\text{V}$ $ V_{\text{IN}} - V_{\text{OUT}} = 40\text{V}$	100 25	200 50	320 120	 mA mA
Rms Output Noise, % of V_{OUT}	$T_A = 25^{\circ}\text{C}$, $10\text{ Hz} \leq f \leq 10\text{ kHz}$		0.003		%
Ripple Rejection Ratio	$V_{\text{OUT}} = -10\text{V}$, $F = 120\text{ Hz}$, $C_{\text{ADJ}} = 0$ $C_{\text{ADJ}} = 10\ \mu\text{F}$	66	65 80		 dB dB
Long-Term Stability	$T_A = 125^{\circ}\text{C}$		0.3	1	%

Note 1: Unless otherwise specified, these specifications apply $-25^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$ for the LM337L; $|V_{\text{IN}} - V_{\text{OUT}}| = 5\text{V}$ and $I_{\text{OUT}} = 40\text{ mA}$. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 625 mW. I_{MAX} is 100 mA.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

Note 3: Thermal resistance of the TO-92 package is $180^{\circ}\text{C}/\text{W}$ junction to ambient with 0.4" leads from a PC board and $160^{\circ}\text{C}/\text{W}$ junction to ambient with 0.125" lead length to PC board. The M package θ_{JA} is $180^{\circ}\text{C}/\text{W}$ in still air.

LM341, LM78MXX Series

3-Terminal Positive Voltage Regulators

General Description

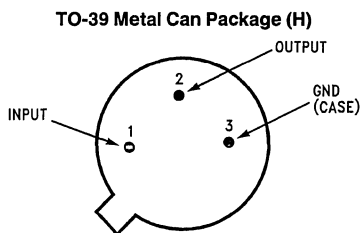
The LM341 and LM78MXX series of three-terminal positive voltage regulators employ built-in current limiting, thermal shutdown, and safe-operating area protection which makes them virtually immune to damage from output overloads.

With adequate heatsinking, they can deliver in excess of 0.5A output current. Typical applications would include local (on-card) regulators which can eliminate the noise and degraded performance associated with single-point regulation.

Features

- Output current in excess of 0.5A
- No external components
- Internal thermal overload protection
- Internal short circuit current-limiting
- Output transistor safe-area compensation
- Available in TO-220, TO-39 and TO-202 packages
- Output voltages of 5V, 6V, 8V, 12V, 15V, and 24V

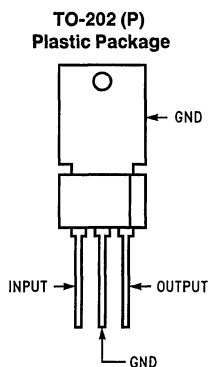
Connection Diagrams



TL/H/10484-5

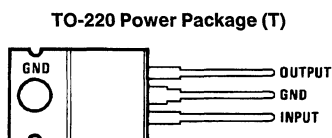
Bottom View

Order Number LM78M05CH, LM78M06CH, LM78M08CH,
 LM78M12CH, LM78M15CH or LM78M24CH
 See NS Package Number H03B



TL/H/10484-2

Order Number LM341P-5.0, LM341P-12 or LM341P-15
 See NS Package Number P03A



TL/H/10484-6

Top View

Order Number LM78M05CT, LM78M06CT, LM78M08CT,
 LM78M12CT, LM78M15CT, LM78M24CT,
 LM341T-5.0, LM341T-12 or LM341T-15
 See NS Package Number T03B

DUAL MARKING: The LM341T-5.0 and the LM78M05CT parts are "dual marked" (these parts are marked with both part numbers) because they have the same specifications. The same is true for the LM341T-12/LM78M12CT and the LM341T-15/LM78M15CT part number sets.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Lead Temperature (Soldering, 10 seconds)

TO-39 Package (H)	300°C
TO-220 Package (T)	260°C
TO-202 Package (P)	230°C

Storage Temperature Range	-65°C to +150°C
Operating Junction Temperature Range	-40°C to +125°C
Power Dissipation (Note 2)	Internally Limited
Input Voltage	
5V ≤ V _O ≤ 15V	35V
V _O = 24V	40V
ESD Susceptibility	TBD

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the -40°C to +125°C operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods.

LM341-5.0, LM78M05C Unless otherwise specified: V_{IN} = 10V, C_{IN} = 0.33 μF, C_O = 0.1 μF

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V _O	Output Voltage	I _L = 500 mA	4.8	5.0	5.2	V
		5 mA ≤ I _L ≤ 500 mA P _D ≤ 7.5W, 7.5V ≤ V _{IN} ≤ 20V	4.75	5.0	5.25	
V _{R LINE}	Line Regulation	7.2V ≤ V _{IN} ≤ 25V	I _L = 100 mA		50	mV
			I _L = 500 mA		100	
V _{R LOAD}	Load Regulation	5 mA ≤ I _L ≤ 500 mA			100	
I _Q	Quiescent Current	I _L = 500 mA		4	10.0	mA
ΔI _Q	Quiescent Current Change	5 mA ≤ I _L ≤ 500 mA			0.5	
		7.5V ≤ V _{IN} ≤ 25V, I _L = 500 mA			1.0	
V _n	Output Noise Voltage	f = 10 Hz to 100 kHz		40		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, I _L = 500 mA		78		dB
V _{IN}	Input Voltage Required to Maintain Line Regulation	I _L = 500 mA	7.2			V
ΔV _O	Long Term Stability	I _L = 500 mA			20	mV/khrs

Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, and limits in **boldface type** apply over the -40°C to $+125^\circ\text{C}$ operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. (Continued)

LM78M06C Unless otherwise specified: $V_{IN} = 11\text{V}$, $C_{IN} = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 350\ \text{mA}$	5.75	6.0	6.25	V
		$5\ \text{mA} \leq I_L \leq 350\ \text{mA}$ $8\text{V} \leq V_{IN} \leq 21\text{V}$	5.7	6.0	6.3	
$V_{R\ \text{LINE}}$	Line Regulation	$9\text{V} \leq V_{IN} \leq 20\text{V}$, $I_L = 200\ \text{mA}$		1.5	50	mV
		$8\text{V} \leq V_{IN} \leq 25\text{V}$, $I_L = 200\ \text{mA}$		5	100	
$V_{R\ \text{LOAD}}$	Load Regulation	$5\ \text{mA} \leq I_L \leq 200\ \text{mA}$		10	60	mV
		$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$		20	120	
I_Q	Quiescent Current	$I_L = 350\ \text{mA}$		4.5	8.0	mA
ΔI_Q	Quiescent Current Change	$5\ \text{mA} \leq I_L \leq 350\ \text{mA}$			0.5	
		$9\text{V} \leq V_{IN} \leq 25\text{V}$, $I_L = 200\ \text{mA}$			0.8	
V_n	Output Noise Voltage	$f = 10\ \text{Hz to } 100\ \text{kHz}$		45		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	$f = 2400\ \text{Hz}$, $I_L = 125\ \text{mA}$	59	80		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 350\ \text{mA}$		$V_O + 2$		V
I_{OS}	Output Short Circuit Current	$V_{IN} = 35\text{V}$		270		mA
I_{PK}	Output Peak Current			700		
$\frac{\Delta V_O}{\Delta T}$	Average Temperature Coefficient of Output Voltage	$I_L = 5\ \text{mA}$		0.5		mV/ $^\circ\text{C}$

Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, and limits in **boldface type** apply over the -40°C to $+125^\circ\text{C}$ operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. (Continued)

LM78M08C Unless otherwise specified: $V_{IN} = 14\text{V}$, $C_{IN} = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 350\ \text{mA}$	7.7	8.0	8.3	V
		$5\ \text{mA} \leq I_L \leq 350\ \text{mA}$ $10.5\ \text{V} \leq V_{IN} \leq 23\ \text{V}$	7.6	8.0	8.4	
$V_{R\ \text{LINE}}$	Line Regulation	$11\ \text{V} \leq V_{IN} \leq 20\ \text{V}$, $I_L = 200\ \text{mA}$		2	50	mV
		$10.5\ \text{V} \leq V_{IN} \leq 25\ \text{V}$, $I_L = 200\ \text{mA}$		6	100	
$V_{R\ \text{LOAD}}$	Load Regulation	$5\ \text{mA} \leq I_L \leq 200\ \text{mA}$		10	80	
		$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$		25	160	
I_Q	Quiescent Current	$I_L = 350\ \text{mA}$		4.6	8.0	mA
ΔI_Q	Quiescent Current Change	$5\ \text{mA} \leq I_L \leq 350\ \text{mA}$			0.5	
		$10.5\ \text{V} \leq V_{IN} \leq 25\ \text{V}$, $I_L = 200\ \text{mA}$			0.8	
V_n	Output Noise Voltage	$f = 10\ \text{Hz to } 100\ \text{kHz}$		52		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	$f = 2400\ \text{Hz}$, $I_L = 125\ \text{mA}$	56	80		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 350\ \text{mA}$		$V_O + 2$		V
I_{OS}	Output Short Circuit Current	$V_{IN} = 35\ \text{V}$		250		mA
I_{PK}	Output Peak Current			700		
$\frac{\Delta V_O}{\Delta T}$	Average Temperature Coefficient of Output Voltage	$I_L = 5\ \text{mA}$		0.5		mV/ $^\circ\text{C}$

Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, and limits in **boldface type** apply over the -40°C to $+125^\circ\text{C}$ operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. (Continued)

LM341-12, LM78M12C Unless otherwise specified: $V_{IN} = 19\text{V}$, $C_{IN} = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 500\ \text{mA}$	11.5	12	12.5	V
		$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$ $P_D \leq 7.5\text{W}$, $14.8\text{V} \leq V_{IN} \leq 27\text{V}$	11.4	12	12.6	
$V_{R\ \text{LINE}}$	Line Regulation	$14.5\text{V} \leq V_{IN} \leq 30\text{V}$	$I_L = 100\ \text{mA}$		120	mV
			$I_L = 500\ \text{mA}$		240	
$V_{R\ \text{LOAD}}$	Load Regulation	$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$			240	
I_Q	Quiescent Current	$I_L = 500\ \text{mA}$		4	10.0	mA
ΔI_Q	Quiescent Current Change	$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$			0.5	
		$14.8\text{V} \leq V_{IN} \leq 30\text{V}$, $I_L = 500\ \text{mA}$			1.0	
V_n	Output Noise Voltage	$f = 10\ \text{Hz to } 100\ \text{kHz}$		75		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	$f = 120\ \text{Hz}$, $I_L = 500\ \text{mA}$		71		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 500\ \text{mA}$	14.5			V
ΔV_O	Long Term Stability	$I_L = 500\ \text{mA}$			48	mV/khrs

LM341-15, LM78M15C Unless otherwise specified: $V_{IN} = 23\text{V}$, $C_{IN} = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 500\ \text{mA}$	14.4	15	15.6	V
		$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$ $P_D \leq 7.5\text{W}$, $18\text{V} \leq V_{IN} \leq 30\text{V}$	14.25	15	15.75	
$V_{R\ \text{LINE}}$	Line Regulation	$17.6\text{V} \leq V_{IN} \leq 30\text{V}$	$I_L = 100\ \text{mA}$		150	mV
			$I_L = 500\ \text{mA}$		300	
$V_{R\ \text{LOAD}}$	Load Regulation	$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$			300	
I_Q	Quiescent Current	$I_L = 500\ \text{mA}$		4	10.0	mA
ΔI_Q	Quiescent Current Change	$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$			0.5	
		$18\text{V} \leq V_{IN} \leq 30\text{V}$, $I_L = 500\ \text{mA}$			1.0	
V_n	Output Noise Voltage	$f = 10\ \text{Hz to } 100\ \text{kHz}$		90		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	$f = 120\ \text{Hz}$, $I_L = 500\ \text{mA}$		69		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 500\ \text{mA}$	17.6			V
ΔV_O	Long Term Stability	$I_L = 500\ \text{mA}$			60	mV/khrs

Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, and limits in **boldface type** apply over the -40°C to $+125^\circ\text{C}$ operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. (Continued)

LM78M24C Unless otherwise specified: $V_{IN} = 33\text{V}$, $C_{IN} = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 350\ \text{mA}$	23.0	24.0	25.0	V
		$5\ \text{mA} \leq I_L \leq 350\ \text{mA}$ $27\text{V} \leq V_{IN} \leq 38\text{V}$	22.8	24.0	25.2	
$V_{R\ \text{LINE}}$	Line Regulation	$28\text{V} \leq V_{IN} \leq 36\text{V}$, $I_L = 200\ \text{mA}$		5	50	mV
		$27\text{V} \leq V_{IN} \leq 38\text{V}$, $I_L = 200\ \text{mA}$		10	100	
$V_{R\ \text{LOAD}}$	Load Regulation	$5\ \text{mA} \leq I_L \leq 200\ \text{mA}$		10	240	
		$5\ \text{mA} \leq I_L \leq 500\ \text{mA}$		30	480	
I_Q	Quiescent Current	$I_L = 350\ \text{mA}$		5.0	8.0	mA
ΔI_Q	Quiescent Current Change	$5\ \text{mA} \leq I_L \leq 350\ \text{mA}$			0.5	
		$27\text{V} \leq V_{IN} \leq 38\text{V}$, $I_L = 200\ \text{mA}$			0.8	
V_n	Output Noise Voltage	$f = 10\ \text{Hz to } 100\ \text{kHz}$		170		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	$f = 2400\ \text{Hz}$, $I_L = 125\ \text{mA}$, $V_{IN} = 30\text{V}$	50	70		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 350\ \text{mA}$		$V_O + 2$		V
I_{OS}	Output Short Circuit Current	$V_{IN} = 35\text{V}$		240		mA
I_{PK}	Output Peak Current			700		
$\frac{\Delta V_O}{\Delta T}$	Average Temperature Coefficient of Output Voltage	$I_L = 5\ \text{mA}$		1.2		mV/ $^\circ\text{C}$

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

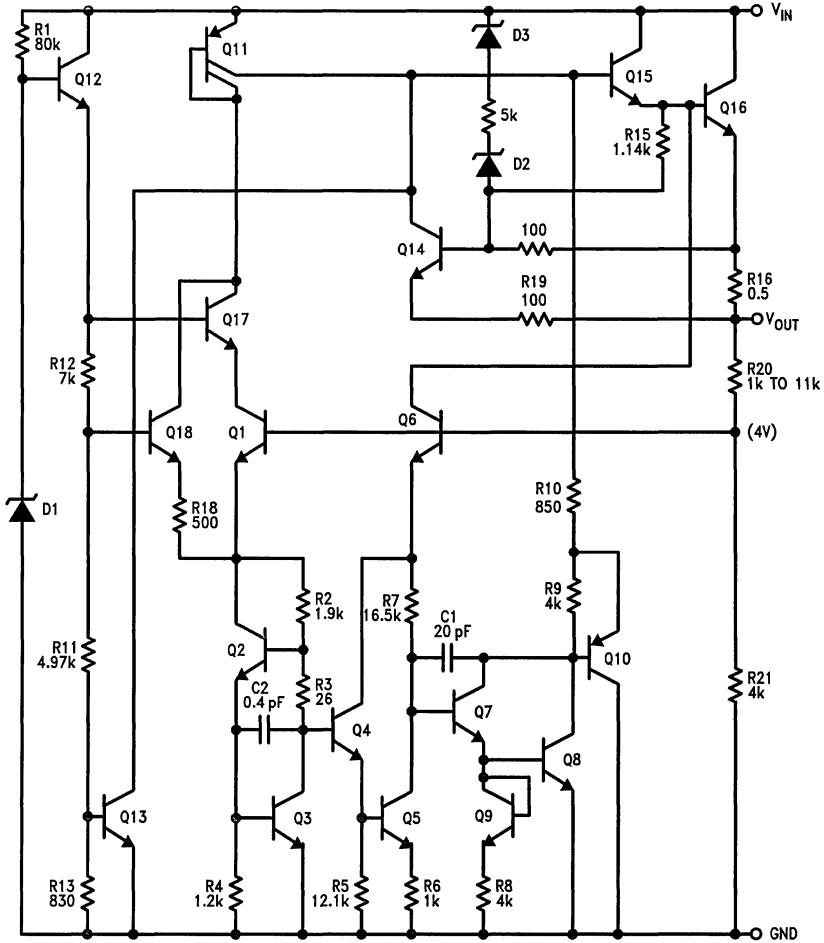
Note 2: The typical thermal resistance of the three package types is:

T (TO-220) package: $\theta_{(J-A)} = 60\ ^\circ\text{C}/\text{W}$, $\theta_{(J-C)} = 5\ ^\circ\text{C}/\text{W}$

P (TO-202) package: $\theta_{(J-A)} = 70\ ^\circ\text{C}/\text{W}$, $\theta_{(J-C)} = 12\ ^\circ\text{C}/\text{W}$

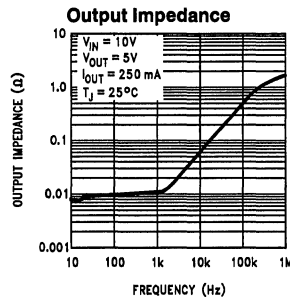
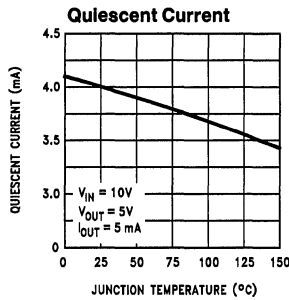
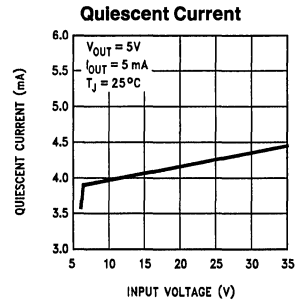
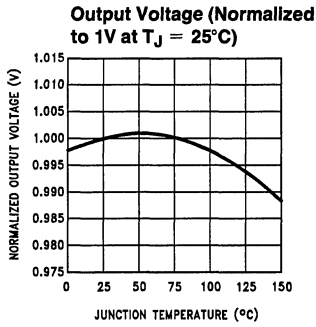
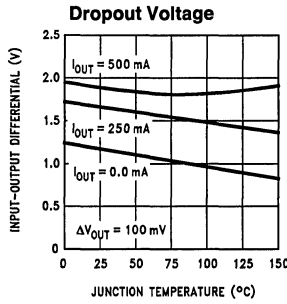
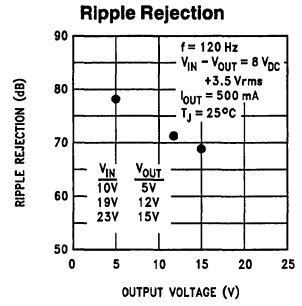
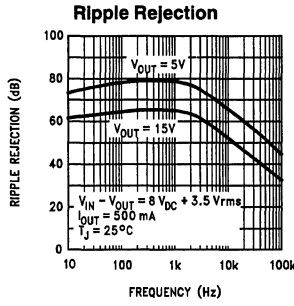
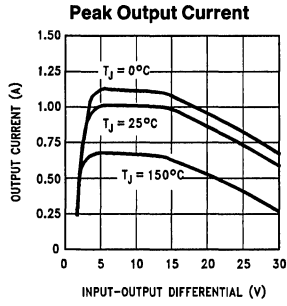
H (TO-39) package: $\theta_{(J-A)} = 120\ ^\circ\text{C}/\text{W}$, $\theta_{(J-C)} = 18\ ^\circ\text{C}/\text{W}$

Schematic Diagram



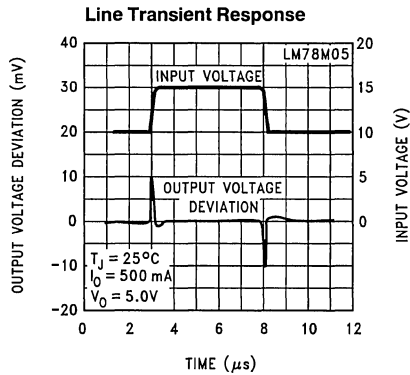
TL/H/10484-1

Typical Performance Characteristics

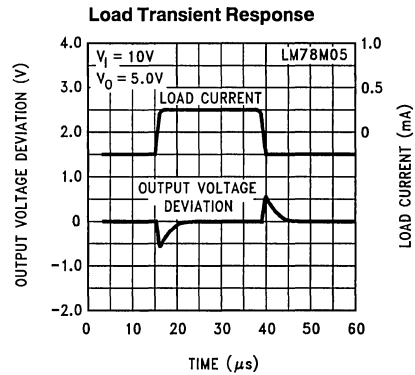


TL/H/10484-4

Typical Performance Characteristics (Continued)



TL/H/10484-7



TL/H/10484-8

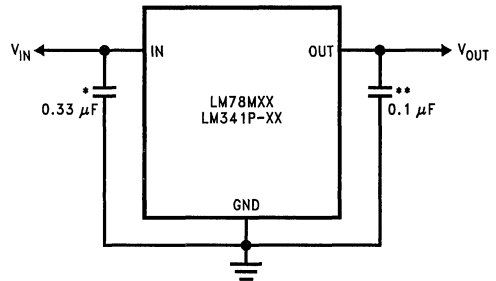
Design Considerations

The LM78MXX/LM341XX fixed voltage regulator series has built-in thermal overload protection which prevents the device from being damaged due to excessive junction temperature.

The regulators also contain internal short-circuit protection which limits the maximum output current, and safe-area protection for the pass transistor which reduces the short-circuit current as the voltage across the pass transistor is increased.

Although the internal power dissipation is automatically limited, the maximum junction temperature of the device must be kept below $+125^\circ\text{C}$ in order to meet data sheet specifications. An adequate heatsink should be provided to assure this limit is not exceeded under worst-case operating conditions (maximum input voltage and load current) if reliable performance is to be obtained.

Typical Application



TL/H/10484-9

*Required if regulator input is more than 4 inches from input filter capacitor (or if no input filter capacitor is used).

**Optional for improved transient response.



LM342 Series 3-Terminal Positive Regulators

General Description

The LM342-XX series of three-terminal regulators is available with several fixed output voltages, making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM342-XX series is available in the plastic TO-202 package. This package allows these regulators to deliver over 0.25A if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over, preventing the IC from overheating.

Considerable effort was expended to make the LM342-XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the

output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

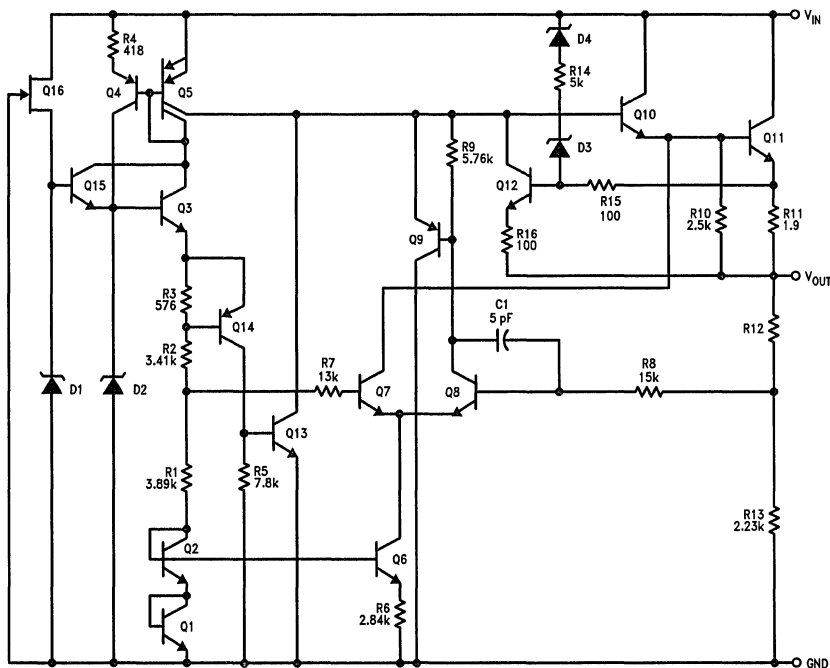
Features

- Output current in excess of 0.25A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-202 package
- Special circuitry allows start-up even if output is pulled to negative voltage (\pm supplies)

Voltage Range

LM342-5.0	5V
LM342-12	12V
LM342-15	15V

Schematic Diagram



TL/H/10485-1

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
$V_O = 5V$	30V
$V_O = 12V$ and $15V$	35V
Internal Power Dissipation	Internally Limited
Operating Temperature Range	0°C to +70°C

Maximum Junction Temperature	125°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C
ESD Susceptibility	TBD

Electrical Characteristics $T_A = 0^\circ\text{C}$ to $+70^\circ\text{C}$, $I_O = 250$ mA (Note 2) unless noted

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Min	Min	Typ	Max	
V_O	Output Voltage (Note 3)	$T_J = 25^\circ\text{C}$	4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		$1\text{ mA} \leq I_O \leq 250\text{ mA}$ and $V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$	4.75		5.25	11.4		12.6	14.25		15.75	V
ΔV_O	Line Regulation	$T_J = 25^\circ\text{C}$, $I_O = 250\text{ mA}$			55			100			100	mV
					($7.3 \leq V_{\text{IN}} \leq 25$)			($14.6 \leq V_{\text{IN}} \leq 30$)			($17.7 \leq V_{\text{IN}} \leq 30$)	
ΔV_O	Load Regulation	$T_J = 25^\circ\text{C}$, $1\text{ mA} \leq I_O \leq 250\text{ mA}$			50			120			150	mV
ΔV_O	Long Term Stability				20			48			60	mV/khrs
I_Q	Quiescent Current	$T_J = 25^\circ\text{C}$			6			6			6	mA
ΔI_Q	Quiescent Current Change	$T_J = 25^\circ\text{C}$, $1\text{ mA} \leq I_O \leq 250\text{ mA}$			0.5			0.5			0.5	mA
		$T_J = 25^\circ\text{C}$, $V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}}$			1.5			1.5			1.5	mA
					($7.3 \leq V_{\text{IN}} \leq 25$)			($14.6 \leq V_{\text{IN}} \leq 30$)			($17.7 \leq V_{\text{IN}} \leq 30$)	
V_n	Output Noise Voltage	$T_J = 25^\circ\text{C}$, $f = 10\text{ Hz} - 10\text{ kHz}$			40			96			120	μV
$\frac{\Delta V_{\text{IN}}}{\Delta V_{\text{OUT}}}$	Ripple Rejection	$f = 120\text{ Hz}$	50	64		44	56		42	56		dB
	Input Voltage Required to Maintain Line Regulation	$T_J = 25^\circ\text{C}$, $I_O = 250\text{ mA}$	7.3			14.6			17.7			V
	Thermal Resistance Junction to Case	P Package			15			15			15	$^\circ\text{C}/\text{W}$
	Thermal Resistance Junction to Ambient	P Package			80			80			80	$^\circ\text{C}/\text{W}$

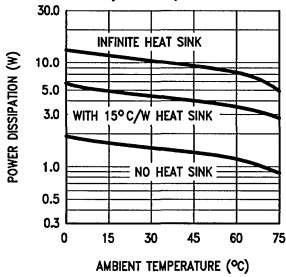
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: The electrical characteristics data represent pulse test conditions with junction temperatures as shown at the initiation of tests.

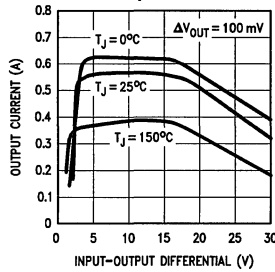
Note 3: The temperature coefficient of V_{OUT} is typically within 0.01% $V_O/^\circ\text{C}$.

Typical Performance Characteristics

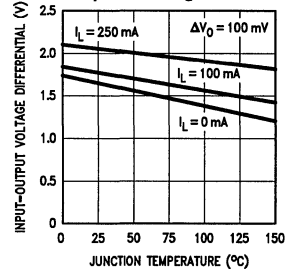
Maximum Average Power Dissipation (TO-202 Package)



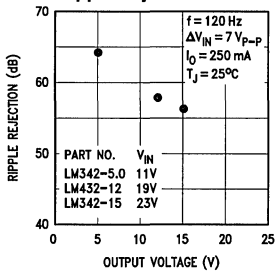
Peak Output Current



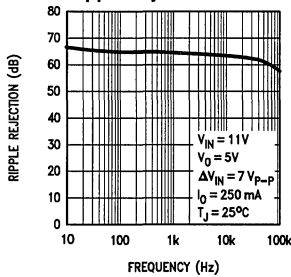
Dropout Voltage



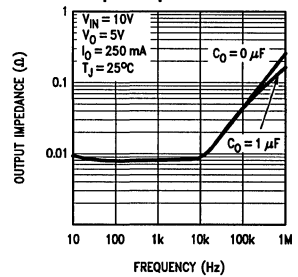
Ripple Rejection



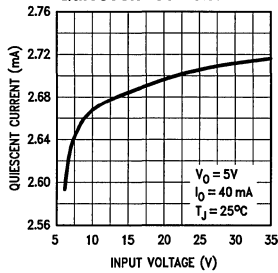
Ripple Rejection



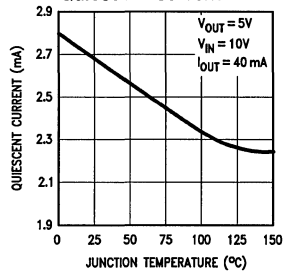
Output Impedance



Quiescent Current



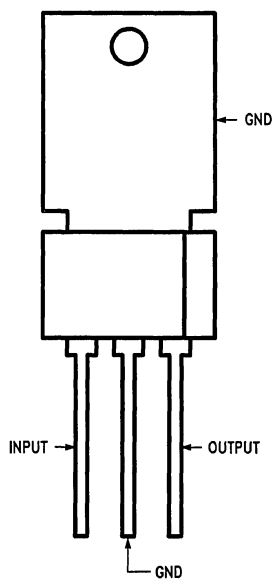
Quiescent Current



TL/H/10485-3

Connection Diagram

TO-202 (P) Plastic Package

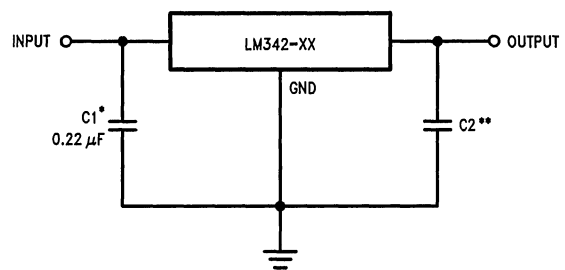


TL/H/10485-2

Order Number LM342P-5.0,
LM342P-12 or LM342P-15
See NS Package Number P03A

Typical Applications

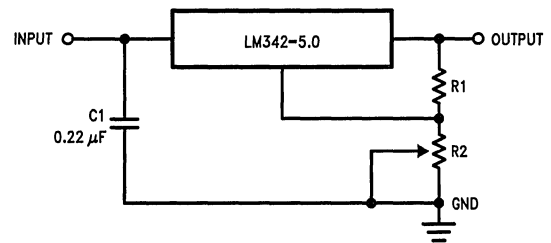
Fixed Output Regulator



TL/H/10485-4

*Required if the regulator is located far from power supply filter
**Although not required, C2 does improve transient response. (If needed, use 0.1 μF ceramic disc.)

Adjustable Output Regulator

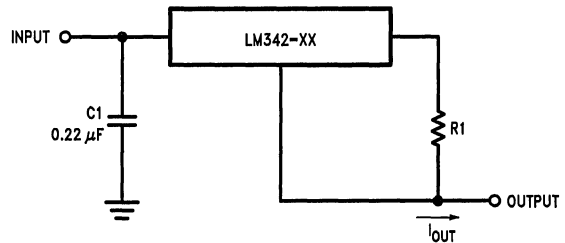


TL/H/10485-5

$$V_O = 5V + (5V/R1 + I_Q) R2$$

$$5V/R1 > 3I_Q, \text{ Load Regulation (L}_R\text{)} = [(R1 + R2)/R1] \times (L_r \text{ of LM342-05})$$

Current Regulator



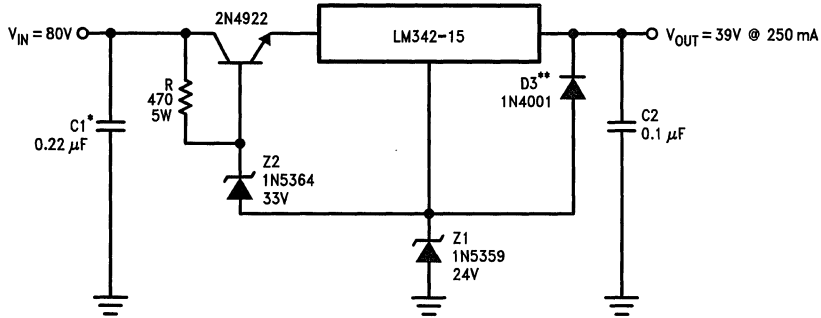
TL/H/10485-6

$$I_{OUT} = V_2^{-3}/R1 + I_Q$$

$$\Delta I_Q \leq 1.5 \text{ mA over line and load changes}$$

Typical Applications (Continued)

High Output Voltage Regulator

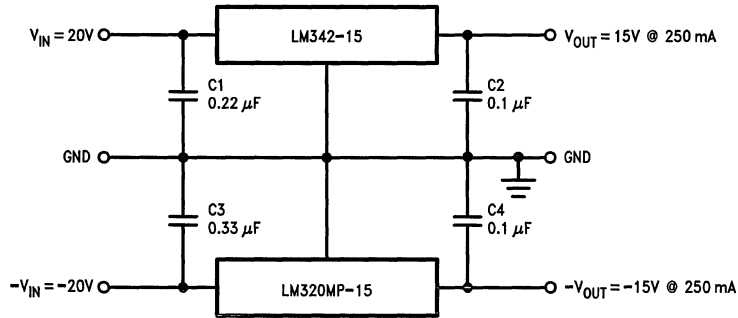


TL/H/10485-7

*Necessary if regulator is located far from the power supply filter

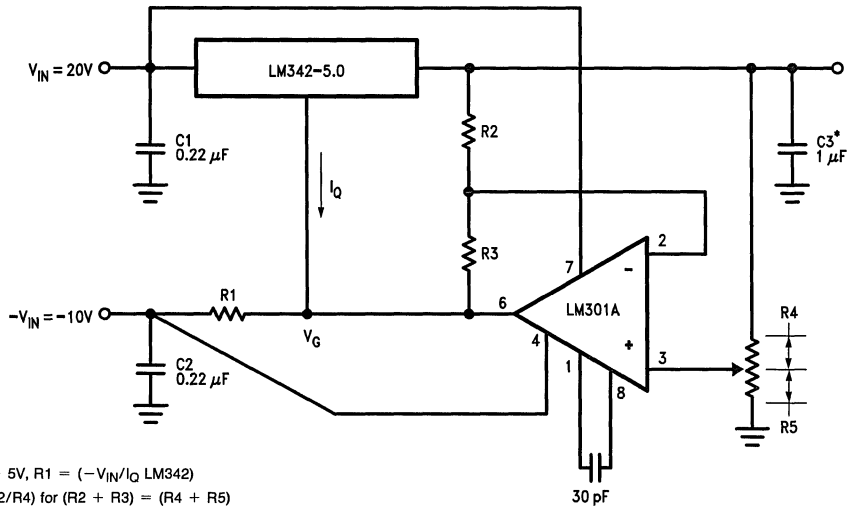
**D3 aids in full load start-up and protects the regulator during short circuits from high input to output voltage differentials

± 15V, 250 mA Dual Power Supply



TL/H/10485-8

Variable Output Regulator 0.5V-18V



$$V_{OUT} = V_G + 5V, R1 = (-V_{IN}/I_Q \text{ LM342})$$

$$V_{OUT} = 5V(R2/R4) \text{ for } (R2 + R3) = (R4 + R5)$$

$$\text{A } 0.5V \text{ output will correspond to } (R2/R4) = 0.1, (R3/R4) = 0.9$$

*Solid tantalum

TL/H/10485-9

LM431A

Adjustable Precision Zener Shunt Regulator

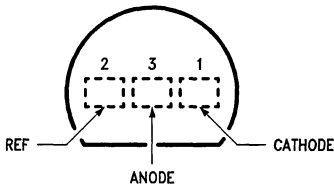
General Description

The LM431A is a 3-terminal adjustable shunt regulator with guaranteed temperature stability over the entire temperature range of operation. The output voltage may be set at any level greater than 2.5V (V_{REF}) up to 36V merely by selecting two external resistors that act as a voltage divided network. Due to the sharp turn-on characteristics this device is an excellent replacement for many zener diode applications.

Features

- Average temperature coefficient 50 ppm/°C
- Temperature compensated for operation over the full temperature range
- Programmable output voltage
- Fast turn-on response
- Low output noise

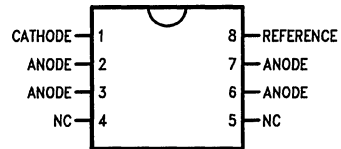
Connection Diagrams



TL/H/10055-1

Top View

Order Number LM431ACZ or LM431AIZ
 See NS Package Number Z03A



TL/H/10055-2

Top View

Order Number LM431ACM
 See NS Package Number M08A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	-65°C to +150°C
Operating Temperature Range	
Industrial (LM431A)	-40°C to +85°C
Commercial (LM431AC)	0°C to +70°C
Lead Temperature	
TO-92 Package/SO-8 Package	
(Soldering, 10 sec.)	265°C
Internal Power Dissipation (Notes 1, 2)	
TO-92 Package	0.78W
SO-8 Package	0.81W

Cathode Voltage		37V
Continuous Cathode Current		-10 mA to +150 mA
Reference Voltage		-0.5V
Reference Input Current		10 mA
Operating Conditions	Min	Max
Cathode Voltage	V_{REF}	37V
Cathode Current	1.0 mA	100 mA

Note 1: T_J Max = 150°C.

Note 2: Ratings apply to ambient temperature at 25°C. Above this temperature, derate the TO-92 at 6.2 mW/°C, and the SO-8 at 6.5 mW/°C.

LM431A

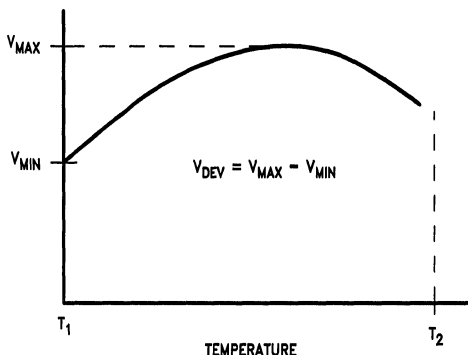
Electrical Characteristics $T_A = 25^\circ\text{C}$ unless otherwise specified

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{REF}	Reference Voltage	$V_Z = V_{REF}$, $I_I = 10\text{ mA}$ (Figure 1)	2.440	2.495	2.550	V
V_{DEV}	Deviation of Reference Input Voltage Over Temperature (Note 3)	$V_Z = V_{REF}$, $I_I = 10\text{ mA}$, $T_A = \text{Full Range}$ (Figure 1)		8.0	17	mV
$\frac{\Delta V_{REF}}{\Delta V_Z}$	Ratio of the Change in Reference Voltage to the Change in Cathode Voltage	$I_Z = 10\text{ mA}$ (Figure 2)				mV/V
		V_Z from V_{REF} to 10V		-1.4	-2.7	
		V_Z from 10V to 36V		-1.0	-2.0	
I_{REF}	Reference Input Current	$R_1 = 10\text{ k}\Omega$, $R_2 = \infty$, $I_I = 10\text{ mA}$ (Figure 2)		2.0	4.0	μA
∞I_{REF}	Deviation of Reference Input Current over Temperature	$R_1 = 10\text{ k}\Omega$, $R_2 = \infty$, $I_I = 10\text{ mA}$, $T_A = \text{Full Range}$ (Figure 2)		0.4	1.2	μA
$I_Z(\text{MIN})$	Minimum Cathode Current for Regulation	$V_Z = V_{REF}$ (Figure 1)		0.4	1.0	mA
$I_Z(\text{OFF})$	Off-State Current	$V_Z = 36\text{V}$, $V_{REF} = 0\text{V}$ (Figure 3)		0.3	1.0	μA
r_Z	Dynamic Output Impedance (Note 4)	$V_Z = V_{REF}$, Frequency = 0 Hz (Figure 1)			0.75	Ω

Note 3: Deviation of reference input voltage, V_{DEV} , is defined as the maximum variation of the reference input voltage over the full temperature range.

The average temperature coefficient of the reference input voltage, ∞V_{REF} , is defined as:

$$\infty V_{REF} \frac{\text{ppm}}{^\circ\text{C}} = \frac{\pm \left[\frac{V_{\text{Max}} - V_{\text{Min}}}{V_{REF}(\text{at } 25^\circ\text{C})} \right] 10^6}{T_2 - T_1} = \pm \left[\frac{V_{DEV}}{V_{REF}(\text{at } 25^\circ\text{C})} \right] 10^6$$



TL/H/10055-7

Where:

$T_2 - T_1$ = full temperature change.

∞V_{REF} can be positive or negative depending on whether the slope is positive or negative.

Example: $V_{DEV} = 8.0\text{ mV}$, $V_{REF} = 2495\text{ mV}$, $T_2 - T_1 = 70^\circ\text{C}$, slope is positive.

$$\infty V_{REF} = \frac{\left[\frac{8.0\text{ mV}}{2495\text{ mV}} \right] 10^6}{70^\circ\text{C}} = +46\text{ ppm}/^\circ\text{C}$$

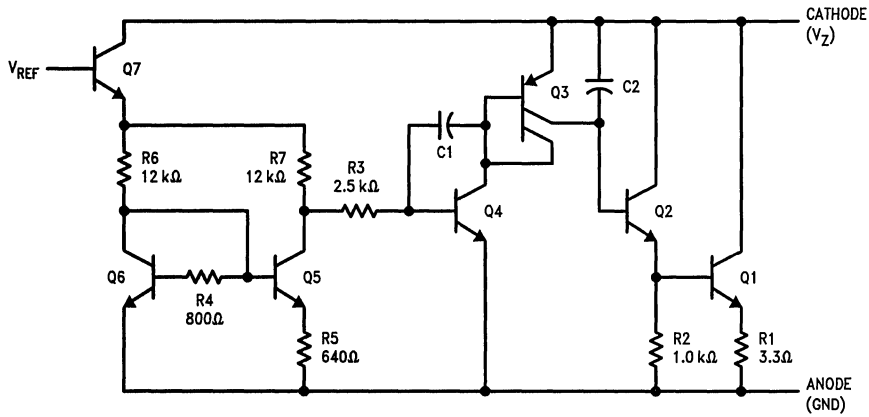
Note 4: The dynamic output impedance, r_Z , is defined as:

$$r_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

When the device is programmed with two external resistors, R_1 and R_2 , (see Figure 2), the dynamic output impedance of the overall circuit, r_Z , is defined as:

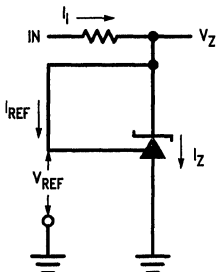
$$r_Z = \frac{\Delta V_Z}{\Delta I_Z} \approx \left[r_Z 1 + \frac{R_1}{R_2} \right]$$

Equivalent Circuit



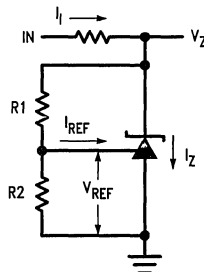
TL/H/10055-3

DC Test Circuits



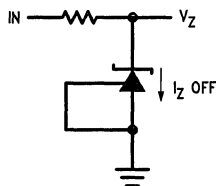
TL/H/10055-4

FIGURE 1. Test Circuit for $V_Z = V_{REF}$



TL/H/10055-5

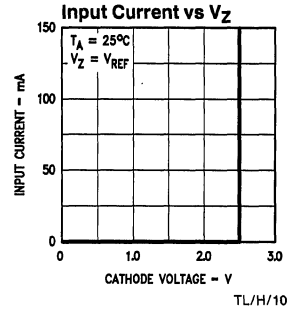
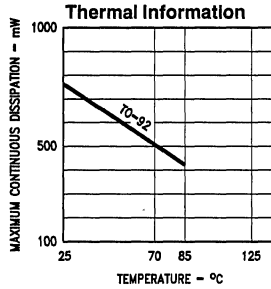
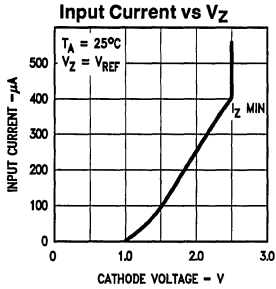
Note: $V_Z = V_{REF} (1 + R_1/R_2) + I_{REF} \cdot R_1$
 FIGURE 2. Test Circuit for $V_Z > V_{REF}$



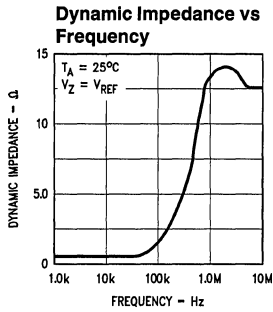
TL/H/10055-6

FIGURE 3. Test Circuit for Off-State Current

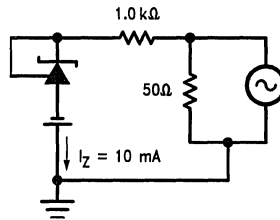
Typical Performance Characteristics



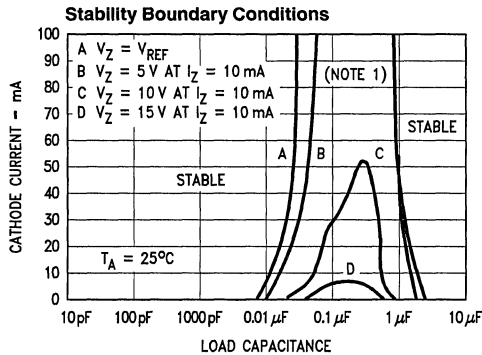
TL/H/10055-8



TL/H/10055-9



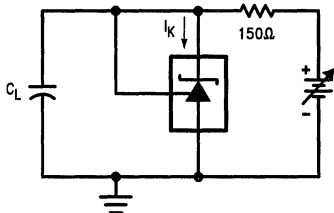
TL/H/10055-10



TL/H/10055-11

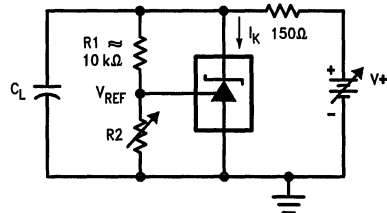
Note 1: The areas under the curves represent conditions that may cause the device to oscillate. For curves B, C, and D, R_2 and V^+ were adjusted to establish the initial V_Z and I_Z conditions with $C_L = 0$. V^+ and C_L were then adjusted to determine the ranges of stability.

Test Circuit for Curve A Above



TL/H/10055-12

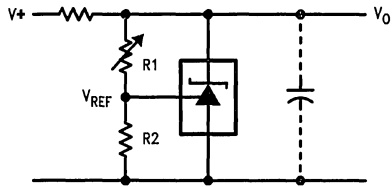
Test Circuit for Curves B, C and D Above



TL/H/10055-13

Typical Applications

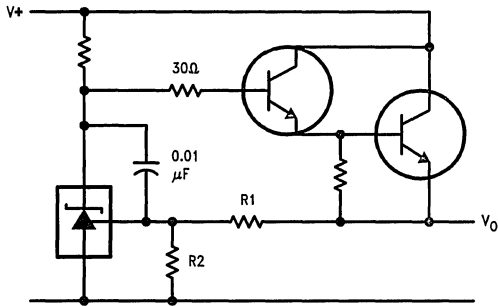
Shunt Regulator



TL/H/10055-14

$$V_O \approx \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

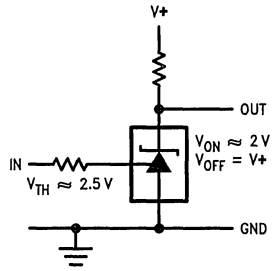
Series Regulator



TL/H/10055-16

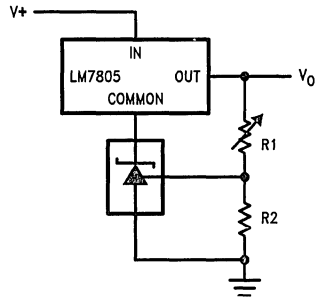
$$V_O \approx \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

Single Supply Comparator with Temperature Compensated Threshold



TL/H/10055-15

Output Control of a Three Terminal Fixed Regulator



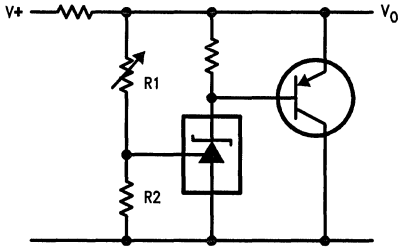
TL/H/10055-17

$$V_O = \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

$$V_{O\ MIN} = V_{REF} + 5V$$

Typical Applications (Continued)

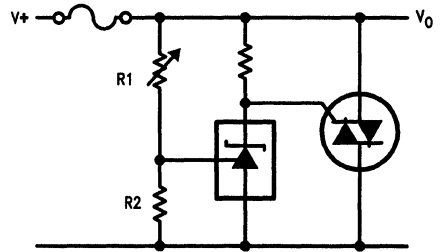
Higher Current Shunt Regulator



TL/H/10055-18

$$V_0 = \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

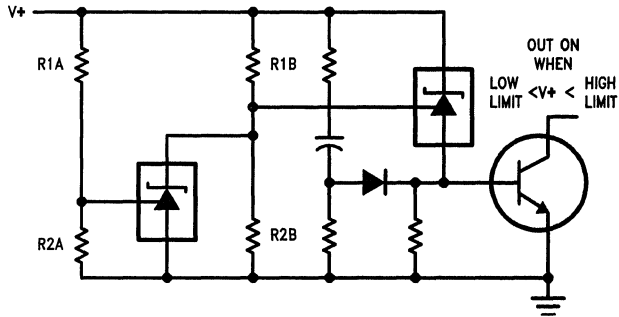
Crow Bar



TL/H/10055-19

$$V_{LIMIT} \approx \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

Over Voltage/Under Voltage Protection Circuit

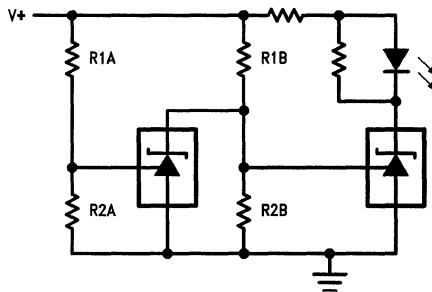


TL/H/10055-20

$$LOW\ LIMIT \approx V_{REF} \left(1 + \frac{R_{1B}}{R_{2B}}\right) + V_{BE}$$

$$HIGH\ LIMIT \approx V_{REF} \left(1 + \frac{R_{1A}}{R_{2A}}\right)$$

Voltage Monitor



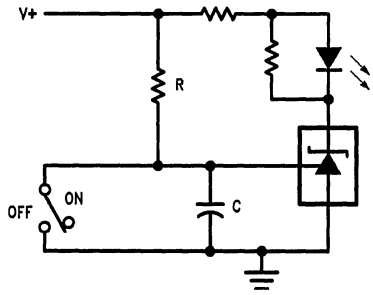
TL/H/10055-21

$$LOW\ LIMIT \approx V_{REF} \left(1 + \frac{R_{1B}}{R_{2B}}\right) \quad LED\ ON\ WHEN\ LOW\ LIMIT < V^+ < HIGH\ LIMIT$$

$$HIGH\ LIMIT \approx V_{REF} \left(1 + \frac{R_{1A}}{R_{2A}}\right)$$

Typical Applications (Continued)

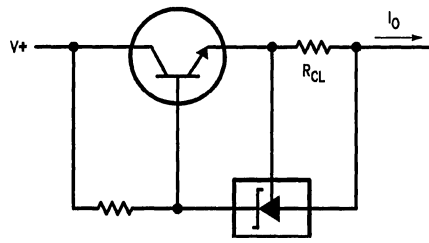
Delay Timer



TL/H/10055-22

$$\text{DELAY} = R \cdot C \cdot \ln \frac{V^+}{(V^+) - V_{REF}}$$

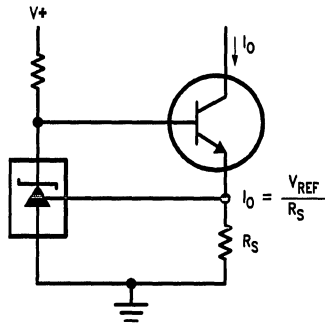
Current Limiter or Current Source



TL/H/10055-23

$$I_o = \frac{V_{REF}}{R_{CL}}$$

Constant Current Sink



TL/H/10055-24

$$I_o = \frac{V_{REF}}{R_S}$$



LM723/LM723C Voltage Regulator

General Description

The LM723/LM723C is a voltage regulator designed primarily for series regulator applications. By itself, it will supply output currents up to 150 mA; but external transistors can be added to provide any desired load current. The circuit features extremely low standby current drain, and provision is made for either linear or foldback current limiting.

The LM723/LM723C is also useful in a wide range of other applications such as a shunt regulator, a current regulator or a temperature controller.

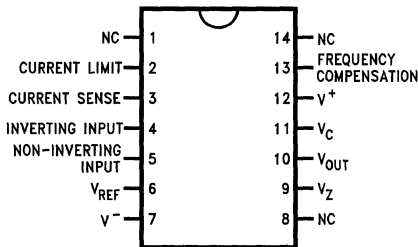
The LM723C is identical to the LM723 except that the LM723C has its performance guaranteed over a 0°C to +70°C temperature range, instead of -55°C to +125°C.

Features

- 150 mA output current without external pass transistor
- Output currents in excess of 10A possible by adding external transistors
- Input voltage 40V max
- Output voltage adjustable from 2V to 37V
- Can be used as either a linear or a switching regulator

Connection Diagrams

Dual-In-Line Package

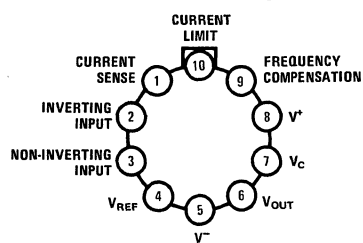


TL/H/8563-2

Top View

Order Number LM723J, LM723J/883, LM723CJ,
LM723CM or LM723CN
See NS Package J14A, M14A or N14A

Metal Can Package



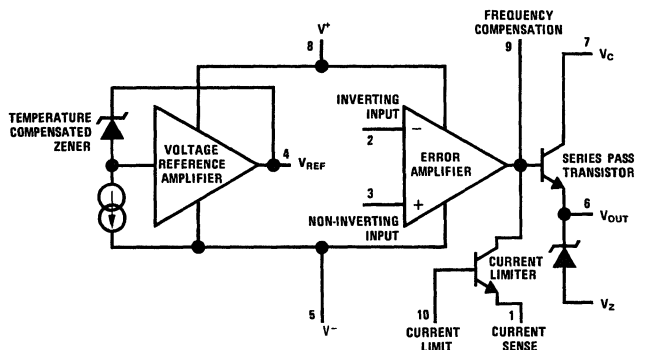
TL/H/8563-3

Note: Pin 5 connected to case.

Top View

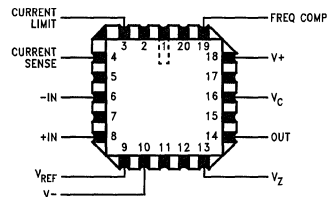
Order Number LM723H or LM723CH
See NS Package H10C

Equivalent Circuit*



TL/H/8563-4

*Pin numbers refer to metal can package.



TL/H/8563-20

Top View

Order Number LM723E/883
See NS Package E20A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 9)

Pulse Voltage from V^+ to V^- (50 ms)	50V
Continuous Voltage from V^+ to V^-	40V
Input-Output Voltage Differential	40V
Maximum Amplifier Input Voltage (Either Input)	8.5V
Maximum Amplifier Input Voltage (Differential)	5V
Current from V_Z	25 mA
Current from V_{REF}	15 mA

Internal Power Dissipation Metal Can (Note 1)	800 mW
Cavity DIP (Note 1)	900 mW
Molded DIP (Note 1)	660 mW
Operating Temperature Range LM723	-55°C to +150°C
LM723C	0°C to +70°C
Storage Temperature Range Metal Can	-65°C to +150°C
Molded DIP	-55°C to +150°C
Lead Temperature (Soldering, 4 sec. max.)	
Hermetic Package	300°C
Plastic Package	260°C
ESD Tolerance	1200V
(Human body model, 1.5 k Ω in series with 100 pF)	

Electrical Characteristics (Notes 2, 9)

Parameter	Conditions	LM723			LM723C			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	$V_{IN} = 12V$ to $V_{IN} = 15V$ $-55^\circ C \leq T_A \leq +125^\circ C$ $0^\circ C \leq T_A \leq +70^\circ C$ $V_{IN} = 12V$ to $V_{IN} = 40V$		0.01	0.1		0.01	0.1	% V_{OUT}
				0.3				% V_{OUT}
			0.02	0.2	0.1	0.5		% V_{OUT}
Load Regulation	$I_L = 1$ mA to $I_L = 50$ mA $-55^\circ C \leq T_A \leq +125^\circ C$ $0^\circ C \leq T_A \leq +70^\circ C$		0.03	0.15	0.03	0.2	% V_{OUT}	
				0.6			% V_{OUT}	
					0.6		% V_{OUT}	
Ripple Rejection	$f = 50$ Hz to 10 kHz, $C_{REF} = 0$ $f = 50$ Hz to 10 kHz, $C_{REF} = 5 \mu F$		74		74		dB	
			86		86		dB	
Average Temperature Coefficient of Output Voltage (Note 8)	$-55^\circ C \leq T_A \leq +125^\circ C$ $0^\circ C \leq T_A \leq +70^\circ C$		0.002	0.015			%/ $^\circ C$	
					0.003	0.015		%/ $^\circ C$
Short Circuit Current Limit	$R_{SC} = 10\Omega$, $V_{OUT} = 0$		65		65		mA	
Reference Voltage		6.95	7.15	7.35	6.80	7.15	7.50	V
Output Noise Voltage	$BW = 100$ Hz to 10 kHz, $C_{REF} = 0$ $BW = 100$ Hz to 10 kHz, $C_{REF} = 5 \mu F$		86		86		μV_{rms}	
			2.5		2.5		μV_{rms}	
Long Term Stability			0.05		0.05		%/1000 hrs	
Standby Current Drain	$I_L = 0$, $V_{IN} = 30V$		1.7	3.5	1.7	4.0	mA	
Input Voltage Range		9.5		40	9.5	40	V	
Output Voltage Range		2.0		37	2.0	37	V	
Input-Output Voltage Differential		3.0		38	3.0	38	V	
θ_{JA}	Molded DIP		105		105		$^\circ C/W$	
θ_{JA}	Cavity DIP		150		150		$^\circ C/W$	
θ_{JA}	H10C Board Mount in Still Air		165		165		$^\circ C/W$	
θ_{JA}	H10C Board Mount in 400 LF/Min Air Flow		66		66		$^\circ C/W$	
θ_{JA}	SO				125		$^\circ C/W$	
θ_{JC}			22		22		$^\circ C/W$	

Note 1: See derating curves for maximum power rating above 25°C.

Note 2: Unless otherwise specified, $T_A = 25^\circ C$, $V_{IN} = V^+ = V_C = 12V$, $V^- = 0$, $V_{OUT} = 5V$, $I_L = 1$ mA, $R_{SC} = 0$, $C_1 = 100$ pF, $C_{REF} = 0$ and divider impedance as seen by error amplifier ≤ 10 k Ω connected as shown in Figure 1. Line and load regulation specifications are given for the condition of constant chip temperature. Temperature drifts must be taken into account separately for high dissipation conditions.

Note 3: L_1 is 40 turns of No. 20 enameled copper wire wound on Ferroxcube P36/22-3B7 pot core or equivalent with 0.009 in. air gap.

Note 4: Figures in parentheses may be used if R1/R2 divider is placed on opposite input of error amp.

Note 5: Replace R1/R2 in figures with divider shown in Figure 13.

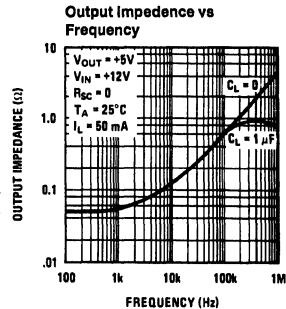
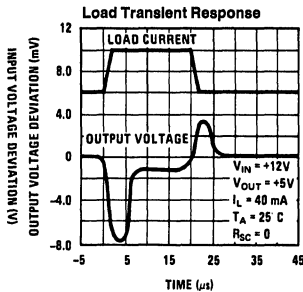
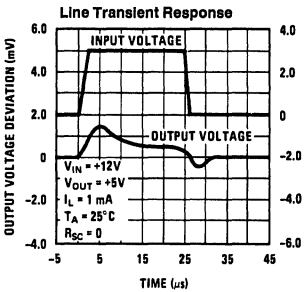
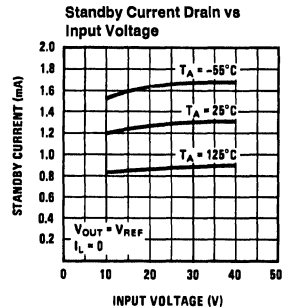
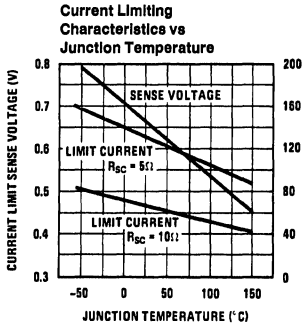
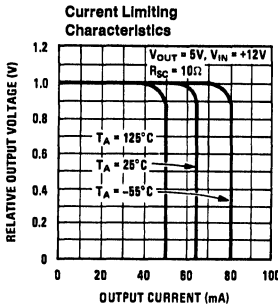
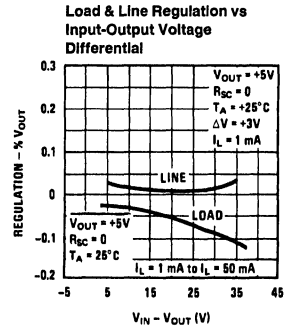
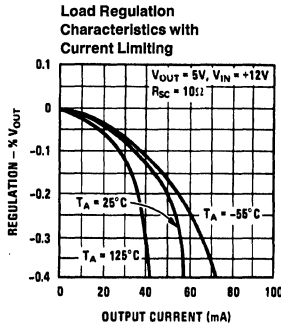
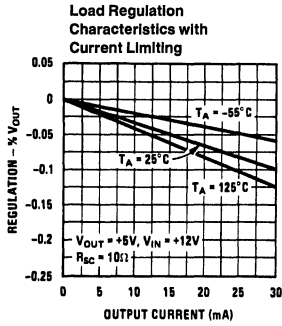
Note 6: V^+ and V_{CC} must be connected to a +3V or greater supply.

Note 7: For metal can applications where V_Z is required, an external 6.2V zener diode should be connected in series with V_{OUT} .

Note 8: Guaranteed by correlation to other tests.

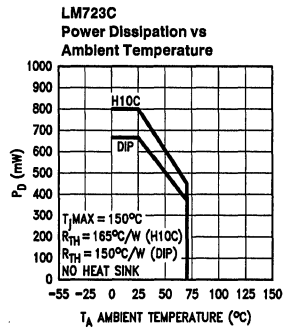
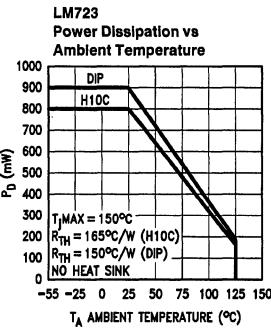
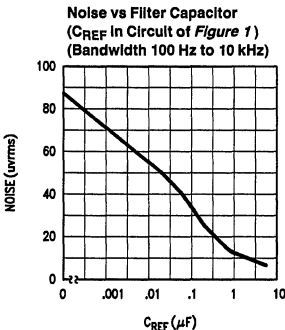
Note 9: A military RETS specification is available on request. At the time of printing, the LM723 RETS specification complied with the Min and Max limits in this table. The LM723E, H, and J may also be procured as a Standard Military Drawing.

Typical Performance Characteristics



TL/H/8563-6

Maximum Power Ratings



TL/H/8563-7

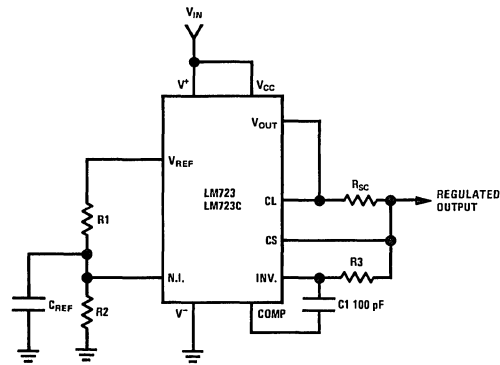
TABLE I. Resistor Values (kΩ) for Standard Output Voltage

Positive Output Voltage	Applicable Figures (Note 4)	Fixed Output ± 5%		Output Adjustable ± 10% (Note 5)			Negative Output Voltage	Applicable Figures	Fixed Output ± 5%		5% Output Adjustable ± 10%		
		R1	R2	R1	P1	R2			R1	R2	R1	P1	R2
+3.0	1, 5, 6, 9, 12 (4)	4.12	3.01	1.8	0.5	1.2	+100	7	3.57	102	2.2	10	91
+3.6	1, 5, 6, 9, 12 (4)	3.57	3.65	1.5	0.5	1.5	+250	7	3.57	255	2.2	10	240
+5.0	1, 5, 6, 9, 12 (4)	2.15	4.99	0.75	0.5	2.2	-6 (Note 6)	3, (10)	3.57	2.43	1.2	0.5	0.75
+6.0	1, 5, 6, 9, 12 (4)	1.15	6.04	0.5	0.5	2.7	-9	3, 10	3.48	5.36	1.2	0.5	2.0
+9.0	2, 4, (5, 6, 9, 12)	1.87	7.15	0.75	1.0	2.7	-12	3, 10	3.57	8.45	1.2	0.5	3.3
+12	2, 4, (5, 6, 9, 12)	4.87	7.15	2.0	1.0	3.0	-15	3, 10	3.65	11.5	1.2	0.5	4.3
+15	2, 4, (5, 6, 9, 12)	7.87	7.15	3.3	1.0	3.0	-28	3, 10	3.57	24.3	1.2	0.5	10
+28	2, 4, (5, 6, 9, 12)	21.0	7.15	5.6	1.0	2.0	-45	8	3.57	41.2	2.2	10	33
+45	7	3.57	48.7	2.2	10	39	-100	8	3.57	97.6	2.2	10	91
+75	7	3.57	78.7	2.2	10	68	-250	8	3.57	249	2.2	10	240

TABLE II. Formulae for Intermediate Output Voltages

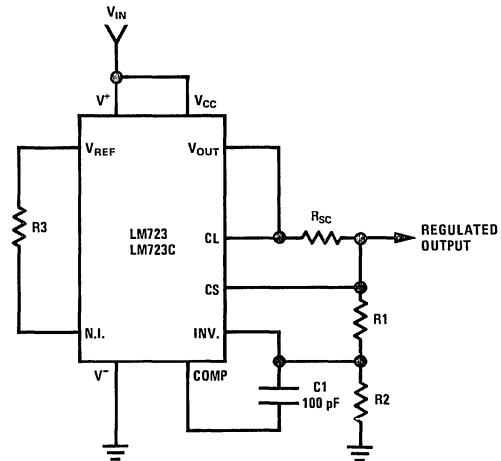
Outputs from +2 to +7 volts <i>(Figures 1, 5, 6, 9, 12, [4])</i> $V_{OUT} = \left(V_{REF} \times \frac{R_2}{R_1 + R_2} \right)$	Outputs from +4 to +250 volts <i>(Figure 7)</i> $V_{OUT} = \left(\frac{V_{REF}}{2} \times \frac{R_2 - R_1}{R_1} \right); R_3 = R_4$	Current Limiting $I_{LIMIT} = \frac{V_{SENSE}}{R_{SC}}$
Outputs from +7 to +37 volts <i>(Figures 2, 4, [5, 6, 9, 12])</i> $V_{OUT} = \left(V_{REF} \times \frac{R_1 + R_2}{R_2} \right)$	Outputs from -6 to -250 volts <i>(Figures 3, 8, 10)</i> $V_{OUT} = \left(\frac{V_{REF}}{2} \times \frac{R_1 + R_2}{R_1} \right); R_3 = R_4$	Foldback Current Limiting $I_{KNEE} = \left(\frac{V_{OUT} R_3}{R_{SC} R_4} + \frac{V_{SENSE} (R_3 + R_4)}{R_{SC} R_4} \right)$ $I_{SHORT\ CT} = \left(\frac{V_{SENSE}}{R_{SC}} \times \frac{R_3 + R_4}{R_4} \right)$

Typical Applications



TL/H/8563-8
Note: $R_3 = \frac{R_1 R_2}{R_1 + R_2}$ for minimum temperature drift.
Typical Performance
 Regulated Output Voltage 5V
 Line Regulation ($\Delta V_{IN} = 3V$) 0.5 mV
 Load Regulation ($\Delta I_L = 50\text{ mA}$) 1.5 mV

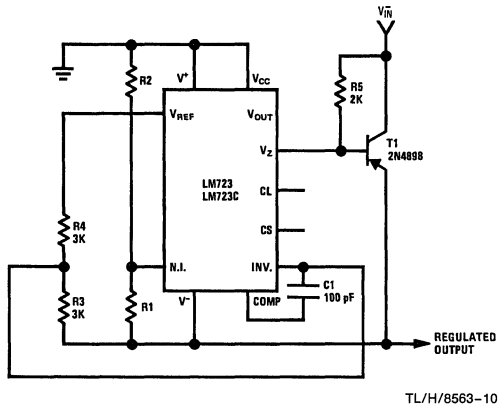
FIGURE 1. Basic Low Voltage Regulator ($V_{OUT} = 2$ to 7 Volts)



TL/H/8563-9
Note: $R_3 = \frac{R_1 R_2}{R_1 + R_2}$ for minimum temperature drift. R3 may be eliminated for minimum component count.
Typical Performance
 Regulated Output Voltage 15V
 Line Regulation ($\Delta V_{IN} = 3V$) 1.5 mV
 Load Regulation ($\Delta I_L = 50\text{ mA}$) 4.5 mV

FIGURE 2. Basic High Voltage Regulator ($V_{OUT} = 7$ to 37 Volts)

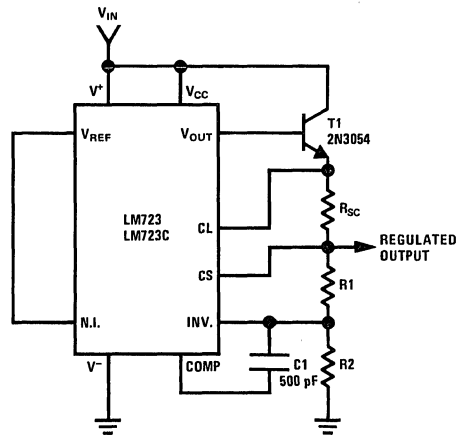
Typical Applications (Continued)



TL/H/8563-10

Typical Performance
 Regulated Output Voltage -15V
 Line Regulation ($\Delta V_{IN} = 3V$) 1 mV
 Load Regulation ($\Delta I_L = 100 \text{ mA}$) 2 mV

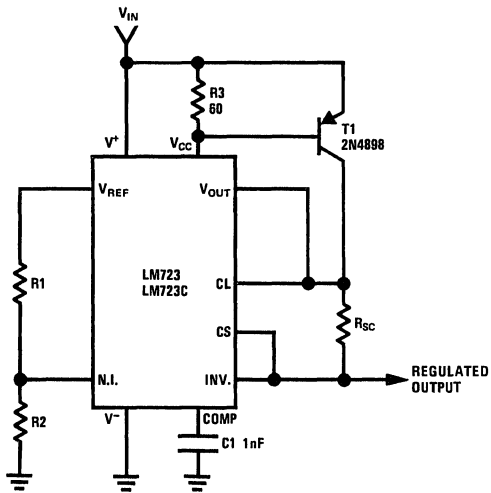
FIGURE 3. Negative Voltage Regulator



TL/H/8563-11

Typical Performance
 Regulated Output Voltage +15V
 Line Regulation ($\Delta V_{IN} = 3V$) 1.5 mV
 Load Regulation ($\Delta I_L = 1A$) 15 mV

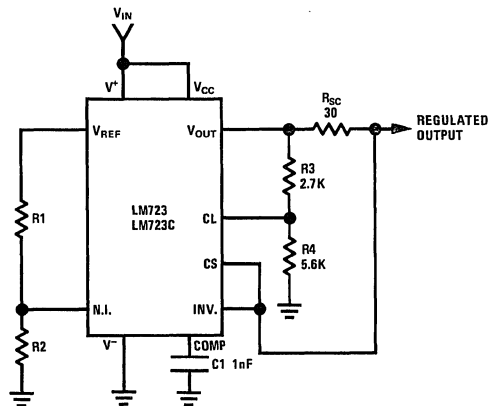
**FIGURE 4. Positive Voltage Regulator
(External NPN Pass Transistor)**



TL/H/8563-12

Typical Performance
 Regulated Output Voltage +5V
 Line Regulation ($\Delta V_{IN} = 3V$) 0.5 mV
 Load Regulation ($\Delta I_L = 1A$) 5 mV

**FIGURE 5. Positive Voltage Regulator
(External PNP Pass Transistor)**

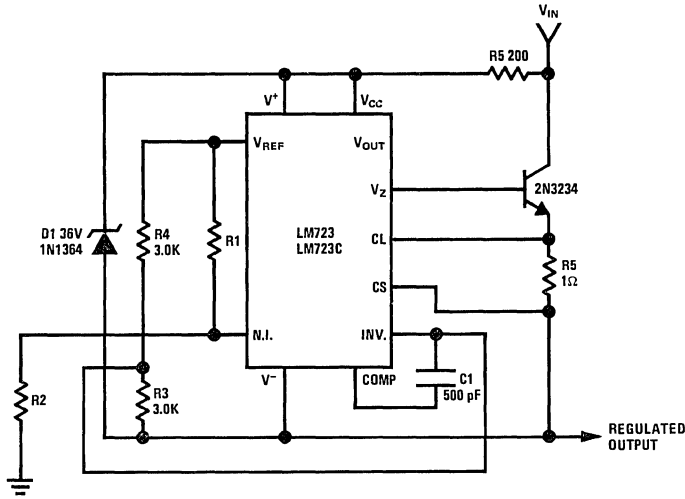


TL/H/8563-13

Typical Performance
 Regulated Output Voltage +5V
 Line Regulation ($\Delta V_{IN} = 3V$) 0.5 mV
 Load Regulation ($\Delta I_L = 10 \text{ mA}$) 1 mV
 Short Circuit Current 20 mA

FIGURE 6. Foldback Current Limiting

Typical Applications (Continued)

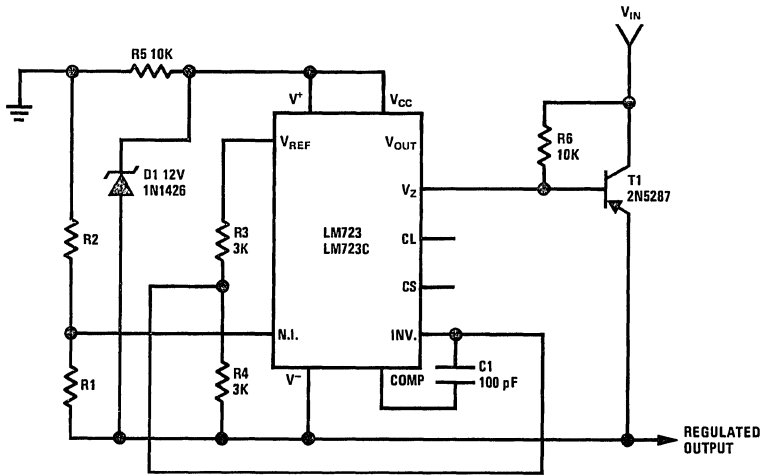


TL/H/8563-14

Typical Performance

Regulated Output Voltage	+ 50V
Line Regulation ($\Delta V_{IN} = 20V$)	15 mV
Load Regulation ($\Delta I_L = 50 \text{ mA}$)	20 mV

FIGURE 7. Positive Floating Regulator



TL/H/8563-15

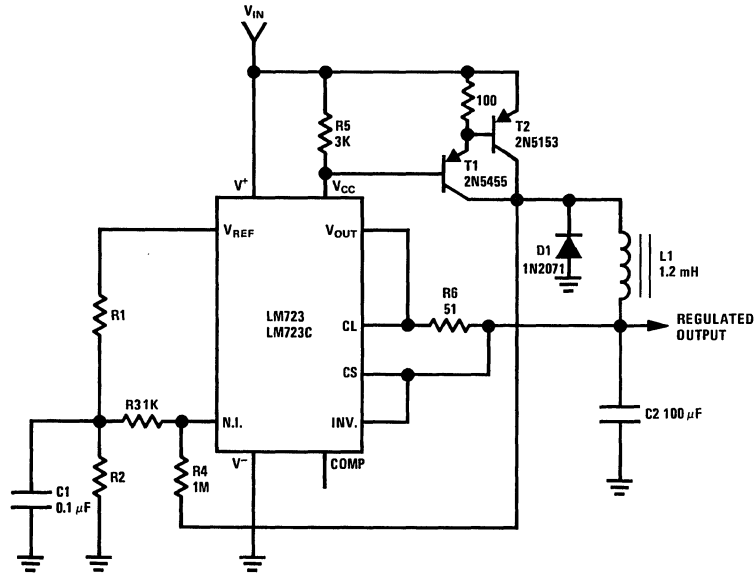
Typical Performance

Regulated Output Voltage	- 100V
Line Regulation ($\Delta V_{IN} = 20V$)	30 mV
Load Regulation ($\Delta I_L = 100 \text{ mA}$)	20 mV

FIGURE 8. Negative Floating Regulator

1

Typical Applications (Continued)

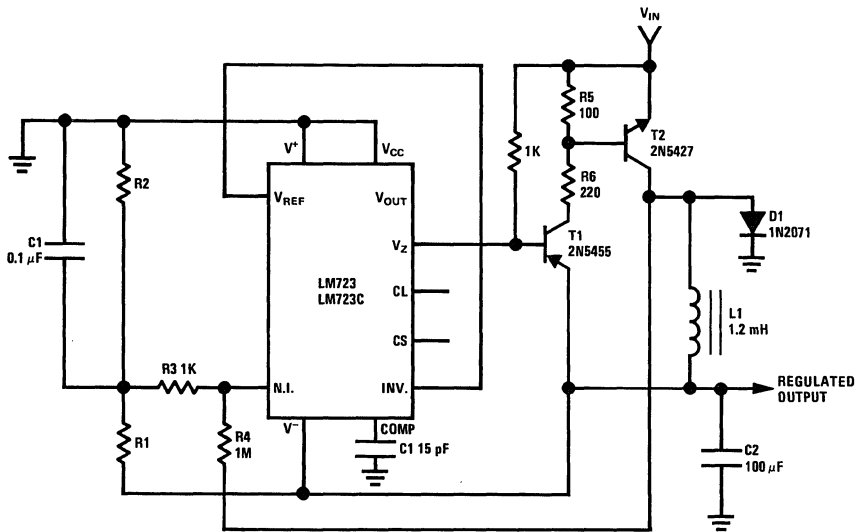


Typical Performance

Regulated Output Voltage	+5V
Line Regulation ($\Delta V_{IN} = 30V$)	10 mV
Load Regulation ($\Delta I_L = 2A$)	80 mV

TL/H/8563-16

FIGURE 9. Positive Switching Regulator



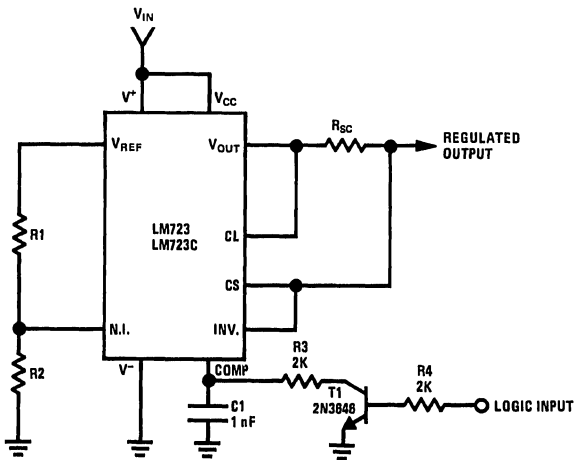
Typical Performance

Regulated Output Voltage	-15V
Line Regulation ($\Delta V_{IN} = 20V$)	8 mV
Load Regulation ($\Delta I_L = 2A$)	6 mV

TL/H/8563-17

FIGURE 10. Negative Switching Regulator

Typical Applications (Continued)



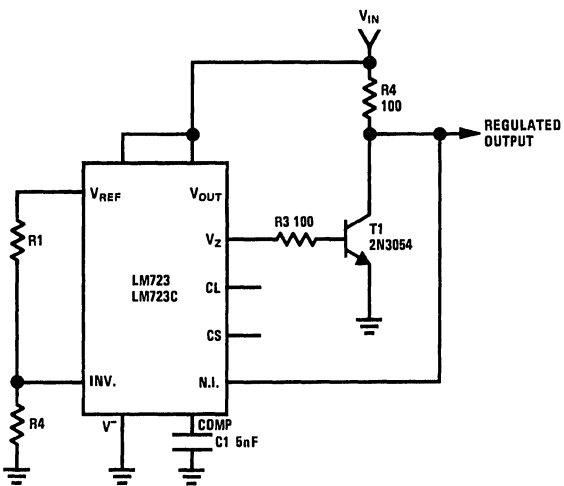
TL/H/8563-18

Note: Current limit transistor may be used for shutdown if current limiting is not required.

Typical Performance

Regulated Output Voltage	+5V
Line Regulation ($\Delta V_{IN} = 3V$)	0.5 mV
Load Regulation ($\Delta I_L = 50 \text{ mA}$)	1.5 mV

FIGURE 11. Remote Shutdown Regulator with Current Limiting



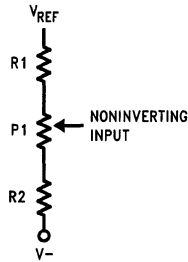
TL/H/8563-19

Typical Performance

Regulated Output Voltage	+5V
Line Regulation ($\Delta V_{IN} = 10V$)	0.5 mV
Load Regulation ($\Delta I_L = 100 \text{ mA}$)	1.5 mV

FIGURE 12. Shunt Regulator

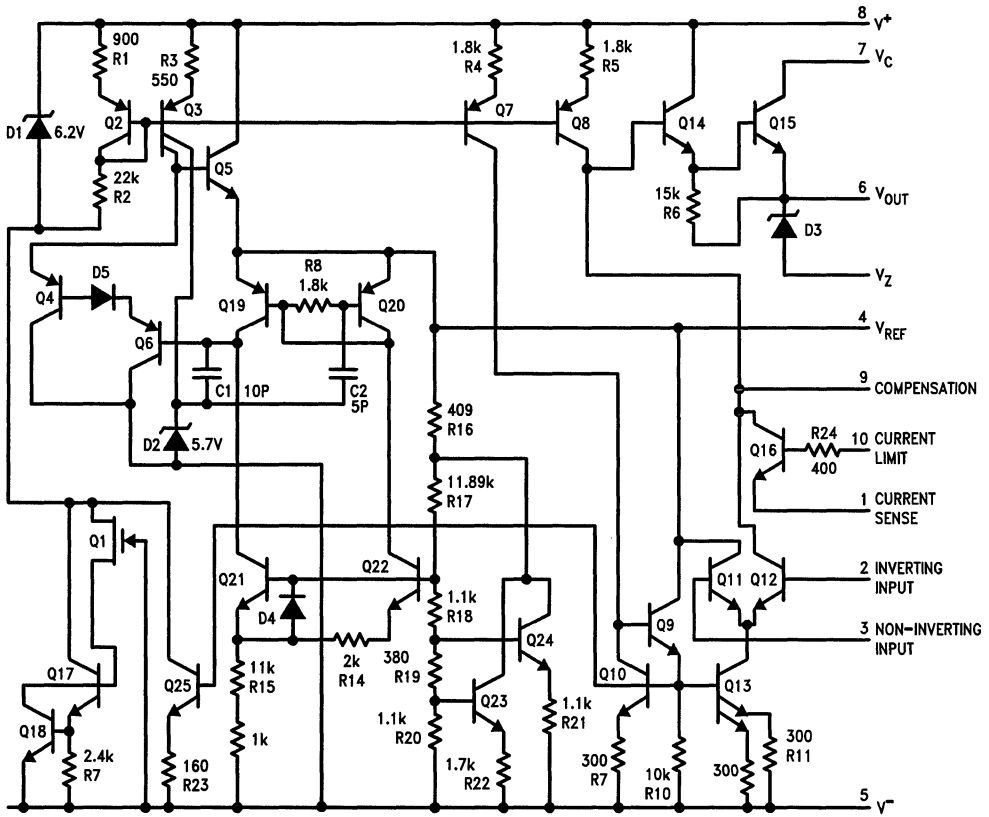
Typical Applications (Continued)



TL/H/8563-21

FIGURE 13. Output Voltage Adjust
(See Note 5)

Schematic Diagram



TL/H/8563-1

LM78G

4-Terminal Adjustable Voltage Regulator

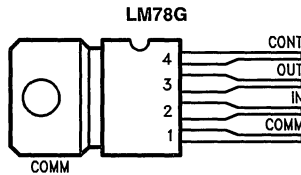
General Description

The LM78G is a 4-terminal adjustable voltage regulator designed to deliver continuous load currents of up to 1.0A with a maximum input voltage of +40V. Output current capability can be increased to greater than 1.0A through use of one or more external transistors. The output voltage range is +5V to +20V.

Features

- Output current in excess of 1A
- Output range of +5V to +30V
- Internal thermal overload protection
- Internal short circuit protection
- Output transistor safe-area protection

Connection Diagram and Ordering Information



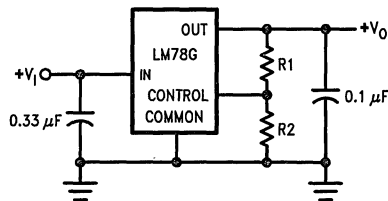
TL/H/10054-1

Top View

Heat sink tabs connected to common through device substrate.

4-Lead, TO-202
Order Number LM78GCP
See NS Package Number P04A

Typical Application



TL/H/10054-12

$$V_O = V_{CONT} \left(\frac{R_1 + R_2}{R_2} \right)$$

1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range -65°C to $+150^{\circ}\text{C}$

Operating Junction

Temperature Range 0°C to $+150^{\circ}\text{C}$

Lead Temperature (Soldering, 10 sec.) 265°C

Power Dissipation

Input Voltage

Control Lead Voltage

Internally Limited

$+40\text{V}$

$0\text{V} \leq V^+ \leq V_O$

Electrical Characteristics

$0^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$, $C_1 = 0.33 \mu\text{F}$, $C_O = 0.1 \mu\text{F}$, $V_I = 10\text{V}$, $I_O = 500 \text{ mA}$, Test Circuit 1, unless otherwise specified

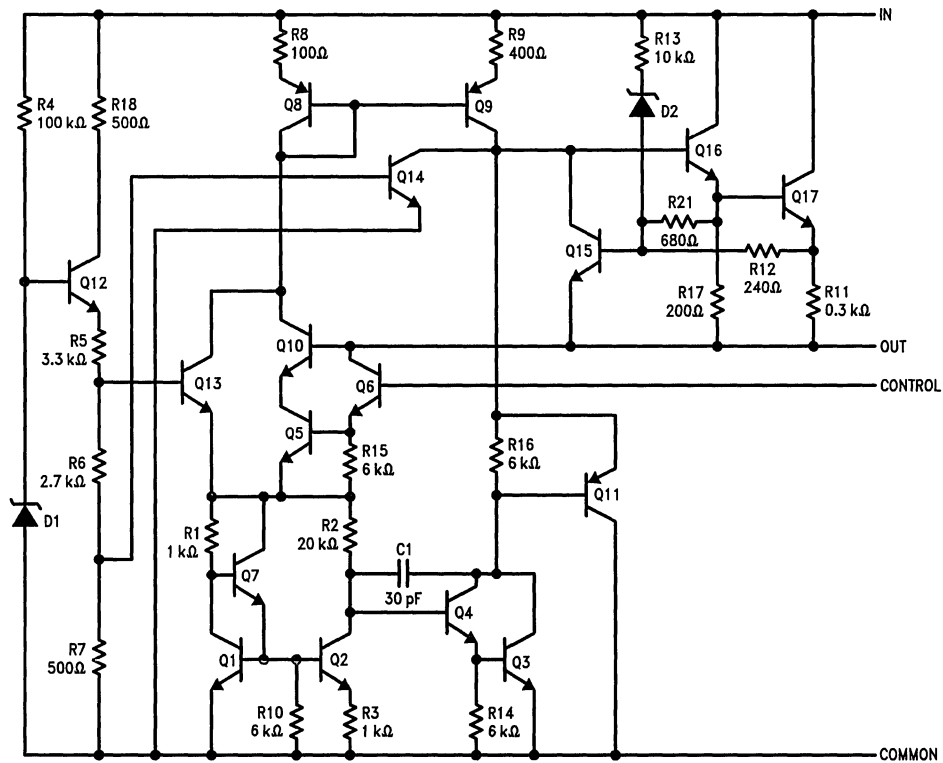
Symbol	Parameter	Conditions (Notes 1, 3)	Min	Typ	Max	Units
V_{IR}	Input Voltage Range	$T_J = 25^{\circ}\text{C}$	7.5		40	V
V_{OR}	Output Voltage Range	$V_I = V_O + 5.0\text{V}$	5.0		30	V
V_O	Output Voltage Tolerance	$(V_O + 3.0\text{V}) \leq V_I \leq (V_O + 15\text{V})$, $5.0 \text{ mA} \leq I_O \leq 1.0\text{A}$ $P_D \leq 15\text{W}$, $V_{I \text{ Max}} = 38\text{V}$		$T_J = 25^{\circ}\text{C}$	4.0	% V_O
					5.0	
$V_{O \text{ LINE}}$	Line Regulation	$T_J = 25^{\circ}\text{C}$, $V_O \leq 10\text{V}$ $(V_O + 2.5\text{V}) \leq V_I \leq (V_O + 20\text{V})$			1.0	% V_O
$V_{O \text{ LOAD}}$	Load Regulation	$T_J = 25^{\circ}\text{C}$, $V_I \leq V_O + 5.0\text{V}$			$250 \text{ mA} \leq I_O \leq 750 \text{ mA}$	1.0
					$5.0 \text{ mA} \leq I_O \leq 1.5\text{A}$	2.0
I_C	Control Lead Current	$T_J = 25^{\circ}\text{C}$			1.0	μA
					8.0	
I_Q	Quiescent Current	$T_J = 25^{\circ}\text{C}$			3.2	mA
					7.0	
$\Delta V_I / \Delta V_O$	Ripple Rejection	$8.0\text{V} \leq V_I \leq 18\text{V}$, $f = 2400 \text{ Hz}$, $V_O = 5.0\text{V}$, $I_C = 350 \text{ mA}$	68	78		dB
N_O	Noise	$T_J = 25^{\circ}\text{C}$, $10 \text{ Hz} < f < 100 \text{ kHz}$, $V_O = 5.0\text{V}$, $I_O = 5.0 \text{ mA}$		8.0	40	$\mu\text{V}/V_O$
V_{DO}	Dropout Voltage (Note 2)			2.0	2.5	V
I_{OS}	Output Short Circuit Current	$T_J = 25^{\circ}\text{C}$, $V_I = 30\text{V}$		0.750	1.2	A
I_{pk}	Peak Output Current	$T_J = 25^{\circ}\text{C}$	1.3	2.2	3.3	A
$\Delta V_O / \Delta T$	Average Temperature Coefficient of Output Voltage	$V_O = 5.0\text{V}$, $I_O = 5.0 \text{ mA}$			$T_A = -55^{\circ}\text{C}$ to $+25^{\circ}\text{C}$	0.4
					$T_A = 25^{\circ}\text{C}$ to $+125^{\circ}\text{C}$	0.3
V_C	Control Lead Voltage (Reference)	$T_J = 25^{\circ}\text{C}$			4.8	V
					4.75	

Note 1: V_O is defined for the LM78G as $V_O = \frac{R1 + R2}{R2} (5.0)$.

Note 2: Dropout Voltage is defined as that input/output voltage differential which causes the output voltage to decrease by 5% of its initial value.

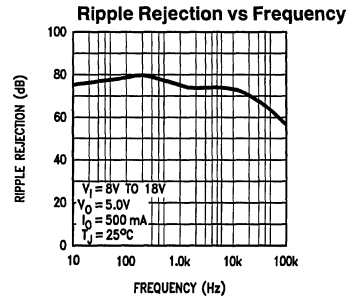
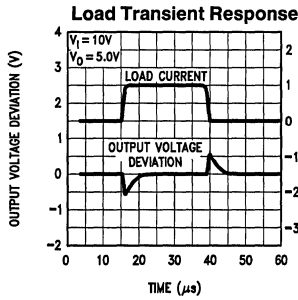
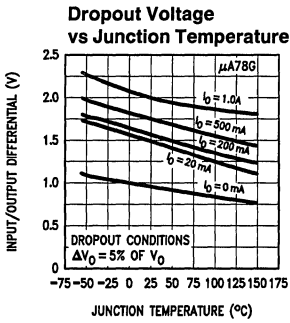
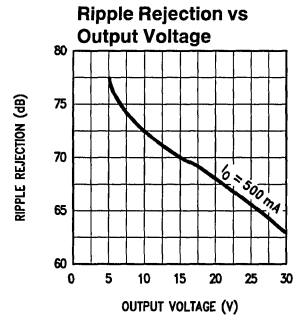
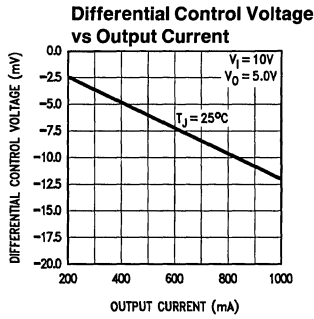
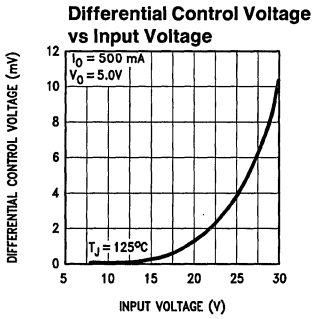
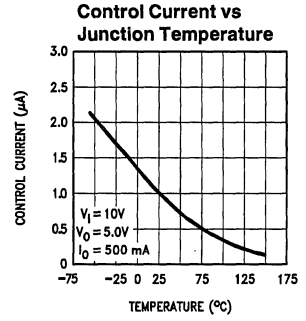
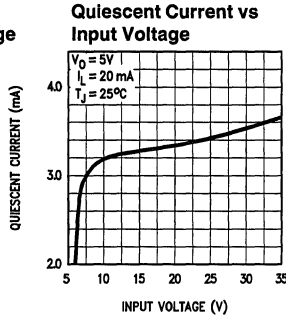
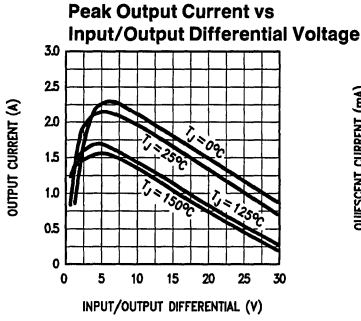
Note 3: All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \leq 10 \text{ ms}$, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

Equivalent Circuit



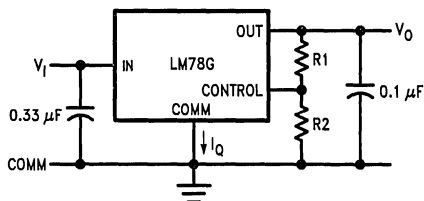
TL/H/10054-3

Typical Performance Curves



TL/H/10054-5

Test Circuit



TL/H/10054-8

$$V_O = \left(\frac{R_1 + R_2}{R_2} \right) V_{CONT}$$

V_{CONT} Nominal = 5.0V

Design Considerations

The LM78G Adjustable Voltage Regulator has an output voltage which varies from V_{CONT} to typically

$$V_1 - 2.0V \text{ by } V_O = V_{CONT} \frac{R_1 + R_2}{R_2}$$

V_{CONT} nominal in the LM78G is 5.0V. If we allow 1.0 mA to flow in the control string to eliminate bias current effects, we can make $R_2 = 5.0 \text{ k}\Omega$. Then, the output voltage is; $V_O = (R_1 + R_2)V$, where R_1 and R_2 are in $\text{k}\Omega$ s.

Example: If $R_2 = 5.0 \text{ k}\Omega$ and $R_1 = 10 \text{ k}\Omega$ then $V_O = 15V$ nominal

By proper wiring of the feedback resistors, load regulation of the device can be improved significantly.

The LM78G regulator has thermal overload protection from excessive power, internal short circuit protection which limits the maximum current, and output transistor safe-area protection for reducing the output current as the voltage across the pass transistor increases.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature in order to meet data sheet specifications. To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

	Typ °C/W	Max °C/W	Typ °C/W	Max °C/W
Package	θ_{JC}	θ_{JC}	θ_{JA}	θ_{JA}
Power Watt	7.5	11	75	80

$$P_{D \text{ Max}} = \frac{T_{J \text{ Max}} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or}$$

$$= \frac{T_{J \text{ Max}} - T_A}{\theta_{JA}} \text{ (without a heat sink)}$$

$$\theta_{CA} = \theta_{CS} + \theta_{SA}$$

Solving for T_J :

$$T_J = T_A + P_D(\theta_{JC} + \theta_{CA}) \text{ or}$$

$$= T_A + P_D\theta_{JA} \text{ (without heat sink)}$$

Where:

T_J = Junction Temperature

T_A = Ambient Temperature

P_D = Power Dissipation

θ_{JA} = Junction to Ambient Thermal Resistance

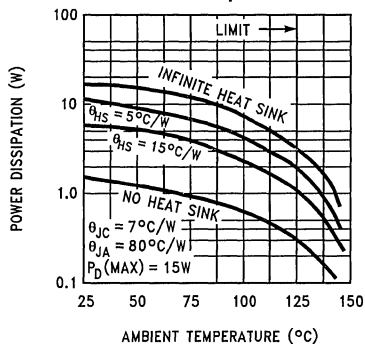
θ_{JC} = Junction to Case Thermal Resistance

θ_{CA} = Case to Ambient Thermal Resistance

θ_{CS} = Case to Heat Sink Resistance

θ_{SA} = Heat Sink to Ambient Thermal Resistance

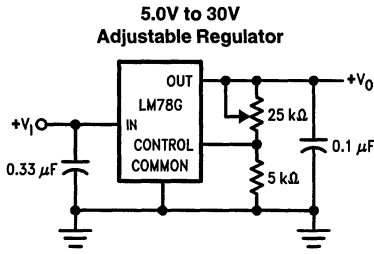
**Power Tab (U1) Package
Worst Case Power Dissipation
vs Ambient Temperature**



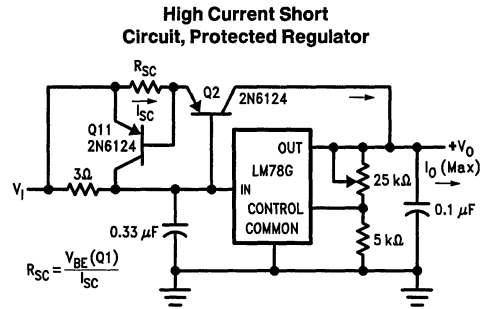
TL/H/10054-11

Typical Applications for LM78G

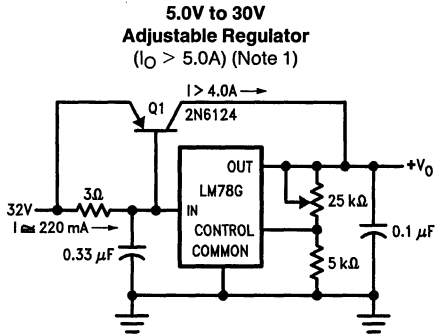
Bypassing of the input and output ($0.33 \mu\text{F}$ and $0.1 \mu\text{F}$, respectively) is necessary.



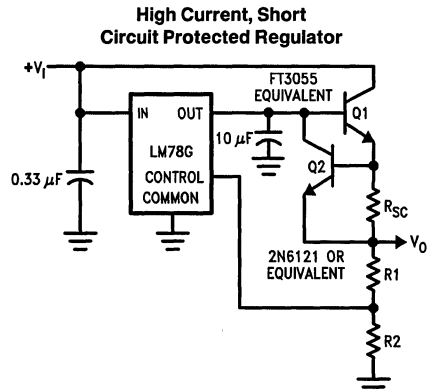
TL/H/10054-13



TL/H/10054-15



TL/H/10054-14



TL/H/10054-17

Note 1: External series pass device is not short circuit protected.

Note 2: If load is not ground referenced, connect reverse biased diodes from outputs to ground.

LM78LXX Series 3-Terminal Positive Regulators

General Description

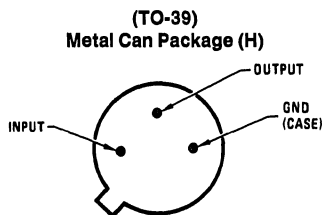
The LM78LXX series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. When used as a zener diode/resistor combination replacement, the LM78LXX usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM78LXX to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment.

The LM78LXX is available in the metal three-lead TO-39(H) package, the plastic TO-92 (Z) package, and the plastic SO-8 (M) package. With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistors is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Features

- Output voltage tolerances of $\pm 5\%$ (LM78LXXAC) over the temperature range
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-92 and metal TO-39 and plastic SO-8 low profile packages
- No external components
- Output voltages of 5.0V, 6.2V, 8.2V, 9.0V, 12V, 15V

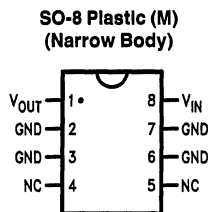
Connection Diagrams



TL/H/7744-1

Bottom View

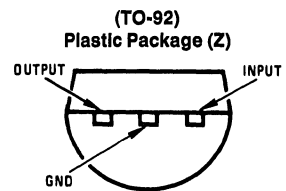
**Order Number LM78L05ACH,
LM78L12ACH or LM78L15ACH
See NS Package Number H03A**



TL/H/7744-2

Top View

**Order Number LM78L05ACM,
LM78L12ACM or LM78L15ACM
See NS Package Number M08A**



TL/H/7744-3

Bottom View

**Order Number
LM78L05ACZ, LM78L09ACZ,
LM78L12ACZ, LM78L15ACZ,
LM78L62ACZ or LM78L82ACZ
See NS Package Number Z03A**

1

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation (Note 5) Internally Limited
Input Voltage 35V

Storage Temperature -65°C to $+150^{\circ}\text{C}$
Operating Junction Temperature 0°C to $+125^{\circ}\text{C}$
Lead Temperature (Soldering, 10 seconds) 265°C
ESD Susceptibility (Note 2) 2 kV

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25^{\circ}\text{C}$, **bold typeface applies over the 0°C to $+125^{\circ}\text{C}$ temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40\text{ mA}$, $C_I = 0.33\text{ }\mu\text{F}$, $C_O = 0.1\text{ }\mu\text{F}$.

LM78L05AC Unless otherwise specified, $V_{IN} = 10\text{V}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		4.8	5	5.2	V
		$7\text{V} \leq V_{IN} \leq 20\text{V}$ $1\text{ mA} \leq I_O \leq 40\text{ mA}$ (Note 3)	4.75		5.25	
		$1\text{ mA} \leq I_O \leq 70\text{ mA}$ (Note 3)	4.75		5.25	
ΔV_O	Line Regulation	$7\text{V} \leq V_{IN} \leq 20\text{V}$		18	75	mV
		$8\text{V} \leq V_{IN} \leq 20\text{V}$		10	54	
ΔV_O	Load Regulation	$1\text{ mA} \leq I_O \leq 100\text{ mA}$		20	60	mV
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$		5	30	
I_Q	Quiescent Current			3	5	mA
ΔI_Q	Quiescent Current Change	$8\text{V} \leq V_{IN} \leq 20\text{V}$			1.0	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			0.1	
V_n	Output Noise Voltage	$f = 10\text{ Hz to }100\text{ kHz}$ (Note 4)		40		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\text{ Hz}$ $8\text{V} \leq V_{IN} \leq 16\text{V}$	47	62		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5\text{ mA}$		-0.65		mV/ $^{\circ}\text{C}$
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			6.7	7	V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface applies over the 0°C to $+125^\circ\text{C}$ temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$. (Continued)

LM78L62AC Unless otherwise specified, $V_{IN} = 12\text{V}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		5.95	6.2	6.45	V
		$8.5\text{V} \leq V_{IN} \leq 20\text{V}$ $1\text{ mA} \leq I_O \leq 40\text{ mA}$ (Note 3)	5.9		6.5	
		$1\text{ mA} \leq I_O \leq 70\text{ mA}$ (Note 3)	5.9		6.5	
ΔV_O	Line Regulation	$8.5\text{V} \leq V_{IN} \leq 20\text{V}$		65	175	mV
		$9\text{V} \leq V_{IN} \leq 20\text{V}$		55	125	
ΔV_O	Load Regulation	$1\text{ mA} \leq I_O \leq 100\text{ mA}$		13	80	mV
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$		6	40	
I_Q	Quiescent Current			2	5.5	mA
ΔI_Q	Quiescent Current Change	$8\text{V} \leq V_{IN} \leq 20\text{V}$			1.5	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			0.1	
V_n	Output Noise Voltage	$f = 10\text{ Hz to } 100\text{ kHz}$ (Note 4)		50		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\text{ Hz}$ $10\text{V} \leq V_{IN} \leq 20\text{V}$	40	46		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5\text{ mA}$		-0.75		mV/ $^\circ\text{C}$
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			7.9		V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface applies over the 0°C to $+125^\circ\text{C}$ temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$. (Continued)

LM78L82AC Unless otherwise specified, $V_{IN} = 14\text{V}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		7.87	8.2	8.53	V
		$11\text{V} \leq V_{IN} \leq 23\text{V}$ $1\text{ mA} \leq I_O \leq 40\text{ mA}$ (Note 3)	7.8		8.6	
		$1\text{ mA} \leq I_O \leq 70\text{ mA}$ (Note 3)	7.8		8.6	
ΔV_O	Line Regulation	$11\text{V} \leq V_{IN} \leq 23\text{V}$		80	175	mV
		$12\text{V} \leq V_{IN} \leq 23\text{V}$		70	125	
ΔV_O	Load Regulation	$1\text{ mA} \leq I_O \leq 100\text{ mA}$		15	80	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$		8	40	
I_Q	Quiescent Current			2	5.5	mA
ΔI_Q	Quiescent Current Change	$12\text{V} \leq V_{IN} \leq 23\text{V}$			1.5	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			0.1	
V_n	Output Noise Voltage	$f = 10\text{ Hz to }100\text{ kHz}$ (Note 4)		60		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\text{ Hz}$ $12\text{V} \leq V_{IN} \leq 22\text{V}$	39	45		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5\text{ mA}$		-0.8		$\text{mV}/^\circ\text{C}$
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			9.9		V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface applies over the 0°C to $+125^\circ\text{C}$ temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$. (Continued)

LM78L09AC Unless otherwise specified, $V_{IN} = 15\text{V}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		8.64	9.0	9.36	V
		$11.5\text{V} \leq V_{IN} \leq 24\text{V}$ $1\text{ mA} \leq I_O \leq 40\text{ mA}$ (Note 3)	8.55		9.45	
		$1\text{ mA} \leq I_O \leq 70\text{ mA}$ (Note 3)	8.55		9.45	
ΔV_O	Line Regulation	$11.5\text{V} \leq V_{IN} \leq 24\text{V}$		100	200	mV
		$13\text{V} \leq V_{IN} \leq 24\text{V}$		90	150	
ΔV_O	Load Regulation	$1\text{ mA} \leq I_O \leq 100\text{ mA}$		20	90	mV
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$		10	45	
I_Q	Quiescent Current			2	5.5	mA
ΔI_Q	Quiescent Current Change	$11.5\text{V} \leq V_{IN} \leq 24\text{V}$			1.5	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			0.1	
V_n	Output Noise Voltage			70		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\text{ Hz}$ $15\text{V} \leq V_{IN} \leq 25\text{V}$	38	44		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5\text{ mA}$		-0.9		mV/ $^\circ\text{C}$
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			10.7		V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface applies over the 0°C to $+125^\circ\text{C}$ temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$. (Continued)

LM78L12AC Unless otherwise specified, $V_{IN} = 19\text{V}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		11.5	12	12.5	V
		$14.5\text{V} \leq V_{IN} \leq 27\text{V}$ $1\text{ mA} \leq I_O \leq 40\text{ mA}$ (Note 3)	11.4		12.6	
		$1\text{ mA} \leq I_O \leq 70\text{ mA}$ (Note 3)	11.4		12.6	
ΔV_O	Line Regulation	$14.5\text{V} \leq V_{IN} \leq 27\text{V}$		30	180	mV
		$16\text{V} \leq V_{IN} \leq 27\text{V}$		20	110	
ΔV_O	Load Regulation	$1\text{ mA} \leq I_O \leq 100\text{ mA}$		30	100	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$		10	50	
I_Q	Quiescent Current			3	5	mA
ΔI_Q	Quiescent Current Change	$16\text{V} \leq V_{IN} \leq 27\text{V}$			1	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			0.1	
V_n	Output Noise Voltage			80		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\text{ Hz}$ $15\text{V} \leq V_{IN} \leq 25\text{V}$	40	54		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5\text{ mA}$		-1.0		mV/ $^\circ\text{C}$
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			13.7	14.5	V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface applies over the 0°C to $+125^\circ\text{C}$ temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40\text{ mA}$, $C_1 = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$. (Continued)

LM78L15AC Unless otherwise specified, $V_{IN} = 23\text{V}$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		14.4	15.0	15.6	V
		$17.5\text{V} \leq V_{IN} \leq 30\text{V}$ $1\text{ mA} \leq I_O \leq 40\text{ mA}$ (Note 3)	14.25		15.75	
		$1\text{ mA} \leq I_O \leq 70\text{ mA}$ (Note 3)	14.25		15.75	
ΔV_O	Line Regulation	$17.5\text{V} \leq V_{IN} \leq 30\text{V}$		37	250	mV
		$20\text{V} \leq V_{IN} \leq 30\text{V}$		25	140	
ΔV_O	Load Regulation	$1\text{ mA} \leq I_O \leq 100\text{ mA}$		35	150	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$		12	75	
I_Q	Quiescent Current			3	5	mA
ΔI_Q	Quiescent Current Change	$20\text{V} \leq V_{IN} \leq 30\text{V}$			1	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			0.1	
V_n	Output Noise Voltage			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\text{ Hz}$ $18.5\text{V} \leq V_{IN} \leq 28.5\text{V}$	37	51		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5\text{ mA}$		-1.3		mV/ $^\circ\text{C}$
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			16.7	17.5	V

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device outside of its stated operating conditions.

Note 2: Human body model, $1.5\text{ k}\Omega$ in series with 100 pF .

Note 3: Power dissipation $\leq 0.75\text{W}$.

Note 4: Recommended minimum load capacitance of $0.01\ \mu\text{F}$ to limit high frequency noise.

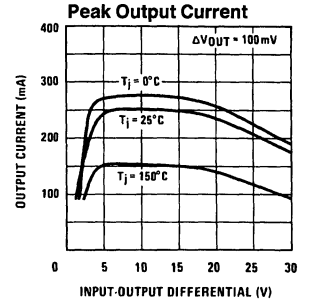
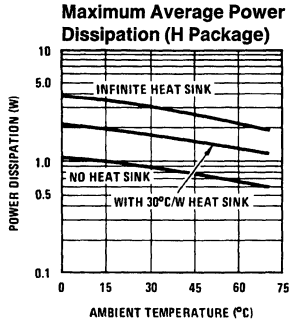
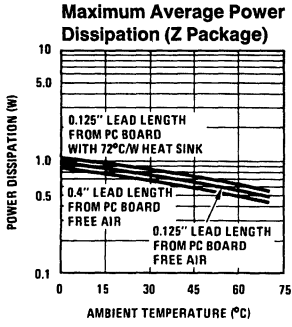
Note 5: Typical thermal resistance values for the packages are:

H Package: $R_{th}(J-C) = 26\ ^\circ\text{C}/\text{W}$, $R_{th}(J-A) = 120\ ^\circ\text{C}/\text{W}$

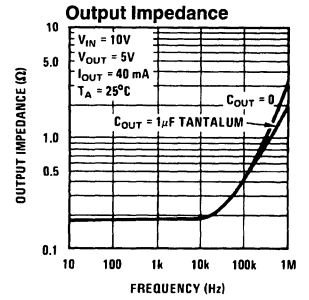
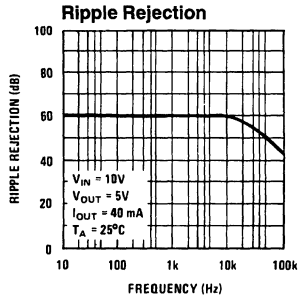
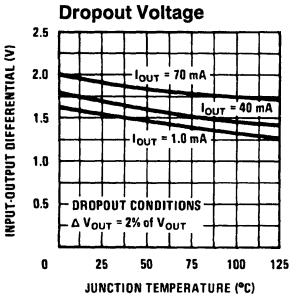
Z Package: $R_{th}(J-C) = 60\ ^\circ\text{C}/\text{W}$, $R_{th}(J-A) = 230\ ^\circ\text{C}/\text{W}$

M Package: $R_{th}(J-A) = 180\ ^\circ\text{C}/\text{W}$

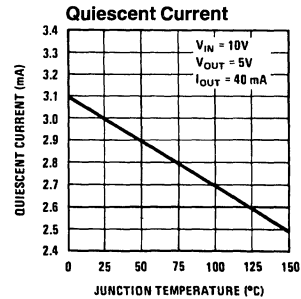
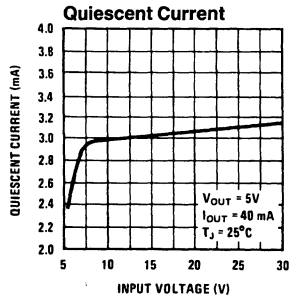
Typical Performance Characteristics



TL/H/7744-4



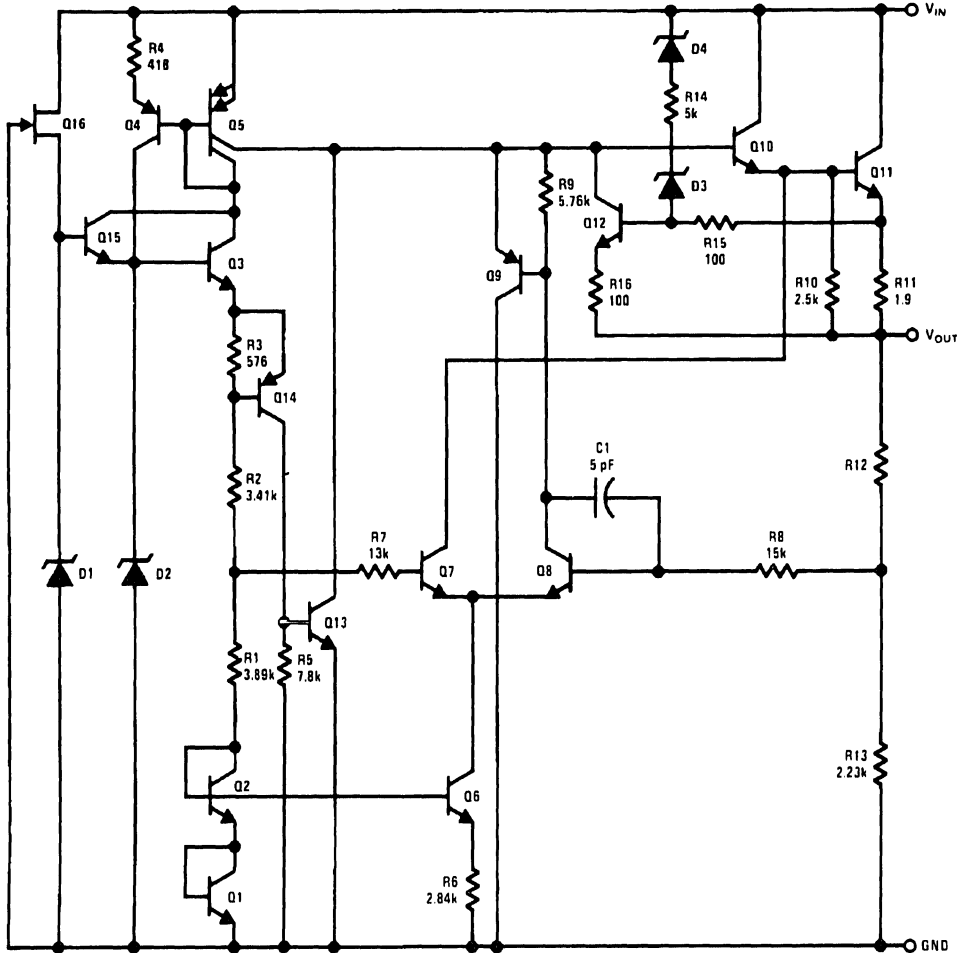
TL/H/7744-5



TL/H/7744-6

Equivalent Circuit

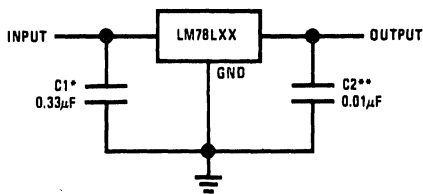
LM78LXX



TL/H/7744-7

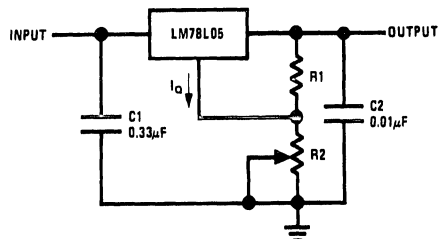
Typical Applications

Fixed Output Regulator



TL/H/7744-8

Adjustable Output Regulator



TL/H/7744-9

*Required if the regulator is located more than 3" from the power supply filter.

**See Note 4 in the electrical characteristics table.

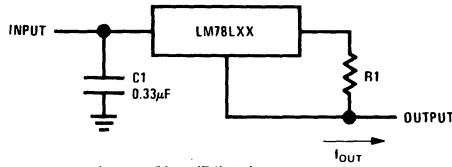
$$V_{OUT} = 5V + (5V/R1 + I_O) R2$$

$$5V/R1 > 3 I_O, \text{ load regulation } (L_r) \approx [(R1 + R2)/R1] (L_r \text{ of LM78L05})$$

1

Typical Applications (Continued)

Current Regulator

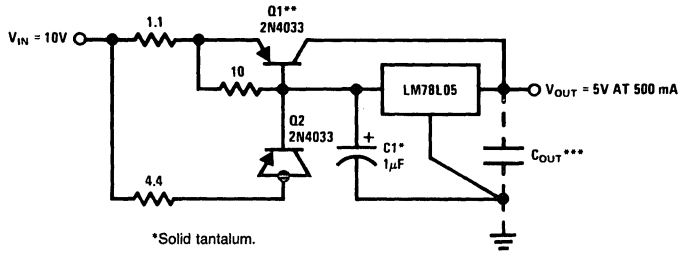


$$I_{OUT} = (V_{OUT}/R1) + I_Q$$

$$> I_Q = 1.5 \text{ mA over line and load changes}$$

TL/H/7744-10

5V, 500 mA Regulator with Short Circuit Protection



*Solid tantalum.

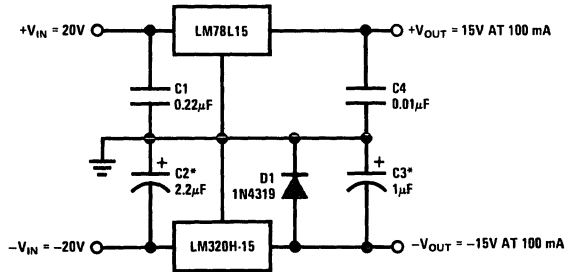
**Heat sink Q1.

***Optional: Improves ripple rejection and transient response.

Load Regulation: $0.6\% \leq I_L \leq 250 \text{ mA}$ pulsed with $t_{ON} = 50 \text{ ms}$.

TL/H/7744-11

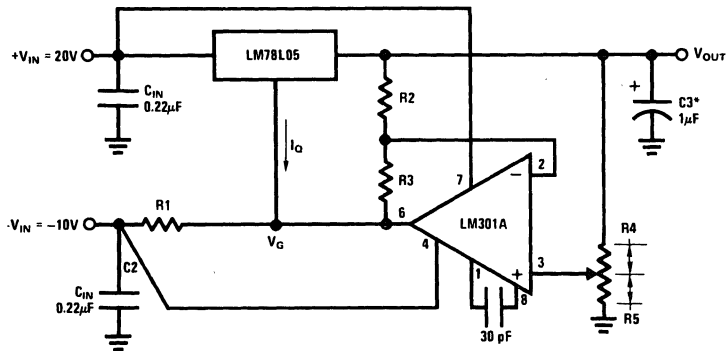
± 15V, 100 mA Dual Power Supply



*Solid tantalum.

TL/H/7744-12

Variable Output Regulator 0.5V-18V



*Solid tantalum.

$$V_{OUT} = V_G + 5V, R1 = (-V_{IN}/I_Q \text{ LM78L05})$$

$$V_{OUT} = 5V (R2/R4) \text{ for } (R2 + R3) = (R4 + R5)$$

$$\text{A } 0.5V \text{ output will correspond to } (R2/R4) = 0.1 (R3/R4) = 0.9$$

TL/H/7744-13

LM78MG

4-Terminal Adjustable Voltage Regulator

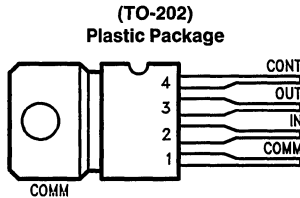
General Description

The LM78MG is a 4-terminal adjustable positive voltage regulator that has an output voltage range between 5V and 30V. It is designed to operate with a maximum input voltage of 40V and to deliver up to 500 mA of load current. Output current capability can be increased to greater than 10A through use of one or more external transistors.

Features

- Output current in excess of 0.5A
- Output voltage adjustable from 5V to 30V
- Internal thermal overload protection
- Internal short circuit current protection
- Output transistor safe-area protection

Connection Diagram and Ordering Information

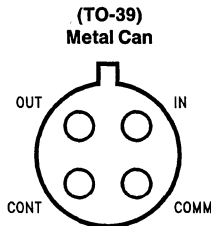


TL/H/10058-1

Top View

Heat sink tabs connected to comm through device substrate. Not recommended for direct electrical connection.

Order Number LM78MGCP
See NS Package Number P04A



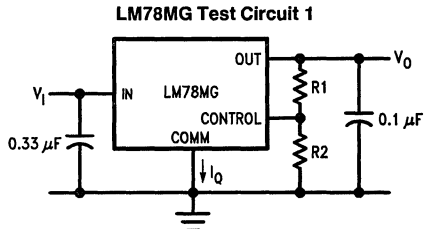
TL/H/10058-23

Bottom View

Order Number LM78MGH/883
See NS Package Number HA04E

$$V_O = \left(\frac{R_1 + R_2}{R_2} \right) V_{CONT}$$

V_{CONT} Nominally = 5V
Recommended R_2 current \approx 1 mA
 $R_2 = 5 \text{ k}\Omega$



TL/H/10058-20

1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	-65°C to +150°C
Junction Temperature Range	
LM78MGC	0°C to +150°C
LM78MG	-55°C to +150°C

Lead Temperature (Soldering, 10 sec.)	265°C
Internal Power Dissipation	Internally Limited
Input Voltage	+40V
Control Lead Voltage	$0V \leq V_C \leq V_O$

LM78MGC

Electrical Characteristics $0^\circ\text{C} \leq T_A \leq 125^\circ\text{C}$ for LM78MGC, $V_I = 10\text{V}$, $I_O = 350\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$, Test Circuit 1, unless otherwise specified

Symbol	Parameter	Conditions (Notes 1, 2)	Min	Typ	Max	Units
V_{IN}	Input Voltage Range	$T_J = 25^\circ\text{C}$	7.5		40	V
V_{OUT}	Output Voltage Range	$V_I = V_O + 5.0\text{V}$	5.0		30	V
V_O	Output Voltage Tolerance	$(V_O + 3.0\text{V}) \leq V_I \leq (V_O + 15\text{V})$, $5.0\text{ mA} \leq I_O \leq 350\text{ mA}$, $P_D \leq 5.0\text{W}$, $V_{I\text{ Max}} = 38\text{V}$		$T_J = 25^\circ\text{C}$	4.0	% (V_O)
					5.0	
$\Delta V_O / \Delta V_{IN}$	Line Regulation	$T_J = 25^\circ\text{C}$, $I_O = 200\text{ mA}$, $V_O \leq 10\text{V}$, $(V_O + 2.5\text{V}) \leq V_I \leq (V_O + 20\text{V})$,			1.0	% (V_O)
$\Delta V_O / \Delta I_{LOAD}$	Load Regulation	$T_J = 25^\circ\text{C}$, $5.0\text{ mA} \leq I_O \leq 500\text{ mA}$, $V_I = V_O + 7.0\text{V}$			1.0	% (V_O)
I_C	Control Lead Current	$T_J = 25^\circ\text{C}$		1.0	6.0	μA
					7.0	
I_Q	Quiescent Current	$T_J = 25^\circ\text{C}$		2.8	5.0	mA
					6.0	
$\Delta V_{IN} / \Delta V_{OUT}$	Ripple Rejection	$I_O = 125\text{ mA}$, $8.0\text{V} \leq V_I \leq 18\text{V}$, $V_O = 5.0\text{V}$, $f = 2400\text{ Hz}$	62	80		dB
e_n	Output Noise Voltage	$10\text{ Hz} \leq f \leq 100\text{ kHz}$, $V_O = 5.0\text{V}$		8	40	$\mu\text{V}/V_O$
$V_{IN} - V_{OUT}$	Dropout Voltage (Note 3)			2	2.5	V
I_{SC}	Short Circuit Current	$V_I = 35\text{V}$, $T_J = 25^\circ\text{C}$			600	mA
I_{pk}	Peak Output Current	$T_J = 25^\circ\text{C}$	0.4	0.8	1.4	A
$\Delta V_O / \Delta T$	Average Temperature Coefficient of Output Voltage	$V_O = 5.0\text{V}$, $I_O = 5.0\text{ mA}$			0.4	mV/°C/ V_O
		$T_A = 0^\circ\text{C}$ to $+25^\circ\text{C}$ $T_A = 25^\circ\text{C}$ to 125°C			0.3	
V_C	Control Lead Voltage (Reference)	$T_J = 25^\circ\text{C}$	4.8	5.0	5.2	V
			4.75		5.25	

LM78MG

Electrical Characteristics $-55^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$ for LM78MG, $V_I = 10\text{V}$, $I_O = 350\text{ mA}$, $C_I = 0.33\ \mu\text{F}$, $C_O = 0.1\ \mu\text{F}$, Test Circuit 1, unless otherwise specified (Note 6).

Symbol	Parameter	Conditions (Notes 1, 2)	Min	Typ	Max	Units
V_{IN}	Input Voltage Range	$T_J = 25^{\circ}\text{C}$	7.5		40	V
V_{OUT}	Output Voltage Range	$V_I = V_O + 5.0\text{V}$	5.0		30	V
V_O	Output Voltage Tolerance	$(V_O + 3.0\text{V}) \leq V_I \leq (V_O + 15\text{V})$, $5.0\text{ mA} \leq I_O \leq 350\text{ mA}$, $P_D \leq 5.0\text{W}$, $V_{I\text{ Max}} = 38\text{V}$	$T_J = 25^{\circ}\text{C}$		4.0	% (V_O)
					5.0	
$\Delta V_O/\Delta V_{IN}$	Line Regulation	$T_J = 25^{\circ}\text{C}$, $I_O = 200\text{ mA}$, $V_O \leq 10\text{V}$, $(V_O + 2.5\text{V}) \leq V_I \leq (V_O + 20\text{V})$,			1.0	%(V_O)
$\Delta V_O/\Delta I_{LOAD}$	Load Regulation	$T_J = 25^{\circ}\text{C}$, $5.0\text{ mA} \leq I_O \leq 500\text{ mA}$, $V_I = V_O + 7.0\text{V}$			1.0	%(V_O)
I_C	Control Lead Current	$T_J = 25^{\circ}\text{C}$		1.0	6.0	μA
					7.0	
I_Q	Quiescent Current (Note 5)	$T_J = 25^{\circ}\text{C}$		2.8	7.0	mA
					8.0	
$\Delta V_{IN}/\Delta V_{OUT}$	Ripple Rejection	$I_O = 125\text{ mA}$, $V_I = 10\text{V}$, $V_O = 5.0\text{V}$, $f = 2400\text{ Hz}$	60	80		dB
e_n	Output Noise Voltage	$10\text{ Hz} \leq f \leq 100\text{ kHz}$, $V_O = 5.0\text{V}$		8	40	$\mu\text{V}/V_O$
$V_{IN}-V_{OUT}$	Dropout Voltage (Note 3)			2	2.5	V
I_{SC}	Short Circuit Current	$V_I = 35\text{V}$, $T_J = 25^{\circ}\text{C}$			600	mA
I_{pk}	Peak Output Current	$T_J = 25^{\circ}\text{C}$, $V_I = 12\text{V}$ (Note 4)	0.4	0.8	1.4	A
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage	$V_O = 5.0\text{V}$, $I_O = 5.0\text{ mA}$	$T_A = 0^{\circ}\text{C}$ to $+25^{\circ}\text{C}$		0.4	mV/ $^{\circ}\text{C}/V_O$
			$T_A = 25^{\circ}\text{C}$ to 125°C		0.3	
V_C	Control Lead Voltage (Reference)	$T_J = 25^{\circ}\text{C}$		4.8	5.0	V
				4.75		

Note 1: V_O is defined as $V_O = \frac{R1 + R2}{R2}(5.0)$.

Note 2: All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W \leq 10\text{ ms}$, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Dropout voltage is defined as that input/output voltage differential which causes the output voltage to decrease by 5% of its initial value.

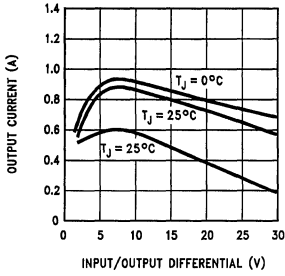
Note 4: The peak output current is defined as the output current when V_{OUT} is equal to 90% of its nominal value.

Note 5: This measurement includes 1 mA provided to the output resistors.

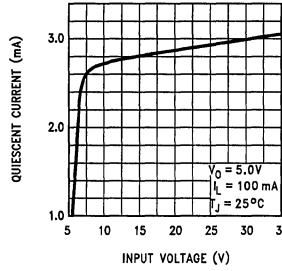
Note 6: A military RETS electrical test specification is available on request. At the time of printing, the LM78MGH RETS specification complied fully with the limits in the table on this page.

Typical Performance Characteristic

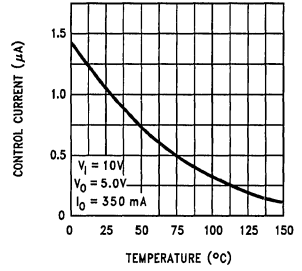
Peak Output Current vs Input/Output Differential Voltage



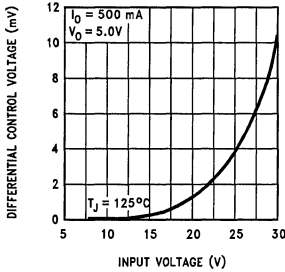
Quiescent Current vs Input Voltage



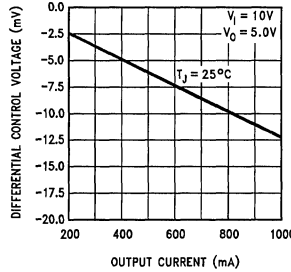
Control Current vs Temperature



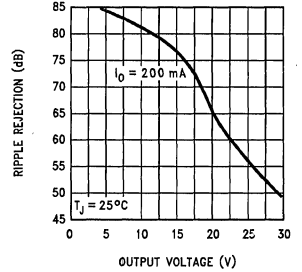
Differential Control Voltage vs Input Voltage



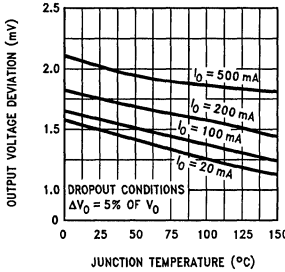
Differential Control Voltage vs Output Current



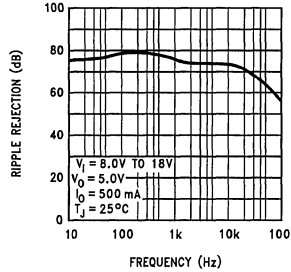
Ripple Rejection vs Output Voltage



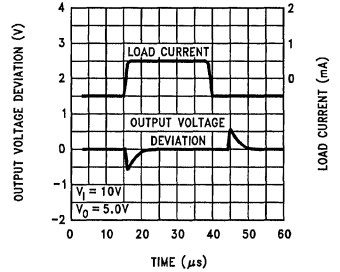
Dropout Voltage vs Junction Temperature



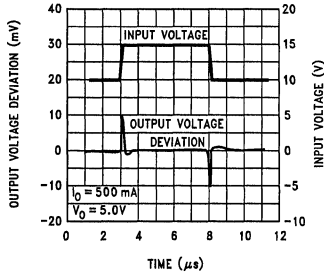
Ripple Rejection vs Frequency



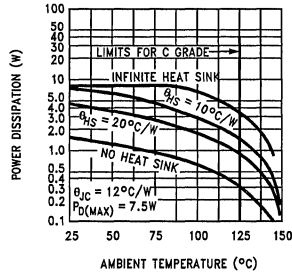
Load Transient Response



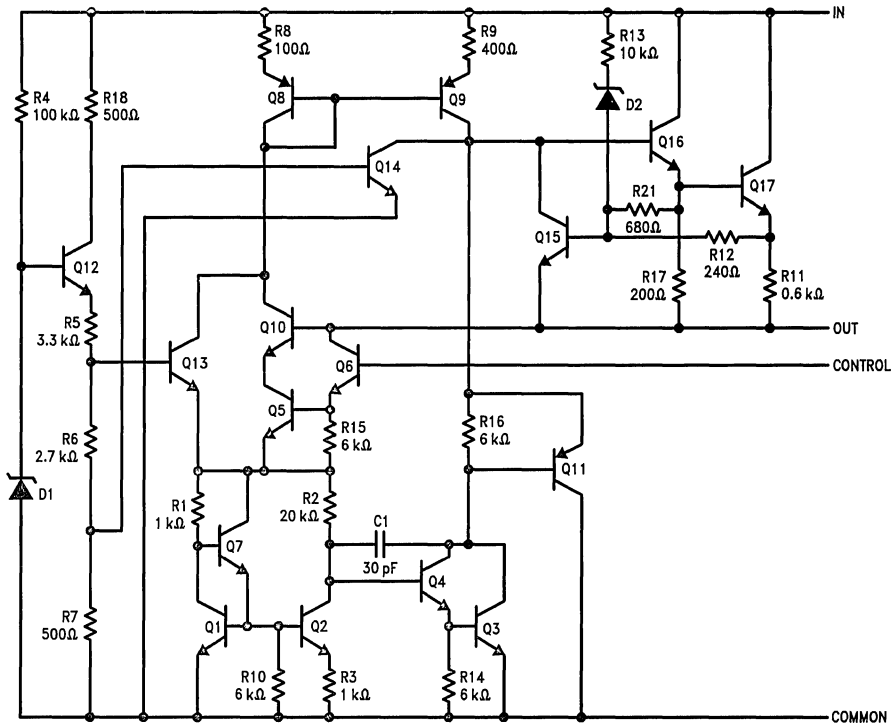
Line Transient Response



Worst Case Power Dissipation vs Ambient Temperature



LM78MG Equivalent Circuit



TL/H/10058-3

Design Considerations

The LM78MGC variable voltage regulator has an output voltage which varies from V_{CONT} to typically

$$V_I - 2.0V \text{ by } V_O = V_{CONT} \frac{(R1 + R2)}{R2}$$

The nominal reference voltage of the LM78MG is 5.0V. If we allow 1.0 mA to flow in the control swing to eliminate bias current effects, we can make $R2 = 5 \text{ k}\Omega$ in the LM78MG. The output voltage is then: $V_O = (R1 + R2)$ Volts, where $R1$ and $R2$ are in $\text{k}\Omega$ s.

Example: If $R2 = 5.0 \text{ k}\Omega$ and $R1 = 10 \text{ k}\Omega$ then $V_O = 15V$ nominal, for the LM78MGC.

By proper wiring of the feedback resistors, load regulation of the device can be improved significantly.

The LM78MGC regulator has thermal overload protection from excessive power, internal short circuit protection which limits the circuit's maximum current, and output transistor safe-area protection for reducing the output current as the voltage across the pass transistor is increased.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature in order to meet data sheet specifications.

To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

Package	Typ θ_{JC}	Max θ_{JC}	Typ θ_{JA}	Max θ_{JA}
Power Watt	8.0	12.0	70	75

$$P_{D \text{ Max}} = \frac{T_{J \text{ Max}} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or}$$

$$\frac{T_{J \text{ Max}} - T_A}{\theta_{JA}} \text{ (without a heat sink)}$$

$$\theta_{CA} = \theta_{CS} + \theta_{SA}$$

Solving for T_J :

$$T_J = T_A + P_D(\theta_{JC} + \theta_{CA}) \text{ or}$$

$$T_A + P_D\theta_{JA} \text{ (without heat sink)}$$

Where

T_J = Junction Temperature

T_A = Ambient Temperature

P_D = Power Dissipation

θ_{JC} = Junction-to-Case Thermal Resistance

θ_{CA} = Case-to-Ambient Thermal Resistance

θ_{CS} = Case-to-Heat Sink Thermal Resistance

θ_{SA} = Heat Sink-to-Ambient Thermal Resistance

θ_{JA} = Junction-to-Ambient Thermal Resistance

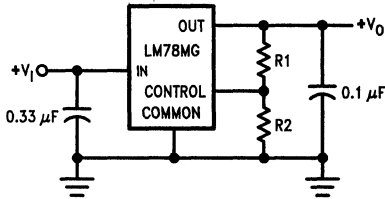
Typical Applications

Bypass capacitors are recommended for stable operation of the LM78MG over the input voltage and output current ranges. Output bypass capacitors will improve the transient response of the regulator.

The bypass capacitors, (0.33 μF on the input, 0.1 μF on the output) should be ceramic or solid tantalum which have good high frequency characteristics. The bypass capacitors should be mounted with the shortest leads, and if possible, directly across the regulator terminals.

Note 1: All resistor values in ohms.

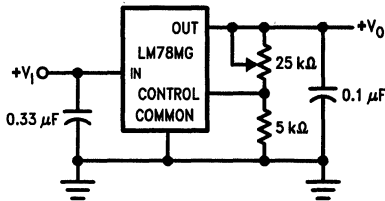
Basic Positive Regulator



TL/H/10058-8

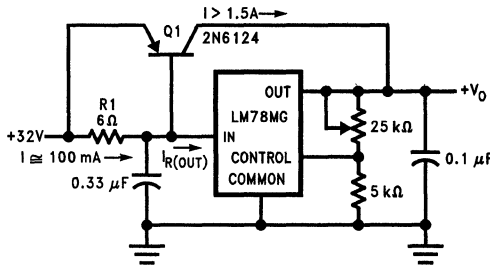
$$V_O = V_{CONT} \left(\frac{R_1 + R_2}{R_2} \right)$$

Positive 5.0V to 30V Adjustable Regulator



TL/H/10058-9

Positive 5.0V to 30V Adjustable Regulator I_O > 1.5A

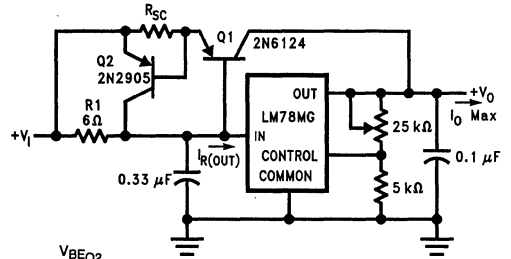


TL/H/10058-10

$$R_1 = \frac{\beta V_{BE(Q1)}}{\beta I_{R \text{ Max}} - I_O \text{ Max}}$$

Note: External series pass device is not short circuit protected.

Positive High Current Short Circuit Protected Regulator

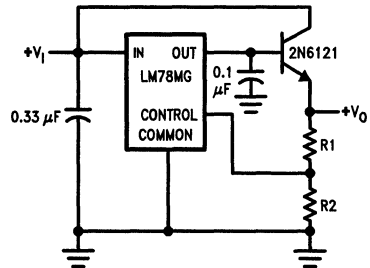


TL/H/10058-14

$$R_{SC} = \frac{V_{BE(Q2)}}{I_{O \text{ Max}}}$$

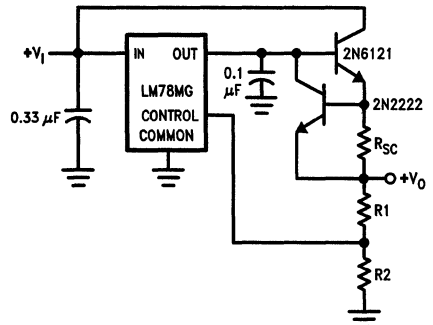
$$R_1 = \frac{\beta V_{BE(Q1)} + \beta I_{O \text{ Max}} R_{SC}}{\beta I_{R \text{ Max}} - I_{O \text{ Max}}}$$

Positive High-Current Voltage Regulators



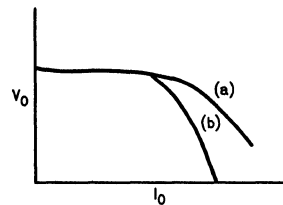
TL/H/10058-12

External Series Pass (a)



TL/H/10058-15

External Series Pass with Short-Circuit Limit (b)



Current Limit Graph

TL/H/10058-13

LM79MXX Series 3-Terminal Negative Regulators

General Description

The LM79MXX series of 3-terminal regulators is available with fixed output voltages of $-5V$, $-8V$, $-12V$, and $-15V$. These devices need only one external component—a compensation capacitor at the output. The LM79MXX series is packaged in the TO-202 power package, TO-220 power package, and TO-39 metal can and is capable of supplying 0.5A of output current.

These regulators employ internal current limiting, safe area protection, and thermal shutdown for protection against virtually all overload conditions.

Low ground pin current of the LM79MXX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

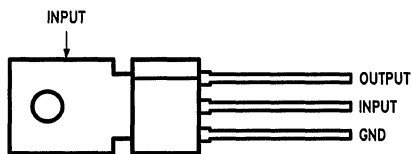
For output voltage other than $-5V$, $-8V$, $-12V$, and $-15V$ the LM137 series provides an output voltage range from $-1.2V$ to $-57V$.

Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 0.5A output current
- 4% tolerance on preset output voltage

Connection Diagrams

TO-202 Plastic Package (P)

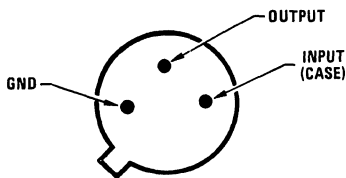


TL/H/10483-5

Front View

Order Number LM79M05CP, LM79M12CP or LM79M15CP
See NS Package Number P03A

TO-39 Metal Can Package (H)

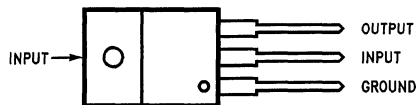


Bottom View

TL/H/10483-6

Order Number LM79M05CH, LM79M08CH,
LM79M12CH or LM79M15CH
See NS Package Number H03A

TO-220 Plastic Package (T)



TL/H/10483-7

Front View

Order Number LM79M05CT, LM79M08CT,
LM79M12CT or LM79M15CT
See NS Package Number T03B

1

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage

$V_O = -5V$	-25V
$V_O = -8V, -12V, -15V$	-35V

Input/Output Differential

$V_O = -5V$	25V
$V_O = -8V, -12V, -15V$	30V

Power Dissipation (Note 2)

Internally Limited

Operating Junction Temperature Range 0°C to +125°C

Storage Temperature Range -65°C to +150°C

Lead Temperature (Soldering, 10 sec.) 230°C

ESD Susceptibility TBD

Electrical Characteristics LM79M05C, LM79M08CConditions unless otherwise noted: $I_{OUT} = 350\text{ mA}$, $C_{IN} = 2.2\ \mu\text{F}$, $C_{OUT} = 1\ \mu\text{F}$, $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$

Part Number			LM79M05C			LM79M08C			Units
Output Voltage			-5V			-8V			
Input Voltage (Unless Otherwise Specified)			-10V			-14V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	$T_J = 25^\circ\text{C}$	-4.8	-5.0	-5.2	-7.7	-8.0	-8.3	V
		$5\text{ mA} \leq I_{OUT} \leq 350\text{ mA}$	-4.75		-5.25	-7.6		-8.4	V
ΔV_O	Line Regulation	$T_J = 25^\circ\text{C}$ (Note 3)	8		50	5		80	mV
			$(-25 \leq V_{IN} \leq -7)$			$(-25 \leq V_{IN} \leq -10.5)$			mV
			2		30	3		50	
			$(-18 \leq V_{IN} \leq -8)$			$(-21 \leq V_{IN} \leq -11)$			
ΔV_O	Load Regulation	$T_J = 25^\circ\text{C}$, (Note 3) $5\text{ mA} \leq I_{OUT} \leq 0.5\text{A}$	30		100	30		160	mV
I_Q	Quiescent Current	$T_J = 25^\circ\text{C}$	1		2	1.5		3	mA
ΔI_Q	Quiescent Current Change	With Input Voltage			0.4			0.4	mA
		With Load, $5\text{ mA} \leq I_{OUT} \leq 350\text{ mA}$						0.4	mA
V_n	Output Noise Voltage	$T_A = 25^\circ\text{C}$, $10\text{ Hz} \leq f \leq 100\text{ Hz}$	150			250			μV
	Ripple Rejection	$f = 120\text{ Hz}$	54	66		54	66		dB
			$(-18 \leq V_{IN} \leq -8)$			$(-21 \leq V_{IN} \leq -11)$			
	Dropout Voltage	$T_J = 25^\circ\text{C}$, $I_{OUT} = 0.5\text{A}$	1.1			1.1			V
I_{OMAX}	Peak Output Current	$T_J = 25^\circ\text{C}$	800			800			mA
	Average Temperature Coefficient of Output Voltage	$I_{OUT} = 5\text{ mA}$, $0^\circ\text{C} \leq T_J \leq 100^\circ\text{C}$	-0.4			-0.6			$\text{mV}/^\circ\text{C}$

Electrical Characteristics LM79M12C, LM79M15CConditions unless otherwise noted: $I_{OUT} = 350 \text{ mA}$, $C_{IN} = 2.2 \mu\text{F}$, $C_{OUT} = 1 \mu\text{F}$, $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$

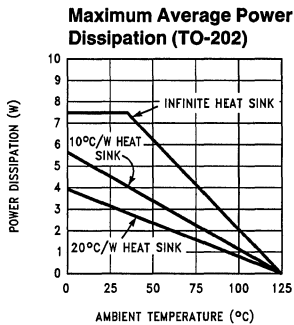
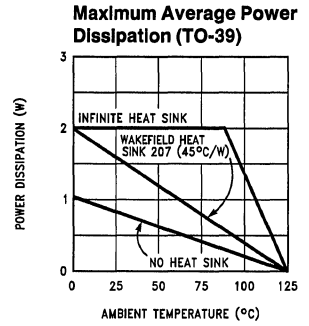
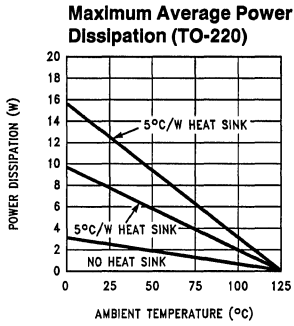
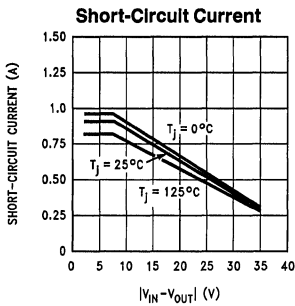
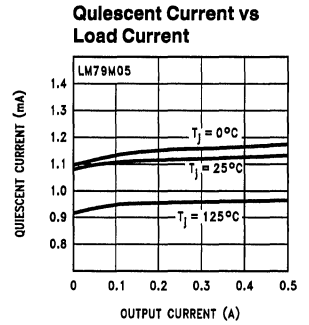
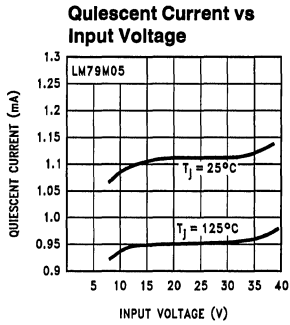
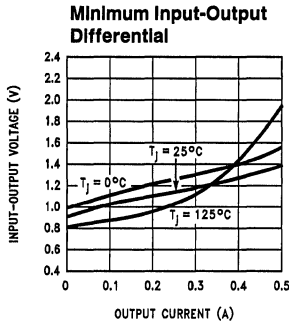
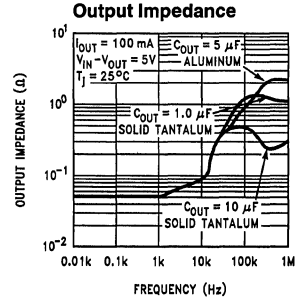
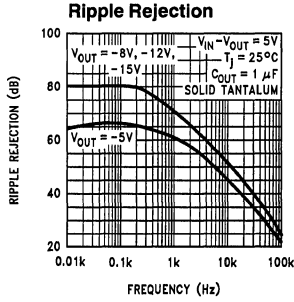
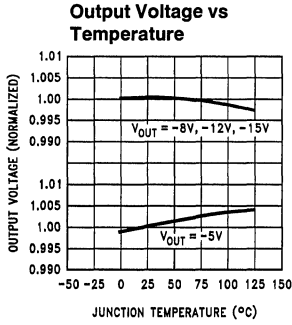
Part Number			LM79M12C			LM79M15C			Units
Output Voltage			-12V			-15V			
Input Voltage (Unless Otherwise Specified)			-19V			-23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	$T_J = 25^\circ\text{C}$	-11.5	-12.0	-12.5	-14.4	-15.0	-15.6	V
		$5 \text{ mA} \leq I_{OUT} \leq 350 \text{ mA}$	-11.4 ($-27 \leq V_{IN} \leq -14.5$)		-12.6	-14.25 ($-30 \leq V_{IN} \leq -10.5$)		-15.75	V
ΔV_O	Line Regulation	$T_J = 25^\circ\text{C}$ (Note 3)		5	80		5	80	mV
				($-30 \leq V_{IN} \leq -14.5$)			($-30 \leq V_{IN} \leq -17.5$)		
				3	50		3	50	mV
			($-25 \leq V_{IN} \leq -15$)			($-28 \leq V_{IN} \leq -18$)			
ΔV_O	Load Regulation	$T_J = 25^\circ\text{C}$, (Note 3) $5 \text{ mA} \leq I_{OUT} \leq 0.5\text{A}$		30	240		30	240	mV
I_Q	Quiescent Current	$T_J = 25^\circ\text{C}$		1.5	3		1.5	3	mA
ΔI_Q	Quiescent Current Change	With Input Voltage Change			0.4			0.4	mA
			($-30 \leq V_{IN} \leq -14.5$)			($-30 \leq V_{IN} \leq -27$)			
		With Load, $5 \text{ mA} \leq I_{OUT} \leq 350 \text{ mA}$			0.4			0.4	mA
V_n	Output Noise Voltage	$T_A = 25^\circ\text{C}$, $10 \text{ Hz} \leq f \leq 100 \text{ Hz}$		400			400		μV
	Ripple Rejection	$f = 120 \text{ Hz}$	54	70		54	70		dB
			($-25 \leq V_{IN} \leq -15$)			($-30 \leq V_{IN} \leq -17.5$)			
	Dropout Voltage	$T_J = 25^\circ\text{C}$, $I_{OUT} = 0.5\text{A}$		1.1			1.1		V
I_{OMAX}	Peak Output Current	$T_J = 25^\circ\text{C}$		800			800		mA
	Average Temperature Coefficient of Output Voltage	$I_{OUT} = 5 \text{ mA}$, $0^\circ\text{C} \leq T_J \leq 100^\circ\text{C}$		-0.8			-1.0		$\text{mV}/^\circ\text{C}$

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Refer to Typical Performance Characteristics and Design Considerations for details.

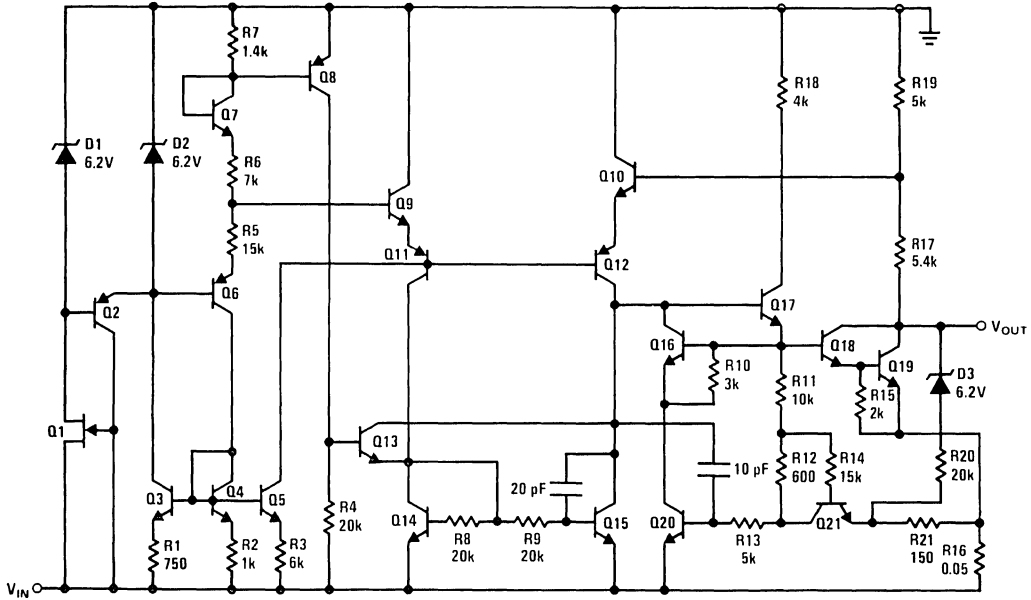
Note 3: Regulation is measured at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

Typical Performance Characteristics



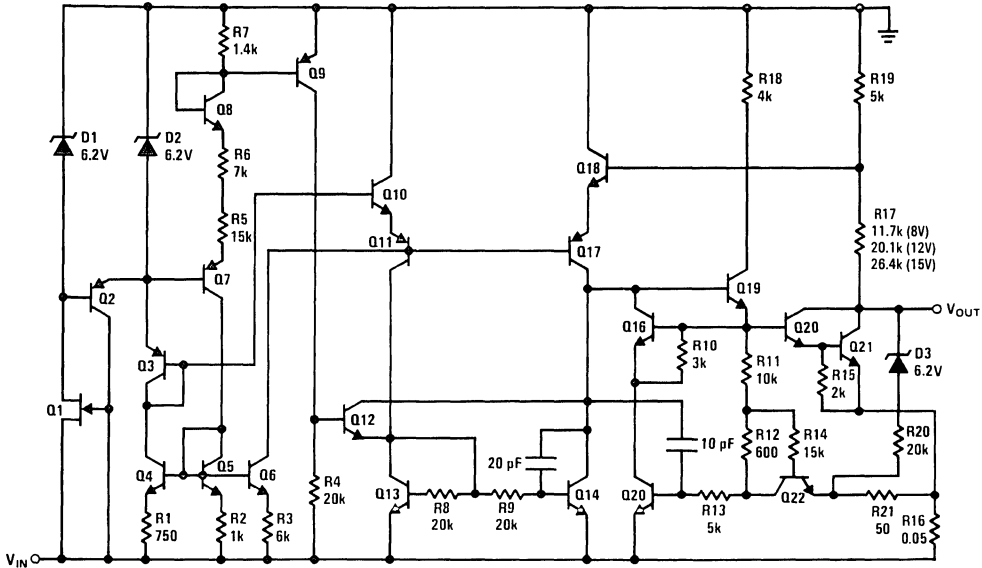
Schematic Diagrams

-5V



TL/H/10483-8

-8V, -12V and -15V



TL/H/10483-9

1

Design Considerations

The LM79MXX fixed voltage regulator series have thermal-overload protection from excessive power, internal short-circuit protection which limits the circuit's maximum current, and output transistor safe-area compensation for reducing the output current as the voltage across the pass transistor is increased.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature in order to meet data sheet specifications. To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

Package	θ_{JC} (°C/W)	θ_{JA} (°C/W)
TO-39	18	120
TO-202	12	70
TO-220	3	40

$$P_{D\text{MAX}} = \frac{T_{J\text{MAX}} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or} \quad (1)$$

$$= \frac{T_{J\text{MAX}} - T_A}{\theta_{JA}} \text{ (Without a Heat Sink)}$$

$$\theta_{CA} = \theta_{CS} + \theta_{SA}$$

Solving for T_J :

$$T_J = T_A + P_D (\theta_{JC} + \theta_{CA}) \text{ or}$$

$$= T_A + P_D \theta_{JA} \text{ (Without a Heat Sink)}$$

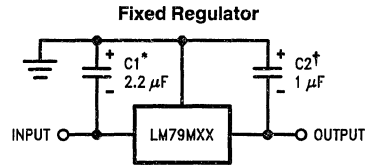
Where

- T_J = Junction Temperature
- T_A = Ambient Temperature
- P_D = Power Dissipation
- θ_{JC} = Junction-to-Case Thermal Resistance
- θ_{CA} = Case-to-Ambient Thermal Resistance
- θ_{CS} = Case-to-Heat Sink Thermal Resistance
- θ_{SA} = Heat Sink-to-Ambient Thermal Resistance
- θ_{JA} = Junction-to-Ambient Thermal Resistance

Typical Applications

Bypass capacitors are necessary for stable operation of the LM79MXX series of regulators over the input voltage and output current ranges. Output bypass capacitors will improve the transient response of the regulator.

The bypass capacitors (2.2 μF on the input, 1.0 μF on the output), should be ceramic or solid tantalum which have good high frequency characteristics. If aluminum electrolytics are used, their values should be 10 μF or larger. The bypass capacitors should be mounted with the shortest leads, and if possible, directly across the regulator terminals.

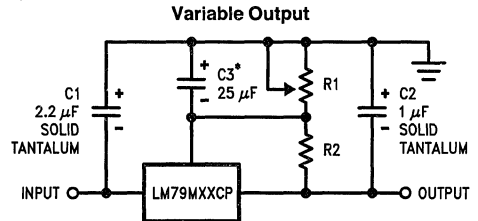


TL/H/10483-2

*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100 μF , a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.



TL/H/10483-3

*Improves transient response and ripple rejection. Do not increase beyond 50 μF .

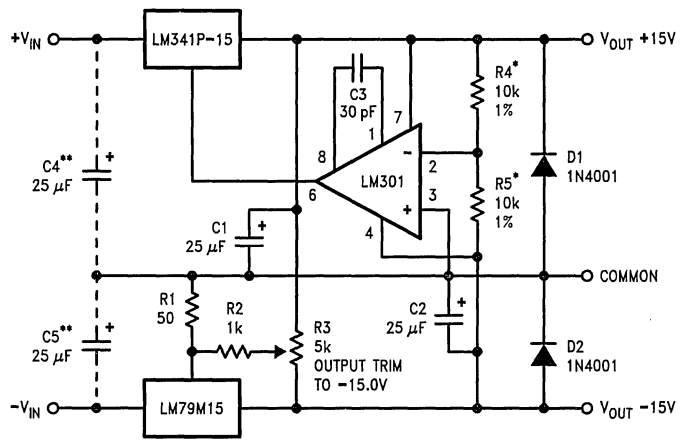
$$V_{\text{OUT}} = V_{\text{SET}} \left(\frac{R1 + R2}{R2} \right)$$

Select R2 as follows:

LM79M05C	300 Ω
LM79M08C	500 Ω
LM79M12C	750 Ω
LM79M15C	1k

Typical Applications (Continued)

± 15V, 1 Amp Tracking Regulators



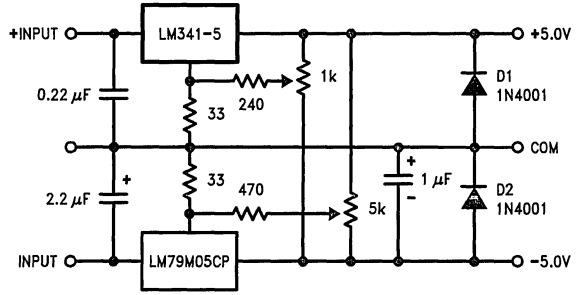
TL/H/10483-1

Performance (Typical)

	(- 15)	(+ 15)
Load Regulation at 0.5A	40 mV	2 mV
Output Ripple, C _{IN} = 3000 μF, I _L = 0.5A	100 μVrms	100 μVrms
Temperature Stability	50 mV	50 mV
Output Noise 10 Hz ≤ f ≤ 10 kHz	150 μVrms	150 μVrms

*Resistor tolerance of R4 and R5 determine matching of (+) and (-) outputs.
 **Necessary only if raw supply filter capacitors are more than 3" from regulators.

Dual Trimmed Supply



TL/H/10483-4



LM79XX Series 3-Terminal Negative Regulators

General Description

The LM79XX series of 3-terminal regulators is available with fixed output voltages of $-5V$, $-8V$, $-12V$, and $-15V$. These devices need only one external component—a compensation capacitor at the output. The LM79XX series is packaged in the TO-220 power package and is capable of supplying 1.5A of output current.

These regulators employ internal current limiting safe area protection and thermal shutdown for protection against virtually all overload conditions.

Low ground pin current of the LM79XX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current drain of

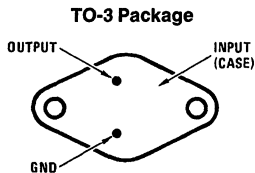
these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

For applications requiring other voltages, see LM137 data sheet.

Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 1.5A output current
- 4% tolerance on preset output voltage

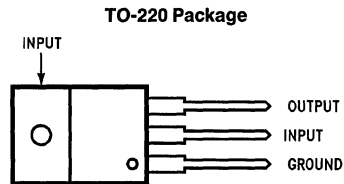
Connection Diagrams



TL/H/7340-10

Bottom View

Order Number LM7905CK, LM7908CK, LM7912CK or LM7915CK
See NS Package Number KC02A

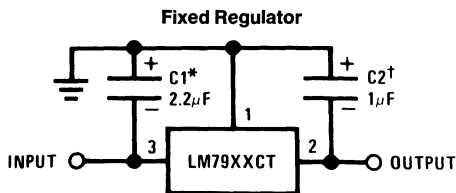


TL/H/7340-14

Front View

Order Number LM7905CT, LM7908CT, LM7912CT or LM7915CT
See NS Package Number TO3B

Typical Applications



TL/H/7340-3

*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100 μF , a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

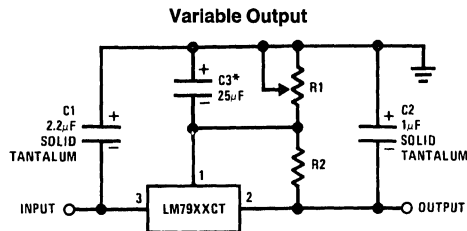
Input Voltage		
($V_o = -5V$)		-25V
($V_o = -8V, -12V, \text{ and } -15V$)		-35V

Input-Output Differential		
($V_o = -5V$)		25V
($V_o = -8V, -12V \text{ - and } 15V$)		30V
Power Dissipation (Note 2)		Internally Limited
Operating Junction Temperature Range		0°C to +125°C
Storage Temperature Range		-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)		230°C

Electrical Characteristics Conditions unless otherwise noted: $I_{OUT} = 500 \text{ mA}$, $C_{IN} = 2.2 \mu\text{F}$, $C_{OUT} = 1 \mu\text{F}$, $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$, Power Dissipation $\leq 1.5\text{W}$.

Part Number			LM7905C			LM7908C			Units	
Output Voltage			-5V			-8V				
Input Voltage (unless otherwise specified)			-10V			-14V				
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max		
V_o	Output Voltage	$T_J = 25^\circ\text{C}$	-4.8	-5.0	-5.2	-7.7	-8.0	-8.3	V	
		$5 \text{ mA} \leq I_{OUT} \leq 1 \text{ A}$,	-4.75		-5.25	-7.6		-8.4	V	
		$P \leq 15\text{W}$	$(-20 \leq V_{IN} \leq -7)$		$(-23 \leq V_{IN} \leq -10.5)$				V	
ΔV_o	Line Regulation	$T_J = 25^\circ\text{C}$, (Note 3)		8	50		5	80	mV	
				$(-25 \leq V_{IN} \leq -7)$		$(-25 \leq V_{IN} \leq -10.5)$				V
				2	15		3	30	mV	
				$(-12 \leq V_{IN} \leq -8)$		$(-17 \leq V_{IN} \leq -11)$				V
ΔV_o	Load Regulation	$T_J = 25^\circ\text{C}$, (Note 3) $5 \text{ mA} \leq I_{OUT} \leq 1.5 \text{ A}$ $250 \text{ mA} \leq I_{OUT} \leq 750 \text{ mA}$		15	100		15	200	mV	
				5	50		5	75	mV	
I_Q	Quiescent Current	$T_J = 25^\circ\text{C}$		1	2		1.5	3	mA	
ΔI_Q	Quiescent Current Change	With Line			0.5			0.5	mA	
		With Load, $5 \text{ mA} \leq I_{OUT} \leq 1 \text{ A}$			0.5			0.5	mA	
V_n	Output Noise Voltage	$T_A = 25^\circ\text{C}$, $10 \text{ Hz} \leq f \leq 100 \text{ Hz}$		125			200		μV	
			Ripple Rejection	$f = 120 \text{ Hz}$	54	66	54	60		dB
					$(-18 \leq V_{IN} \leq -8)$		$(-21 \leq V_{IN} \leq -11)$			V
	Dropout Voltage	$T_J = 25^\circ\text{C}$, $I_{OUT} = 1 \text{ A}$		1.1			1.1		V	
I_{OMAX}	Peak Output Current	$T_J = 25^\circ\text{C}$		2.2			2.2		A	
	Average Temperature Coefficient of Output Voltage	$I_{OUT} = 5 \text{ mA}$, $0^\circ\text{C} \leq T_J \leq 100^\circ\text{C}$		0.4			-0.6		$\text{mV}/^\circ\text{C}$	

Typical Applications (Continued)



*Improves transient response and ripple rejection. Do not increase beyond 50 μF .

TL/H/7340-2

$$V_{OUT} = V_{SET} \left(\frac{R1 + R2}{R2} \right)$$

Select R2 as follows:

LM7905CT	300 Ω
LM7908CT	500 Ω
LM7912CT	750 Ω
LM7915CT	1k

Electrical Characteristics (Continued)

Conditions unless otherwise noted: $I_{OUT} = 500 \text{ mA}$, $C_{IN} = 2.2 \mu\text{F}$, $C_{OUT} = 1 \mu\text{F}$, $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$, Power Dissipation = 1.5W.

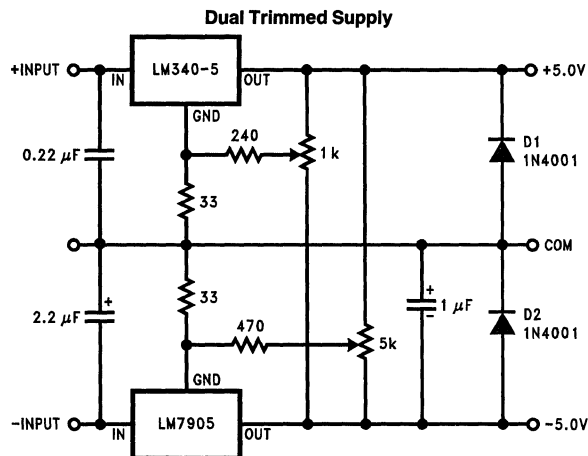
Part Number			LM7912C			LM7915C			Units	
Output Voltage			-12V			-15V				
Input Voltage (unless otherwise specified)			-19V			-23V				
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max		
V_O	Output Voltage	$T_J = 25^\circ\text{C}$ $5 \text{ mA} \leq I_{OUT} \leq 1 \text{ A}$, $P \leq 15 \text{ W}$	-11.5	-12.0	-12.5	-14.4	-15.0	-15.6	V	
			-11.4		-12.6	-14.25		-15.75	V	
			$(-27 \leq V_{IN} \leq -14.5)$			$(-30 \leq V_{IN} \leq -17.5)$				V
ΔV_O	Line Regulation	$T_J = 25^\circ\text{C}$, (Note 3)	5	80		5	100		mV	
			$(-30 \leq V_{IN} \leq -14.5)$			$(-30 \leq V_{IN} \leq -17.5)$				V
			3	30		3	50		mV	
			$(-22 \leq V_{IN} \leq -16)$			$(-26 \leq V_{IN} \leq -20)$				V
ΔV_O	Load Regulation	$T_J = 25^\circ\text{C}$, (Note 3) $5 \text{ mA} \leq I_{OUT} \leq 1.5 \text{ A}$ $250 \text{ mA} \leq I_{OUT} \leq 750 \text{ mA}$	15	200		15	200		mV	
			5	75		5	75		mV	
I_Q	Quiescent Current	$T_J = 25^\circ\text{C}$	1.5	3		1.5	3		mA	
ΔI_Q	Quiescent Current Change	With Line		0.5			0.5		mA	
		With Load, $5 \text{ mA} \leq I_{OUT} \leq 1 \text{ A}$		0.5			0.5		mA	
V_n	Output Noise Voltage	$T_A = 25^\circ\text{C}$, $10 \text{ Hz} \leq f \leq 100 \text{ Hz}$	300			375			μV	
	Ripple Rejection	$f = 120 \text{ Hz}$	54	70		54	70		dB	
			$(-25 \leq V_{IN} \leq -15)$			$(-30 \leq V_{IN} \leq -17.5)$			V	
	Dropout Voltage	$T_J = 25^\circ\text{C}$, $I_{OUT} = 1 \text{ A}$	1.1			1.1			V	
I_{OMAX}	Peak Output Current	$T_J = 25^\circ\text{C}$	2.2			2.2			A	
	Average Temperature Coefficient of Output Voltage	$I_{OUT} = 5 \text{ mA}$, $0^\circ\text{C} \leq T_J \leq 100^\circ\text{C}$	-0.8			-1.0			$\text{mV}/^\circ\text{C}$	

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee Specific Performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Refer to Typical Performance Characteristics and Design Considerations for details.

Note 3: Regulation is measured at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

Typical Applications (Continued)



TL/H/7340-4

Design Considerations

The LM79XX fixed voltage regulator series has thermal overload protection from excessive power dissipation, internal short circuit protection which limits the circuit's maximum current, and output transistor safe-area compensation for reducing the output current as the voltage across the pass transistor is increased.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature (125°C) in order to meet data sheet specifications. To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

Package	Typ θ_{JC} °C/W	Max θ_{JC} °C/W	Typ θ_{JA} °C/W	Max θ_{JA} °C/W
TO-3	3.5	5.5	40	35
TO-220	3.0	5.0	60	40

$$P_{D\text{ MAX}} = \frac{T_{J\text{ MAX}} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or } \frac{T_{J\text{ MAX}} - T_A}{\theta_{JA}}$$

$$\theta_{CA} = \theta_{CS} + \theta_{SA} \text{ (without heat sink)}$$

Solving for T_J :

$$T_J = T_A + P_D (\theta_{JC} + \theta_{CA}) \text{ or}$$

$$= T_A + P_D \theta_{JA} \text{ (without heat sink)}$$

Where:

T_J = Junction Temperature

T_A = Ambient Temperature

P_D = Power Dissipation

θ_{JA} = Junction-to-Ambient Thermal Resistance

θ_{JC} = Junction-to-Case Thermal Resistance

θ_{CA} = Case-to-Ambient Thermal Resistance

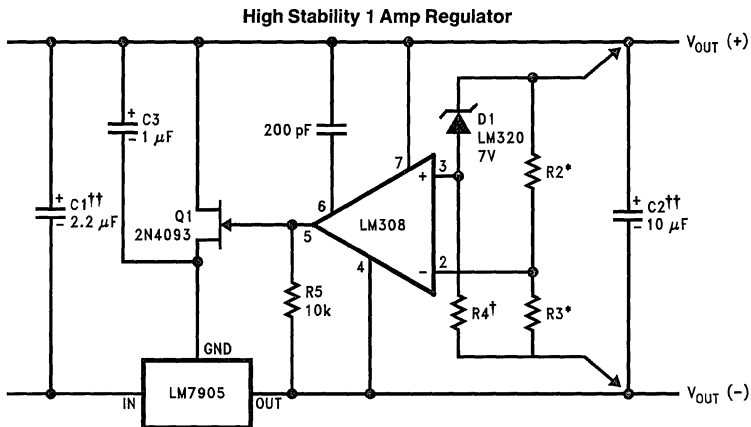
θ_{CS} = Case-to-Heat Sink Thermal Resistance

θ_{SA} = Heat Sink-to-Ambient Thermal Resistance

Typical Applications (Continued)

Bypass capacitors are necessary for stable operation of the LM79XX series of regulators over the input voltage and output current ranges. Output bypass capacitors will improve the transient response by the regulator.

The bypass capacitors, (2.2 μF on the input, 1.0 μF on the output) should be ceramic or solid tantalum which have good high frequency characteristics. If aluminum electrolytics are used, their values should be 10 μF or larger. The bypass capacitors should be mounted with the shortest leads, and if possible, directly across the regulator terminals.



TL/H/7340-5

Load and line regulation < 0.01% temperature stability \leq 0.2%

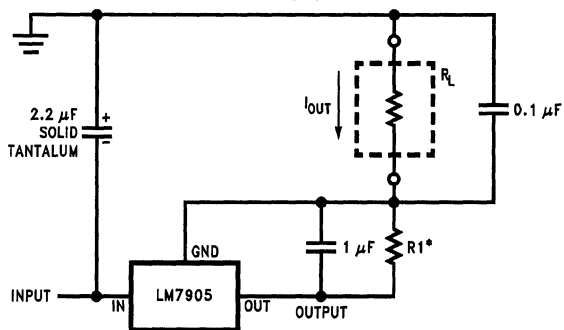
†Determine Zener current

††Solid tantalum

*Select resistors to set output voltage. 2 ppm/°C tracking suggested

Typical Applications (Continued)

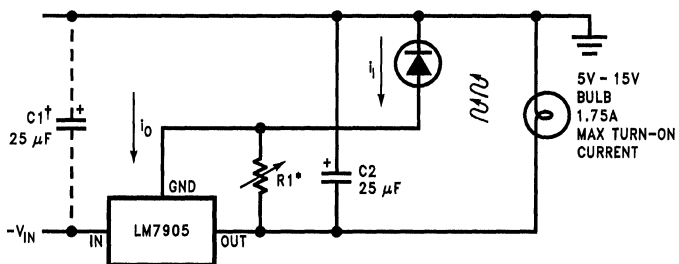
Current Source



$$*I_{OUT} = 1 \text{ mA} + \frac{5V}{R1}$$

TL/H/7340-7

Light Controller Using Silicon Photo Cell

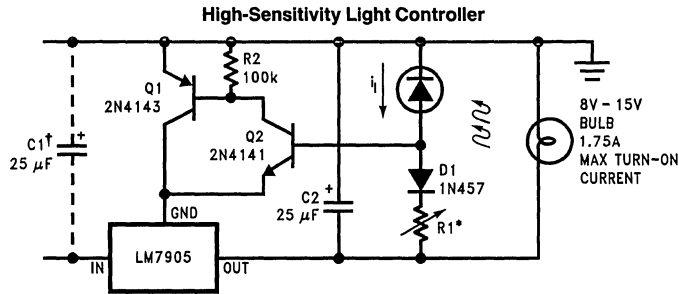


*Lamp brightness increase until $I_i = I_Q (\approx 1 \text{ mA}) + 5V/R1$.

†Necessary only if raw supply filter capacitor is more than 2" from LM7905CT

TL/H/7340-8

Typical Applications (Continued)

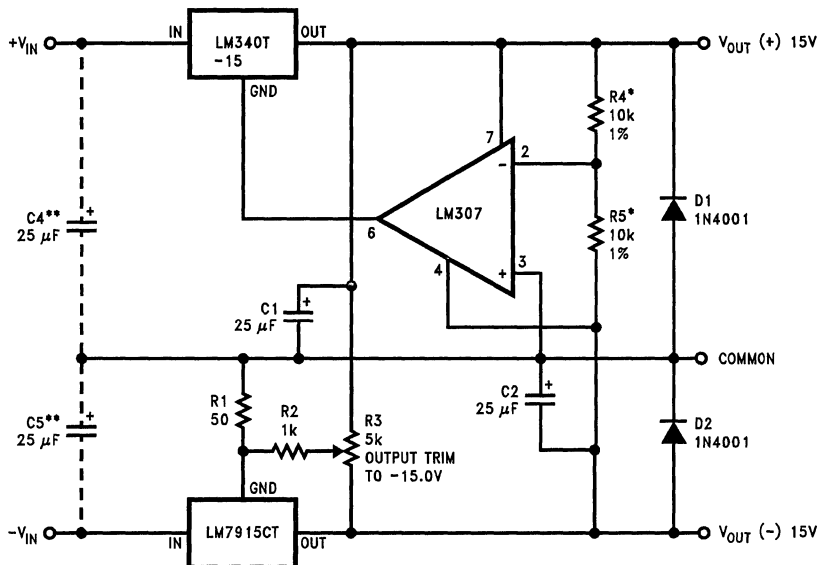


TL/H/7340-9

*Lamp brightness increases until $i_l = 5V/R1$ (i_l can be set as low as $1\mu A$)

†Necessary only if raw supply filter capacitor is more than 2" from LM7905

± 15V, 1 Amp Tracking Regulators

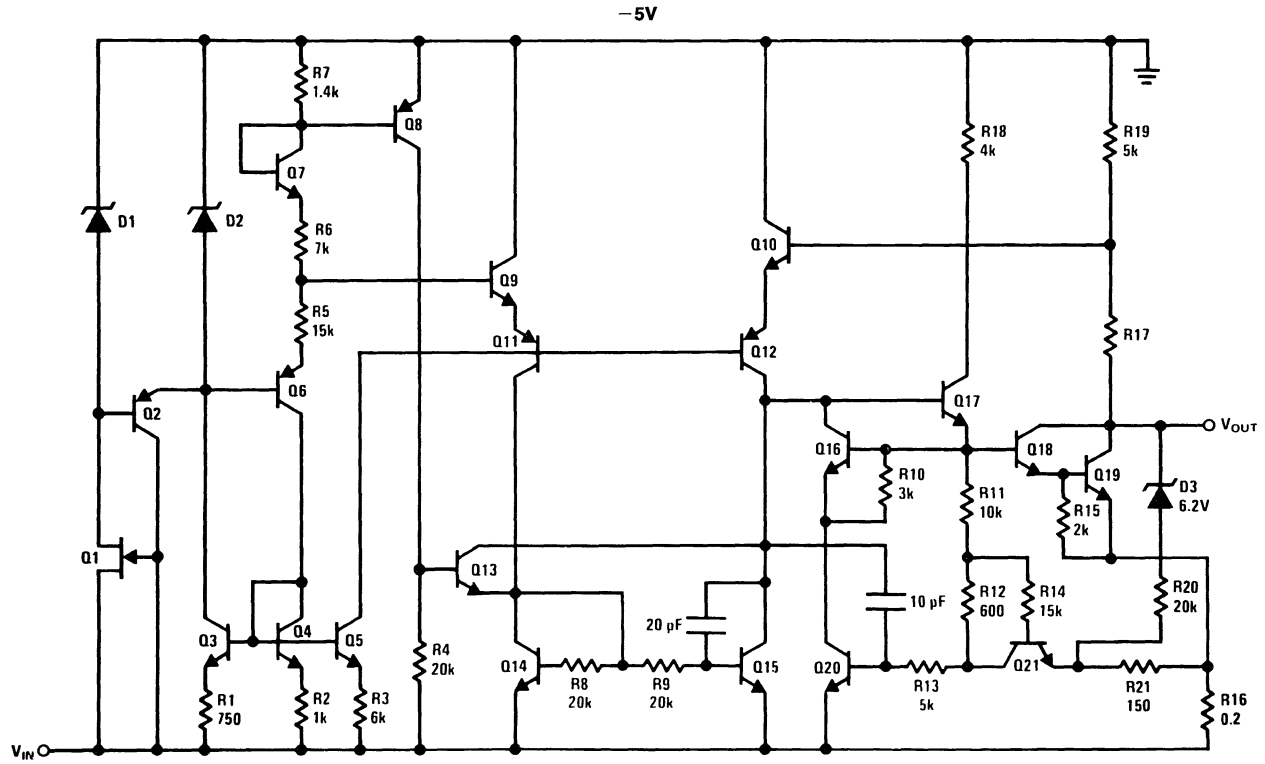


TL/H/7340-1

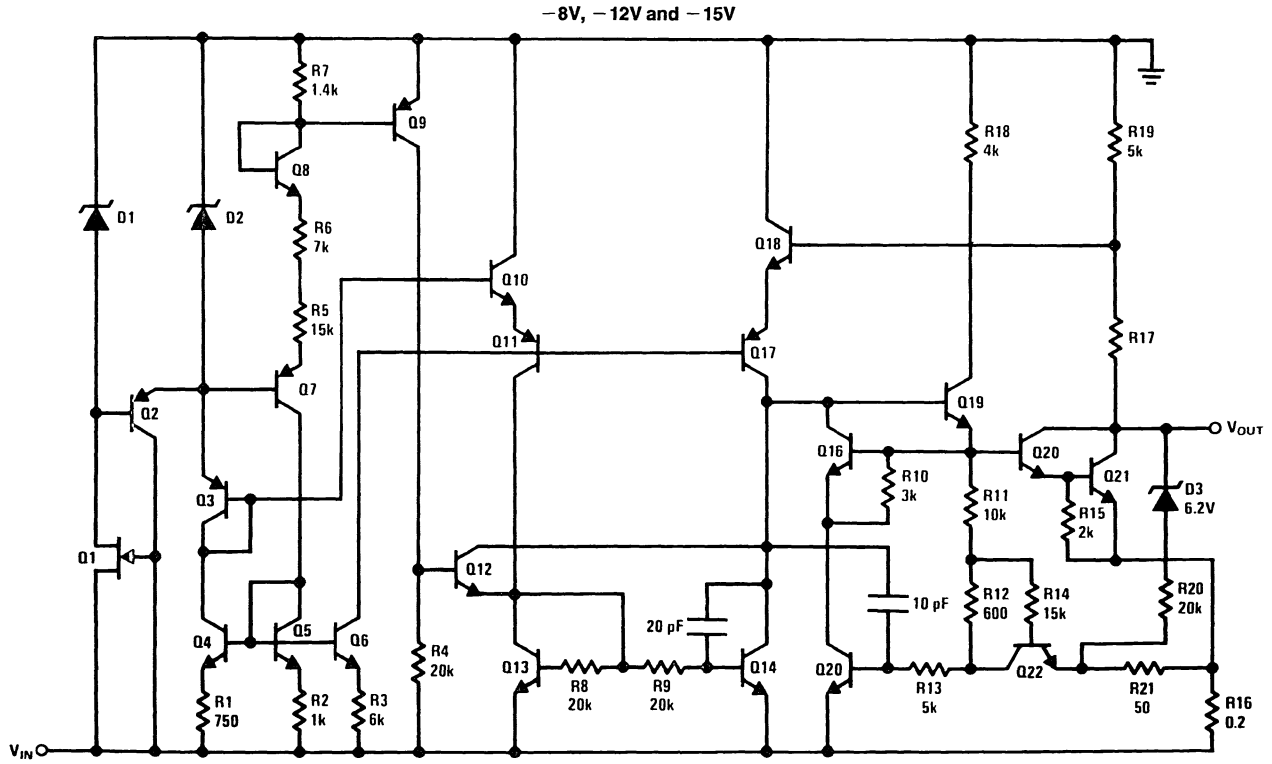
	(-15)	(+15)
Load Regulation at $\Delta I_L = 1A$	40 mV	2 mV
Output Ripple, $C_{IN} = 3000\mu F, I_L = 1A$	100 μV_{rms}	100 μV_{rms}
Temperature Stability	50 mV	50 mV
Output Noise 10 Hz $\leq f \leq 10$ kHz	150 μV_{rms}	150 μV_{rms}

*Resistor tolerance of R4 and R5 determine matching of (+) and (-) outputs.

**Necessary only if raw supply filter capacitors are more than 3" from regulators.



1-226



TL/H/7340-13



Section 2
**Low Dropout
Voltage Regulators**



Section 2 Contents

Low Dropout Voltage Regulators—Definition of Terms	2-3
Low Dropout Regulators—Selection Guide	2-4
LM330 3-Terminal Positive Regulator	2-6
LM2925 Low Dropout Regulator with Delayed Reset	2-10
LM2926/LM2927 Low Dropout Regulators with Delayed Reset	2-16
LM2930 3-Terminal Positive Regulator	2-24
LM2931 Series Low Dropout Regulators	2-29
LM2935 Low Dropout Dual Regulator	2-36
LM2936 Ultra-Low Quiescent Current 5V Regulator	2-44
LM2937 500 mA Low Dropout Regulator	2-49
LM2940/LM2940C 1A Low Dropout Regulators	2-54
LM2941/LM2941C 1A Low Dropout Adjustable Regulators	2-63
LM2984 Microprocessor Power Supply System	2-69
LM2990 Negative Low Dropout Regulator	2-82
LM2991 Negative Low Dropout Adjustable Regulator	2-89
LP2950/LP2950AC/LP2950C 5V and LP2951/LP2951AC/LP2951C Adjustable Micropower Voltage Regulators	2-95
LP2952/LP2952A/LP2953/LP2953A Adjustable Micropower Low-Dropout Voltage Regulators	2-108
LP2954/LP2954A 5V Micropower Low-Dropout Voltage Regulators	2-121

Low-Dropout Voltage Regulators Definition of Terms

Dropout Voltage: The input-voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at ($V_{OUT} + 5V$) input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O : The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.



Low Dropout Regulators Selection Guide

Output Current (A)	Device	Output Voltage (V)	Dropout Voltage (V)	Maximum Input Voltage (V)	Typical Quiescent Current (mA)	Reverse Polarity Protection (V)	Transient Protection (V)	Operating Temperature (T _J °C)	Package Availability†	Page No.
1.0	LM2940	5, 8, 12, 15	1.0*	26	10	-15	+60**/-50	-55 to +150	K2‡	2-54
		5, 8, 9, 10, 12	1.0*	26	10	-15	+60**/-50	-40 to +150	T3	2-54
	LM2940C	5, 12, 15	1.0*	26	10	-15	+45/-45	0 to +150	T3	2-54
	LM2941	Adj. (5 to 20)	1.0*	26	10	-15	+60**/-50	-55 to +150	K4‡	2-63
		Adj. (5 to 20)	1.0*	26	10	-15	+60**/-50	-40 to +150	T5	2-63
	LM2941C	Adj. (5 to 20)	1.0*	26	10	-15	+45**/-45	0 to +150	T5	2-63
	LM2990	-5, -5.2, -12, -15	1.0*	-26	1			-40 to +125	T3	2-82
LM2991	Adj. (-2 to -25)	1.0*	-26	0.7			-40 to +125	T5	2-89	
0.75	LM2925	5	0.82	26	3	-15	+60**/-50	-40 to +150	T5	2-10
	LM2935	Two 5V Outputs	0.82	26	3	-15	+60**/-50	-40 to +150	T5	2-36
0.5	LM2926	5	0.7*	26	2	-18	+80**/-50	-40 to +125	T5	2-16
	LM2927	5	0.7*	26	2	-18	+80**/-50	-40 to +125	T5	2-16
	LM2937	5, 8, 10, 12, 15	1.0*	26	2	-15	+60**/-50	-40 to +125	T3	2-49
	LM2984	Three 5V Outputs	1.1*	26	14	-15	+60**/-35	-40 to +150	T11	2-69
0.25	LP2952I	5, Adj. (1.23 to 29)	0.8*	30	0.130	-20		-40 to +125	M16, N14	2-108
	LP2952AI	5, Adj. (1.23 to 29)	0.8*	30	0.130	-20		-40 to +125	M16, N14	2-108
	LP2953I	5, Adj. (1.23 to 29)	0.8*	30	0.130	-20		-40 to +125	M16, N16	2-108
	LP2953AI	5, Adj. (1.23 to 29)	0.8*	30	0.130	-20		-40 to +125	M16, N16	2-108
	LP2953AM	5, Adj. (1.23 to 29)	0.8*	30	0.130	-20		-55 to +125	J16‡	2-108
	LP2954I	5	0.8*	30	0.090	-20		-40 to +125	T3	2-121
	LP2954AI	5	0.8*	30	0.090	-20		-40 to +125	T3	2-121

Low Dropout Regulators Selection Guide (Continued)

Output Current (A)	Device	Output Voltage (V)	Dropout Voltage (V)	Maximum Input Voltage (V)	Typical Quiescent Current (mA)	Reverse Polarity Protection (V)	Transient Protection (V)	Operating Temperature (T _J °C)	Package Availability†	Page No.
0.15	LM330	5	0.6	26	3.5	-12	+50/-30	0 to +125	T3	2-6
	LM2930	5, 8	0.6	26	4	-6	+40**/-12	-40 to +125	T3	2-24
0.1	LM2931	5	0.6	24	0.400	-15	+60**/-50	-40 to +125	M8, T3, Z3	2-29
	LM2931C	Adj. (3 to 29)	0.6	24	0.400	-15	+60**/-50	-40 to +125	M8, T5	2-29
	LP2950C	5	0.6*	30	0.075			-40 to +125	Z3	2-95
	LP2950AC	5	0.6*	30	0.075			-40 to +125	Z3	2-95
	LP2951	5V Adj. (1.24V to 29)	0.6*	30	0.075			-55 to +150	H8, J8, E20‡	2-95
	LP2951C	5V Adj. (1.24V to 29)	0.6*	30	0.075			-40 to +125	M8, N8	2-95
	LP2951AC	5V Adj. (1.24V to 29)	0.6*	30	0.075			-40 to +125	M8, N8	2-95
0.05	LP2936	5	0.4	40	0.009	-15	+60/-50	-40 to +125	M8, Z3	2-44

*Guaranteed maximum dropout voltage at full load over temperature.

**Positive transient protection value also indicates the regulator's load dump capability.

†Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the indicated package.

For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.

E: Leadless Ceramic Chip Carrier

H: Metal Can (TO-99)

J: Ceramic Dual-In-Line Package

K: Metal Can (TO-3)

M: Small Outline Molded Package (Surface Mount)

N: Molded Dual-In-Line Package

T: TO-220

Z: TO-92

‡Available in indicated package only as a military specified device.

LM330 3-Terminal Positive Regulator

General Description

The LM330 5V 3-terminal positive voltage regulator features an ability to source 150 mA of output current with an input-output differential of 0.6V or less. Familiar regulator features such as current limit and thermal overload protection are also provided.

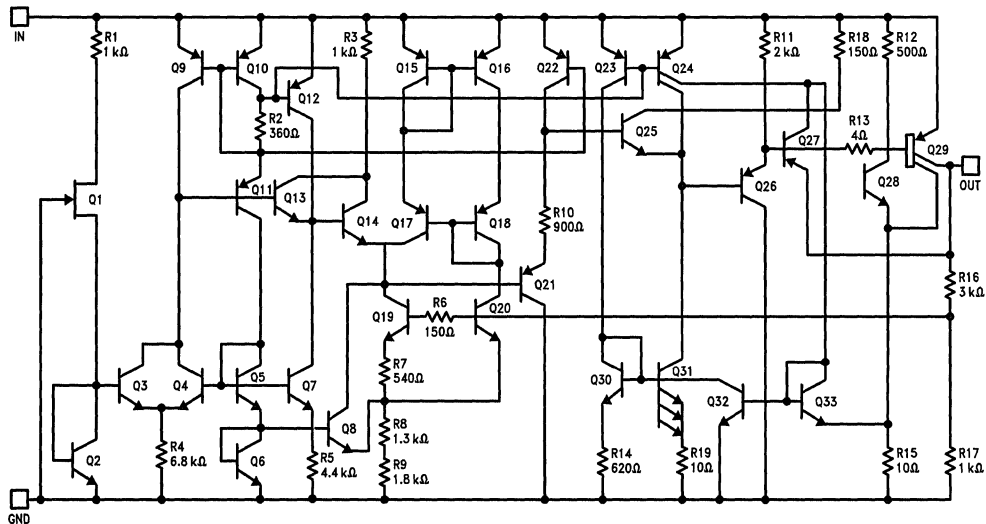
The low dropout voltage makes the LM330 useful for certain battery applications since this feature allows a longer battery discharge before the output falls out of regulation. For example, a battery supplying the regulator input voltage may discharge to 5.6V and still properly regulate the system and load voltage. Supporting this feature, the LM330 protects both itself and regulated systems from negative voltage inputs resulting from reverse installations of batteries.

Other protection features include line transient protection up to 26V, when the output actually shuts down to avoid damaging internal and external circuits. Also, the LM330 regulator cannot be harmed by a temporary mirror-image insertion.

Features

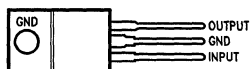
- Input-output differential less than 0.6V
- Output current of 150 mA
- Reverse battery protection
- Line transient protection
- Internal short circuit current limit
- Internal thermal overload protection
- Mirror-image insertion protection
- P+ Product Enhancement tested

Schematic and Connection Diagrams



TL/H/9306-1

(TO-220)
Plastic Package



Front View

Order Number LM330T-5.0
See NS Package Number T03B

TL/H/9306-2

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Line Transient Protection (1000 ms)	40V

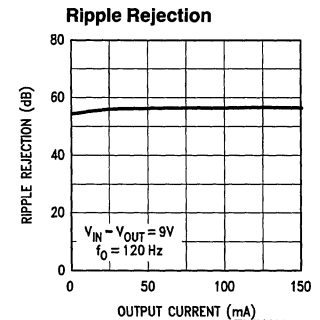
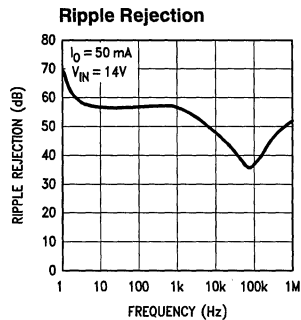
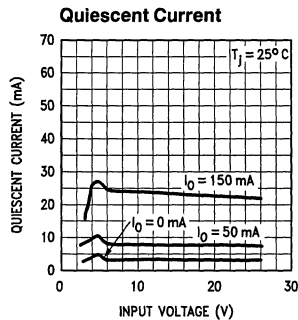
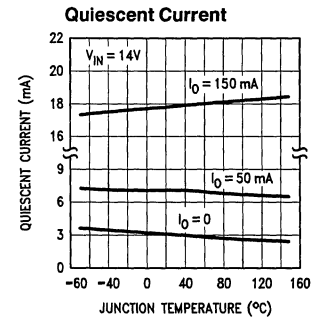
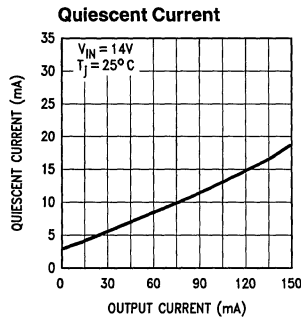
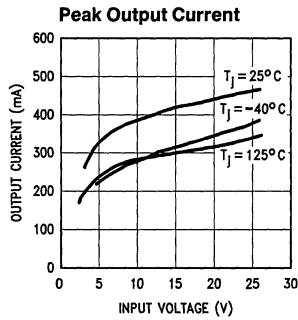
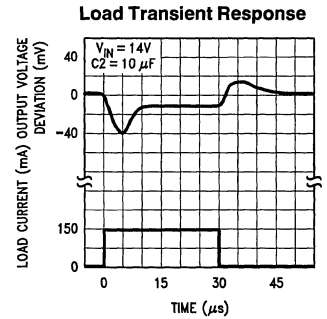
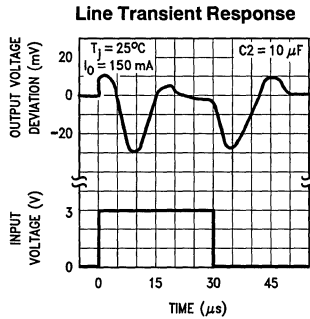
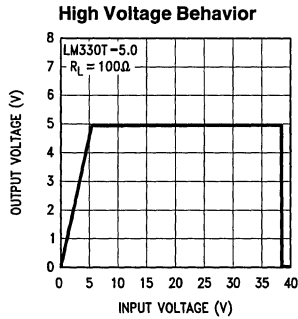
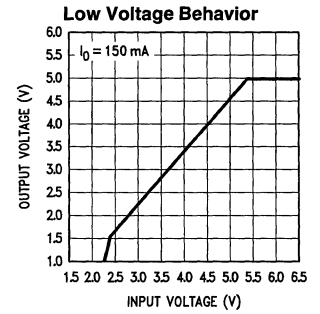
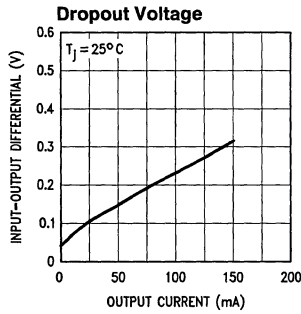
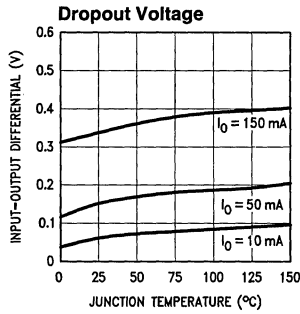
Internal Power Dissipation	Internally Limited
Operating Temperature Range	0°C to +70°C
Maximum Junction Temperature	+125°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	+300°C

Electrical Characteristics (Note 1)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_o	Output Voltage	$T_j = 25^\circ\text{C}$	4.8	5	5.2	V
	Output Voltage Over Temp	$5 < I_o < 150 \text{ mA}$ $6 < V_{IN} < 26\text{V}; 0^\circ\text{C} \leq T_j \leq 100^\circ\text{C}$	4.75		5.25	
ΔV_o	Line Regulation	$9 < V_{IN} < 16\text{V}, I_o = 5 \text{ mA}$ $6 < V_{IN} < 26\text{V}, I_o = 5 \text{ mA}$		7 30	25 60	mV
	Load Regulation	$5 < I_o < 150 \text{ mA}$		14	50	
	Long Term Stability			20		
I_Q	Quiescent Current	$I_o = 10 \text{ mA}$ $I_o = 50 \text{ mA}$ $I_o = 150 \text{ mA}$		3.5 5 18	7 11 40	mA
	Line Transient Reverse Polarity	$V_{IN} = 40\text{V}, R_L = 100\Omega, 1\text{s}$ $V_{IN} = -6\text{V}, R_L = 100\Omega$		14 -80		
ΔI_Q	Quiescent Current Change	$6 < V_{IN} < 26\text{V}$		10		%
V_{IN}	Overshoot Shutdown Voltage		26	38		V
	Max Line Transient			60		
		$1\text{s}, V_o \leq 5.5\text{V}$			50	
Reverse Polarity Input Voltage				-30		
	$\text{DC } V_o > -0.3\text{V}, R_L = 100\Omega$			-12		
	Output Noise Voltage	10 Hz–100 kHz		50		μV
	Output Impedance	$I_o = 100 \text{ mADC} + 10 \text{ mArms}$		200		$\text{m}\Omega$
	Ripple Rejection			56		dB
	Current Limit		150	400	700	mA
	Dropout Voltage	$I_o = 150 \text{ mA}$		0.32	0.6	V
	Thermal Resistance	Junction to Case		4		$^\circ\text{C/W}$
		Junction to Ambient		50		

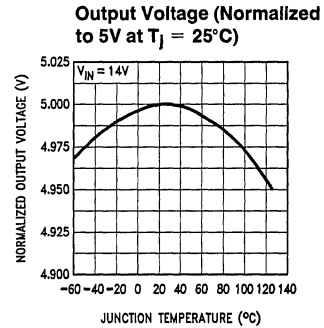
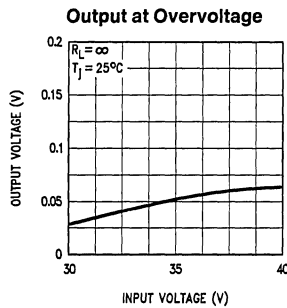
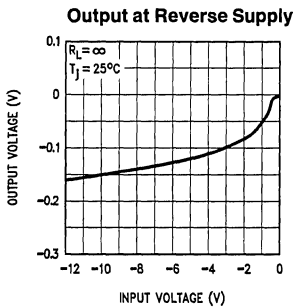
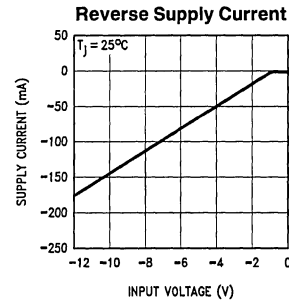
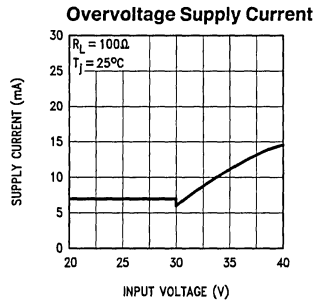
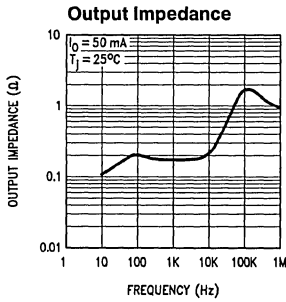
Note 1: Unless otherwise specified: $V_{IN} = 14\text{V}$, $I_o = 150 \text{ mA}$, $T_j = 25^\circ\text{C}$, $C_1 = 0.1 \mu\text{F}$, $C_2 = 10 \mu\text{F}$. All characteristics except noise voltage and ripple rejection are measured using pulse techniques ($t_W \leq 10 \text{ ms}$, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

Typical Performance Characteristics



TL/H/9306-3

Typical Performance Characteristics (Continued)

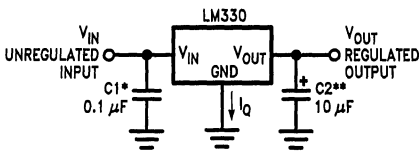


TL/H/8306-4

Typical Applications

The LM330 is designed specifically to operate at lower input to output voltages. The device is designed utilizing a power lateral PNP transistor which reduces dropout voltage from 2.0V to 0.3V when compared to IC regulators using NPN pass transistors. Since the LM330 can operate at a much lower input voltage, the device power dissipation is reduced, heat sinking can be simpler and device reliability im-

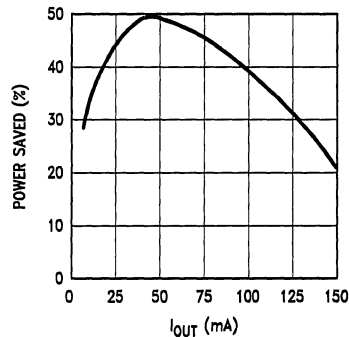
proved through lower chip operating temperature. Also, a cost savings can be utilized through use of lower power/voltage components. In applications utilizing battery power, the LM330 allows the battery voltage to drop to within 0.3V of output voltage prior to the voltage regulator dropping out of regulation.



TL/H/8306-5

* Required if regulator is located far from power supply filter.

** C2 may be either an Aluminum or Tantalum type capacitor but must be rated to operate at -40°C to guarantee regulator stability to that temperature extreme. $10\ \mu\text{F}$ is the minimum value required for stability and may be increased without bound. Locate as close as possible to the regulation.



TL/H/8306-6

Note: Compared to IC regulator with 2.0V dropout voltage and $I_{Omax} = 6.0\ \text{mA}$.



LM2925 Low Dropout Regulator with Delayed Reset

General Description

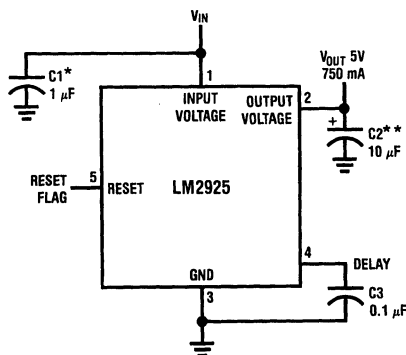
The LM2925 features a low dropout, high current regulator. Also included on-chip is a reset function with an externally set delay time. Upon power up, or after the detection of any error in the regulated output, the reset pin remains in the active low state for the duration of the delay. Types of errors detected include any that cause the output to become unregulated: low input voltage, thermal shutdown, short circuit, input transients, etc. No external pull-up resistor is necessary. The current charging the delay capacitor is very low, allowing long delay times.

Designed primarily for automotive applications, the LM2925 and all regulated circuitry are protected from reverse battery installations or two-battery jumps. During line transients, such as a load dump (60V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the 0.75A regulator will automatically shut down to protect both internal circuits and the load. The LM2925 cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

Features

- 5V, 750 mA output
- Externally set delay for reset
- Input-output differential less than 0.6V at 0.5A
- Reverse battery protection
- 60V load dump protection
- -50V reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- Available in plastic TO-220
- Long delay times available
- P+ Product Enhancement tested

Typical Application Circuit



*Required if regulator is located far from power supply filter.

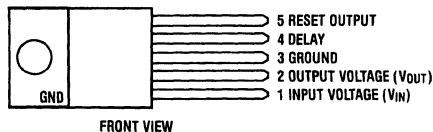
** C_{OUT} must be at least 10 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

TL/H/5268-1

FIGURE 1. Test and Application Circuit

Connection Diagram

TO-220 5-Lead



FRONT VIEW

Order Number LM2925T
See NS Package Number T05A

TL/H/5268-2

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage

Operating Range	26V
Overvoltage Protection	60V

Internal Power Dissipation (Note 1) Internally Limited

Operating Temperature Range	-40°C to + 125°C
Maximum Junction Temperature	150°C
Storage Temperature Range	-65°C to + 150°C
Lead Temperature (Soldering, 10 seconds)	260°C
ESD rating is to be determined	

Electrical Characteristics for V_{OUT}

$V_{IN} = 14V$, $C_2 = 10 \mu F$, $I_O = 500 \text{ mA}$, $T_J = 25^\circ\text{C}$ (Note 3) (unless otherwise specified)

Parameter	Conditions	Min	Typ	Max	Units
		Note 2			
Output Voltage	$6V \leq V_{IN} \leq 26V$, $I_O \leq 500 \text{ mA}$, $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$	4.75	5.00	5.25	V
Line Regulation	$9V \leq V_{IN} \leq 16V$, $I_O = 5 \text{ mA}$ $6V \leq V_{IN} \leq 26V$, $I_O = 5 \text{ mA}$		4 10	25 50	mV mV
Load Regulation	$5 \text{ mA} \leq I_O \leq 500 \text{ mA}$		10	50	mV
Output Impedance	500 mA_{DC} and 10 mArms , 100 Hz-10 kHz		200		$\text{m}\Omega$
Quiescent Current	$I_O \leq 10 \text{ mA}$ $I_O = 500 \text{ mA}$ $I_O = 750 \text{ mA}$		3 40 90	100	mA mA mA
Output Noise Voltage	10 Hz-100 kHz		100		μV_{rms}
Long Term Stability			20		mV/1000 hr
Ripple Rejection	$f_o = 120 \text{ Hz}$		66		dB
Dropout Voltage	$I_O = 500 \text{ mA}$ $I_O = 750 \text{ mA}$		0.45 0.82	0.6	V V
Current Limit		0.75	1.2		A
Maximum Operational Input Voltage		26	31		V
Maximum Line Transient	$V_O \leq 5.5V$	60	70		V
Reverse Polarity Input Voltage, DC	$V_O \geq -0.6V$, 10 Ω Load	-15	-30		V
Reverse Polarity Input Voltage, Transient	1% Duty Cycle, $\tau \leq 100 \text{ ms}$, 10 Ω Load	-50	-80		V

Electrical Characteristics for Reset Output

$V_{IN} = 14V$, $C_3 = 0.1 \mu F$, $T_A = 25^\circ\text{C}$ (Note 3) (unless otherwise specified)

Parameter	Conditions	Min	Typ	Max	Units
		Note 2			
Reset Voltage					
Output Low	$I_{SINK} = 1.6 \text{ mA}$, $V_{IN} = 35V$ $I_{SOURCE} = 0$	4.5	0.3	0.6	V
Output High			5.0	5.5	V
Reset Internal Pull-up Resistor			30		k Ω
Reset Output Current Limit	$V_{RESET} = 1.2 V$		5		mA
V_{OUT} Threshold			4.5		V
Delay Time	$C_3 = .005 \mu F$ $C_3 = 0.1 \mu F$ $C_3 = 4.7 \mu F$ tantalum	150	12	300	ms
			250		ms
			12		s
Delay Current	Pin 4	1.2	1.95	2.5	μA

Note 1: Thermal resistance without a heat sink for junction to case temperature is 3°C/W (TO-220). Thermal resistance for TO-220 case to ambient temperature is 50°C/W.

Note 2: These parameters are guaranteed and 100% production tested.

Note 3: To ensure constant junction temperature, low duty cycle pulse testing is used.

Typical Circuit Waveforms

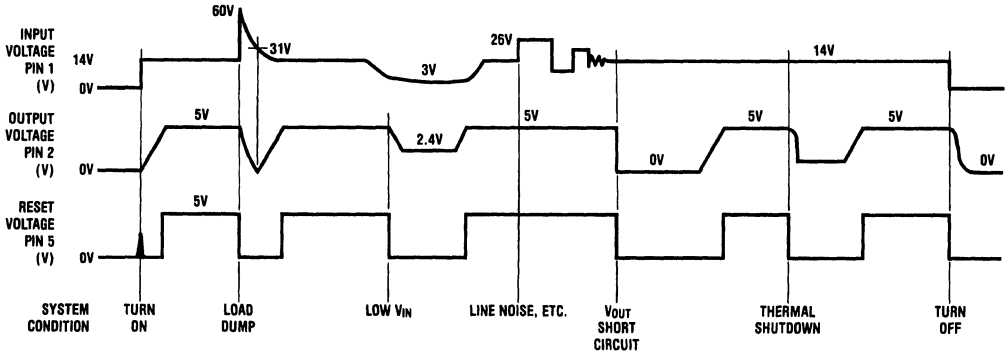
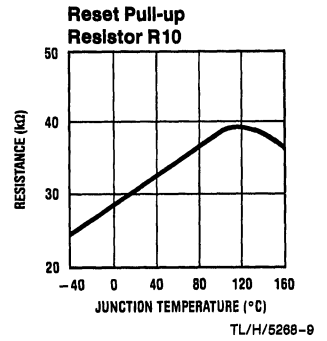
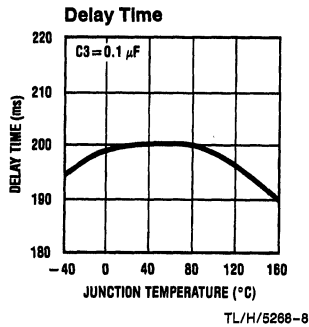
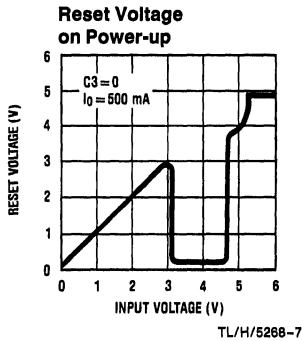
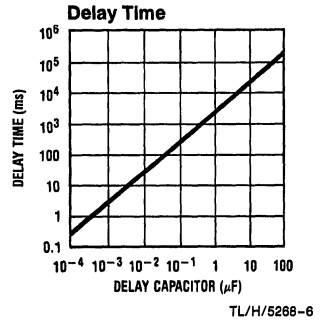
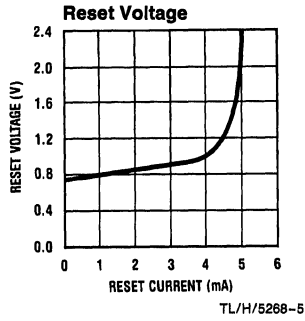
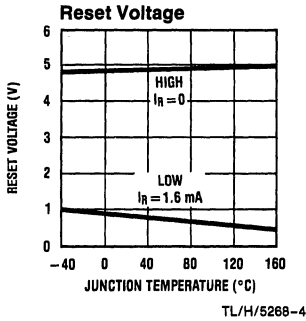


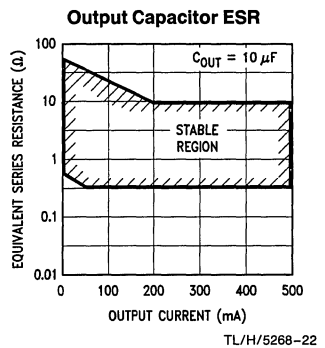
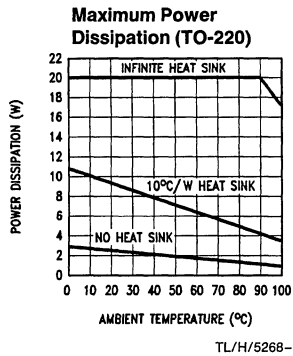
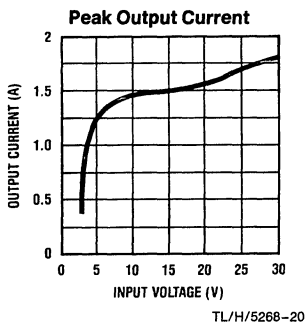
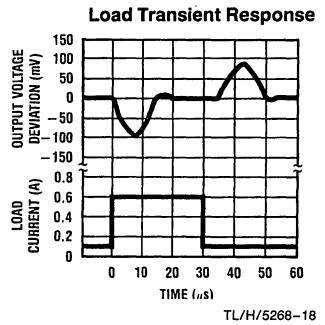
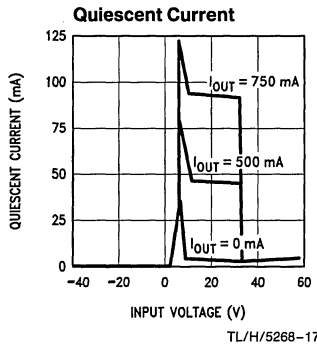
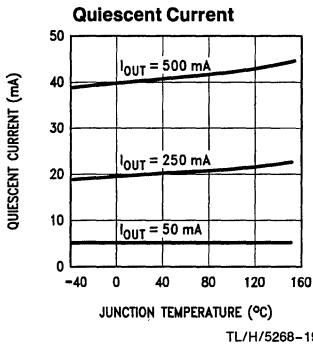
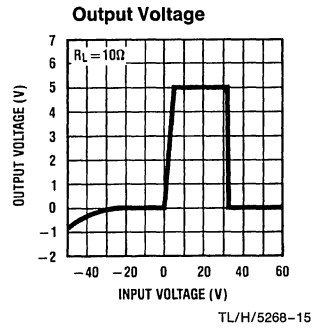
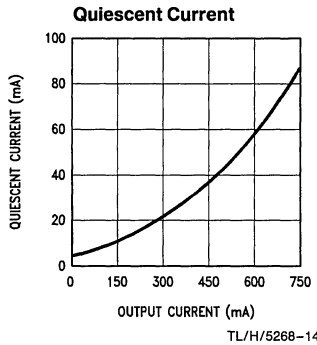
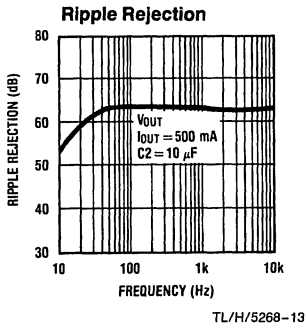
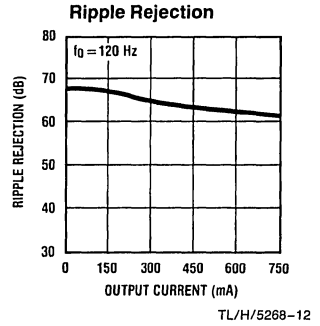
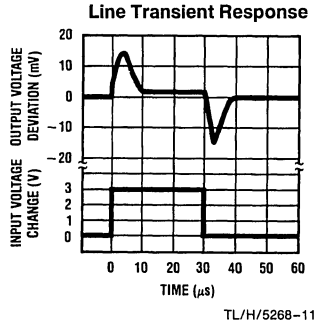
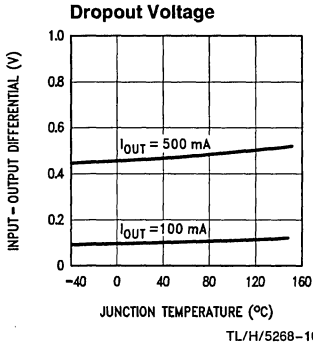
FIGURE 2

TL/H/5268-3

Typical Performance Characteristics



Typical Performance Characteristics (Continued)



Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: The part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O : The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Application Hints

EXTERNAL CAPACITORS

The LM2925 output capacitor is required for stability. Without it, the regulator output will oscillate, sometimes by many volts. Though the 10 μ F shown is the minimum recommended value, actual size and type may vary depending upon the application load and temperature range. Capacitor effective series resistance (ESR) also affects the IC stability. Since ESR varies from one brand to the next, some bench work may be required to determine the minimum capacitor value to use in production. Worst-case is usually determined at the minimum junction and ambient temperature and maximum load expected.

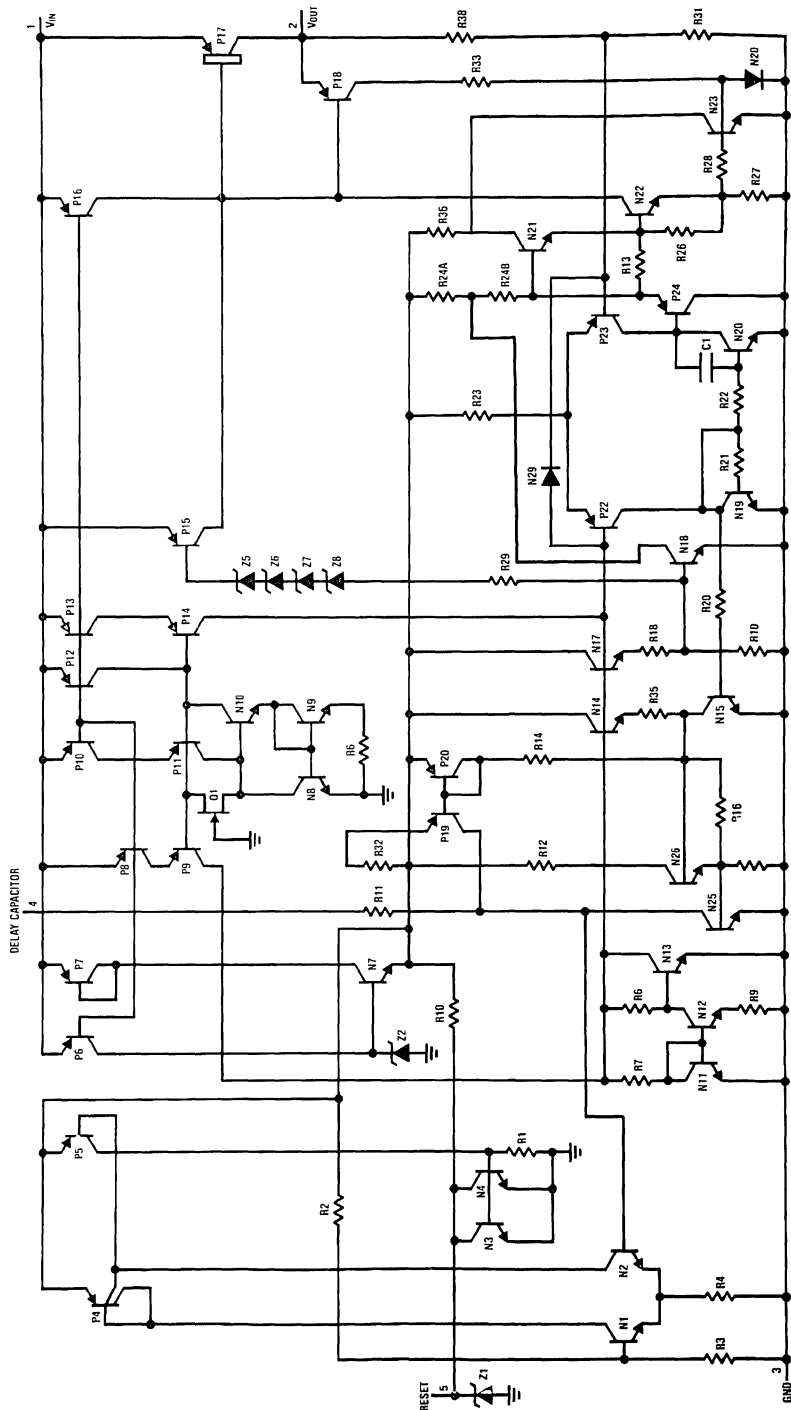
Output capacitors can be increased in size to any desired value above the minimum. One possible purpose of this would be to maintain the output voltages during brief conditions of negative input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum type electrolytics will freeze at temperatures less than -30°C , reducing their effective capacitance to zero. To maintain regulator stability down to -40°C , capacitors rated at that temperature (such as tantalums) must be used.

RESET OUTPUT

The range of values for the delay capacitor is limited only by stray capacitances on the lower extreme and capacitance leakage on the other. Thus, delay times from microseconds to seconds are possible. The low charging current, typically 2.0 microamps, allows the use of small, inexpensive disc capacitors for the nominal range of 100 to 500 milliseconds. This is the time required in many microprocessor systems for the clock oscillator to stabilize when initially powered up. The RESET output of the regulator will thus prevent erroneous data and/or timing functions to occur during this part of operation. The same delay is incorporated after any other fault condition in the regulator output is corrected.

Circuit Schematic



LL/5266-23

FIGURE 3



LM2926/LM2927

Low Dropout Regulator with Delayed Reset

General Description

The LM2926 is a 5V, 500 mA, low dropout regulator with delayed reset. The microprocessor reset flag is set low by thermal shutdown, short circuits, overvoltage conditions, dropout, and power-up. After the fault condition is corrected, the reset flag remains low for a delay time determined by the delay capacitor. Hysteresis is included in the reset circuit to prevent oscillations, and a reset output is guaranteed down to 3.2V supply input. A latching comparator is used to discharge the delay capacitor, which guarantees a full reset pulse even when triggered by a relatively short fault condition. A patented quiescent current reduction circuit drops the ground pin current to 8 mA at full load when the input-output differential is 3V or more.

Familiar PNP regulator features such as reverse battery protection, transient protection, and overvoltage shutdown are included in the LM2926 making it suitable for use in automotive and battery operated equipment.

The LM2927 is electrically identical to the LM2926 but has a different pin-out. The LM2927 is pin-for-pin compatible with

the L4947 and TLE4260 alternatives. The LM2926 is pin-for-pin compatible with the LM2925.

Features

- 5% output accuracy over entire operating range
- Dropout voltage typically 350 mV at 500 mA output
- Externally programmed reset delay
- Short circuit proof
- Reverse battery proof
- Thermally protected
- LM2926 is pin-for-pin compatible with the LM2925
- P+ Product Enhancement tested

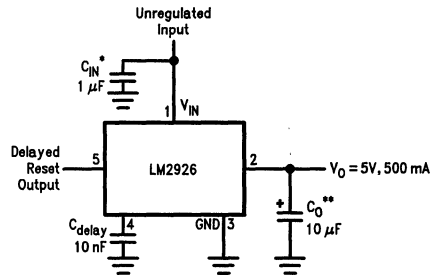
Applications

- Battery operated equipment
- Microprocessor-based systems
- Portable instruments

Typical Application

*Required if regulator is located far (>2") from power supply filter.

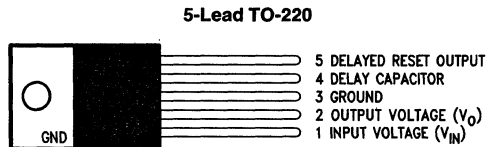
** C_O must be at least 10 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve under **Typical Performance Characteristics**.



TL/H/10759-1

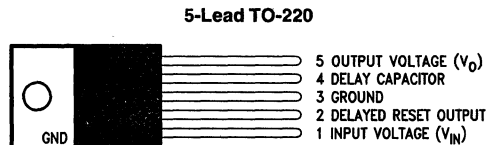
Connection Diagrams and Ordering Information

Front View
Order Number LM2926T
See NS Package Number TO5A



TL/H/10759-2

Front View
Order Number LM2927T
See NS Package Number TO5A



TL/H/10759-14

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Survival	
$t = 100$ ms	80V
$t = 1$ ms	-50V
Continuous	-18V to +26V
Reset Output Sink Current	10 mA

ESD Susceptibility (Note 2)	2 kV
Power Dissipation (Note 3)	Internally Limited
Junction Temperature (T_{JMAX})	150°C
Storage Temperature Range	-40°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

Operating Ratings (Note 1)

Junction Temperature Range (T_J)	-40°C to +125°C
Maximum Input Voltage	26V

Electrical Characteristics $V_{IN} = 14.4V$, $C_O = 10 \mu F$, $-40^\circ C \leq T_J \leq 125^\circ C$, unless otherwise specified.

Parameter	Conditions	Typ (Note 4)	Limit (Note 5)	Units (Limit)
REGULATOR OUTPUT				
Output Voltage	$5 \text{ mA} \leq I_O \leq 500 \text{ mA}$, $T_J = 25^\circ C$	5	4.85	V (min)
			5.15	V (max)
	$5 \text{ mA} \leq I_O \leq 500 \text{ mA}$	5	4.75	V (min)
			5.25	V (max)
Line Regulation	$I_O = 5 \text{ mA}$, $9V \leq V_{IN} \leq 16V$	1	25	mV (max)
	$I_O = 5 \text{ mA}$, $7V \leq V_{IN} \leq 26V$		3	50
Load Regulation	$5 \text{ mA} \leq I_O \leq 500 \text{ mA}$	5	60	mV (max)
Quiescent Current	$I_O = 5 \text{ mA}$	2	3	mA (max)
	$I_O = 500 \text{ mA}$		8	30
Quiescent Current at Low V_{IN}	$I_O = 5 \text{ mA}$, $V_{IN} = 5V$	3	10	mA (max)
	$I_O = 500 \text{ mA}$, $V_{IN} = 6V$		25	60
Dropout Voltage (Note 6)	$I_O = 5 \text{ mA}$, $T_J = 25^\circ C$	60	200	mV (max)
	$I_O = 5 \text{ mA}$		300	mV (max)
	$I_O = 500 \text{ mA}$, $T_J = 25^\circ C$	350	600	mV (max)
	$I_O = 500 \text{ mA}$		700	mV (max)
Short Circuit Current	$V_{IN} = 8V$, $R_L = 1\Omega$	2	800	mA (min)
			3	A (max)
Ripple Rejection	$f_{RIPPLE} = 120 \text{ Hz}$, $V_{RIPPLE} = 1 \text{ Vrms}$, $I_O = 50 \text{ mA}$		60	dB (min)
Output Impedance	$I_O = 50 \text{ mAdc}$ and 10 mArms @ 1 kHz	100		m Ω
Output Noise	10 Hz to 100 kHz, $I_O = 50 \text{ mA}$	1		mVrms
Long Term Stability		20		mV/1000 Hr
Maximum Operational Input Voltage	Continuous		26	V (min)

Electrical Characteristics

$V_{IN} = 14.4V$, $C_O = 10 \mu F$, $-40^\circ C \leq T_J \leq 125^\circ C$, unless otherwise specified (Continued)

Parameter	Conditions	Typ (Note 4)	Limit (Note 5)	Units (Limit)
REGULATOR OUTPUT (Continued)				
Peak Transient Input Voltage	$V_O \leq 7V$, $R_L = 100\Omega$, $t_f = 100 \text{ ms}$		80	V (min)
Reverse DC Input Voltage	$V_O \geq -0.6V$, $R_L = 100\Omega$		-18	V (min)
Reverse Transient Input Voltage	$t_r = 1 \text{ ms}$, $R_L = 100\Omega$		-50	V (min)
RESET OUTPUT				
Threshold	ΔV_O Required for Reset Condition (Note 7)	-250	-80 -400	mV (min) mV mV (max)
Output Low Voltage	$I_{SINK} = 1.6 \text{ mA}$, $V_{IN} = 3.2V$	0.15	0.4	V (max)
Internal Pull-Up Resistance		30		k Ω
Delay Time	$C_{DELAY} = 10 \text{ nF}$ (See Timing Curve)	19		ms
Minimum Operational V_{IN} on Power Up	Delayed Reset Output $\leq 0.8V$, $I_{SINK} = 1.6 \text{ mA}$, $R_L = 100\Omega$	2.2	3.2	V V (min)
Minimum Operational V_O on Power Down	Delay Reset Output $\leq 0.8V$, $I_{SINK} = 10 \mu A$, $V_{IN} = 0V$	0.7		V
DELAY CAPACITOR PIN				
Threshold Difference (ΔV_{DELAY})	Change in Delay Capacitor Voltage Required for Reset Output to Return High	3.75	3.5 4.1	V (min) V V (max)
Charging Current (I_{DELAY})		2.0	1.0 3.0	μA (min) μA μA (max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. **Operating Ratings** indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the **Electrical Characteristics**.

Note 2: Human body model; 100 pF discharged through a 1.5 k Ω resistor.

Note 3: The maximum power dissipation is a function of T_{JMAX} , and θ_{JA} , and T_A , and is limited by thermal shutdown. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{JMAX} - T_A) / \theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the device will go into thermal shutdown. For the LM2926 and LM2927, the junction-to-ambient thermal resistance is 53°C/W, and the junction-to-case thermal resistance is 3°C/W.

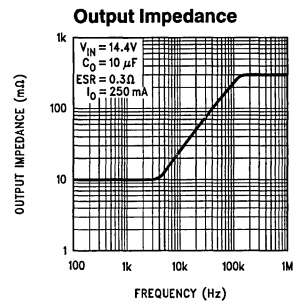
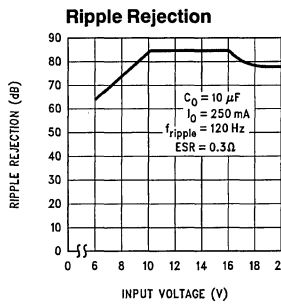
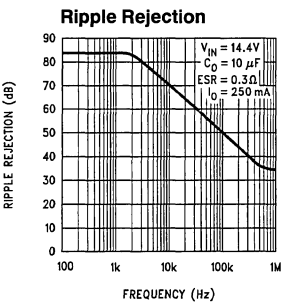
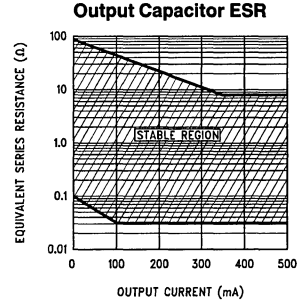
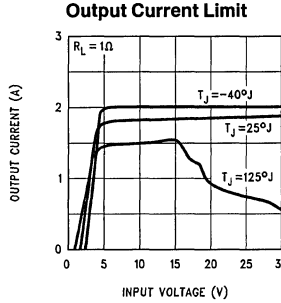
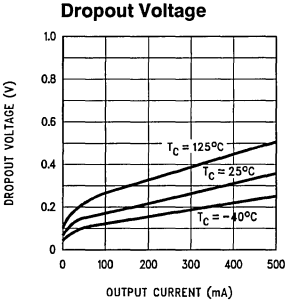
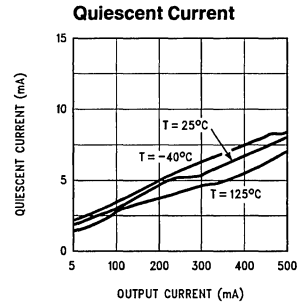
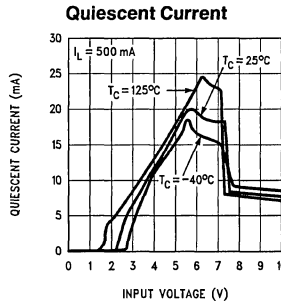
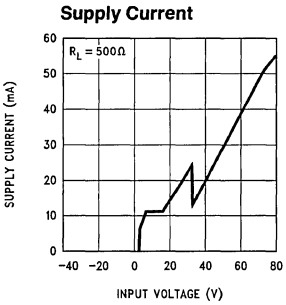
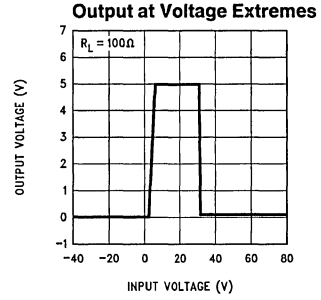
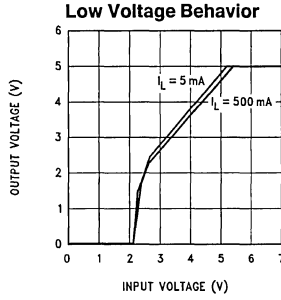
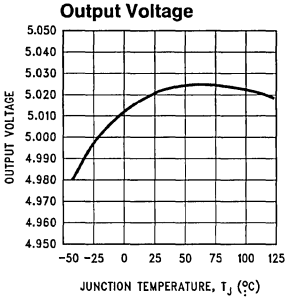
Note 4: Typicals are at $T_J = 25^\circ C$ and represent the most likely parametric norm.

Note 5: Limits are 100% guaranteed by production testing.

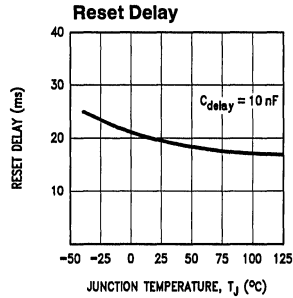
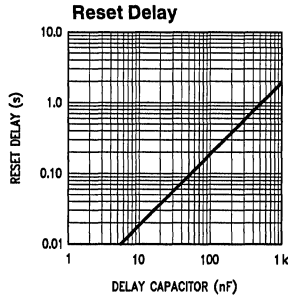
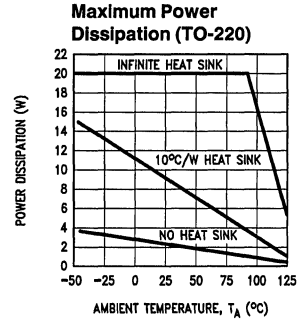
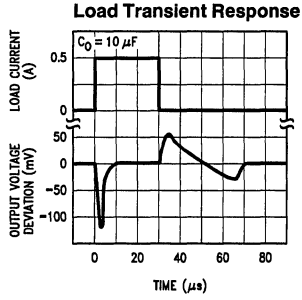
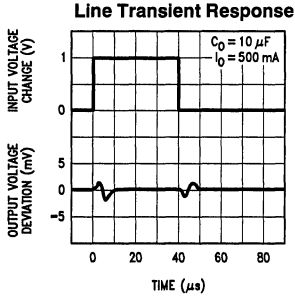
Note 6: Dropout voltage is the input-output differential at which the circuit ceases to regulate against any further reduction in input voltage. Dropout voltage is measured when the output voltage (V_O) has dropped 100 mV from the nominal value measured at $V_{IN} = 14.4V$.

Note 7: The reset flag is set LOW when the output voltage has dropped an amount, ΔV_O , from the nominal value measured at $V_{IN} = 14.4V$.

Typical Performance Characteristics

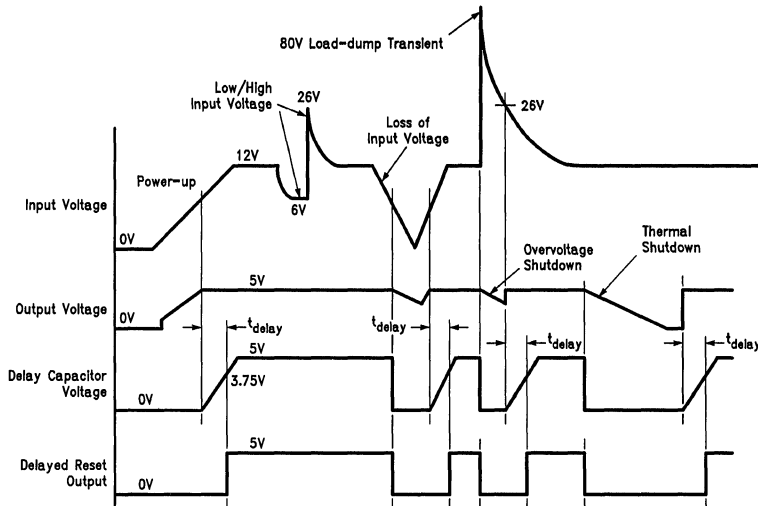


Typical Performance Characteristics (Continued)



TL/H/10759-4

Typical Circuit Waveforms



TL/H/10759-5

Applications Information

EXTERNAL CAPACITORS

The LM2926/7 output capacitor is required for stability. Without it, the regulator output will oscillate at amplitudes as high as several volts peak-to-peak at frequencies up to 500 kHz. Although 10 μF is the minimum recommended value, the actual size and type may vary depending upon the application load and temperature range. Capacitor equivalent series resistance (ESR) also affects stability. The region of stable operation is shown in the **Typical Performance Characteristics** (Output Capacitor ESR curve).

Output capacitors can be increased in size to any desired value above 10 μF . One possible purpose of this would be to maintain the output voltage during brief conditions of input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum electrolytics freeze at temperatures below -30°C , reducing their effective capacitance to zero. To maintain regulator stability down to -40°C , capacitors rated at that temperature (such as tantalums) must be used.

DELAYED RESET

The delayed reset output is designed to hold a microprocessor in a reset state on system power-up for a programmable time interval to allow the system clock and other powered circuitry to stabilize. A full reset interval is also generated whenever the output voltage falls out of regulation. The circuit is tripped whenever the output voltage of the regulator is out of regulation by the Reset Threshold value. This can be caused by low input voltages, over current conditions, over-voltage shutdown, thermal shutdown, and by both power-up and power-down sequences. When the reset circuit detects one of these conditions, the delay capacitor is discharged by an SCR and held in a discharged state by a saturated NPN switch. As long as the delay capacitor is held low, the reset output is also held low. Because of the action of the SCR, the reset output cannot glitch on noise or transient fault conditions. A full reset pulse is obtained for any fault condition that trips the reset circuit.

When the output regains regulation, the SCR is switched off and a small current ($I_{\text{DELAY}} = 2 \mu\text{A}$) begins charging the delay capacitor. When the capacitor voltage increases 3.75V (ΔV_{DELAY}) from its discharged value, the reset output is again set HIGH. The delay time is calculated by:

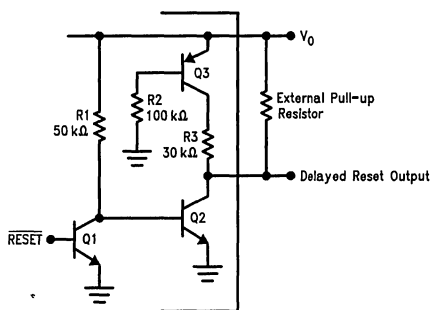
$$\text{delay time} = \frac{C_{\text{DELAY}} \Delta V_{\text{DELAY}}}{I_{\text{DELAY}}} \quad (1)$$

or

$$\text{delay time} \approx 1.9 \times 10^6 C_{\text{DELAY}} \quad (2)$$

The constant, 1.9×10^6 , has a $\pm 20\%$ tolerance from device to device. The total delay time error budget is the sum of the 20% device tolerance and the tolerance of the external capacitor. For a 20% timing capacitor tolerance, the worst case total timing variation would amount to $\pm 40\%$, or a ratio of 2.33:1. In most applications the minimum expected reset pulse is of interest. This occurs with minimum C_{DELAY} , minimum ΔV_{DELAY} , and maximum I_{DELAY} . ΔV_{DELAY} and I_{DELAY} are fully specified in the **Electrical Characteristics**. Graphs showing the relationship between delay time and both temperature and C_{DELAY} are shown in the **Typical Performance Characteristics**.

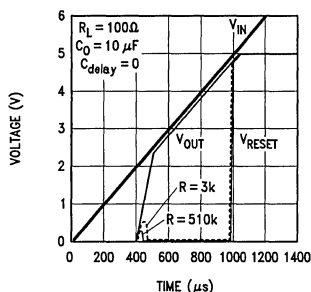
As shown in *Figure 1*, the delayed reset output is pulled low by an NPN transistor (Q2), and pulled high to V_O by an internal 30 k Ω resistor (R3) and PNP transistor (Q3). The reset output will operate when V_O is sufficient to bias Q2 (0.7V or more). At lower voltages the reset output will be in a high impedance condition. Because of differences in the V_{BE} of Q2 and Q3 and the values of R1 and R2, Q2 is guaranteed by design to bias *before* Q3, providing a smooth transition from the high impedance state when $V_O < 0.7\text{V}$, to the active low state when $V_O > 0.7\text{V}$.



TL/H/10759-6

FIGURE 1. Delay Reset Output

The static reset characteristics are shown in *Figure 2*. This shows the relationship between the input voltage, the regulator output and reset output. Plots are shown for various external pull-up resistors ranging in value from 3 k Ω to an open circuit. Any external pull-up resistance causes the reset output to follow the regulator output until Q2 is biased ON. C_{DELAY} has no effect on this characteristic.



TL/H/10759-7

FIGURE 2. Reset Output Behavior during Power-Up

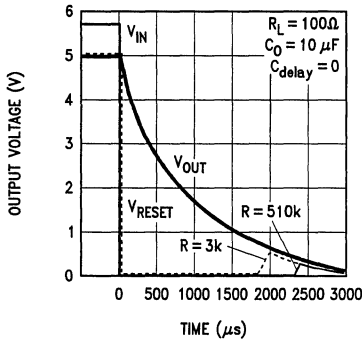
Figure 2 is useful for determining reset performance at any particular input voltage. Dynamic performance at power-up will closely follow the characteristics illustrated in *Figure 2*, except for the delay added by C_{DELAY} when V_O reaches 5V.

The dynamic reset characteristics at power-down are illustrated by the curve shown in *Figure 3*. At time $t = 0$ the input voltage is instantaneously brought to 0V, leaving the output powered by C_O . As the voltage on C_O decays (discharged by a 100 Ω load resistor), the reset output is held low. As V_O drops below 0.7V, the reset rises up slightly should there be any external pull-up resistance. With no external resistance, the reset line stays low throughout the entire power down cycle. If the input voltage does not fall instantaneously, the reset signal will tend to follow the performance characteristics shown in *Figure 2*.

Applications Information (Continued)

SYSTEM DESIGN CONSIDERATIONS

Many microprocessors are specified for operation at $5V \pm 10\%$, although they often continue operating well outside this range. Others, such as certain members of the COPS family of microcontrollers, are specified for operation as low as 2.4V.



TL/H/10759-8

FIGURE 3. Reset Output Behavior during Power-Down

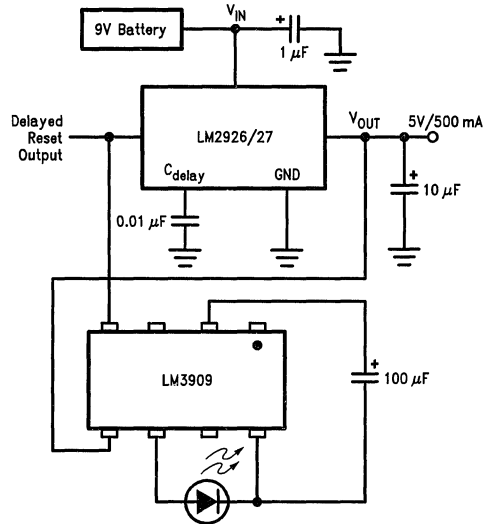
Of particular concern is low voltage operation, which occurs in battery operated systems when the battery reaches the end of its discharge cycle. Under this condition, when the supply voltage is outside the guaranteed operating range, the clock may continue to run and the microprocessor will attempt to execute instructions. If the supply voltage is outside the guaranteed operating range, the instructions may not execute properly and a hardware reset such as is supplied by the LM 2926/7 may fail to bring the processor under control. The LM 2926/7 reset output may be more efficiently employed in certain applications as a means of defeating memory WRITE lines, clocks, or external loads, rather than depending on unspecified microprocessor operating conditions.

In critical applications the microprocessor reset input should be fully characterized and guaranteed to operate until the clock ceases oscillating.

INPUT TRANSIENTS

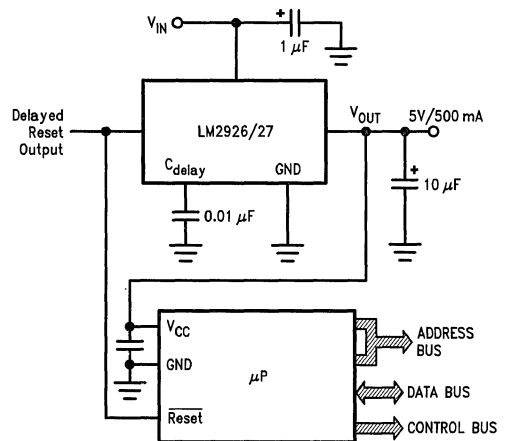
The LM2926/7 are guaranteed to withstand positive input transients to 80V followed by an exponential decay of $\tau = 20$ ms ($t_f = 100$ ms, or 5 time constants) while maintaining an output of less than 7V. The regulator remains operational to $26 V_{DC}$, and shuts down if this value is exceeded.

Battery Powered Regulator with Flashing LED for Low Battery Indication



TL/H/10759-9

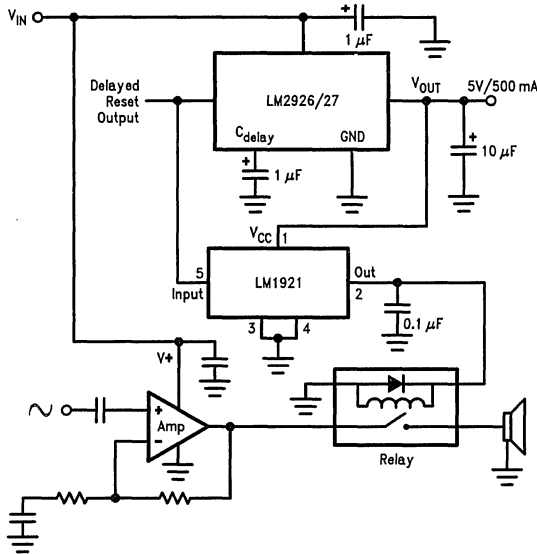
General Microprocessor Configuration



TL/H/10759-10

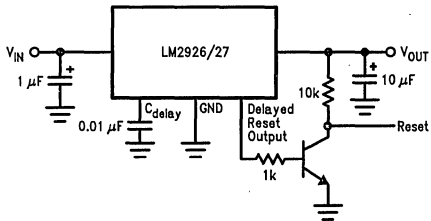
Applications Information (Continued)

Using the Reset to De-Activate Power Loads. The LM1921 is a Fully Protected 1 Amp High-Side Driver.



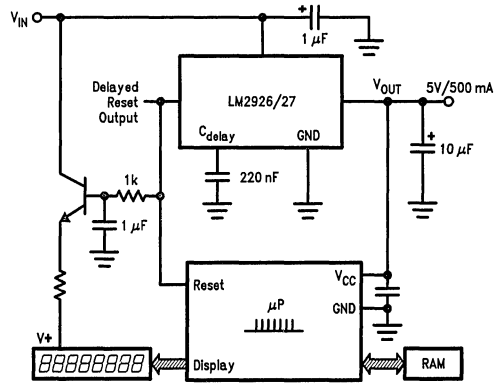
TL/H/10759-11

Generating an Active High Reset Signal



TL/H/10759-12

Using the Reset to Ensure an Accurate Display on Power-Up or Power-Down



TL/H/10759-13

LM2930 3-Terminal Positive Regulator

General Description

The LM2930 3-terminal positive regulator features an ability to source 150 mA of output current with an input-output differential of 0.6V or less. Efficient use of low input voltages obtained, for example, from an automotive battery during cold crank conditions, allows 5V circuitry to be properly powered with supply voltages as low as 5.6V. Familiar regulator features such as current limit and thermal overload protection are also provided.

Designed originally for automotive applications, the LM2930 and all regulated circuitry are protected from reverse battery installations or 2 battery jumps. During line transients, such as a load dump (40V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both internal circuits and the load. The LM2930 cannot be harmed by temporary mirror-image insertion.

Fixed outputs of 5V and 8V are available in the plastic TO-220 power package.

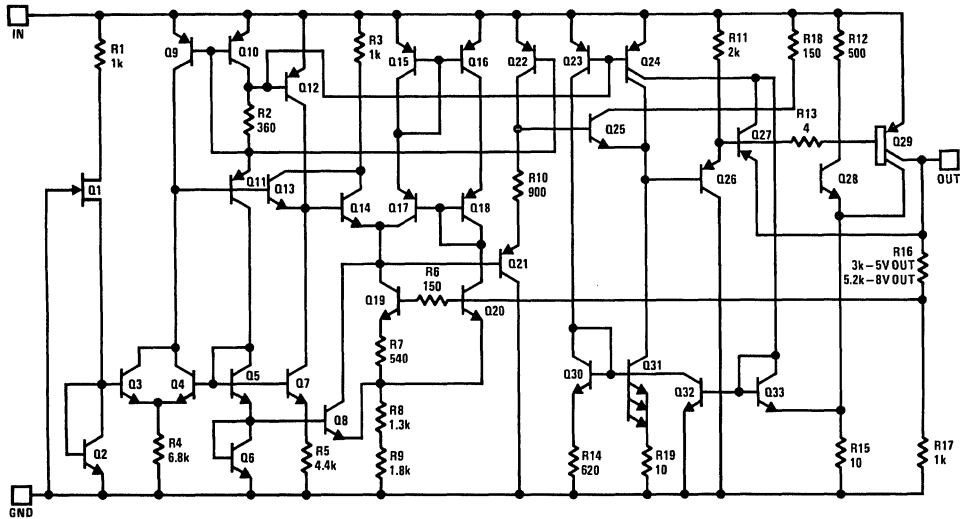
Features

- Input-output differential less than 0.6V
- Output current in excess of 150 mA
- Reverse battery protection
- 40V load dump protection
- Internal short circuit current limit
- Internal thermal overload protection
- Mirror-image insertion protection
- P+ Product Enhancement tested

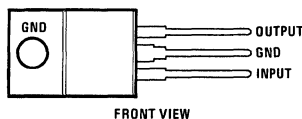
Voltage Range

LM2930T-5.0	5V
LM2930T-8.0	8V

Schematic and Connection Diagrams



(TO-220)
Plastic Package



Order Number LM2930T-5.0 or LM2930T-8.0
See NS Package T03B

TL/H/5539-1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Overvoltage Protection	40V
Reverse Voltage (100 ms)	-12V
Reverse Voltage (DC)	-6V

Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range	-40°C to +85°C
Maximum Junction Temperature	125°C
Storage Temperature Range	-65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	230°C

Electrical Characteristics (Note 2)

LM2930T-5.0 $V_{IN} = 14V$, $I_O = 150\text{ mA}$, $T_J = 25^\circ\text{C}$ (Note 5), $C_2 = 10\ \mu\text{F}$, unless otherwise specified

Parameter	Conditions	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Unit
Output Voltage		5	5.3 4.7		V_{MAX} V_{MIN}
	$6V \leq V_{IN} \leq 26V$, $5\text{ mA} \leq I_O \leq 150\text{ mA}$ $-40^\circ\text{C} \leq T_J \leq 125^\circ\text{C}$			5.5 4.5	V_{MAX} V_{MIN}
Line Regulation	$9V \leq V_{IN} \leq 16V$, $I_O = 5\text{ mA}$	7	25		mV_{MAX}
	$6V \leq V_{IN} \leq 26V$, $I_O = 5\text{ mA}$	30	80		mV_{MAX}
Load Regulation	$5\text{ mA} \leq I_O \leq 150\text{ mA}$	14	50		mV_{MAX}
Output Impedance	100 mA_{DC} & 10 mA_{rms} , 100 Hz – 10 kHz	200			$m\Omega$
Quiescent Current	$I_O = 10\text{ mA}$	4	7		mA_{MAX}
	$I_O = 150\text{ mA}$	18	40		mA_{MAX}
Output Noise Voltage	10 Hz – 100 kHz	140			μV_{rms}
Long Term Stability		20			$mV/1000\text{ hr}$
Ripple Rejection	$f_O = 120\text{ Hz}$	56			dB
Current Limit		400	700 150		mA_{MAX} mA_{MIN}
Dropout Voltage	$I_O = 150\text{ mA}$	0.32	0.6		V_{MAX}
Output Voltage Under Transient Conditions	$-12V \leq V_{IN} \leq 40V$, $R_L = 100\Omega$		5.5 -0.3		V_{MAX} V_{MIN}

Electrical Characteristics (Note 2)

LM2930T-8.0 ($V_{IN} = 14V$, $I_O = 150\text{ mA}$, $T_J = 25^\circ\text{C}$ (Note 5), $C_2 = 10\ \mu\text{F}$, unless otherwise specified)

Parameter	Conditions	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Unit
Output Voltage		8	8.5 7.5		V_{MAX} V_{MIN}
	$9.4V \leq V_{IN} \leq 26V$, $5\text{ mA} \leq I_O \leq 150\text{ mA}$, $-40^\circ\text{C} \leq T_J \leq 125^\circ\text{C}$			8.8 7.2	V_{MAX} V_{MIN}
Line Regulation	$9.4V \leq V_{IN} \leq 16V$, $I_O = 5\text{ mA}$	12	50		mV_{MAX}
	$9.4V \leq V_{IN} \leq 26V$, $I_O = 5\text{ mA}$	50	100		mV_{MAX}
Load Regulation	$5\text{ mA} \leq I_O \leq 150\text{ mA}$	25	50		mV_{MAX}
Output Impedance	100 mA_{DC} & 10 mA_{rms} , 100 Hz – 10 kHz	300			$m\Omega$
Quiescent Current	$I_O = 10\text{ mA}$	4	7		mA_{MAX}
	$I_O = 150\text{ mA}$	18	40		mA_{MAX}
Output Noise Voltage	10 Hz – 100 kHz	170			μV_{rms}
Long Term Stability		30			$mV/1000\text{ hr}$
Ripple Rejection	$f_O = 120\text{ Hz}$	52			dB
Current Limit		400	700 150		mA_{MAX} mA_{MIN}
Dropout Voltage	$I_O = 150\text{ mA}$	0.32	0.6		V_{MAX}
Output Voltage Under Transient Conditions	$-12V \leq V_{IN} \leq 40V$, $R_L = 100\Omega$		8.8 -0.3		V_{MAX} V_{MIN}

Note 1: Thermal resistance without a heat sink for junction to case temperature is 3°C/W and for case to ambient temperature is 50°C/W.

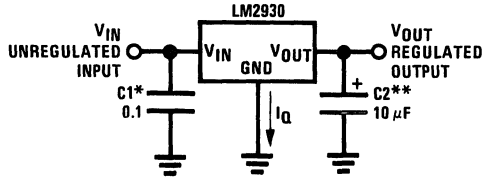
Note 2: All characteristics are measured with a capacitor across the input of 0.1 μF and a capacitor across the output of 10 μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W \leq 10$ ms, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Guaranteed and 100% production tested.

Note 4: Guaranteed (but not 100% production tested) over the operating temperature and input current ranges. These limits are not used to calculate outgoing quality levels.

Note 5: To ensure constant junction temperature, low duty cycle pulse testing is used.

Typical Application

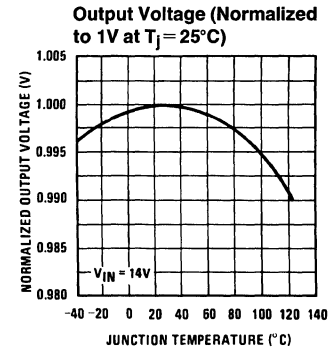
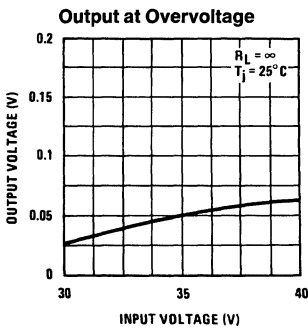
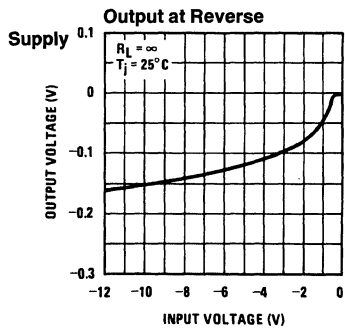
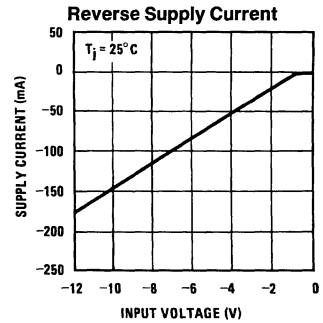
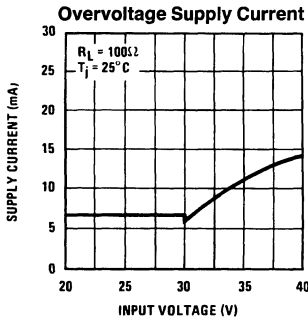
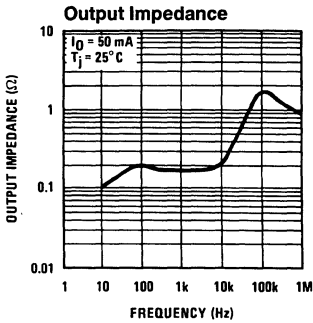


TL/H/5539-5

*Required if regulator is located far from power supply filter.

** C_{OUT} must be at least 10 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor should be less than 1Ω over the expected operating temperature range.

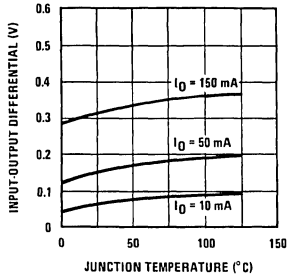
Typical Performance Characteristics



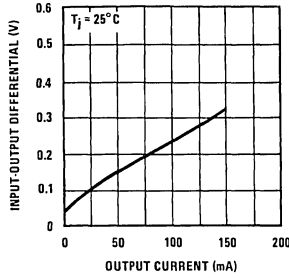
TL/H/5539-4

Typical Performance Characteristics (Continued)

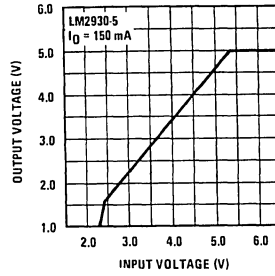
Dropout Voltage



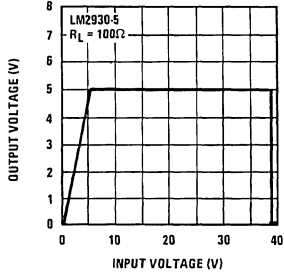
Dropout Voltage



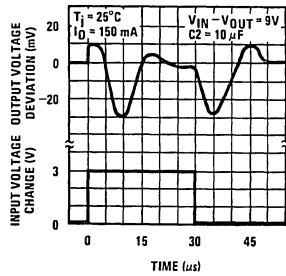
Low Voltage Behavior



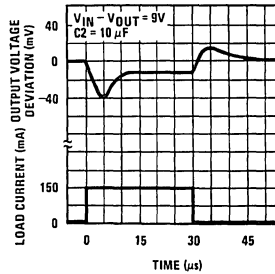
High Voltage Behavior



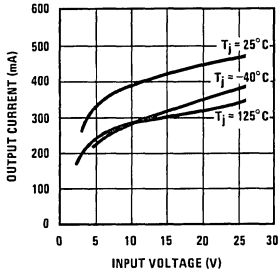
Line Transient Response



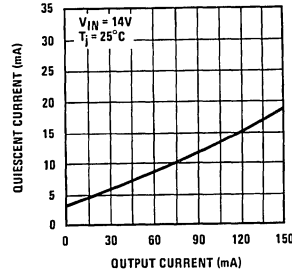
Load Transient Response



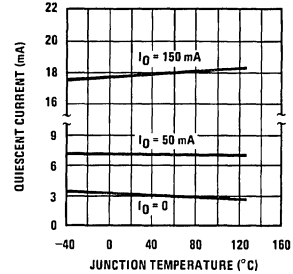
Peak Output Current



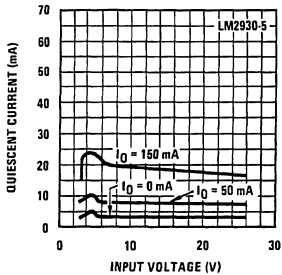
Quiescent Current



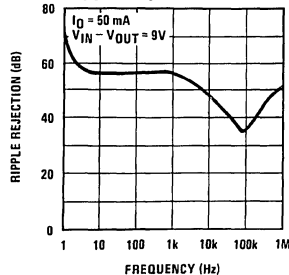
Quiescent Current



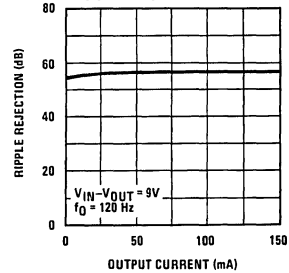
Quiescent Current



Ripple Rejection



Ripple Rejection



TL/H/5539-2

Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

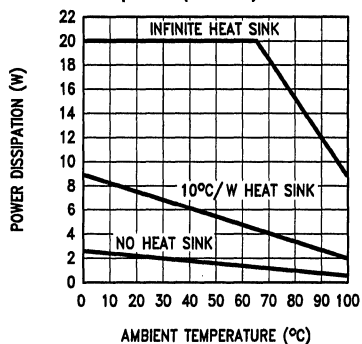
Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O : The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Maximum Power Dissipation (TO-220)



TL/H/5539-6

LM2931 Series Low Dropout Regulators

General Description

The LM2931 positive voltage regulator features a very low quiescent current of 1 mA or less when supplying 10 mA loads. This unique characteristic and the extremely low input-output differential required for proper regulation (0.2V for output currents of 10 mA) make the LM2931 the ideal regulator for standby power systems. Applications include memory standby circuits, CMOS and other low power processor power supplies as well as systems demanding as much as 100 mA of output current.

Designed originally for automotive applications, the LM2931 and all regulated circuitry are protected from reverse battery installations or 2 battery jumps. During line transients, such as a load dump (60V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both internal circuits and the load. The LM2931 cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

The LM2931 family includes a fixed 5V output ($\pm 3.8\%$ tolerance for A grade) or an adjustable output with ON/OFF pin. Both versions are available in a TO-220 power package and an 8-lead surface mount package. The fixed output version is also available in the TO-92 plastic package.

Features

- Very low quiescent current
- Output current in excess of 100 mA
- Input-output differential less than 0.6V
- Reverse battery protection
- 60V load dump protection
- -50V reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- Mirror-image insertion protection
- Available in TO-220, TO-92 or SO-8 packages
- Available as adjustable with TTL compatible switch

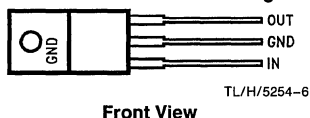
Output Voltage Options

LM2931T-5.0, LM2931AT-5.0	5V
LM2931Z-5.0, LM2931AZ-5.0	5V
LM2931M-5.0, LM2931AM-5.0	5V
LM2931CT	Adjustable from 3V to 24V
LM2931CM	Adjustable from 3V to 24V

Connection Diagrams and Ordering Information

FIXED 5V OUTPUT

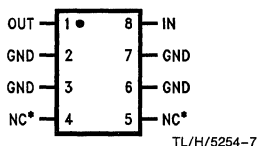
TO-220 3-Lead Power Package



Order Number **LM2931T-5.0** or
LM2931AT-5.0

See NS Package Number **T03B**

8-Pin Surface Mount



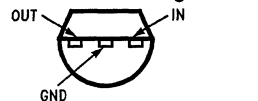
*NC = Not internally connected

Top View

Order Number **LM2931M-5.0** or
LM2931AM-5.0

See NS Package Number **M08A**

TO-92 Plastic Package



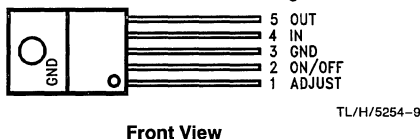
Bottom View

Order Number **LM2931Z-5.0** or
LM2931AZ-5.0

See NS Package Number **Z03A**

ADJUSTABLE OUTPUT VOLTAGE

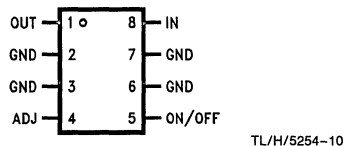
TO-220 5-Lead Power Package



Front View

Order Number **LM2931CT**
See NS Package Number **T05A**

8-Pin Surface Mount



Top View

Order Number **LM2931CM**
See NS Package Number **M08A**

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Overshoot Protection	
LM2931A, LM2931CT Adjustable	60V
LM2931	50V

Internal Power Dissipation (Notes 1 and 3)	Internally Limited
Operating Ambient Temperature Range	-40°C to +85°C
Maximum Junction Temperature	125°C
Storage Temperature Range	-65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	230°C
ESD Tolerance (Note 4)	2000V

Electrical Characteristics for Fixed 5V Version

$V_{IN} = 14V$, $I_O = 10\text{ mA}$, $T_J = 25^\circ\text{C}$, $C_2 = 100\ \mu\text{F}$ (unless otherwise specified) (Note 1)

Parameter	Conditions	LM2931A-5.0		LM2931-5.0		Units Limit
		Typ	Limit (Note 2)	Typ	Limit (Note 2)	
Output Voltage		5	5.19 4.81		5.25 4.75	V_{MAX} V_{MIN}
	$6.0V \leq V_{IN} \leq 26V$, $I_O = 100\text{ mA}$ $-40^\circ\text{C} \leq T_J \leq 125^\circ\text{C}$		5.25 4.75		5.5 4.5	V_{MAX} V_{MIN}
Line Regulation	$9V \leq V_{IN} \leq 16V$	2	10	2	10	mV_{MAX}
	$6V \leq V_{IN} \leq 26V$	4	30	4	30	mV_{MAX}
Load Regulation	$5\text{ mA} \leq I_O \leq 100\text{ mA}$	14	50	14	50	mV_{MAX}
Output Impedance	100 mA_{DC} and 10 mA_{rms} , 100 Hz–10 kHz	200		200		$m\Omega_{MAX}$
Quiescent Current	$I_O \leq 10\text{ mA}$, $6V \leq V_{IN} \leq 26V$ $-40^\circ\text{C} \leq T_J \leq 125^\circ\text{C}$	0.4	1.0	0.4	1.0	mA_{MAX}
	$I_O = 100\text{ mA}$, $V_{IN} = 14V$, $T_J = 25^\circ\text{C}$	15	30 5	15		mA_{MAX} mA_{MIN}
Output Noise Voltage	10 Hz–100 kHz, $C_{OUT} = 100\ \mu\text{F}$	500		500		μV_{rmsMAX}
Long Term Stability		20		20		$\text{mV}/1000\text{ hr}$
Ripple Rejection	$f_O = 120\text{ Hz}$	80	55	80		dB_{MIN}
Dropout Voltage	$I_O = 10\text{ mA}$	0.05	0.2	0.05	0.2	V_{MAX}
	$I_O = 100\text{ mA}$	0.3	0.6	0.3	0.6	V_{MAX}
Maximum Operational Input Voltage		33		33		V_{MAX}
			26		26	V_{MIN}
Maximum Line Transient	$R_L = 500\Omega$, $V_O \leq 5.5V$, $T = 1\text{ ms}$, $\tau \leq 100\text{ ms}$	70	60	70	50	V_{MIN}
Reverse Polarity Input Voltage, DC	$V_O \geq -0.3V$, $R_L = 500\Omega$	-30	-15	-30	-15	V_{MIN}
Reverse Polarity Input Voltage, Transient	$T = 1\text{ ms}$, $\tau \leq 100\text{ ms}$, $R_L = 500\Omega$	-80	-50	-80	-50	V_{MIN}

Note 1: See circuit in Typical Applications. To ensure constant junction temperature, low duty cycle pulse testing is used.

Note 2: All limits are guaranteed for $T_J = 25^\circ\text{C}$ (standard type face) or over the full operating junction temperature range of -40°C to $+125^\circ\text{C}$ (**bold type face**).

Note 3: The maximum power dissipation is a function of maximum junction temperature T_{Jmax} , total thermal resistance θ_{JA} , and ambient temperature T_A . The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2931 will go into thermal shutdown. For the LM2931 in the TO-92 package, θ_{JA} is $195^\circ\text{C}/\text{W}$; in the SO-8 package, θ_{JA} is $160^\circ\text{C}/\text{W}$, and in the TO-220 package, θ_{JA} is $50^\circ\text{C}/\text{W}$. If the TO-220 package is used with a heat sink, θ_{JA} is the sum of the package thermal resistance junction-to-case of $3^\circ\text{C}/\text{W}$ and the thermal resistance added by the heat sink and thermal interface.

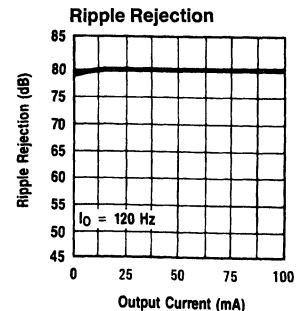
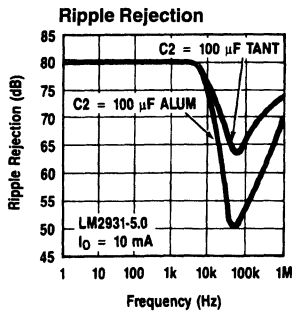
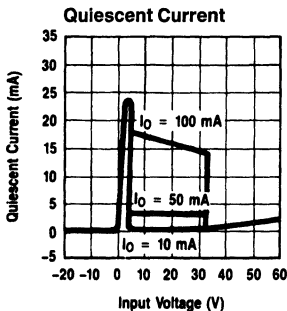
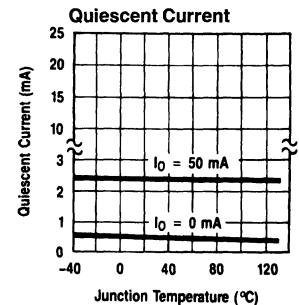
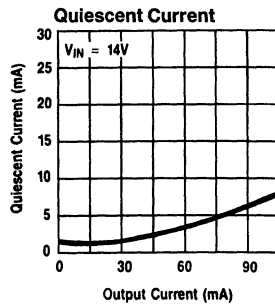
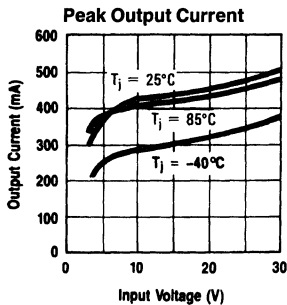
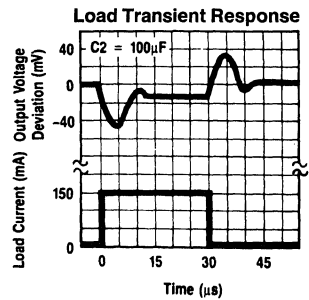
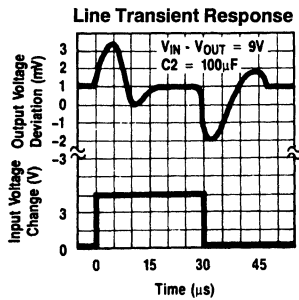
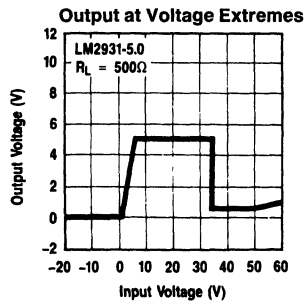
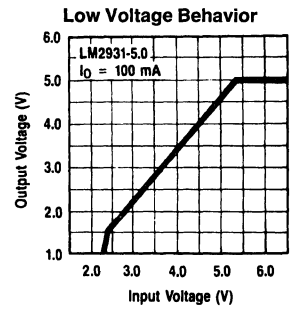
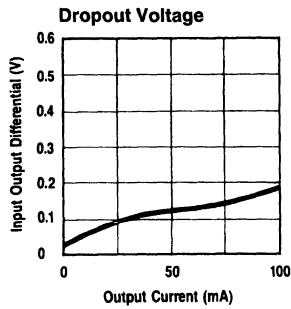
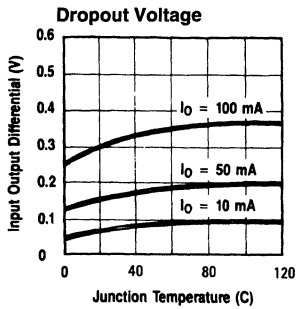
Note 4: Human body model, 100 pF discharged through 1.5 k Ω .

Electrical Characteristics for Adjustable Version

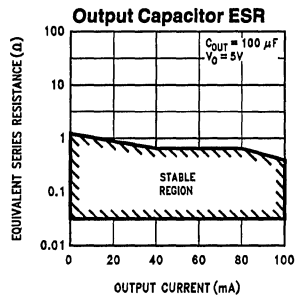
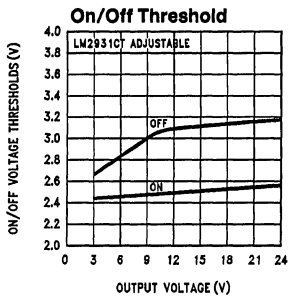
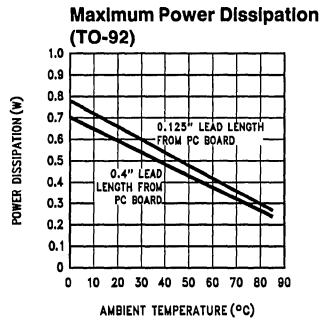
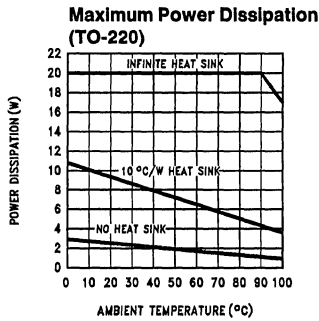
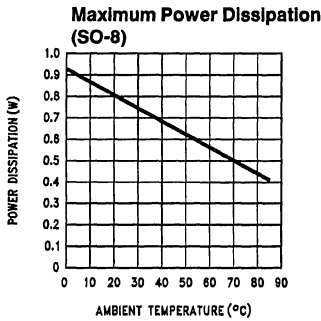
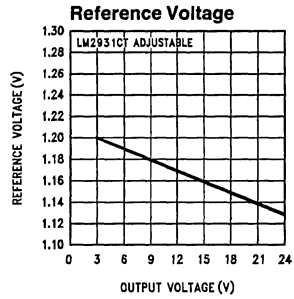
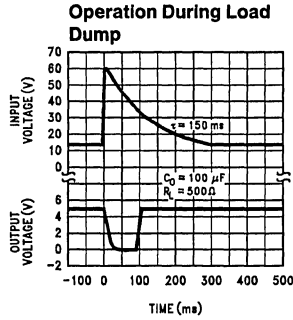
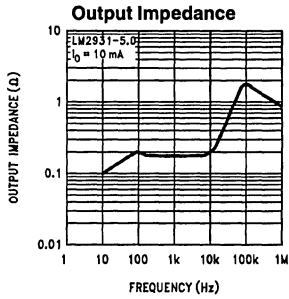
$V_{IN} = 14V$, $V_{OUT} = 3V$, $I_O = 10\text{ mA}$, $T_J = 25^\circ\text{C}$, $R_1 = 27k$, $C_2 = 100\ \mu\text{F}$ (unless otherwise specified) (Note 1)

Parameter	Conditions	Typ	Limit	Units Limit
Reference Voltage		1.20	1.26 1.14	V_{MAX} V_{MIN}
	$I_O \leq 100\text{ mA}$, $-40^\circ\text{C} \leq T_J \leq 125^\circ\text{C}$, $R_1 = 27k$ Measured from V_{OUT} to Adjust Pin		1.32 1.08	V_{MAX} V_{MIN}
Output Voltage Range			24 3	V_{MAX} V_{MIN}
Line Regulation	$V_{OUT} + 0.6V \leq V_{IN} \leq 26V$	0.2	1.5	mV/V_{MAX}
Load Regulation	$5\text{ mA} \leq I_O \leq 100\text{ mA}$	0.3	1	$\%_{MAX}$
Output Impedance	100 mA_{DC} and 10 mA_{rms} , 100 Hz–10 kHz	40		$\text{m}\Omega/V$
Quiescent Current	$I_O = 10\text{ mA}$ $I_O = 100\text{ mA}$ During Shutdown $R_L = 500\Omega$	0.4	1	mA_{MAX}
		15		mA
		0.8	1	mA_{MAX}
Output Noise Voltage	10 Hz–100 kHz	100		$\mu\text{V}_{rms}/V$
Long Term Stability		0.4		$\%/1000\text{ hr}$
Ripple Rejection	$f_O = 120\text{ Hz}$	0.02		$\%/V$
Dropout Voltage	$I_O \leq 10\text{ mA}$ $I_O = 100\text{ mA}$	0.05	0.2	V_{MAX}
		0.3	0.6	V_{MAX}
Maximum Operational Input Voltage		33	26	V_{MIN}
Maximum Line Transient	$I_O = 10\text{ mA}$, Reference Voltage $\leq 1.5V$ $T = 1\text{ ms}$, $\tau \leq 100\text{ ms}$	70	60	V_{MIN}
Reverse Polarity Input Voltage, DC	$V_O \geq -0.3V$, $R_L = 500\Omega$	-30	-15	V_{MIN}
Reverse Polarity Input Voltage, Transient	$T = 1\text{ ms}$, $\tau \leq 100\text{ ms}$, $R_L = 500\Omega$	-80	-50	V_{MIN}
On/Off Threshold Voltage	$V_O = 3V$	2.0	1.2	V_{MAX}
		2.2	3.25	V_{MIN}
On/Off Threshold Current		20	50	μA_{MAX}

Typical Performance Characteristics



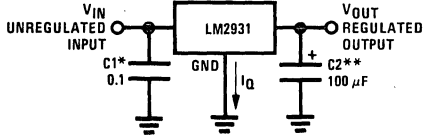
Typical Performance Characteristics



TL/H/5254-3

Typical Applications

LM2931 Fixed Output

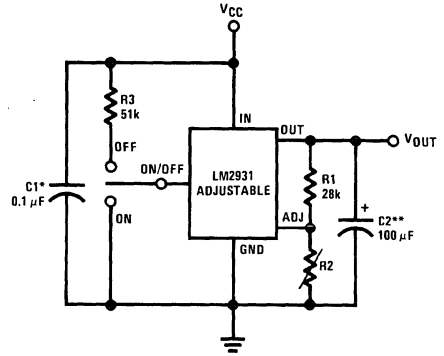


TL/H/5254-4

*Required if regulator is located far from power supply filter.

**C2 must be at least 100 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

LM2931 Adjustable Output

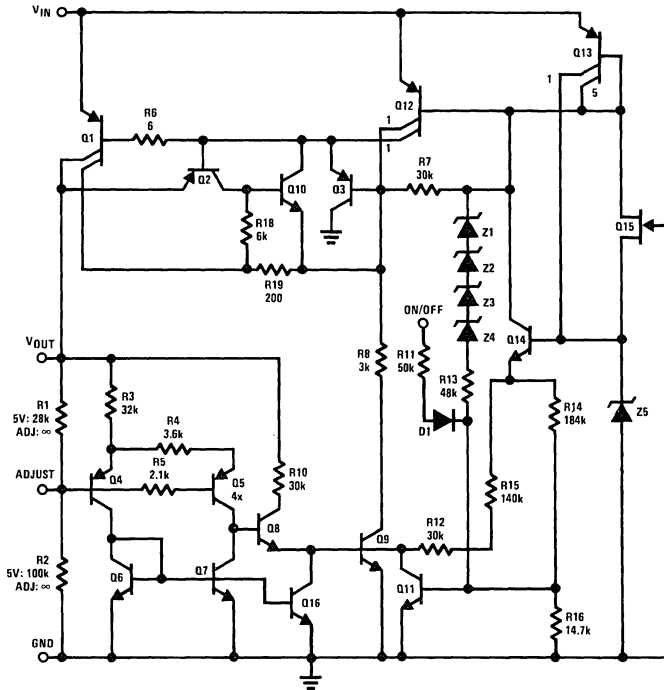


TL/H/5254-5

$$V_{OUT} = \text{Reference Voltage} \times \frac{R1 + R2}{R1}$$

Note: Using 27k for R1 will automatically compensate for errors in V_{OUT} due to the input bias current of the ADJ pin (approximately 1 μA).

Schematic Diagram



TL/H/5254-1

Application Hints

One of the distinguishing factors of the LM2931 series regulators is the requirement of an output capacitor for device stability. The value required varies greatly depending upon the application circuit and other factors. Thus some comments on the characteristics of both capacitors and the regulator are in order.

High frequency characteristics of electrolytic capacitors depend greatly on the type and even the manufacturer. As a result, a value of capacitance that works well with the LM2931 for one brand or type may not necessarily be sufficient with an electrolytic of different origin. Sometimes actual bench testing, as described later, will be the only means to determine the proper capacitor type and value. Experience has shown that, as a rule of thumb, the more expensive and higher quality electrolytics generally allow a smaller value for regulator stability. As an example, while a high-quality 100 μF aluminum electrolytic covers all general application circuits, similar stability can be obtained with a tantalum electrolytic of only 47 μF . This factor of two can generally be applied to any special application circuit also.

Another critical characteristic of electrolytics is their performance over temperature. While the LM2931 is designed to operate to -40°C , the same is not always true with all electrolytics (hot is generally not a problem). The electrolyte in many aluminum types will freeze around -30°C , reducing their effective value to zero. Since the capacitance is needed for regulator stability, the natural result is oscillation (and lots of it) at the regulator output. For all application circuits where cold operation is necessary, the output capacitor must be rated to operate at the minimum temperature. By coincidence, worst-case stability for the LM2931 also occurs at minimum temperatures. As a result, in applications where the regulator junction temperature will never be less than 25°C , the output capacitor can be reduced approximately by a factor of two over the value needed for the entire temperature range. To continue our example with the tantalum electrolytic, a value of only 22 μF would probably thus suffice. For high-quality aluminum, 47 μF would be adequate in such an application.

Another regulator characteristic that is noteworthy is that stability decreases with higher output currents. This sensible fact has important connotations. In many applications, the LM2931 is operated at only a few milliamps of output current or less. In such a circuit, the output capacitor can be further reduced in value. As a rough estimation, a circuit that is required to deliver a maximum of 10 mA of output current from the regulator would need an output capacitor of only half the value compared to the same regulator required to deliver the full output current of 100 mA. If the example of the tantalum capacitor in the circuit rated at 25°C junction temperature and above were continued to include a maximum of 10 mA of output current, then the 22 μF output capacitor could be reduced to only 10 μF .

In the case of the LM2931CT adjustable regulator, the minimum value of output capacitance is a function of the output voltage. As a general rule, the value decreases with higher output voltages, since internal loop gain is reduced.

At this point, the procedure for bench testing the minimum value of an output capacitor in a special application circuit should be clear. Since worst-case occurs at minimum operating temperatures and maximum operating currents, the entire circuit, including the electrolytic, should be cooled to the minimum temperature. The input voltage to the regulator should be maintained at 0.6V above the output to keep internal power dissipation and die heating to a minimum. Worst-case occurs just after input power is applied and before the die has had a chance to heat up. Once the minimum value of capacitance has been found for the brand and type of electrolytic in question, the value should be doubled for actual use to account for production variations both in the capacitor and the regulator. (All the values in this section and the remainder of the data sheet were determined in this fashion.)

Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage at a specified frequency.

Temperature Stability of V_O : The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.



LM2935 Low Dropout Dual Regulator

General Description

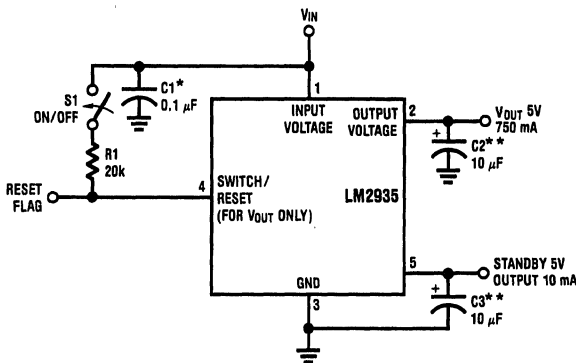
The LM2935 dual 5V regulator provides a 750 mA output as well as a 10 mA standby output. It features a low quiescent current of 3 mA or less when supplying 10 mA loads from the 5V standby regulator output. This unique characteristic and the extremely low input-output differential required for proper regulation (0.55V for output currents of 10 mA) make the LM2935 the ideal regulator for power systems that include standby memory. Applications include microprocessor power supplies demanding as much as 750 mA of output current.

Designed for automotive applications, the LM2935 and all regulated circuitry are protected from reverse battery installations or 2 battery jumps. During line transients, such as a load dump (60V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the 0.75A regulator will automatically shut down to protect both internal circuits and the load while the standby regulator will continue to power any standby load. The LM2935 cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

Features

- Two 5V regulated outputs
- Output current in excess of 750 mA
- Low quiescent current standby regulator
- Input-output differential less than 0.6V at 0.5A
- Reverse battery protection
- 60V load dump protection
- -50V reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- Available in 5-lead TO-220
- ON/OFF switch controls high current output
- Reset error flag
- P+ Product Enhancement tested

Typical Application Circuit



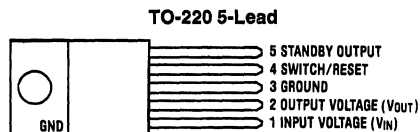
TL/H/5232-1

FIGURE 1. Test and Application Circuit

*Required if regulator is located far from power supply filter.

** C_{OUT} must be at least 10 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

Connection Diagram



Front View

TL/H/5232-8

Order Number LM2935T
See NS Package Number T05A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage

Operating Range	26V
Overvoltage Protection	60V

Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range	-40°C to + 125°C
Maximum Junction Temperature	150°C
Storage Temperature Range	-65°C to + 150°C
Lead Temp. (Soldering, 10 seconds)	230°C

Electrical Characteristics for V_{OUT}

$V_{IN} = 14V$, $I_O = 500\text{ mA}$, $T_J = 25^\circ\text{C}$ (Note 4), $C_2 = 10\ \mu\text{F}$ (unless otherwise specified)

Parameter	Conditions	Typ	Tested Limit (Note 3)	Units Limit
Output Voltage	$6V \leq V_{IN} \leq 26V$, $5\text{ mA} \leq I_O \leq 500\text{ mA}$, -40°C ≤ T _J ≤ 125°C (Note 2)	5.00	5.25 4.75	V _{MAX} V _{MIN}
Line Regulation	$9V \leq V_{IN} \leq 16V$, $I_O = 5\text{ mA}$ $6V \leq V_{IN} \leq 26V$, $I_O = 5\text{ mA}$	4 10	25 50	mV _{MAX} mV _{MAX}
Load Regulation	$5\text{ mA} \leq I_O \leq 500\text{ mA}$	10	50	mV _{MAX}
Output Impedance	500 mA _{DC} and 10 mA _{rms} , 100 Hz–10 kHz	200		mΩ
Quiescent Current	$I_O \leq 10\text{ mA}$, No Load on Standby $I_O = 500\text{ mA}$, No Load on Standby $I_O = 750\text{ mA}$, No Load on Standby	3 40 90	100	mA mA _{MAX} mA
Output Noise Voltage	10 Hz–100 kHz	100		μV _{rms}
Long Term Stability		20		mV/1000 hr
Ripple Rejection	f _O = 120 Hz	66		dB
Dropout Voltage	$I_O = 500\text{ mA}$ $I_O = 750\text{ mA}$	0.45 0.82	0.6	V _{MAX}
Current Limit		1.2	0.75	A _{MIN}
Maximum Operational Input Voltage		31	26	V _{MIN}
Maximum Line Transient	$V_O \leq 5.5V$	70	60	V
Reverse Polarity Input Voltage, DC		-30	-15	V
Reverse Polarity Input Voltage, Transient	1% Duty Cycle, τ ≤ 100 ms, 10Ω Load	-80	-50	V
Reset Output Voltage				
Low	R1 = 20k, V _{IN} = 4.0V	0.9	1.2	V _{MAX}
High	R1 = 20k, V _{IN} = 14V	5.0	6.0 4.5	V _{MAX} V _{MIN}
Reset Output Current	Reset = 1.2V	5		mA
ON/OFF Resistor	R1 (± 10% Tolerance)		20	kΩ _{MAX}

Note 1: Thermal resistance without a heat sink for junction to case temperature is 3°C/W(TO-220). Thermal resistance for TO-220 case to ambient temperature is 50° C/W.

Note 2: The temperature extremes are guaranteed but not 100% production tested. This parameter is not used to calculate outgoing AQL.

Note 3: Tested Limits are guaranteed and 100% tested in production.

Note 4: To ensure constant junction temperature, low duty cycle pulse testing is used.

Electrical Characteristics for Standby Output

$I_O = 10 \text{ mA}$, $V_{IN} = 14 \text{ V}$, S1 open, $C_{OUT} = 10 \mu\text{F}$, $T_J = 25^\circ\text{C}$ (Note 4), (unless otherwise specified)

Parameter	Standby Output Conditions	Typ	Tested Limit	Units Limit
Output Voltage	$I_O \leq 10 \text{ mA}$, $6 \text{ V} \leq V_{IN} \leq 26 \text{ V}$, $-40^\circ\text{C} \leq T_J \leq 125^\circ\text{C}$	5.00	5.25 4.75	V_{MAX} V_{MIN}
Tracking	V_{OUT} —Standby Output Voltage	50	200	mV_{MAX}
Line Regulation	$6 \text{ V} \leq V_{IN} \leq 26 \text{ V}$	4	50	mV_{MAX}
Load Regulation	$1 \text{ mA} \leq I_O \leq 10 \text{ mA}$	10	50	mV_{MAX}
Output Impedance	10 mA_{DC} and 1 mA_{rms} , 100 Hz–10 kHz	1		Ω
Quiescent Current	$I_O \leq 10 \text{ mA}$, V_{OUT} OFF (Note 2)	2	3	mA_{MAX}
Output Noise Voltage	10 Hz–100 kHz	300		μV
Long Term Stability		20		$\text{mV}/1000 \text{ hr}$
Ripple Rejection	$f_O = 120 \text{ Hz}$	66		dB
Dropout Voltage	$I_O \leq 10 \text{ mA}$	0.55	0.7	V_{MAX}
Current Limit		70	25	mA_{MIN}
Maximum Operational Input Voltage	$V_O \leq 6 \text{ V}$	70	60	V_{MIN}
Reverse Polarity Input Voltage, DC	$V_O \geq -0.3 \text{ V}$, 510Ω Load	-30	-15	V_{MIN}
Reverse Polarity Input Voltage, Transient	1% Duty Cycle $T \leq 100 \text{ ms}$ 500Ω Load	-80	-50	V_{MIN}

Typical Circuit Waveforms

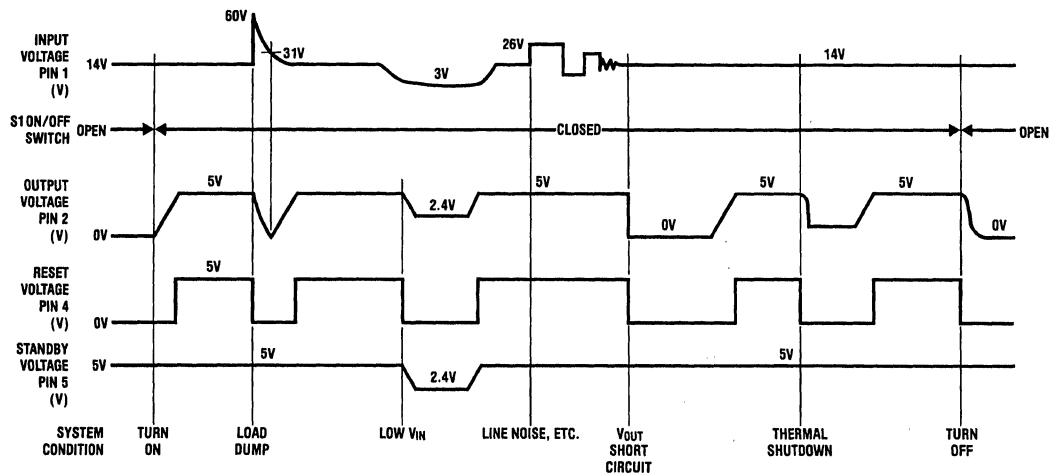
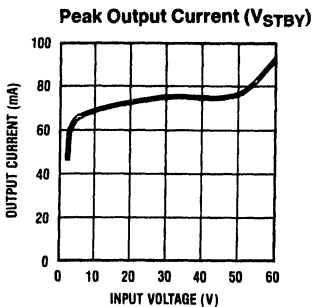
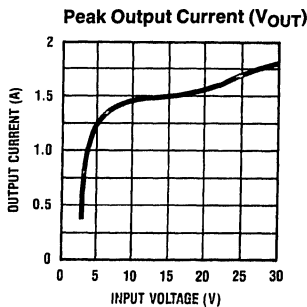
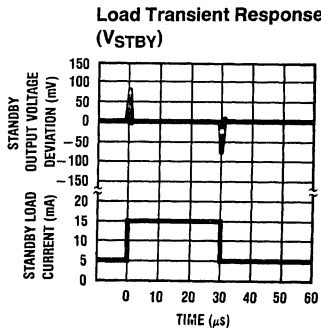
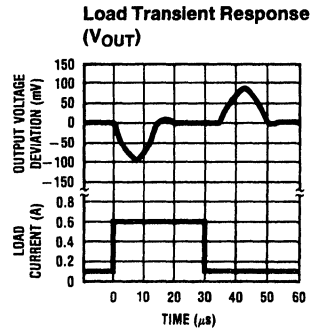
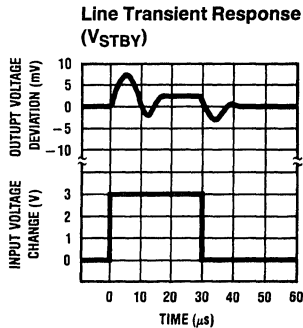
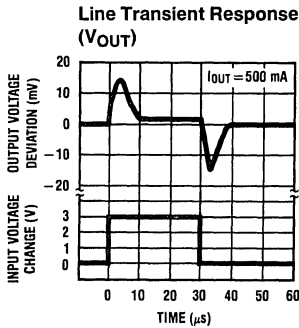
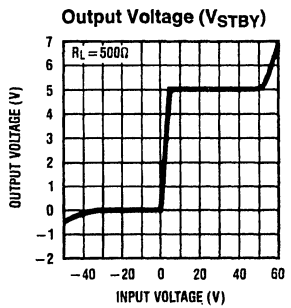
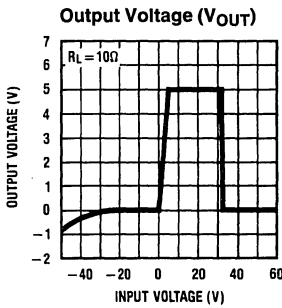
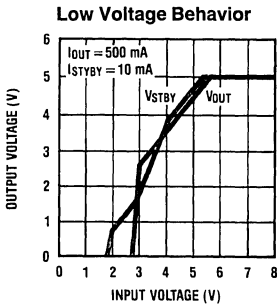
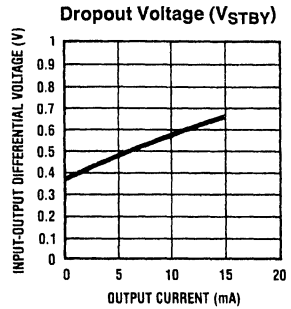
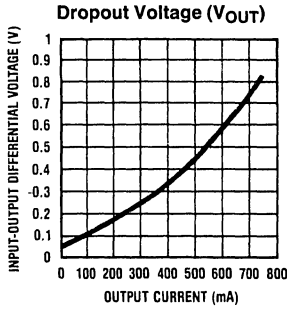
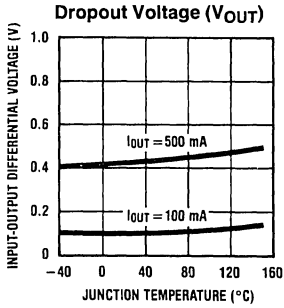


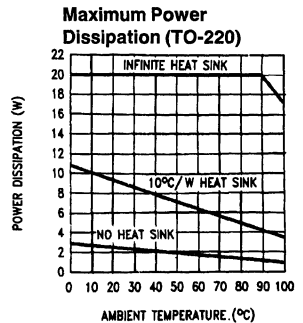
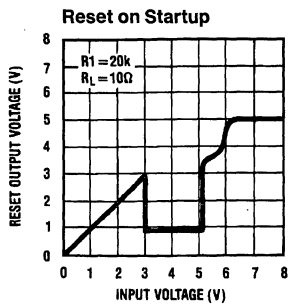
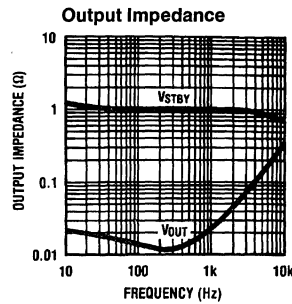
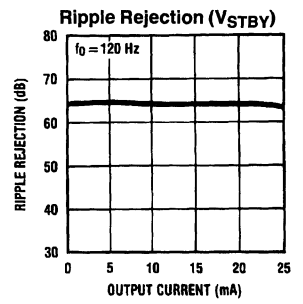
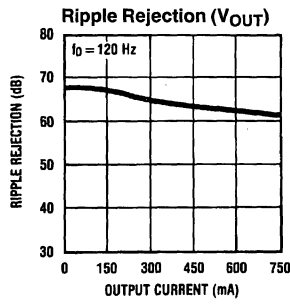
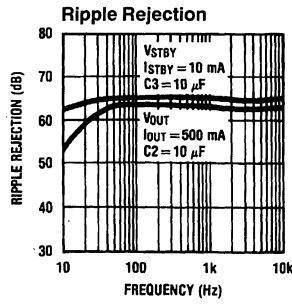
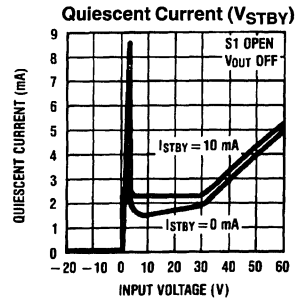
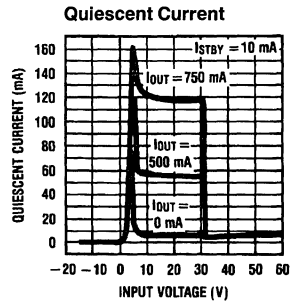
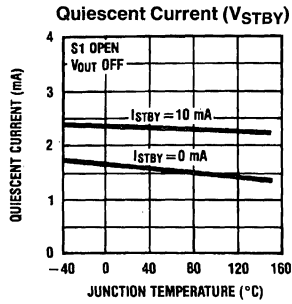
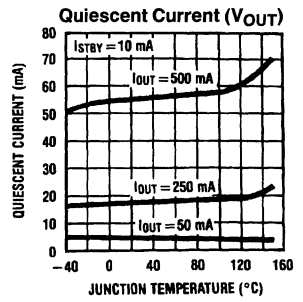
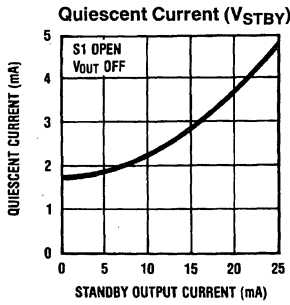
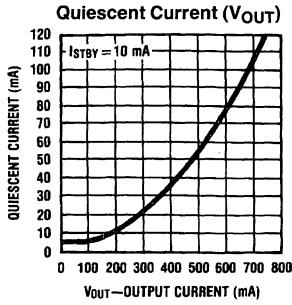
FIGURE 2

TL/H/5232-2

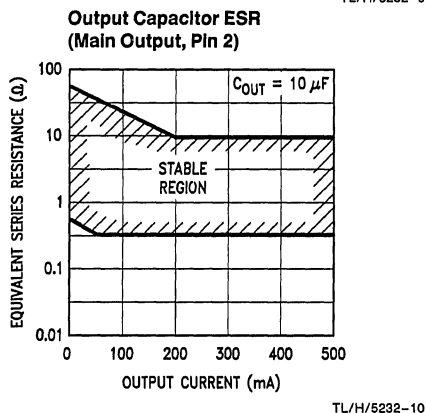
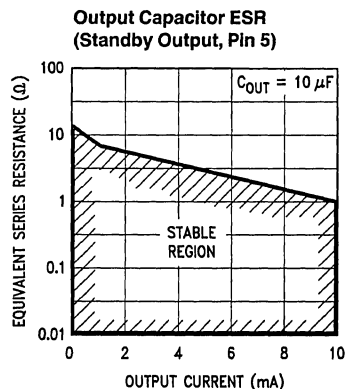
Typical Performance Characteristics



Typical Performance Characteristics (Continued)



Typical Performance Characteristics (Continued)



Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: The part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O : The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Application Hints

EXTERNAL CAPACITORS

The LM2935 output capacitors are required for stability. Without them, the regulator outputs will oscillate, sometimes by many volts. Though the 10 μ F shown are the minimum recommended values, actual size and type may vary depending upon the application load and temperature range. Capacitor effective series resistance (ESR) also factors in the IC stability. Since ESR varies from one brand to the next, some bench work may be required to determine the minimum capacitor value to use in production. Worst-case is usually determined at the minimum ambient temperature and maximum load expected.

Output capacitors can be increased in size to any desired value above the minimum. One possible purpose of this would be to maintain the output voltage during brief conditions of negative input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum type electrolytics will freeze at temperatures less than -30°C , reducing their effective capacitance to zero. To maintain regulator stability down to -40°C , capacitors rated at that temperature (such as tantalums) must be used.

No capacitor must be attached to the ON/OFF and ERROR FLAG pin. Due to the internal circuits of the IC, oscillation on this pin could result.

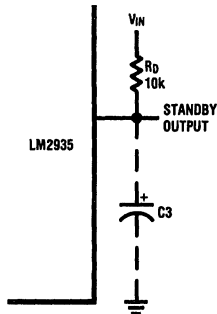
STANDBY OUTPUT

The LM2935 differs from most fixed voltage regulators in that it is equipped with two regulator outputs instead of one. The additional output is intended for use in systems requiring standby memory circuits. While the high current regulator output can be controlled with the ON/OFF pin described below, the standby output remains on under all conditions as long as sufficient input voltage is applied to the IC. Thus, memory and other circuits powered by this output remain unaffected by positive line transients, thermal shutdown, etc.

The standby regulator circuit is designed so that the quiescent current to the IC is very low (<3 mA) when the other regulator output is off.

Application Hints (Continued)

In applications where the standby output is not needed, it may be disabled by connecting a resistor from the standby output to the supply voltage. This eliminates the need for a more expensive capacitor on the output to prevent unwanted oscillations. The value of the resistor depends upon the minimum input voltage expected for a given system. Since the standby output is shunted with an internal 5.7V zener (Figure 3), the current through the external resistor should be sufficient to bias R2 and R3 up to this point. Approximately 60 μA will suffice, resulting in a 10k external resistor for most applications (Figure 4).

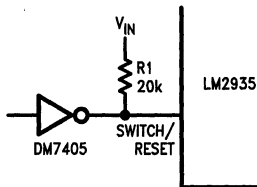


TL/H/5232-6

FIGURE 4. Disabling Standby Output to Eliminate C3

HIGH CURRENT OUTPUT

Unlike the standby regulated output, which must remain on whenever possible, the high current regulated output is fault protected against overvoltage and also incorporates thermal shutdown. If the input voltage rises above approximately 30V (e.g., load dump), this output will automatically shut-down. This protects the internal circuitry and enables the IC to survive higher voltage transients than would otherwise be expected. Thermal shutdown is effective against die overheating since the high current output is the dominant source of power dissipation in the IC.



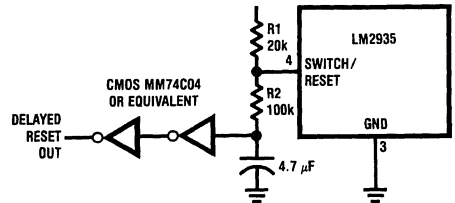
TL/H/5232-7

FIGURE 5. Controlling ON/OFF Terminal with a Typical Open Collector Logic Gate

ON/OFF AND ERROR FLAG PIN

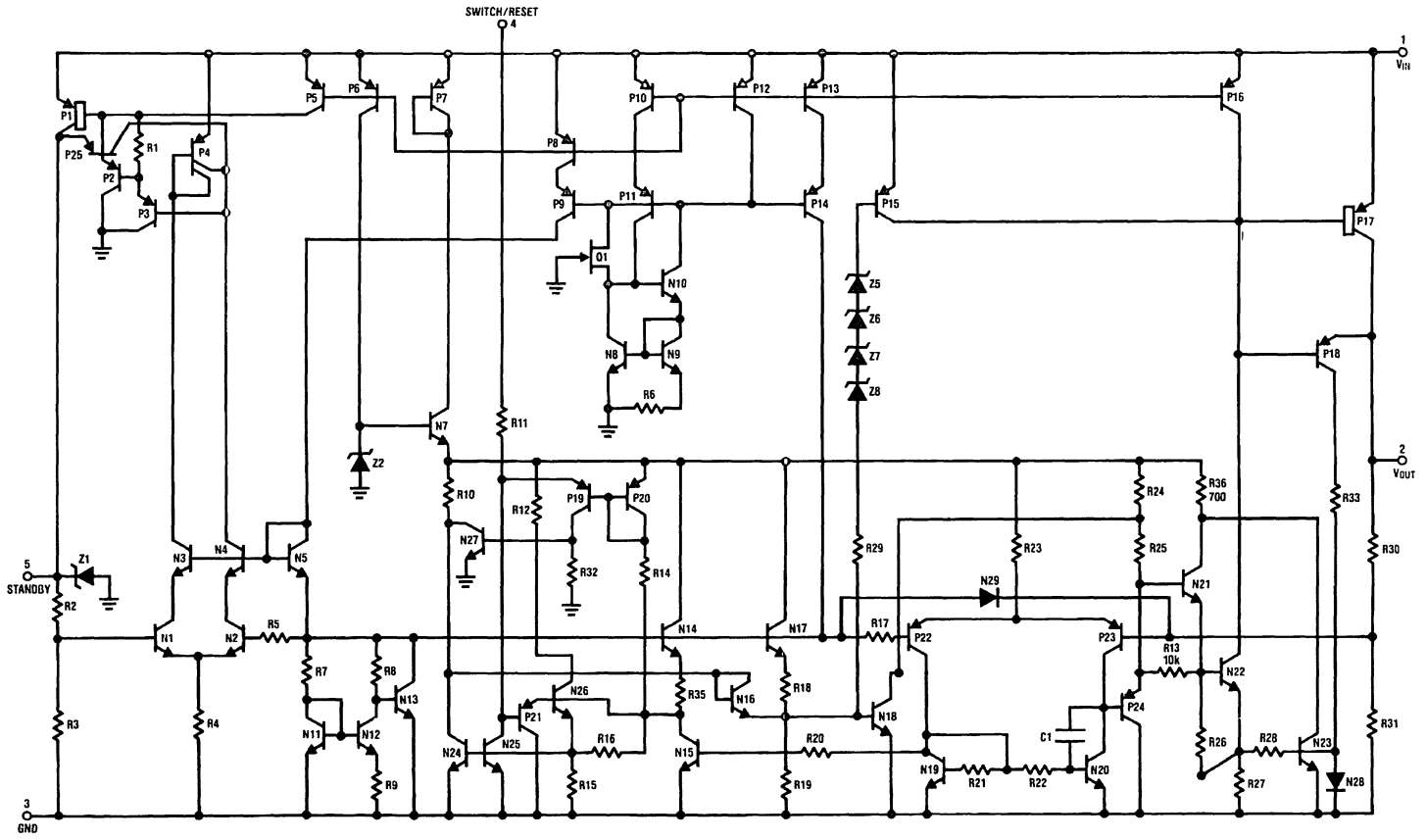
This pin has the ability to serve a dual purpose if desired. When controlled in the manner shown in Figure 1 (common in automotive systems where S1 is the ignition switch), the pin also serves as an output flag that is active low whenever a fault condition is detected with the high current regulated output. In other words, under normal operating conditions, the output voltage of this pin is high (5V). This is set by an internal clamp. If the high current output becomes unregulated for any reason (line transients, short circuit, thermal shutdown, low input voltage, etc.) the pin switches to the active low state, and is capable of sinking several milliamps. This output signal can be used to initiate any reset or start-up procedure that may be required of the system.

The ON/OFF pin can also be driven directly from open collector logic circuits. The only requirement is that the 20k pull-up resistor remain in place (Figure 5). This will not affect the logic gate since the voltage on this pin is limited by the internal clamp in the LM2935 to 5V.



TL/H/5232-11

FIGURE 6. Reset Pulse on Power-Up (with approximately 300 ms delay)



2-43

FIGURE 3

TL/H/5232-5



LM2936 Ultra-Low Quiescent Current 5V Regulator

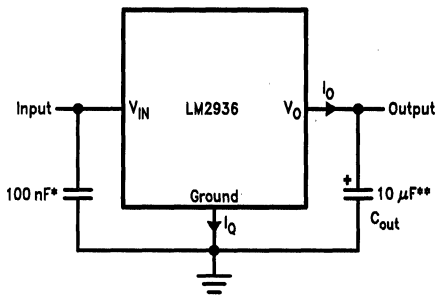
General Description

The LM2936 ultra-low quiescent current regulator features low dropout voltage and low current in the standby mode. With less than 15 μA quiescent current at a 100 μA load, the LM2936 is ideally suited for automotive and other battery operated systems. The LM2936 retains all of the features that are common to low dropout regulators including a low dropout PNP pass device, short circuit protection, reverse battery protection, and thermal shutdown. The LM2936 has a 40V operating voltage limit, -40°C to $+125^\circ\text{C}$ operating temperature range, and $\pm 3\%$ output voltage tolerance over the entire output current, input voltage, and temperature range. The LM2936 is available in both a TO-92 package and an 8-pin surface mount package with a fixed 5V output.

Features

- Ultra low quiescent current ($I_Q \leq 15 \mu\text{A}$ for $I_O \leq 100 \mu\text{A}$)
- Fixed 5V, 50 mA output
- Output tolerance $\pm 3\%$ over line, load, and temperature
- Dropout voltage typically 200 mV @ $I_O = 50 \text{ mA}$
- Reverse battery protection
- -50V reverse transient protection
- Internal short circuit current limit
- Internal thermal shutdown protection
- 40V operating voltage limit

Typical Application



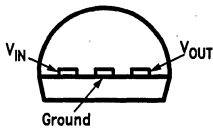
TL/H/9759-1

* Required if regulator is located more than 2" from power supply filter capacitor.

** Required for stability. Must be rated for 10 μF minimum over intended operating temperature range. Effective series resistance (ESR) is critical, see curve. Locate capacitor as close as possible to the regulator output and ground pins. Capacitance may be increased without bound.

Connection Diagrams

TO-92 Plastic Package (Z)

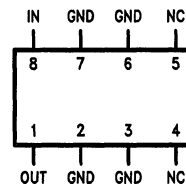


Bottom View

Order Number LM2936Z-5.0
See NS Package Number Z03A

TL/H/9759-2

8-Pin SO (M)



Top View

Order Number LM2936M-5.0
See NS Package Number M08A

TL/H/9759-6

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage (Survival)	+60V, -50V
ESD Susceptibility (Note 2)	2000V
Power Dissipation (Note 3)	Internally limited
Junction Temperature (T_{Jmax})	150°C

Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

Operating Ratings

Operating Temperature Range	-40°C to +125°C
Maximum Input Voltage (Operational)	40V

Electrical Characteristics

$V_{IN} = 14V$, $I_O = 10 mA$, $T_J = 25^\circ C$, unless otherwise specified. **Boldface** limits apply over entire operating temperature range

Parameter	Conditions	Typical (Note 4)	Tested Limit (Note 5)	Design Limit (Note 6)	Units
Output Voltage	$5.5V \leq V_{IN} \leq 26V$, $I_O \leq 50 mA$ (Note 7)		4.85		V_{min}
		5			V
			5.15		V_{max}
Line Regulation	$9V \leq V_{IN} \leq 16V$	5	10		mV_{max}
	$6V \leq V_{IN} \leq 40V$, $I_O = 1 mA$	10	30		
Load Regulation	$100 \mu A \leq I_O \leq 5 mA$	10	30		mV_{max}
	$5 mA \leq I_O \leq 50 mA$	10	30		
Output Impedance	$I_O = 30 mA_{dc}$ and $10 mA_{rms}$, $f = 1000 Hz$	450			$m\Omega$
Quiescent Current	$I_O = 100 \mu A$, $8V \leq V_{IN} \leq 24V$	9	15		μA_{max}
	$I_O = 10 mA$, $8V \leq V_{IN} \leq 24V$	0.20	0.50		mA_{max}
	$I_O = 50 mA$, $8V \leq V_{IN} \leq 24V$	1.5	2.5		mA_{max}
Output Noise Voltage	10 Hz–100 kHz	500			μV_{rms}
Long Term Stability		20			$mV/1000 Hr$
Ripple Rejection	$V_{ripple} = 1 V_{rms}$, $f_{ripple} = 120 Hz$	60	40		dB_{min}
Dropout Voltage	$I_O = 100 \mu A$	0.05	0.10		V_{max}
	$I_O = 50 mA$	0.20	0.40		V_{max}
Reverse Polarity DC Input Voltage	$R_L = 500\Omega$, $V_O \geq -0.3V$			-15	V_{min}
Reverse Polarity Transient Input Voltage	$R_L = 500\Omega$, $T = 1 ms$	-80	-50		V_{min}
Output Leakage with Reverse Polarity Input	$V_{IN} = -15V$, $R_L = 500\Omega$	-0.1	-600		μA_{max}
Maximum Line Transient	$R_L = 500\Omega$, $V_O \leq 5.5V$, $T = 40 ms$		60		V_{min}
Short Circuit Current	$V_O = 0V$	120	250		mA_{max}
			65		mA_{min}

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its specified operating ratings.

Note 2: Human body model, 100 pF discharge through a 1.5 k Ω resistor.

Note 3: The maximum power dissipation is a function of T_{Jmax} , θ_{JA} , and T_A . The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2936 will go into thermal shutdown. For the LM2936Z, the junction-to-ambient thermal resistance (θ_{JA}) is 195°C/W. For the LM2936M, θ_{JA} is 160°C/W.

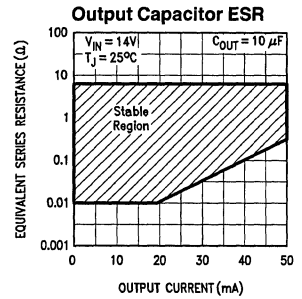
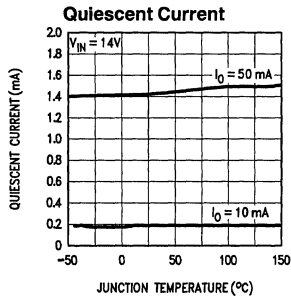
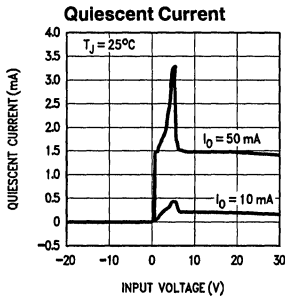
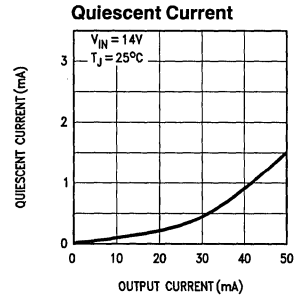
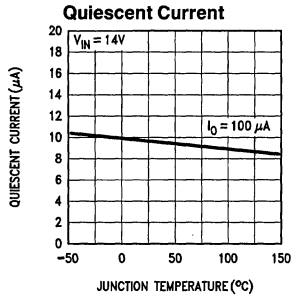
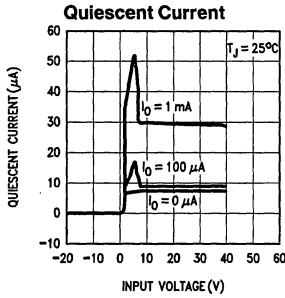
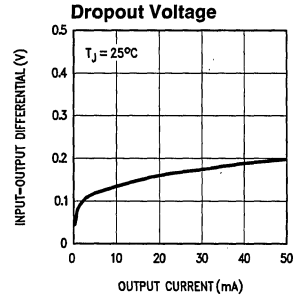
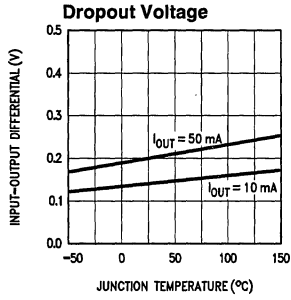
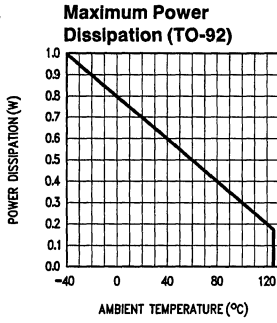
Note 4: Typical values are at 25°C (unless otherwise specified) and represent the most likely parametric norm.

Note 5: Tested limits are guaranteed to National's AOQL (Average Outgoing Quality Level) and 100% tested.

Note 6: Design limits are guaranteed to National's AOQL (Average Outgoing Quality Level) but not 100% tested.

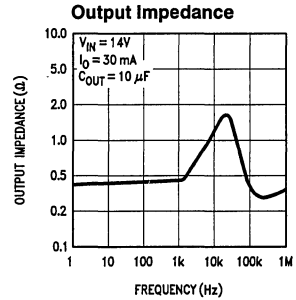
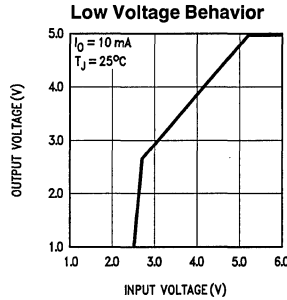
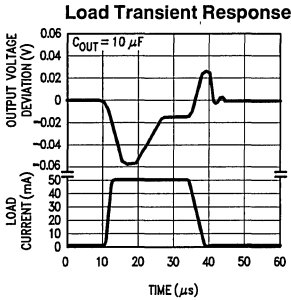
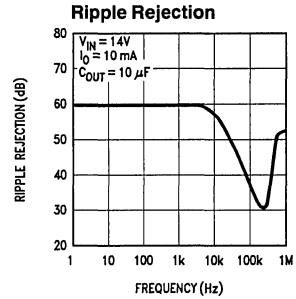
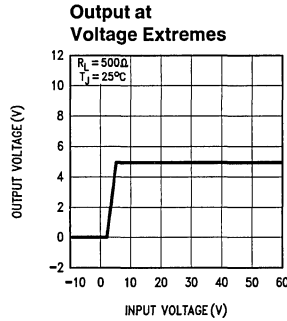
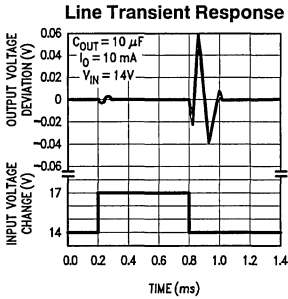
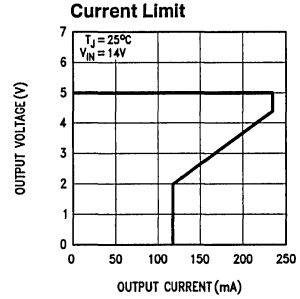
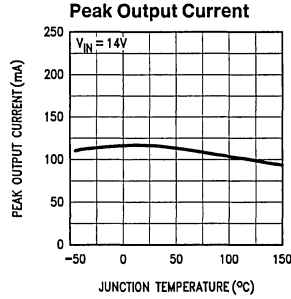
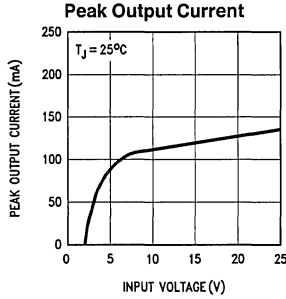
Note 7: To ensure constant junction temperature, pulse testing is used.

Typical Performance Characteristics



TL/H/9759-3

Typical Performance Characteristics (Continued)



TL/H/9759-4

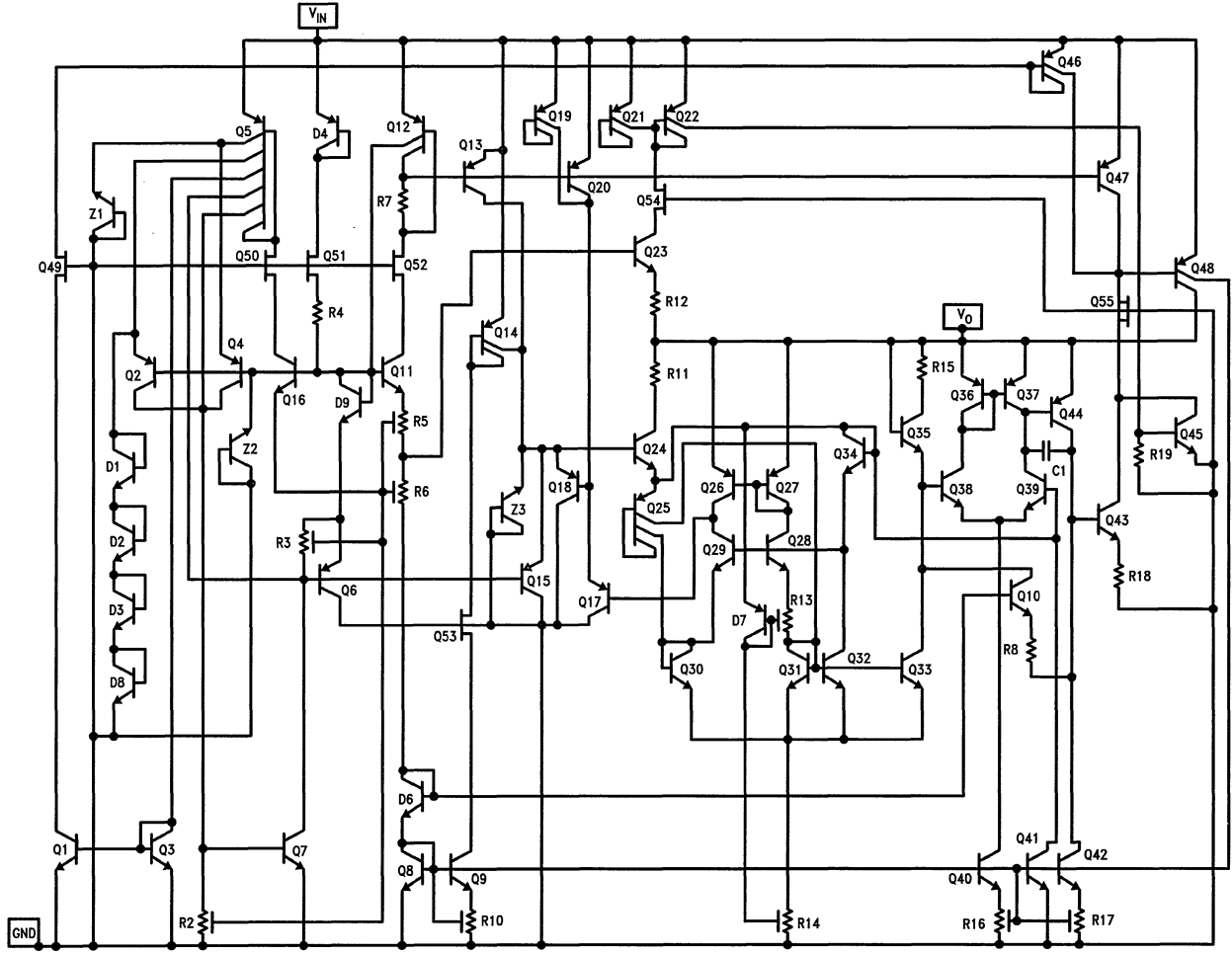
2

Applications Information

Unlike other PNP low dropout regulators, the LM2936 remains fully operational to 40V. Owing to power dissipation characteristics of the TO-92 package, full output current cannot be guaranteed for all combinations of ambient temperature and input voltage. As an example, consider an LM2936 operating at 25°C ambient. Using the formula for maximum allowable power dissipation given in Note 3, we find that $P_{Dmax} = 641\ \text{mW}$ at 25°C. Including the small contribution of the quiescent current to total power dissipation the maximum input voltage (while still delivering 50 mA output current) is 17.3V. The device will go into thermal shutdown if it attempts to deliver full output current with an input voltage of more than 17.3V. Similarly, at 40V input and 25°C ambient the LM2936 can deliver 18 mA maximum.

Under conditions of higher ambient temperatures, the voltage and current calculated in the previous examples will drop. For instance, at the maximum ambient of 125°C the LM2936 can only dissipate 128 mW, limiting the input voltage to 7.34V for a 50 mA load, or 3.5 mA output current for a 40V input.

While the LM2936 maintains regulation to 60V, it will not withstand a short circuit above 40V because of safe operating area limitations in the internal PNP pass device. Above 60V the LM2936 will break down with catastrophic effects on the regulator and possibly the load as well. Do not use this device in a design where the input operating voltage may exceed 40V, or where transients are likely to exceed 60V.



2-48

LM2937 500 mA Low Dropout Regulator

General Description

The LM2937 is a positive voltage regulator capable of supplying up to 500 mA of load current. The use of a PNP power transistor provides a low dropout voltage characteristic. With a load current of 500 mA the minimum input to output voltage differential required for the output to remain in regulation is typically 0.5V (1V guaranteed maximum over the full operating temperature range). Special circuitry has been incorporated to minimize the quiescent current to typically only 10 mA with a full 500 mA load current when the input to output voltage differential is greater than 3V.

The LM2937 requires an output bypass capacitor for stability. As with most low dropout regulators, the ESR of this capacitor remains a critical design parameter, but the LM2937 includes special compensation circuitry that relaxes ESR requirements. The LM2937 is stable for all ESR below 3Ω. This allows the use of low ESR chip capacitors.

Ideally suited for automotive applications, the LM2937 will protect itself and any load circuitry from reverse battery connections, two-battery jumps and up to +60V/-50V load dump transients. Familiar regulator features such as short circuit and thermal shutdown protection are also built in.

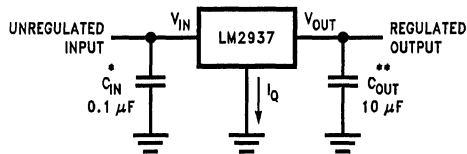
Features

- Fully specified for operation over -40°C to $+125^{\circ}\text{C}$
- Output current in excess of 500 mA
- Output trimmed for 5% tolerance under all operating conditions
- Typical dropout voltage of 0.5V at full rated load current
- Wide output capacitor ESR range, up to 3Ω
- Internal short circuit and thermal overload protection
- Reverse battery protection
- 60V input transient protection
- Mirror image insertion protection

Output Voltages

LM2937ET-5.0	5V
LM2937ET-8.0	8V
LM2937ET-10	10V
LM2937ET-12	12V
LM2937ET-15	15V

Typical Application



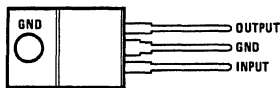
TL/H/11280-1

*Required if the regulator is located more than 3 inches from the power supply filter capacitors.

**Required for stability. C_{OUT} must be at least 10 μF (over the full expected operating temperature range) and located as close as possible to the regulator. The equivalent series resistance, ESR, of this capacitor may be as high as 3Ω.

Connection Diagram and Ordering Information

TO-220 Plastic Package



Front View

TL/H/11280-2

Order Number LM2937ET-5.0,
LM2937ET-8.0, LM2937ET-10, LM2937ET-12,
or LM2937ET-15
See NS Package Number T03B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Continuous	26V
Transient ($t \leq 100$ ms)	60V
Internal Power Dissipation (Note 2)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	230°C
ESD Susceptibility (Note 3)	2 kV

Operating Conditions (Note 1)

Temperature Range (T_J) (Note 2)	-40°C to +125°C
Maximum Input Voltage	26V

Electrical Characteristics

$V_{IN} = V_{NOM} + 5V$ (Note 4), $I_{OUT} = 500$ mA, $C_{OUT} = 10$ μ F unless otherwise indicated. **Boldface limits apply over the entire operating temperature range, -40°C \leq T_J \leq +125°C**, all other specifications are for $T_A = T_J = 25^\circ\text{C}$.

Output Voltage (V_{OUT})		5V		8V		10V		Units
Parameter	Conditions	Typ	Limit	Typ	Limit	Typ	Limit	
Output Voltage	$5 \text{ mA} \leq I_{OUT} \leq 0.5 \text{ A}$	5.00	4.85	8.00	7.76	10.00	9.70	V(Min)
			4.75		7.60		9.50	V(Min)
			5.15		8.24		10.30	V(Max)
			5.25		8.40		10.50	V(Max)
Line Regulation	$(V_{OUT} + 2V) \leq V_{IN} \leq 26V$, $I_{OUT} = 5 \text{ mA}$	15	50	24	80	30	100	mV(Max)
Load Regulation	$5 \text{ mA} \leq I_{OUT} \leq 0.5 \text{ A}$	5	50	8	80	10	100	mV(Max)
Quiescent Current	$(V_{OUT} + 2V) \leq V_{IN} \leq 26V$, $I_{OUT} = 5 \text{ mA}$	2	10	2	10	2	10	mA(Max)
	$V_{IN} = (V_{OUT} + 5V)$, $I_{OUT} = 0.5 \text{ A}$	10	20	10	20	10	20	mA(Max)
Output Noise Voltage	10 Hz–100 kHz $I_{OUT} = 5 \text{ mA}$	150		240		300		μ Vrms
Long Term Stability	1000 Hrs.	20		32		40		mV
Dropout Voltage	$I_{OUT} = 500 \text{ mA}$	0.5	1.0	0.5	1.0	0.5	1.0	V(Max)
	$I_{OUT} = 50 \text{ mA}$	110	250	110	250	110	250	mV(Max)
Short-Circuit Current		1.0	0.6	1.0	0.6	1.0	0.6	A(Min)
Peak Line Transient Voltage	$t_f < 100$ ms, $R_L = 100\Omega$	75	60	75	60	75	60	V(Min)
Maximum Operational Input Voltage			26		26		26	V(Min)
Reverse DC Input Voltage	$V_{OUT} \geq -0.6V$, $R_L = 100\Omega$	-30	-15	-30	-15	-30	-15	V(Min)
Reverse Transient Input Voltage	$t_f < 1$ ms, $R_L = 100\Omega$	-75	-50	-75	-50	-75	-50	V(Min)

Electrical Characteristics

$V_{IN} = V_{NOM} + 5V$ (Note 4), $I_{OUT} = 500\text{ mA}$, $C_{OUT} = 10\ \mu\text{F}$ unless otherwise indicated. **Boldface limits apply over the entire operating temperature range, $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$** , all other specifications are for $T_A = T_J = 25^\circ\text{C}$.

Output Voltage (V_{OUT})		12V		15V		Units
Parameter	Conditions	Typ	Limit	Typ	Limit	
Output Voltage	$5\text{ mA} \leq I_{OUT} \leq 0.5\text{ A}$	12.00	11.64 11.40 12.36 12.60	15.00	14.55 14.25 15.45 15.75	V (Min) V (Min) V (Max) V (Max)
Line Regulation	$(V_{OUT} + 2V) \leq V_{IN} \leq 26V$, $I_{OUT} = 5\text{ mA}$	36	120	45	150	mV(Max)
Load Regulation	$5\text{ mA} \leq I_{OUT} \leq 0.5\text{ A}$	12	120	15	150	mV(Max)
Quiescent Current	$(V_{OUT} + 2V) \leq V_{IN} \leq 26V$, $I_{OUT} = 5\text{ mA}$	2	10	2	10	mA(Max)
	$V_{IN} = (V_{OUT} + 5V)$, $I_{OUT} = 0.5\text{ A}$	10	20	10	20	mA(Max)
Output Noise Voltage	10 Hz–100 kHz, $I_{OUT} = 5\text{ mA}$	360		450		μVrms
Long Term Stability	1000 Hrs.	44		56		mV
Dropout Voltage	$I_{OUT} = 500\text{ mA}$	0.5	1.0	0.5	1.0	V(Max)
	$I_{OUT} = 50\text{ mA}$	110	250	110	250	mV(Max)
Short-Circuit Current		1.0	0.6	1.0	0.6	A(Min)
Peak Line Transient Voltage	$t_f < 100\text{ ms}$, $R_L = 100\Omega$	75	60	75	60	V(Min)
Maximum Operational Input Voltage			26		26	V(Min)
Reverse DC Input Voltage	$V_{OUT} \geq -0.6V$, $R_L = 100\Omega$	-30	-15	-30	-15	V(Min)
Reverse Transient Input Voltage	$t_f < 1\text{ ms}$, $R_L = 100\Omega$	-75	-50	-75	-50	V(Min)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device outside of its rated Operating Conditions.

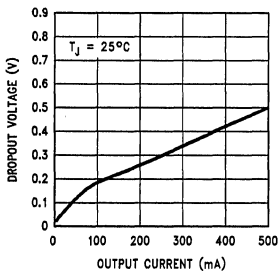
Note 2: The maximum allowable power dissipation at any ambient temperature is $P_{MAX} = (125 - T_A)/\theta_{JA}$, where 125 is the maximum junction temperature for operation, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance. If this dissipation is exceeded, the die temperature will rise above 125°C and the electrical specifications do not apply. If the die temperature rises above 150°C , the LM2937 will go into thermal shutdown. For the LM2937, the junction-to-ambient thermal resistance θ_{JA} is 65°C/W . When used with a heatsink, θ_{JA} is the sum of the LM2937 junction-to-case thermal resistance θ_{JC} of 3°C/W and the heatsink case-to-ambient thermal resistance.

Note 3: ESD rating is based on the human body model, 100 pF discharged through 1.5 k Ω .

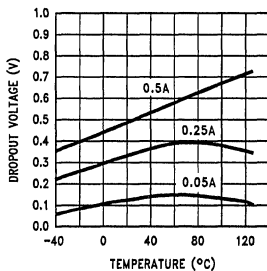
Note 4: Typicals are at $T_J = 25^\circ\text{C}$ and represent the most likely parametric norm.

Typical Performance Characteristics

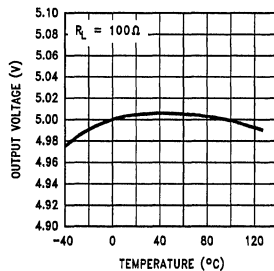
Dropout Voltage vs Output Current



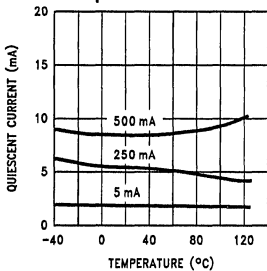
Dropout Voltage vs Temperature



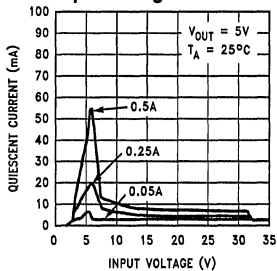
Output Voltage vs Temperature



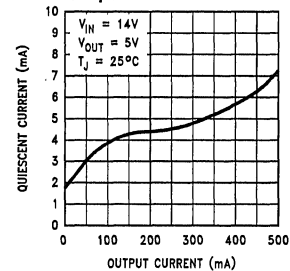
Quiescent Current vs Temperature



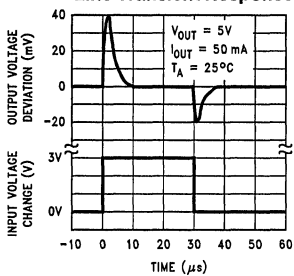
Quiescent Current vs Input Voltage



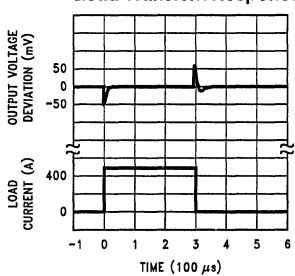
Quiescent Current vs Output Current



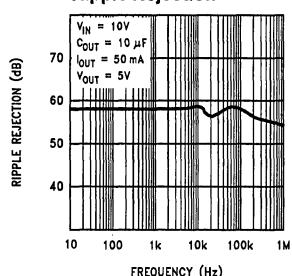
Line Transient Response



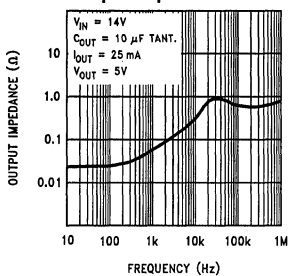
Load Transient Response



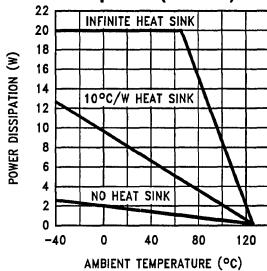
Ripple Rejection



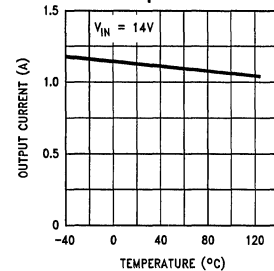
Output Impedance



Maximum Power Dissipation (TO-220)

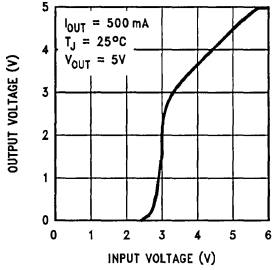


Peak Output Current

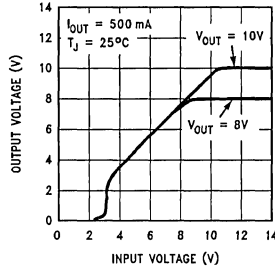


Typical Performance Characteristics (Continued)

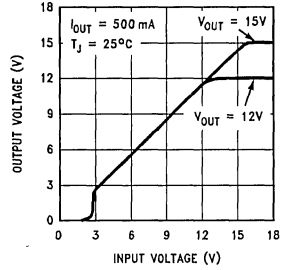
Low Voltage Behavior



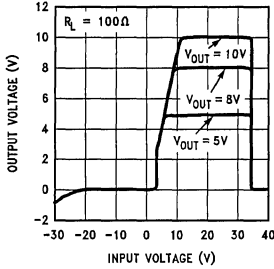
Low Voltage Behavior



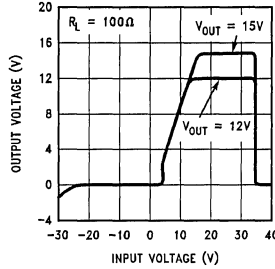
Low Voltage Behavior



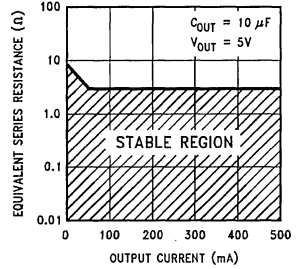
Output at Voltage Extremes



Output at Voltage Extremes



Output Capacitor ESR



TL/H/11280-4



LM2940/LM2940C 1A Low Dropout Regulator

General Description

The LM2940/LM2940C positive voltage regulator features the ability to source 1A of output current with a dropout voltage of typically 0.5V and a maximum of 1V over the entire temperature range. Furthermore, a quiescent current reduction circuit has been included which reduces the ground current when the differential between the input voltage and the output voltage exceeds approximately 3V. The quiescent current with 1A of output current and an input-output differential of 5V is therefore only 30 mA. Higher quiescent currents only exist when the regulator is in the dropout mode ($V_{IN} - V_{OUT} \leq 3V$).

Designed also for vehicular applications, the LM2940/LM2940C and all regulated circuitry are protected from reverse battery installations or 2-battery jumps. During line transients, such as load dump when the input voltage can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both the internal circuits and the load. The LM2940/LM2940C cannot be harmed by temporary mirror-image

insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

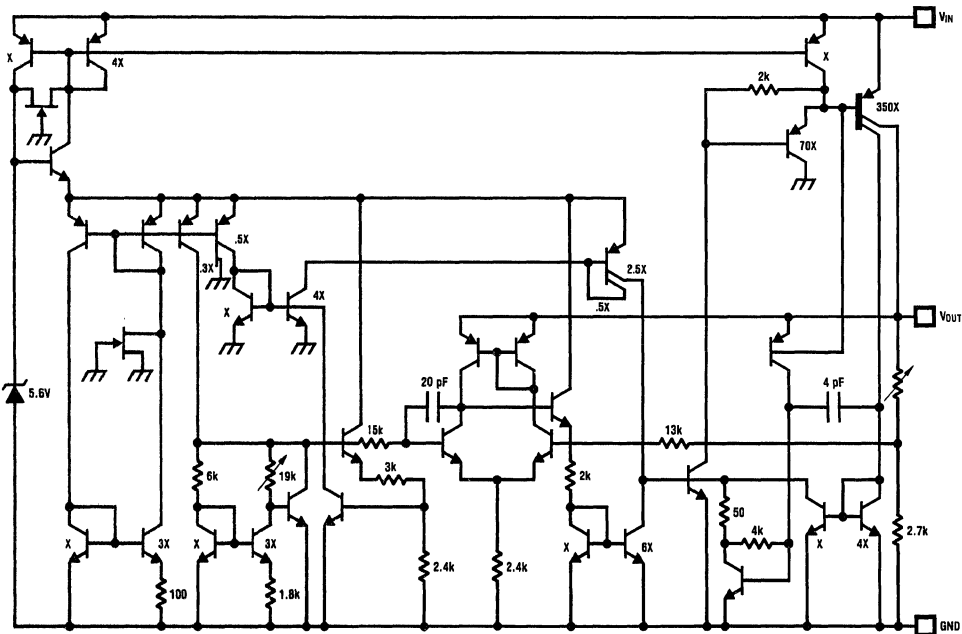
Features

- Dropout voltage typically 0.5V @ $I_O = 1A$
- Output current in excess of 1A
- Output voltage trimmed before assembly
- Reverse battery protection
- Internal short circuit current limit
- Mirror image insertion protection
- P+ Product Enhancement tested

Device	Output Voltages	Package
LM2940CT	5, 12, 15	TO-220
LM2940T	5, 8, 9, 10, 12	TO-220
LM2940K/883*	5, 8, 12, 15	TO-3

*Available only as a military specified device.

Equivalent Schematic Diagram



TL/H/8822-1

Order Number LM2940T-5.0, LM2940T-8.0, LM2940T-9.0,
 LM2940T-10, LM2940T-12, LM2940CT-5.0, LM2940CT-12, LM2940CT-15,
 LM2940K-5.0/883, LM2940K-8.0/883, LM2940K-12/883 or LM2940K-15/883
 See NS Package Number KO2A or TO3B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 2)

Input Voltage (Survival Voltage)	
LM2940T, $T \leq 100$ ms	60V
LM2940K/883, $T \leq 20$ ms	40V
LM2940CT, $T \leq 1$ ms	45V
Internal Power Dissipation (Note 3)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	$-65^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$

Lead Temperature (Soldering, 10 seconds)	
TO-3 (K) Package	300°C
TO-220 (T) Package	260°C
ESD Susceptibility (Note 4)	2 kV

Operating Conditions (Note 1)

Input Voltage	26V
Temperature Range	
LM2940K/883	$-55^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$
LM2940T	$-40^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$
LM2940CT	$0^{\circ}\text{C} \leq T_A \leq 125^{\circ}\text{C}$

Electrical Characteristics

$V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22 \mu\text{F}$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25^{\circ}\text{C}$.

Output Voltage (V_O)		5V			8V			Units
Parameter	Conditions	Typ	LM2940T-5.0	LM2940K-5.0/883	Typ	LM2940T-8.0	LM2940K-8.0/883	
			Limit (Note 5)	Limit (Note 6)		Limit (Note 5)	Limit (Note 6)	
			$6.25V \leq V_{IN} \leq 26V$		$9.4V \leq V_{IN} \leq 26V$			
Output Voltage	$5 \text{ mA} \leq I_O \leq 1A$	5.00	4.85/ 4.75 5.15/ 5.25	4.85/ 4.75 5.15/ 5.25	8.00	7.76/ 7.60 8.24/ 8.40	7.76/ 7.60 8.24/ 8.40	V_{MIN} V_{MAX}
Line Regulation	$V_O + 2V \leq V_{IN} \leq 26V$, $I_O = 5 \text{ mA}$	20	50	40/ 50	20	80	50/ 80	mV_{MAX}
Load Regulation	$50 \text{ mA} \leq I_O \leq 1A$ LM2940, LM2940/883 LM2940C	35 35	50/ 80 50	50/ 100	55	80/ 130	80/ 130	mV_{MAX} mV_{MAX}
Output Impedance	100 mADC and 20 mArms, $f_O = 120 \text{ Hz}$	35		1000/ 1000	55		1000/ 1000	$\text{m}\Omega$
Quiescent Current	$V_O + 2V \leq V_{IN} \leq 26V$, $I_O = 5 \text{ mA}$ LM2940, LM2940/883 LM2940C	10 10	15/ 20 15	15/ 20	10	15/ 20	15/ 20	mA_{MAX} mA_{MAX}
	$V_{IN} = V_O + 5V$, $I_O = 1A$	30	45/ 60	50/ 60	30	45/ 60	50/ 60	mA_{MAX}
Output Noise Voltage	10 Hz – 100 kHz, $I_O = 5 \text{ mA}$	150		700/ 700	240		1000/ 1000	μV_{rms}
Ripple Rejection	$f_O = 120 \text{ Hz}$, $1 V_{rms}$, $I_O = 100 \text{ mA}$ LM2940 LM2940C	72 72	60/ 54 60		66	54/ 48		dB_{MIN} dB_{MIN}
	$f_O = 1 \text{ kHz}$, $1 V_{rms}$, $I_O = 5 \text{ mA}$			60/ 50			54/ 48	dB_{MIN}
Long Term Stability		20			32			$\text{mV}/$ 1000 Hr
Dropout Voltage	$I_O = 1A$	0.5	0.8/ 1.0	0.7/ 1.0	0.5	0.8/ 1.0	0.7/ 1.0	V_{MAX}
	$I_O = 100 \text{ mA}$	110	150/ 200	150/ 200	110	150/ 200	150/ 200	mV_{MAX}

Electrical Characteristics (Continued)

$V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22 \mu F$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25^\circ C$.

Output Voltage (V_O)		5V			8V			Units
Parameter	Conditions	Typ	LM2940T-5.0	LM2940K-5.0/883	Typ	LM2940T-8.0	LM2940K-8.0/883	
			Limit	Limit		Limit	Limit	
			(Note 5)	(Note 6)		(Note 5)	(Note 6)	
$6.25V \leq V_{IN} \leq 26V$				$9.4V \leq V_{IN} \leq 26V$				
Short Circuit Current	(Note 7)	1.9	1.6	1.5/ 1.3	1.9	1.6	1.6/ 1.3	A_{MIN}
Maximum Line Transient	$R_O = 100\Omega$							
	LM2940, $T \leq 100 \text{ ms}$	75	60/ 60		75	60/ 60		V_{MIN}
	LM2940/883, $T \leq 20 \text{ ms}$			40/ 40			40/ 40	V_{MIN}
Reverse Polarity DC Input Voltage	LM2940C, $T \leq 1 \text{ ms}$	55	45					V_{MIN}
	$R_O = 100\Omega$							
Reverse Polarity DC Input Voltage	LM2940, LM2940/883	-30	-15/- 15	-15/- 15	-30	-15/- 15	-15/- 15	V_{MIN}
	LM2940C	-30	-15					V_{MIN}
Reverse Polarity Transient Input Voltage	$R_O = 100\Omega$							
	LM2940, $T \leq 100 \text{ ms}$	-75	-50/- 50		-75	-50/- 50		V_{MIN}
	LM2940/883, $T \leq 20 \text{ ms}$			-45/- 45			-45/- 45	V_{MIN}
LM2940C, $T \leq 1 \text{ ms}$	-55	-45/- 45					V_{MIN}	

Electrical Characteristics (Continued)

$V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22 \mu F$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25^\circ C$.

Output Voltage (V_O)		9V		10V		Units
Parameter	Conditions	Typ	LM2940T-9.0 Limit (Note 5)	Typ	LM2940T-10 Limit (Note 5)	
		$10.5V \leq V_{IN} \leq 26V$		$11.5V \leq V_{IN} \leq 26V$		
Output Voltage	$5 mA \leq I_O \leq 1A$	9.00	8.73/ 8.55 9.27/ 9.45	10.00	9.70/ 9.50 10.30/ 10.50	V_{MIN} V_{MAX}
Line Regulation	$V_O + 2V \leq V_{IN} \leq 26V$, $I_O = 5 mA$	20	90	20	100	mV_{MAX}
Load Regulation	$50 mA \leq I_O \leq 1A$	60	90/ 150	65	100/ 165	mV_{MAX}
Output Impedance	100 mADC and 20 mArms, $f_O = 120 Hz$	60		65		$m\Omega$
Quiescent Current	$V_O + 2V \leq V_{IN} < 26V$, $I_O = 5 mA$	10	15/ 20	10	15/ 20	mA_{MAX}
	$V_{IN} = V_O + 5V$, $I_O = 1A$	30	45/ 60	30	45/ 60	mA_{MAX}
Output Noise Voltage	10 Hz – 100 kHz, $I_O = 5 mA$	270		300		μV_{rms}
Ripple Rejection	$f_O = 120 Hz$, $1 V_{rms}$, $I_O = 100 mA$	64	52/ 46	63	51/ 45	dB_{MIN}
Long Term Stability		34		36		$mV/$ 1000 Hr
Dropout Voltage	$I_O = 1A$	0.5	0.8/ 1.0	0.5	0.8/ 1.0	V_{MAX}
	$I_O = 100 mA$	110	150/ 200	110	150/ 200	mV_{MAX}
Short Circuit Current	(Note 7)	1.9	1.6	1.9	1.6	A_{MIN}
Maximum Line Transient	$R_O = 100\Omega$ $T \leq 100 ms$	75	60/ 60	75	60/ 60	V_{MIN}
Reverse Polarity DC Input Voltage	$R_O = 100\Omega$	-30	-15/- 15	-30	-15/- 15	V_{MIN}
Reverse Polarity Transient Input Voltage	$R_O = 100\Omega$ $T \leq 100 ms$	-75	-50/- 50	-75	-50/- 50	V_{MIN}

Electrical Characteristics (Continued)

$V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22 \mu F$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25^\circ C$.

Output Voltage (V_O)		12V			15V			Units
Parameter	Conditions	Typ	LM2940T-12 LM2940CT-12.0	LM2940K-12/883 Limit (Note 6)	Typ	LM2940CT-15 Limit (Note 5)	LM2940K-15/883 Limit (Note 6)	
			Limit (Note 5)	Limit (Note 6)		Limit (Note 5)	Limit (Note 6)	
		$13.6V \leq V_{IN} \leq 26V$			$16.75V \leq V_{IN} \leq 26V$			
Output Voltage	$5 mA \leq I_O \leq 1A$	12.00	11.64/ 11.40 12.36/ 12.60	11.64/ 11.40 12.36/ 12.60	15.00	14.55/ 14.25 15.45/ 15.75	14.55/ 14.25 15.45/ 15.75	V_{MIN} V_{MAX}
Line Regulation	$V_O + 2V \leq V_{IN} \leq 26V$, $I_O = 5 mA$	20	120	75/ 120	20	150	95/ 150	mV_{MAX}
Load Regulation	$50 mA \leq I_O \leq 1A$ LM2940, LM2940/883 LM2940C	55 55	120/ 200 120	120/ 190		70	150/ 240	mV_{MAX} mV_{MAX}
Output Impedance	100 mADC and 20 mArms, $f_O = 120 Hz$	80		1000/ 1000	100		1000/ 1000	$m\Omega$
Quiescent Current	$V_O + 2V \leq V_{IN} \leq 26V$, $I_O = 5 mA$ LM2940, LM2940/883 LM2940C	10 10	15/ 20 15	15/ 20		10 15	15/ 20	mA_{MAX} mA_{MAX}
	$V_{IN} = V_O + 5V$, $I_O = 1A$	30	45/ 60	50/ 60	30	45/ 60	50/ 60	mA_{MAX}
Output Noise Voltage	10 Hz – 100 kHz, $I_O = 5 mA$	360		1000/ 1000	450		1000/ 1000	μV_{rms}
Ripple Rejection	$f_O = 120 Hz$, $1 V_{rms}$, $I_O = 100 mA$ LM2940	66	54/ 48					dB_{MIN}
	LM2940C	66	54		64	52		dB_{MIN}
	$f_O = 1 kHz$, $1 V_{rms}$, $I_O = 5 mA$			52/ 46			48/ 42	dB_{MIN}
Long Term Stability		48			60			$mV/$ 1000 Hr
Dropout Voltage	$I_O = 1A$	0.5	0.8/ 1.0	0.7/ 1.0	0.5	0.8/ 1.0	0.7/ 1.0	V_{MAX}
	$I_O = 100 mA$	110	150/ 200	150/ 200	110	150/ 200	150/ 200	mV_{MAX}
Short Circuit Current	(Note 7)	1.9	1.6	1.6/ 1.3	1.9	1.6	1.6/ 1.3	A_{MIN}
Maximum Line Transient	$R_O = 100\Omega$ LM2940, $T \leq 100 ms$	75	60/ 60					V_{MIN}
	LM2940/883, $T \leq 20 ms$			40/ 40			40/ 40	V_{MIN}
	LM2940C, $T \leq 1 ms$	55	45		55	45		V_{MIN}
Reverse Polarity DC Input Voltage	$R_O = 100\Omega$ LM2940, LM2940/883	-30 -30	-15/- 15 -15	-15/- 15			-15/- 15	V_{MIN} V_{MIN}
	LM2940C				-30	-15		
Reverse Polarity Transient Input Voltage	$R_O = 100\Omega$ LM2940, $T \leq 100 ms$	-75	-50/- 50					V_{MIN}
	LM2940/883, $T \leq 20 ms$			-45/- 45			-45/- 45	V_{MIN}
	LM2940C, $T \leq 1 ms$	-55	-45/- 45		-55	-45/- 45		V_{MIN}

Note 1: Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Conditions are conditions under which the device functions but the specifications might not be guaranteed. For guaranteed specifications and test conditions see the Electrical Characteristics.

Note 2: Military specifications complied with RETS/SMD at the time of printing. For current specifications refer to RETS LM2940K-5.0, LM2940K-8.0, LM2940K-12, and LM2940K-15. SMD numbers are 5962-8958701YA(5V), 5962-9083301YA(8V), 5962-9088401YA(12V), and 5962-9088501YA(15V).

Note 3: The maximum power dissipation is a function of the maximum junction temperature, $T_J = 150^\circ\text{C}$, the junction-to-ambient thermal resistance, θ_{JA} , and the ambient temperature, T_A . The maximum allowable power dissipation at any ambient temperature is $P_{\text{DMAX}} = (150 - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2940 will go into thermal shutdown. For the LM2940T and LM2940CT, the junction-to-ambient thermal resistance (θ_{JA}) is $53^\circ\text{C}/\text{W}$. When using a heatsink, θ_{JA} is the sum of the $3^\circ\text{C}/\text{W}$ junction-to-case thermal resistance (θ_{JC}) of the LM2940T or LM2940CT and the case-to-ambient thermal resistance of the heatsink. For the LM2940K, θ_{JA} is $39^\circ\text{C}/\text{W}$ and θ_{JC} is $4^\circ\text{C}/\text{W}$.

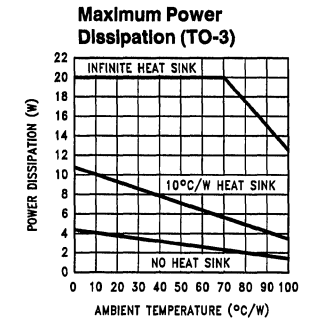
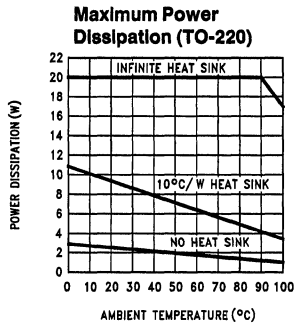
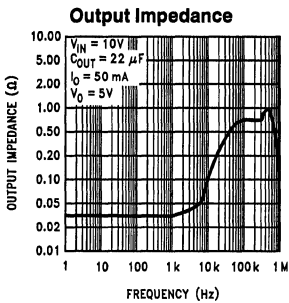
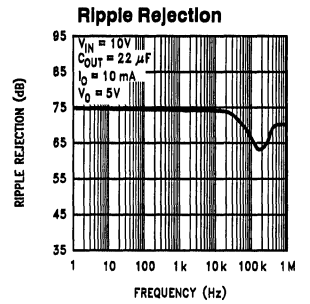
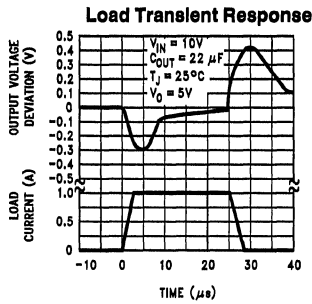
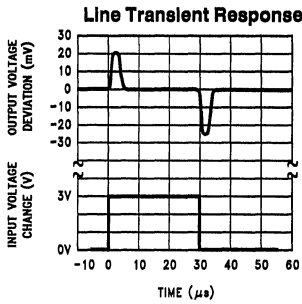
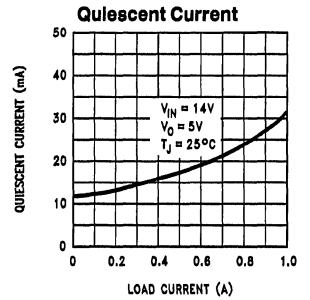
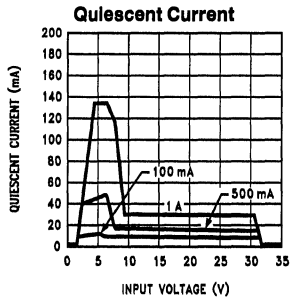
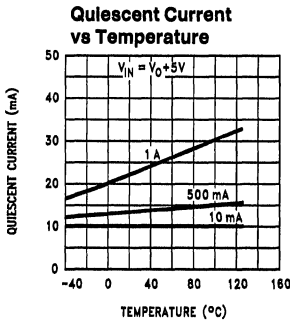
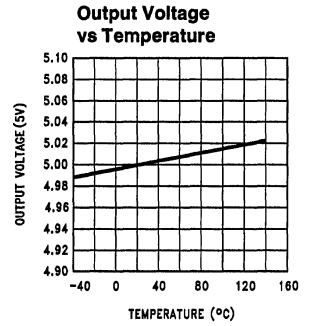
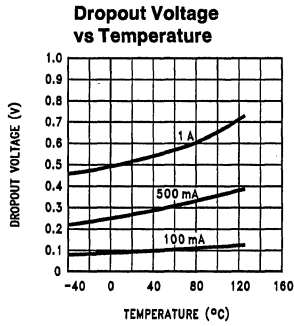
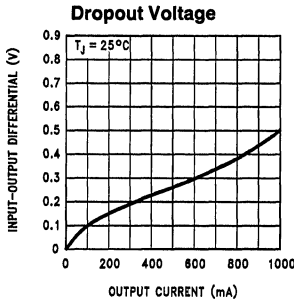
Note 4: ESD rating is based on the human body model, 100 pF discharged through 1.5 k Ω .

Note 5: All limits are guaranteed at $T_A = T_J = 25^\circ\text{C}$ only (standard typeface) or over the entire operating temperature range of the indicated device (boldface type). All limits at $T_A = T_J = 25^\circ\text{C}$ are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control methods.

Note 6: All limits are guaranteed at $T_A = T_J = 25^\circ\text{C}$ only (standard typeface) or over the entire operating temperature range of the indicated device (boldface type). All limits are 100% production tested and are used to calculate Outgoing Quality Levels.

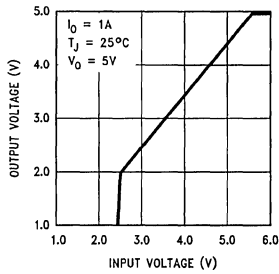
Note 7: Output current will decrease with increasing temperature but will not drop below 1A at the maximum specified temperature.

Typical Performance Characteristics

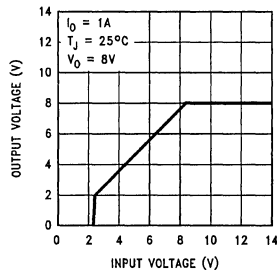


Typical Performance Characteristics (Continued)

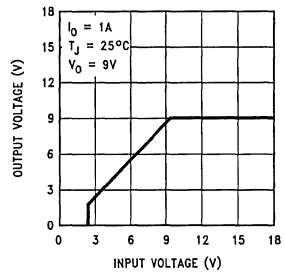
Low Voltage Behavior



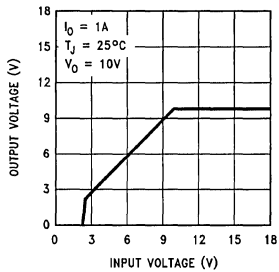
Low Voltage Behavior



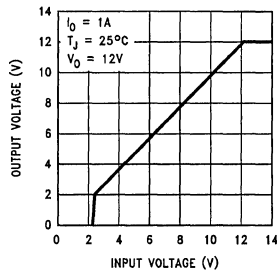
Low Voltage Behavior



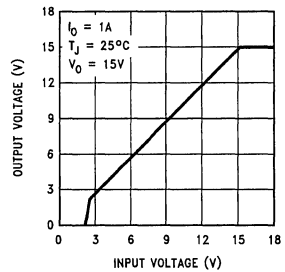
Low Voltage Behavior



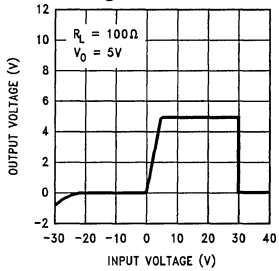
Low Voltage Behavior



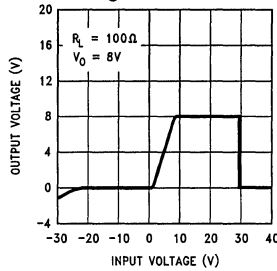
Low Voltage Behavior



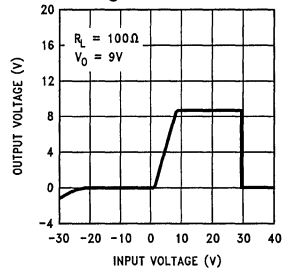
Output at Voltage Extremes



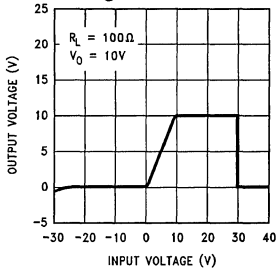
Output at Voltage Extremes



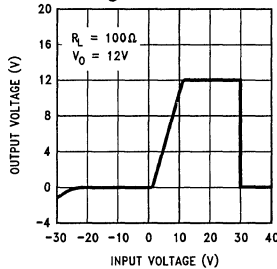
Output at Voltage Extremes



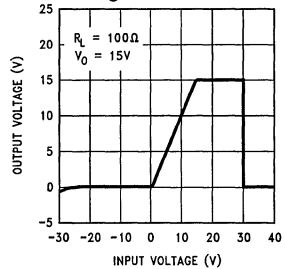
Output at Voltage Extremes



Output at Voltage Extremes

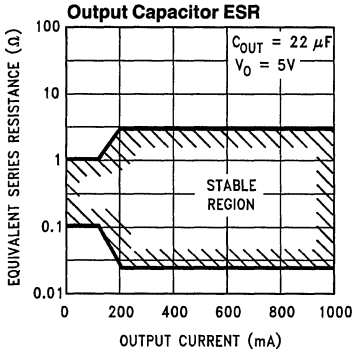


Output at Voltage Extremes

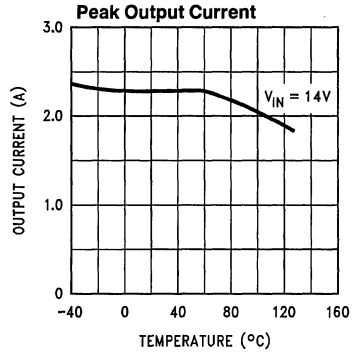


TL/H/8822-5

Typical Performance Characteristics (Continued)

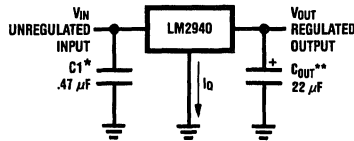


TL/H/8822-6



TL/H/8822-8

Typical Application



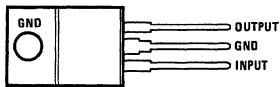
TL/H/8822-3

*Required if regulator is located far from power supply filter.

** C_{OUT} must be at least $22 \mu F$ to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator and the ESR is critical; see curve.

Connection Diagram

(TO-220) Plastic Package

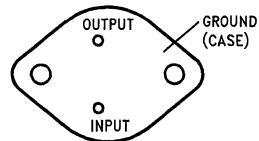


TL/H/8822-2

Front View

Order Number LM2940T-5.0, LM2940T-8.0,
LM2940T-9.0, LM2940T-10, LM2940T-12,
LM2940CT-5.0, LM2940CT-12 or LM2940CT-15
See NS Package Number T03B

TO-3 Metal Can Package (K)



TL/H/8822-7

Bottom View

Order Number LM2940K-5.0/883,
LM2940K-8.0/883, LM2940K-12/883, LM2940K-15/883
See NS Package Number K02A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage (Survival Voltage, ≤ 100 ms)	
LM2941K, LM2941T	60V
LM2941CT	45V
Internal Power Dissipation (Note 3)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	$-65^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$

Lead Temperature (Soldering, 10 seconds)	
TO-3 (K) Package	300°C
TO-220 (T) Package	260°C

ESD susceptibility to be determined.

Operating Ratings

Maximum Input Voltage	26V
Temperature Range	
LM2941K	$-55^{\circ}\text{C} \leq T_J \leq 150^{\circ}\text{C}$
LM2941T	$-40^{\circ}\text{C} \leq T_J \leq 125^{\circ}\text{C}$
LM2941CT	$-0^{\circ}\text{C} \leq T_J \leq 125^{\circ}\text{C}$

Electrical Characteristics—LM2941K, LM2941T

$5\text{V} \leq V_O \leq 20\text{V}$, $V_{IN} = V_O + 5\text{V}$, $C_O = 22 \mu\text{F}$, unless otherwise specified. Specifications in standard typeface apply for $T_J = 25^{\circ}\text{C}$, while those in **boldface type** apply over the full **Operating Temperature Range**.

Parameter	Conditions	Typ	LM2941K Limit (Notes 2, 4)	LM2941T Limit (Note 5)	Units (Limits)
Reference Voltage	$5\text{ mA} \leq I_O \leq 1\text{ A}$ (Note 6)	1.275	1.237/ 1.211 1.313/ 1.339	1.237/ 1.211 1.313/ 1.339	V(min) V(max)
Line Regulation	$V_O + 2\text{V} \leq V_{IN} \leq 26\text{V}$, $I_O = 5\text{ mA}$	4	10/ 10	10/ 10	mV/V(max)
Load Regulation	$50\text{ mA} \leq I_O \leq 1\text{ A}$	7	10/ 10	10/ 10	mV/V(max)
Output Impedance	100 mADC and 20 mArms $f_O = 120\text{ Hz}$	7			m Ω /V
Quiescent Current	$V_O + 2\text{V} \leq V_{IN} < 26\text{V}$, $I_O = 5\text{ mA}$	10	15/ 20	15/ 20	mA(max)
	$V_{IN} = V_O + 5\text{V}$, $I_O = 1\text{ A}$	30	45/ 60	45/ 60	mA(max)
RMS Output Noise, % of V_{OUT}	10 Hz–100 kHz $I_O = 5\text{ mA}$	0.003			%
Ripple Rejection	$f_O = 120\text{ Hz}$, 1 Vrms, $I_L = 100\text{ mA}$	0.005	0.02/ 0.04	0.02/ 0.04	%/V(max)
Long Term Stability		0.4			%/1000 Hr
Dropout Voltage	$I_O = 1\text{ A}$	0.5	0.8/ 1.0	0.8/ 1.0	V(max)
	$I_O = 100\text{ mA}$	110	200/ 200	200/ 200	mV(max)
Short Circuit Current	$V_{IN\text{ max}} = 26\text{V}$ (Note 7)	1.9	1.6/ 1.3	1.6	A(min)
Maximum Line Transient	V_O max 1V above nominal V_O $R_O = 100\Omega$, $T \leq 100\text{ ms}$	75	60/ 60	60/ 60	V(min)
Maximum Operational Input Voltage		31	26/ 26	26/ 26	V _{DC}
Reverse Polarity DC Input Voltage	$R_O = 100\Omega$, $V_O \geq -0.6\text{V}$	-30	-15/- 15	-15/- 15	V(min)
Reverse Polarity Transient Input Voltage	$T \leq 100\text{ ms}$, $R_O = 100\Omega$	-75	-50/- 50	-50/- 50	V(min)
ON/OFF Threshold Voltage ON	$I_O \leq 1\text{ A}$	1.30	0.80/ 0.80	0.80/ 0.80	V(max)
ON/OFF Threshold Voltage OFF	$I_O \leq 1\text{ A}$	1.30	2.00/ 2.00	2.00/ 2.00	V(min)
ON/OFF Threshold Current	$V_{ON/OFF} = 2.0\text{V}$, $I_O \leq 1\text{ A}$	50	100/ 300	100/ 300	μA (max)

Electrical Characteristics—LM2941CT

5V ≤ V_O ≤ 20V, V_{IN} = V_O + 5V, C_O = 22 μF, unless otherwise specified. Specifications in standard typeface apply for T_J = 25°C, while those in **boldface type** apply over the full **Operating Temperature Range**.

Parameter	Conditions	Typ	Limit (Note 5)	Units (Limits)
Reference Voltage	5 mA ≤ I _O ≤ 1A (Note 6)	1.275	1.237/ 1.211 1.313/ 1.339	V(min) V(max)
Line Regulation	V _O + 2V ≤ V _{IN} ≤ 26V, I _O = 5 mA	4	10	mV/V(max)
Load Regulation	50 mA ≤ I _O ≤ 1A	7	10	mV/V(max)
Output Impedance	100 mADC and 20 mArms f _O = 120 Hz	7		mΩ/V
Quiescent Current	V _O + 2V ≤ V _{IN} < 26V, I _O = 5 mA	10	15	mA(max)
	V _{IN} = V _O + 5V, I _O = 1A	30	45/ 60	mA(max)
RMS Output Noise, % of V _{OUT}	10 Hz–100 kHz I _O = 5 mA	0.003		%
Ripple Rejection	f _O = 120 Hz, 1 Vrms, I _L = 100 mA	0.005	0.02	%/V(max)
Long Term Stability		0.4		%/1000 Hr
Dropout Voltage	I _O = 1A	0.5	0.8/ 1.0	V(max)
	I _O = 100 mA	110	200/ 200	mV(max)
Short Circuit Current	V _{IN} max = 26V (Note 7)	1.9	1.6	A(min)
Maximum Line Transient	V _O max 1V above nominal V _O R _O = 100Ω, T ≤ 100 ms	55	45	V(min)
Maximum Operational Input Voltage		31	26	V _{DC}
Reverse Polarity DC Input Voltage	R _O = 100Ω, V _O ≥ -0.6V	-30	-15	V(min)
Reverse Polarity Transient Input Voltage	T ≤ 100 ms, R _O = 100Ω	-55	-45	V(min)
ON/OFF Threshold Voltage ON	I _O ≤ 1A	1.30	0.80	V(max)
ON/OFF Threshold Voltage OFF	I _O ≤ 1A	1.30	2.00	V(min)
ON/OFF Threshold Current	V _{ON/OFF} = 2.0V, I _O ≤ 1A	50	100	μA(max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions for which the device is intended to be functional, but device parameter specifications may not be guaranteed under these conditions. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: A military RETS specification available upon request. At the time of printing, the LM2941/883 RETS specification complied with the boldface limits in this column. The LM2941K/883 may also be procured to a Standard Military Drawing.

Note 3: The maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is P_D = (T_J(max) - T_A)/θ_{JA}. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2941 will go into thermal shutdown. For the LM2941T and LM2941CT, the junction-to-ambient thermal resistance (θ_{JA}) is 53°C/W, and the junction-to-case thermal resistance (θ_{JC}) is 3°C/W. For the LM2941K, θ_{JA} is 35°C/W and θ_{JC} is 4°C/W.

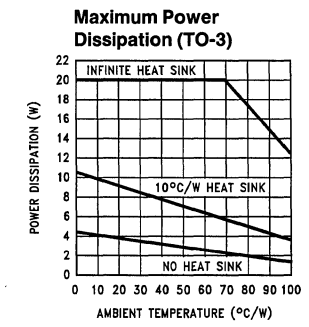
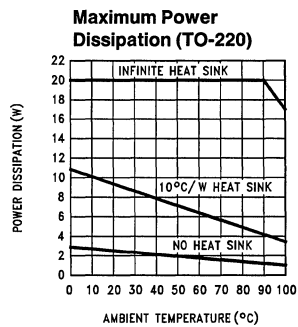
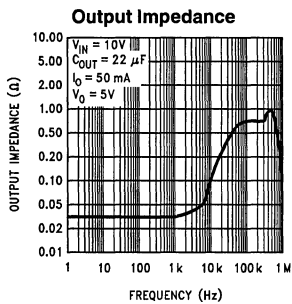
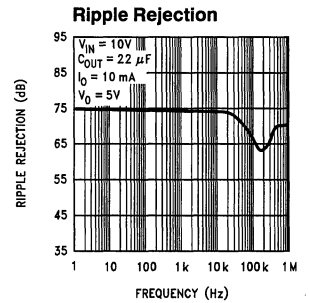
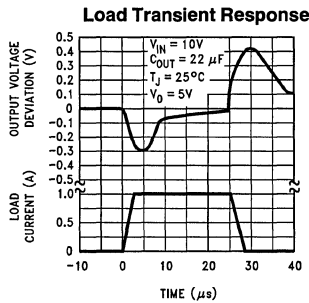
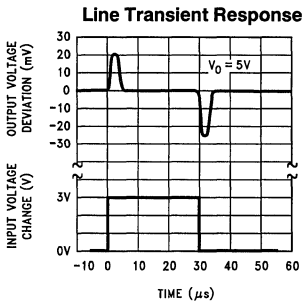
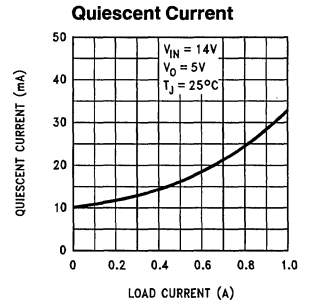
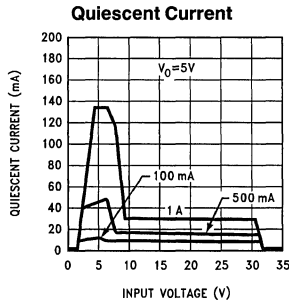
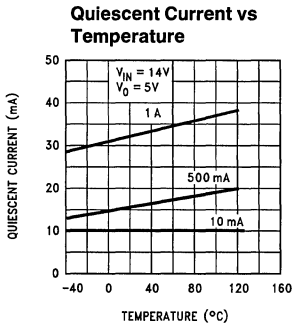
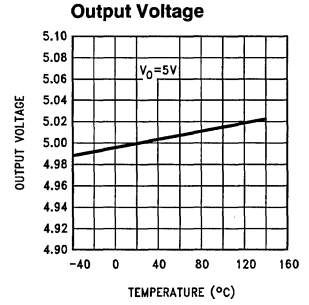
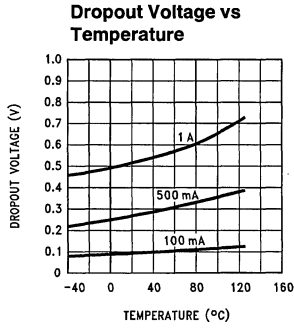
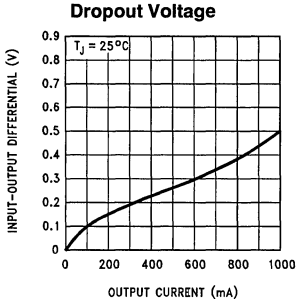
Note 4: All limits guaranteed at room temperature (standard typeface) and at temperature extremes (boldface type). All limits are used to calculate Outgoing Quality Level, and are 100% production tested.

Note 5: All limits guaranteed at room temperature (standard typeface) and at temperature extremes (boldface type). All room temperature limits are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

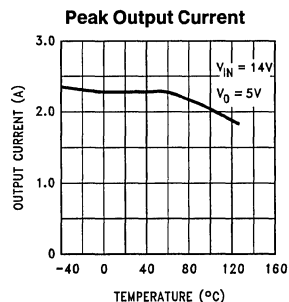
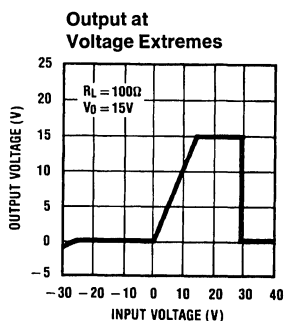
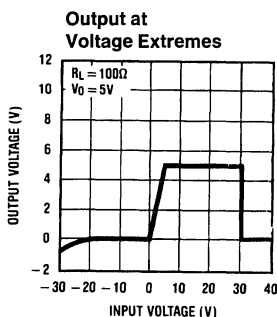
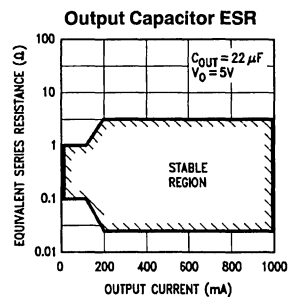
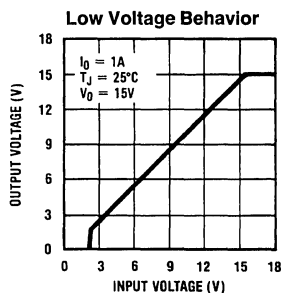
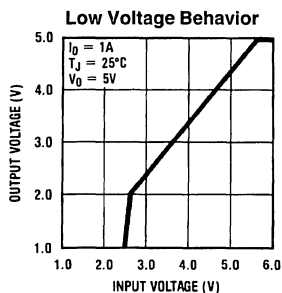
Note 6: The output voltage range is 5V to 20V and is determined by the two external resistors, R1 and R2. See Typical Application Circuit.

Note 7: Output current capability will decrease with increasing temperature, but will not go below 1A at the maximum specified temperatures.

Typical Performance Characteristics



Typical Performance Characteristics (Continued)



TL/H/8823-5

Definition of Terms

Dropout Voltage: The input-voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at ($V_{OUT} + 5V$) input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

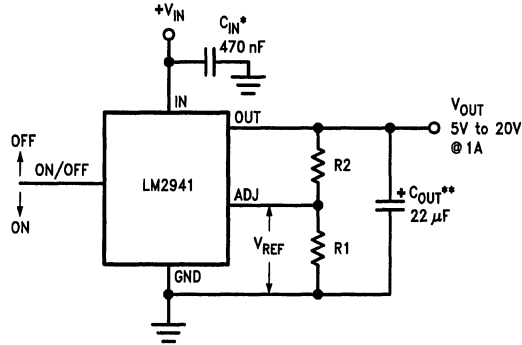
Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O : The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Typical Applications

5V to 20V Adjustable Regulator



TL/H/8823-3

$V_{OUT} = \text{Reference voltage} \times \frac{R1 + R2}{R1}$ where $V_{REF} = 1.275$ typical

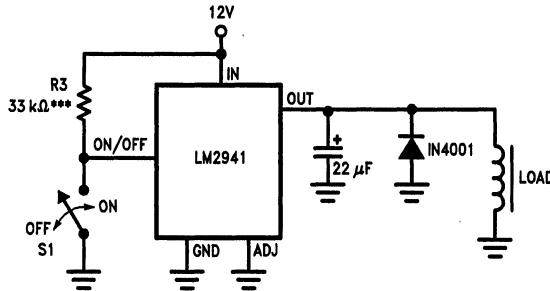
Solving for R2: $R2 = R1 \left(\frac{V_o}{V_{REF}} - 1 \right)$

Note: Using 1k for R1 will ensure that the input bias current error of the adjust pin will be negligible. Do not bypass R1 or R2. This will lead to instabilities.

*Required if regulator is located far from power supply filter.

** C_{OUT} must be at least 22 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator and the ESR is critical; see curve.

1A Switch



TL/H/8823-6

***To assure shutdown, select Resistor R3 to guarantee at least 300 μA of pull-up current when S1 is open. (Assume 2V at the ON/OFF pin.)

LM2984 Microprocessor Power Supply System

General Description

The LM2984 positive voltage regulator features three independent and tracking outputs capable of delivering the power for logic circuits, peripheral sensors and standby memory in a typical microprocessor system. The LM2984 includes circuitry which monitors both its own high-current output and also an external μP . If any error conditions are sensed in either, a reset error flag is set and maintained until the malfunction terminates. Since these functions are included in the same package with the three regulators, a great saving in board space can be realized in the typical microprocessor system. The LM2984 also features very low dropout voltages on each of its three regulator outputs (0.6V at the rated output current). Furthermore, the quiescent current can be reduced to 1 mA in the standby mode.

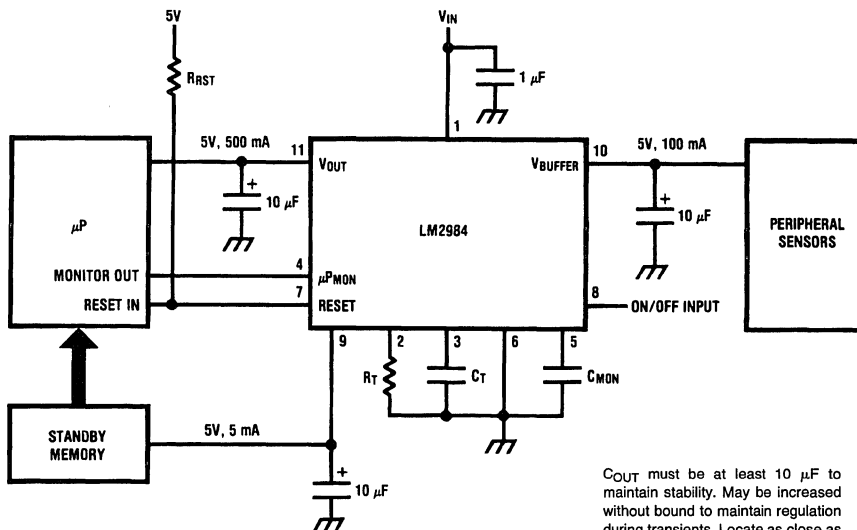
Designed also for vehicular applications, the LM2984 and all regulated circuitry are protected from reverse battery installations or 2-battery jumps. Familiar regulator features such as short circuit and thermal overload protection are

also provided. Fixed outputs of 5V are available in the plastic TO-220 power package.

Features

- Three low dropout tracking regulators
- Output current in excess of 500 mA
- Fully specified for -40°C to $+125^{\circ}\text{C}$ operation
- Low quiescent current standby regulator
- Microprocessor malfunction RESET flag
- Delayed RESET on power-up
- Accurate pretrimmed 5V outputs
- Reverse battery protection
- Overvoltage protection
- Reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- ON/OFF switch for high current outputs
- P+ Product Enhancement tested

Typical Application Circuit



Order Number LM2984T
See NS Package Number TA11B

C_{OUT} must be at least $10\ \mu\text{F}$ to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

TL/H/11252-1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Survival Voltage (< 100 ms)	60V
Operational Voltage	26V

Internal Power Dissipation	Internally Limited
Operating Temperature Range (T_A)	-40°C to +125°C
Maximum Junction Temperature (Note 1)	150°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	230°C
ESD Susceptibility (Note 3)	2000V

Electrical Characteristics

$V_{IN} = 14V$, $I_{OUT} = 5 mA$, $C_{OUT} = 10 \mu F$, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, $-40^\circ C \leq T_A \leq +125^\circ C$, all other limits are for $T_A = T_j = 25^\circ C$ (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
V_{OUT} (Pin 11)				
Output Voltage	$5 mA \leq I_O \leq 500 mA$ $6V \leq V_{IN} \leq 26V$	5.00	4.85/ 4.75 5.15/ 5.25	V_{min} V_{max}
Line Regulation	$9V \leq V_{IN} \leq 16V$	2	25/25	mV_{max}
	$7V \leq V_{IN} \leq 26V$	5	50/50	mV_{max}
Load Regulation	$5 mA \leq I_{OUT} \leq 500 mA$	12	50/50	mV_{max}
Output Impedance	$250 mA_{dc}$ and $10 mA_{rms}$, $f_o = 120 Hz$	24		$m\Omega$
Quiescent Current	$I_{OUT} = 500 mA$	38	100/ 100	mA_{max}
	$I_{OUT} = 250 mA$	14	50/50	mA_{max}
Output Noise Voltage	10 Hz–100 kHz, $I_{OUT} = 100 mA$	100		μV
Long Term Stability		20		$mV/1000 hr$
Ripple Rejection	$f_o = 120 Hz$	70	60/50	dB_{min}
Dropout Voltage	$I_{OUT} = 500 mA$	0.53	0.80/ 1.1	V_{max}
	$I_{OUT} = 250 mA$	0.28	0.50/0.70	V_{max}
Current Limit		0.92	0.75/0.60	A_{min}
Maximum Operational Input Voltage	Continuous DC	32	26/26	V_{min}
Maximum Line Transient	$V_{OUT} \leq 6V$, $R_{OUT} = 100\Omega$, $T \leq 100 ms$	65	60/60	V_{min}
Reverse Polarity Input Voltage DC	$V_{OUT} \geq -0.6V$, $R_{OUT} = 100\Omega$	-30	-15/-15	V_{min}
Reverse Polarity Input Voltage Transient	$T \leq 100 ms$, $R_{OUT} = 100\Omega$	-55	-35/-35	V_{min}

Electrical Characteristics (Continued)

$V_{IN} = 14V$, $I_{buf} = 5\text{ mA}$, $C_{buf} = 10\text{ }\mu\text{F}$, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$, all other limits are for $T_A = T_J = 25^{\circ}\text{C}$ (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
V_{buffer} (Pin 10)				
Output Voltage	$5\text{ mA} \leq I_O \leq 100\text{ mA}$ $6V \leq V_{IN} \leq 26V$	5.00	4.85/ 4.75 5.15/ 5.25	V_{min} V_{max}
Line Regulation	$9V \leq V_{IN} \leq 16V$	2	25/ 25	mV_{max}
	$7V \leq V_{IN} \leq 26V$	5	50/ 50	mV_{max}
Load Regulation	$5\text{ mA} \leq I_{buf} \leq 100\text{ mA}$	15	50/ 50	mV_{max}
Output Impedance	50 mA_{dc} and 10 mA_{rms} , $f_O = 120\text{ Hz}$	200		$m\Omega$
Quiescent Current	$I_{buf} = 100\text{ mA}$	8.0	15/ 15	mA_{max}
Output Noise Voltage	10 Hz–100 kHz, $I_{OUT} = 100\text{ mA}$	100		μV
Long Term Stability		20		$mV/1000\text{ hr}$
Ripple Rejection	$f_o = 120\text{ Hz}$	70	60/ 50	dB_{min}
Dropout Voltage	$I_{buf} = 100\text{ mA}$	0.35	0.50/ 0.80	V_{max}
Current Limit		0.23	0.15/ 0.15	A_{min}
Maximum Operational Input Voltage	Continuous DC	32	26/ 26	V_{min}
Maximum Line Transient	$V_{buf} \leq 6V$, $R_{buf} = 100\Omega$, $T \leq 100\text{ ms}$	65	60/ 60	V_{min}
Reverse Polarity Input Voltage DC	$V_{buf} \geq -0.6V$, $R_{buf} = 100\Omega$	-30	-15/- 15	V_{min}
Reverse Polarity Input Voltage Transient	$T \leq 100\text{ ms}$, $R_{buf} = 100\Omega$	-55	-35/- 35	V_{min}

Electrical Characteristics

$V_{IN} = 14V$, $I_{stby} = 1\text{ mA}$, $C_{stby} = 10\text{ }\mu\text{F}$, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$, all other limits are for $T_A = T_J = 25^{\circ}\text{C}$ (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
V_{standby} (Pin 9)				
Output Voltage	$1\text{ mA} \leq I_O \leq 7.5\text{ mA}$ $6V \leq V_{IN} \leq 26V$	5.00	4.85/ 4.75 5.15/ 5.25	V_{min} V_{max}
Line Regulation	$9V \leq V_{IN} \leq 16V$	2	25/ 25	mV_{max}
	$7V \leq V_{IN} \leq 26V$	5	50/ 50	mV_{max}
Load Regulation	$0.5\text{ mA} \leq I_{OUT} \leq 7.5\text{ mA}$	6	50/ 50	mV_{max}
Output Impedance	5 mA_{dc} and 1 mA_{rms} , $f_o = 120\text{ Hz}$	0.9		Ω
Quiescent Current	$I_{stby} = 7.5\text{ mA}$	1.2	2.0/ 4.0	mA_{max}
	$I_{stby} = 2\text{ mA}$	0.9	1.5/ 4.0	mA_{max}

Electrical Characteristics (Continued)

$V_{IN} = 14V$, $I_{stby} = 1\text{ mA}$, $C_{stby} = 10\ \mu\text{F}$, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$, all other limits are for $T_A = T_J = 25^{\circ}\text{C}$ (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
V_{standby} (Pin 9) (Continued)				
Output Noise Voltage	10 Hz–100 kHz, $I_{stby} = 1\text{ mA}$	100		μV
Long Term Stability		20		mV/1000 hr
Ripple Rejection	$f_o = 120\text{ Hz}$	70	60/ 50	dB _{min}
Dropout Voltage	$I_{stby} = 1\text{ mA}$	0.26	0.50/ 0.60	V_{max}
	$I_{stby} = 7.5\text{ mA}$	0.38	0.60/ 0.70	V_{max}
Current Limit		15	12/ 12	mA _{min}
Maximum Operational Input Voltage	$4.5V \leq V_{stby} \leq 6V$, $R_{stby} = 1000\Omega$	65	60/ 60	V_{min}
Maximum Line Transient	$V_{stby} \leq 6V$, $T \leq 100\text{ ms}$, $R_{stby} = 1000\Omega$	65	60/ 60	V_{min}
Reverse Polarity Input Voltage DC	$V_{stby} \geq -0.6V$, $R_{stby} = 1000\Omega$	-30	-15/- 15	V_{min}
Reverse Polarity Input Voltage Transient	$T \leq 100\text{ ms}$, $R_{stby} = 1000\Omega$	-55	-35/- 35	V_{min}

Electrical Characteristics

$V_{IN} = 14V$, $C_{OUT} = 10\ \mu\text{F}$, $C_{buf} = 10\ \mu\text{F}$, $C_{stby} = 10\ \mu\text{F}$, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$, all other limits are for $T_A = T_J = 25^{\circ}\text{C}$ (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
Tracking and Isolation				
Tracking $V_{OUT} - V_{stby}$	$I_{OUT} \leq 500\text{ mA}$, $I_{buf} = 5\text{ mA}$, $I_{stby} \leq 7.5\text{ mA}$	± 30	$\pm 100 / \pm \mathbf{100}$	mV _{max}
Tracking $V_{buf} - V_{stby}$	$I_{OUT} = 5\text{ mA}$, $I_{buf} \leq 100\text{ mA}$, $I_{stby} \leq 7.5\text{ mA}$	± 30	$\pm 100 / \pm \mathbf{100}$	mV _{max}
Tracking $V_{OUT} - V_{buf}$	$I_{OUT} \leq 500\text{ mA}$, $I_{buf} \leq 100\text{ mA}$, $I_{stby} = 1\text{ mA}$	± 30	$\pm 100 / \pm \mathbf{100}$	mV _{max}
Isolation* V_{buf} from V_{OUT}	$R_{OUT} = 1\Omega$, $I_{buf} \leq 100\text{ mA}$	5.00	4.50/ 4.50 5.50/ 5.50	V_{min} V_{max}
Isolation* V_{stby} from V_{OUT}	$R_{OUT} = 1\Omega$, $I_{stby} \leq 7.5\text{ mA}$	5.00	4.50/ 4.50 5.50/ 5.50	V_{min} V_{max}
Isolation* V_{OUT} from V_{buf}	$R_{buf} = 1\Omega$, $I_{OUT} \leq 500\text{ mA}$	5.00	4.50/ 4.50 5.50/ 5.50	V_{min} V_{max}
Isolation* V_{stby} from V_{buf}	$R_{buf} = 1\Omega$, $I_{stby} \leq 7.5\text{ mA}$	5.00	4.50/ 4.50 5.50/ 5.50	V_{min} V_{max}

*Isolation refers to the ability of the specified output to remain within the tested limits when the other output is shorted to ground.

Electrical Characteristics (Continued)

$V_{IN} = 14V$, $I_{OUT} = 5\text{ mA}$, $I_{buf} = 5\text{ mA}$, $I_{stby} = 5\text{ mA}$, $R_t = 130\text{ k}\Omega$, $C_t = 0.33\text{ }\mu\text{F}$, $C_{mon} = 0.47\text{ }\mu\text{F}$, unless otherwise indicated, **Boldface** type refers to limits over the entire operating temperature range, $-40^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$, all other limits are for $T_A = T_J = 25^\circ\text{C}$ (Note 6)

Parameter	Conditions	Typical	Limit (Note 2)	Units
Computer Monitor/Reset Functions				
$I_{reset\ Low}$	$V_{IN} = 4V$, $V_{rst} = 0.4V$	5	2/ 0.50	mA_{min}
$V_{reset\ Low}$	$V_{IN} = 4V$, $I_{rst} = 1\text{ mA}$	0.10	0.40/ 0.40	V_{max}
R_t voltage	(Pin 2)	1.22	1.15/ 0.75	V_{min}
		1.22	1.30/ 2.00	V_{max}
Power On Reset Delay	$V_{\mu P_{mon}} = 5V$ ($T_{dly} = 1.2 R_t C_t$)	50	45/ 17.0	ms_{min}
		50	55/ 80.0	ms_{max}
ΔV_{OUT} Low Reset Threshold	(Note 4)	-350	-225/ - 175	mV_{min}
			-500/ - 550	mV_{max}
ΔV_{OUT} High Reset Threshold	(Note 4)	600	225/ 175	mV_{min}
			750/ 800	mV_{max}
Reset Output Leakage	$V_{\mu P_{mon}} = 5V$, $V_{rst} = 12V$	0.01	1/ 5.0	μA_{max}
μP_{mon} Input Current (Pin 4)	$V_{\mu P_{mon}} = 2.4V$	7.5	25/ 25	μA_{max}
	$V_{\mu P_{mon}} = 0.4V$	0.01	10/ 15	μA_{max}
μP_{mon} Input Threshold Voltage		1.22	0.80/ 0.80	V_{min}
		1.22	2.00/ 2.00	V_{max}
μP Monitor Reset Oscillator Period	$V_{\mu P_{mon}} = 0V$ ($T_{window} = 0.82 R_t C_{mon}$)	50	45/ 30	ms_{min}
		50	55/ 70	ms_{max}
μP Monitor Reset Oscillator Pulse Width	$V_{\mu P_{mon}} = 0V$ ($RESET_{pw} = 2000 C_{mon}$)	1.0	0.7/ 0.4	ms_{min}
		1.0	1.3/ 2.10	ms_{max}
Minimum μP Monitor Input Pulse Width	(Note 5)	2		μs
Reset Fall Time	$R_{rst} = 10\text{ k}\Omega$, $V_{rst} = 5V$, $C_{rst} \leq 10\text{ pF}$	0.20	1.00/ 1.00	μs_{max}
Reset Rise Time	$R_{rst} = 10\text{ k}\Omega$, $V_{rst} = 5V$, $C_{rst} \leq 10\text{ pF}$	0.60	1.00/ 1.50	μs_{max}
On/Off Switch Input Current (Pin 8)	$V_{ON} = 2.4V$	7.5	25/ 25	μA_{max}
	$V_{ON} = 0.4V$	0.01	10/ 10	μA_{max}
On/Off Switch Input Threshold Voltage		1.22	0.80/ 0.80	V_{min}
		1.22	2.00/ 2.00	V_{max}

Note 1: Thermal resistance without a heatsink for junction-to-case temperature is $3^\circ\text{C}/\text{W}$. Thermal resistance case-to-ambient is $40^\circ\text{C}/\text{W}$.

Note 2: Tested Limits are guaranteed and 100% production tested.

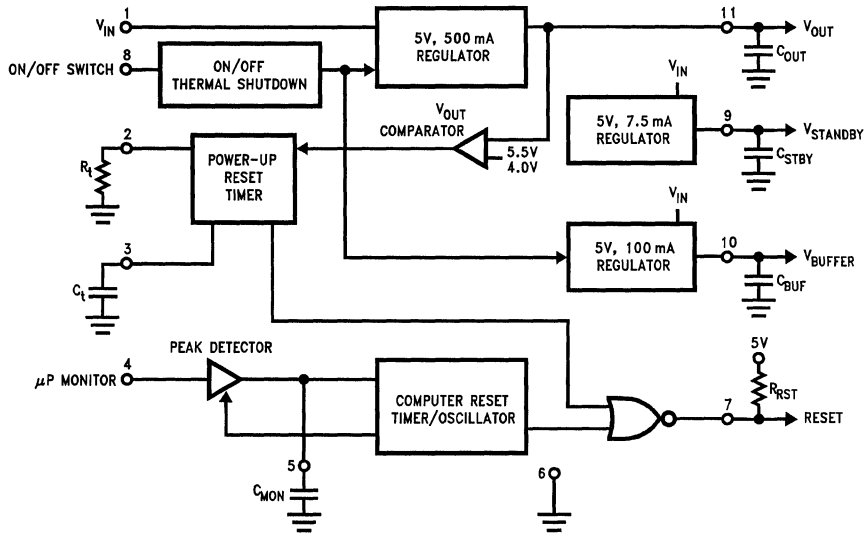
Note 3: Human body model, 100 pF capacitor discharged through a 1500 Ω resistor.

Note 4: Internal comparators detect when the main regulator output (V_{OUT}) changes from the measured output voltage (with $V_{IN} = 14V$) by the specified amount, ΔV_{OUT} High or ΔV_{OUT} Low, and set the Reset Error Flag low. The Reset Error Flag is held low until V_{OUT} returns to regulation. The Reset Error Flag is then allowed to go high again after a delay set by R_t and C_t (see application section).

Note 5: This parameter is a measure of how short a pulse can be detected at the μP Monitor Input. This parameter is primarily influenced by the value of C_{mon} . (See Application Hints Section.)

Note 6: To ensure constant junction temperature, low duty cycle pulse testing is used.

Block Diagram



TL/H/11252-2

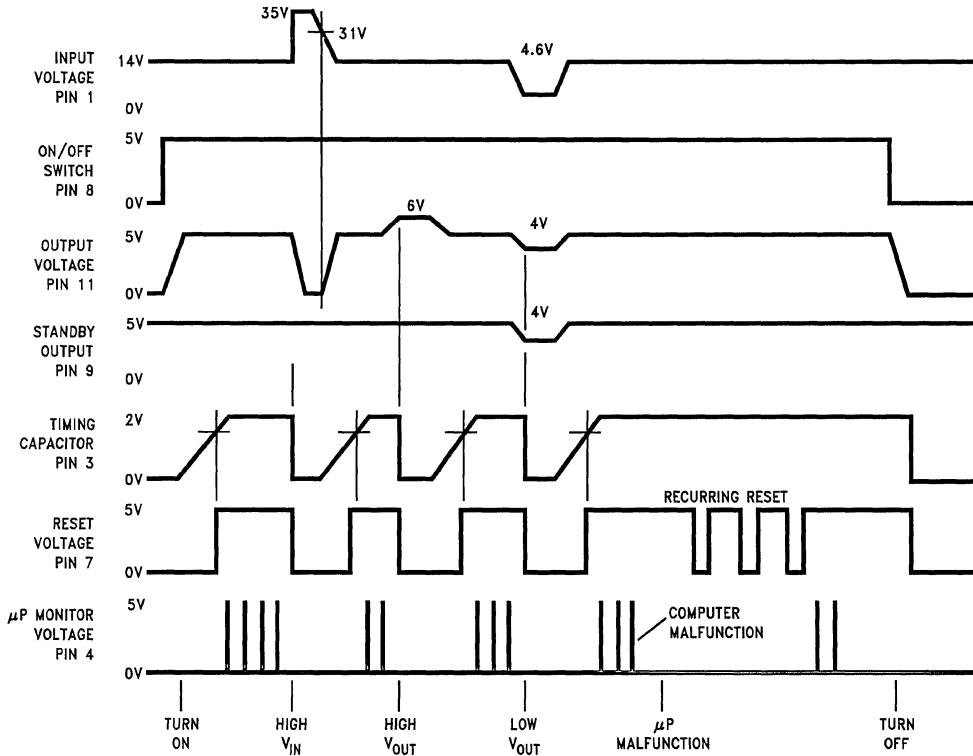
Pin Description

Pin No.	Pin Name	Comments
1	V _{IN}	Positive supply input voltage
2	R _t	Sets internal timing currents
3	C _t	Sets power-up reset delay timing
4	μP _{mon}	Microcomputer monitor input
5	C _{mon}	Sets μC monitor timing
6	Ground	Regulator ground
7	Reset	Reset error flag output
8	ON/OFF	Enables/disables high current regulators
9	V _{standby}	Standby regulator output (7.5 mA)
10	V _{buffer}	Buffer regulator output (100 mA)
11	V _{OUT}	Main regulator output (500 mA)

External Components

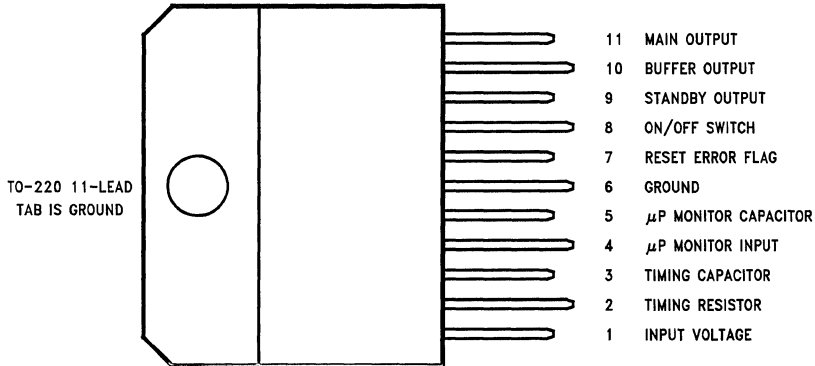
Component	Typical Value	Component Range	Comments
C _{IN}	1 μF	0.47 μF–10 μF	Required if device is located far from power supply filter.
R _t	130k	24k–1.2M	Sets internal timing currents.
C _t	0.33 μF	0.033 μF–3.3 μF	Sets power-up reset delay.
C _{tc}	0.01 μF	0.001 μF–0.1 μF	Establishes time constant of AC coupled computer monitor.
R _{tc}	10k	1k–100k	Establishes time constant of AC coupled computer monitor. (See applications section.)
C _{mon}	0.47 μF	0.047 μF–4.7 μF	Sets time window for computer monitor. Also determines period and pulse width of computer malfunction reset. (See applications section.)
R _{rst}	10k	5k–100k	Load for open collector reset output. Determined by computer reset input requirements.
C _{stby}	10 μF	10 μF–no bound	A 10 μF is required for stability but larger values can be used to maintain regulation during transient conditions.
C _{buf}	10 μF	10 μF–no bound	A 10 μF is required for stability but larger values can be used to maintain regulation during transient conditions.
C _{OUT}	10 μF	10 μF–no bound	A 10 μF is required for stability but larger values can be used to maintain regulation during transient conditions.

Typical Circuit Waveforms



TL/H/11252-3

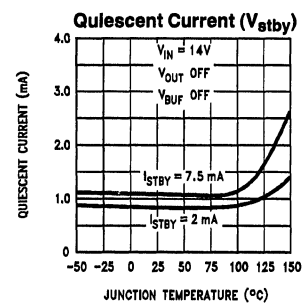
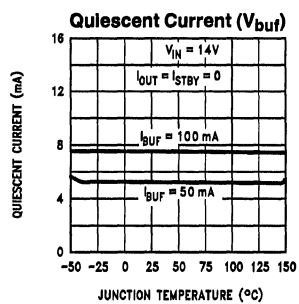
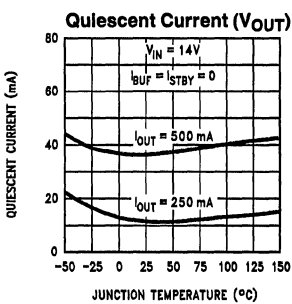
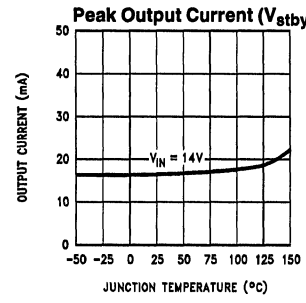
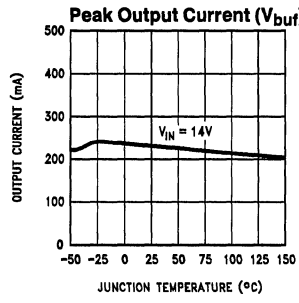
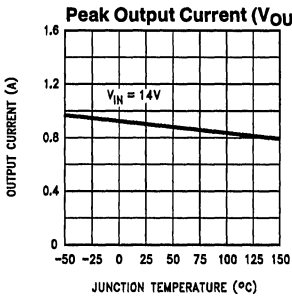
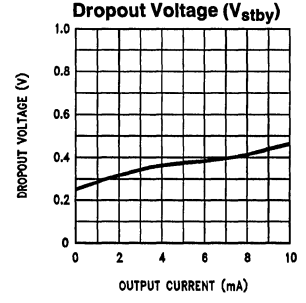
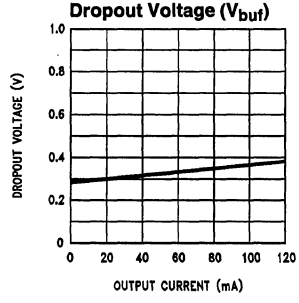
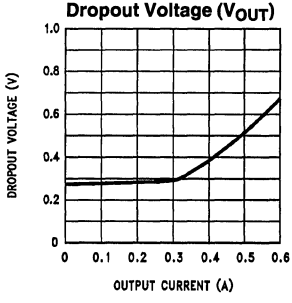
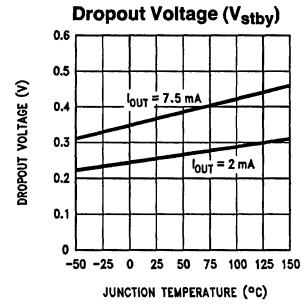
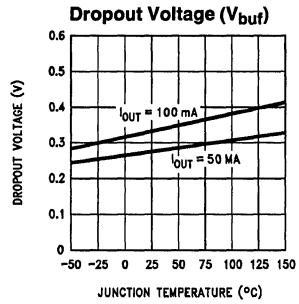
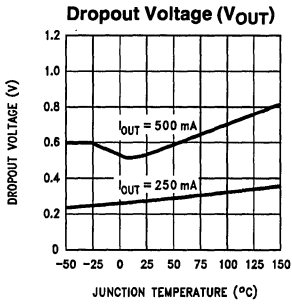
Connection Diagram



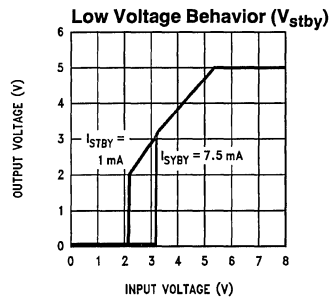
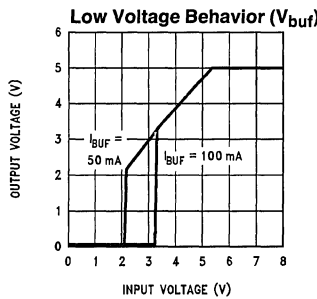
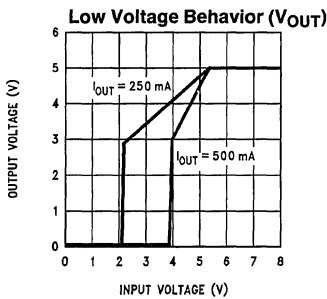
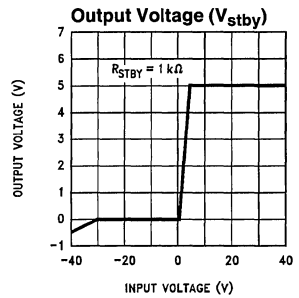
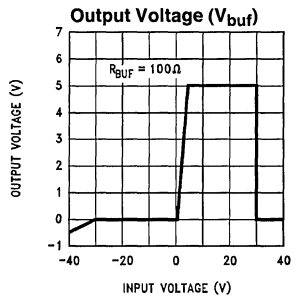
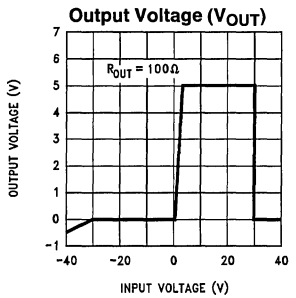
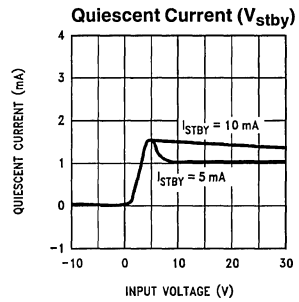
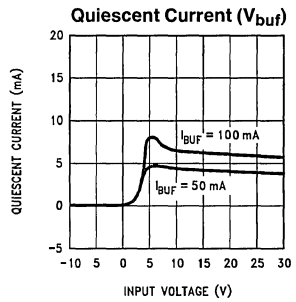
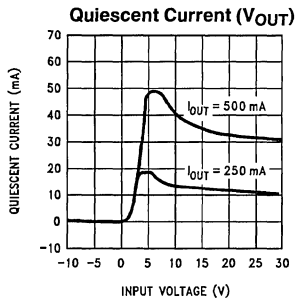
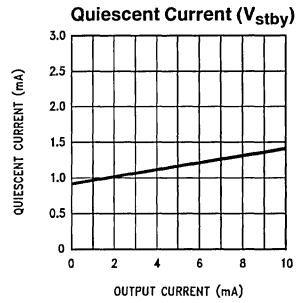
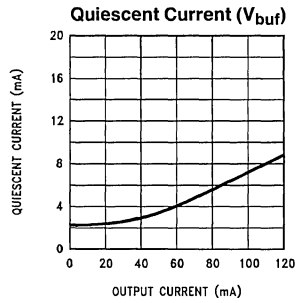
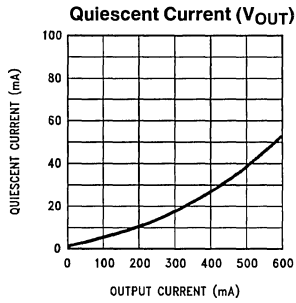
Order Number LM2984T
See NS Package Number TA11B

TL/H/11252-4

Typical Performance Characteristics

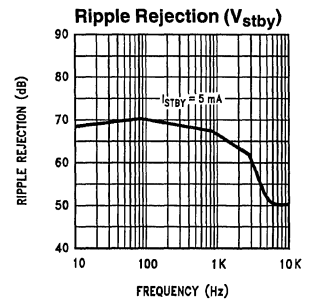
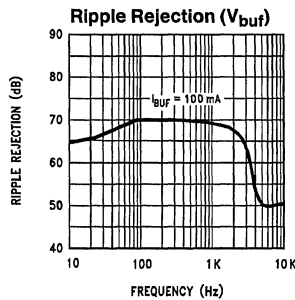
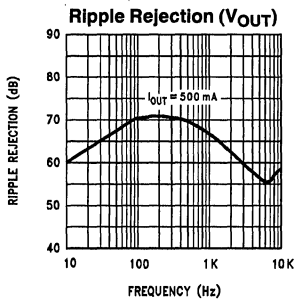
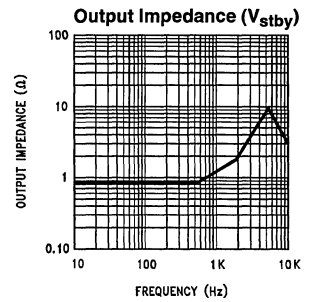
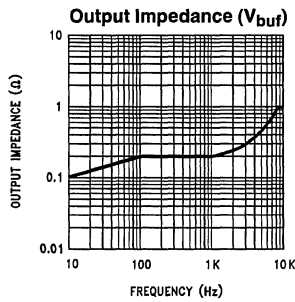
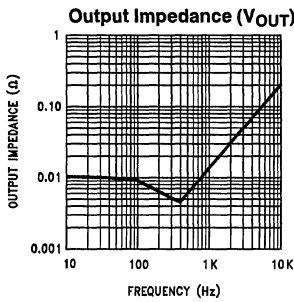
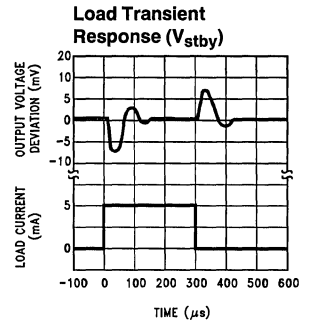
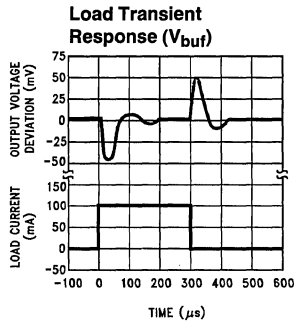
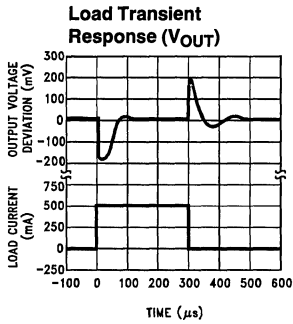
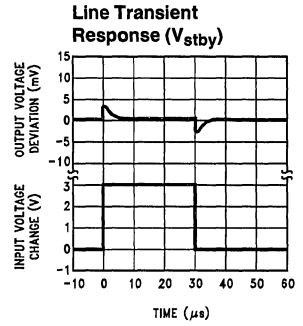
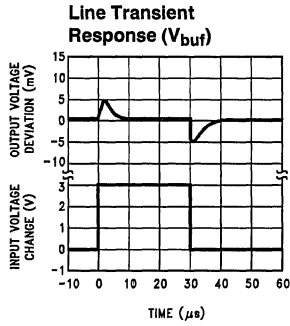
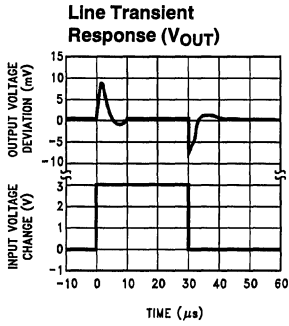


Typical Performance Characteristics (Continued)

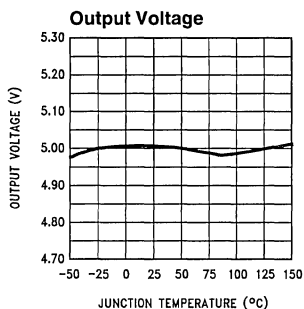


TL/H/11252-6

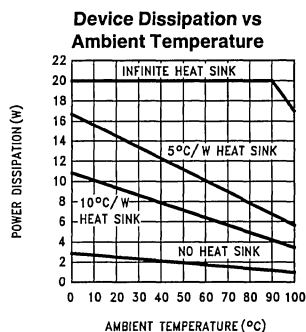
Typical Performance Characteristics (Continued)



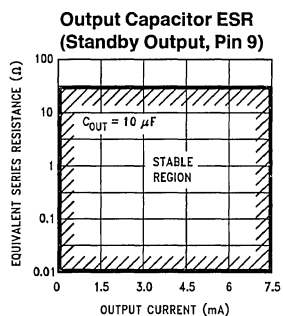
Typical Performance Characteristics (Continued)



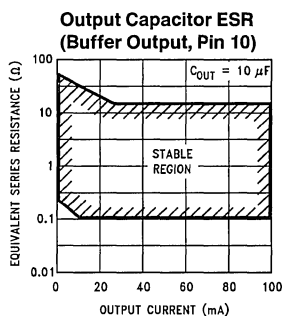
TL/H/11252-8



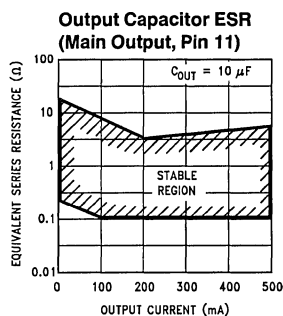
TL/H/11252-9



TL/H/11252-10



TL/H/11252-11



TL/H/11252-12

Application Hints

OUTPUT CAPACITORS

The LM2984 output capacitors are required for stability. Without them, the regulator outputs will oscillate, sometimes by many volts. Though the 10 μF shown are the minimum recommended values, actual size and type may vary depending upon the application load and temperature range. Capacitor effective series resistance (ESR) also affects the IC stability. Since ESR varies from one brand to the next, some bench work may be required to determine the minimum capacitor value to use in production. Worst case is usually determined at the minimum ambient temperature and the maximum load expected.

Output capacitors can be increased in size to any desired value above the minimum. One possible purpose of this would be to maintain the output voltages during brief conditions of negative input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum type electrolytics will freeze at temperatures less than -30°C, reducing their effective capacitance to zero. To maintain regulator stability down to -40°C, capacitors rated at that temperature (such as tantalums) must be used.

Each output **must** be terminated by a capacitor, even if it is not used.

STANDBY OUTPUT

The standby output is intended for use in systems requiring standby memory circuits. While the high current regulator

outputs are controlled with the ON/OFF pin described later, the standby output remains on under all conditions as long as sufficient input voltage is supplied to the IC. Thus, memory and other circuits powered by this output remain unaffected by positive line transients, thermal shutdown, etc.

The standby regulator circuit is designed so that the quiescent current to the IC is very low (<1.5 mA) when the other regulator outputs are off.

The capacitor on the output of this regulator can be increased without bound. This will help maintain the output voltage during negative input transients and will also help to reduce the noise on all three outputs. Because the other two track the standby output, therefore any noise reduction here will also reduce the other two noise voltages.

BUFFER OUTPUT

The buffer output is designed to drive peripheral sensor circuitry in a μP system. It will track the standby and main regulator within a few millivolts in normal operation. Therefore, a peripheral sensor can be powered off this supply and have the same operating voltage as the μP system. This is important if a ratiometric sensor system is being used.

The buffer output can be short circuited while the other two outputs are in normal operation. This protects the μP system from disruption of power when a sensor wire, etc. is temporarily shorted to ground, i.e. only the sensor signal would be interrupted, while the μP and memory circuits would remain operational.

The buffer output is similar to the main output in that it is controlled by the ON/OFF switch in order to save power in

Application Hints (Continued)

the standby mode. It is also fault protected against overvoltage and thermal overload. If the input voltage rises above approximately 30V (e.g. load dump), this output will automatically shut down. This protects the internal circuitry and enables the IC to survive higher voltage transients than would otherwise be expected. Thermal shutdown is necessary since this output is one of the dominant sources of power dissipation in the IC.

MAIN OUTPUT

The main output is designed to power relatively large loads, i.e. approximately 500 mA. It is therefore also protected against overvoltage and thermal overload.

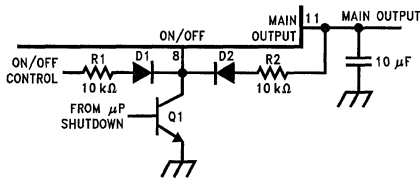
This output will track the other two within a few millivolts in normal operation. It can therefore be used as a reference voltage for any signal derived from circuitry powered off the standby or buffer outputs. This is important in a ratiometric sensor system or any system requiring accurate matching of power supply voltages.

ON/OFF SWITCH

The ON/OFF switch controls the main output and the buffer output. The threshold voltage is compatible with most logic families and has about 20 mV of hysteresis to insure 'clean' switching from the standby mode to the active mode and vice versa. This pin can be tied to the input voltage through a 10 k Ω resistor if the regulator is to be powered continuously.

POWER DOWN OVERRIDE

Another possible approach is to use a diode in series with the ON/OFF signal and another in series with the main output in order to maintain power for some period of time after the ON/OFF signal has been removed (see *Figure 1*). When the ON/OFF switch is initially pulled high through diode D1, the main output will turn on and supply power through diode D2 to the ON/OFF switch effectively latching the main output. An open collector transistor Q1 is connected to the ON/OFF pin along with the two diodes and forces the regulators off after a period of time determined by the μ P. In this way, the μ P can override a power down command and store data, do housekeeping, etc. before reverting back to the standby mode.



TL/H/11252-13

FIGURE 1. Power Down Override

RESET OUTPUT

This output is an open collector NPN transistor which is forced low whenever an error condition is present at the main output or when a μ P error is sensed (see μ P Monitor section). If the main output voltage drops by 350 mV or rises out of regulation by 600 mV typically, the RESET output is forced low and held low for a period of time set by two external components, R_t and C_t . There is a slight amount of hysteresis in these two threshold voltages so that the RESET output has a fast rise and fall time compatible with the requirements of most μ P RESET inputs.

DELAYED RESET

Resistor R_t and capacitor C_t set the period of time that the RESET output is held low after a main output error condition has been sensed. The delay is given by the formula:

$$T_{dly} = 1.2 R_t C_t \text{ (seconds)}$$

The delayed RESET will be initiated any time the main output is out of regulation, i.e. during power-up, short circuit, overvoltage, low line, thermal shutdown or power-down. The μ P is therefore RESET whenever the output voltage is out of regulation. (It is important to note that a RESET is only initiated when the main output is in error. The buffer and standby outputs are not directly monitored for error conditions.)

μ P MONITOR RESET

There are two distinct and independent error monitoring systems in the LM2984. The one described above monitors the main regulator output and initiates a delayed RESET whenever this output is in error. The other error monitoring system is the μ P watchdog. These two systems are OR'd together internally and both force the RESET output low when either type of error occurs.

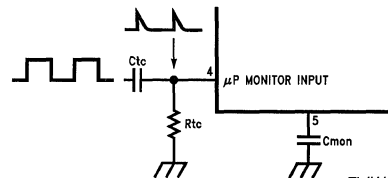
This watchdog circuitry continuously monitors a pin on the μ P that generates a positive going pulse during normal operation. The period of this pulse is typically on the order of milliseconds and the pulse width is typically on the order of 10's of microseconds. If this pulse ever disappears, the watchdog circuitry will time out and a RESET low will be sent to the μ P. The time out period is determined by two external components, R_t and C_{mon} , according to the formula:

$$T_{window} = 0.82 R_t C_{mon} \text{ (seconds)}$$

The width of the RESET pulse is set by C_{mon} and an internal resistor according to the following:

$$RESET_{pw} = 2000 C_{mon} \text{ (seconds)}$$

A square wave signal can also be monitored for errors by filtering the C_{mon} input such that only the positive edges of the signal are detected. *Figure 2* is a schematic diagram of a typical circuit used to differentiate the input signal. Resistor R_{tc} and capacitor C_{tc} pass only the rising edge of the square wave and create a short positive pulse suitable for the μ P monitor input. If the incoming signal continues in a high state or in a low state for too long a period of time, a RESET low will be generated.



TL/H/11252-14

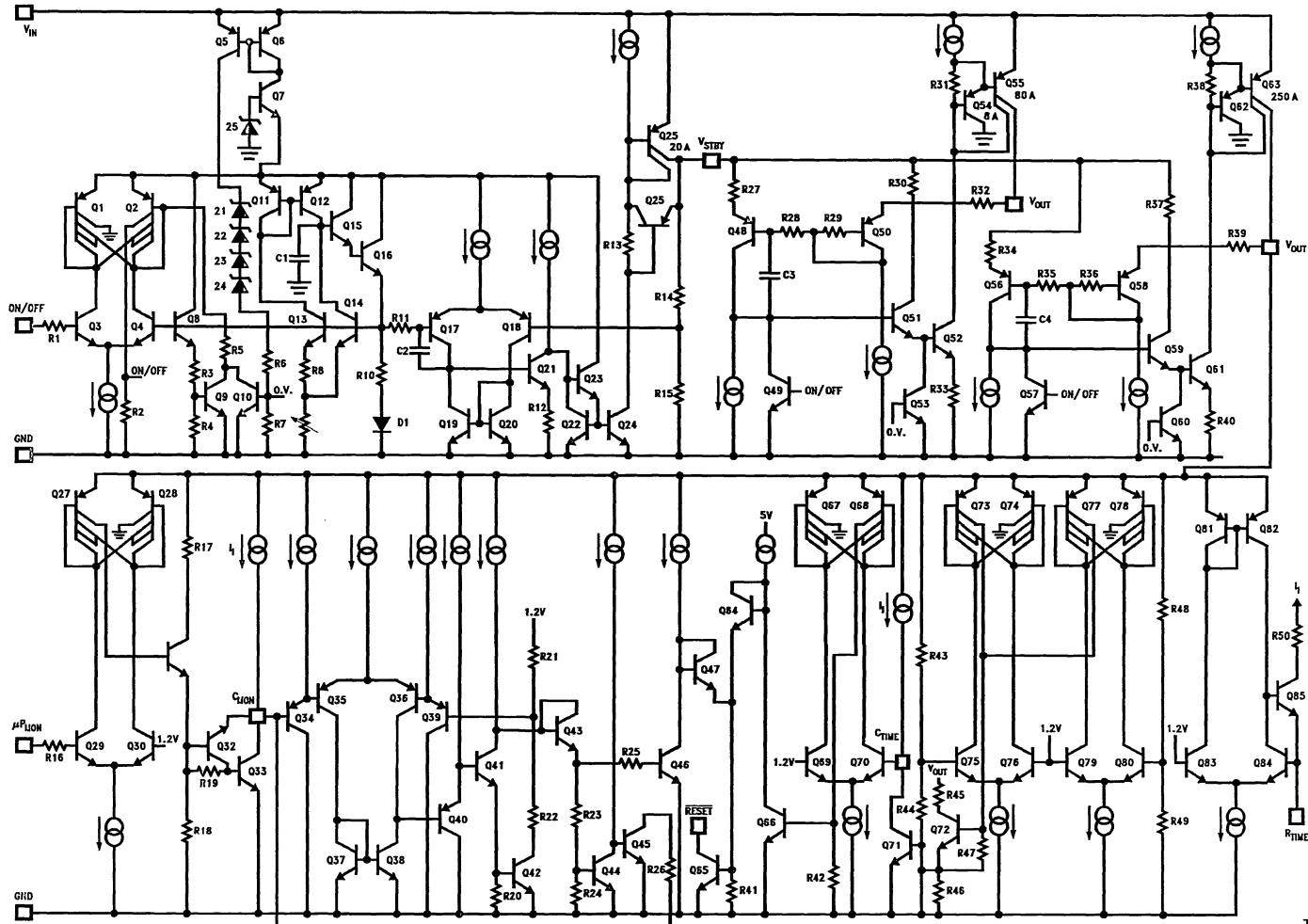
FIGURE 2. Monitoring Square Wave μ P Signals

The threshold voltage and input characteristics of this pin are compatible with nearly all logic families.

There is a limit on the width of a pulse that can be reliably detected by the watchdog circuit. This is due to the output resistance of the transistor which discharges C_{mon} when a high state is detected at the input. The minimum detectable pulse width can be determined by the following formula:

$$PW_{min} = 20 C_{mon} \text{ (seconds)}$$

Equivalent Schematic Diagram



TL/H/11252-15



LM2990 Negative Low Dropout Regulator

General Description

The LM2990 is a three-terminal, low dropout, 1 ampere negative voltage regulator available with fixed output voltages of -5 , -5.2 , -12 , and -15 V.

The LM2990 uses new circuit design techniques to provide low dropout and low quiescent current. The dropout voltage at 1A load current is typically 0.6V and a guaranteed worst-case maximum of 1V over the entire operating temperature range. The quiescent current is typically 1 mA with 1A load current and an input-output voltage differential greater than 3V. A unique circuit design of the internal bias supply limits the quiescent current to only 9 mA (typical) when the regulator is in the dropout mode ($V_{OUT} - V_{IN} \leq 3$ V). Output voltage accuracy is guaranteed to $\pm 5\%$ over load, and temperature extremes.

The LM2990 is short-circuit proof, and thermal shutdown includes hysteresis to enhance the reliability of the device when overloaded for an extended period of time. The LM2990 is available in a 3-lead TO-220 package and is rated for operation over the automotive temperature range of -40°C to $+125^{\circ}\text{C}$.

Features

- 5% output accuracy over entire operating range
- Output current in excess of 1A
- Dropout voltage typically 0.6V at 1A load
- Low quiescent current
- Internal short circuit current limit
- Internal thermal shutdown with hysteresis
- Functional complement to the LM2940 series

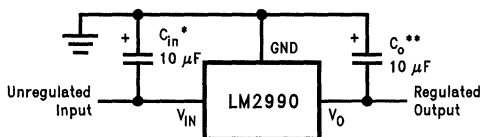
Applications

- Post switcher regulator
- Local, on-card, regulation
- Battery operated equipment

Output Voltages

LM2990T-5.0	-5V
LM2990T-5.2	-5.2V
LM2990T-12	-12V
LM2990T-15	-15V

Typical Application

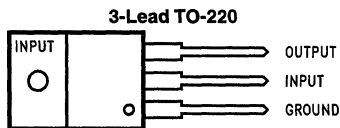


TL/H/10801-1

*Required if the regulator is located further than 6 inches from the power supply filter capacitors. A 1 μF solid tantalum or a 10 μF aluminum electrolytic capacitor is recommended.

**Required for stability. Must be at least a 10 μF aluminum electrolytic or a 1 μF solid tantalum to maintain stability. May be increased without bound to maintain regulation during transients. Locate the capacitor as close as possible to the regulator. The equivalent series resistance (ESR) is critical, and should be less than 10 Ω over the same operating temperature range as the regulator.

Connection Diagram and Ordering Information



Front View

TL/H/10801-2

Order Number LM2990T-5.0, LM2990T-5.2, LM2990T-12 or LM2990T-15
See NS Package Number T03B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	-26V to +0.3V
ESD Susceptibility (Note 2)	2 kV
Power Dissipation (Note 3)	Internally Limited
Junction Temperature (T_{Jmax})	125°C

Storage Temperature	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

Operating Ratings (Note 1)

Junction Temperature Range (T_J)	-40°C to +125°C
Maximum Input Voltage (Operational)	-26V

Electrical Characteristics $V_{IN} = -5V + V_{O(NOM)}$ (Note 6), $I_O = 1A$, $C_O = 47 \mu F$, unless otherwise specified. **Boldface** limits apply over the entire operating temperature range, $-40^\circ C \leq T_J \leq 125^\circ C$, all other limits apply for $T_J = 25^\circ C$.

Parameter	Conditions	LM2990T-5.0		LM2990T-5.2		Units (Limit)
		Typ (Note 4)	Limit (Note 5)	Typ (Note 4)	Limit (Note 5)	
Output Voltage (V_O)	$5 \text{ mA} \leq I_O \leq 1 \text{ A}$	-5	-4.90 -5.10	-5.2	-5.10 -5.30	V (max) V (min) V
	$5 \text{ mA} \leq I_O \leq 1 \text{ A}$		-4.75 -5.25		-4.94 -5.46	V (max) V (min)
Line Regulation	$I_O = 5 \text{ mA}$, $V_{O(NOM)} - 1V > V_{IN} > -26V$	4	40	4	40	mV (max)
Load Regulation	$50 \text{ mA} \leq I_O \leq 1 \text{ A}$	1	40	1	40	mV (max)
Dropout Voltage	$I_O = 0.1 \text{ A}$, $\Delta V_O \leq 100 \text{ mV}$	0.1	0.3	0.1	0.3	V (max)
	$I_O = 1 \text{ A}$, $\Delta V_O \leq 100 \text{ mV}$	0.6	1	0.6	1	V (max)
Quiescent Current (I_Q)	$I_O \leq 1 \text{ A}$	1	5	1	5	mA (max)
	$I_O = 1 \text{ A}$, $V_{IN} = V_{O(NOM)}$	9	50	9	50	mA (max)
Short Circuit Current	$R_L = 1 \Omega$ (Note 7)	1.8	1.5	1.8	1.5	A (min)
Maximum Output Current	(Note 7)	1.8	1.5	1.8	1.5	A (min)
Ripple Rejection	$V_{\text{ripple}} = 1 V_{\text{rms}}$, $f_{\text{ripple}} = 1 \text{ kHz}$, $I_O = 5 \text{ mA}$	58	50	58	50	dB (min)
Output Noise Voltage	10 Hz–100 kHz, $I_O = 5 \text{ mA}$	250	750	250	750	μV (max)
Long Term Stability	1000 Hours	2000		2000		ppm

Electrical Characteristics $V_{IN} = -5V + V_{O(NOM)}$ (Note 6), $I_O = 1A$, $C_O = 47 \mu F$, unless otherwise specified. **Boldface** limits apply over the entire operating temperature range, $-40^\circ C \leq T_J \leq 125^\circ C$, all other limits apply for $T_J = 25^\circ C$. (Continued)

Parameter	Conditions	LM2990T-12		LM2990T-15		Units (Limit)
		Typ (Note 4)	Limit (Note 5)	Typ (Note 4)	Limit (Note 5)	
Output Voltage (V_O)	$5 mA \leq I_O \leq 1 A$	-12	-11.76 -12.24	-15	-14.70 -15.30	V (max) V (min) V
	$5 mA \leq I_O \leq 1 A$		-11.40 -12.60		-14.25 -15.75	V (max) V (min)
Line Regulation	$I_O = 5 mA$, $V_{O(NOM)} - 1V > V_{IN} > -26V$	6	60	6	60	mV (max)
Load Regulation	$50 mA \leq I_O \leq 1 A$	3	50	3	50	mV (max)
Dropout Voltage	$I_O = 0.1 A$, $\Delta V_O \leq 100 mV$	0.1	0.3	0.1	0.3	V (max)
	$I_O = 1 A$, $\Delta V_O \leq 100 mV$	0.6	1	0.6	1	V (max)
Quiescent Current (I_Q)	$I_O \leq 1 A$	1	5	1	5	mA (max)
	$I_O = 1 A$, $V_{IN} = V_{O(NOM)}$	9	50	9	50	mA (max)
Short Circuit Current	$R_L = 1 \Omega$ (Note 7)	1.2	0.9	1.0	0.75	A (min)
Maximum Output Current	(Note 7)	1.8	1.4	1.8	1.4	A (min)
Ripple Rejection	$V_{ripple} = 1 V_{rms}$, $f_{ripple} = 1 kHz$, $I_O = 5 mA$	52	42	52	42	dB (min)
Output Noise Voltage	10 Hz–100 kHz, $I_O = 5 mA$	500	1500	600	1800	μV (max)
Long Term Stability	1000 Hours	2000		2000		ppm

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Human body model, 100 pF discharged through a 1.5 k Ω resistor.

Note 3: The maximum power dissipation is a function of T_{Jmax} , θ_{JA} , and T_A . The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 125°C, and the LM2990 will eventually go into thermal shutdown at a T_J of approximately 160°C. For the LM2990, the junction-to-ambient thermal resistance, is 53°C/W, and the junction-to-case thermal resistance is 3°C/W.

Note 4: Typical values are at $T_J = 25^\circ C$ and represent the most likely parametric norm.

Note 5: Limits are guaranteed and 100% production tested.

Note 6: $V_{O(NOM)}$ is the nominal (typical) regulator output voltage, -5V, -5.2V, -12V or -15V.

Note 7: The short circuit current is less than the maximum output current with the -12V and -15V versions due to internal foldback current limiting. The -5V and -5.2V versions, tested with a lower input voltage, does not reach the foldback current limit and therefore conducts a higher short circuit current level. If the LM2990 output is pulled above ground, the maximum allowed current sunk back into the LM2990 is 1.5A.

Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at ($V_O + 5V$) input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

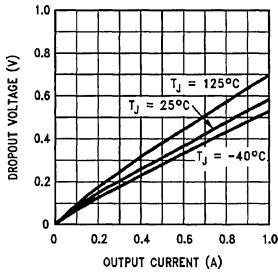
Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

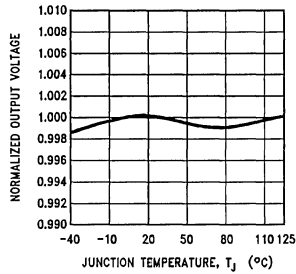
Temperature Stability of V_O : The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Typical Performance Characteristics

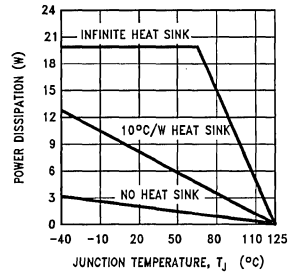
Dropout Voltage



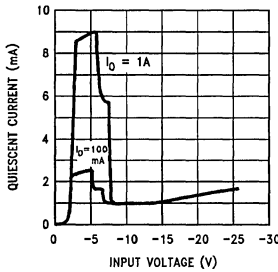
Normalized Output Voltage



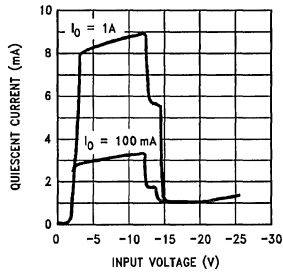
Maximum Power Dissipation (TO-220)



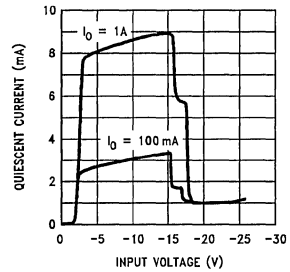
LM2990-5.0 and LM2990-5.2 Quiescent Current



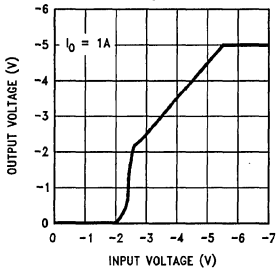
LM2990-12 Quiescent Current



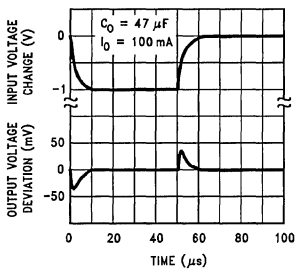
LM2990-15 Quiescent Current



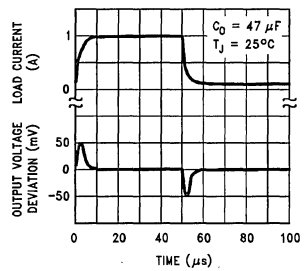
LM2990-5 and LM2990-5.2 Low Voltage Behavior



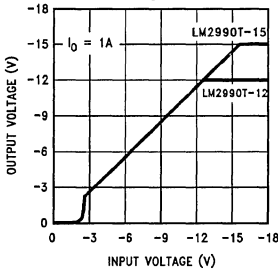
LM2990-5 and LM2990-5.2 Line Transient Response



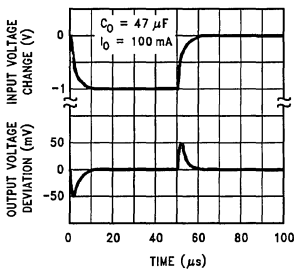
LM2990-5 and LM2990-5.2 Load Transient Response



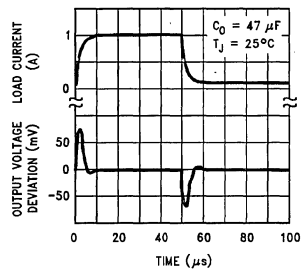
LM2990-12 and LM2990-15 Low Voltage Behavior



LM2990-12 and LM2990-15 Line Transient Response



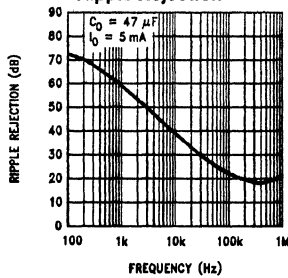
LM2990-12 and LM2990-15 Load Transient Response



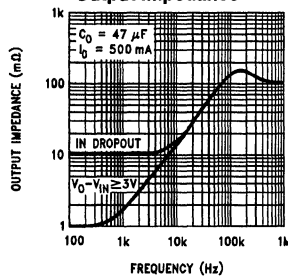
TL/H/10801-3

Typical Performance Characteristics (Continued)

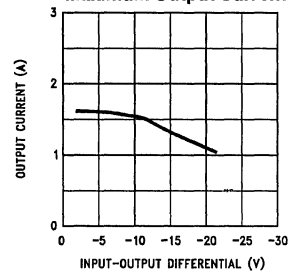
**LM2990-5 and LM2990-5.2
Ripple Rejection**



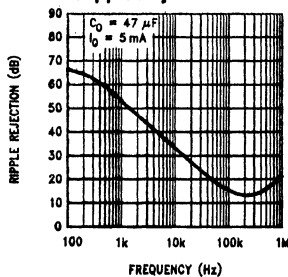
**LM2990-5 and LM2990-5.2
Output Impedance**



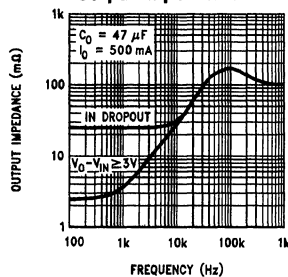
Maximum Output Current



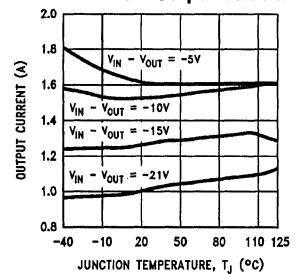
**LM2990-12 and LM2990-15
Ripple Rejection**



**LM2990-12 and LM2990-15
Output Impedance**



Maximum Output Current



TL/H/10801-4

Application Hints

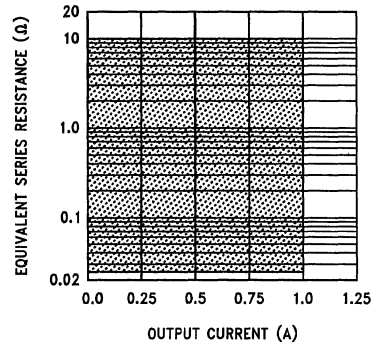
EXTERNAL CAPACITORS

The LM2990 regulator requires an output capacitor to maintain stability. The capacitor must be at least 10 μF aluminum electrolytic or 1 μF solid tantalum. The output capacitor's ESR must be less than 10 Ω , or the zero added to the regulator frequency response by the ESR could reduce the phase margin, creating oscillations (refer to the graph on the right). An input capacitor, of at least 1 μF solid tantalum or 10 μF aluminum electrolytic, is also needed if the regulator is situated more than 6" from the input power supply filter.

FORCING THE OUTPUT POSITIVE

Due to an internal clamp circuit, the LM2990 can withstand positive voltages on its output. If the voltage source pulling the output positive is DC, the current must be limited to 1.5A. A current over 1.5A fed back into the LM2990 could damage the device. The LM2990 output can also withstand fast positive voltage transients up to 26V, without any current limiting of the source. However, if the transients have a duration of over 1 ms, the output should be clamped with a Schottky diode to ground.

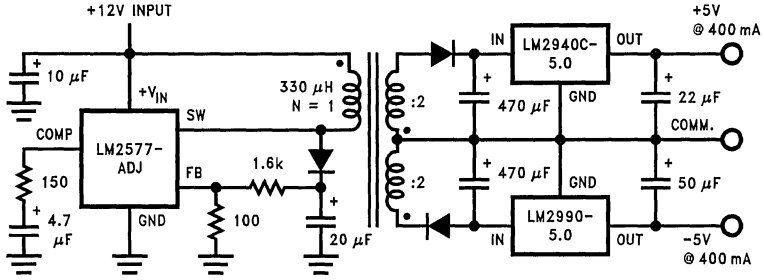
Output Capacitor ESR



TL/H/10801-9

Typical Applications

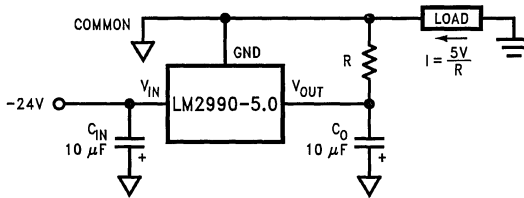
Post Regulator for an Isolated Switching Power Supply



TL/H/10801-5

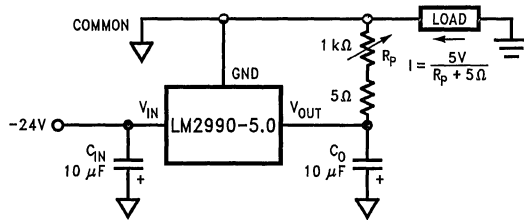
The LM2490 is a positive 1A low dropout regulator; refer to its datasheet for further information.

Fixed Current Sink



TL/H/10801-7

Adjustable Current Sink



TL/H/10801-10

LM2991 Negative Low Dropout Adjustable Regulator

General Description

The LM2991 is a low dropout adjustable negative regulator with a output voltage range between $-2V$ to $-25V$. The LM2991 provides up to 1A of load current and features a \overline{ON}/OFF pin for remote shutdown capability.

The LM2991 uses new circuit design techniques to provide a low dropout voltage, low quiescent current and low temperature coefficient precision reference. The dropout voltage at 1A load current is typically 0.6V and a guaranteed worst-case maximum of 1V over the entire operating temperature range. The quiescent current is typically 1 mA with a 1A load current and an input-output voltage differential greater than 3V. A unique circuit design of the internal bias supply limits the quiescent current to only 9 mA (typical) when the regulator is in the dropout mode ($V_{OUT} - V_{IN} \leq 3V$).

The LM2991 is short-circuit proof, and thermal shutdown includes hysteresis to enhance the reliability of the device when inadvertently overloaded for extended periods. The LM2991 is available in a 5-lead TO-220 and is rated for operation over the automotive temperature range of $-40^{\circ}C$ to $+125^{\circ}C$.

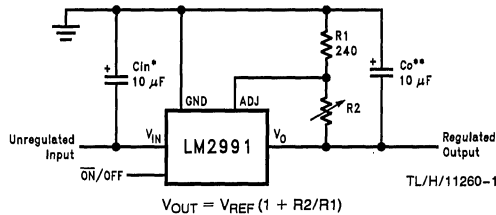
Features

- Output voltage adjustable from $-2V$ to $-25V$
- Output current in excess of 1A
- Dropout voltage typically 0.6V at 1A load
- Low quiescent current
- Internal short circuit current limit
- Internal thermal shutdown with hysteresis
- TTL, CMOS compatible \overline{ON}/OFF switch
- Functional complement to the LM2941 series

Applications

- Post switcher regulator
- Local, on-card, regulation
- Battery operated equipment

Typical Application



*Required if the regulator is located further than 6 inches from the power supply filter capacitors. A $1 \mu F$ solid tantalum or a $10 \mu F$ aluminum electrolytic capacitor is recommended.

**Required for stability. Must be at least a $10 \mu F$ aluminum electrolytic or a $1 \mu F$ solid tantalum to maintain stability. May be increased without bound to maintain regulation during transients. Locate the capacitor as close as possible to the regulator. The equivalent series resistance (ESR) is critical, and should be less than 10Ω over the same operating temperature range as the regulator.

Connection Diagrams and Ordering Information

5-Lead TO-220 Straight Leads



TL/H/11260-9

Front View
Order Number LM2991T
See NS Package Number T05A

5-Lead TO-220 Bent, Staggered Leads



TL/H/11260-2

Front View
Order Number LM2991T
See NS Package Number T05D

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	-26V to +0.3V
ESD Susceptibility (Note 2)	2 kV
Power Dissipation (Note 3)	Internally limited
Junction Temperature (T_{Jmax})	125°C

Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	230°C

Operating Ratings (Note 1)

Junction Temperature Range (T_J)	-40°C to +125°C
Maximum Input Voltage (Operational)	-26V

Electrical Characteristics $V_{IN} = -10V$, $V_O = -3V$, $I_O = 1A$, $C_O = 47 \mu F$, $R_1 = 2.7k$, $T_J = 25^\circ C$, unless otherwise specified. **Boldface** limits apply over the entire operating junction temperature range.

Parameter	Conditions	Typical (Note 4)	Min	Max	Units
Reference Voltage	$5 \text{ mA} \leq I_O \leq 1 \text{ A}$	-1.210	-1.234	-1.186	V
	$5 \text{ mA} \leq I_O \leq 1 \text{ A}$, $V_O - 1V \geq V_{IN} \geq -26V$		-1.27	-1.15	V
Output Voltage Range		-2		-3	V
	$V_{IN} = -26V$	-25	-24		V
Line Regulation	$I_O = 5 \text{ mA}$, $V_O - 1V \geq V_{IN} \geq -26V$	0.004		0.04	%/V
Load Regulation	$50 \text{ mA} \leq I_O \leq 1 \text{ A}$	0.04		0.4	%
Dropout Voltage	$I_O = 0.1 \text{ A}$, $\Delta V_O \leq 100 \text{ mV}$	0.1		0.2 0.3	V
	$I_O = 1 \text{ A}$, $\Delta V_O \leq 100 \text{ mV}$	0.6		0.8 1	V
Quiescent Current	$I_O \leq 1 \text{ A}$	0.7		5	mA
Dropout Quiescent Current	$V_{IN} = V_O$, $I_O \leq 1 \text{ A}$	16		50	mA
Ripple Rejection	$V_{\text{ripple}} = 1 \text{ V}_{\text{rms}}$, $f_{\text{ripple}} = 1 \text{ kHz}$, $I_O = 5 \text{ mA}$	60	50		dB
Output Noise	10 Hz – 100 kHz, $I_O = 5 \text{ mA}$	200		450	μV
$\overline{\text{ON}}$ /OFF Input Voltage	($V_{\text{OUT}}: \text{ON}$)	1.2		0.8	V
	($V_{\text{OUT}}: \text{OFF}$)	1.3	2.4		
$\overline{\text{ON}}$ /OFF Input Current	$V_{\overline{\text{ON}}/\text{OFF}} = 0.8V$ ($V_{\text{OUT}}: \text{ON}$)	0.1		10	μA
	$V_{\overline{\text{ON}}/\text{OFF}} = 2.4V$ ($V_{\text{OUT}}: \text{OFF}$)	40		100	
Output Leakage Current	$V_{IN} = -26V$, $V_{\overline{\text{ON}}/\text{OFF}} = 2.4V$ $V_{\text{OUT}} = 0V$	60		250	μA
Current Limit	$V_{\text{OUT}} = 0V$	2	1.5		A

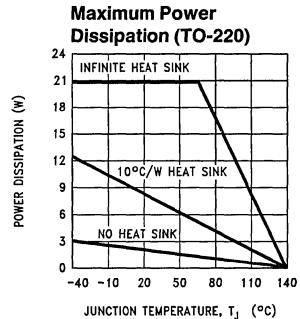
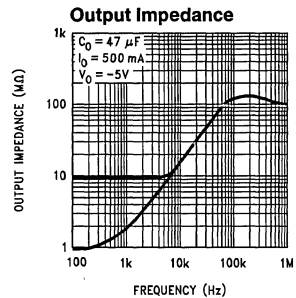
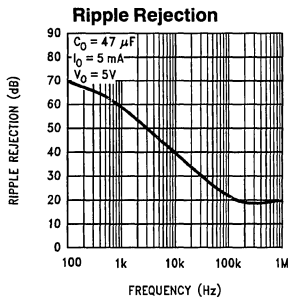
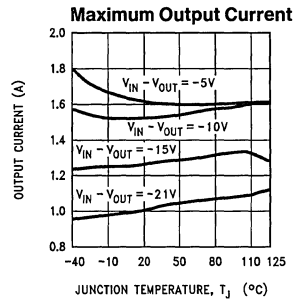
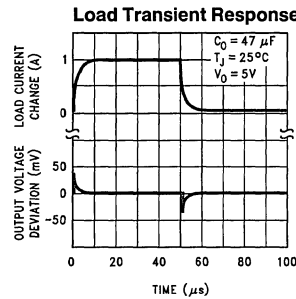
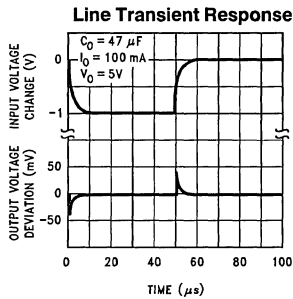
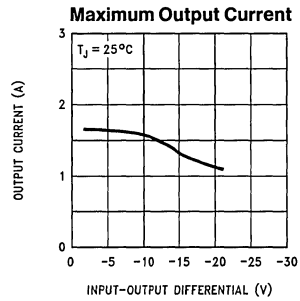
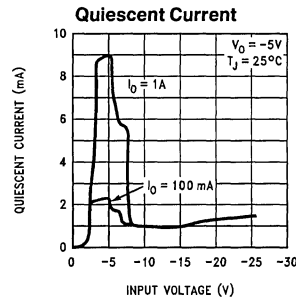
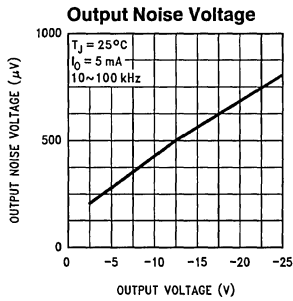
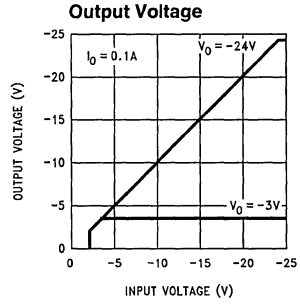
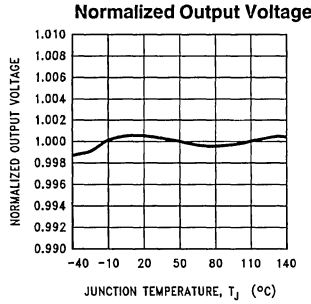
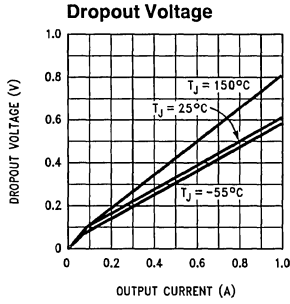
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Human body model, 100 pF discharged through a 1.5 k Ω resistor.

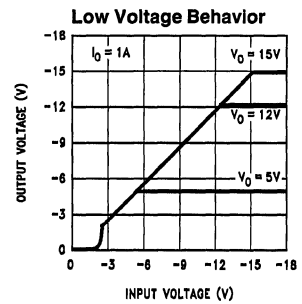
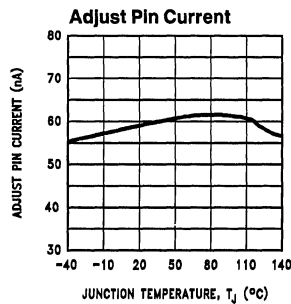
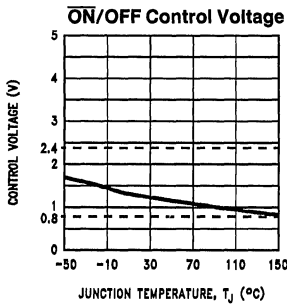
Note 3: The maximum power dissipation is a function of T_{Jmax} , θ_{JA} and T_A . The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 125°C and the LM2991 will go into thermal shutdown. For the LM2991, the junction-to-ambient thermal resistance is 53°C/W, and the junction-to-case thermal resistance is 3°C/W.

Note 4: Typicals are at $T_J = 25^\circ C$ and represent the most likely parametric norm.

Typical Performance Characteristics



Typical Performance Characteristics (Continued)



TL/H/11260-4

Application Hints

EXTERNAL CAPACITORS

The LM2991 regulator requires an output capacitor to maintain stability. The capacitor must be at least 10 μF aluminum electrolytic or 1 μF solid tantalum. The output capacitor's ESR must be less than 10 Ω , or the zero added to the regulator frequency response by the ESR could reduce the phase margin, creating oscillations. The shaded area in the Output Capacitor ESR graph indicates the recommended ESR range. An input capacitor, of at least 1 μF solid tantalum or 10 μF aluminum electrolytic, is also needed if the regulator is situated more than 6 inches from the input power supply filter.

MINIMUM LOAD

A minimum load current of 500 μA is required for proper operation. The external resistor divider can provide the minimum load, with the resistor from the adjust pin to ground set to 2.4 k Ω .

SETTING THE OUTPUT VOLTAGE

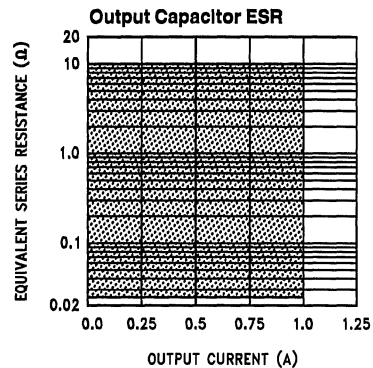
The output voltage of the LM2991 is set externally by a resistor divider and the adjust pin current using the following equation:

$$V_{OUT} = V_{REF} * (1 + R_2/R_1) - I_{ADJ} * R_2$$

where $V_{REF} = -1.21\text{V}$. The output voltage can be programmed within the range of -2V to -25V . The adjust pin current is about 60 nA, causing a slight error in the output voltage. However, using resistors lower than 100 k Ω makes the adjust pin current negligible. For example, neglecting the adjust pin current, and setting R_2 to 100 k Ω and V_{OUT} to -5V , results in an output voltage error of only 0.16%.

ON/OFF PIN

The LM2991 regulator can be turned off by applying a TTL or CMOS level high signal to the ON/OFF pin (see Current Sink Application).



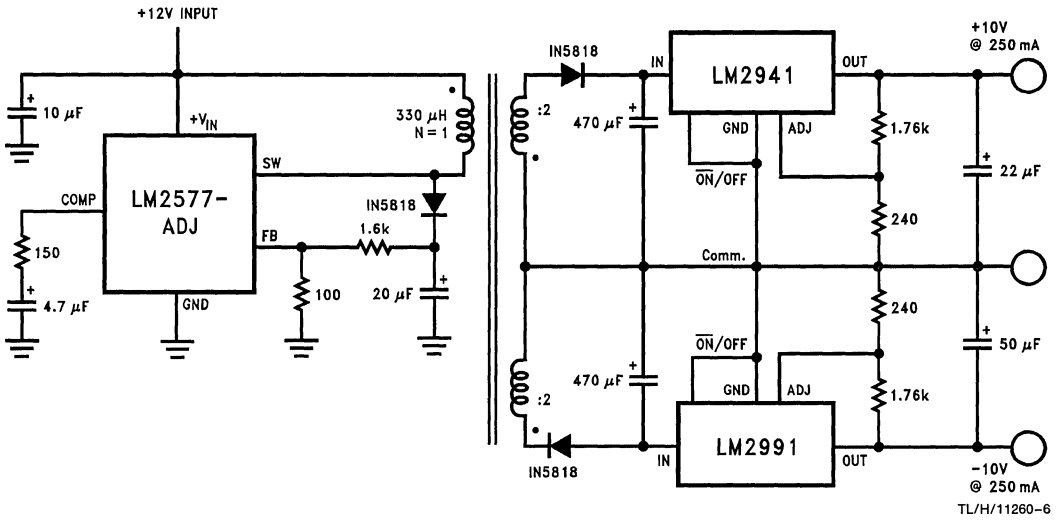
TL/H/11260-5

FORCING THE OUTPUT POSITIVE

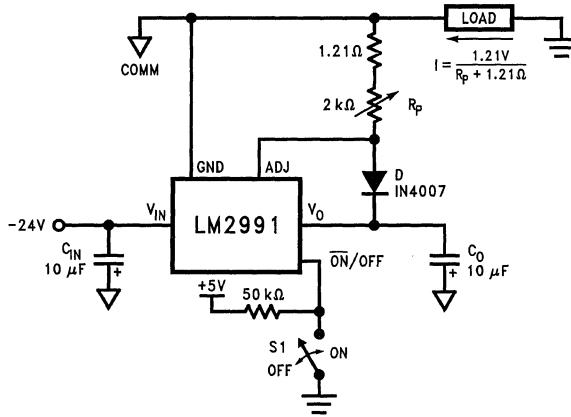
Due to an internal clamp circuit, the LM2991 can withstand positive voltages on its output. If the voltage source pulling the output positive is DC, the current must be limited to 1.5A. A current over 1.5A fed back into the LM2991 could damage the device. The LM2991 output can also withstand fast positive voltage transients up to 26V, without any current limiting of the source. However, if the transients have a duration of over 1 ms, the output should be clamped with a Schottky diode to ground.

Typical Applications

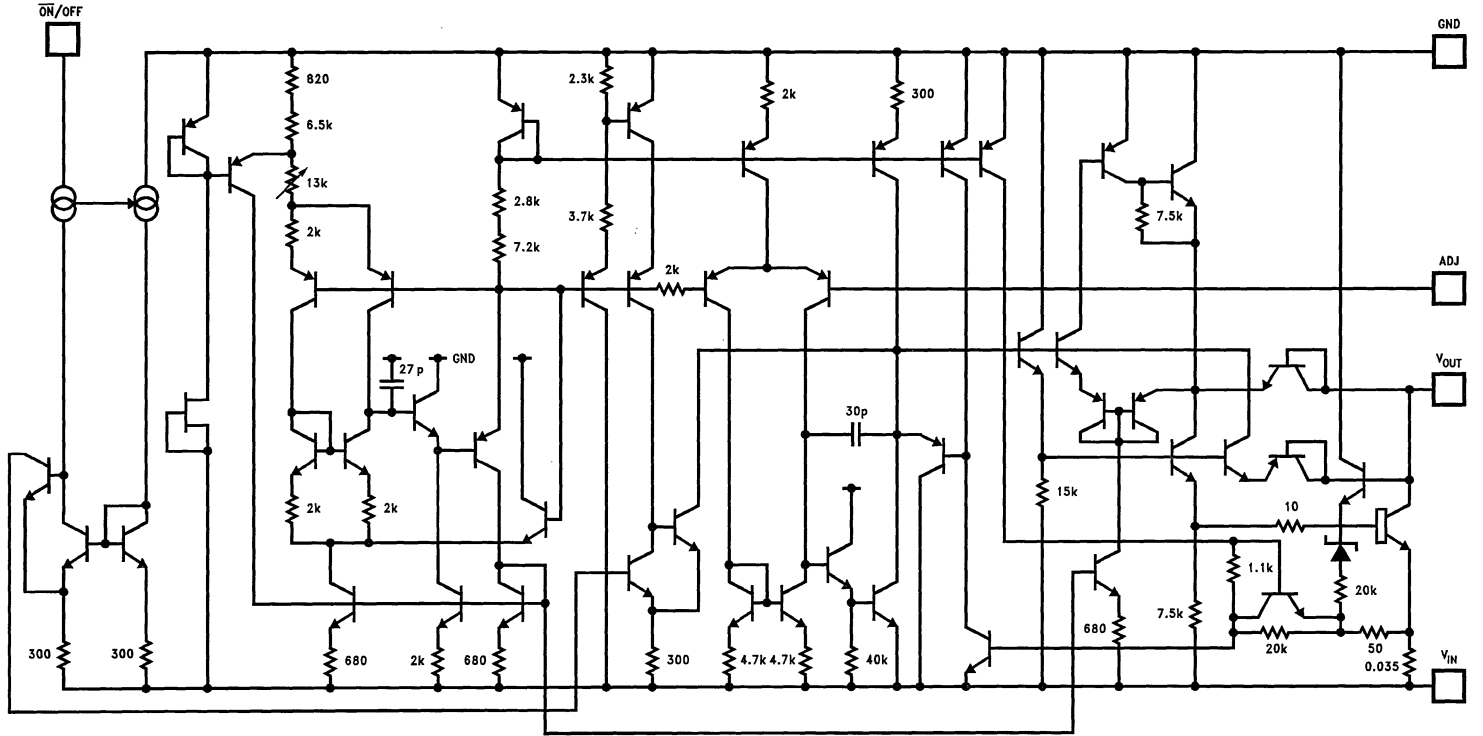
Fully Isolated Post-Switcher Regulator



Adjustable Current Sink



Equivalent Schematic



2-94

LP2950/LP2950AC/LP2950C 5V and LP2951/LP2951AC/LP2951C Adjustable Micropower Voltage Regulators

General Description

The LP2950 and LP2951 are micropower voltage regulators with very low quiescent current (75 μ A typ.) and very low dropout voltage (typ. 40 mV at light loads and 380 mV at 100 mA). They are ideally suited for use in battery-powered systems. Furthermore, the quiescent current of the LP2950/LP2951 increases only slightly in dropout, prolonging battery life.

The LP2950 in the popular 3-pin TO-92 package is pin-compatible with older 5V regulators. The 8-lead LP2951 is available in plastic, ceramic dual-in-line, or metal can packages and offers additional system functions.

One such feature is an error flag output which warns of a low output voltage, often due to falling batteries on the input. It may be used for a power-on reset. A second feature is the logic-compatible shutdown input which enables the regulator to be switched on and off. Also, the part may be pin-strapped for a 5V output or programmed from 1.24V to 29V with an external pair of resistors.

Careful design of the LP2950/LP2951 has minimized all contributions to the error budget. This includes a tight initial

tolerance (.5% typ.), extremely good load and line regulation (.05% typ.) and a very low output voltage temperature coefficient, making the part useful as a low-power voltage reference.

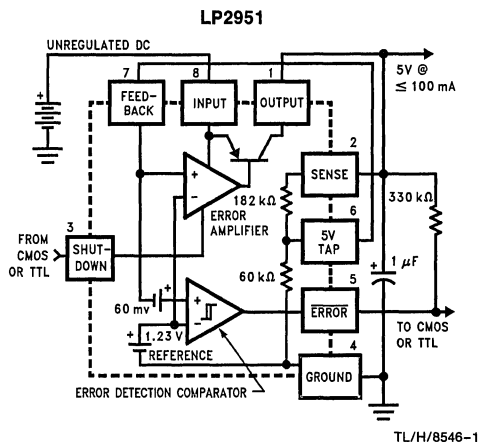
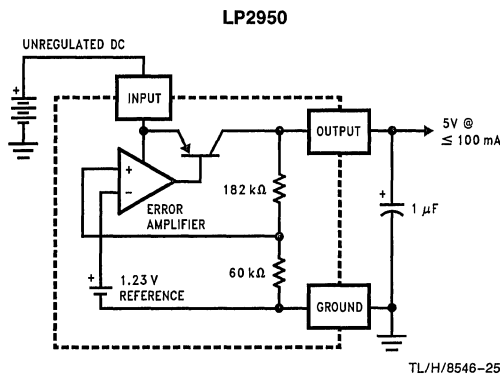
Features

- High accuracy 5V, guaranteed 100 mA output
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Use as Regulator or Reference
- Needs only 1 μ F for stability
- Current and Thermal Limiting

LP2951 versions only

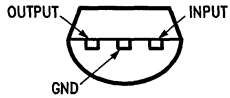
- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24 to 29V

Block Diagram and Typical Applications



Connection Diagrams and Ordering Information

TO-92 Plastic Package (Z)

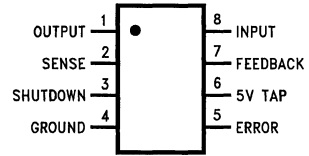


Bottom View

TL/H/8546-2

Order Number LP2950ACZ-5.0 or LP2950CZ-5.0
See NS Package Number Z03A

Dual-In-Line Packages (N, J) Surface-Mount Package (M)



Top View

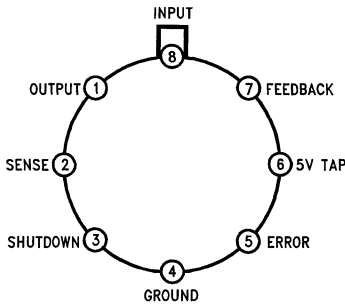
TL/H/8546-26

Order Number LP2951CJ, LP2951ACJ, LP2951J,
LP2951J/883 or 5962-3870501MPA
See NS Package Number J08A

Order Number LP2951ACN or LP2951CN
See NS Package Number N08E

Order Number LP2951ACM or LP2951CM
See NS Package Number M08A

Metal Can Package (H)

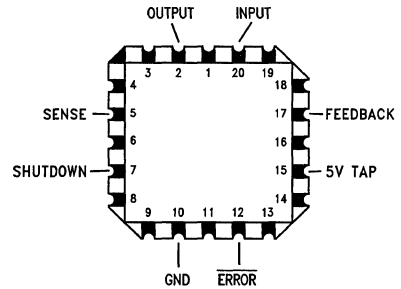


Top View

TL/H/8546-19

Order Number LP2951H, LP2951H/883 or
5962-3870501MGA
See NS Package Number H08C

Leadless Chip Carrier (E)



Top View

TL/H/8546-24

Order Number LP2951E/883 or 5962-3870501M2A
See NS Package Number E20A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Lead Temp. (Soldering, 5 seconds)	260°C
Storage Temperature Range	-65° to +150°C
Operating Junction Temperature Range (Note 8)	
LP2951	-55° to +150°C
LP2950AC/LP2950C,	
LP2951AC/LP2951C	-40° to +125°C

Input Supply Voltage	-0.3 to +30V
Feedback Input Voltage (Notes 9 and 10)	-1.5 to +30V
Shutdown Input Voltage (Note 9)	-0.3 to +30V
Error Comparator Output Voltage (Note 9)	-0.3 to +30V
ESD Rating is to be determined.	

Electrical Characteristics (Note 1)

Parameter	Conditions (Note 2)	LP2951		LP2950AC LP2951AC			LP2950C LP2951C			Units
		Typ	Tested Limit (Notes 3, 16)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
Output Voltage	$T_J = 25^\circ\text{C}$	5.0	5.025 4.975	5.0	5.025 4.975		5.0	5.05 4.95		V max V min
	$-25^\circ\text{C} \leq T_J \leq 85^\circ\text{C}$					5.05 4.95		5.075 4.925		V max V min
	Full Operating Temperature Range		5.06 4.94			5.06 4.94		5.1 4.9		V max V min
Output Voltage	$100\ \mu\text{A} \leq I_L \leq 100\ \text{mA}$ $T_J \leq T_{J\text{MAX}}$		5.075 4.925			5.07 4.93		5.12 4.88		V max V min
Output Voltage Temperature Coefficient	(Note 12)	20	120	20		100	50		150	ppm/°C
Line Regulation (Note 14)	$6\text{V} \leq V_{\text{in}} \leq 30\text{V}$ (Note 15)	0.03	0.1 0.5	0.03	0.1	0.2	0.04	0.2	0.4	% max % max
Load Regulation (Note 14)	$100\ \mu\text{A} \leq I_L \leq 100\ \text{mA}$	0.04	0.1 0.3	0.04	0.1	0.2	0.1	0.2	0.3	% max % max
Dropout Voltage (Note 5)	$I_L = 100\ \mu\text{A}$	50	80 150	50	80	150	50	80	150	mV max mV max
	$I_L = 100\ \text{mA}$	380	450 600	380	450	600	380	450	600	mV max mV max
Ground Current	$I_L = 100\ \mu\text{A}$	75	120 140	75	120	140	75	120	140	μA max μA max
	$I_L = 100\ \text{mA}$	8	12 14	8	12	14	8	12	14	mA max mA max
Dropout Ground Current	$V_{\text{in}} = 4.5\text{V}$ $I_L = 100\ \mu\text{A}$	110	170 200	110	170	200	110	170	200	μA max μA max
Current Limit	$V_{\text{out}} = 0$	160	200 220	160	200	220	160	200	220	mA max mA max
Thermal Regulation	(Note 13)	0.05	0.2	0.05	0.2		0.05	0.2		%/W max
Output Noise, 10 Hz to 100 KHz	$C_L = 1\ \mu\text{F}$		430		430			430		μV rms
	$C_L = 200\ \mu\text{F}$		160		160			160		μV rms
	$C_L = 3.3\ \mu\text{F}$ (Bypass = 0.01 μF Pins 7 to 1 (LP2951))	100		100			100			μV rms
8-Pin Versions only		LP2951		LP2951AC			LP2951C			
Reference Voltage		1.235	1.25 1.26 1.22 1.2	1.235	1.25 1.22	1.26 1.2	1.235	1.26 1.21	1.27 1.2	V max V max V min V min
Reference Voltage	(Note 7)		1.27 1.19			1.27 1.19		1.285 1.185		V max V min

Electrical Characteristics (Note 1) (Continued)

Parameter	Conditions (Note 2)	LP2951		LP2951AC			LP2951C			Units
		Typ	Tested Limit (Notes 3, 16)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
8-Pin Versions only (Continued)										
Feedback Pin Bias Current		20	40 60	20	40	60	20	40	60	nA max nA max
Reference Voltage Temperature Coefficient	(Note 12)	20		20			50			ppm/°C
Feedback Pin Bias Current Temperature Coefficient		0.1		0.1			0.1			nA/°C
Error Comparator										
Output Leakage Current	V _{OH} = 30V	0.01	1 2	0.01	1	2	0.01	1	2	μA max μA max
Output Low Voltage	V _{in} = 4.5V I _{OL} = 400 μA	150	250 400	150	250	400	150	250	400	mV max mV max
Upper Threshold Voltage	(Note 6)	60	40 25	60	40	25	60	40	25	mV min mV min
Lower Threshold Voltage	(Note 6)	75	95 140	75	95	140	75	95	140	mV max mV max
Hysteresis	(Note 6)	15		15			15			mV
Shutdown Input										
Input Logic Voltage	Low (Regulator ON) High (Regulator OFF)	1.3	0.6 2.0	1.3		0.7 2.0	1.3		0.7 2.0	V V max V min
Shutdown Pin Input Current	V _{shutdown} = 2.4V	30	50 100	30	50	100	30	50	100	μA max μA max
	V _{shutdown} = 30V	450	600 750	450	600	750	450	600	750	μA max μA max
Regulator Output Current in Shutdown	(Note 11)	3	10 20	3	10	20	3	10	20	μA max μA max

Note 1: Boldface limits apply at temperature extremes.

Note 2: Unless otherwise specified all limits guaranteed for T_J = 25°C, V_{in} = 6V, I_L = 100 μA and C_L = 1 μF. Additional conditions for the 8-pin versions are Feedback tied to 5V Tap and Output tied to Output Sense (V_{out} = 5V) and V_{shutdown} ≤ 0.8V.

Note 3: Guaranteed and 100% production tested.

Note 4: Guaranteed but not 100% production tested. These limits are not used to calculate outgoing AQL levels.

Note 5: Dropout Voltage is defined as the input to output differential at which the output voltage drops 100 mV below its nominal value measured at 1V differential. At very low values of programmed output voltage, the minimum input supply voltage of 2V (**2.3V over temperature**) must be taken into account.

Note 6: Comparator thresholds are expressed in terms of a voltage differential at the Feedback terminal below the nominal reference voltage measured at 6V input. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = V_{out}/V_{ref} = (R1 + R2)/R2. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95 mV × 5V/1.235V = 384 mV. Thresholds remain constant as a percent of V_{out} as V_{out} is varied, with the dropout warning occurring at typically 5% below nominal, 7.5% guaranteed.

Note 7: V_{ref} ≤ V_{out} ≤ (V_{in} - 1V), 2.3V ≤ V_{in} ≤ 30V, 100 μA ≤ I_L ≤ 100 mA, T_J ≤ T_{JMAX}.

Note 8: The junction-to-ambient thermal resistance of the TO-92 package is 180°C/W with 0.4" leads and 160°C/W with 0.25" leads to a PC board. The thermal resistance of the 8-pin DIP packages is 105°C/W for the molded plastic (N) and 130°C/W for the cerdip (J) junction to ambient when soldered directly to a PC board. Thermal resistance for the metal can (H) is 160°C/W junction to ambient and 20°C/W junction to case. Junction to ambient thermal resistance for the S.O. (M) package is 160°C/W. Thermal resistance for the leadless chip carrier (E) package is 95°C/W junction to ambient and 24°C/W junction to case.

Note 9: May exceed input supply voltage.

Note 10: When used in dual-supply systems where the output terminal sees loads returned to a negative supply, the output voltage should be diode-clamped to ground.

Note 11: V_{shutdown} ≥ 2V, V_{in} ≤ 30V, V_{out} = 0, Feedback pin tied to 5V Tap.

Note 12: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 13: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 50 mA load pulse at V_{IN} = 30V (1.25V pulse) for T = 10 ms.

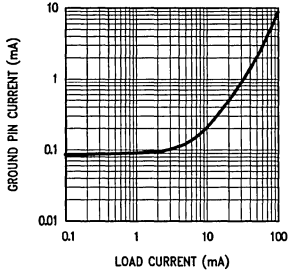
Note 14: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

Note 15: Line regulation for the LP2951 is tested at 150°C for I_L = 1 mA. For I_L = 100 μA and T_J = 125°C, line regulation is guaranteed by design to 0.2%. See Typical Performance Characteristics for line regulation versus temperature and load current.

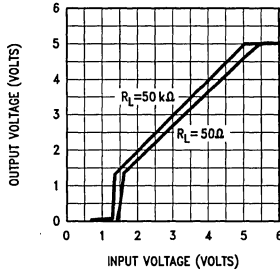
Note 16: A Military RETS spec is available on request. At time of printing, the LP2951 RETS spec complied with the boldface limits in this column. The LP2951H, E, or J may also be procured as Standard Military Drawing Spec #5962-3870501MGA, M2A, or MPA.

Typical Performance Characteristics

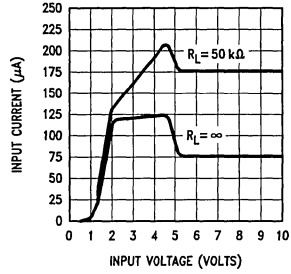
Quiescent Current



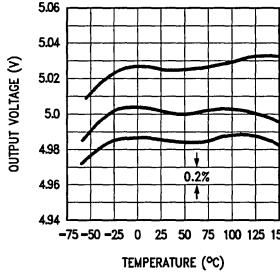
Dropout Characteristics



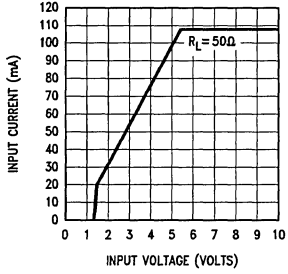
Input Current



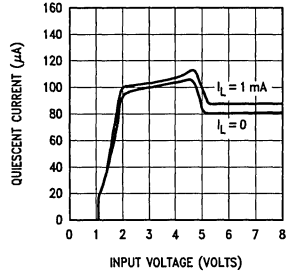
Output Voltage vs. Temperature of 3 Representative Units



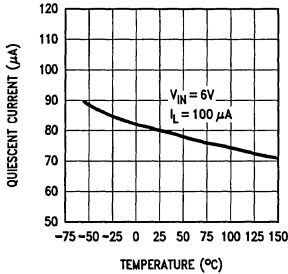
Input Current



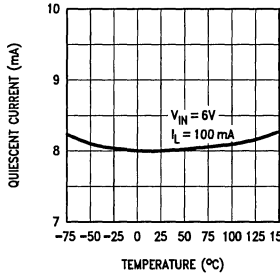
Quiescent Current



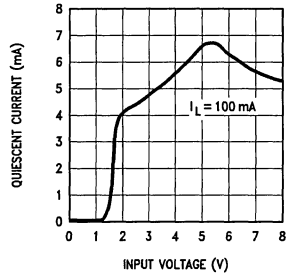
Quiescent Current



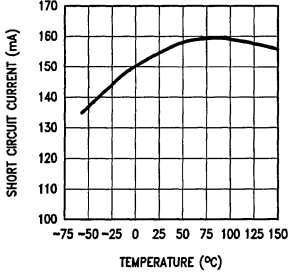
Quiescent Current



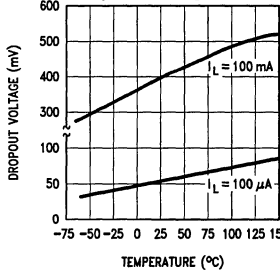
Quiescent Current



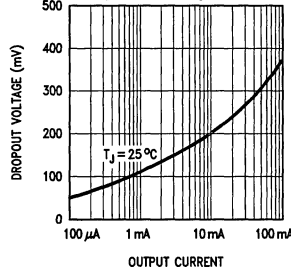
Short Circuit Current



Dropout Voltage

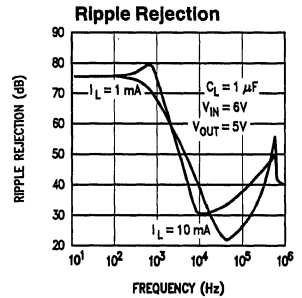
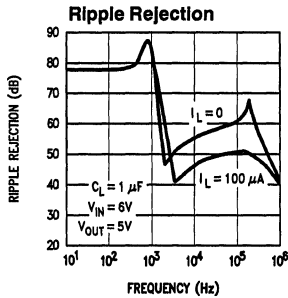
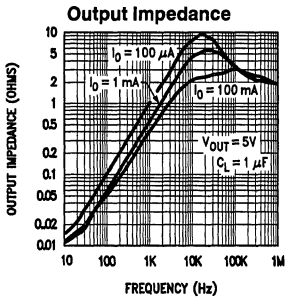
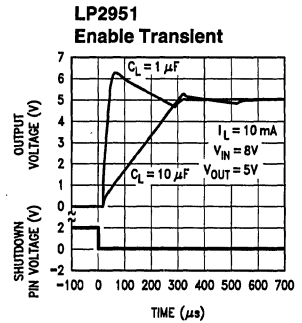
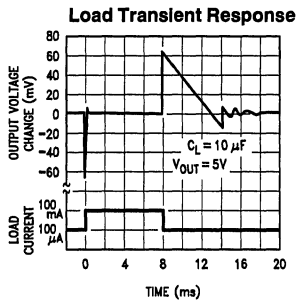
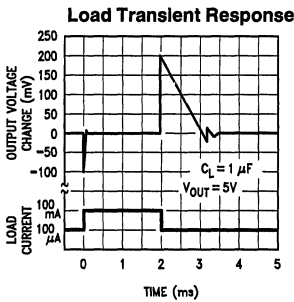
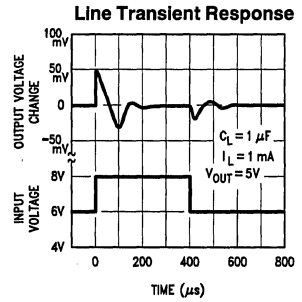
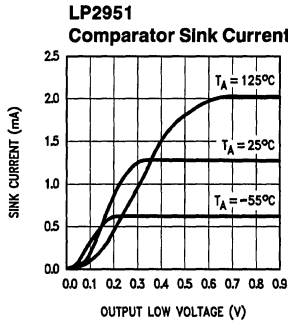
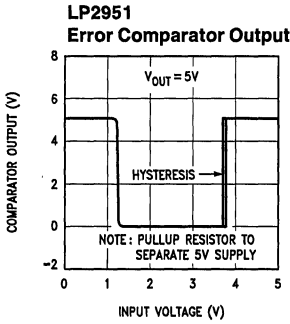
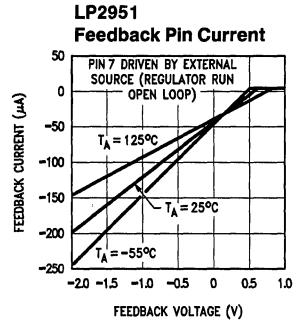
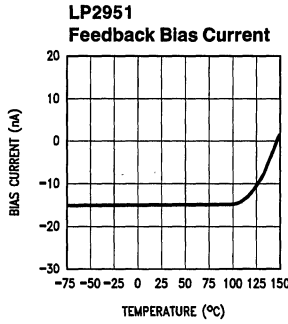
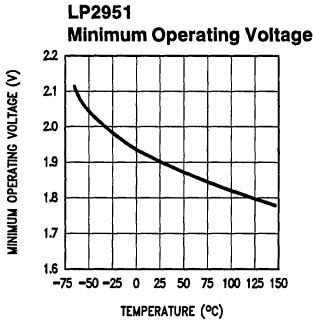


Dropout Voltage

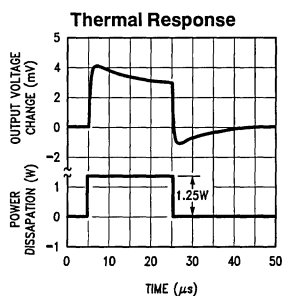
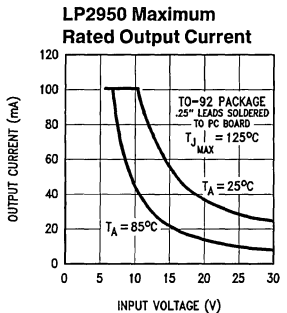
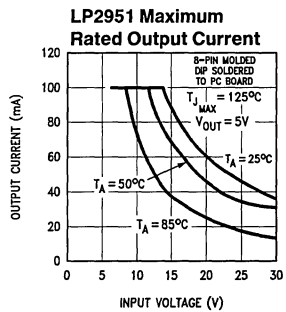
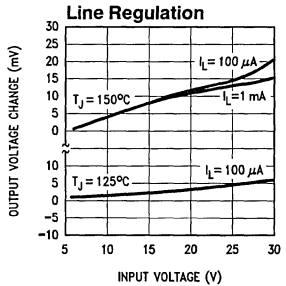
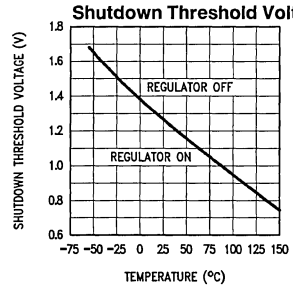
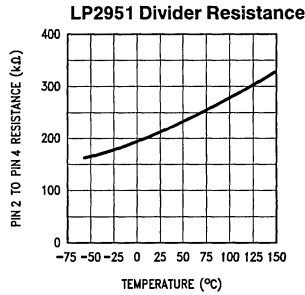
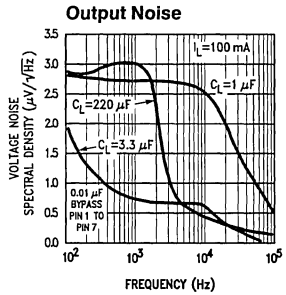
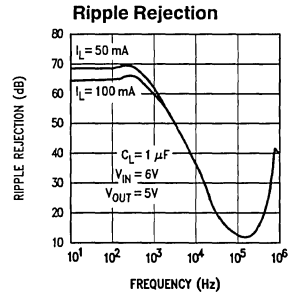


TL/H/8546-3

Typical Performance Characteristics (Continued)



Typical Performance Characteristics (Continued)



Application Hints

EXTERNAL CAPACITORS

A 1.0 μF (or greater) capacitor is required between the LP2950/LP2951 output and ground for stability. Without this capacitor the part will oscillate. Most types of tantalum or aluminum electrolytics work fine here; even film types work but are not recommended for reasons of cost. Many aluminum electrolytics have electrolytes that freeze at about -30°C , so solid tantalums are recommended for operation below -25°C . The important parameters of the capacitor are an ESR of about 5 Ω or less and a resonant frequency above 500 kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for stability. The capacitor can be reduced to 0.33 μF for currents below 10 mA or 0.1 μF for currents below 1 mA. Using the 8-Pin versions at voltages below 5V

runs the error amplifier at lower gains so that *more* output capacitance is needed. For the worst-case situation of a 100 mA load at 1.23V output (Output shorted to Feedback) a 3.3 μF (or greater) capacitor should be used.

Unlike many other regulators, the LP2950 will remain stable and in regulation with no load in addition to the internal voltage divider. This is especially important in CMOS RAM keep-alive applications. When setting the output voltage of the LP2951 version with external resistors, a minimum load of 1 μA is recommended.

A 1 μF tantalum or aluminum electrolytic capacitor should be placed from the LP2950/LP2951 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the LP2951 Feedback terminal (pin 7) can cause instability. This may especially be a problem

TL/H/8546-5

Application Hints (Continued)

when using high value external resistors to set the output voltage. Adding a 100 pF capacitor between Output and Feedback and increasing the output capacitor to at least 3.3 μF will fix this problem.

ERROR DETECTION COMPARATOR OUTPUT

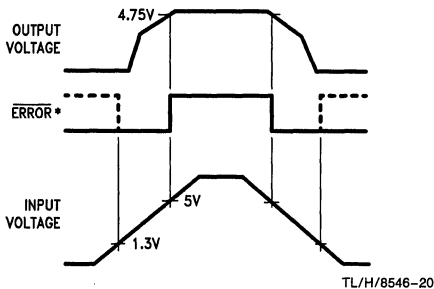
The comparator produces a logic low output whenever the LP2951 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60 mV divided by the 1.235 reference voltage. (Refer to the block diagram in the front of the datasheet.) This trip level remains "5% below normal" regardless of the programmed output voltage of the 2951. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, current limiting, or thermal limiting.

Figure 1 below gives a timing diagram depicting the ERROR signal and the regulated output voltage as the LP2951 input is ramped up and down. The ERROR signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which $V_{OUT} = 4.75$). Since the LP2951's dropout voltage is load-dependent (see curve in typical performance characteristics), the input voltage trip point (about 5V) will vary with the load current. The output voltage trip point (approx. 4.75V) does not vary with load.

The error comparator has an open-collector output which requires an external pullup resistor. This resistor may be returned to the 5V output or some other supply voltage depending on system requirements. In determining a value for this resistor, note that while the output is rated to sink 400 μA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1 MΩ. The resistor is not required if this output is unused.

PROGRAMMING THE OUTPUT VOLTAGE (LP2951)

The LP2951 may be pin-strapped for 5V using its internal voltage divider by tying Pin 1 (output) to Pin 2 (sense) and Pin 7 (feedback) to Pin 6 (5V Tap). Alternatively, it may be programmed for any output voltage between its 1.235V reference and its 30V maximum rating. As seen in Figure 2, an external pair of resistors is required.



*When $V_{IN} \leq 1.3V$, the error flag pin becomes a high impedance, and the error flag voltage rises to its pull-up voltage. Using V_{OUT} as the pull-up voltage (see Figure 2), rather than an external 5V source, will keep the error flag voltage under 1.2V (typ.) in this condition. The user may wish to divide down the error flag voltage using equal-value resistors (10 kΩ suggested), to ensure a low-level logic signal during any fault condition, while still allowing a valid high logic level during normal operation.

FIGURE 1. ERROR Output Timing

The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \cdot \left(1 + \frac{R_1}{R_2} \right) + I_{FB}R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the feedback pin bias current, nominally -20 nA. The minimum recommended load current of 1 μA forces an upper limit of 1.2 MΩ on the value of R_2 , if the regulator must work with no load (a condition often found in CMOS in standby). I_{FB} will produce a 2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1 . For better accuracy, choosing $R_2 = 100k$ reduces this error to 0.17% while increasing the resistor program current to 12 μA. Since the LP2951 typically draws 60 μA at no load with Pin 2 open-circuited, this is a small price to pay.

REDUCING OUTPUT NOISE

In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output capacitor. This is the only way noise can be reduced on the 3 lead LP2950 but is relatively inefficient, as increasing the capacitor from 1 μF to 220 μF only decreases the noise from 430 μV to 160 μV rms for a 100 kHz bandwidth at 5V output.

Noise can be reduced fourfold by a bypass capacitor across R_1 , since it reduces the high frequency gain from 4 to unity. Pick

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \cdot 200 \text{ Hz}}$$

or about 0.01 μF. When doing this, the output capacitor must be increased to 3.3 μF to maintain stability. These changes reduce the output noise from 430 μV to 100 μV rms for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.

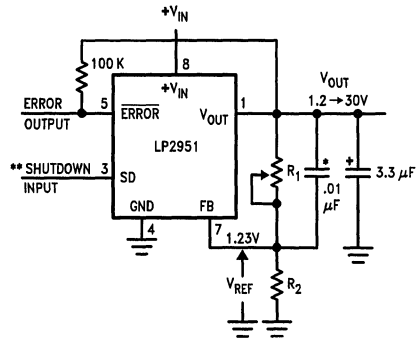


FIGURE 2. Adjustable Regulator

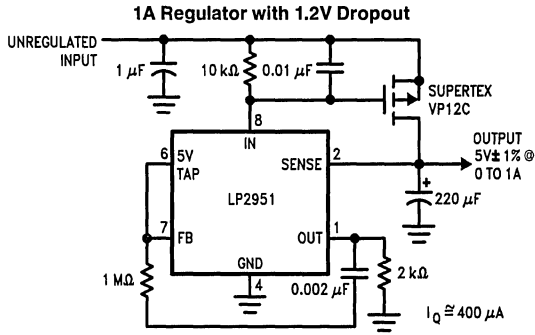
*See Application Hints

$$V_{out} = V_{Ref} \left(1 + \frac{R_1}{R_2} \right)$$

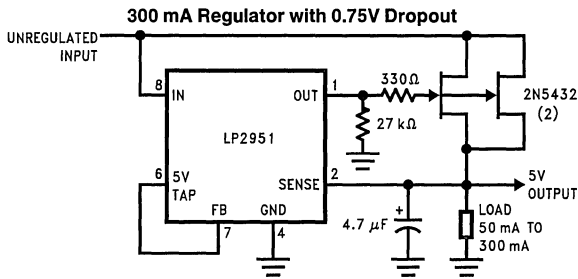
**Drive with TTL-high to shut down. Ground or leave open if shutdown feature is not to be used.

Note: Pins 2 and 6 are left open.

Typical Applications

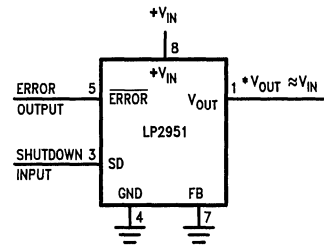


TL/H/8546-22



TL/H/8546-21

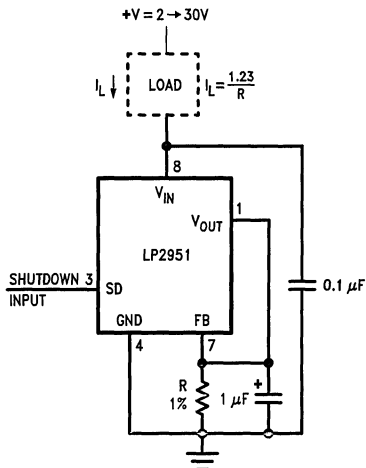
Wide Input Voltage Range Current Limiter



TL/H/8546-9

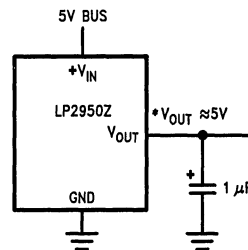
*Minimum input-output voltage ranges from 40 mV to 400 mV, depending on load current. Current limit is typically 160 mA.

Low Drift Current Source



TL/H/8546-8

5 Volt Current Limiter

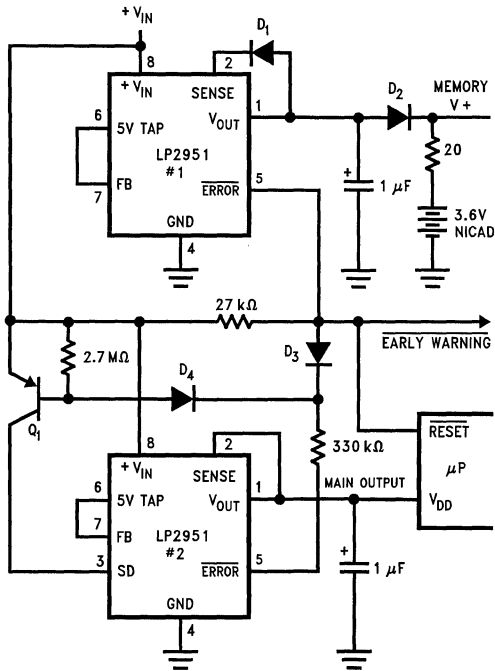


TL/H/8546-10

*Minimum input-output voltage ranges from 40 mV to 400 mV, depending on load current. Current limit is typically 160 mA.

Typical Applications (Continued)

Regulator with Early Warning and Auxiliary Output

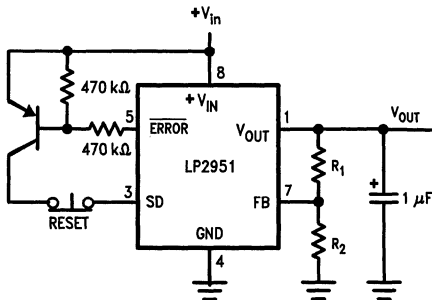


TL/H/8546-11

- Early warning flag on low input voltage
- Main output latches off at lower input voltages
- Battery backup on auxiliary output

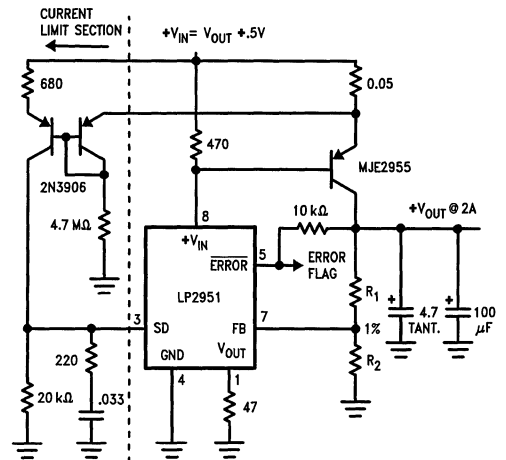
Operation: Reg. #1's V_{out} is programmed one diode drop above 5V. Its error flag becomes active when $V_{in} \leq 5.7V$. When V_{in} drops below 5.3V, the error flag of Reg. #2 becomes active and via Q1 latches the main output off. When V_{in} again exceeds 5.7V Reg. #1 is back in regulation and the early warning signal rises, unlatching Reg. #2 via D3.

Latch Off When Error Flag Occurs



TL/H/8546-12

2 Ampere Low Dropout Regulator

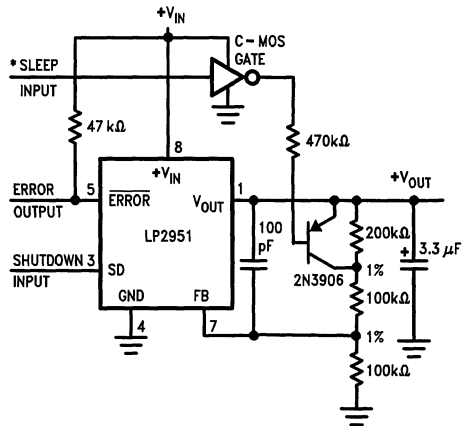


$$V_{out} = 1.23V \left(1 + \frac{R_1}{R_2} \right)$$

TL/H/8546-13

For 5V $_{out}$, use internal resistors. Wire pin 6 to 7, & wire pin 2 to +V $_{out}$ Buss.

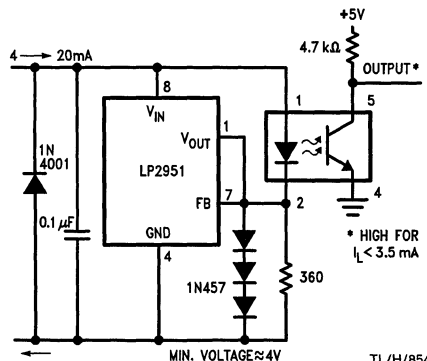
5V Regulator with 2.5V Sleep Function



*High input lowers V_{out} to 2.5V

TL/H/8546-14

Open Circuit Detector for 4 → 20 mA Current Loop

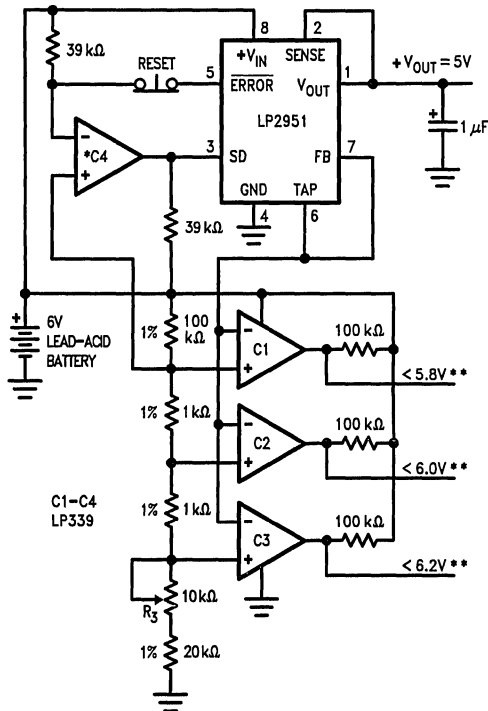


* HIGH FOR $I_L < 3.5$ mA

TL/H/8546-15

Typical Applications (Continued)

Regulator with State-of-Charge Indicator



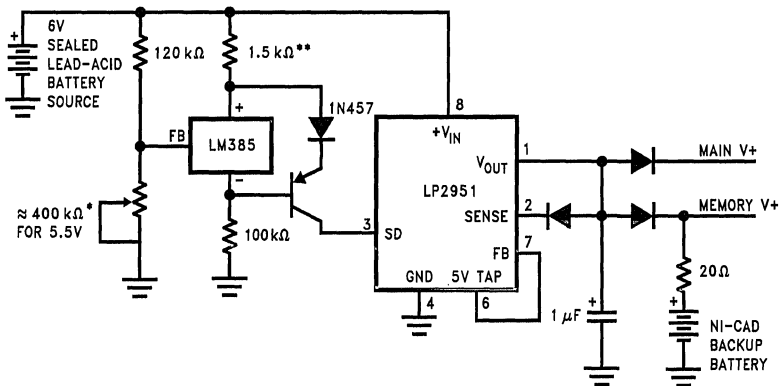
TL/H/8546-16

*Optional Latch off when drop out occurs. Adjust R3 for C2 Switching when V_{in} is 6.0V.

**Outputs go low when V_{in} drops below designated thresholds.

Low Battery Disconnect

For values shown, Regulator shuts down when $V_{in} < 5.5V$ and turns on again at 6.0V. Current drain in disconnected mode is $\approx 150 \mu A$.



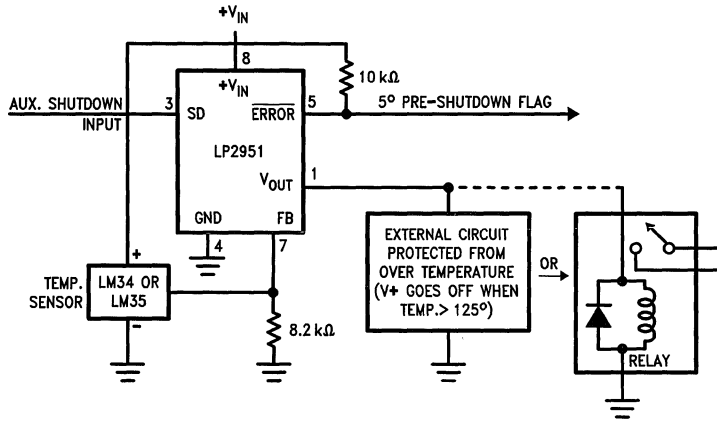
*Sets disconnect Voltage

**Sets disconnect Hysteresis

TL/H/8546-17

Typical Applications (Continued)

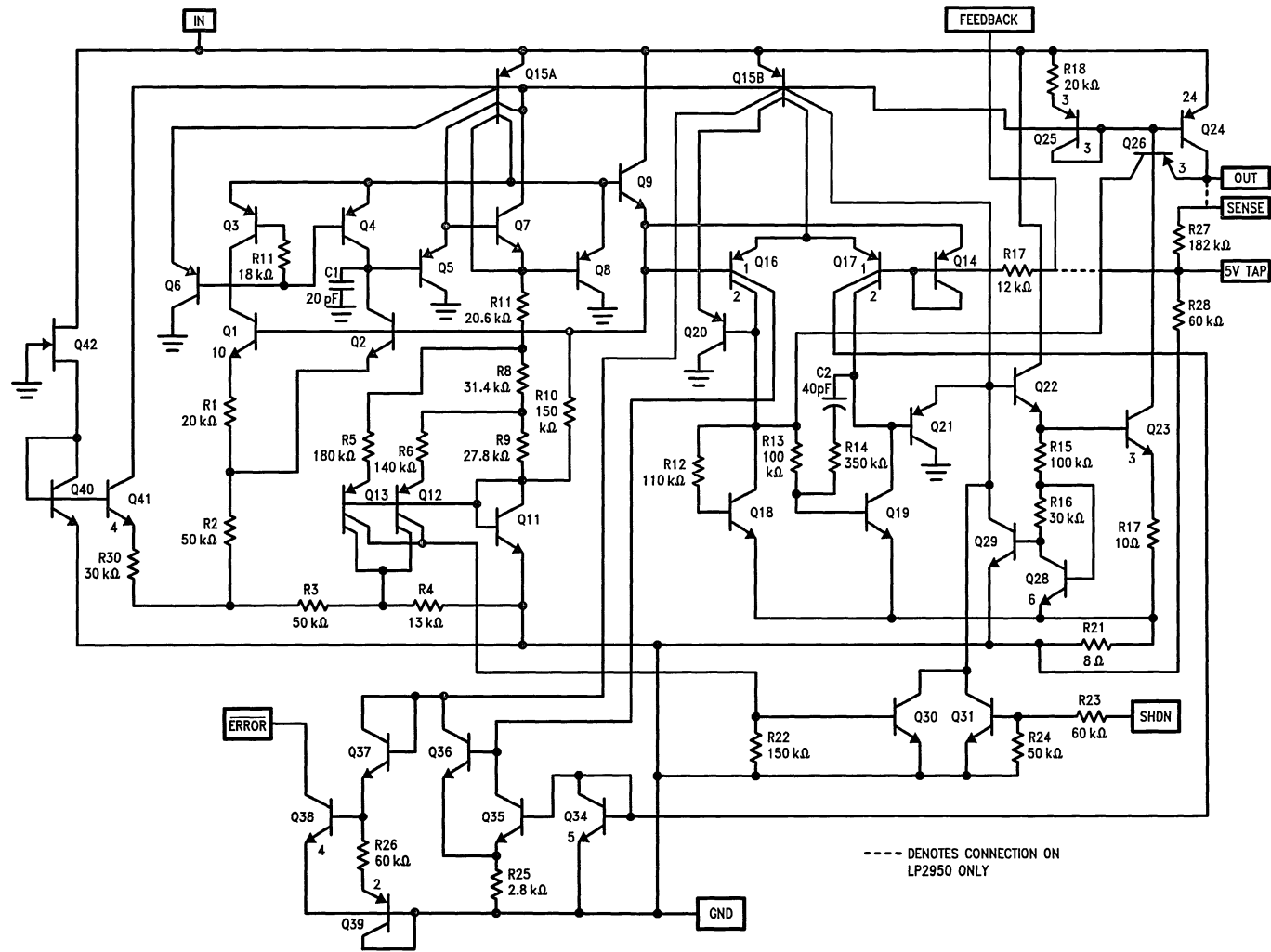
System Overtemperature Protection Circuit



LM34 for 125°F Shutdown
 LM35 for 125°C Shutdown

TL/H/8546-18

Schematic Diagram



TL/H/8546-23

LP2950/LP2950AC/LP2950C/LP2951/LP2951AC/LP2951C



LP2952/LP2952A/LP2953/LP2953A

Adjustable Micropower Low-Dropout Voltage Regulators

General Description

The LP2952 and LP2953 are micropower voltage regulators with very low quiescent current (130 μ A typical at 1 mA load) and very low dropout voltage (typ. 60 mV at light load and 470 mV at 250 mA load current). They are ideally suited for battery-powered systems. Furthermore, the quiescent current increases only slightly at dropout, which prolongs battery life.

The LP2952 and LP2953 retain all the desirable characteristics of the LP2951, but offer increased output current, additional features, and an improved shutdown function.

The internal crowbar pulls the output down quickly when the shutdown is activated.

The error flag goes low if the output voltage drops out of regulation.

Reverse battery protection is provided.

The internal voltage reference is made available for external use, providing a low-T.C. reference with very good line and load regulation.

The parts are available in plastic DIP and surface mount packages.

Features

- Output voltage adjusts from 1.23V to 29V
- Guaranteed 250 mA output current
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight line and load regulation
- Very low temperature coefficient
- Current and thermal limiting
- Reverse battery protection
- 50 mA (typical) output pulldown crowbar

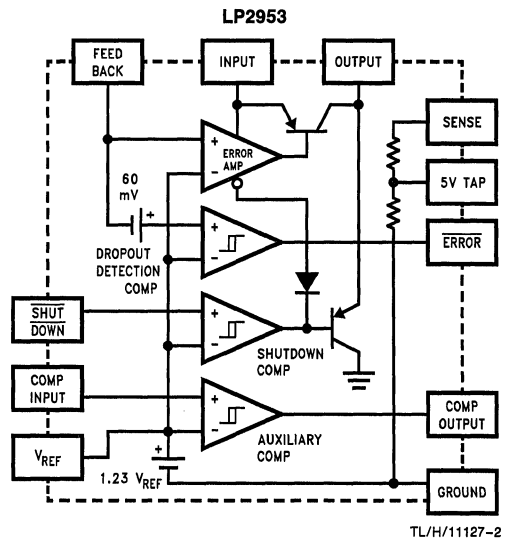
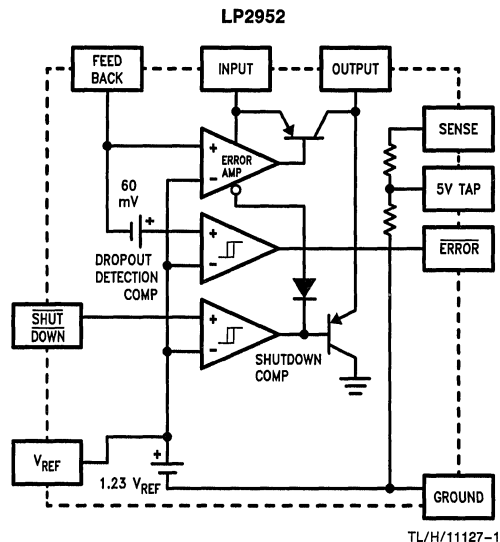
LP2953 Versions Only

- Auxiliary comparator included with CMOS/TTL compatible output levels. Can be used for fault detection, low input line detection, etc.

Applications

- High-efficiency linear regulator
- Regulator with under-voltage shutdown
- Low dropout battery-powered regulator
- Snap-ON/Snap-OFF regulator

Block Diagrams



Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature	-65°C to +150°C
Operating Junction Temperature Range	
LP2952AI/LP2952I	-40°C to +125°C
LP2953AI/LP2953I	-40°C to +125°C

Lead Temp. (Soldering, 5 seconds)	260°C
Power Dissipation (Note 2)	Internally Limited
Input Supply Voltage	-20V to +30V
Feedback Input Voltage (Note 3)	-0.3V to +5V
Comparator Input Voltage (Note 4)	-0.3V to +30V
Shutdown Input Voltage (Note 4)	-0.3V to +30V
Comparator Output Voltage (Note 4)	-0.3V to +30V
ESD Rating (Note 15)	2 kV

Electrical Characteristics Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface** applies over the -40°C to $+125^\circ\text{C}$ junction temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $V_{IN} = 6\text{V}$, $I_L = 1\text{ mA}$, $C_L = 2.2\ \mu\text{F}$, Feedback pin is tied to 5V Tap pin, Output pin is tied to Output Sense pin, $V_{OUT} = 5\text{V}$.

Symbol	Parameter	Conditions	Typical	2952AI 2953AI		2952I 2953I		Units
				Min	Max	Min	Max	
V_O	Output Voltage		5.0	4.975 4.940	5.025 5.060	4.950 4.900	5.050 5.100	V
		$1\text{ mA} \leq I_L \leq 250\text{ mA}$	5.0	4.930	5.070	4.880	5.120	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temp. Coefficient	(Note 5)	20		100		150	ppm/°C
$\frac{\Delta V_O}{V_O}$	Output Voltage Line Regulation	$V_{IN} = 6\text{V to }30\text{V}$	0.03		0.1 0.2		0.2 0.4	%
$\frac{\Delta V_O}{V_O}$	Output Voltage Load Regulation (Note 6)	$I_L = 1\text{ mA to }250\text{ mA}$ $I_L = 0.1\text{ mA to }1\text{ mA}$	0.04		0.16 0.20		0.20 0.30	%
V_{IN-V_O}	Dropout Voltage (Note 7)	$I_L = 1\text{ mA}$	60		100 150		100 150	mV
		$I_L = 50\text{ mA}$	240		300 420		300 420	
		$I_L = 100\text{ mA}$	310		400 520		400 520	
		$I_L = 250\text{ mA}$	470		600 800		600 800	
I_{GND}	Ground Pin Current (Note 8)	$I_L = 1\text{ mA}$	130		170 200		170 200	μA
		$I_L = 50\text{ mA}$	1.1		2 2.5		2 2.5	
		$I_L = 100\text{ mA}$	4.5		6 8		6 8	mA
		$I_L = 250\text{ mA}$	21		28 33		28 33	
I_{GND}	Ground Pin Current at Dropout (Note 8)	$V_{IN} = 4.5\text{V}$ $I_L = 100\ \mu\text{A}$	165		210 240		210 240	μA
I_{GND}	Ground Pin Current at Shutdown (Note 8)	(Note 9)	105		140		140	μA

Electrical Characteristics Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface** applies over the -40°C to $+125^\circ\text{C}$ junction temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $V_{IN} = 6\text{V}$, $I_L = 1\text{mA}$, $C_L = 2.2\ \mu\text{F}$, Feedback pin is tied to 5V Tap pin, Output pin is tied to Output Sense pin, $V_{OUT} = 5\text{V}$. (Continued)

Symbol	Parameter	Conditions	Typical	2952AI 2953AI		2952I 2953I		Units
				Min	Max	Min	Max	
I_{LIMIT}	Current Limit	$V_{OUT} = 0$	380		500 530		500 530	mA
$\frac{\Delta V_{O}}{\Delta P_d}$	Thermal Regulation	(Note 10)	0.05		0.2		0.2	%/W
e_n	Output Noise Voltage (10 Hz to 100 kHz) $I_L = 100\text{mA}$	$C_L = 2.2\ \mu\text{F}$	400					$\mu\text{V RMS}$
		$C_L = 33\ \mu\text{F}$	260					
		$C_L = 33\ \mu\text{F}$ (Note 11)	80					
V_{REF}	Reference Voltage	(Note 12)	1.230	1.215 1.205	1.245 1.255	1.205 1.190	1.255 1.270	V
$\frac{\Delta V_{REF}}{V_{REF}}$	Reference Voltage Line Regulation	$V_{IN} = 2.5\text{V to }6\text{V}$ $V_{IN} = 6\text{V to }30\text{V}$ (Note 13)	0.03		0.1 0.2		0.2 0.4	%
$\frac{\Delta V_{REF}}{V_{REF}}$	Reference Voltage Load Regulation	$I_{REF} = 0\text{ to }200\ \mu\text{A}$	0.25		0.4 0.6		0.8 1.0	%
$\frac{\Delta V_{REF}}{\Delta T}$	Reference Voltage Temp. Coefficient	(Note 5)	20					ppm/ $^\circ\text{C}$
$I_{B(FB)}$	Feedback Pin Bias Current		20		40 60		40 60	nA
I_O (SINK)	Output "OFF" Pulldown Current	(Note 9)	50	30 20		30 20		mA
DROPOUT DETECTION COMPARATOR								
I_{OH}	Output "HIGH" Leakage	$V_{OH} = 30\text{V}$	0.01		1 2		1 2	μA
V_{OL}	Output "LOW" Voltage	$V_{IN} = 4\text{V}$ $I_O(\text{COMP}) = 400\ \mu\text{A}$	150		250 400		250 400	mV
V_{THR} (MAX)	Upper Threshold Voltage	(Note 14)	-240	-320 -380	-150 -100	-320 -380	-150 -100	mV
V_{THR} (MIN)	Lower Threshold Voltage	(Note 14)	-350	-450 -640	-230 -160	-450 -640	-230 -160	mV
HYST	Hysteresis	(Note 14)	60					mV
SHUTDOWN INPUT (Note 16)								
V_{OS}	Input Offset Voltage	(Referred to V_{REF})	± 3	-7.5 -10	7.5 10	-7.5 -10	7.5 10	mV
HYST	Hysteresis		6					mV
I_B	Input Bias Current	$V_{IN}(\text{S/D}) = 0\text{ to }5\text{V}$	10	-30 -50	30 50	-30 -50	30 50	nA

Electrical Characteristics Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface** applies over the -40°C to $+125^\circ\text{C}$ junction temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $V_{IN} = 6\text{V}$, $I_L = 1\text{mA}$, $C_L = 2.2\ \mu\text{F}$, Feedback pin is tied to 5V Tap pin, Output pin is tied to Output Sense pin, $V_{OUT} = 5\text{V}$. (Continued)

Symbol	Parameter	Conditions	Typical	2952AI 2953AI		2952I 2953I		Units
				Min	Max	Min	Max	
				AUXILIARY COMPARATOR (LP2953 Only)				
V_{OS}	Input Offset Voltage	(Referred to V_{REF})	± 3	-7.5 -10	7.5 10	-7.5 -10	7.5 10	mV
HYST	Hysteresis		6					mV
I_B	Input Bias Current	$V_{IN}(\text{COMP}) = 0$ to 5V	10	-30 -50	30 50	-30 -50	30 50	nA
I_{OH}	Output "HIGH" Leakage	$V_{OH} = 30\text{V}$ $V_{IN}(\text{COMP}) = 1.3\text{V}$	0.01		1 2		1 2	μA
V_{OL}	Output "LOW" Voltage	$V_{IN}(\text{COMP}) = 1.1\text{V}$ $I_O(\text{COMP}) = 400\ \mu\text{A}$	150		250 400		250 400	mV

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The maximum allowable power dissipation is a function of the maximum junction temperature, $T_J(\text{MAX})$, the junction-to-ambient thermal resistance, θ_{J-A} , and the ambient temperature, T_A . The maximum allowable power dissipation at any ambient temperature is calculated using: $P(\text{MAX}) = \frac{T_J(\text{MAX}) - T_A}{\theta_{J-A}}$.

Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. See APPLICATION HINTS for additional information on heatsinking and thermal resistance.

Note 3: When used in dual-supply systems where the regulator load is returned to a negative supply, the output voltage must be diode-clamped to ground.

Note 4: May exceed the input supply voltage.

Note 5: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 6: Load regulation is measured at constant junction temperature using low duty cycle pulse testing. Two separate tests are performed, one for the range of $100\ \mu\text{A}$ to 1mA and one for the 1mA to 250mA range. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 7: Dropout voltage is defined as the input to output differential at which the output voltage drops 100mV below the value measured with a 1V differential. At very low values of programmed output voltage, the input voltage minimum of 2V (**2.3V over temperature**) must be observed.

Note 8: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the ground pin current, output load current, and current through the external resistive divider (if used).

Note 9: $V_{\text{SHUTDOWN}} \leq 1.1\text{V}$, $V_{\text{OUT}} = 5\text{V}$.

Note 10: Thermal regulation is the change in output voltage at a time T after a change in power dissipation, excluding load or line regulation effects. Specifications are for a 200mA load pulse at $V_{IN} = 20\text{V}$ (3W pulse) for $T = 10\text{ms}$.

Note 11: Connect a $0.1\ \mu\text{F}$ capacitor from the output to the feedback pin.

Note 12: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\text{V})$, $2.3\text{V} \leq V_{IN} \leq 30\text{V}$, $100\ \mu\text{A} \leq I_L \leq 250\text{mA}$.

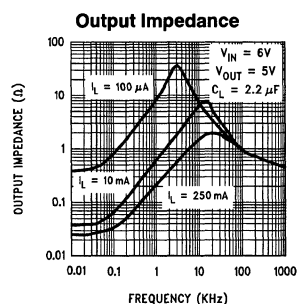
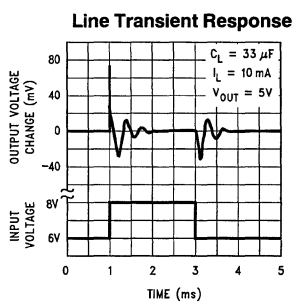
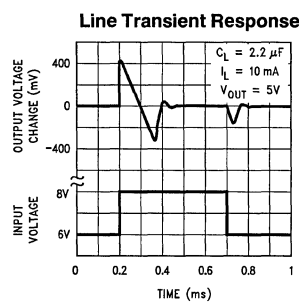
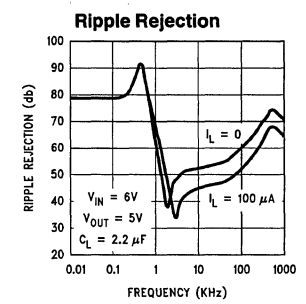
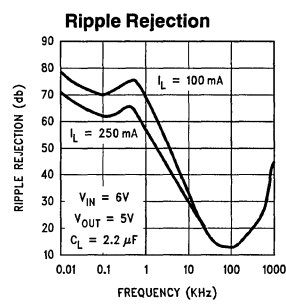
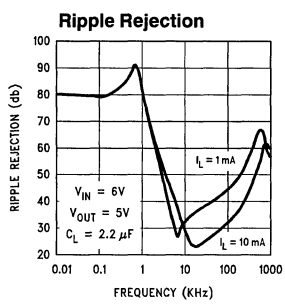
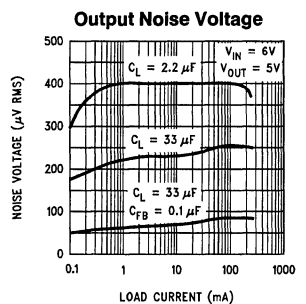
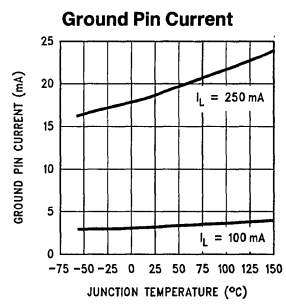
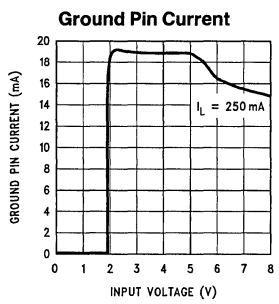
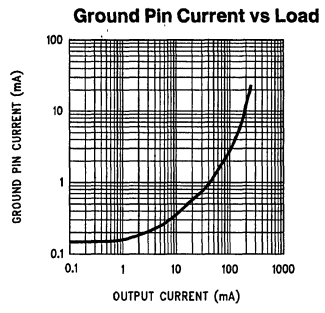
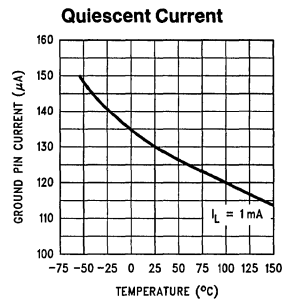
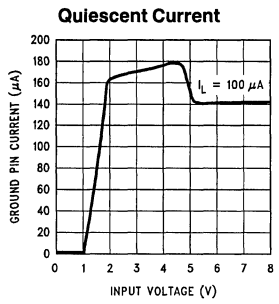
Note 13: Two separate tests are performed, one covering $2.5\text{V} \leq V_{IN} \leq 6\text{V}$ and the other test for $6\text{V} \leq V_{IN} \leq 30\text{V}$.

Note 14: Comparator thresholds are referred to a 5V output. To express the threshold voltages in terms of a differential at the Feedback terminal, divide by the error amplifier gain = $V_{\text{OUT}}/V_{\text{REF}}$.

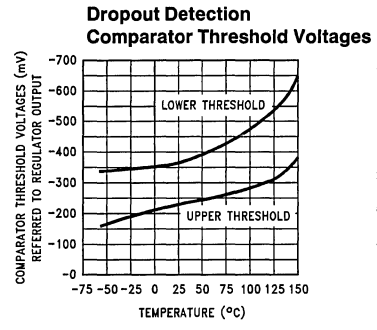
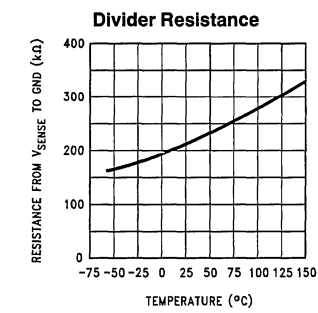
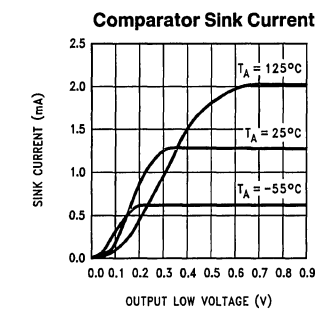
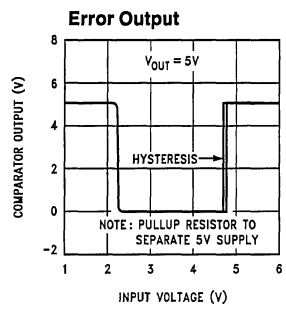
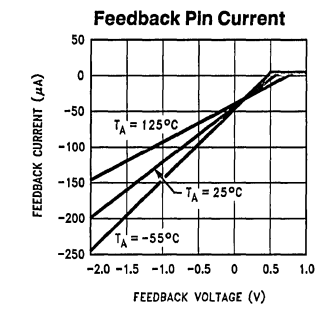
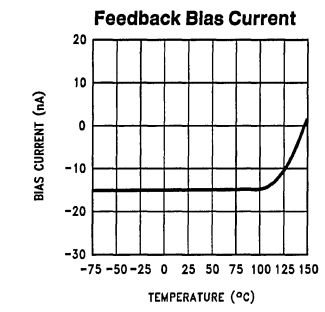
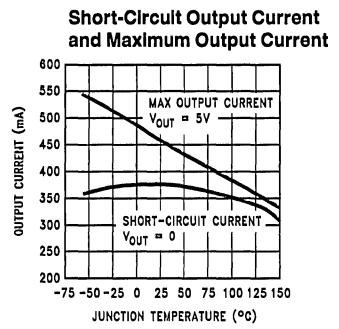
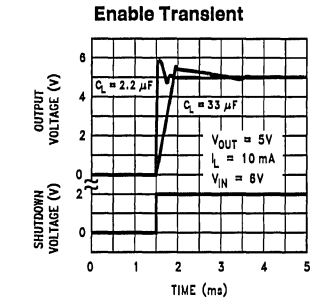
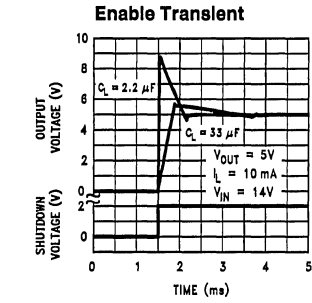
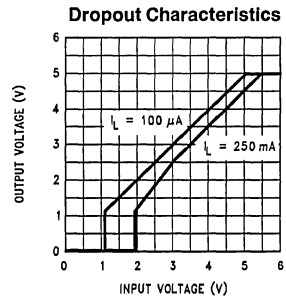
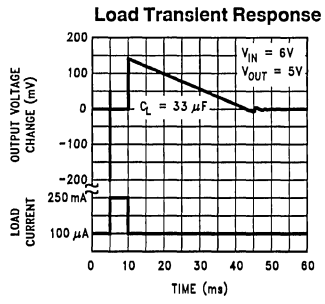
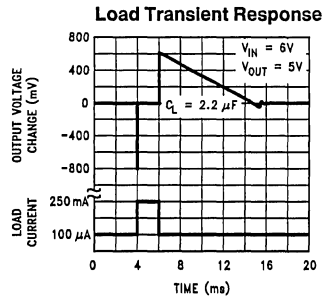
Note 15: Human body model, 200pF discharged through $1.5\text{k}\Omega$.

Note 16: Drive Shutdown pin with TTL or CMOS-low level to shut regulator OFF, high level to turn regulator ON.

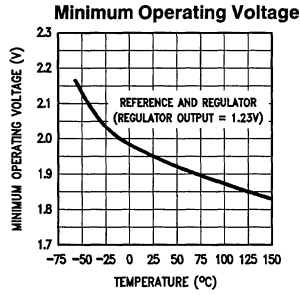
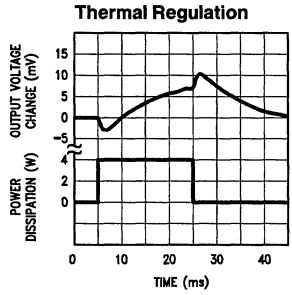
Typical Performance Characteristics



Typical Performance Characteristics (Continued)

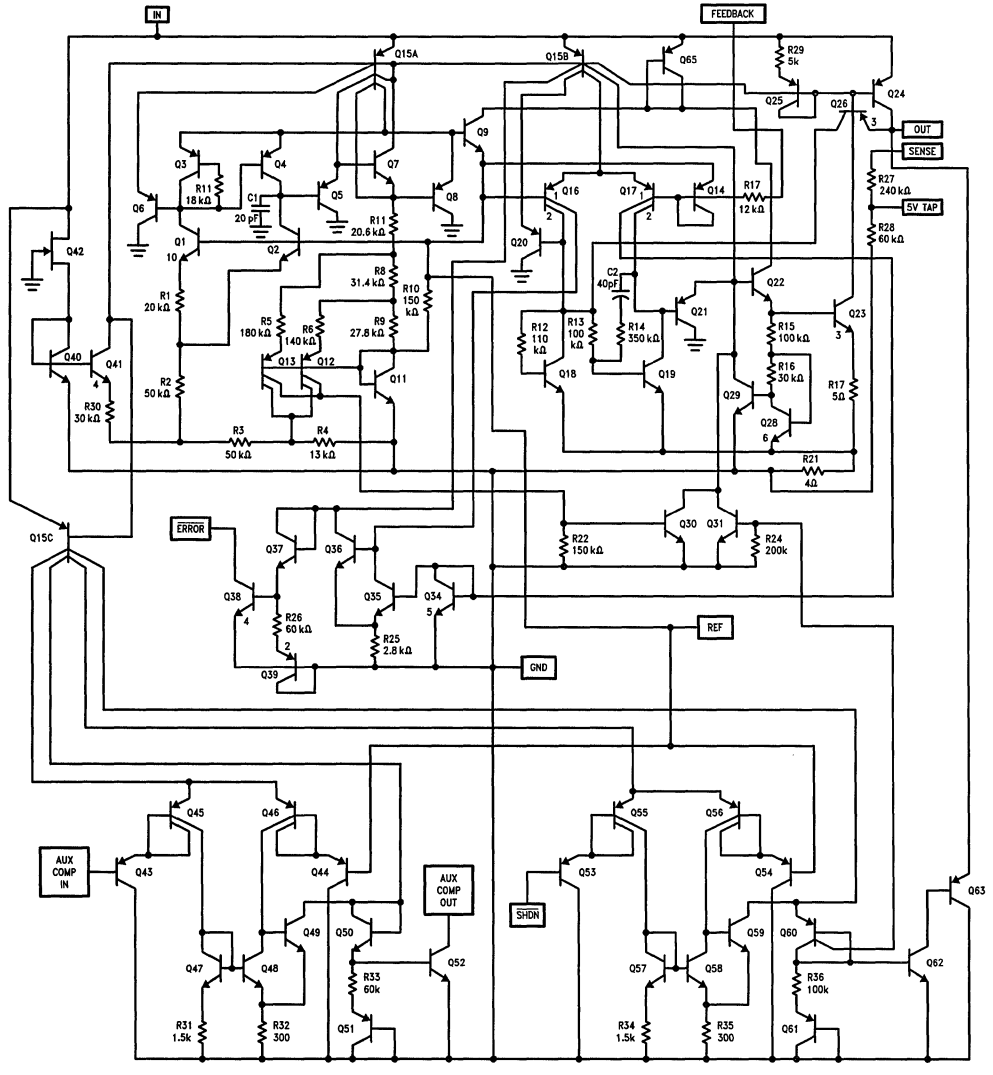


Typical Performance Characteristics (Continued)



TL/H/11127-5

Schematic Diagram



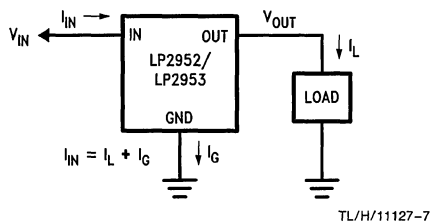
TL/H/11127-6

Application Hints

HEATSINK REQUIREMENTS

A heatsink may be required with the LP2952/LP2953 depending on the maximum power dissipation and maximum ambient temperature of the application. Under all possible operating conditions, the junction temperature must be within the range specified under Absolute Maximum Ratings.

To determine if a heatsink is required, the maximum power dissipated by the regulator, $P(\max)$, must be calculated. It is important to remember that if the regulator is powered from a transformer connected to the AC line, the **maximum specified AC input voltage** must be used (since this produces the maximum DC input voltage to the regulator). *Figure 1* shows the voltages and currents which are present in the circuit. The formula for calculating the power dissipated in the regulator is also shown in *Figure 1*:



$$P_{\text{TOTAL}} = (V_{\text{IN}} - V_{\text{OUT}}) I_L + (V_{\text{IN}}) I_G$$

FIGURE 1. Current/Voltage Diagram

The next parameter which must be calculated is the maximum allowable temperature rise, $T_R(\max)$. This is calculated by using the formula:

$$T_R(\max) = T_J(\max) - T_A(\max)$$

where: $T_J(\max)$ is the maximum allowable junction temperature

$T_A(\max)$ is the maximum ambient temperature

Using the calculated values for $T_R(\max)$ and $P(\max)$, the required value for junction-to-ambient thermal resistance, $\theta_{(J-A)}$, can now be found:

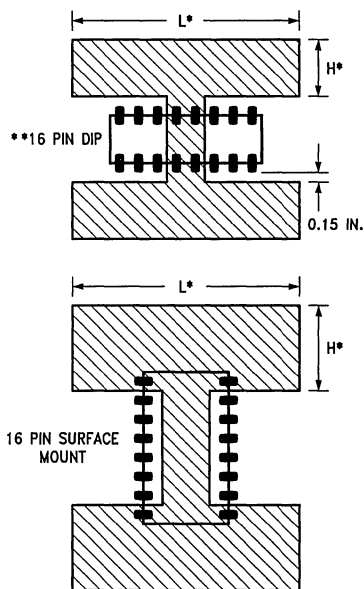
$$\theta_{(J-A)} = T_R(\max)/P(\max)$$

The heatsink for the LP2952 and LP2953 is made using the PC board copper. The heat is conducted from the die, through the lead frame (inside the part), and out the pins which are soldered to the PC board. The pins used for heat conduction are:

TABLE I

Part	Package	Pins
LP2952N	14-Pin DIP	3, 4, 5, 10, 11, 12
LP2953N	16-Pin DIP	4, 5, 12, 13
LP2952M	16-Pin Surface Mt.	1, 8, 9, 16
LP2953M	16-Pin Surface Mt.	1, 8, 9, 16

Figure 2 shows copper patterns which may be used to dissipate heat from the LP2952 and LP2953:



*For best results, use $L = 2H$

**14-Pin DIP is similar, refer to Table I for pins designated for heatsinking.

FIGURE 2. Copper Heatsink Patterns

Table II shows some values of junction-to-ambient thermal resistance ($\theta_{(J-A)}$) for values of L and W for 1 oz. copper:

TABLE II

Package	L (in.)	H (in.)	$\theta_{(J-A)}$ ($^{\circ}\text{C}/\text{W}$)
16-Pin DIP	1	0.5	70
	2	1	60
	3	1.5	58
	4	0.19	66
	6	0.19	66
14-Pin DIP	1	0.5	65
	2	1	51
	3	1.5	49
Surface Mount	1	0.5	83
	2	1	70
	3	1.5	67
	6	0.19	69
	4	0.19	71
	2	0.19	73

Application Hints (Continued)

EXTERNAL CAPACITORS

A 2.2 μF (or greater) capacitor is required between the output pin and ground to assure stability. Without this capacitor, the part may oscillate. Most type of tantalum or aluminum electrolytics will work here. Film types will work, but are more expensive. Many aluminum electrolytics contain electrolytes which freeze at -30°C , which requires the use of solid tantalums below -25°C . The important parameters of the capacitor are an ESR of about 5Ω or less and a resonant frequency above 500 kHz (the ESR may increase by a factor of 20 or 30 as the temperature is reduced from 25°C to -30°C). The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for stability. The capacitor can be reduced to 0.68 μF for currents below 10 mA or 0.22 μF for currents below 1 mA.

Programming the output for voltages below 5V runs the error amplifier at lower gains requiring *more* output capacitance for stability. For the worst-case condition of 1.23V output and 250 mA of load current, a 6.8 μF (or larger) capacitor should be used.

A 1 μF capacitor should be placed from the input pin to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery input is used. Stray capacitance to the Feedback terminal can cause instability. This problem is most likely to appear when using high value external resistors to set the output voltage. Adding a 100 pF capacitor between the Output and Feedback pins and increasing the output capacitance to 6.8 μF (or greater) will cure the problem.

MINIMUM LOAD

When setting the output voltage using an external resistive divider, a minimum current of 1 μA is recommended through the resistors to provide a minimum load.

It should be noted that a minimum load current is specified in several of the electrical characteristic test conditions, so this value must be used to obtain correlation on these tested limits.

PROGRAMMING THE OUTPUT VOLTAGE

The regulator may be pin-strapped for 5V operation using its internal resistive divider by tying the Output and Sense pins together and also tying the Feedback and 5V Tap pins together.

Alternatively, it may be programmed for any voltage between the 1.23V reference and the 30V maximum rating using an external pair of resistors (see Figure 3). The complete equation for the output voltage is:

$$V_{\text{OUT}} = V_{\text{REF}} \times \left(1 + \frac{R_1}{R_2} \right) + (I_{\text{FB}} \times R_1)$$

where V_{REF} is the 1.23V reference and I_{FB} is the Feedback pin bias current (~ 20 nA typical). The minimum recommended load current of 1 μA sets an upper limit of 1.2 M Ω on the value of R_2 in cases where the regulator must work with no load (see **MINIMUM LOAD**). I_{FB} will produce a typical 2% error in V_{OUT} which can be eliminated at room temperature by trimming R_1 . For better accuracy, choosing $R_2 = 100$ k Ω will reduce this error to 0.17% while increasing the resistor program current to 12 μA . Since the typical quiescent current is 120 μA , this added current is negligible.

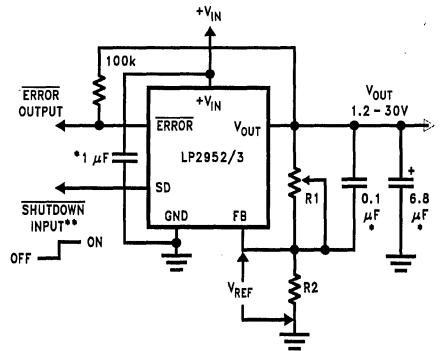


FIGURE 3. Adjustable Regulator

*See Application Hints

**Drive with TTL-low to shut down

DROPOUT VOLTAGE

The dropout voltage of the regulator is defined as the minimum input-to-output voltage differential required for the output voltage to stay within 100 mV of the output voltage measured with a 1V differential. The dropout voltage is independent of the programmed output voltage.

DROPOUT DETECTION COMPARATOR

This comparator produces a logic "LOW" whenever the output falls out of regulation by more than about 5%. This figure results from the comparator's built-in offset of 60 mV divided by the 1.23V reference (refer to block diagrams on page 1). The 5% low trip level remains constant regardless of the programmed output voltage. An out-of-regulation condition can result from low input voltage, current limiting, or thermal limiting.

Figure 4 gives a timing diagram showing the relationship between the output voltage, the ERROR output, and input voltage as the input voltage is ramped up and down to a regulator programmed for 5V output. The ERROR signal becomes low at about 1.3V input. It goes high at about 5V input, where the output equals 4.75V. Since the dropout voltage is load dependent, the input voltage trip points will vary with load current. The output voltage trip point does not vary.

The comparator has an open-collector output which requires an external pull-up resistor. This resistor may be connected to the regulator output or some other supply voltage. Using the regulator output prevents an invalid "HIGH" on the comparator output which occurs if it is pulled up to an external voltage while the regulator input voltage is reduced below 1.3V. In selecting a value for the pull-up resistor, note that while the output can sink 400 μA , this current adds to battery drain. Suggested values range from 100 k Ω to 1 M Ω . This resistor is not required if the output is unused.

When $V_{\text{IN}} \leq 1.3\text{V}$, the error flag pin becomes a high impedance, allowing the error flag voltage to rise to its pull-up voltage. Using V_{OUT} as the pull-up voltage (rather than an external 5V source) will keep the error flag voltage below 1.2V (typical) in this condition. The user may wish to divide down the error flag voltage using equal-value resistors (10 k Ω suggested) to ensure a low-level logic signal during any fault condition, while still allowing a valid high logic level during normal operation.

TL/H/11127-9

Application Hints (Continued)

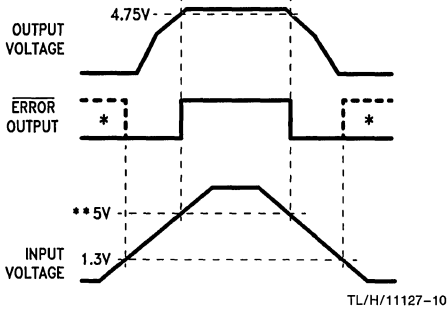


FIGURE 4. ERROR Output Timing

*In shutdown mode, ERROR will go high if it has been pulled up to an external supply. To avoid this invalid response, pull up to regulator output.

**Exact value depends on dropout voltage. (See Application Hints)

OUTPUT ISOLATION

The regulator output can be left connected to an active voltage source (such as a battery) with the regulator input power shut off, as long as the regulator ground pin is connected to ground. If the ground pin is left floating, damage to the regulator can occur if the output is pulled up by an external voltage source.

REDUCING OUTPUT NOISE

In reference applications it may be advantageous to reduce the AC noise present on the output. One method is to reduce regulator bandwidth by increasing output capacitance. This is relatively inefficient, since large increases in capacitance are required to get significant improvement.

Noise can be reduced more effectively by a bypass capacitor placed across R1 (refer to Figure 3). The formula for selecting the capacitor to be used is:

$$C_B = \frac{1}{2\pi R_1 \times 20 \text{ Hz}}$$

This gives a value of about 0.1 μF . When this is used, the output capacitor must be 6.8 μF (or greater) to maintain stability. The 0.1 μF capacitor reduces the high frequency gain of the circuit to unity, lowering the output noise from 260 μV to 80 μV using a 10 Hz to 100 kHz bandwidth. Also, noise is no longer proportional to the output voltage, so improvements are more pronounced at high output voltages.

AUXILIARY COMPARATOR (LP2953 only)

The LP2953 contains an auxiliary comparator whose inverting input is connected to the 1.23V reference. The auxiliary comparator has an open-collector output whose electrical characteristics are similar to the dropout detection comparator. The non-inverting input and output are brought out for external connections.

SHUTDOWN INPUT

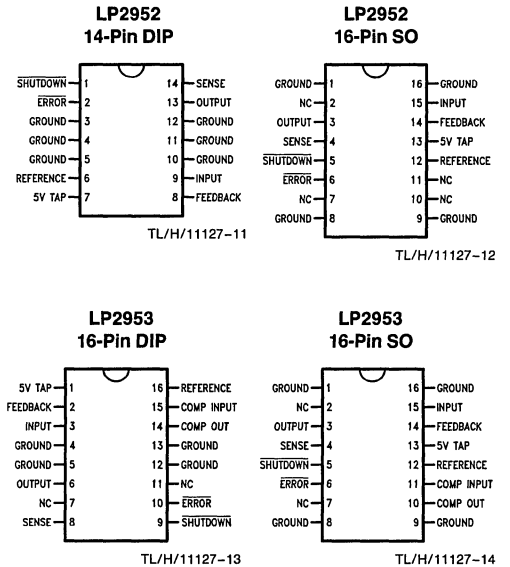
When the operating junction temperature is between -40°C and $+125^\circ\text{C}$, the shutdown input may be left open (floating) for normal regulator operation (regulator output ON).

Operation at junction temperatures above the 125°C maximum (which is **not recommended**) has shown that leaving the shutdown pin open may cause the part to turn ON and OFF. This occurs when internal leakage current activates the shutdown pin, causing the output to go OFF. This

reduces power dissipation, which results in die cooling. This allows the part to turn back ON, and the cycle starts over.

If the part is operated above 125°C , the shutdown pin must be connected to the regulator input voltage through a pull-up resistor to assure that the regulator remains ON. This resistor is not required for operation between -40°C and $+125^\circ\text{C}$, but can be used without affecting performance.

Pinout Drawings



Ordering Information

LP2952

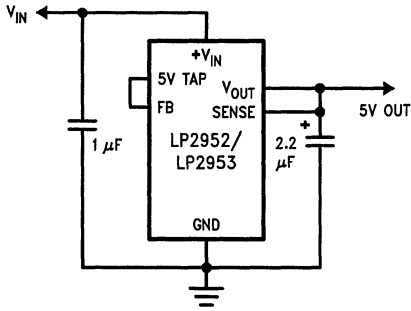
Order Number	Temp. Range (T _J) °C	Package	NSC Drawing Number
LP2952IN	-40 to +125	14-Pin Molded DIP	N14A
LP2952AIN			
LP2952IM	-40 to +125	16-Pin Surface Mt.	M16A
LP2952AIM			

LP2953

Order Number	Temp. Range (T _J) °C	Package	NSC Drawing Number
LP2953IN	-40 to +125	16-Pin Molded DIP	N16A
LP2953AIN			
LP2953IM	-40 to +125	16-Pin Surface Mt.	M16A
LP2953AIM			

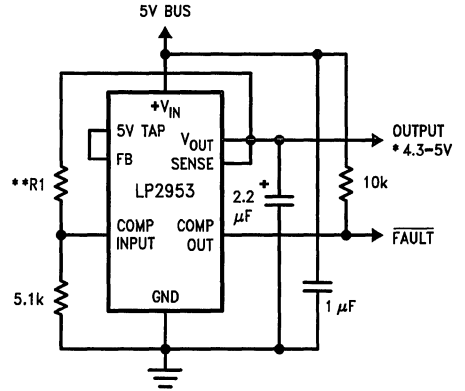
Typical Applications

Basic 5V Regulator



TL/H/11127-15

5V Current Limiter with Load Fault Indicator

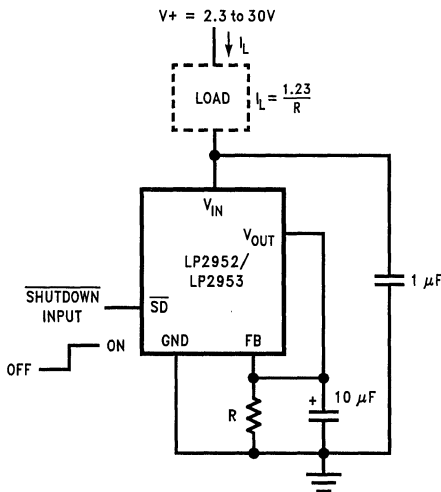


TL/H/11127-16

*Output voltage equals +V_{IN} minium dropout voltage, which varies with output current. Current limits at a maximum of 380 mA (typical).

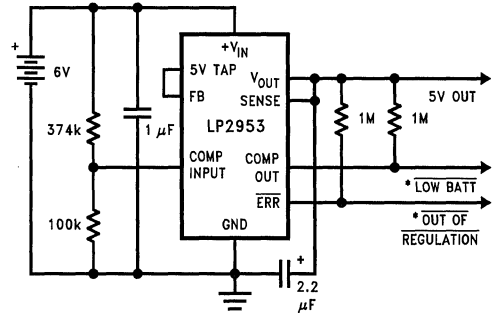
**Select R1 so that the comparator input voltage is 1.23V at the output voltage which corresponds to the desired fault current value.

Low T.C. Current Sink



TL/H/11127-17

5V Regulator with Error Flags for LOW BATTERY and OUT OF REGULATION



TL/H/11127-18

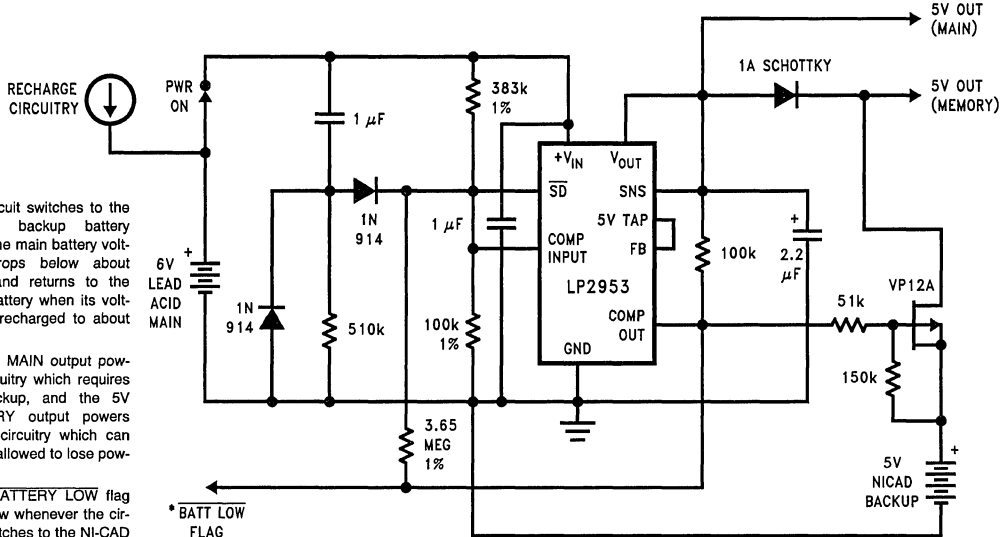
*Connect to Logic or μP control inputs.

LOW BATT flag warns the user that the battery has discharged down to about 5.8V, giving the user time to recharge the battery or power down some hardware with high power requirements. The output is still in regulation at this time.

OUT OF REGULATION flag indicates when the battery is almost completely discharged, and can be used to initiate a power-down sequence.

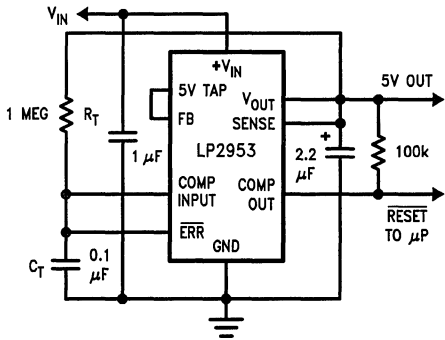
Typical Applications (Continued)

5V Battery Powered Supply with Backup and Low Battery Flag



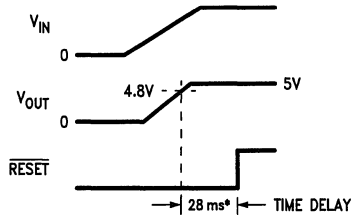
TL/H/11127-19

5V Regulator with Timed Power-On Reset



TL/H/11127-20

Timing Diagram for Timed Power-On Reset

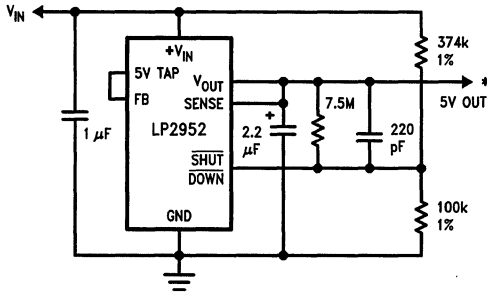


* $R_T = 1 \text{ MEG}$, $C_T = 0.1 \mu\text{F}$

TL/H/11127-21

Typical Applications (Continued)

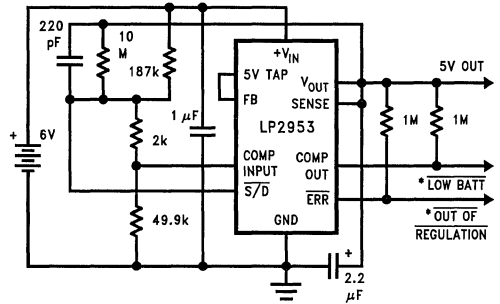
5V Regulator with Snap-On/Snap-Off Feature and Hysteresis



TL/H/11127-22

*Turns ON at $V_{IN} = 5.87V$
 Turns OFF at $V_{IN} = 5.64V$
 (for component values shown)

5V Regulator with Error Flags for LOW BATTERY and OUT OF REGULATION with SNAP-ON/SNAP-OFF Output



TL/H/11127-23

*Connect to Logic or μP control inputs.

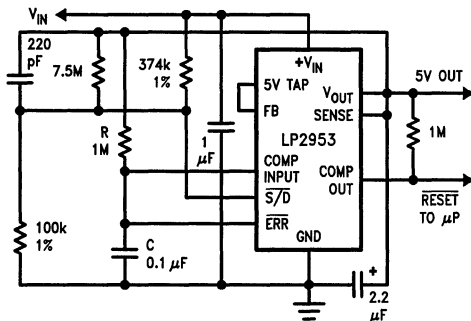
OUTPUT has SNAP-ON/SNAP-OFF feature.

LOW BATT flag warns the user that the battery has discharged down to about 5.8V, giving the user time to recharge the battery or shut down hardware with high power requirements. The output is still in regulation at this time.

OUT OF REGULATION flag goes low if the output goes below about 4.7V, which could occur from a load fault.

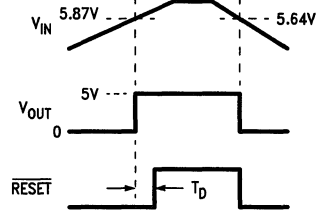
OUTPUT has SNAP-ON/SNAP-OFF feature. Regulator snaps ON at about 5.7V input, and OFF at about 5.6V.

5V Regulator with Timed Power-On Reset, Snap-On/Snap-Off Feature and Hysteresis



TL/H/11127-24

Timing Diagram



TL/H/11127-25

$T_d = (0.28) RC = 28 \text{ ms}$ for components shown.

LP2954/LP2954A

5V Micropower Low-Dropout Voltage Regulators

General Description

The LP2954 is a three-terminal, 5V micropower voltage regulator with very low quiescent current (90 μ A typical at 1 mA load) and very low dropout voltage (typically 60 mV at light loads and 470 mV at 250 mA load current).

The quiescent current increases only slightly at dropout (120 μ A typical), which prolongs battery life.

The LP2954 is available in the three-lead TO-220 package, which makes heatsinking very simple.

Reverse battery protection is provided.

The tight line and load regulation (0.04% typical), as well as very low output temperature coefficient make the LP2954 well suited for use as a low-power voltage reference.

The accuracy of the 5V output is guaranteed at both room temperature and over the entire operating temperature range.

Features

- 5V output within 1.2% over temperature (A grade)
- Guaranteed 250 mA output current
- Extremely low quiescent current
- Low dropout voltage
- Reverse battery protection
- Extremely tight line and load regulation
- Very low temperature coefficient
- Current and thermal limiting
- Pin compatible with LM2940 and LM340

Applications

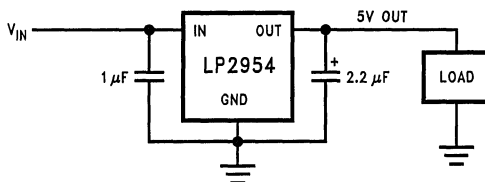
- High-efficiency linear regulator
- Low dropout battery-powered regulator

Package Outline and Ordering Information

Ordering Information

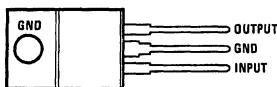
Order Number	Temp. Range (T _J) °C	Package (JEDEC)	NS Package Number
LP2954AIT	-40 to +125	TO-220	TO3B
LP2954IT			

Typical Application Circuit



TL/H/11128-1

TO-220 3-Lead Plastic Package



Front View

TL/H/11128-2

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Operating Junction Temperature Range
 LP2954A/LP2954I -40°C to +125°C
 Storage Temperature Range -65°C to +150°C

Lead Temperature (Soldering, 5 seconds) 260°C
 Power Dissipation (Note 2) Internally Limited
 Input Supply Voltage -20V to +30V
 ESD Rating 2 kV

Electrical Characteristics Limits in standard typeface are for $T_J = 25^\circ\text{C}$, **bold typeface applies over the -40°C to +125°C temperature range**. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise noted: $V_{IN} = 6\text{V}$, $I_L = 1\text{ mA}$, $C_L = 2.2\ \mu\text{F}$.

Symbol	Parameter	Conditions	Typical	2954A		2954I		Units
				Min	Max	Min	Max	
V_O	Output Voltage		5.0	4.975 4.940	5.025 5.060	4.950 4.900	5.050 5.100	V
		$1\text{ mA} \leq I_L \leq 250\text{ mA}$	5.0	4.930	5.070	4.880	5.120	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temp. Coefficient	(Note 3)	20		100		150	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = 6\text{V to }30\text{V}$	0.03		0.10 0.20		0.20 0.40	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	$I_L = 1\text{ to }250\text{ mA}$ $I_L = 0.1\text{ to }1\text{ mA}$ (Note 4)	0.04		0.16 0.20		0.20 0.30	%
$V_{IN}-V_O$	Dropout Voltage (Note 5)	$I_L = 1\text{ mA}$	60		100 150		100 150	mV
		$I_L = 50\text{ mA}$	240		300 420		300 420	
		$I_L = 100\text{ mA}$	310		400 520		400 520	
		$I_L = 250\text{ mA}$	470		600 800		600 800	
I_{GND}	Ground Pin Current (Note 6)	$I_L = 1\text{ mA}$	90		150 180		150 180	μA
		$I_L = 50\text{ mA}$	1.1		2 2.5		2 2.5	mA
		$I_L = 100\text{ mA}$	4.5		6 8		6 8	
		$I_L = 250\text{ mA}$	21		28 33		28 33	
I_{GND}	Ground Pin Current at Dropout (Note 6)	$V_{IN} = 4.5\text{V}$	120		170 210		170 210	μA
I_{LIMIT}	Current Limit	$V_{OUT} = 0\text{V}$	380		500 530		500 530	mA
$\frac{\Delta V_O}{\Delta P_d}$	Thermal Regulation	(Note 7)	0.05		0.2		0.2	%/W
e_n	Output Noise Voltage (10 Hz to 100 kHz) $I_L = 100\text{ mA}$	$C_L = 2.2\ \mu\text{F}$	400					$\mu\text{V RMS}$
		$C_L = 33\ \mu\text{F}$	260					

Electrical Characteristics (Continued)

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The maximum allowable power dissipation is a function of the maximum junction temperature, T_J (MAX), the junction-to-ambient thermal resistance, θ_{J-A} , and the ambient temperature, T_A . The maximum allowable power dissipation at any ambient temperature is calculated using: $P(\text{MAX}) = \frac{T_J(\text{MAX}) - T_A}{\theta_{J-A}}$.

Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The junction-to-ambient thermal resistance of the LP2954 (without external heatsink) is 60° C/W. The junction-to-case thermal resistance is 3 °C/W. If an external heatsink is used, the effective junction-to-ambient thermal resistance is the sum of the junction-to-case resistance (3 °C/W), the specified thermal resistance of the heatsink selected, and the thermal resistance of the interface between the heatsink and the LP2954. Some typical values are listed for interface materials used with TO-220 packages:

Typical Values of Case-to-Heatsink Thermal Resistance (°C/W)

TABLE I. (Data from AAVID Eng.)

Silicone grease	1.0
Dry interface	1.3
Mica with grease	1.4

TABLE II. (Data from Thermalloy)

Thermasil III	1.3
Thermasil II	1.5
Thermalfilm (0.002) with grease	2.2

Note 3: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 4: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested separately for load regulation in the load ranges 0.1–1 mA and 1–250 mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

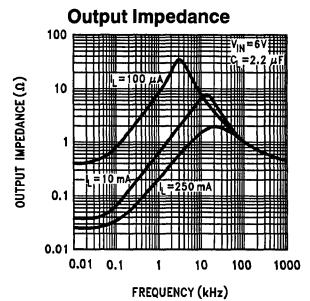
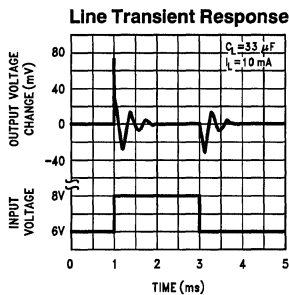
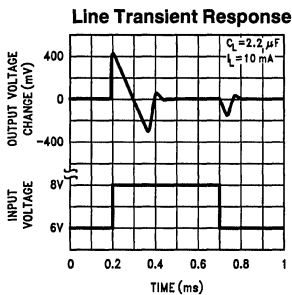
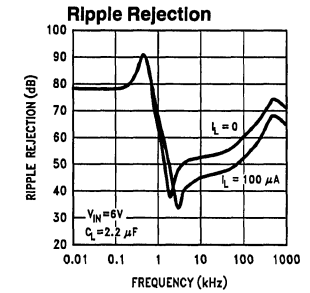
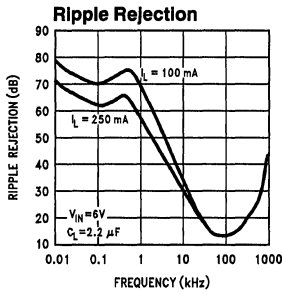
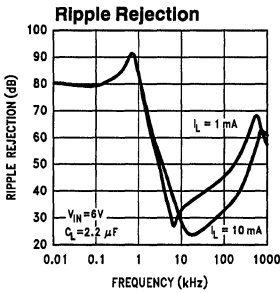
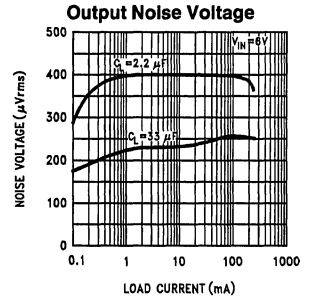
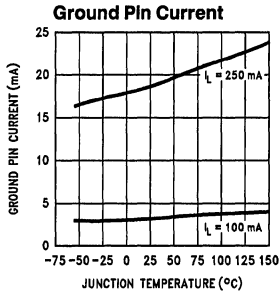
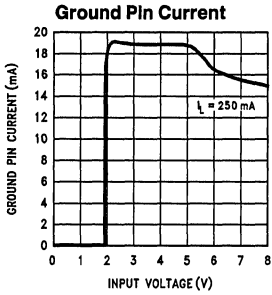
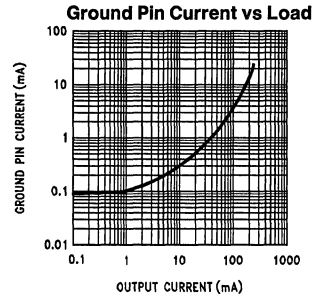
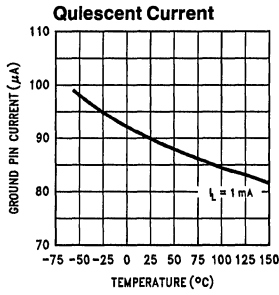
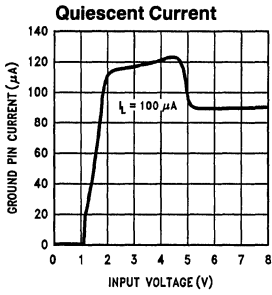
Note 5: Dropout voltage is defined as the input to output differential at which the output voltage drops 100 mV below the value measured with a 1V differential.

Note 6: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

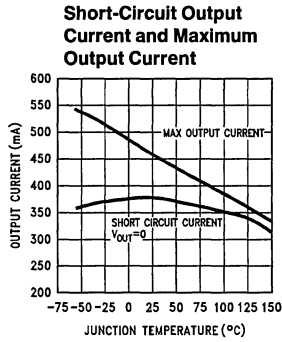
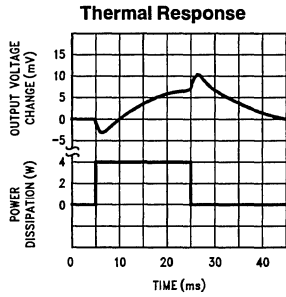
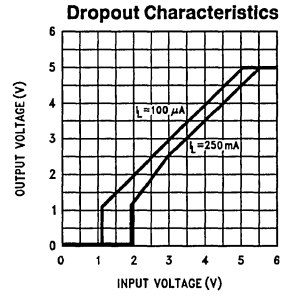
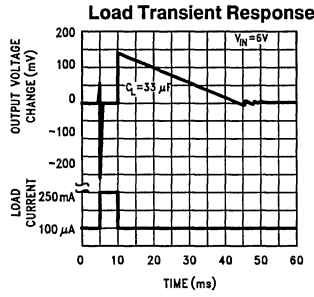
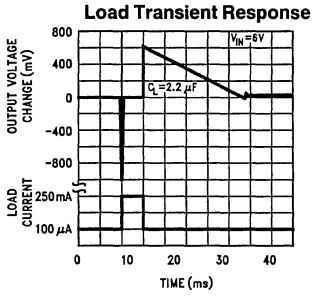
Note 7: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for 200 mA load pulse at $V_{IN} = 20V$ (3W pulse) for $T = 10$ ms.

Note 8: When used in dual-supply systems where the regulator load is returned to a negative supply, the output voltage must be diode-clamped to ground.

Typical Performance Characteristics



Typical Performance Characteristics (Continued)



TL/H/11128-4

Application Hints

EXTERNAL CAPACITORS

A 2.2 μF (or greater) capacitor is **required** between the output pin and the ground to assure stability (refer to *Figure 1*). Without this capacitor, the part may oscillate. Most types of tantalum or aluminum electrolytics will work here. Film types will work, but are more expensive. Many aluminum electrolytics contain electrolytes which freeze at -30°C , which requires the use of solid tantalums below -25°C . The important parameters of the capacitor are an ESR of about 5Ω or less and a resonant frequency above 500 kHz (the ESR may increase by a factor of **20** or **30** as the temperature is reduced from 25°C to -30°C). The value of this capacitor may be increased without limit. At lower values of output current, less output capacitance is required for stability. The capacitor can be reduced to 0.68 μF for currents below 10 mA or 0.22 μF for currents below 1 mA.

A 1 μF capacitor should be placed from the input pin to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery input is used.

MINIMUM LOAD

It should be noted that a minimum load current is specified in several of the electrical characteristic test conditions, so this value must be used to obtain correlation on these tested limits. The part is parametrically tested down to 100 μA , but is functional with no load.

DROPOUT VOLTAGE

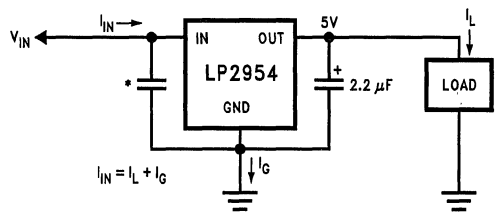
The dropout voltage of the regulator is defined as the minimum input-to-output voltage differential required for the output voltage to stay within 100 mV of the output voltage measured with a 1V differential. The dropout voltages for various values of load current are listed under Electrical Characteristics.

If the regulator is powered from a rectified AC source with a capacitive filter, the minimum AC line voltage and maximum load current must be used to calculate the minimum voltage at the input of the regulator. The minimum input voltage, **including AC ripple on the filter capacitor**, must not drop below the voltage required to keep the LP2954 in regulation. It is also advisable to verify operating at **minimum** operating ambient temperature, since the increasing ESR of the filter capacitor makes this a worst-case test for dropout voltage due to increased ripple amplitude.

HEATSINK REQUIREMENTS

A heatsink may be required with the LP2954 depending on the maximum power dissipation and maximum ambient temperature of the application. Under all possible operating conditions, the junction temperature must be within the range specified under Absolute Maximum Ratings.

To determine if a heatsink is required, the maximum power dissipated by the regulator, $P(\text{max})$, must be calculated. It is important to remember that if the regulator is powered from a transformer connected to the AC line, the **maximum specified AC input voltage** must be used (since this produces the maximum DC input voltage to the regulator). *Figure 1* shows the voltages and currents which are present in



*See External Capacitors

$$P_{\text{Total}} = (V_{\text{IN}} - 5) I_L + (V_{\text{IN}}) I_G$$

FIGURE 1. Basic 5V Regulator Circuit

the circuit. The formula for calculating the power dissipated in the regulator is also shown in *Figure 1*.

The next parameter which must be calculated is the maximum allowable temperature rise, $T_R(\text{max})$. This is calculated by using the formula:

$$T_R(\text{max}) = T_J(\text{max}) - T_A(\text{max})$$

where: $T_J(\text{max})$ is the maximum allowable junction temperature

$T_A(\text{max})$ is the maximum ambient temperature

Using the calculated values for $T_R(\text{max})$ and $P(\text{max})$, the required value for junction-to-ambient thermal resistance, $\theta_{(J-A)}$, can now be found:

$$\theta_{(J-A)} = T_R(\text{max})/P(\text{max})$$

If the calculated value is **60° C/W or higher**, the regulator may be operated without an external heatsink. If the calculated value is **below 60° C/W**, an external heatsink is required. The required thermal resistance for this heatsink can be calculated using the formula:

$$\theta_{(H-A)} = \theta_{(J-A)} - \theta_{(J-C)} - \theta_{(C-H)}$$

where:

$\theta_{(J-C)}$ is the junction-to-case thermal resistance, which is specified as 3° C/W maximum for the LP2954.

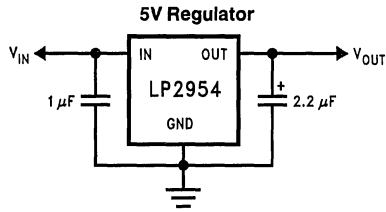
$\theta_{(C-H)}$ is the case-to-heatsink thermal resistance, which is dependent on the interfacing material (if used). For details and typical values, refer to Note 2 listed at the end of the ELECTRICAL CHARACTERISTICS section.

$\theta_{(H-A)}$ is the heatsink-to-ambient thermal resistance. It is this specification (listed on the heatsink manufacturers data sheet) which defines the effectiveness of the heatsink. The heatsink selected must have a thermal resistance which is **equal to or lower** than the value of $\theta_{(H-A)}$ calculated from the above listed formula.

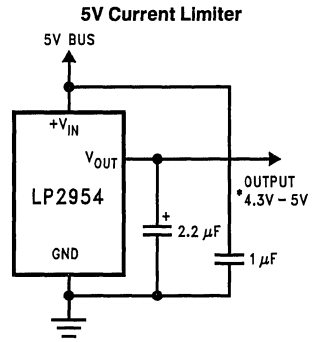
OUTPUT ISOLATION

The regulator output can be left connected to an active voltage source (such as a battery) with the regulator input power turned off, **as long as the regulator ground pin is connected to ground**. If the ground pin is left floating, **damage to the regulator can occur** if the output is pulled up by an external voltage source.

Typical Applications



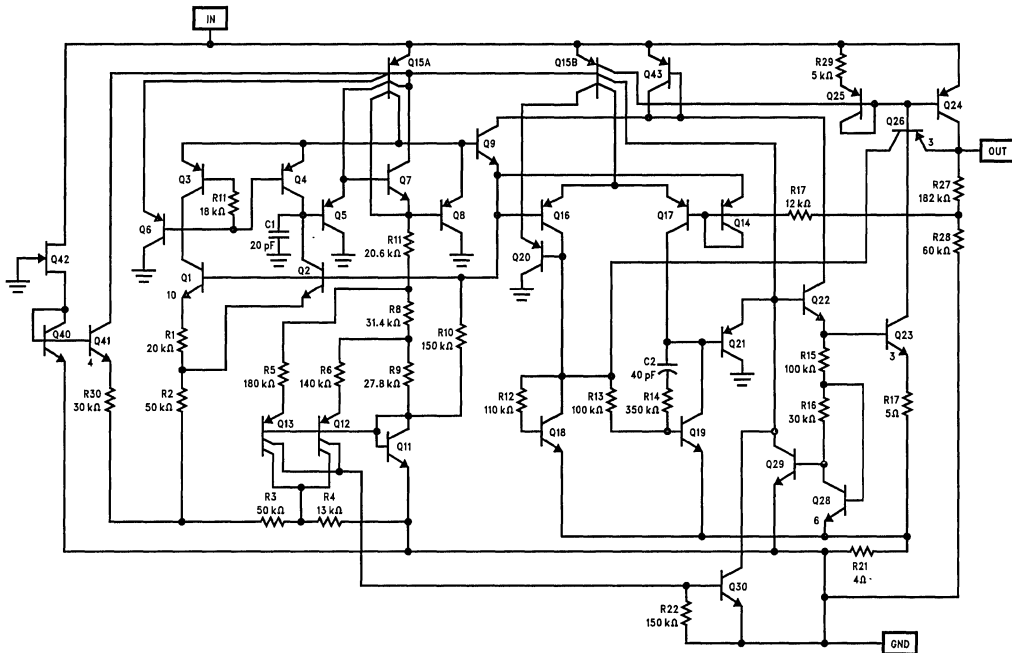
TL/H/11128-6



TL/H/11128-7

*Output voltage equals $+V_{IN}$ minus dropout voltage, which varies with output current. Current limits at 380 mA (typical).

Schematic Diagram



TL/H/11128-8



Section 3
**Switching Voltage
Regulators**



Section 3 Contents

Switching Voltage Regulators Definition of Terms	3-3
Switching Voltage Regulators Selection Guide	3-5
HS7067 7-Amp, Multimode, High Efficiency Switching Regulator	3-7
LH1605/LH1605C 5 Amp, High Efficiency Switching Regulators	3-16
LM1524D/LM2524D/LM3524D Regulating Pulse Width Modulators	3-19
LM2574/LM2574HV Series Simple Switcher 0.5A Step-Down Voltage Regulators	3-36
LM1575/LM1575HV/LM2575/LM2575HV Simple Switcher 1A Step-Down Voltage Regulators	3-54
LM2576/LM2576HV Simple Switcher 3A Step-Down Voltage Regulators	3-71
LM1577/LM2577 Simple Switcher Step-Up Voltage Regulators	3-87
LM1578A/LM2578A/LM3578A Switching Regulators	3-109
LM78S40 Universal Switching Regulator Subsystem	3-123
LMC7660 Switched Capacitor Voltage Converter	3-130

Switching Regulators Definition of Terms

Boost Regulator: A switching regulator topology in which a lower DC voltage is converted to a higher DC voltage. Also known as a *Step-Up Regulator*.

Buck Regulator: A switching regulator topology in which a higher DC voltage is converted to a lower DC voltage. Also known as a *Step-Down Regulator*.

Buck-Boost Regulator: A switching regulator topology in which a positive DC voltage is converted to a negative DC voltage without the use of a transformer. A variation of this topology produces a positive DC output voltage which is between the positive DC input voltage maximum and minimum limits, i.e., providing both buck and boost functions.

Burst Mode: The mode of operation in a switching regulator that results when the load current is reduced to the point where the minimum duty cycle of each pulse provides more energy than the load demands, thus causing the controller to "skip" pulses (or sets of pulses) to maintain the output voltage at its correct value.

Duty Cycle (D): The ratio of the period of time the output switch is ON to the total oscillator period.

$$D = t_{ON}/T$$

Capacitor Ripple Current: The RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature. This parameter is specified by the capacitor manufacturer, and must be considered when a capacitor is used as part of a switching regulator input or output filter.

Catch Diode: The diode which provides a return path for the load current when the regulator switch is OFF. For switching regulators, the types of diodes normally used include Schottky-barrier, fast-recovery, and ultra-fast recovery. Also known as a *steering diode* or *free-wheeling diode*.

Collector Saturation Voltage: With the emitter grounded and the switch ON, the collector-to-emitter voltage of an NPN transistor switch at a specified collector current.

Compensation: The circuitry required to provide adequate stability for the regulator control loop.

Continuous Mode Operation: Relates to the inductor current. In the continuous mode, the inductor current is always greater than zero. In discontinuous mode, the inductor current falls to zero before the end of each switching cycle.

Current Limit Sense Voltage: For regulator ICs that have externally-controlled current limit, the current limit sense voltage is the voltage that must be applied (between two specified pins) to turn the output transistor OFF and start other current limit functions within the IC.

Current-Mode Control: A method of feedback control used in switching regulators where both the output voltage and the switch current are used to control the switching element.

Diode Recovery Time: The period of time it takes the current through a diode to return to zero after the forward voltage is removed (i.e., the diode is turned OFF).

Discontinuous Mode Operation: See *Continuous Mode Operation*.

Efficiency (η): The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

Electromagnetic Interference (EMI): A generic term which is used to refer to any type of unwanted electromagnetic radiation coming from a system such as a switching regulator.

Emitter Saturation Voltage: With the collector pulled up to the DC input voltage and the switch ON, the collector-to-emitter voltage of a NPN transistor switch at a specified emitter current.

Error Amplifier (or Comparator): An amplifier (or comparator) which is used to detect the difference between a feedback voltage (usually proportional to the output voltage) and a DC reference voltage. The resulting error voltage is used in the regulator control circuitry to adjust the switch on-time. This error amplifier may be either a transconductance-type or an operational amplifier.

ESR: A parasitic element of every capacitor, the ESR (equivalent series resistance) is the purely resistive component of a real capacitor's impedance. It is modeled as a resistor in series with the capacitive element, and its value is usually determined by the device construction.

ESL: A parasitic element of every capacitor, which limits its effectiveness at high frequencies. The ESL (equivalent series inductance) is the pure inductance component of a device. Its value is usually determined by the device construction, especially its leads. It is modeled as an inductor in series with the capacitive element.

E•Top: See *Operating Volt-Microsecond Constant*.

Flyback Regulator: A switching regulator topology in which a DC voltage is converted to another DC voltage by means of a transformer which stores energy delivered by a switch during the switch ON time, and transfers the energy to an output storage capacitor during the switch OFF time.

Inductor Ripple Current (ΔI_{IND}): The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode.

Inductor Saturation: The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, its inductance appears to decrease and the resistive component dominates. Inductor current is then

limited only by the DC resistance of the wire and the available source current.

Inverting Regulator: A switching regulator which converts a positive DC voltage to a negative DC voltage. The *buck-boost* topology is often used for this function.

Magnetic Flux Interference: Unwanted interference emitted by magnetic components (transformers and inductors) in the form of magnetic flux. Magnetic flux interference can be minimized by the use of magnetic cores (such as toroid or pot core) which contain the flux, or by shielding with materials such as steel or mu-metal. Aluminum and copper are not effective in shielding flux.

Operating Volt-Microsecond Constant: The product (in Volts \times microseconds) of the voltage applied to the switching regulator inductor and the period of time the voltage is applied. Abbreviated as $E \cdot T_{OP}$, this constant is a measure of the energy-handling capability of an inductor, and is dependent upon the type of core used, its core area, the number of turns of wire used, and the applied duty cycle.

Oscillator Frequency: The frequency of the internal oscillator used in the control of the switching regulator. Generally the same as the *switching frequency*, for most regulators the oscillator frequency is fixed, either internally or by an external resistor and/or capacitor.

Output Ripple Voltage: The AC component of the switching regulator output voltage. It is usually dominated by the output capacitor ESR multiplied by the applied ripple current, but may have high-frequency spikes caused by effects of output capacitor ESL.

Pulse-Width Modulation (PWM): A method of control used in a switching regulator where the duty cycle of the switching element is used to control the output voltage.

Radio Frequency Interference (RFI): High-frequency electromagnetic radiation resulting from the high switching speeds of switching transistors and rectifiers, often causing problems in nearby circuitry that is sensitive to the large noise "spikes" that are often associated with it. RFI can be easily shielded by a good electrical conductor such as copper or aluminum.

Snubber: A network used to limit the voltage developed across a component. The network usually consists of a zener diode, or a diode in series with a parallel resistor and capacitor. In a switching regulator, the snubber is most often used to limit the switch voltage of a flyback regulator.

Soft Start: In a switching regulator, a soft start limits the duty cycle of the regulator during startup. This in turn limits the energy the regulator demands from its source while building up the output voltage from its initial condition of 0V.

Standby Quiescent Current: For a regulator with an ON/OFF pin, this is the supply current (or ground pin current) required by the regulator IC when in the standby (OFF) mode.

Switch: In a switching regulator, a transistor or MOSFET used to deliver energy, in pulses, into energy storage devices (such as inductors, transformers, or capacitors) for use by a load.

Switching Frequency: See *Oscillator Frequency*.

Step Response: The transient response of a regulator output after the load current is "stepped" from one value to another. This test is often used for evaluating the loop stability of a regulator.

Transient Response Time: The period of time it takes the output of a regulator to return to a steady-state value after a change in line voltage or load current. See also *Step Response*.

Voltage Mode Control: A method of control used in a switching regulator where feedback from the output voltage is used to provide control of the switching element.



Switching Voltage Regulators Selection Guide

Switching Voltage Regulators

Switch Current (A)	Device	Standard Operating Modes	Input Voltage (V)	Output Voltage (V)	Switching Frequency (kHz)	Operating Temperature (T _J)	Package Availability**	Page No.
7.0	HS7067	Step-Down, Flyback, Invert	10 to 60	Adjustable	25 to 200	-55°C to +150°C	K8	3-7
	HS7067C	Step-Down, Flyback, Invert	10 to 60	Adjustable	25 to 200	-25°C to +150°C	K8	3-7
5.0	LH1605	Step-Down	8 to 35	3 to 30	6 to 100	-55°C to +150°C	K8	3-16
	LH1605C	Step-Down	8 to 35	3 to 30	6 to 100	-25°C to +150°C	K8	3-16
1.5	LM78S40	Step-Up, Step-Down, Invert	2.5 to 50	Adjustable	0.1 to 100	-55°C to +150°C	J16	3-123
	LM78S40	Step-Up, Step-Down, Invert	2.5 to 50	Adjustable	0.1 to 100	-40°C to +125°C	N16	3-123
	LM78S40C	Step-Up, Step-Down, Invert	2.5 to 50	Adjustable	0.1 to 100	0°C to +125°C	J16, N16	3-123
0.75	LM1578A	Step-Up, Step-Down, Flyback, Invert	2 to 40	Adjustable	0.001 to 100	-55°C to +150°C	H8	3-109
	LM2578A	Step-Up, Step-Down, Flyback, Invert	2 to 40	Adjustable	0.001 to 100	-40°C to +125°C	H8, M8, N8	3-109
	LM3578A	Step-Up, Step-Down, Flyback, Invert	2 to 40	Adjustable	0.001 to 100	0°C to +125°C	H8, M8, N8	3-109
0.2	LM1524D*	Step-Up, Step-Down, Flyback, Invert	5 to 40	Adjustable	1 to 550	-55°C to +150°C	J16	3-19
	LM2524D*	Step-Up, Step-Down, Flyback, Invert	5 to 40	Adjustable	1 to 550	-40°C to +125°C	N16	3-19
	LM3524D*	Step-Up, Step-Down, Flyback, Invert	5 to 40	Adjustable	1 to 350	0°C to +125°C	M16, N16	3-19

*The 0.2A switch current specification is the maximum capability for each of the dual internal NPN transistor switches.

**Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the indicated package. For example: T5 = 5-Lead TO-220, and M14 = 14-Lead Surface Mount.

H: Metal Can (TO-99)

J: Ceramic Dual-In-Line Package

K: Metal Can (TO-3)

M: Small Outline Molded Package (Surface Mount)

N: Molded Dual-In-Line Package

DC/DC Voltage Converters

Output Current (A)	Device	Standard Operating Modes	Input Voltage (V)	Output Voltage (V)	Switching Frequency (kHz)	Efficiency (%)	Operating Temperature (T _J)	Package Availability**	Page No.
3.0	LM1577*	Step-Up, Flyback	3.5 to 40	12, 15, Adjustable	52	80	-55°C to +150°C	K4***	3-87
	LM2577*	Step-Up, Flyback	3.5 to 40	12, 15, Adjustable	52	80	-55°C to +150°C	M24, N16, T5	3-87
	LM2576	Step-Down	4 to 40	3.3, 5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	-40°C to +125°C	T5	3-71
	LM2576HV	Step-Down	4 to 60	3.3, 5, 12, 15, Adj. (1.23 to 57)	52	77 to 88	-40°C to +125°C	T5	3-71
1.0	LM1575	Step-Down	4 to 40	5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	-55°C to +150°C	K4***	3-54
	LM2575	Step-Down	4 to 40	3.3, 5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	-40°C to +125°C	M24, N16, T5	3-54
	LM2575HV	Step-Down	4 to 60	3.3, 5, 12, 15, Adj. (1.23 to 57)	52	77 to 88	-40°C to +125°C	M24, N16, T5	3-54
0.5	LM2574	Step-Down	4 to 40	3.3, 5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	-40°C to +125°C	M14, N8	3-36
	LM2574HV	Step-Down	4 to 60	3.3, 5, 12, 15, Adj. (1.23 to 57)	52	77 to 88	-40°C to +125°C	M14, N8	3-36
0.05	LMC7660I	Invert	1.5 to 10	-1.5 to -10	10	90	-40°C to +125°C	N8	3-130

*For the LM1577 and LM2577 the 3.0A output current specification indicates the current rating of the internal NPN transistor switch.

**Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the indicated package. For example: T5 = 5-Lead TO-220, and M14 = 14-Lead Surface Mount.

K: Metal Can (TO-3)

M: Small Outline Molded Package (Surface Mount)

N: Molded Dual-In-Line Package

T: TO-220

***Available in indicated package only as a military specified device.

HS7067 7 Amp, Multimode, High Efficiency Switching Regulator

General Description

The HS7067 is a hybrid high efficiency switching regulator with high output current capability. The device is housed in a standard TO-3 package containing a temperature compensated voltage reference, a pulse-width modulator with programmable oscillator frequency, error amplifier, high current, high voltage output switch and steering diode. The HS7067 operates in a step-down, inverting, as well as in a transformer-coupled mode.

The HS7067 can supply up to 7A of continuous output current over a wide range of input and output voltages.

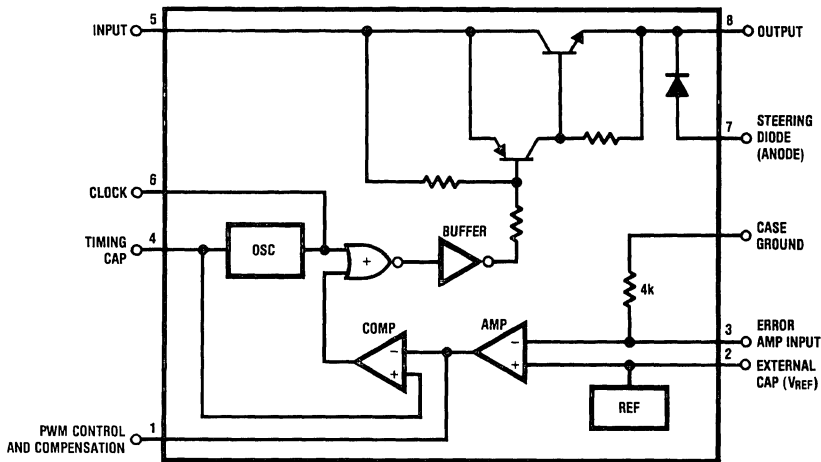
Features

- HS7067—10V to 60V input
- 7A continuous output current
- Frequency adjustable to 200 kHz
- High-efficiency (>75%)
- Standard 8-pin TO-3 package

Typical Applications

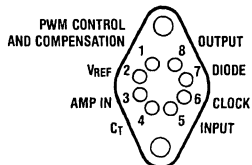
- 7A step-down regulator
- Inverting regulator
- Multiple-output regulator
- Isolated regulator

Block and Connection Diagrams



TL/K/6746-1

Metal Can Package



Top View

Case is ground

TL/K/6746-2

Order Number
 HS7067CK, HS7067K or HS7067K-MIL
 See NS Package Number K08A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

V_{IN} , Input Voltage	65V
I_{OUT} , Output Current	8A
T_J , Operating Temperature	150°C
P_D , Internal Power Dissipation	25W

T_A , Operating Temperature Range	HS7067C	-25°C to +85°C
	HS7067	-55°C to +125°C
T_{STG} , Storage Temperature Range		-65°C to +150°C
$V_R(V_{B-7})$, Steering Diode Reverse Voltage		105V
$I_D(I_{7-8})$, Steering Diode Forward Current		8A

Electrical Characteristics $T_C = 25^\circ\text{C}$, $V_{IN} = 20\text{V}$ (unless otherwise specified) (Note 8)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
$V_{IN}-V_{OUT}$	Min V_{IN}/V_{OUT} Differential	$10\text{V} \leq V_{IN} \leq V_{IN(MAX)}$ $I_{OUT} = 2\text{A}$ (Note 6)		3.0		V
V_S	Switch Saturation Voltage	$I_C = 7.0\text{A}$, $V_{IN} = 10\text{V}$		1.6	1.9	V
		$I_C = 2.0\text{A}$, $V_{IN} = 10\text{V}$		1.0		V
V_F	Steering Diode On Voltage	$I_D = 7.0\text{A}$		1.3	1.7	V
		$I_D = 2.0\text{A}$		0.9		V
V_{IN}	Supply Voltage Range (Note 7)	$T_{MIN} \leq T_A \leq T_{MAX}$	10		60	V
I_R	Steering Diode Reverse Current	$V_R = 100\text{V}$			60	μA
I_Q	Quiescent Current (Note 3)	0% Duty Cycle ($V_3 = 3.0\text{V}$)		6		mA
		100% Duty Cycle ($V_3 = 0\text{V}$)		26		mA
V_2	Reference Voltage on Pin 2	$T_{MIN} \leq T_A \leq T_{MAX}$	2.3	2.5	2.7	V
V_{CLKH}	Clock Output High	$I_{CLK} = -750\ \mu\text{A}$	1.2	1.6		V
V_{CLKL}	Clock Output Low	$I_{CLK} = 80\ \mu\text{A}$			0.9	V
ΔV_2	Line Regulation of Reference Voltage on Pin 2	$V_{MIN} \leq V_{IN} \leq V_{MAX}$		5		mV
R_A	Resistance on Pin 3 to Ground	(Note 4)		4.0		k Ω
V_{OUT}	Output Voltage Tolerance	Feedback Resistor R_f Tol. $\pm 1\%$		4	9	%
V_4	Voltage Swing—Pin 4			3.0		V
I_4	Charging Current—Pin 4			330		μA
I_{CLK}	Clock Input Current—Pin 6	$V_{CLK} = 3.5\text{V}$		1.75	4	mA
t_r	Transistor Current Rise Time	$I_O = 2.0\text{A}$ (Note 6)		70		ns
		$I_O = 7.0\text{A}$ (Note 6)		120		ns
t_f	Transistor Current Fall Time	$I_O = 2.0\text{A}$ (Note 6)		100		ns
		$I_O = 7.0\text{A}$ (Note 6)		160		ns
t_s	Diode Storage Time	$I_O = 7.0\text{A}$ (Note 6)		120		ns
t_d	Delay Time	$I_O = 7.0\text{A}$ (Note 6)		600		ns
f_{MAX}	Max Clock Frequency	(Note 5)			200	kHz
Z_{PIN1}	Impedance at Pin 1	(Note 6)		5		M Ω
η	Efficiency	$V_{OUT} = 5\text{V}$ $I_{OUT} = 1\text{A}$	$f_O = 25\text{ kHz}$ (Note 6)	80		%
			$f_O = 200\text{ kHz}$ (Note 5)	70		%
θ_{JC}	Thermal Resistance	(Note 1)		4.0		$^\circ\text{C}/\text{W}$

Electrical Characteristics (Continued)

Note 1: θ_{JA} is typically 35°C/W for natural convection cooling.

Note 2: V_{OUT} and I_{OUT} refer to the output DC voltage and output current of a switching supply after the output LC filter as shown in *Figure 1*.

Note 3: Quiescent current depends on the duty cycle of the switching translator.

Note 4: This test includes the input bias current of the error amplifier.

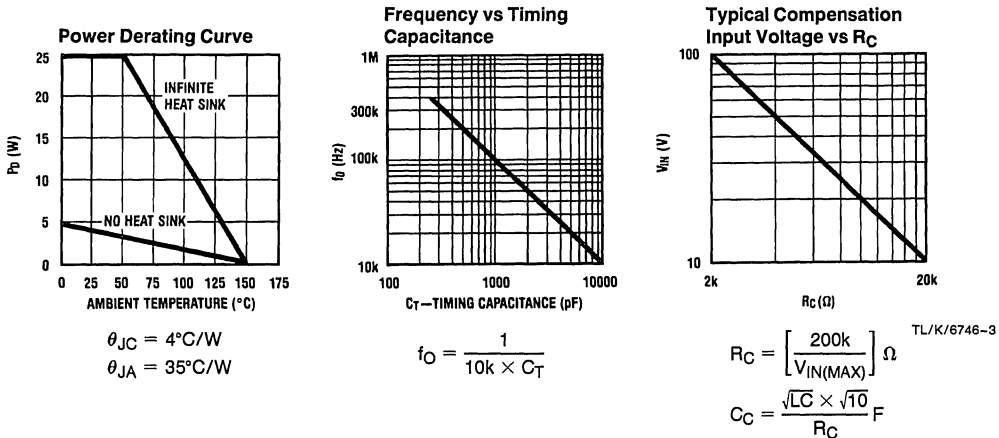
Note 5: Circuit configured as shown in *Figure 1*.

Note 6: These parameters are not tested. They are given for informational purposes only.

Note 7: Functionally tested at limits only (pass-fail).

Note 8: A military RETS specification is available upon request. At the time of printing, the HS7067 RETS specification complied with the Min and Max limits in this table. The HS7067K may also be procured as a Standard Military Drawing.

Typical Performance Characteristics



Typical Applications

THE BUCK CONVERTER (Step Down)

The buck converter is the most common application in switching-power conversion. It provides a step-down of voltage with a minimum of components and a maximum of efficiency (for further information on the theory of operation of a buck converter, see AN-343). The complete circuit is shown in *Figure 1*.

f_o	25 kHz	200 kHz
L	86 μH	21 μH
C_T	0.0039 μF	330 pF
C_C	0.2 μF	0.068 μF
R_f	4 k Ω	4 k Ω
R_C	5.7 k Ω	5.7 k Ω
C_{OUT}	1500 μF	680 μF

$V_{IN} = 10\text{V to }35\text{V}$
 $V_{OUT} = 5\text{V}$
 $I_{OUT} = 1\text{A to }6\text{A}$

Load Regulation = 40 mV
Line Regulation = 5 mV

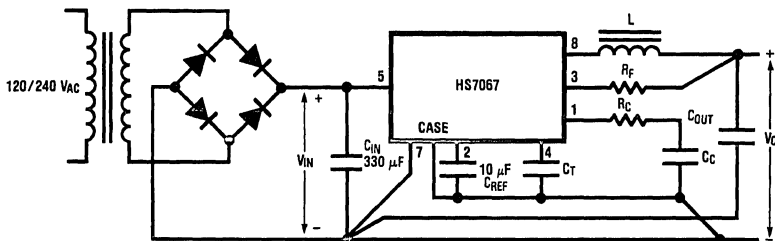


FIGURE 1. Buck (Step-Down) Converter

TL/K/6746-4

Typical Applications (Continued)

Design equations:

Following are the design equations for a buck converter application using the HS 7067:

$$C_T = \frac{1}{10^4 \times f_O}$$

$$L_{MIN} = \frac{(V_{IN(MAX)} - V_O) V_O}{V_{IN(MAX)} \times f_O \times \Delta I} \quad (\text{Note 7, 9})$$

$$C_{MIN} = \frac{\Delta I}{4 f_O (e_O - \Delta I \times ESR)} \quad (\text{Note 8, 9})$$

$$C_C = \frac{\sqrt{10 LC}}{R_C}$$

$$R_C = \frac{2 \times 10^5}{V_{IN(MAX)}}$$

$$R_f = 4k \left(\frac{V_O - 2.5}{2.5} \right) \Omega$$

Note 7: L_{MIN} is the minimum value of output filter inductance, L, for stable operation.

Note 8: C_{MIN} is the minimum value of output filter capacitance, C, necessary to achieve an output ripple voltage, e_O . ESR is the Effective Series Resistance of the output filter capacitor, C, at the operating frequency, f_O .

Note 9: ΔI = Peak to Peak Ripple current through the inductor and the capacitor. $\frac{\Delta I}{2} < I_{O MIN}$ and $\frac{\Delta I}{2} < 7 - I_{O MAX}$.

Efficiency Equations

Since high efficiency is the principal advantage of switched-mode power conversion, switching regulator losses are an important design concern. Losses and efficiency of a buck converter can be calculated with the following equations.

I_O is the load current, and is the average output current at pin 8.

Switching Period (T)

$$T = \frac{1}{f_O} = t_{ON} + t_{OFF}$$

Duty Cycle (D)

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{V_O + V_F}{V_{IN} - V_S + V_F}$$

Transistor DC Losses (P_T)

$$P_T = V_S \times I_O \times D$$

Transistor Switching Losses (P_S)

$$P_S = (V_{IN} + V_F) \times I_O \times \frac{(t_r + t_f + 2t_s) f_O}{2}$$

Capacitor Losses (P_C)

$$P_C = ESR \times \left(\frac{V_O (T - DT)}{4L} \right)^2$$

Diode DC Losses (P_D)

$$P_D = V_f \times I_O \times (1 - D)$$

Drive Circuit Losses (D_L)

$$D_L = 0.02 \times V_{IN} \times D$$

Inductor Losses (P_L)

$$P_L = I_O^2 \times R_L \text{ (DC winding resistance)}$$

Power Output (P_O)

$$P_O = \frac{((V_{IN} - V_S) t_{ON}) - ((V_F) t_{OFF})}{t_{ON} + t_{OFF}} \times I_O$$

Efficiency (η)

$$\eta = \frac{P_O}{P_{IN}} = \frac{P_O}{P_O + P_T + P_S + P_D + D_L + P_L + P_C}$$

TRANSFORMER COUPLED CONVERTERS

In addition to the implementation of a buck converter, the HS 7067 can be used in various transformer coupled configurations. They can be used in various topologies such as: step-up, step-down, inverter, multiple outputs and isolated converters.

There are basically two different methods in implementing transformer coupled converters: the flyback and the forward topology.

The Flyback Principle

Figure 2 shows a functional diagram of a flyback converter. Depending on the turn ratio N_2/N_1 and the feedback voltage, it can be implemented as a step-down or step-up converter.

When the switch is on, the current (I_p) flows through the primary winding creating a magnetic flux in the core and storing the energy. At this time, the voltage at the secondary keeps the same polarity (with respect to the dotted terminals), the diode is off and no current flows through it. When the switch is off, the voltage at the secondary and primary becomes reversed and the diode turns-on (I_d). The stored energy is then transferred to the load and the output filter capacitor. The energy stored in the capacitor will supply the load current during the next turn-on.

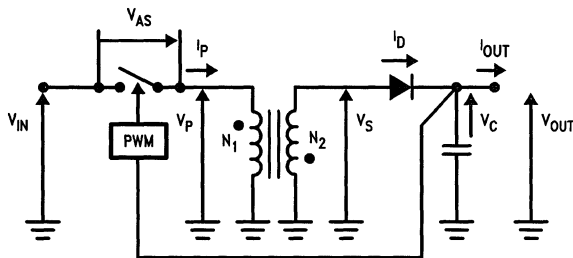
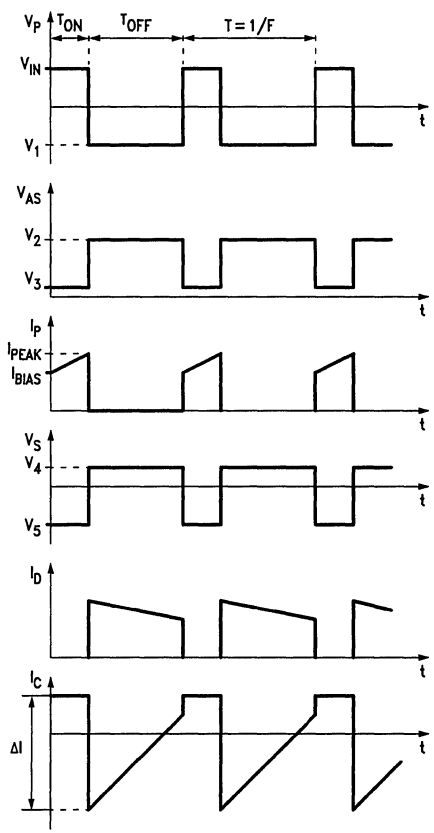


FIGURE 2. Typical Flyback Functional Diagram

TL/K/6746-5

Typical Applications (Continued)

- V_p = Voltage at primary
- V_{as} = Voltage across the switch
- V_s = Voltage at the secondary
- I_p = Current at primary
- I_d = Current through diode
- I_c = Current through output cap
- I_{out} = Output current of the converter
- ΔI = Ripple current
- D = $T_{on}/(T_{off} + T_{on})$
- F = Switching frequency
- V_{df} = Forward voltage drop of the diode
- $V_1 = V_{out} \times N_1/N_2$ $V_2 = V_{in} + V_{out} N_1/N_2$
- V_3 = Saturation voltage of the switch
- $V_4 = V_{out} + V_{df}$ $V_5 = V_{in} \times N_2/N_1$



TL/K/6746-6

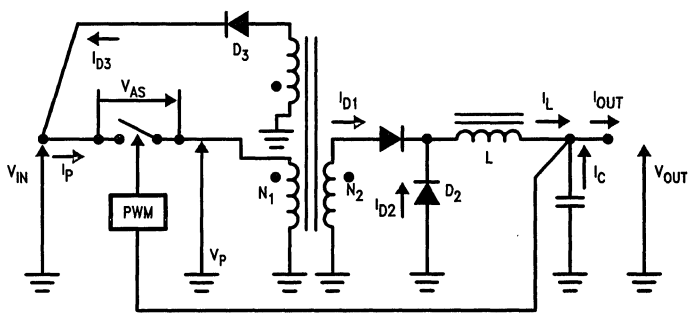
FIGURE 3. Typical Flyback Waveforms

The load current is not supplied directly by the input source when the switch is on, but only by the energy stored in the output capacitor. The output voltage is monitored by the feedback loop which controls the duty cycle (D) through the PWM (Pulse Width Modulator) which in turn, modulates the amount of energy being transferred from the input to the output. *Figure 3* shows the waveforms of a continuous mode flyback converter (primary current I_p is DC biased).

The Forward Principle

The forward converter is a little more complex and requires more components than the flyback, but the output ripple voltage is smaller. *Figure 4* shows a simplified diagram of a forward converter.

When the switch turns-on, a voltage $V_5 = V_1 \times N_2/N_1$ appears at the secondary of the transformer. The diode D_2



TL/K/6746-7

FIGURE 4. Typical Forward Functional Diagram

Typical Applications (Continued)

is off while D_1 turns-on, allowing the current to flow through the inductor L (I_{d1} and I_L), storing energy in its core, and supplying the load current (I_{out}) and the capacitor current (I_C) at the same time. When the switch turns-off, the magnetic energy stored in the core of the inductor creates a current (I_{d2}) which flows through the diode D_2 . The load current I_{out} therefore, equals to $I_{d2} + I_C$.

During the "off" time of the switch, some residual magnetism will stay in the core of the transformer and has to be removed before the next cycle, so that it does not accumulate, leading to core saturation.

A demagnetizing winding is used to "dump" the residual energy back to the input or output of the converter. The

functional principle of the demagnetizing winding is similar to the flyback in the sense that, during the turn-off time, the residual magnetism will generate a reverse voltage at the demagnetizing winding (with respect to the dotted terminals) turning on the diode D_3 .

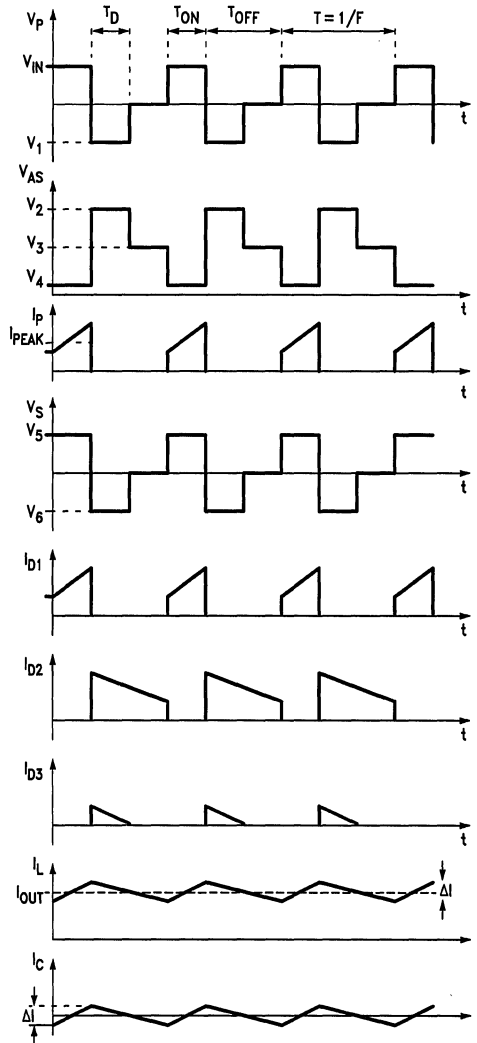
In the forward mode, when the switch is off, the load current is supplied by the energy stored in the output capacitor and the choke inductor but when the switch is on, it is supplied by the input source through the transformer. This accounts for the lower output ripple voltage.

The output voltage is monitored by the feedback loop, which controls the duty cycle through the PWM, which in turn modulates the amount of energy being transferred from the input to the output.

- V_p = Voltage at primary
- V_{as} = Voltage across the switch
- V_s = Voltage at secondary
- I_p = Current at primary
- I_{d1} = Current through diode D_1
- I_{d2} = Current through diode D_2
- I_{d3} = Current through diode D_3
- I_L = Current through inductor L
- I_c = Current through output cap
- I_{out} = Output current of the converter
- ΔI = Ripple current
- F = Switching frequency
- D = $T_{on} / (T_{off} + T_{on})$
- $V_1 = V_{in} \times N_1/N_3 \quad V_3 = V_{in}$
- $V_2 = V_{in} + V_1$
- V_4 = Saturation voltage of the switch
- $V_5 = V_{in} \times N_2/N_1 \quad V_6 = V_{in} \times N_2/N_3$

Figure 5 shows the waveforms of the forward converter.

When the switch is off, $V_{as} = V_{in} + (V_{in} \times N_1/N_3)$ during the demagnetization time (T_d) and then, drops to $V_{as} = V_{in}$ as indicated in Figure 5.



TL/K/6746-8

FIGURE 5. Typical Forward Waveforms

Typical Applications (Continued)

With both flyback and forward topologies, it is possible to design an inverting converter by using an external op-amp (Figure 6).

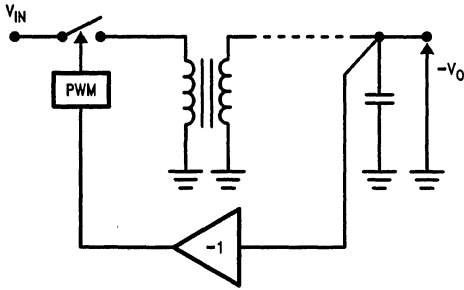


FIGURE 6

TL/K/6746-10

Flyback Step-Up Application

Figure 7 shows flyback converter in a step-up mode where an input voltage of +12V to +30V will be converted into a regulated output voltage of +50V.

Performance Data

Parameter	Conditions	Result
Efficiency	$V_{out} = 50V @ 300\text{ mA}$ $V_{in} = 15V$	82%
Line Regulation	$V_{out} = 50V @ 300\text{ mA}$ $12V \leq V_{in} \leq 30V$	0.2%
Load Regulation	$V_{in} = 15V$ $V_{out} = 50V$ $50\text{ mA} \leq I_{out} \leq 300\text{ mA}$	0.2%

Isolated Flyback Converter

Figure 8 shows an isolated flyback converter using a sense winding for feedback. Although, in practice the line regulation is acceptable, the load regulation can be marginal if the coupling between the windings is poor. However, the sense winding cannot detect any ohmic voltage drop in the main output so, a heavier gauge wire should be used to reduce this regulation error. Also, the sense winding will not sense the non-linear voltage drop across the diode, and this accounts for most of the load regulation inaccuracy. Therefore, the sense winding method is only recommended for applications where load variations are small.

Figure 8 shows an isolated flyback converter with an output of 5V at 2A. The input voltage range is from +10V to +40V. The output can be adjusted to +5V by using the 5 kΩ trimpot.

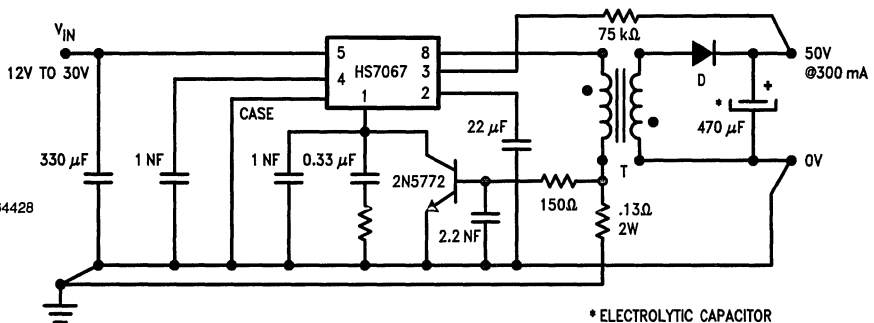
Performance Data

Parameter	Conditions	Result
Efficiency	$V_{out} = 5V @ 2A$ $V_{in} = 30V$	75%
Line Regulation	$V_{out} = 5V @ 2A$ $10V \leq V_{in} \leq 40V$	5%
Load Regulation	$V_{in} = 30V$ $1A \leq I_{out} \leq 2A$	7%

Isolated Forward Converter

As described previously, forward converters exhibit lower output ripple voltage and the opto-coupler feedback scheme provides good regulation as well as input to output isolation.

An opto-coupler feedback is usually difficult to implement because the transfer function of the opto-coupler is non-linear, the current transfer ratio changes with time and temperature and also from one unit to another. Figure 9a shows the circuit diagram of a 5V @ 3A power converter with an input voltage range of +14V to +30V using an isolated forward topology.



D = Unitrode UES1302
T = Pulse Engineering PE64428
 $f_o = 100\text{ kHz}$
 $I_{out}(\text{min}) = 50\text{ mA}$

* ELECTROLYTIC CAPACITOR

FIGURE 7. Flyback Step-Up Converter

TL/K/6746-11

Typical Applications (Continued)

- D₁ = International Rectifier 50SQ060
 - D₂ = 1N4148
 - I_{out (min)} = 1A
 - f_O = 100 kHz
 - T = Transformer made of a core Fenoxcube 1811PA2503B7
 - Primary = 8 turns with 5 strands #29
 - Secondary = 6 turns with 15 strands #30
 - Sense = 25 turns with 1 strand #30
- windings should be interleaved in order to improve the coupling and regulation.

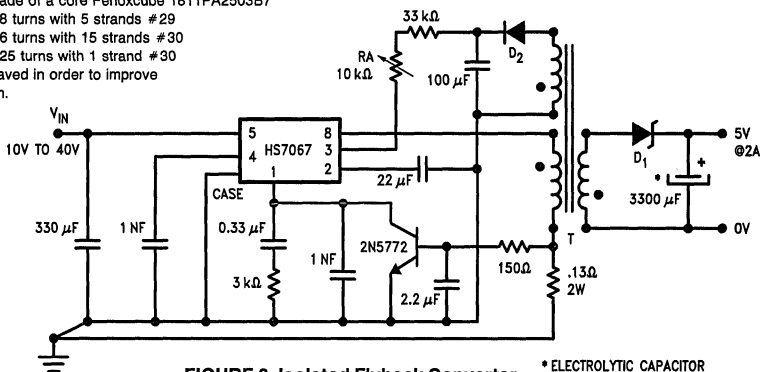
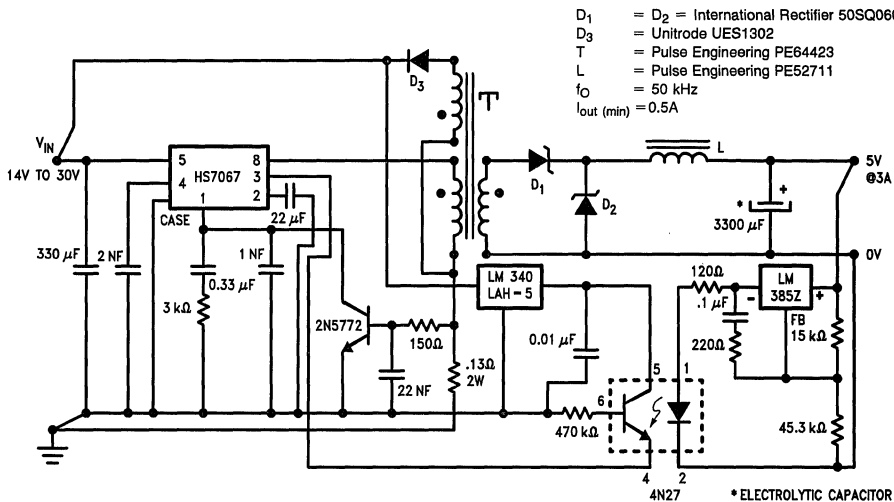


FIGURE 8. Isolated Flyback Converter

*ELECTROLYTIC CAPACITOR

TL/K/6746-12

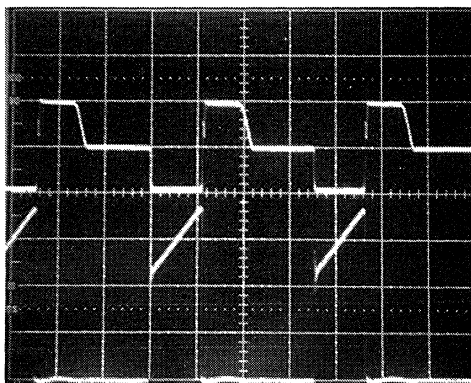


- D₁ = D₂ = International Rectifier 50SQ060
- D₃ = Unitrode UES1302
- T = Pulse Engineering PE64423
- L = Pulse Engineering PE52711
- f_O = 50 kHz
- I_{out (min)} = 0.5A

FIGURE 9a. Isolated Forward Converter

*ELECTROLYTIC CAPACITOR

TL/K/6746-13



TL/K/6746-9

Figure 9b shows the typical forward converter waveforms in continuous mode which can be observed using the circuit from Figure 9a. Top waveform is the voltage across the switch (20V/div). Bottom waveform is the current through the switch (1A/div). Horizontal Scale = 5 μs/div. V_{in} = 20V; V_{out} = 5V @ 3A.

FIGURE 9b.

Typical Applications (Continued)

An LM385Z (adjustable reference) is used as a comparator and error amplifier. This reference always wants to maintain 1.2V between pins 1 and 2 and will draw as much current as necessary from the opto-coupler to achieve this. Therefore, the feedback loop is virtually independent of the gain of the opto-coupler.

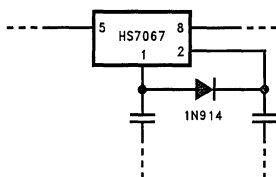
Performance Data

Parameter	Conditions	Result
Efficiency	$V_{out} = 5V @ 3A$ $V_{in} = 30V$	78%
Line Regulation	$V_{out} = 5V @ 3A$ $14V \leq V_{in} \leq 30V$	0.1%
Load Regulation	$V_{out} = 5V$ $V_{in} = 20V$ $0.5A \leq I_{out} \leq 3A$	0.1%

Application Hints

DUTY CYCLE LIMITING

In a flyback converter, the error amplifier sees 0V at the output of the converter during the initial turn-on, and forces the duty cycle to 100% until it sees the output voltage rising to the final value; but no voltage will appear if the switch does not turn off (see flyback principle). The result is that the core will saturate, reducing the effective impedance of the transformer to about 0Ω , and destroying the pass transistor. To prevent this, the duty cycle must be limited to a value at which the core does not saturate. A diode connected between pins 1 and 2 (Figure 11), will limit the duty cycle to about 80%.



TL/K/6746-15

FIGURE 11. Duty Cycle Limiting Circuit

SOFT START

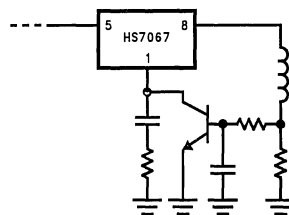
For any converter, connecting a large capacitor (20 to 200 μF) between pin 2 and the case is recommended to allow the reference voltage to slowly reach its final value after start-up. This allows the HS 7067 to start-up smoothly and minimizes the inrush current. The time constant can be calculated by:

$$T = 10^3 \times C$$

It is always a good practice to incorporate soft start and duty cycle limiting when designing a switching power converter, especially when a current limit circuitry is not utilized.

CURRENT LIMIT

The schematic in Figure 12 shows how to protect the pass transistor against excessive current, by sensing the current through a series resistor, and shorting the PWM control voltage at pin 1 to ground, using transistor 2N5772 (this is made possible by the 5 M Ω output impedance of the error amplifier), which will cause the pass transistor to turn off.



TL/K/6746-16

FIGURE 12. Current Limit Circuitry

The sense resistor should be a low inductance type, otherwise the series inductance creates a high impedance at transients and activates the shutdown circuitry. If such a resistor cannot be found, a 0.1 μF connected in parallel with it will compensate the series inductance.

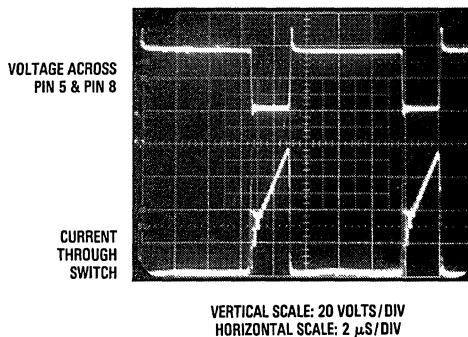
When such a circuitry is used, the duty cycle limiting diode becomes optional, but the soft start capacitor should still be at least 10 μF .

DECOUPLING AND GROUNDING

Special attention should be given to the decoupling of the HS 7067 itself at the input (pin 5), where the capacitor must be at least 100 μF and connected as close to the device as possible. Large switching spikes at the input of the pass transistor can cause breakdown of the junction and destroy the device. (See Figure 13.)

The waveform at the top of the picture represents the voltage across the switch of a typical BUCK (step down) converter. When the switch is turned off, the current in the inductor falls to zero (see waveform at the bottom) and a switching spike occurs across the switch. This spike can reach several tens of volts on top of the normally expected voltage across the switch and lead to stress on the device if the overall voltage exceeds the maximum rating.

The picture below shows a spike of about ten volts with a 330 μF capacitor of average quality.



VERTICAL SCALE: 20 VOLTS/DIV
HORIZONTAL SCALE: 2 μS /DIV

FIGURE 13

TL/K/6746-17

The reference voltage (pin 2) must be decoupled with at least 10 μF and the compensation network (pin 1) should be decoupled with a ceramic capacitor of 1 nF to 10 nF. Switching noise on the reference voltage pin (pin 2) or on the compensation pin (pin 1) can create different types of oscillations and instabilities.

Because of the high current and high voltage capability of the HS 7067 a single point grounding or, at least a grounding where the force ground is separated from the circuit ground, is highly recommended.



LH1605/LH1605C

5 Amp, High Efficiency Switching Regulator

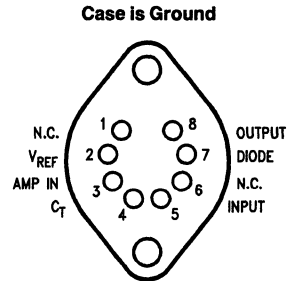
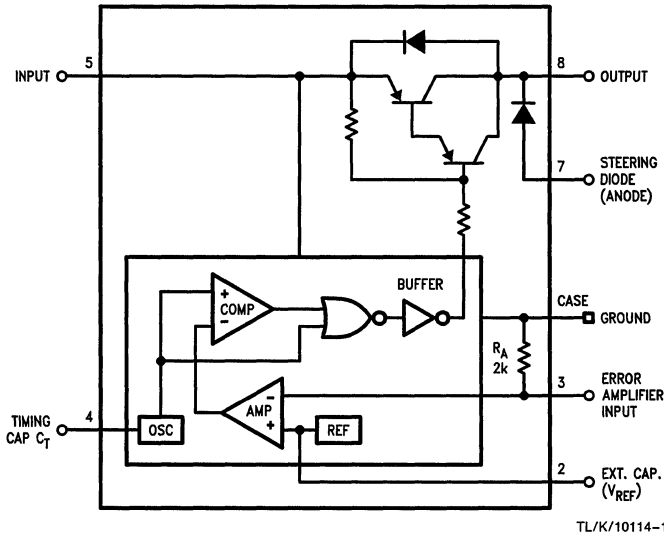
General Description

The LH1605 is a hybrid switching regulator with high output current capabilities. It incorporates a temperature-compensated voltage reference, a duty cycle modulator with the oscillator frequency programmable, error amplifier, high current-high voltage output switch, and a power diode. The LH1605 can supply up to 5A of output current over a wide range of regulated output voltage.

Features

- Step down switching regulator
- Output adjustable from 3.0V to 30V
- 5A output current
- High efficiency
- Frequency adjustable to 100 kHz
- Standard 8-pin TO-3 package

Block and Connection Diagrams



Top View
Order Number LH1605K or LH1605CK
See NS Package Number K08A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage (V_{IN})	35V max
Output Current (I_O)	6A
Operating Temperature (T_J)	150°C
Internal Power Dissipation (P_D) (Note 1)	20W
Operating Temperature (T_A)	
LH1605C	-25°C to +85°C
LH1605	-55°C to +125°C

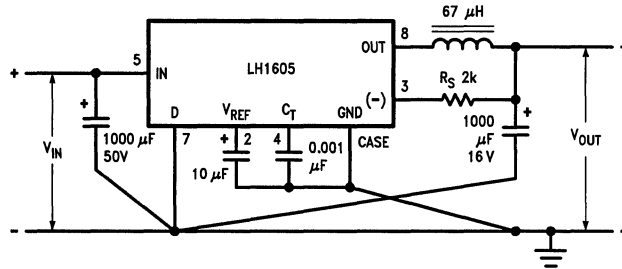
Storage Temperature Range (T_{STG})	-65°C to +150°C
Duty Cycle (D.C.)	20% to 80%
Steering Diode Reverse Voltage (V_R) (V_{8-7})	60V
Steering Diode Forward Current (I_D) (I_{7-8})	6A

Electrical Characteristics $T_C = 25^\circ\text{C}$, $V_{IN} = 15\text{V}$, $V_{OUT} = 10\text{V}$ unless otherwise specified

Symbol	Characteristics	Conditions	LH1605			LH1605C			Units
			Min	Typ	Max	Min	Typ	Max	
V_{OUT}	Output Voltage Range	$V_{IN} \geq V_O + 5V$ $I_O = 2A$ (Note 2)	3.0		30	3.0		30	
V_S	Switch Saturation Voltage	$I_C = 5.0A$ $I_C = 2.0A$		1.6 1.0	2.0 1.2		1.6 1.0	2.0 1.2	V
V_F	Steering Diode On Voltage	$I_D = 5.0A$ $I_D = 2.0A$		1.2 1.0	2.8 2.0		1.2 1.0	2.8 2.0	
V_{IN}	Supply Voltage Range		10		35	10		35	
I_R	Steering Diode Reverse Current	$V_R = 25V$		0.1	5.0		0.1	5.0	μA
I_Q	Quiescent Current	$I_{OUT} = 0.2A$		20			20		mA
V_2	Voltage on Pin 2			2.5			2.5		V
$\Delta V_2/\Delta T$	V_2 Temperature Coeff.			100			100		ppm/°C
V_4	Voltage Swing—Pin 4			3.0			3.0		V
I_4	Charging Current—Pin 4			70			70		μA
R_A	Resistance Pin 3 to GND			2.0			2.0		k Ω
$\Delta R_A/\Delta T$	Resistance Temp. Coeff.			75			75		ppm/°C
t_r	Voltage Rise Time	$I_{OUT} = 2.0A$ $I_{OUT} = 5.0A$		350 500			350 500		ns
t_f	Voltage Fall Time	$I_{OUT} = 2.0A$ $I_{OUT} = 5.0A$		300 400			300 400		
t_s	Storage Time	$I_{OUT} = 5.0A$		1.5			1.5		μs
t_d	Delay Time			100			100		ns
P_D	Power Dissipation	$V_{OUT} = 10V$ $I_{OUT} = 5.0A$		16			16		W
η	Efficiency			75			75		%
θ_{JC}	Thermal Resistance (Note 1)			5.0			5.0		°C/W

Note 1: θ_{JA} is typically 30°C/W for natural convection cooling.

Note 2: V_{OUT} refers to the output voltage range of switching supply after the output LC filter as shown in the Typical Application circuit.



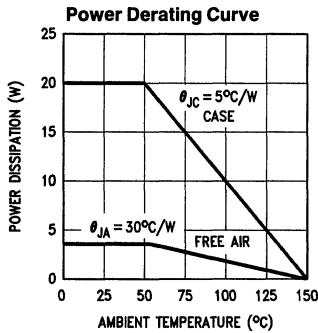
TL/K/10114-3

Minimum $V_{IN} - V_{OUT} = 5V$ for Proper Operation

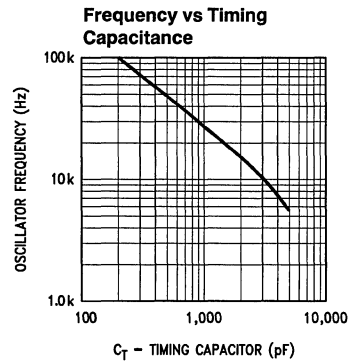
$$R_S = \frac{2 \times 10^3 (V_{OUT} - 2.5)}{2.5}$$

$V_{IN} = 10 - 18V$
 $V_{OUT} = 5V$
 $I_{OUT} = 3A$ (Max)
 $I_{OUT} = 1A$ (Min)
 $\eta \cong 70\%$

Load Reg. = 50 mV
 Line Reg. = 10 mV
 Ripple = 20 mV



TL/K/10114-4



TL/K/10114-5

Design Equations

$$\text{Efficiency } (\eta) = \frac{P_{OUT} \times 100}{P_{IN}}$$

$$\text{Transistor DC Losses } (P_T) = I_{OUT} \times V_S \left(\frac{t_{ON}}{t_{ON} + t_{OFF}} \right)$$

$$\text{Diode DC Losses } (P_D) = I_{OUT} \times V_F \left(\frac{t_{OFF}}{t_{ON} + t_{OFF}} \right)$$

$$\text{Drive Circuit Losses } (D_L) = \frac{V_{IN}^2}{300} \times \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

$$\text{Switching Losses Transistor } (P_S) = V_{IN} \times I_{OUT} \times \frac{t_r + t_f}{2(t_{ON} + t_{OFF})}$$

$$\text{Transistor Duty Cycle} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{V_{OUT}}{V_{IN}}$$

$$\text{Diode Duty Cycle} = \frac{t_{OFF}}{t_{ON} + t_{OFF}} = 1 - \frac{V_{OUT}}{V_{IN}}$$

$$\text{Power Inductor } (P_L) = I_{OUT}^2 \times R_L \text{ (Winding Resistance)}$$

$$\text{Efficiency } (\eta) = \frac{V_{OUT} I_{OUT}}{V_{OUT} I_{OUT} + P_T + P_D + D_L + P_S + P_L} \times 100\%$$

LM1524D/LM2524D/LM3524D

Regulating Pulse Width Modulator

General Description

The LM1524D family is an improved version of the industry standard LM1524. It has improved specifications and additional features yet is pin for pin compatible with existing 1524 families. New features reduce the need for additional external circuitry often required in the original version.

The LM1524D has a $\pm 1\%$ precision 5V reference. The current carrying capability of the output drive transistors has been raised to 200 mA while reducing V_{CEsat} and increasing V_{CE} breakdown to 60V. The common mode voltage range of the error-amp has been raised to 5.5V to eliminate the need for a resistive divider from the 5V reference.

In the LM1524D the circuit bias line has been isolated from the shut-down pin. This prevents the oscillator pulse amplitude and frequency from being disturbed by shut-down. Also at high frequencies (≈ 300 kHz) the max. duty cycle per output has been improved to 44% compared to 35% max. duty cycle in other 1524s.

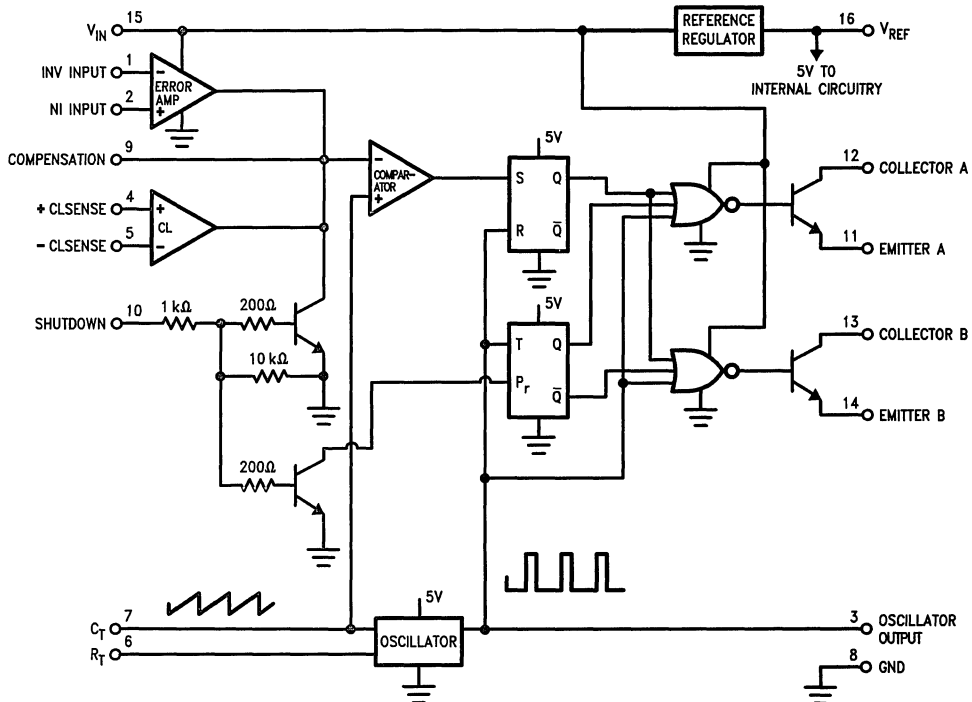
In addition, the LM1524D can now be synchronized externally, through pin 3. Also a latch has been added to insure

one pulse per period even in noisy environments. The LM1524D includes double pulse suppression logic that insures when a shut-down condition is removed the state of the T-flip-flop will change only after the first clock pulse has arrived. This feature prevents the same output from being pulsed twice in a row, thus reducing the possibility of core saturation in push-pull designs.

Features

- Fully interchangeable with standard LM1524 family
- $\pm 1\%$ precision 5V reference with thermal shut-down
- Output current to 200 mA DC
- 60V output capability
- Wide common mode input range for error-amp
- One pulse per period (noise suppression)
- Improved max. duty cycle at high frequencies
- Double pulse suppression
- Synchronize through pin 3

Block Diagram


3

Absolute Maximum Ratings (Note 5)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	40V
Collector Supply Voltage (LM1524D)	60V
(LM2524D)	55V
(LM3524D)	40V
Output Current DC (each)	200 mA
Oscillator Charging Current (Pin 7)	5 mA
Internal Power Dissipation	1W

Operating Junction Temperature Range (Note 2)

LM1524D	-55°C to +150°C
LM2524D	-40°C to +125°C
LM3524D	0°C to +125°C

Maximum Junction Temperature 150°C

Storage Temperature Range -65°C to +150°C

Lead Temperature (Soldering 10 sec.) J Pkg. 300°C

Lead Temperature (Soldering 4 sec.) M, N Pkg. 260°C

Electrical Characteristics (Note 1)

Symbol	Parameter	Conditions	LM1524D			LM2524D			LM3524D			Units
			Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	

REFERENCE SECTION

V _{REF}	Output Voltage		5	4.95		5	4.85	4.80	5	4.75		V _{Min}
				4.90				5.20				5.25
				5.05			5.15					
				5.10				5.20				
V _{RLine}	Line Regulation	V _{IN} = 8V to 40V	10	20		10	15	30	10	25	50	mV _{Max}
V _{RLoad}	Load Regulation	I _L = 0 mA to 20 mA	5	15		10	15	25	10	25	50	mV _{Max}
$\frac{\Delta V_{IN}}{\Delta V_{REF}}$	Ripple Rejection	f = 120 Hz	66			66			66			dB
I _{OS}	Short Circuit Current	V _{REF} = 0	50	25		50	25		50	25		mA Min
				150			180			200		mA Max
N _O	Output Noise	10 Hz ≤ f ≤ 10 kHz	40		100	40		100	40		100	μV _{rms} Max
	Long Term Stability	T _A = 125°C	20			20			20			

OSCILLATOR SECTION

f _{OSC}	Max. Freq.	R _T = 1k, C _T = 0.001 μF (Note 7)	550		500	550		500	350			kHz _{Min}
f _{OSC}	Initial Accuracy	R _T = 5.6k, C _T = 0.01 μF (Note 7)	20				17.5			17.5		kHz _{Min}
						20		22.5		22.5		kHz _{Max}
		R _T = 2.7k, C _T = 0.01 μF (Note 7)	38		36		38		34		30	
				40			42			46		kHz _{Max}
Δf _{OSC}	Freq. Change with V _{IN}	V _{IN} = 8 to 40V	0.5	1		0.5	1		0.5	1.0		% _{Max}
Δf _{OSC}	Freq. Change with Temp.	T _A = -55°C to +125°C at 20 kHz R _T = 5.6k, C _T = 0.01 μF	5			5			5			%
V _{OSC}	Output Amplitude (Pin 3) (Note 8)	R _T = 5.6k, C _T = 0.01 μF	3	2.4		3	2.4		3	2.4		V _{Min}
t _{PW}	Output Pulse Width (Pin 3)	R _T = 5.6k, C _T = 0.01 μF	0.5	1.5		0.5	1.5		0.5	1.5		μS _{Max}

Electrical Characteristics (Continued)

Symbol	Parameter	Conditions	LM1524D			LM2524D			LM3524D			Units
			Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
OSCILLATOR SECTION (Continued)												
	Sawtooth Peak Voltage	$R_T = 5.6k, C_T = 0.01 \mu F$	3.4	3.6		3.4	3.6	3.8		3.8		V_{Max}
	Sawtooth Valley Voltage	$R_T = 5.6k, C_T = 0.01 \mu F$	1.1	0.8		1.1	0.8	0.6		0.6		V_{Min}
ERROR-AMP SECTION												
V_{IO}	Input Offset Voltage	$V_{CM} = 2.5V$	0.5	5		2	8	10	2	10		mV_{Max}
I_{IB}	Input Bias Current	$V_{CM} = 2.5V$	1	5		1	8	10	1	10		μA_{Max}
I_{IO}	Input Offset Current	$V_{CM} = 2.5V$	0.5	1		0.5	1.0	1	0.5	1		μA_{Max}
I_{COSI}	Compensation Current (Sink)	$V_{IN(I)} - V_{IN(NI)} = 150 mV$	95	75		95	65		95	65		μA_{Min}
				115			125			125		μA_{Max}
I_{COSO}	Compensation Current (Source)	$V_{IN(NI)} - V_{IN(I)} = 150 mV$	-95	-115		-95	-125		-95	-125		μA_{Min}
				-75			-65			-65		μA_{Max}
A_{VOL}	Open Loop Gain	$R_L = \infty, V_{CM} = 2.5 V$	80	74		80	74	60	80	70	60	dB_{Min}
V_{CMR}	Common Mode Input Voltage Range			1.5			1.5	1.4		1.5		V_{Min}
				5.5			5.5	5.4		5.5		V_{Max}
$CMRR$	Common Mode Rejection Ratio		90	80		90	80		90	70		dB_{Min}
G_{BW}	Unity Gain Bandwidth	$A_{VOL} = 0 dB, V_{CM} = 2.5V$	3			3			2			MHz
V_O	Output Voltage Swing	$R_L = \infty$		0.5			0.5			0.5		V_{Min}
				5.5			5.5			5.5		V_{Max}
$PSRR$	Power Supply Rejection Ratio	$V_{IN} = 8 to 40V$	80		76	80		70	80	65		dB_{Min}
COMPARATOR SECTION												
t_{ON}	Minimum Duty Cycle	Pin 9 = 0.8V, $[R_T = 5.6k, C_T = 0.01 \mu F]$	0	0		0	0		0	0		$\%_{Max}$
t_{OSC}	Maximum Duty Cycle	Pin 9 = 3.9V, $[R_T = 5.6k, C_T = 0.01 \mu F]$	49	47		49	45		49	45		$\%_{Min}$
t_{ON}	Minimum Duty Cycle	Pin 9 = 3.9V, $[R_T = 1k, C_T = 0.001 \mu F]$	44	40		44	35		44	35		$\%_{Min}$
V_{COMPZ}	Input Threshold (Pin 9)	Zero Duty Cycle	1			1			1			V
V_{COMPM}	Input Threshold (Pin 9)	Maximum Duty Cycle	3.5			3.5			3.5			V
I_{IB}	Input Bias Current		-1			-1			-1			μA

Electrical Characteristics (Continued)

Symbol	Parameter	Conditions	LM1524D			LM2524D			LM3524D			Units
			Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
CURRENT LIMIT SECTION												
V _{SEN}	Sense Voltage	V _(Pin 2) - V _(Pin 1) ≥ 150 mV	200	190		200	180		200	180		mV _{Min}
				210			220			220		
TC-V _{sense}	Sense Voltage T.C.		0.2			0.2			0.2			mV/°C
	Common Mode Voltage Range	V ₅ - V ₄ = 300 mV	-0.7 1			-0.7 1			-0.7 1			V _{Min} V _{Max}
SHUT DOWN SECTION												
V _{SD}	High Input Voltage	V _(Pin 2) - V _(Pin 1) ≥ 150 mV	1	0.5 1.5		1	0.5 1.5		1	0.5 1.5		V _{Min} V _{Max}
I _{SD}	High Input Current	I _(pin 10)	1			1			1			mA
OUTPUT SECTION (EACH OUTPUT)												
V _{CES}	Collector Emitter Voltage Breakdown	I _C ≤ 100 μA		60			55			40		V _{Min}
I _{CES}	Collector Leakage Current	V _{CE} = 60V	0.1	50								μA _{Max}
		V _{CE} = 55V				0.1	50					
		V _{CE} = 40V							0.1	50		
V _{CESAT}	Saturation Voltage	I _E = 20 mA	0.2	0.4		0.2	0.5		0.2	0.7		V _{Max}
		I _E = 200 mA	1.5	2.2		1.5	2.2		1.5	2.5		
V _{EO}	Emitter Output Voltage	I _E = 50 mA	18	17		18	17		18	17		V _{Min}
t _R	Rise Time	V _{IN} = 20V, I _E = -250 μA R _C = 2k	200			200			200			ns
t _F	Fall Time	R _C = 2k	100			100			100			ns
SUPPLY CHARACTERISTICS SECTION												
V _{IN}	Input Voltage Range	After Turn-on		8 40			8 40			8 40		V _{Min} V _{Max}
T	Thermal Shutdown Temp.	(Note 2)	160			160			160			°C
I _{IN}	Stand By Current	V _{IN} = 40V (Note 6)	5	10		5	10		5	10		mA

Note 1: Unless otherwise stated, these specifications apply for T_A = T_J = 25°C. Boldface numbers apply over the rated temperature range: LM1524D is -55°C to 125°C, LM2524D is -40° to 85°C and LM3524D is 0°C to 70°C. V_{IN} = 20V and f_{OSC} = 20 kHz.

Note 2: For operation at elevated temperatures, devices in the J package must be derated based on a thermal resistance of 132°C/W, junction to ambient, and devices in the N package must be derated based on a thermal resistance of 86°C/W, junction to ambient. Devices in the M package must be derated at 125°C/W, junction to ambient.

Note 3: Tested limits are guaranteed and 100% tested in production.

Note 4: Design limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage range. These limits are not used to calculate outgoing quality level.

Note 5: Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

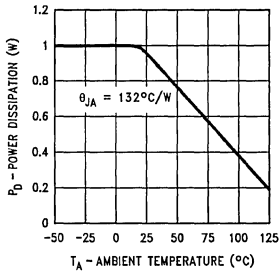
Note 6: Pins 1, 4, 7, 8, 11, and 14 are grounded; Pin 2 = 2V. All other inputs and outputs open.

Note 7: The value of a C_t capacitor can vary with frequency. Careful selection of this capacitor must be made for high frequency operation. Polystyrene was used in this test. NPO ceramic or polypropylene can also be used.

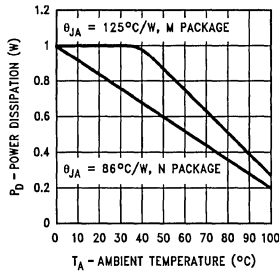
Note 8: OSC amplitude is measured open circuit. Available current is limited to 1 mA so care must be exercised to limit capacitive loading of fast pulses.

Typical Performance Characteristics

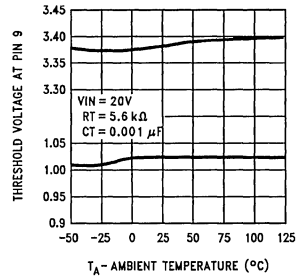
Maximum Average Power Dissipation (J Package)



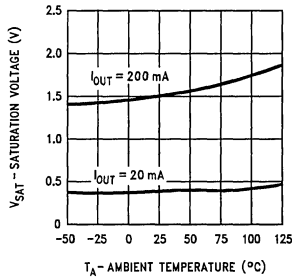
Maximum Average Power Dissipation (N, M Packages)



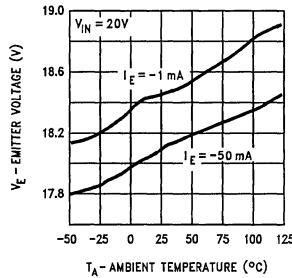
Maximum & Minimum Duty Cycle Threshold Voltage



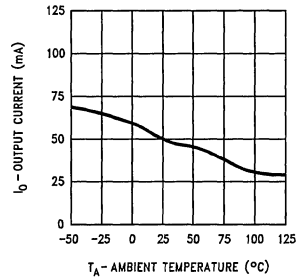
Output Transistor Saturation Voltage



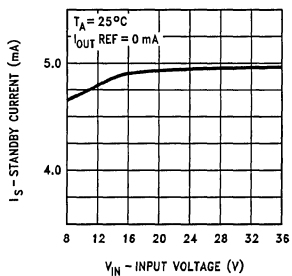
Output Transistor Emitter Voltage



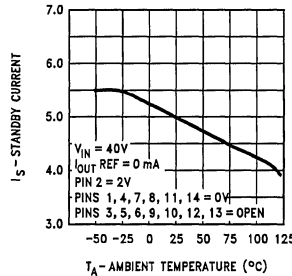
Reference Transistor Peak Output Current



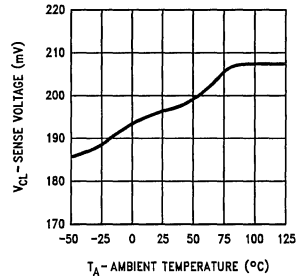
Standby Current vs Voltage



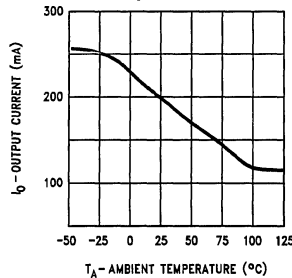
Standby Current vs Temperature



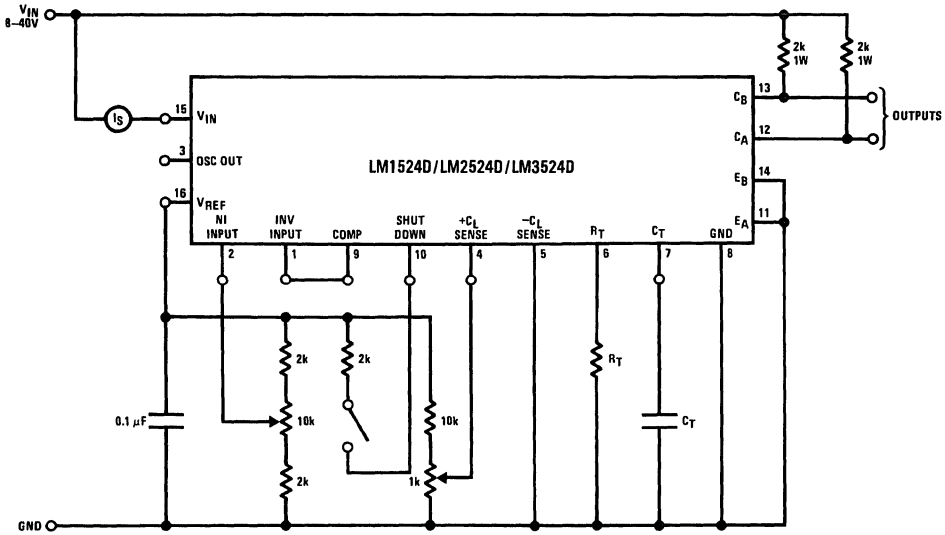
Current Limit Sense Voltage



Switching Transistor Peak Output Current vs Temperature



Test Circuit



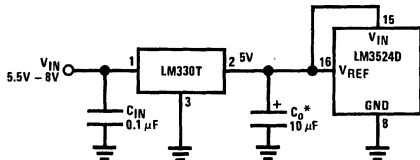
TL/H/8650-4

Functional Description

INTERNAL VOLTAGE REGULATOR

The LM1524D has an on-chip 5V, 50 mA, short circuit protected voltage regulator. This voltage regulator provides a supply for all internal circuitry of the device and can be used as an external reference.

For input voltages of less than 8V the 5V output should be shorted to pin 15, V_{IN} , which disables the 5V regulator. With these pins shorted the input voltage must be limited to a maximum of 6V. If input voltages of 6V–8V are to be used, a pre-regulator, as shown in *Figure 1*, must be added.



TL/H/8650-10

*Minimum C_O of 10 μF required for stability.

FIGURE 1

OSCILLATOR

The LM1524D provides a stable on-board oscillator. Its frequency is set by an external resistor, R_T and capacitor, C_T . A graph of R_T , C_T vs oscillator frequency is shown in *Figure 2*. The oscillator's output provides the signals for triggering an internal flip-flop, which directs the PWM information to the outputs, and a blanking pulse to turn off both outputs during transitions to ensure that cross conduction does not occur. The width of the blanking pulse, or dead time, is controlled by the value of C_T , as shown in *Figure 3*. The recommended values of R_T are 1.8 k Ω to 100 k Ω , and for C_T , 0.001 μF to 0.1 μF .

If two or more LM1524D's must be synchronized together, the easiest method is to interconnect all pin 3 terminals, tie all pin 7's (together) to a single C_T , and leave all pin 6's open except one which is connected to a single R_T . This method works well unless the LM1524D's are more than 6" apart.

A second synchronization method is appropriate for any circuit layout. One LM1524D, designated as master, must have its R_T - C_T set for the correct period. The other slave LM1524D(s) should each have an R_T - C_T set for a 10% longer period. All pin 3's must then be interconnected to allow the master to properly reset the slave units.

The oscillator may be synchronized to an external clock source by setting the internal free-running oscillator frequency 10% slower than the external clock and driving pin 3 with a pulse train (approx. 3V) from the clock. Pulse width should be greater than 50 ns to insure full synchronization.

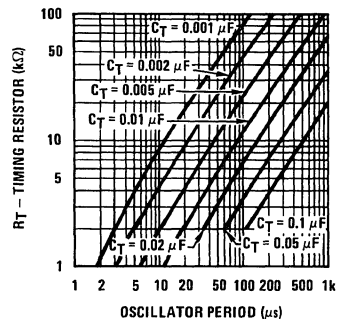


FIGURE 2

TL/H/8650-5

Functional Description (Continued)

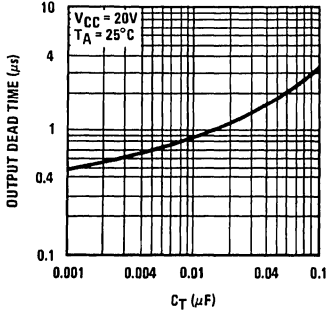


FIGURE 3

TL/H/8650-6

ERROR AMPLIFIER

The error amplifier is a differential input, transconductance amplifier. Its gain, nominally 86 dB, is set by either feedback or output loading. This output loading can be done with either purely resistive or a combination of resistive and reactive components. A graph of the amplifier's gain vs output load resistance is shown in *Figure 4*.

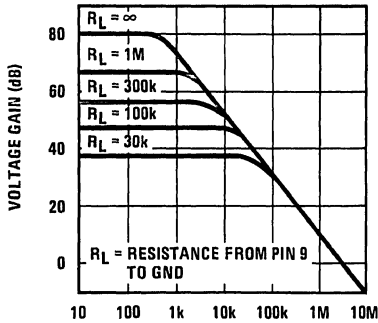


FIGURE 4

TL/H/8650-7

The output of the amplifier, or input to the pulse width modulator, can be overridden easily as its output impedance is very high ($Z_O \approx 5 \text{ M}\Omega$). For this reason a DC voltage can be applied to pin 9 which will override the error amplifier and force a particular duty cycle to the outputs. An example of this could be a non-regulating motor speed control where a variable voltage was applied to pin 9 to control motor speed. A graph of the output duty cycle vs the voltage on pin 9 is shown in *Figure 5*.

The duty cycle is calculated as the percentage ratio of each output's ON-time to the oscillator period. Paralleling the outputs doubles the observed duty cycle.

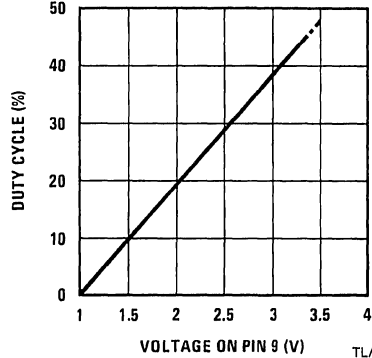


FIGURE 5

TL/H/8650-8

The amplifier's inputs have a common-mode input range of 1.5V–5.5V. The on board regulator is useful for biasing the inputs to within this range.

CURRENT LIMITING

The function of the current limit amplifier is to override the error amplifier's output and take control of the pulse width. The output duty cycle drops to about 25% when a current limit sense voltage of 200 mV is applied between the $+C_L$ and $-C_L$ sense terminals. Increasing the sense voltage approximately 5% results in a 0% output duty cycle. Care should be taken to ensure the -0.7V to $+1.0\text{V}$ input common-mode range is not exceeded.

OUTPUT STAGES

The outputs of the LM1524D are NPN transistors, capable of a maximum current of 200 mA. These transistors are driven 180° out of phase and have non-committed open collectors and emitters as shown in *Figure 6*.

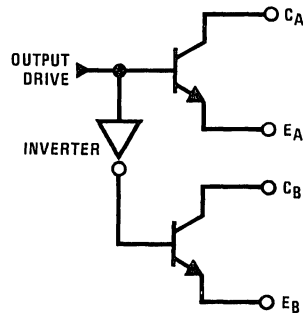
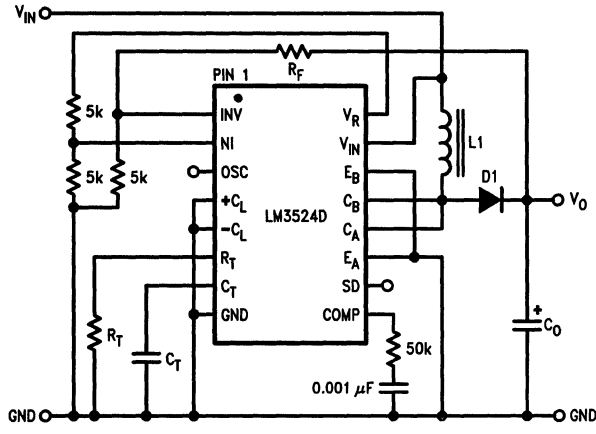


FIGURE 6

TL/H/8650-9

Typical Applications



Design Equations

$$R_F = 5k \left(\frac{V_O}{2.5} - 1 \right)$$

$$f_{OSC} \approx \frac{1}{R_T C_T}$$

$$L_1 = \frac{2.5 V_{IN}^2 (V_O - V_{IN})}{f_{OSC}^2 \Delta V_O V_O^2}$$

$$C_0 = \frac{I_O (V_O - V_{IN})}{f_{OSC} \Delta V_O V_O}$$

$$I_O(MAX) = I_{IN} \frac{V_{IN}}{V_O}$$

FIGURE 7. Positive Regulator, Step-Up Basic Configuration ($I_{IN(MAX)} = 80 \text{ mA}$)

TL/H/8650-11

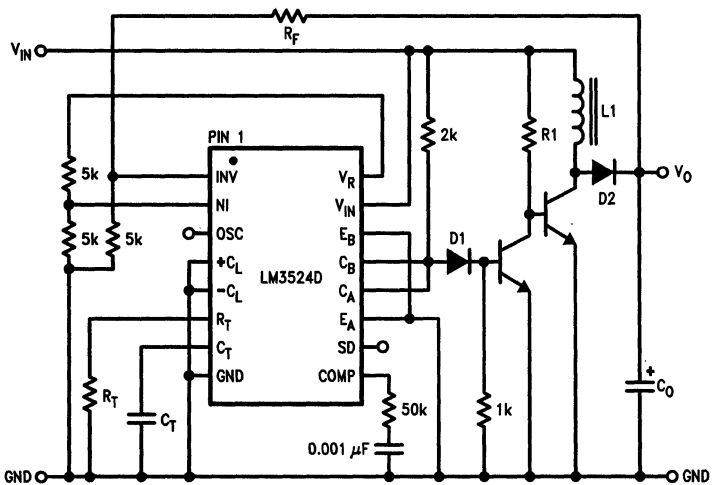
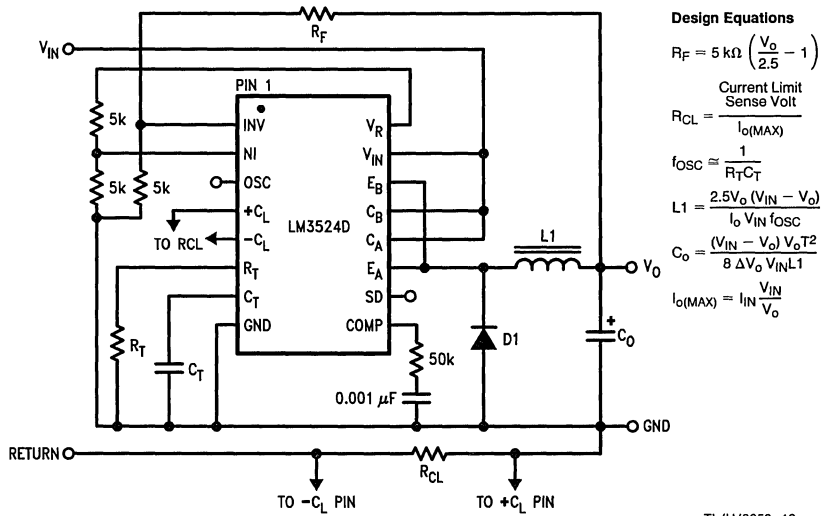


FIGURE 8. Positive Regulator, Step-Up Boosted Current Configuration

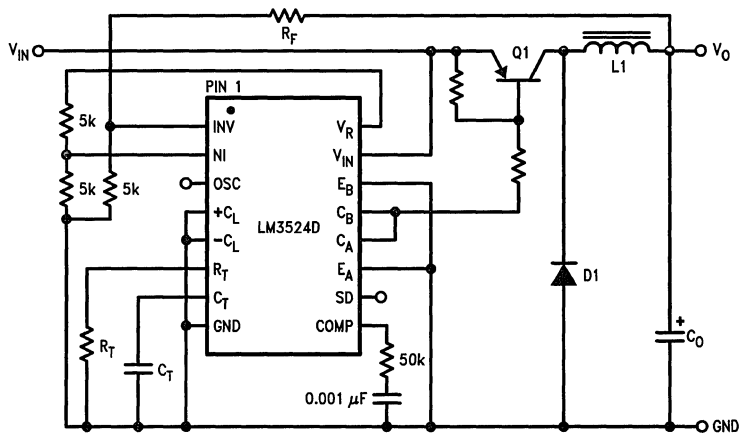
TL/H/8650-12

Typical Applications (Continued)



TL/H/8650-13

FIGURE 9. Positive Regulator, Step-Down Basic Configuration ($I_{IN(\text{MAX})} = 80 \text{ mA}$)



TL/H/8650-14

FIGURE 10. Positive Regulator, Step-Down Boosted Current Configuration

Typical Applications (Continued)

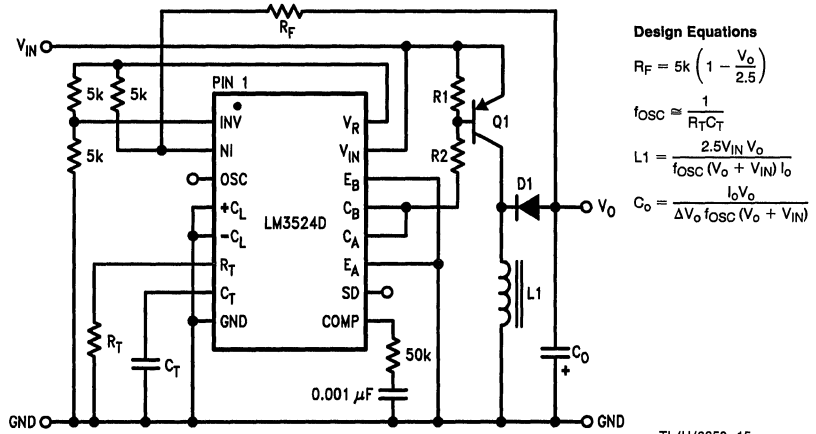
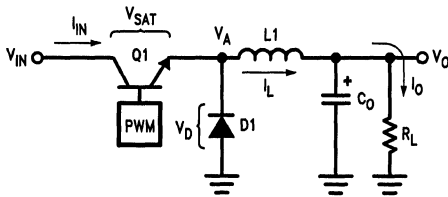


FIGURE 11. Boosted Current Polarity Inverter

TL/H/8650-15

BASIC SWITCHING REGULATOR THEORY AND APPLICATIONS

The basic circuit of a step-down switching regulator circuit is shown in Figure 12, along with a practical circuit design using the LM3524D in Figure 15.



TL/H/8650-16

FIGURE 12. Basic Step-Down Switching Regulator

The circuit works as follows: Q1 is used as a switch, which has ON and OFF times controlled by the pulse width modulator. When Q1 is ON, power is drawn from V_{IN} and supplied to the load through L1; V_A is at approximately V_{IN} , D1 is reverse biased, and C_O is charging. When Q1 turns OFF the inductor L1 will force V_A negative to keep the current flowing in it, D1 will start conducting and the load current will flow through D1 and L1. The voltage at V_A is smoothed by the L1, C_O filter giving a clean DC output. The current flowing through L1 is equal to the nominal DC load current plus some ΔI_L which is due to the changing voltage across it. A good rule of thumb is to set $\Delta/L_{p,p} \approx 40\% \times I_O$.

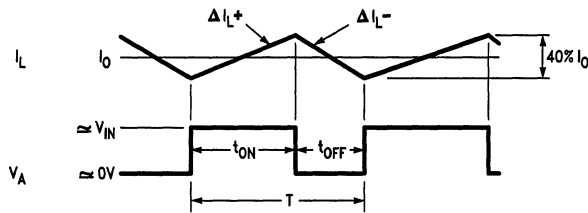


FIGURE 13

TL/H/8650-17

Typical Applications (Continued)

From the relation $V_L = L \frac{di}{dt}$, $\Delta I_L \approx \frac{V_L T}{L1}$

$$\Delta I_L^+ = \frac{(V_{IN} - V_o) t_{ON}}{L1}; \Delta I_L^- = \frac{V_o t_{OFF}}{L1}$$

Neglecting V_{SAT} , V_D , and settling $\Delta I_L^+ = \Delta I_L^-$;

$$V_o \approx V_{IN} \left(\frac{t_{ON}}{t_{OFF} + t_{ON}} \right) = V_{IN} \left(\frac{T}{T} \right);$$

where T = Total Period

The above shows the relation between V_{IN} , V_o and duty cycle.

$$I_{IN(DC)} = I_{OUT(DC)} \left(\frac{t_{ON}}{t_{ON} + t_{OFF}} \right),$$

as Q1 only conducts during t_{ON} .

$$P_{IN} = I_{IN(DC)} V_{IN} = (I_o(DC)) \left(\frac{t_{ON}}{t_{ON} + t_{OFF}} \right) V_{IN}$$

$$P_o = I_o V_o$$

The efficiency, η , of the circuit is:

$$\eta_{MAX} = \frac{P_o}{P_{IN}} = \frac{I_o V_o}{I_o \left(\frac{t_{ON}}{T} \right) V_{IN} + \frac{(V_{SAT} t_{ON} + V_{D1} t_{OFF}) I_o}{T}}$$

$$= \frac{V_o}{V_o + 1} \text{ for } V_{SAT} = V_{D1} = 1V.$$

η_{MAX} will be further decreased due to switching losses in Q1. For this reason Q1 should be selected to have the maximum possible f_T , which implies very fast rise and fall times.

CALCULATING INDUCTOR L1

$$t_{ON} \approx \frac{(\Delta I_L^+) \times L1}{(V_{IN} - V_o)}, t_{OFF} = \frac{(\Delta I_L^-) \times L1}{V_o}$$

$$t_{ON} + t_{OFF} = T = \frac{(\Delta I_L^+) \times L1}{(V_{IN} - V_o)} + \frac{(\Delta I_L^-) \times L1}{V_o}$$

$$= \frac{0.4 I_o L1}{(V_{IN} - V_o)} + \frac{0.4 I_o L1}{V_o}$$

Since $\Delta I_L^+ = \Delta I_L^- = 0.4 I_o$

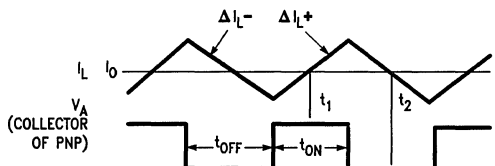


FIGURE 14

TL/H/8650-18

Solving the above for L1

$$L1 = \frac{2.5 V_o (V_{IN} - V_o)}{I_o V_{IN} f}$$

where: L1 is in Henrys

f is switching frequency in Hz

Also, see LM1578 data sheet for graphical methods of inductor selection.

CALCULATING OUTPUT FILTER CAPACITOR C_o:

Figure 14 shows L1's current with respect to Q1's t_{ON} and t_{OFF} times. This current must flow to the load and C_o . C_o 's current will then be the difference between I_L and I_o .

$$I_{C_o} = I_L - I_o$$

From Figure 14 it can be seen that current will be flowing into C_o for the second half of t_{ON} through the first half of t_{OFF} , or a time, $t_{ON}/2 + t_{OFF}/2$. The current flowing for this time is $\Delta I_L/4$. The resulting ΔV_o or ΔV_o is described by:

$$\Delta V_{op-p} = \frac{1}{C} \times \frac{\Delta I_L}{4} \times \left(\frac{t_{ON}}{2} + \frac{t_{OFF}}{2} \right)$$

$$= \frac{\Delta I_L}{4C} \left(\frac{t_{ON} + t_{OFF}}{2} \right)$$

Since $\Delta I_L = \frac{V_o(T - t_{ON})}{L1}$ and $t_{ON} = \frac{V_o T}{V_{IN}}$

$$\Delta V_{op-p} = \frac{V_o \left(T - \frac{V_o T}{V_{IN}} \right)}{4C L1} \left(\frac{T}{2} \right) = \frac{(V_{IN} - V_o) V_o T^2}{8V_{IN} C_o L1} \text{ or}$$

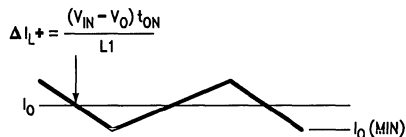
$$C_o = \frac{(V_{IN} - V_o) V_o T^2}{8 \Delta V_o V_{IN} L1}$$

where: C is in farads, T is $\frac{1}{\text{switching frequency}}$

ΔV_o is p-p output ripple

For best regulation, the inductor's current cannot be allowed to fall to zero. Some minimum load current I_o , and thus inductor current, is required as shown below:

$$I_o(MIN) = \frac{(V_{IN} - V_o) t_{ON}}{2L1} = \frac{(V_{IN} - V_o) V_o}{2fV_{IN}L1}$$



TL/H/8650-19

Typical Applications (Continued)

A complete step-down switching regulator schematic, using the LM3524D, is illustrated in *Figure 15*. Transistors Q1 and Q2 have been added to boost the output to 1A. The 5V regulator of the LM3524D has been divided in half to bias the error amplifier's non-inverting input to within its common-mode range. Since each output transistor is on for half the period, actually 45%, they have been paralleled to allow longer possible duty cycle, up to 90%. This makes a lower possible input voltage. The output voltage is set by:

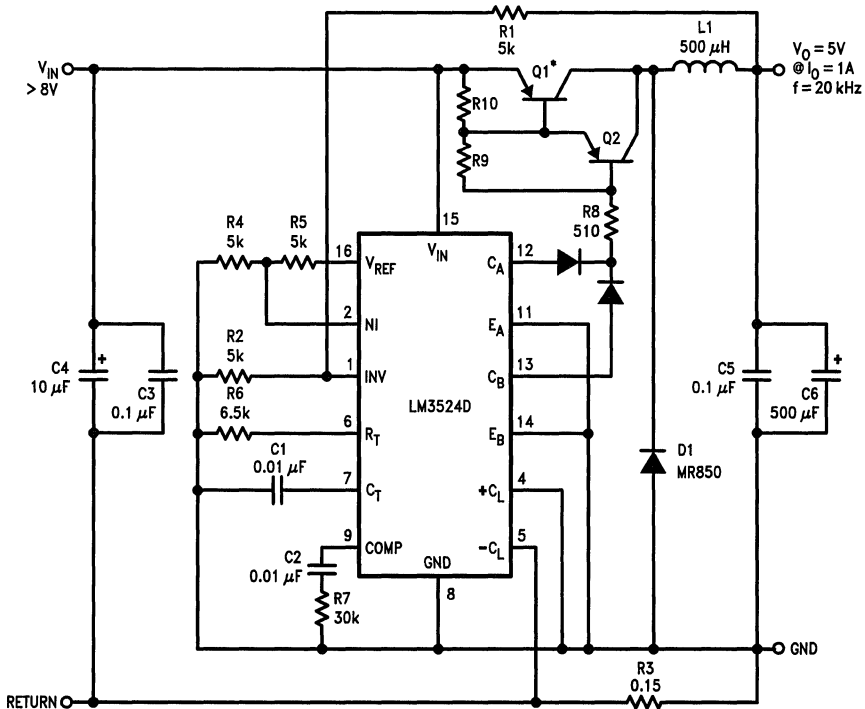
$$V_o = V_{NI} \left(1 + \frac{R_1}{R_2} \right),$$

where V_{NI} is the voltage at the error amplifier's non-inverting input.

Resistor R3 sets the current limit to:

$$\frac{200 \text{ mV}}{R_3} = \frac{200 \text{ mV}}{0.15} = 1.3\text{A}.$$

Figure 16 and *17* show a PC board layout and stuffing diagram for the 5V, 1A regulator of *Figure 15*. The regulator's performance is listed in *Table I*.



*Mounted to Staver Heatsink No. V5-1.

Q1 = BD344

Q2 = 2N5023

L1 = >40 turns No. 22 wire on Ferroxcube No. K300502 Torroid core.

FIGURE 15. 5V, 1 Amp Step-Down Switching Regulator

TL/H/8650-20

Typical Applications (Continued)

TABLE I

Parameter	Conditions	Typical Characteristics
Output Voltage	$V_{IN} = 10V, I_o = 1A$	5V
Switching Frequency	$V_{IN} = 10V, I_o = 1A$	20 kHz
Short Circuit Current Limit	$V_{IN} = 10V$	1.3A
Load Regulation	$V_{IN} = 10V$ $I_o = 0.2 - 1A$	3 mV
Line Regulation	$\Delta V_{IN} = 10 - 20V,$ $f_o = 1A$	6 mV
Efficiency	$V_{IN} = 10V, I_o = 1A$	80%
Output Ripple	$V_{IN} = 10V, I_o = 1A$	10 mVp-p

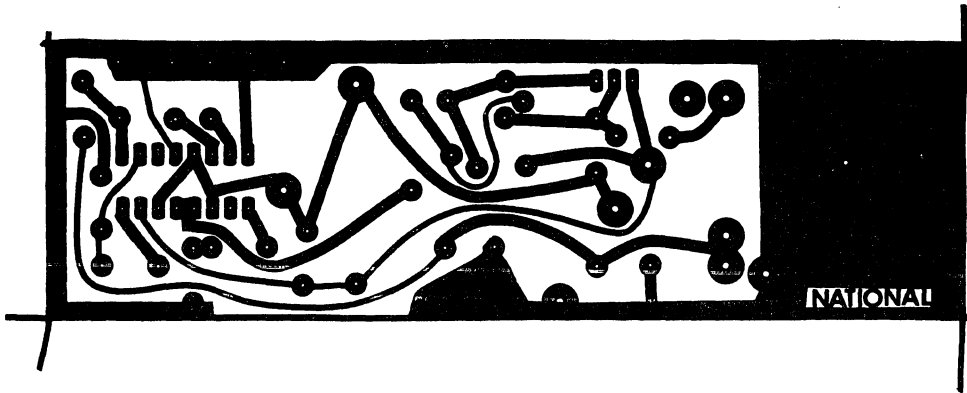


FIGURE 16. 5V, 1 Amp Switching Regulator, Foil Side

TL/H/8650-21

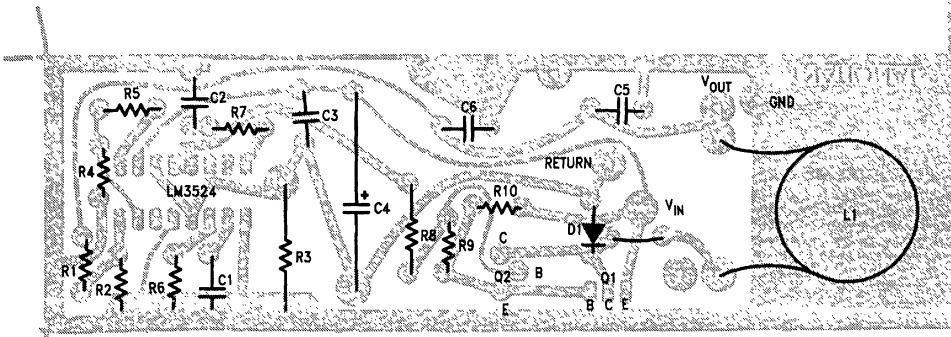


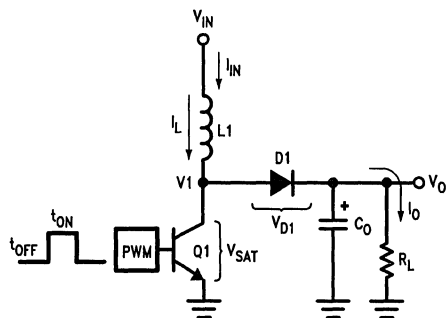
FIGURE 17. Stuffing Diagram, Component Side

TL/H/8650-22

Typical Applications (Continued)

THE STEP-UP SWITCHING REGULATOR

Figure 18 shows the basic circuit for a step-up switching regulator. In this circuit Q1 is used as a switch to alternately apply V_{IN} across inductor L1. During the time, t_{ON} , Q1 is ON and energy is drawn from V_{IN} and stored in L1; D1 is reverse biased and I_o is supplied from the charge stored in C_o . When Q1 opens, t_{OFF} , voltage V1 will rise positively to the point where D1 turns ON. The output current is now supplied through L1, D1 to the load and any charge lost from C_o during t_{ON} is replenished. Here also, as in the step-down regulator, the current through L1 has a DC component plus some ΔI_L . ΔI_L is again selected to be approximately 40% of I_L . Figure 19 shows the inductor's current in relation to Q1's ON and OFF times.



TL/H/8650-23

FIGURE 18. Basic Step-Up Switching Regulator

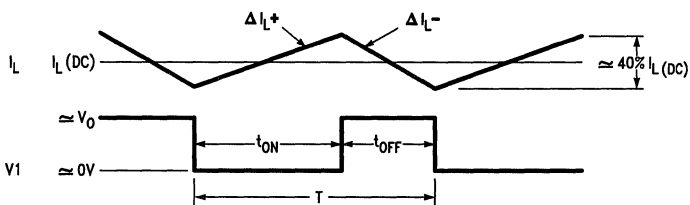


FIGURE 19

TL/H/8650-24

Typical Applications (Continued)

$$\text{From } \Delta I_L = \frac{V_L T}{L}, \Delta I_L^+ \approx \frac{V_{IN} t_{ON}}{L1}$$

$$\text{and } \Delta I_L^- \approx \frac{(V_o - V_{IN}) t_{OFF}}{L1}$$

Since $\Delta I_L^+ = \Delta I_L^-$, $V_{IN} t_{ON} = V_o t_{OFF} - V_{IN} t_{OFF}$, and neglecting V_{SAT} and V_{D1}

$$V_o \approx V_{IN} \left(1 + \frac{t_{ON}}{t_{OFF}} \right)$$

The above equation shows the relationship between V_{IN} , V_o and duty cycle.

In calculating input current $I_{IN(DC)}$, which equals the inductor's DC current, assume first 100% efficiency:

$$P_{IN} = I_{IN(DC)} V_{IN}$$

$$P_{OUT} = I_o V_o = I_o V_{IN} \left(1 + \frac{t_{ON}}{t_{OFF}} \right)$$

for $\eta = 100\%$, $P_{OUT} = P_{IN}$

$$I_o V_{IN} \left(1 + \frac{t_{ON}}{t_{OFF}} \right) = I_{IN(DC)} V_{IN}$$

$$I_{IN(DC)} = I_o \left(1 + \frac{t_{ON}}{t_{OFF}} \right)$$

This equation shows that the input, or inductor, current is larger than the output current by the factor $(1 + t_{ON}/t_{OFF})$. Since this factor is the same as the relation between V_o and V_{IN} , $I_{IN(DC)}$ can also be expressed as:

$$I_{IN(DC)} = I_o \left(\frac{V_o}{V_{IN}} \right)$$

So far it is assumed $\eta = 100\%$, where the actual efficiency or η_{MAX} will be somewhat less due to the saturation voltage of Q1 and forward on voltage of D1. The internal power loss due to these voltages is the average I_L current flowing, or I_{IN} , through either V_{SAT} or V_{D1} . For $V_{SAT} = V_{D1} = 1V$ this power loss becomes $I_{IN(DC)} (1V)$. η_{MAX} is then:

$$\Delta_{MAX} = \frac{P_o}{P_{IN}} = \frac{V_o I_o}{V_o I_o + I_{IN} (1V)} = \frac{V_o I_o}{V_o I_o + I_o \left(1 + \frac{t_{ON}}{t_{OFF}} \right)}$$

$$\text{From } V_o = V_{IN} \left(1 + \frac{t_{ON}}{t_{OFF}} \right)$$

$$\eta_{max} = \frac{V_{IN}}{V_{IN} + 1}$$

This equation assumes only DC losses, however η_{MAX} is further decreased because of the switching time of Q1 and D1.

In calculating the output capacitor C_o it can be seen that C_o supplies I_o during t_{ON} . The voltage change on C_o during this time will be some $\Delta V_c = \Delta V_o$ or the output ripple of the regulator. Calculation of C_o is:

$$\Delta V_o = \frac{I_o t_{ON}}{C_o} \text{ or } C_o = \frac{I_o t_{ON}}{\Delta V_o}$$

$$\text{From } V_o = V_{IN} \left(\frac{T}{t_{OFF}} \right); t_{OFF} = \frac{V_{IN}}{V_o} T$$

$$\text{where } T = t_{ON} + t_{OFF} = \frac{1}{f}$$

$$t_{ON} = T - \frac{V_{IN}}{V_o} T = T \left(\frac{V_o - V_{IN}}{V_o} \right) \text{ therefore:}$$

$$C_o = \frac{I_o T \left(\frac{V_o - V_{IN}}{V_o} \right)}{\Delta V_o} = \frac{I_o (V_o - V_{IN})}{f \Delta V_o V_o}$$

where: C_o is in farads, f is the switching frequency, ΔV_o is the p-p output ripple

Calculation of inductor L1 is as follows:

$$L1 = \frac{V_{IN} t_{ON}}{\Delta I_L^+}, \text{ since during } t_{ON},$$

V_{IN} is applied across L1

$$\Delta I_{L-p-p} = 0.4 I_L = 0.4 I_{IN} = 0.4 I_o \left(\frac{V_o}{V_{IN}} \right), \text{ therefore:}$$

$$L1 = \frac{V_{IN} t_{ON}}{0.4 I_o \left(\frac{V_o}{V_{IN}} \right)} \text{ and since } t_{ON} = \frac{T (V_o - V_{IN})}{V_o}$$

$$L1 = \frac{2.5 V_{IN}^2 (V_o - V_{IN})}{f I_o V_o^2}$$

where: L1 is in henrys, f is the switching frequency in Hz

Typical Applications (Continued)

To apply the above theory, a complete step-up switching regulator is shown in *Figure 20*. Since V_{IN} is 5V, V_{REF} is tied to V_{IN} . The input voltage is divided by 2 to bias the error amplifier's inverting input. The output voltage is:

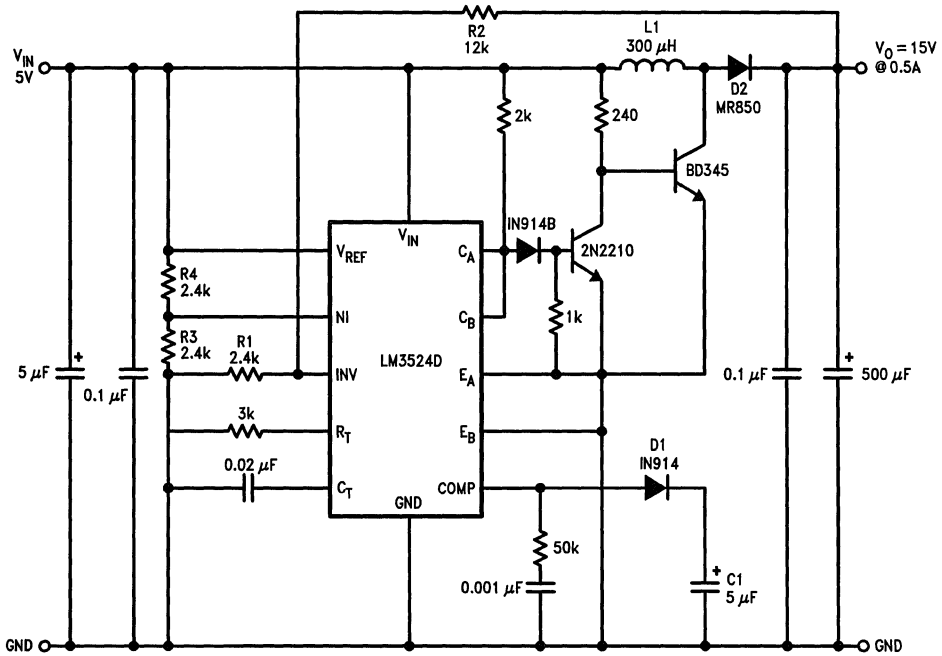
$$V_{OUT} = \left(1 + \frac{R_2}{R_1}\right) \times V_{IN} = 2.5 \times \left(1 + \frac{R_2}{R_1}\right)$$

The network D1, C1 forms a slow start circuit.

This holds the output of the error amplifier initially low thus reducing the duty-cycle to a minimum. Without the slow start

circuit the inductor may saturate at turn-on because it has to supply high peak currents to charge the output capacitor from 0V. It should also be noted that this circuit has no supply rejection. By adding a reference voltage at the non-inverting input to the error amplifier, see *Figure 21*, the input voltage variations are rejected.

The LM3524D can also be used in inductorless switching regulators. *Figure 22* shows a polarity inverter which if connected to *Figure 20* provides a -15V unregulated output.



L1 = > 25 turns No. 24 wire on Ferroxcube No. K300502 Torroid core.

FIGURE 20. 15V, 0.5A Step-Up Switching Regulator

TL/H/8650-25

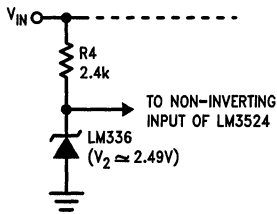


FIGURE 21

TL/H/8650-26

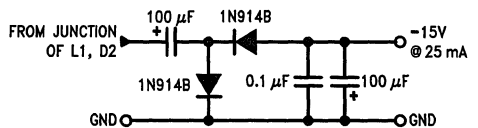
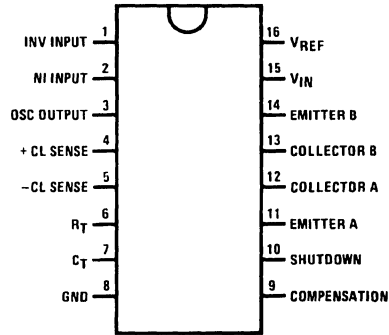


FIGURE 22

TL/H/8650-27

Connection Diagram



TL/H/8650-2

Top View

Order Number LM1524DJ
See NS Package Number J16A

Order Number LM2524DN or LM3524DN
See NS Package Number N16E

Order Number LM3524DM
See NS Package Number M16A



LM2574/LM2574HV Series Simple Switcher™ 0.5A Step-Down Voltage Regulator

General Description

The LM2574 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 0.5A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2574 series offers a high-efficiency replacement for popular three-terminal linear regulators. Because of its high efficiency, the copper traces on the printed circuit board are normally the only heat sinking needed.

A standard series of inductors optimized for use with the LM2574 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed $\pm 4\%$ tolerance on output voltage within specified input voltages and output load conditions, and $\pm 10\%$ on the oscillator frequency. External shutdown is included, featuring $50 \mu\text{A}$ (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

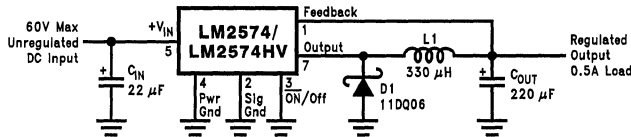
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) $\pm 4\%$ max over line and load conditions
- Guaranteed 0.5A output current
- Wide input voltage range, 40V, up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

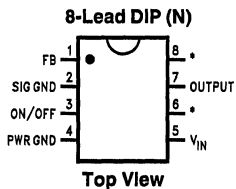
Typical Application (Fixed Output Voltage Versions)



Note: Pin numbers are for 8-pin DIP package.

TL/H/11394-1

Connection Diagrams

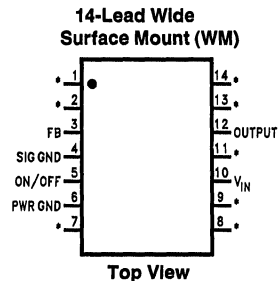


*No internal connection, but should be soldered to PC board for best heat transfer.

TL/H/11394-2

Order Number LM2574-3.3HVN, LM2574HVN-5.0,
LM2574HVN-12, LM2574HVN-15, LM2574HVN-ADJ,
LM2574N-3.3, LM2574N-5.0, LM2574N-12,
LM2574N-15 or LM2574N-ADJ
See NS Package Number N08A

Patent Pending



TL/H/11394-3

Order Number LM2574HVM-3.3, LM2574HVM-5.0,
LM2574HVM-12, LM2574HVM-15, LM2574HVM-ADJ,
LM2574M-3.3, LM2574M-5.0, LM2574M-12,
LM2574M-15 or LM2574M-ADJ
See NS Package Number M14B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM2574	45V
LM2574HV	63V
$\overline{\text{ON}}/\text{OFF}$ Pin Input Voltage	$-0.3\text{V} \leq V \leq +V_{\text{IN}}$
Output Voltage to Ground (Steady State)	-1V
Power Dissipation	Internally Limited
Storage Temperature Range	-65°C to +150°C

Minimum ESD Rating (C = 100 pF, R = 1.5 k Ω)	2 kV
Lead Temperature (Soldering, 10 seconds)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range LM2574/LM2574HV	$-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$
Supply Voltage LM2574	40V
LM2574HV	60V

LM2574-3.3, LM2574HV-3.3

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-3.3 LM2574HV-3.3		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{OUT}	Output Voltage	$V_{\text{IN}} = 12\text{V}, I_{\text{LOAD}} = 100\text{ mA}$	3.3	3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574	$4.75\text{V} \leq V_{\text{IN}} \leq 40\text{V}, 0.1\text{A} \leq I_{\text{LOAD}} \leq 0.5\text{A}$	3.3	3.168/ 3.135 3.432/ 3.465	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574HV	$4.75\text{V} \leq V_{\text{IN}} \leq 60\text{V}, 0.1\text{A} \leq I_{\text{LOAD}} \leq 0.5\text{A}$	3.3	3.168/ 3.135 3.450/ 3.482	V(Min) V(Max)
η	Efficiency	$V_{\text{IN}} = 12\text{V}, I_{\text{LOAD}} = 0.5\text{A}$	72		%

LM2574-5.0, LM2574HV-5.0

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-5.0 LM2574HV-5.0		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{OUT}	Output Voltage	$V_{\text{IN}} = 12\text{V}, I_{\text{LOAD}} = 100\text{ mA}$	5	4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574	$7\text{V} \leq V_{\text{IN}} \leq 40\text{V}, 0.1\text{A} \leq I_{\text{LOAD}} \leq 0.5\text{A}$	5	4.800/ 4.750 5.200/ 5.250	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574HV	$7\text{V} \leq V_{\text{IN}} \leq 60\text{V}, 0.1\text{A} \leq I_{\text{LOAD}} \leq 0.5\text{A}$	5	4.800/ 4.750 5.225/ 5.275	V(Min) V(Max)
η	Efficiency	$V_{\text{IN}} = 12\text{V}, I_{\text{LOAD}} = 0.5\text{A}$	77		%

LM2574-12, LM2574HV-12

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-12 LM2574HV-12		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V _{OUT}	Output Voltage	V _{IN} = 25V, I _{LOAD} = 100 mA	10	11.76 12.24	V V(Min) V(Max)
V _{OUT}	Output Voltage LM2574	15V ≤ V _{IN} ≤ 40V, 0.1A ≤ I _{LOAD} ≤ 0.5A	12	11.52/ 11.40 12.48/ 12.60	V V(Min) V(Max)
V _{OUT}	Output Voltage LM2574HV	15V ≤ V _{IN} ≤ 60V, 0.1A ≤ I _{LOAD} ≤ 0.5A	12	11.52/ 11.40 12.54/ 12.66	V(Min) V(Max)
η	Efficiency	V _{IN} = 15V, I _{LOAD} = 0.5A	88		%

LM2574-15, LM2574HV-15

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-15 LM2574HV-15		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V _{OUT}	Output Voltage	V _{IN} = 30V, I _{LOAD} = 100 mA	15	14.70 15.30	V V(Min) V(Max)
V _{OUT}	Output Voltage LM2574	18V ≤ V _{IN} ≤ 40V, 0.1A ≤ I _{LOAD} ≤ 0.5A	15	14.40/ 14.25 15.60/ 15.75	V V(Min) V(Max)
V _{OUT}	Output Voltage LM2574HV	18V ≤ V _{IN} ≤ 60V, 0.1A ≤ I _{LOAD} ≤ 0.5A	15	14.40/ 14.25 15.68/ 15.83	V(Min) V(Max)
η	Efficiency	V _{IN} = 18V, I _{LOAD} = 0.5A	88		%

LM2574-ADJ, LM2574HV-ADJ

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12\text{V}$, $I_{LOAD} = 100\text{mA}$.

Symbol	Parameter	Conditions	LM2574-ADJ LM2574HV-ADJ		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{FB}	Feedback Voltage	$V_{IN} = 12\text{V}$, $I_{LOAD} = 100\text{mA}$	1.230	1.217 1.243	V V(Min) V(Max)
V_{FB}	Feedback Voltage LM2574	$7\text{V} \leq V_{IN} \leq 40\text{V}$, $0.1\text{A} \leq I_{LOAD} \leq 0.5\text{A}$ V_{OUT} Programmed for 5V. Circuit of <i>Figure 2</i>	1.230	1.193/ 1.180 1.267/ 1.280	V V(Min) V(Max)
V_{FB}	Feedback Voltage LM2574HV	$7\text{V} \leq V_{IN} \leq 60\text{V}$, $0.1\text{A} \leq I_{LOAD} \leq 0.5\text{A}$ V_{OUT} Programmed for 5V. Circuit of <i>Figure 2</i>	1.230	1.193/ 1.180 1.273/ 1.286	V(Min) V(Max)
η	Efficiency	$V_{IN} = 12\text{V}$, $V_{OUT} = 5\text{V}$, $I_{LOAD} = 0.5\text{A}$	77		%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12\text{V}$ for the 3.3V, 5V, and Adjustable version, $V_{IN} = 25\text{V}$ for the 12V version, and $V_{IN} = 30\text{V}$ for the 15V version. $I_{LOAD} = 100\text{mA}$.

Symbol	Parameter	Conditions	LM2574-XX LM2574HV-XX		Units (Limits)
			Typ	Limit (Note 2)	
DEVICE PARAMETERS					
I_b	Feedback Bias Current	Adjustable Version Only, $V_{OUT} = 5\text{V}$	50	100/ 500	nA
f_O	Oscillator Frequency	(see Note 10)	52	47/ 42 58/ 63	kHz kHz(Min) kHz(Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 0.5\text{A}$ (Note 4)	0.9	1.2/ 1.4	V V(max)
DC	Max Duty Cycle (ON)	(Note 5)	98	93	% %(Min)
I_{CL}	Current Limit	Peak Current, (Notes 4, 10)	1.0	0.7/ 0.65 1.6/ 1.8	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 6, 7) Output = 0V Output = -1V Output = -1V	7.5	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 6)	5	10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{\text{ON}}/\text{OFF}$ Pin = 5V (OFF)	50	200	μA $\mu\text{A}(\text{Max})$
θ_{JA} θ_{JA} θ_{JA} θ_{JA}	Thermal Resistance	N Package, Junction to Ambient (Note 8) N Package, Junction to Ambient (Note 9) M Package, Junction to Ambient (Note 8) M Package, Junction to Ambient (Note 9)	92 72 102 78		$^\circ\text{C}/\text{W}$

ON/OFF CONTROL Test Circuit *Figure 2*

V_{IH}	$\overline{\text{ON}}/\text{OFF}$ Pin Logic Input Level	$V_{OUT} = 0\text{V}$	1.4	2.2/ 2.4	V(Min)
V_{IL}		$V_{OUT} = \text{Nominal Output Voltage}$	1.2	1.0/ 0.8	V(Max)
I_H	$\overline{\text{ON}}/\text{OFF}$ Pin Input Current	$\overline{\text{ON}}/\text{OFF}$ Pin = 5V (OFF)	12	30	μA $\mu\text{A}(\text{Max})$
I_{IL}		$\overline{\text{ON}}/\text{OFF}$ Pin = 0V (ON)	0	10	μA $\mu\text{A}(\text{Max})$

Electrical Characteristics (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (Standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2574 is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 4: Output pin sourcing current. No diode, inductor or capacitor connected to output pin.

Note 5: Feedback pin removed from output and connected to 0V.

Note 6: Feedback pin removed from output and connected to +12V for the Adjustable, 3.3V, 5V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

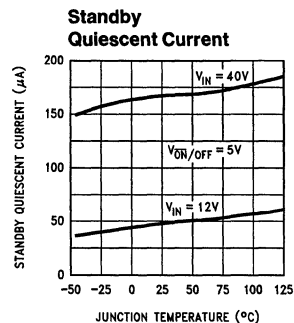
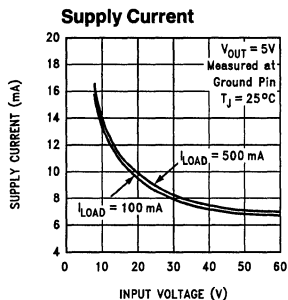
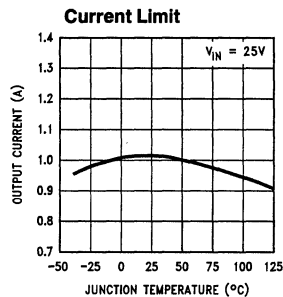
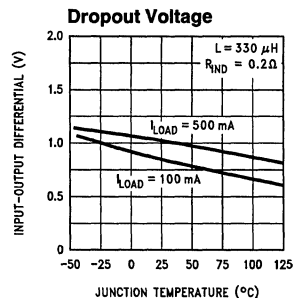
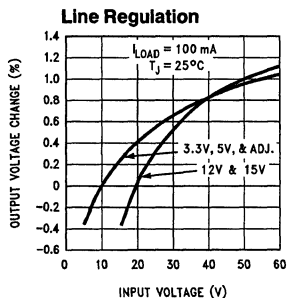
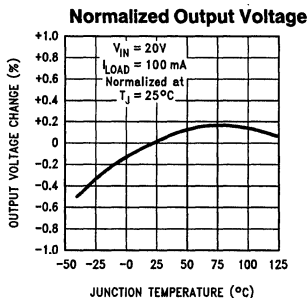
Note 7: $V_{IN} = 40V$ (60V for high voltage version).

Note 8: Junction to ambient thermal resistance with approximately 1 square inch of printed circuit board copper surrounding the leads. Additional copper area will lower thermal resistance further. See application hints in this data sheet and the thermal model in *Switchers Made Simple* software.

Note 9: Junction to ambient thermal resistance with approximately 4 square inches of 1 oz. (0.0014 in. thick) printed circuit board copper surrounding the leads. Additional copper area will lower thermal resistance further. (See Note 8.)

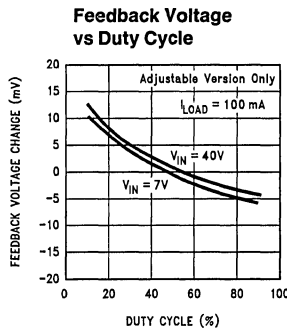
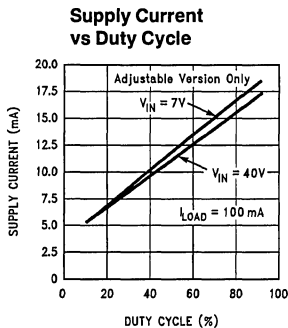
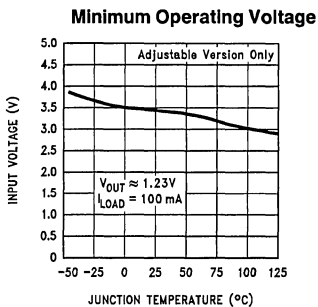
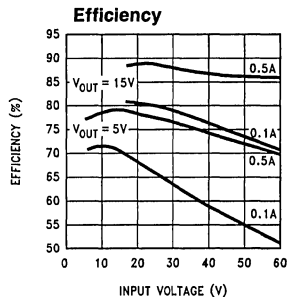
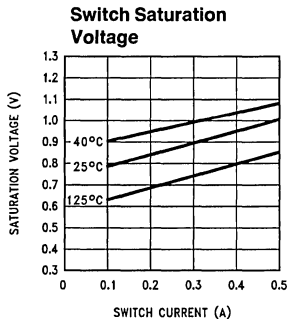
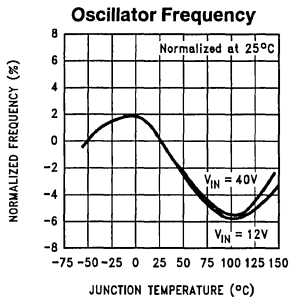
Note 10: The oscillator frequency reduces to approximately 18 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

Typical Performance Characteristics (Circuit of *Figure 2*)

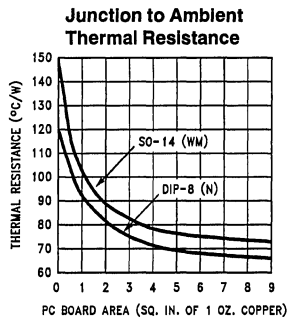
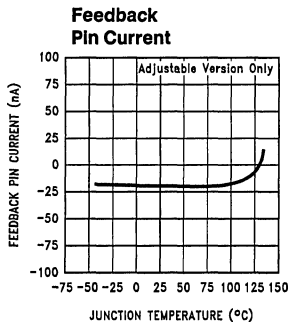


TL/H/11394-17

Typical Performance Characteristics (Circuit of Figure 2) (Continued)

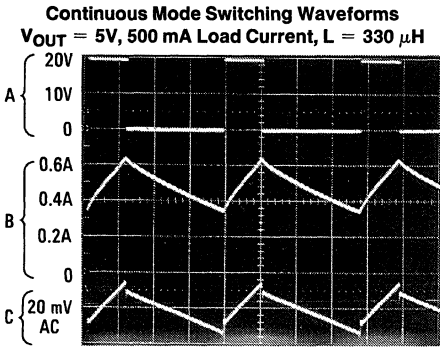


TL/H/11394-4



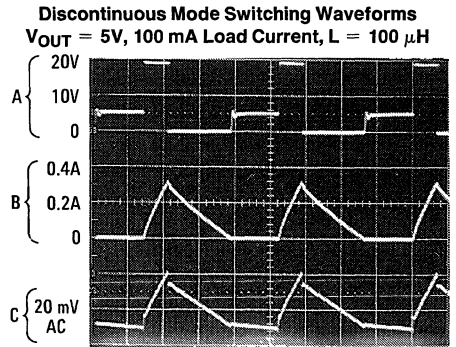
TL/H/11394-5

Typical Performance Characteristics (Circuit of Figure 2) (Continued)



TL/H/11394-6

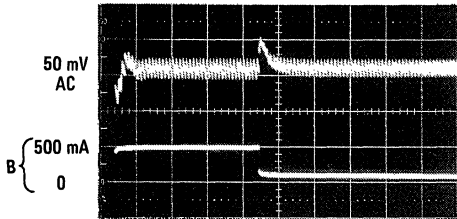
A: Output Pin Voltage, 10V/div
B: Inductor Current, 0.2 A/div
C: Output Ripple Voltage, 20 mV/div,
 AC-Coupled
 Horizontal Time Base: 5 $\mu\text{s}/\text{div}$



TL/H/11394-7

A: Output Pin Voltage, 10V/div
B: Inductor Current, 0.2 A/div
C: Output Ripple Voltage, 20 mV/div,
 AC-Coupled
 Horizontal Time Base: 5 $\mu\text{s}/\text{div}$

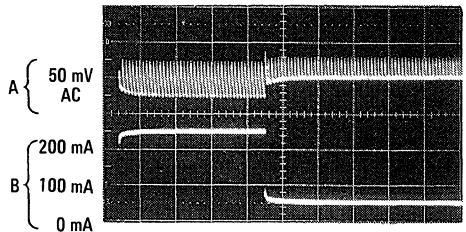
500 mA Load Transient Response for Continuous Mode Operation, $L = 330\ \mu\text{H}, C_{OUT} = 300\ \mu\text{F}$



TL/H/11394-8

A: Output Voltage, 50 mV/div.
 AC Coupled
B: 100 mA to 500 mA Load Pulse
 Horizontal Time Base: 200 $\mu\text{s}/\text{div}$

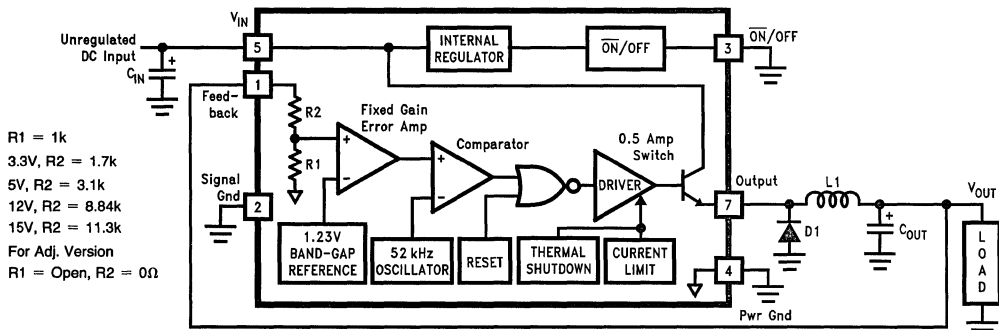
250 mA Load Transient Response for Discontinuous Mode Operation. $L = 68\ \mu\text{H}, C_{OUT} = 470\ \mu\text{F}$



TL/H/11394-9

A: Output Voltage, 50 mV/div.
 AC Coupled
B: 50 mA to 250 mA Load Pulse
 Horizontal Time Base: 200 $\mu\text{s}/\text{div}$

Block Diagram



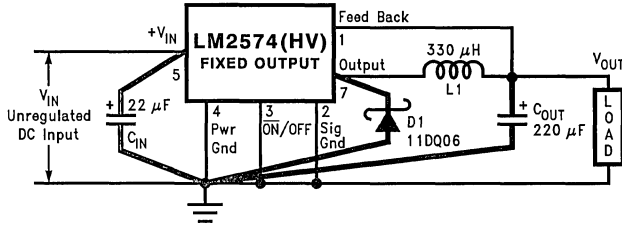
Note: Pin numbers are for the 8-pin DIP package.

FIGURE 1

TL/H/11394-10

Test Circuit and Layout Guidelines

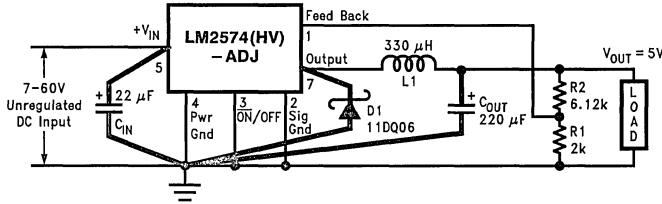
Fixed Output Voltage Versions



- C_{IN}— 22 μF, 75V
Aluminum Electrolytic
- C_{OUT}— 220 μF, 25V
Aluminum Electrolytic
- D1— Schottky, 11DQ06
- L1— 330 μH, 52627
(for 5V in, 3.3V out, use
100 μH, RL-1284-100)
- R1— 2k, 0.1%
- R2— 6.12k, 0.1%

TL/H/11394-11

Adjustable Output Voltage Version



$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right)$$

$$R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right)$$

where V_{REF} = 1.23V,
R1 between 1k & 5k.

TL/H/11394-12

FIGURE 2

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by **heavy lines should be kept as short as possible**. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Inductor Value	Pulse Eng. (Note 1)	Renco (Note 2)	NPI (Note 3)
68 μH	*	RL-1284-68	NP5915
100 μH	*	RL-1284-100	NP5916
150 μH	52625	RL-1284-150	NP5917
220 μH	52626	RL-1284-220	NP5918/5919
330 μH	52627	RL-1284-330	NP5920/5921
470 μH	52628	RL-1284-470	NP5922
680 μH	52629	RL-1283-680	NP5923
1000 μH	52631	RL-1283-1000	*
1500 μH	*	RL-1283-1500	*
2200 μH	*	RL-1283-2200	*

FIGURE 3. Inductor Selection by Manufacturer's Part Number

U.S. Source

Note 1: Pulse Engineering, (619) 674-8100
P.O. Box 12236, San Diego, CA 92112

Note 2: Renco Electronics Inc., (516) 586-5566
60 Jeffryn Blvd. East, Deer Park, NY 11729

*Contact Manufacturer

European Source

Note 3: NPI/APC +44 (0) 634 290588
47 Riverside, Medway City Estate
Strood, Rochester, Kent ME2 4DP. UK

*Contact Manufacturer

LM2574 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)

Given:

V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V)
 $V_{IN(Max)}$ = Maximum Input Voltage
 $I_{LOAD(Max)}$ = Maximum Load Current

1. Inductor Selection (L_1)

A. Select the correct Inductor value selection guide from *Figures 4, 5, 6 or 7*. (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version.

B. From the inductor value selection guide, identify the inductance region intersected by $V_{IN(Max)}$ and $I_{LOAD(Max)}$.

C. Select an appropriate inductor from the table shown in *Figure 3*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2574 switching frequency (52 kHz) and for a current rating of $1.5 \times I_{LOAD}$. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.

2. Output Capacitor Selection (C_{OUT})

A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 μ F and 470 μ F is recommended.

B. The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended.

Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.

3. Catch Diode Selection (D_1)

A. The catch-diode current rating must be at least 1.5 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2574. The most stressful condition for this diode is an overload or shorted output condition.

B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.

4. Input Capacitor (C_{IN})

An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.

EXAMPLE (Fixed Output Voltage Versions)

Given:

$V_{OUT} = 5V$
 $V_{IN(Max)} = 15V$
 $I_{LOAD(Max)} = 0.4A$

1. Inductor Selection (L_1)

A. Use the selection guide shown in *Figure 5*.

B. From the selection guide, the inductance area intersected by the 15V line and 0.4A line is 330.

C. Inductor value required is 330 μ H. From the table in *Figure 3*, choose Pulse Engineering PE-52627, Renco RL-1284-330, or NPI NP5920/5921.

2. Output Capacitor Selection (C_{OUT})

A. $C_{OUT} = 100 \mu$ F to 470 μ F standard aluminum electrolytic.

B. Capacitor voltage rating = 20V.

3. Catch Diode Selection (D_1)

A. For this example, a 1A current rating is adequate.

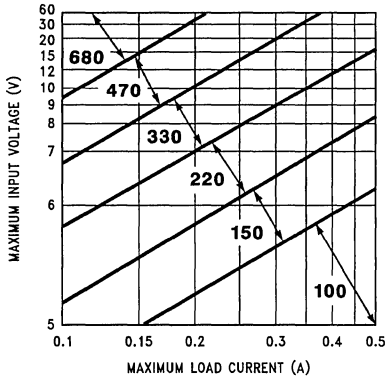
B. Use a 20V 1N5817 or SR102 Schottky diode, or any of the suggested fast-recovery diodes shown in *Figure 9*.

4. Input Capacitor (C_{IN})

A 22 μ F aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

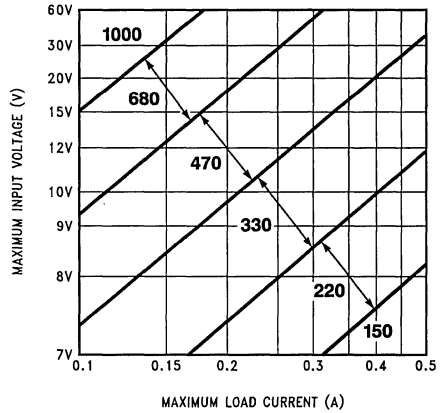
LM2574 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)



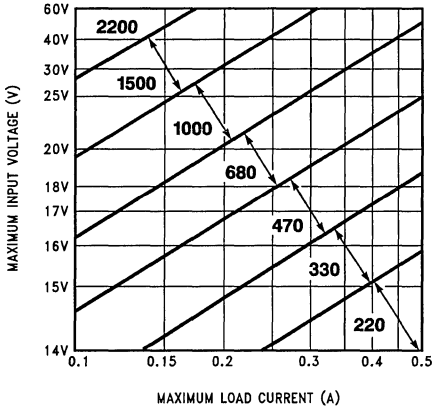
TL/H/11394-26

FIGURE 4. LM2574HV-3.3 Inductor Selection Guide



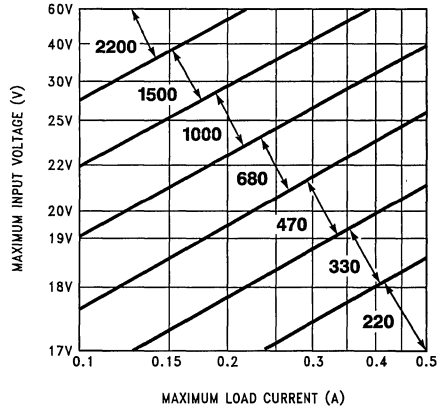
TL/H/11394-13

FIGURE 5. LM2574HV-5.0 Inductor Selection Guide



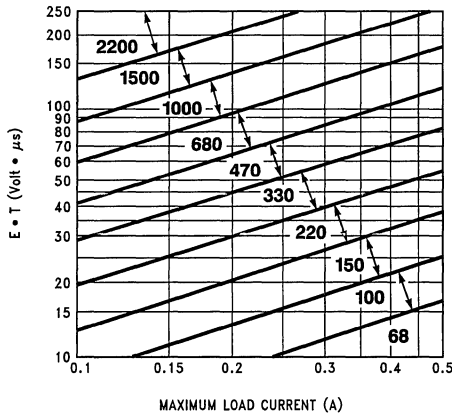
TL/H/11394-14

FIGURE 6. LM2574HV-12 Inductor Selection Guide



TL/H/11394-15

FIGURE 7. LM2574HV-15 Inductor Selection Guide



TL/H/11394-16

FIGURE 8. LM2574HV-ADJ Inductor Selection Guide

LM2574 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = Regulated Output Voltage
 $V_{IN(Max)}$ = Maximum Input Voltage
 $I_{LOAD(Max)}$ = Maximum Load Current
 F = Switching Frequency (*Fixed at 52 kHz*)

1. Programming Output Voltage (Selecting R1 and R2, as shown in Figure 2)

Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) \quad \text{where } V_{REF} = 1.23V$$

R_1 can be between 1k and 5k. (*For best temperature coefficient and stability with time, use 1% metal film resistors*)

$$R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right)$$

2. Inductor Selection (L1)

A. Calculate the inductor Volt • microsecond constant, $E \cdot T$ ($V \cdot \mu s$), from the following formula:

$$E \cdot T = (V_{IN} - V_{OUT}) \frac{V_{OUT}}{V_{IN}} \cdot \frac{1000}{F \text{ (in kHz)}} (V \cdot \mu s)$$

B. Use the $E \cdot T$ value from the previous formula and match it with the $E \cdot T$ number on the vertical axis of the **Inductor Value Selection Guide** shown in Figure 8.

C. On the horizontal axis, select the maximum load current.

D. Identify the inductance region intersected by the $E \cdot T$ value and the maximum load current value, and note the inductor value for that region.

E. Select an appropriate inductor from the table shown in Figure 3. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2574 switching frequency (52 kHz) and for a current rating of $1.5 \times I_{LOAD}$. For additional inductor information, see the inductor section in the application hints section of this data sheet.

3. Output Capacitor Selection (C_{OUT})

A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:

$$C_{OUT} \geq 13,300 \frac{V_{IN(Max)}}{V_{OUT} \cdot L(\mu H)} (\mu F)$$

The above formula yields capacitor values between 5 μF and 1000 μF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields.

B. The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 24V regulator, a rating of at least 35V is recommended.

Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.

EXAMPLE (Adjustable Output Voltage Versions)

Given:

$V_{OUT} = 24V$
 $V_{IN(Max)} = 40V$
 $I_{LOAD(Max)} = 0.4A$
 $F = 52 \text{ kHz}$

1. Programming Output Voltage (Selecting R1 and R2)

$$V_{OUT} = 1.23 \left(1 + \frac{R_2}{R_1} \right) \quad \text{Select } R_1 = 1k$$

$$R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right) = 1k \left(\frac{24V}{1.23V} - 1 \right)$$

$R_2 = 1k (19.51 - 1) = 18.51k$, closest 1% value is 18.7k

2. Inductor Selection (L1)

A. Calculate $E \cdot T$ ($V \cdot \mu s$)

$$E \cdot T = (40 - 24) \cdot \frac{24}{40} \cdot \frac{1000}{52} = 185 V \cdot \mu s$$

B. $E \cdot T = 185 V \cdot \mu s$

C. $I_{LOAD(Max)} = 0.4A$

D. Inductance Region = 1000

E. Inductor Value = 1000 μH Choose from **Pulse Engineering Part #PE-52631**, or **Renco Part #RL-1283-1000**.

3. Output Capacitor Selection (C_{OUT})

$$A. C_{OUT} > 13,300 \frac{40}{24 \cdot 1000} = 22.2 \mu F$$

However, for acceptable output ripple voltage select

$$C_{OUT} \geq 100 \mu F$$

$C_{OUT} = 100 \mu F$ electrolytic capacitor

LM2574 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)

4. Catch Diode Selection (D1)

A. The catch-diode current rating must be at least 1.5 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2574. The most stressful condition for this diode is an overload or shorted output condition. Suitable diodes are shown in the selection guide of *Figure 9*.

B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.

5. Input Capacitor (C_{IN})

An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.

EXAMPLE (Adjustable Output Voltage Versions)

4. Catch Diode Selection (D1)

A. For this example, a 1A current rating is adequate.

B. Use a 50V MBR150 or 11DQ05 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 9*.

5. Input Capacitor (C_{IN})

A 22 μ F aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

V _R	1 Amp Diodes	
	Schottky	Fast Recovery
20V	1N5817 SR102 MBR120P	The following diodes are all rated to 100V 11DF1 10JF1 MUR110 HER102
30V	1N5818 SR103 11DQ03 MBR130P 10JQ030	
40V	1N5819 SR104 11DQ04 11JQ04 MBR140P	
50V	MBR150 SR105 11DQ05 11JQ05	
60V	MBR160 SR106 11DQ06 11JQ06	
90V	11DQ09	

FIGURE 9. Diode Selection Guide

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line of switching regulators.

Switchers Made Simple (version 3.3) is available on a (3½") diskette for IBM compatible computers from a National Semiconductor sales office in your area.

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 22 μ F electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below -25°C , the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{ON}}{T} \right) \times I_{LOAD}$$

$$\text{where } \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}} \text{ for a buck regulator}$$

$$\text{and } \frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}} \text{ for a buck-boost regulator.}$$

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2574 (or any of the Simple Switcher family) can be used for both continuous and discontinuous modes of operation.

In many cases the preferred mode of operation is in the continuous mode. It offers better load regulation, lower peak switch, inductor and diode currents, and can have lower output ripple voltage. But it does require relatively large inductor values to keep the inductor current flowing continuously, especially at low output load currents.

To simplify the inductor selection process, an inductor selection guide (nomograph) was designed (see *Figures 4 through 8*). This guide assumes continuous mode operation, and selects an inductor that will allow a peak-to-peak inductor ripple current (ΔI_{IND}) to be a certain percentage of the maximum design load current. In the LM2574 Simple Switcher, the peak-to-peak inductor ripple current percentage (of load current) is allowed to change as different design load currents are selected. By allowing the percentage of inductor ripple current to increase for lower current applications, the inductor size and value can be kept relatively low.

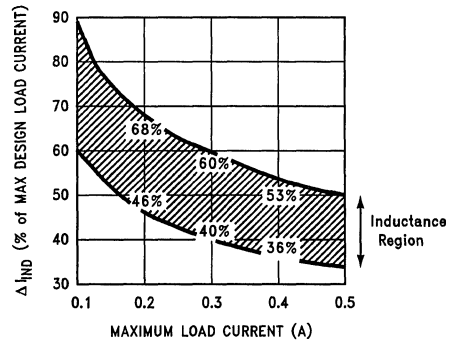
INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains

constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

The curve shown in *Figure 10* illustrates how the peak-to-peak inductor ripple current (ΔI_{IND}) is allowed to change as different maximum load currents are selected, and also how it changes as the operating point varies from the upper border to the lower border within an inductance region (see Inductor Selection guides).



TL/H/11394-18

FIGURE 10. Inductor Ripple Current (ΔI_{IND}) Range Based on Selection Guides from *Figures 4-8*.

Consider the following example:

$$V_{OUT} = 5V @ 0.4A$$

$$V_{IN} = 10V \text{ minimum up to } 20V \text{ maximum}$$

The selection guide in *Figure 5* shows that for a 0.4A load current, and an input voltage range between 10V and 20V, the inductance region selected by the guide is 330 μ H. This value of inductance will allow a peak-to-peak inductor ripple current (ΔI_{IND}) to flow that will be a percentage of the maximum load current. For this inductor value, the ΔI_{IND} will also vary depending on the input voltage. As the input voltage increases to 20V, it approaches the upper border of the inductance region, and the inductor ripple current increases. Referring to the curve in *Figure 10*, it can be seen that at the 0.4A load current level, and operating near the upper border of the 330 μ H inductance region, the ΔI_{IND} will be 53% of 0.4A, or 212 mA p-p.

This ΔI_{IND} is important because from this number the peak inductor current rating can be determined, the minimum load current required before the circuit goes to discontinuous operation, and also, knowing the ESR of the output capacitor, the output ripple voltage can be calculated, or conversely, measuring the output ripple voltage and knowing the ΔI_{IND} , the ESR can be calculated.

Application Hints (Continued)

From the previous example, the Peak-to-peak Inductor Ripple Current (ΔI_{IND}) = 212 mA p-p. Once the ΔI_{IND} value is known, the following three formulas can be used to calculate additional information about the switching regulator circuit:

1. Peak Inductor or peak switch current

$$= \left(I_{LOAD} + \frac{\Delta I_{IND}}{2} \right) = \left(0.4A + \frac{212}{2} \right) = 506 \text{ mA}$$

2. Minimum load current before the circuit becomes discontinuous

$$= \frac{\Delta I_{IND}}{2} = \frac{212}{2} = 106 \text{ mA}$$

3. Output Ripple Voltage = (ΔI_{IND}) \times (ESR of C_{OUT})

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software *Switchers Made Simple* will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toroid, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This can cause the inductor current to rise very rapidly and will affect the energy storage capabilities of the inductor and could cause inductor overheating. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor. The inductor manufacturers' data sheets include current and energy limits to avoid inductor saturation.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2574 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current

(ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (100 μF – 330 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

$$\text{Output Ripple Voltage} = (\Delta I_{IND}) (\text{ESR of } C_{OUT})$$

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.03 Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2574 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable**. See *Figure 9* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 μH & 100 μF) can be added to the output (as shown in *Figure 16*) to further reduce the amount of output ripple and transients. A 10 \times reduction in output ripple voltage and transients is possible with this filter.

Application Hints (Continued)

FEEDBACK CONNECTION

The LM2574 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2574 to avoid picking up unwanted noise. Avoid using resistors greater than 100 k Ω because of the increased chance of noise pickup.

ON/OFF INPUT

For normal operation, the $\overline{\text{ON/OFF}}$ pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON/OFF}}$ pin can be safely pulled up to $+V_{\text{IN}}$ without a resistor in series with it. The $\overline{\text{ON/OFF}}$ pin should not be left open.

GROUNDING

The 8-pin molded DIP and the 14-pin surface mount package have separate power and signal ground pins. Both ground pins should be soldered directly to wide printed circuit board copper traces to assure low inductance connections and good thermal properties.

THERMAL CONSIDERATIONS

The 8-pin DIP (N) package and the 14-pin Surface Mount (M) package are molded plastic packages with solid copper lead frames. The copper lead frame conducts the majority of the heat from the die, through the leads, to the printed circuit board copper, which acts as the heat sink. For best thermal performance, wide copper traces should be used, and all ground and unused pins should be soldered to generous amounts of printed circuit board copper, such as a ground plane. Large areas of copper provide the best transfer of heat (lower thermal resistance) to the surrounding air, and even double-sided or multilayer boards provide better heat paths to the surrounding air. Unless the power levels are small, using a socket for the 8-pin package is not recommended because of the additional thermal resistance it introduces, and the resultant higher junction temperature.

Because of the 0.5A current rating of the LM2574, the total package power dissipation for this switcher is quite low, ranging from approximately 0.1W up to 0.75W under varying conditions. In a carefully engineered printed circuit board, both the N and the M package can easily dissipate up to 0.75W, even at ambient temperatures of 60°C, and still keep the maximum junction temperature below 125°C.

A curve displaying thermal resistance vs. pc board area for the two packages is shown in the Typical Performance Characteristics curves section of this data sheet.

These thermal resistance numbers are approximate, and there can be many factors that will affect the final thermal resistance. Some of these factors include board size, shape, thickness, position, location, and board temperature. Other factors are, the area of printed circuit copper, copper thickness, trace width, multi-layer, single- or double-sided, and the amount of solder on the board. The effectiveness of the pc board to dissipate heat also depends on the size, number and spacing of other components on the board. Furthermore, some of these components, such as the catch diode and inductor will generate some additional heat. Also, the thermal resistance decreases as the power level increases because of the increased air current activity at the higher power levels, and the lower surface to air resistance coefficient at higher temperatures.

The data sheet thermal resistance curves and the thermal model in *Switchers Made Simple* software (version 3.3) can estimate the maximum junction temperature based on operating conditions. In addition, the junction temperature can be estimated in actual circuit operation by using the following equation.

$$T_j = T_{\text{cu}} + (\theta_{\text{j-cu}} \times P_D)$$

With the switcher operating under worst case conditions and all other components on the board in the intended enclosure, measure the copper temperature (T_{cu}) near the IC. This can be done by temporarily soldering a small thermocouple to the pc board copper near the IC, or by holding a small thermocouple on the pc board copper using thermal grease for good thermal conduction.

The thermal resistance ($\theta_{\text{j-cu}}$) for the two packages is:

$$\theta_{\text{j-cu}} = 42^\circ\text{C/W} \text{ for the N-8 package}$$

$$\theta_{\text{j-cu}} = 52^\circ\text{C/W} \text{ for the M-14 package}$$

The power dissipation (P_D) for the IC could be measured, or it can be estimated by using the formula:

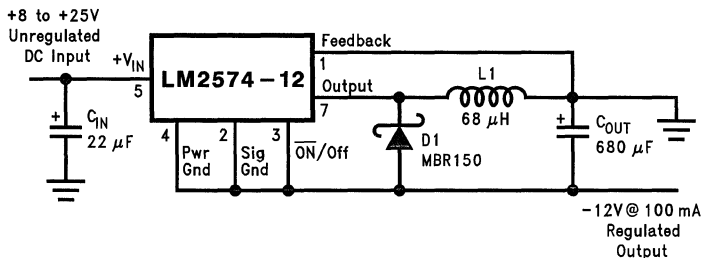
$$P_D = (V_{\text{IN}})(I_S) + \left(\frac{V_O}{V_{\text{IN}}}\right)(I_{\text{LOAD}})(V_{\text{SAT}})$$

Where I_S is obtained from the typical supply current curve (adjustable version use the supply current vs. duty cycle curve).

Additional Applications

INVERTING REGULATOR

Figure 11 shows a LM2574-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to -12V .



Note: Pin numbers are for the 8-pin DIP package.

FIGURE 11. Inverting Buck-Boost Develops -12V

TL/H/11394-19

Additional Applications (Continued)

For an input voltage of 8V or more, the maximum available output current in this configuration is approximately 100 mA. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 0.6A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 μ H and 220 μ H, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD} (V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN} |V_O|}{V_{IN} + |V_O|} \times \frac{1}{2L_1 f_{osc}}$$

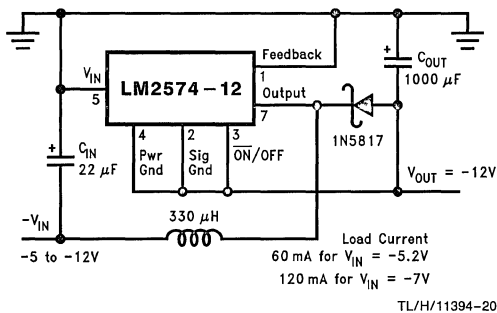
Where $f_{osc} = 52$ kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a -12V output, the maximum input voltage for the LM2574 is +28V, or +48V for the LM2574HV.

The *Switchers Made Simple* (version 3.3) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in Figure 12 accepts an input voltage ranging from -5V to -12V and provides a regulated -12V output. Input voltages greater than -12V will cause the output to rise above -12V, but will not damage the regulator.



Note: Pin numbers are for 8-pin DIP package.

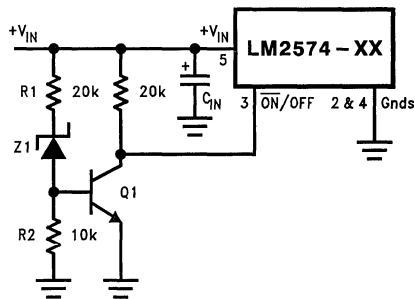
FIGURE 12. Negative Boost

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in Figure 13, while Figure 14 shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

$$V_{TH} \approx V_{Z1} + 2V_{BE}(Q1)$$

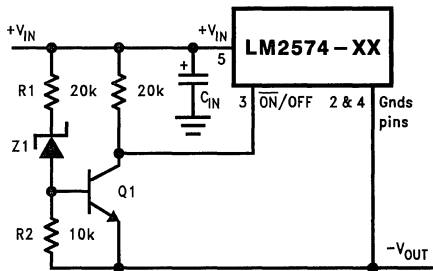


TL/H/11394-21

Note: Complete circuit not shown.

Note: Pin numbers are for 8-pin DIP package.

FIGURE 13. Undervoltage Lockout for Buck Circuit



TL/H/11394-22

Note: Complete circuit not shown (see Figure 11).

Note: Pin numbers are for 8-pin DIP package.

FIGURE 14. Undervoltage Lockout for Buck-Boost Circuit

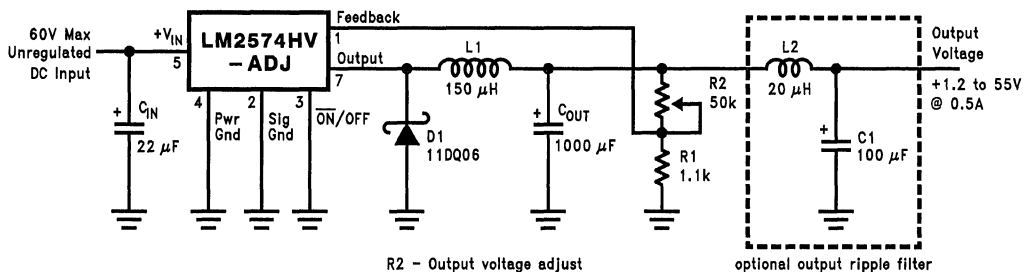
Additional Applications (Continued)

DELAYED STARTUP

The $\overline{\text{ON/OFF}}$ pin can be used to provide a delayed startup feature as shown in Figure 15. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the $\overline{\text{ON/OFF}}$ pin.

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

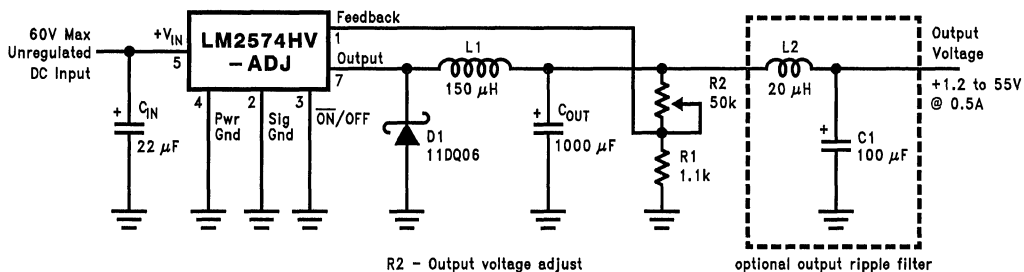
A 500 mA power supply that features an adjustable output voltage is shown in Figure 16. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.



Note: Complete circuit not shown.

Note: Pin numbers are for 8-pin DIP package.

FIGURE 15. Delayed Startup



Note: Pin numbers are for 8-pin DIP package.

FIGURE 16. 1.2V to 55V Adjustable 500 mA Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

$$\text{for buck regulator} \quad D = \frac{t_{\text{ON}}}{T} = \frac{V_{\text{OUT}}}{V_{\text{IN}}}$$

$$\text{for buck-boost regulator} \quad D = \frac{t_{\text{ON}}}{T} = \frac{|V_{\text{O}}|}{|V_{\text{O}}| + V_{\text{IN}}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2574 switch is OFF.

EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{IN}}} = \frac{P_{\text{OUT}}}{P_{\text{OUT}} + P_{\text{LOSS}}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see Figure 17). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.

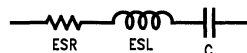


FIGURE 17. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 μF –1000 μF range have 0.5 Ω to 0.1 Ω ESR. Higher-grade capacitors ("low-ESR", "high-frequency", or "low-inductance") in the 100 μF –1000 μF range generally have ESR of less than 0.15 Ω .

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see Figure 17). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

TL/H/11394-25

Definition of Terms (Continued)

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2574 when in the standby mode (\overline{ON}/OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

OPERATING VOLT MICROSECOND CONSTANT ($E \cdot T_{OP}$)

The product (in Volt $\cdot\mu$ s) of the voltage applied to the inductor and the time the voltage is applied. This $E \cdot T_{OP}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.



LM1575/LM1575HV/LM2575/LM2575HV Series Simple Switcher™ 1A Step-Down Voltage Regulator

General Description

The LM2575 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 1A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2575 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in many cases no heat sink is required.

A standard series of inductors optimized for use with the LM2575 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed $\pm 4\%$ tolerance on output voltage within specified input voltages and output load conditions, and $\pm 10\%$ on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

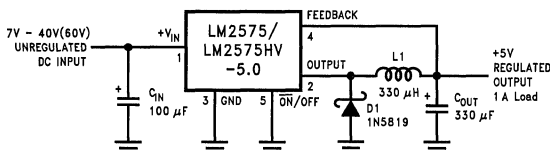
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) $\pm 4\%$ max over line and load conditions
- Guaranteed 1A output current
- Wide input voltage range, 40V up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P+ Product Enhancement tested

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

Typical Application (Fixed Output Voltage Versions)



Note: Pin numbers are for the TO-220 package.

Block Diagram and Typical Application

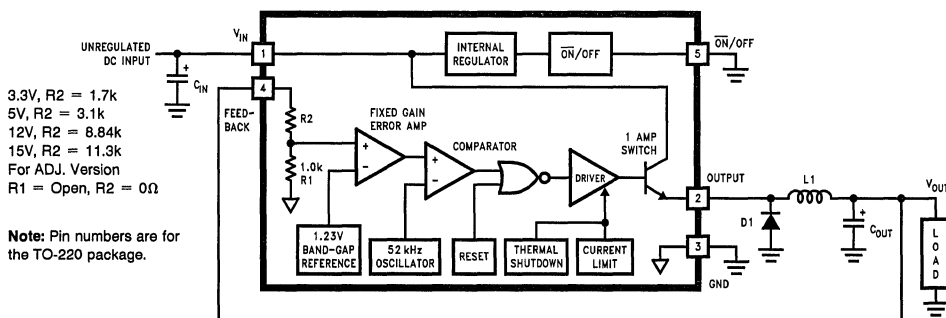


FIGURE 1

TL/H/11475-2

Patent Pending

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM1575/LM2575	45V
LM1575HV/LM2575HV	63V
ON/OFF Pin Input Voltage	$-0.3V \leq V \leq +V_{IN}$
Output Voltage to Ground (Steady State)	-1V
Power Dissipation	Internally Limited
Storage Temperature Range	-65°C to $+150^{\circ}\text{C}$

Minimum ESD Rating (C = 100 pF, R = 1.5 k Ω)	2 kV
Lead Temperature (Soldering, 10 sec.)	260 $^{\circ}\text{C}$
Maximum Junction Temperature	150 $^{\circ}\text{C}$

Operating Ratings

Temperature Range	
LM1575/LM1575HV	$-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$
LM2575/LM2575HV	$-40^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$
Supply Voltage	
LM1575/LM2575	40V
LM1575HV/LM2575HV	60V

LM1575-3.3, LM1575HV-3.3, LM2575-3.3, LM2575HV-3.3

Electrical Characteristics Specifications with standard type face are for $T_J = 25^{\circ}\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-3.3 LM1575HV-3.3	LM2575-3.3 LM2575HV-3.3	Units (Limits)
				Limit (Note 2)	Limit (Note 3)	
SYSTEM PARAMETERS (Note 4) Test Circuit <i>Figure 2</i>						
V_{OUT}	Output Voltage	$V_{IN} = 12V, I_{LOAD} = 0.2A$ Circuit of <i>Figure 2</i>	3.3	3.267 3.333	3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$4.75V \leq V_{IN} \leq 40V, 0.2A \leq I_{LOAD} \leq 1A$ Circuit of <i>Figure 2</i>	3.3	3.200/ 3.168 3.400/ 3.432	3.168/ 3.135 3.432/ 3.465	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$4.75V \leq V_{IN} \leq 60V, 0.2A \leq I_{LOAD} \leq 1A$ Circuit of <i>Figure 2</i>	3.3	3.200/ 3.168 3.416/ 3.450	3.168/ 3.135 3.450/ 3.482	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V, I_{LOAD} = 1A$	75			%

LM1575-5.0, LM1575HV-5.0, LM2575-5.0, LM2575HV-5.0

Electrical Characteristics Specifications with standard type face are for $T_J = 25^{\circ}\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-5.0 LM1575HV-5.0	LM2575-5.0 LM2575HV-5.0	Units (Limits)
				Limit (Note 2)	Limit (Note 3)	
SYSTEM PARAMETERS (Note 4) Test Circuit <i>Figure 2</i>						
V_{OUT}	Output Voltage	$V_{IN} = 12V, I_{LOAD} = 0.2A$ Circuit of <i>Figure 2</i>	5.0	4.950 5.050	4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$0.2A \leq I_{LOAD} \leq 1A,$ $8V \leq V_{IN} \leq 40V$ Circuit of <i>Figure 2</i>	5.0	4.850/ 4.800 5.150/ 5.200	4.800/ 4.750 5.200/ 5.250	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$0.2A \leq I_{LOAD} \leq 1A,$ $8V \leq V_{IN} \leq 60V$ Circuit of <i>Figure 2</i>	5.0	4.850/ 4.800 5.175/ 5.225	4.800/ 4.750 5.225/ 5.275	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V, I_{LOAD} = 1A$	77			%

LM1575-12, LM1575HV-12, LM2575-12, LM2575HV-12**Electrical Characteristics** Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-12 LM1575HV-12	LM2575-12 LM2575HV-12	Units (Limits)
				Limit (Note 2)	Limit (Note 3)	
SYSTEM PARAMETERS (Note 4) Test Circuit <i>Figure 2</i>						
V_{OUT}	Output Voltage	$V_{IN} = 25\text{V}$, $I_{LOAD} = 0.2\text{A}$ Circuit of <i>Figure 2</i>	12	11.88 12.12	11.76 12.24	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$0.2\text{A} \leq I_{LOAD} \leq 1\text{A}$, $15\text{V} \leq V_{IN} \leq 40\text{V}$ Circuit of <i>Figure 2</i>	12	11.64/ 11.52 12.36/ 12.48	11.52/ 11.40 12.48/ 12.60	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$0.2\text{A} \leq I_{LOAD} \leq 1\text{A}$, $15\text{V} \leq V_{IN} \leq 60\text{V}$ Circuit of <i>Figure 2</i>	12	11.64/ 11.52 12.42/ 12.54	11.52/ 11.40 12.54/ 12.66	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 15\text{V}$, $I_{LOAD} = 1\text{A}$	88			%

LM1575-15, LM1575HV-15, LM2575-15, LM2575HV-15**Electrical Characteristics** Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-15 LM1575HV-15	LM2575-15 LM2575HV-15	Units (Limits)
				Limit (Note 2)	Limit (Note 3)	
SYSTEM PARAMETERS (Note 4) Test Circuit <i>Figure 2</i>						
V_{OUT}	Output Voltage	$V_{IN} = 30\text{V}$, $I_{LOAD} = 0.2\text{A}$ Circuit of <i>Figure 2</i>	15	14.85 15.15	14.70 15.30	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$0.2\text{A} \leq I_{LOAD} \leq 1\text{A}$, $18\text{V} \leq V_{IN} \leq 40\text{V}$ Circuit of <i>Figure 2</i>	15	14.55/ 14.40 15.45/ 15.60	14.40/ 14.25 15.60/ 15.75	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$0.2\text{A} \leq I_{LOAD} \leq 1\text{A}$, $18\text{V} \leq V_{IN} \leq 60\text{V}$ Circuit of <i>Figure 2</i>	15	14.55/ 14.40 15.525/ 15.675	14.40/ 14.25 15.68/ 15.83	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 18\text{V}$, $I_{LOAD} = 1\text{A}$	88			%

LM1575-ADJ, LM1575HV-ADJ, LM2575-ADJ, LM2575HV-ADJ**Electrical Characteristics**Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-ADJ LM1575HV-ADJ	LM2575-ADJ LM2575HV-ADJ	Units (Limits)
				Limit (Note 2)	Limit (Note 3)	
SYSTEM PARAMETERS (Note 4) Test Circuit <i>Figure 2</i>						
V_{OUT}	Feedback Voltage	$V_{IN} = 12\text{V}$, $I_{LOAD} = 0.2\text{A}$ $V_{OUT} = 5\text{V}$ Circuit of <i>Figure 2</i>	1.230	1.217 1.243	1.217 1.243	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM1575/LM2575	$0.2\text{A} \leq I_{LOAD} \leq 1\text{A}$, $8\text{V} \leq V_{IN} \leq 40\text{V}$ $V_{OUT} = 5\text{V}$, Circuit of <i>Figure 2</i>	1.230	1.205/ 1.193 1.255/ 1.267	1.193/ 1.180 1.267/ 1.280	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM1575HV/LM2575HV	$0.2\text{A} \leq I_{LOAD} \leq 1\text{A}$, $8\text{V} \leq V_{IN} \leq 60\text{V}$ $V_{OUT} = 5\text{V}$, Circuit of <i>Figure 2</i>	1.230	1.205/ 1.193 1.261/ 1.273	1.193/ 1.180 1.273/ 1.286	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12\text{V}$, $I_{LOAD} = 1\text{A}$, $V_{OUT} = 5\text{V}$	77			%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12\text{V}$ for the 3.3V, 5V, and Adjustable version, $V_{IN} = 25\text{V}$ for the 12V version, and $V_{IN} = 30\text{V}$ for the 15V version. $I_{LOAD} = 200\text{ mA}$.

Symbol	Parameter	Conditions	Typ	LM1575-XX	LM2575-XX	Units (Limits)
				LM1575HV-XX	LM2575HV-XX	
				Limit (Note 2)	Limit (Note 3)	
DEVICE PARAMETERS						
I_b	Feedback Bias Current	$V_{OUT} = 5\text{V}$ (Adjustable Version Only)	50	100/ 500	100/ 500	nA
f_O	Oscillator Frequency	(Note 12)	52	47/ 43 58/ 62	47/ 42 58/ 63	kHz (Min) kHz (Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 1\text{A}$ (Note 5)	0.9	1.2/ 1.4	1.2/ 1.4	V (Max)
DC	Max Duty Cycle (ON)	(Note 6)	98	93	93	% (Min)
I_{CL}	Current Limit	Peak Current (Notes 5 and 12)	2.2	1.7/ 1.3 3.0/ 3.2	1.7/ 1.3 3.0/ 3.2	A (Min) A (Max)
I_L	Output Leakage Current	(Notes 7 and 8) Output = 0V Output = -1V Output = -1V	7.5	2 30	2 30	mA (Max) mA (Max)
I_Q	Quiescent Current	(Note 7)	5	10/ 12	10	mA (Max)
I_{STBY}	Standby Quiescent Current	$\overline{\text{ON}}/\text{OFF}$ Pin = 5V (OFF)	50	200/ 500	200	μA (Max)
θ_{JA} θ_{JC} θ_{JA} θ_{JA} θ_{JC} θ_{JA} θ_{JA}	Thermal Resistance	K Package, Junction to Ambient K Package, Junction to Case T Package, Junction to Ambient (Note 9) T Package, Junction to Ambient (Note 10) T Package, Junction to Case N Package, Junction to Ambient (Note 11) M Package, Junction to Ambient (Note 11)	35 1.5 65 45 2 85 100			$^\circ\text{C}/\text{W}$
ON/OFF CONTROL Test Circuit Figure 2						
V_{IH}	$\overline{\text{ON}}/\text{OFF}$ Pin Logic	$V_{OUT} = 0\text{V}$	1.4	2.2/ 2.4	2.2/ 2.4	V (Min)
V_{IL}	Input Level	$V_{OUT} = \text{Nominal Output Voltage}$	1.2	1.0/ 0.8	1.0/ 0.8	V (Max)
I_{IH}	$\overline{\text{ON}}/\text{OFF}$ Pin Input Current	$\overline{\text{ON}}/\text{OFF}$ Pin = 5V (OFF)	12	30	30	μA (Max)
I_{IL}		$\overline{\text{ON}}/\text{OFF}$ Pin = 0V (ON)	0	10	10	μA (Max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All limits are used to calculate Average Outgoing Quality Level, and all are 100% production tested.

Note 3: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 4: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM1575/LM2575 is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 5: Output (pin 2) sourcing current. No diode, inductor or capacitor connected to output pin.

Note 6: Feedback (pin 4) removed from output and connected to 0V.

Note 7: Feedback (pin 4) removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

Note 8: $V_{IN} = 40\text{V}$ (60V for the high voltage version).

Note 9: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with $\frac{1}{2}$ inch leads in a socket, or on a PC board with minimum copper area.

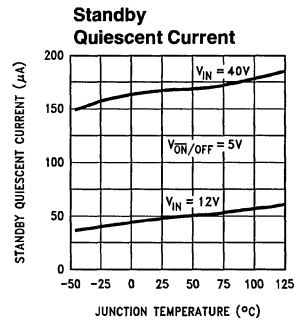
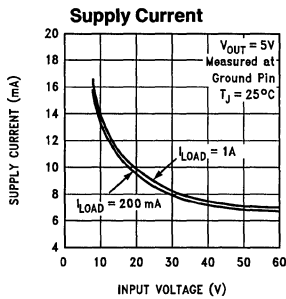
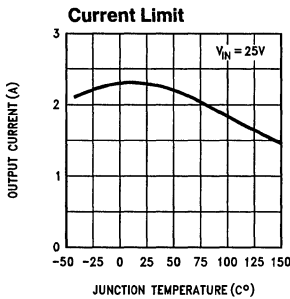
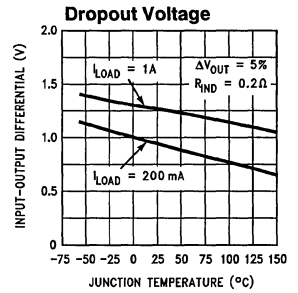
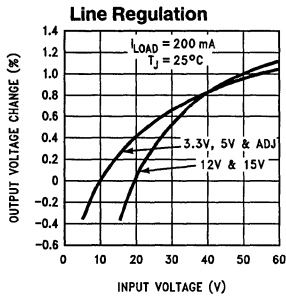
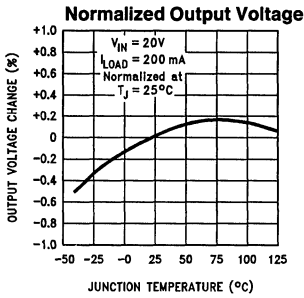
Note 10: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with $\frac{1}{2}$ inch leads soldered to a PC board containing approximately 4 square inches of copper area surrounding the leads.

Note 11: Junction to ambient thermal resistance with approximately 1 square inch of pc board copper surrounding the leads. Additional copper area will lower thermal resistance further. See thermal model in Switchers made Simple software.

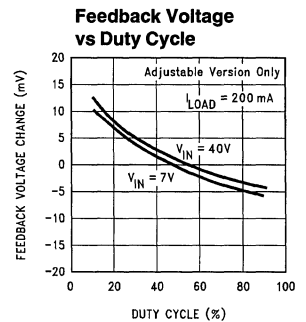
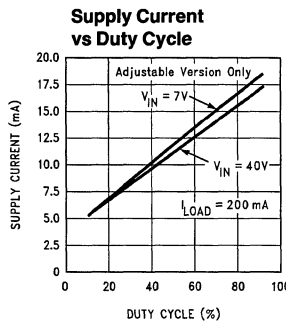
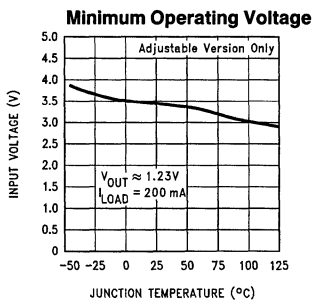
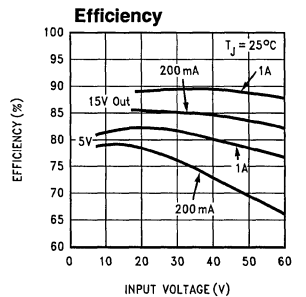
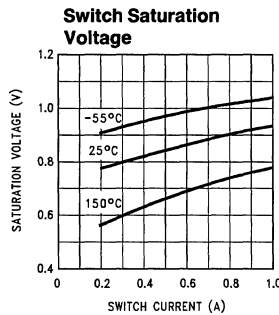
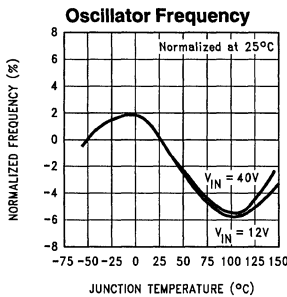
Note 12: The oscillator frequency reduces to approximately 18 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

Note 13: Refer to RETS LM1575K, LM1575HVK for current revision of military RETS/SMD.

Typical Performance Characteristics (Circuit of Figure 2)



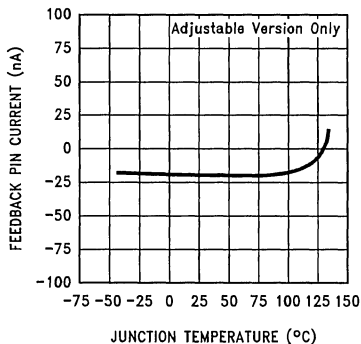
TL/H/11475-3



TL/H/11475-4

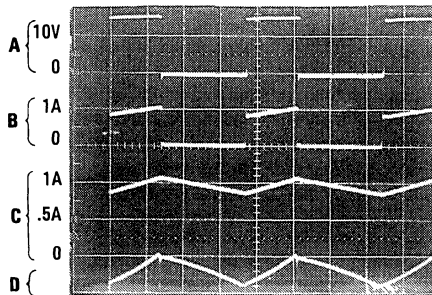
Typical Performance Characteristics (Circuit of Figure 2) (Continued)

Feedback Pin Current



TL/H/11475-5

Switching Waveforms



TL/H/11475-6

$V_{OUT} = 5V$

A: Output Pin Voltage, 10V/div

B: Output Pin Current, 1A/div

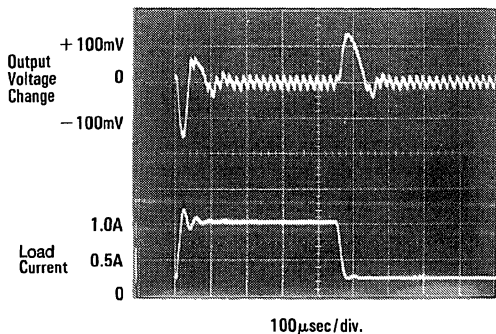
C: Inductor Current, 0.5A/div

D: Output Ripple Voltage, 20 mV/div,

AC-Coupled

Horizontal Time Base: 5 μ s/div

Load Transient Response

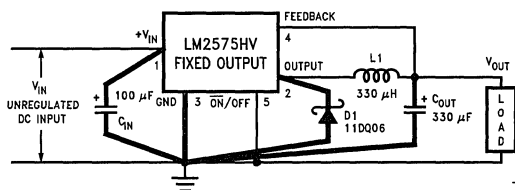


TL/H/11475-7

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Test Circuit and Layout Guidelines

Fixed Output Voltage Versions



TL/H/11475-8

C_{IN} — 100 μ F, 75V, Aluminum Electrolytic

C_{OUT} — 330 μ F, 25V, Aluminum Electrolytic

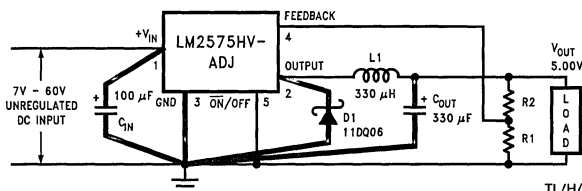
D1 — Schottky, 11DQ06

L1 — 330 μ H, PE-52627 (for 5V in, 3.3V out, use 100 μ H, PE-92108)

R1 — 2k, 0.1%

R2 — 6.12k, 0.1%

Adjustable Output Voltage Version



TL/H/11475-9

$$V_{OUT} = V_{REF} \left(1 + \frac{R2}{R1} \right)$$

$$R2 = R1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right)$$

where $V_{REF} = 1.23V$, R1 between 1k and 5k.

Note: Pin numbers are for the TO-220 package.

FIGURE 2

LM2575 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
<p>Given:</p> <p>V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) $V_{IN(Max)}$ = Maximum Input Voltage $I_{LOAD(Max)}$ = Maximum Load Current</p> <p>1. Inductor Selection (L1)</p> <p>A. Select the correct Inductor value selection guide from <i>Figures 3, 4, 5, or 6</i>. (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version.</p> <p>B. From the inductor value selection guide, identify the inductance region intersected by $V_{IN(Max)}$ and $I_{LOAD(Max)}$, and note the inductor code for that region.</p> <p>C. Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in <i>Figure 9</i>. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2575 switching frequency (52 kHz) and for a current rating of $1.15 \times I_{LOAD}$. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.</p> <p>2. Output Capacitor Selection (C_{OUT})</p> <p>A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 μF and 470 μF is recommended.</p> <p>B. The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended.</p> <p>Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.</p> <p>3. Catch Diode Selection (D1)</p> <p>A. The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2575. The most stressful condition for this diode is an overload or shorted output condition.</p> <p>B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.</p> <p>4. Input Capacitor (C_{IN})</p> <p>An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.</p>	<p>Given:</p> <p>V_{OUT} = 5V $V_{IN(Max)}$ = 20V $I_{LOAD(Max)}$ = 0.8A</p> <p>1. Inductor Selection (L1)</p> <p>A. Use the selection guide shown in <i>Figure 4</i>.</p> <p>B. From the selection guide, the inductance area intersected by the 20V line and 0.8A line is L330.</p> <p>C. Inductor value required is 330 μH. From the table in <i>Figure 9</i>, choose AIE 415-0926, Pulse Engineering PE-52627, or RL1952.</p> <p>2. Output Capacitor Selection (C_{OUT})</p> <p>A. C_{OUT} = 100 μF to 470 μF standard aluminum electrolytic.</p> <p>B. Capacitor voltage rating = 20V.</p> <p>3. Catch Diode Selection (D1)</p> <p>A. For this example, a 1A current rating is adequate.</p> <p>B. Use a 30V 1N5818 or SR103 Schottky diode, or any of the suggested fast-recovery diodes shown in <i>Figure 8</i>.</p> <p>4. Input Capacitor (C_{IN})</p> <p>A 47 μF, 25V aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.</p>

LM2575 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

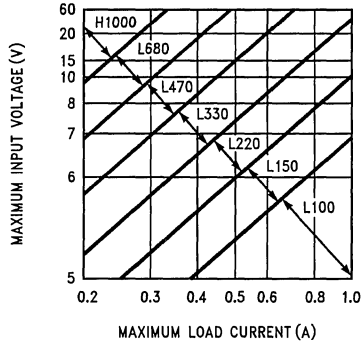


FIGURE 3. LM2575(HV)-3.3

TL/H/11475-10

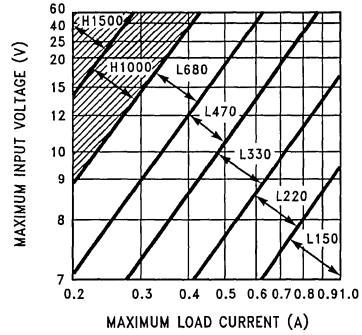


FIGURE 4. LM2575(HV)-5.0

TL/H/11475-11

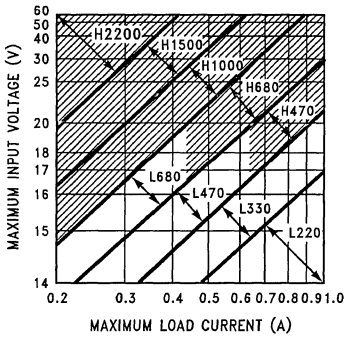


FIGURE 5. LM2575(HV)-12

TL/H/11475-12

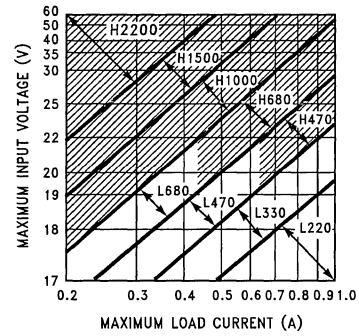


FIGURE 6. LM2575(HV)-15

TL/H/11475-13

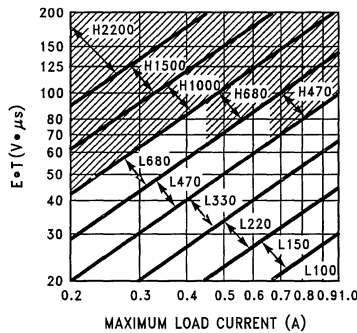


FIGURE 7. LM2575(HV)-ADJ

TL/H/11475-14

LM2575 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = Regulated Output Voltage
 $V_{IN(Max)}$ = Maximum Input Voltage
 $I_{LOAD(Max)}$ = Maximum Load Current
 F = Switching Frequency (*Fixed at 52 kHz*)

1. Programming Output Voltage (Selecting R_1 and R_2 , as shown in Figure 2)

Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) \quad \text{where } V_{REF} = 1.23V$$

R_1 can be between 1k and 5k. (*For best temperature coefficient and stability with time, use 1% metal film resistors*)

$$R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right)$$

2. Inductor Selection (L1)

A. Calculate the inductor Volt • microsecond constant, $E \cdot T$ ($V \cdot \mu s$), from the following formula:

$$E \cdot T = (V_{IN} - V_{OUT}) \frac{V_{OUT}}{V_{IN}} \cdot \frac{1000}{F \text{ (in kHz)}} (V \cdot \mu s)$$

B. Use the $E \cdot T$ value from the previous formula and match it with the $E \cdot T$ number on the vertical axis of the **Inductor Value Selection Guide** shown in Figure 7.

C. On the horizontal axis, select the maximum load current.

D. Identify the inductance region intersected by the $E \cdot T$ value and the maximum load current value, and note the inductor code for that region.

E. Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in Figure 9. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2575 switching frequency (52 kHz) and for a current rating of $1.15 \times I_{LOAD}$. For additional inductor information, see the inductor section in the application hints section of this data sheet.

3. Output Capacitor Selection (C_{OUT})

A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:

$$C_{OUT} \geq 7,785 \frac{V_{IN(Max)}}{V_{OUT} \cdot L(\mu H)} (\mu F)$$

The above formula yields capacitor values between 10 μF and 2000 μF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields.

B. The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 10V regulator, a rating of at least 15V or more is recommended.

Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.

EXAMPLE (Adjustable Output Voltage Versions)

Given:

$V_{OUT} = 10V$
 $V_{IN(Max)} = 25V$
 $I_{LOAD(Max)} = 1A$
 $F = 52 \text{ kHz}$

1. Programming Output Voltage (Selecting R_1 and R_2)

$$V_{OUT} = 1.23 \left(1 + \frac{R_2}{R_1} \right) \quad \text{Select } R_1 = 1k$$

$$R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right) = 1k \left(\frac{10V}{1.23V} - 1 \right)$$

$$R_2 = 1k (8.13 - 1) = 7.13k, \text{ closest 1\% value is } 7.15k$$

2. Inductor Selection (L1)

A. Calculate $E \cdot T$ ($V \cdot \mu s$)

$$E \cdot T = (25 - 10) \cdot \frac{10}{25} \cdot \frac{1000}{52} = 115 V \cdot \mu s$$

B. $E \cdot T = 115 V \cdot \mu s$

C. $I_{LOAD(Max)} = 1A$

D. Inductance Region = H470

E. Inductor Value = 470 μH Choose from **AIE** part #430-0634, **Pulse Engineering** part #PE-53118, or **Renco** part #RL-1961.

3. Output Capacitor Selection (C_{OUT})

$$A. C_{OUT} > 7,785 \frac{25}{10 \cdot 150} = 130 \mu F$$

However, for acceptable output ripple voltage select

$$C_{OUT} \geq 220 \mu F$$

$C_{OUT} = 220 \mu F$ electrolytic capacitor

LM2575 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
<p>4. Catch Diode Selection (D1) A. The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2575. The most stressful condition for this diode is an overload or shorted output. See diode selection guide in <i>Figure 8</i>. B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.</p> <p>5. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.</p>	<p>4. Catch Diode Selection (D1) A. For this example, a 3A current rating is adequate. B. Use a 40V MBR340 or 31DQ04 Schottky diode, or any of the suggested fast-recovery diodes in <i>Figure 8</i>.</p> <p>5. Input Capacitor (C_{IN}) A 100 μF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.</p>

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line of switching regulators. *Switchers Made Simple* (version 3.3) is available on a (3½") diskette for IBM compatible computers from a National Semiconductor sales office in your area.

V _R	Schottky		Fast Recovery	
	1A	3A	1A	3A
20V	1N5817 MBR120P SR102	1N5820 MBR320P SR302	The following diodes are all rated to 100V 11DF1 MUR110 HER102	The following diodes are all rated to 100V 31DF1 MUR310 HER302
30V	1N5818 MBR130P 11DQ03 SR103	1N5821 MBR330 31DQ03 SR303		
40V	1N5819 MBR140P 11DQ04 SR104	1N5822 MBR340 31DQ04 SR304		
50V	MBR150 11DQ05 SR105	MBR350 31DQ05 SR305		
60V	MBR1601 11DQ06 SR106	MBR3603 31DQ06 SR306		

FIGURE 8. Diode Selection Guide

Inductor Code	Inductor Value	AIE (Note 1)	Pulse Eng. (Note 2)	Renco (Note 3)
L100	100 μ H	415-0930	PE-92108	RL2444
L150	150 μ H	415-0953	PE-53113	RL1954
L220	220 μ H	415-0922	PE-52626	RL1953
L330	330 μ H	415-0926	PE-52627	RL1952
L470	470 μ H	415-0927	PE-53114	RL1951
L680	680 μ H	415-0928	PE-52629	RL1950
H150	150 μ H	415-0936	PE-53115	RL2445
H220	220 μ H	430-0636	PE-53116	RL2446
H330	330 μ H	430-0635	PE-53117	RL2447
H470	470 μ H	430-0634	PE-53118	RL1961
H680	680 μ H	415-0935	PE-53119	RL1960
H1000	1000 μ H	415-0934	PE-53120	RL1959
H1500	1500 μ H	415-0933	PE-53121	RL1958
H2200	2200 μ H	415-0945	PE-53122	RL2448

Note 1: AIE Magnetics, div. Vernatron Corp., Passive Components Group, (813) 347-2181, 2801 72nd Street North, St Petersburg, FL 33710.

Note 2: Pulse Engineering, (619) 674-8100, P.O. Box 12236, San Diego, CA 92112.

Note 3: Renco Electronics Inc., (516) 586-5566, 60 Jeffry Blvd. East, Deer Park, NY 11729.

FIGURE 9. Inductor Selection by Manufacturer's Part Number

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 47 μF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below -25°C , the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{ON}}{T} \right) \times I_{LOAD}$$

$$\text{where } \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}} \text{ for a buck regulator}$$

$$\text{and } \frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}} \text{ for a buck-boost regulator.}$$

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2575 (or any of the Simple Switcher family) can be used for both continuous and discontinuous modes of operation.

The inductor value selection guides in *Figures 3* through *7* were designed for buck regulator designs of the continuous inductor current type. When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current will be approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit operates in the continuous mode (inductor current always flowing), but under light load conditions, the circuit will be forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 200 mA) it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software *Switchers Made Simple* will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toroid, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least ex-

pensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include ferrite pot core construction for AIE, powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This will cause the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2575 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (220 μF –680 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

$$\text{Output Ripple Voltage} = (\Delta I_{IND}) (\text{ESR of } C_{OUT})$$

Application Hints (Continued)

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.05Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2575 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable**. See *Figure 8* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 μ H & 100 μ F) can be added to the output (as shown in *Figure 15*) to further reduce the amount of output ripple and transients. A 10 \times reduction in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2575 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2575 to avoid picking up unwanted noise. Avoid using resistors greater than 100 k Ω because of the increased chance of noise pickup.

ON/OFF INPUT

For normal operation, the $\overline{\text{ON/OFF}}$ pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON/OFF}}$ pin can be safely pulled up to $+V_{\text{IN}}$ without a resistor in series with it. The $\overline{\text{ON/OFF}}$ pin should not be left open.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 2*). For the TO-3 style package, the case is ground. For the 5-lead TO-220 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

With the N or M packages, all the pins labeled ground, power ground, or signal ground should be soldered directly to wide printed circuit board copper traces. This assures both low inductance connections and good thermal properties.

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, no heat sink is required to keep the LM2575 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (150°C for the LM1575 or 125°C for the LM2575). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperature should be selected.
4. LM2575 package thermal resistances θ_{JA} and θ_{JC} .

Total power dissipated by the LM2575 can be estimated as follows:

$$P_D = (V_{\text{IN}})(I_Q) + (V_O/V_{\text{IN}})(I_{\text{LOAD}})(V_{\text{SAT}})$$

where I_Q (quiescent current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

Application Hints (Continued)

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D) (\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D) (\theta_{JC} + \theta_{interface} + \theta_{Heat\ sink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

When using the LM2575 in the plastic DIP (N) or surface mount (M) packages, several items about the thermal properties of the packages should be understood. The majority of the heat is conducted out of the package through the leads, with a minor portion through the plastic parts of the package. Since the lead frame is solid copper, heat from the die is readily conducted through the leads to the printed circuit board copper, which is acting as a heat sink.

For best thermal performance, the ground pins and all the unconnected pins should be soldered to generous amounts of printed circuit board copper, such as a ground plane. Large areas of copper provide the best transfer of heat to the surrounding air. Copper on both sides of the board is also helpful in getting the heat away from the package, even if there is no direct copper contact between the two sides. Thermal resistance numbers as low as 40°C/W for the SO package, and 30°C/W for the N package can be realized with a carefully engineered pc board.

Included on the *Switchers Made Simple* design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulators junction temperature below the maximum operating temperature.

Additional Applications

INVERTING REGULATOR

Figure 10 shows a LM2575-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to -12V.

For an input voltage of 12V or more, the maximum available output current in this configuration is approximately 0.35A. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 1.5A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 μ H and 220 μ H, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD} (V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN} |V_O|}{V_{IN} + |V_O|} \times \frac{1}{2 L_1 f_{osc}}$$

Where $f_{osc} = 52$ kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a -12V output, the maximum input voltage for the LM2575 is +28V, or +48V for the LM2575HV.

The *Switchers Made Simple* (version 3.3) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

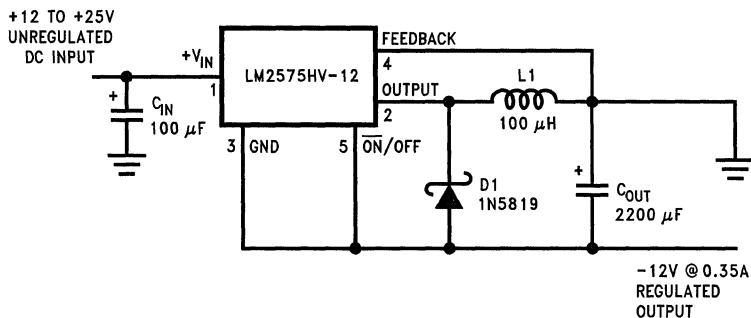


FIGURE 10. Inverting Buck-Boost Develops -12V

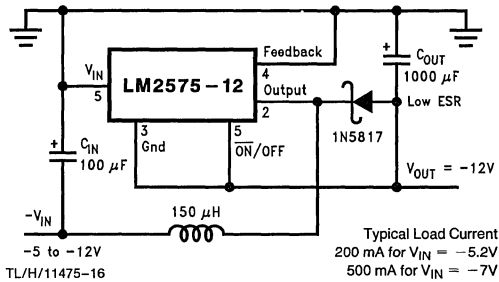
TL/H/11475-15

Additional Applications (Continued)

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in *Figure 11* accepts an input voltage ranging from -5V to -12V and provides a regulated -12V output. Input voltages greater than -12V will cause the output to rise above -12V , but will not damage the regulator.

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.



TL/H/11475-16

Note: Pin numbers are for TO-220 package.

FIGURE 11. Negative Boost

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in *Figure 12*, while *Figure 13* shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

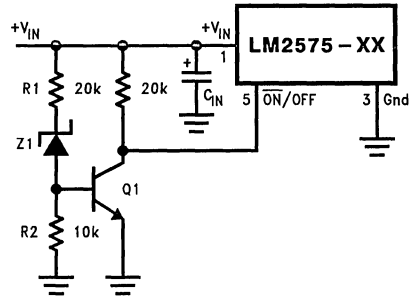
$$V_{TH} \approx V_{Z1} + 2V_{BE}(Q1)$$

DELAYED STARTUP

The ON/OFF pin can be used to provide a delayed startup feature as shown in *Figure 14*. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60Hz or 120Hz ripple, by coupling the ripple into the ON/OFF pin.

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

A 1A power supply that features an adjustable output voltage is shown in *Figure 15*. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.

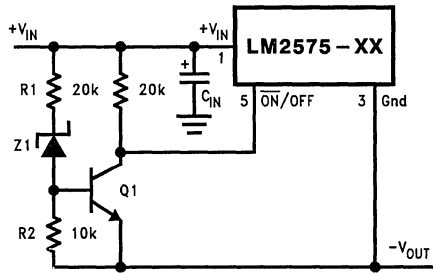


TL/H/11475-17

Note: Complete circuit not shown.

Note: Pin numbers are for the TO-220 package.

FIGURE 12. Undervoltage Lockout for Buck Circuit

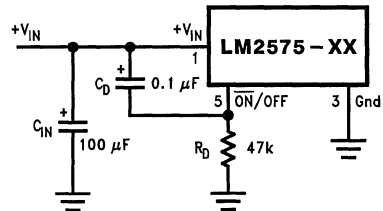


TL/H/11475-18

Note: Complete circuit not shown (see *Figure 10*).

Note: Pin numbers are for the TO-220 package.

FIGURE 13. Undervoltage Lockout for Buck-Boost Circuit



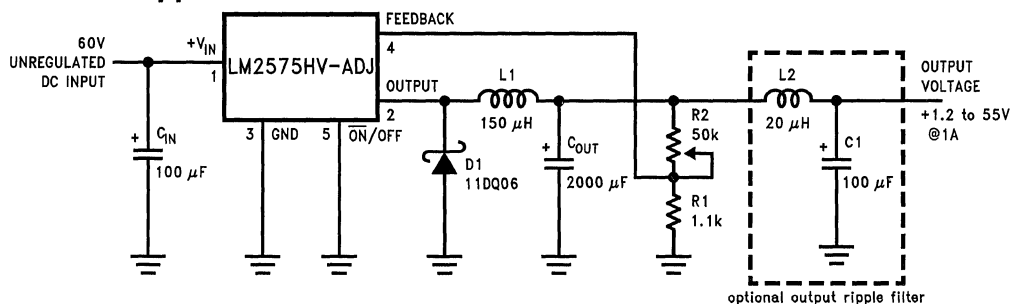
TL/H/11475-19

Note: Complete circuit not shown.

Note: Pin numbers are for the TO-220 package.

FIGURE 14. Delayed Startup

Additional Applications (Continued)



Note: Pin numbers are for the TO-220 package.

FIGURE 15. 1.2V to 55V Adjustable 1A Power Supply with Low Output Ripple

TL/H/11475-20

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

$$\text{for buck regulator} \quad D = \frac{t_{\text{ON}}}{T} = \frac{V_{\text{OUT}}}{V_{\text{IN}}}$$

$$\text{for buck-boost regulator} \quad D = \frac{t_{\text{ON}}}{T} = \frac{|V_{\text{O}}|}{|V_{\text{O}}| + V_{\text{IN}}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2575 switch is OFF.

EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{IN}}} = \frac{P_{\text{OUT}}}{P_{\text{OUT}} + P_{\text{LOSS}}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see Figure 16). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.



TL/H/11475-21

FIGURE 16. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 μF –1000 μF range have 0.5 Ω to 0.1 Ω ESR. Higher-grade capacitors ("low-ESR", "high-frequency", or "low-inductance") in the 100 μF –1000 μF range generally have ESR of less than 0.15 Ω .

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see Figure 16). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2575 when in the standby mode ($\overline{\text{ON/OFF}}$ pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

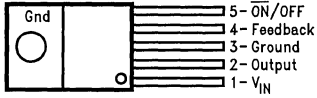
OPERATING VOLT MICROSECOND CONSTANT ($E \cdot T_{\text{OP}}$)

The product (in Volt $\cdot\mu\text{s}$) of the voltage applied to the inductor and the time the voltage is applied. This $E \cdot T_{\text{OP}}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

Connection Diagrams

(XX indicates output voltage option. See ordering information table for complete part number.)

**Straight Leads
5-Lead TO-220 (T)**

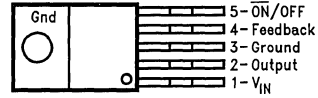


TL/H/11475-22

Top View

LM2575T-XX or LM2575HVT-XX
See NS Package Number T05A

**Bent, Staggered Leads
5-Lead TO-220 (T)**



TL/H/11475-23

Top View

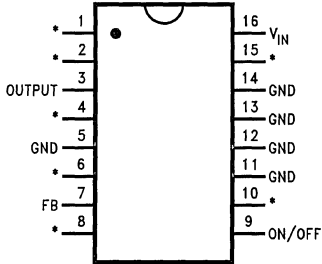


TL/H/11475-24

Side View

LM2575T-XX Flow LB03 or LM2575HVT-XX Flow LB03
See NS Package Number T05D

16-Lead DIP (N)



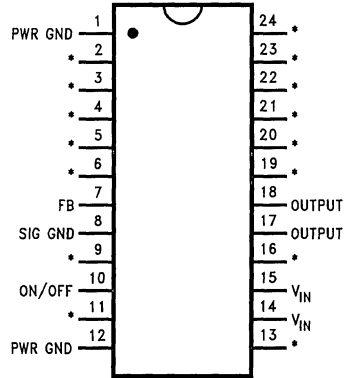
TL/H/11475-25

Top View

*No Internal Connection

LM2575N-XX or LM2575HVN-XX
See NS Package Number N16A

24-Lead Surface Mount (M)



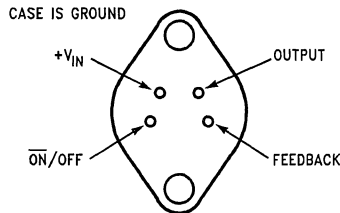
TL/H/11475-26

Top View

*No Internal Connection

LM2575M-XX or LM2575HVM-XX
See NS Package Number M24B

4-Lead TO-3 (K)



TL/H/11475-27

Bottom View

LM1575K-XX or LM1575HVK-XX/883
See NS Package Number K04A

Ordering Information

Package Type	NSC Package Number	Standard Voltage Rating (40V)	High Voltage Rating (60V)	Temperature Range
5-Lead TO-220 Straight Leads	T05A	LM2575T-3.3 LM2575T-5.0 LM2575T-12 LM2575T-15 LM2575T-ADJ	LM2575HVT-3.3 LM2575HVT-5.0 LM2575HVT-12 LM2575HVT-15 LM2575HVT-ADJ	-40°C ≤ T _J ≤ +125°C
5-Lead TO-220 Bent and Staggered Leads	T05D	LM2575T-3.3 Flow LB03 LM2575T-5.0 Flow LB03 LM2575T-12 Flow LB03 LM2575T-15 Flow LB03 LM2575T-ADJ Flow LB03	LM2575HVT-3.3 Flow LB03 LM2575HVT-5.0 Flow LB03 LM2575HVT-12 Flow LB03 LM2575HVT-15 Flow LB03 LM2575HVT-ADJ Flow LB03	
16-Pin Molded DIP	N16A	LM2575N-5.0 LM2575N-12 LM2575N-15 LM2575N-ADJ	LM2575HVN-5.0 LM2575HVN-12 LM2575HVN-15 LM2575HVN-ADJ	
24-Pin Surface Mount	M24B	LM2575M-5.0 LM2575M-12 LM2575M-15 LM2575M-ADJ	LM2575HVM-5.0 LM2575HVM-12 LM2575HVM-15 LM2575HVM-ADJ	
4-Pin TO-3	K04A	LM1575K-3.3/883 LM1575K-5.0/883 LM1575K-12/883 LM1575K-15/883 LM1575K-ADJ/883	LM1575HVK-3.3/883 LM1575HVK-5.0/883 LM1575HVK-12/883 LM1575HVK-15/883 LM1575HVK-ADJ/883	-55°C ≤ T _J ≤ +150°C

LM2576/LM2576HV Series

Simple Switcher™ 3A Step-Down Voltage Regulator

General Description

The LM2576 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2576 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in some cases no heat sink is required.

A standard series of inductors optimized for use with the LM2576 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed $\pm 4\%$ tolerance on output voltage within specified input voltages and output load conditions, and $\pm 10\%$ on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) $\pm 4\%$ max over line and load conditions
- Guaranteed 3A output current
- Wide input voltage range, 40V up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P+ Product Enhancement tested

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

Typical Application (Fixed Output Voltage Versions)

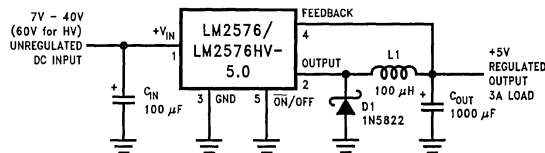
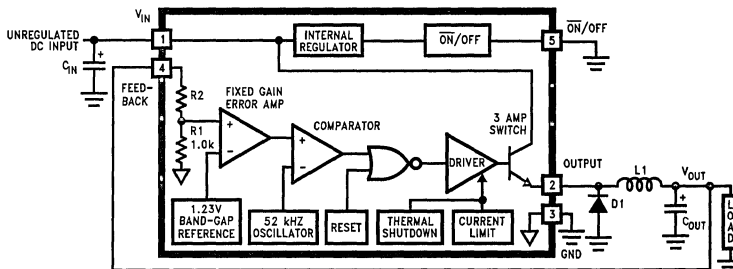


FIGURE 1

TL/H/11476-1

Block Diagram



3.3V R2 = 1.7k
5V, R2 = 3.1k
12V, R2 = 8.84k
15V, R2 = 11.3k
For ADJ. Version
R1 = Open, R2 = 0 Ω

TL/H/11476-2

Patent Pending

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM2576	45V
LM2576HV	63V
\overline{ON} /OFF Pin Input Voltage	$-0.3V \leq V \leq +V_{IN}$
Output Voltage to Ground (Steady State)	-1V
Power Dissipation	Internally Limited
Storage Temperature Range	-65°C to +150°C

Minimum ESD Rating	
(C = 100 pF, R = 1.5 k Ω)	2 kV
Lead Temperature (Soldering, 10 Seconds)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	
LM2576/LM2576HV	$-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$
Supply Voltage	
LM2576	40V
LM2576HV	60V

LM2576-3.3, LM2576HV-3.3

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-3.3 LM2576HV-3.3		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{OUT}	Output Voltage	$V_{IN} = 12V, I_{LOAD} = 0.5A$ Circuit of <i>Figure 2</i>	3.3	3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$6V \leq V_{IN} \leq 40V, 0.5A \leq I_{LOAD} \leq 3A$ Circuit of <i>Figure 2</i>	3.3	3.168/ 3.135 3.432/ 3.465	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$6V \leq V_{IN} \leq 60V, 0.5A \leq I_{LOAD} \leq 3A$ Circuit of <i>Figure 2</i>	3.3	3.168/ 3.135 3.450/ 3.482	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V, I_{LOAD} = 3A$	75		%

LM2576-5.0, LM2576HV-5.0

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-5.0 LM2576HV-5.0		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{OUT}	Output Voltage	$V_{IN} = 12V, I_{LOAD} = 0.5A$ Circuit of <i>Figure 2</i>	5.0	4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5A \leq I_{LOAD} \leq 3A,$ $8V \leq V_{IN} \leq 40V$ Circuit of <i>Figure 2</i>	5.0	4.800/ 4.750 5.200/ 5.250	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5A \leq I_{LOAD} \leq 3A,$ $8V \leq V_{IN} \leq 60V$ Circuit of <i>Figure 2</i>	5.0	4.800/ 4.750 5.225/ 5.275	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V, I_{LOAD} = 3A$	77		%

LM2576-12, LM2576HV-12

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-12 LM2576HV-12		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{OUT}	Output Voltage	$V_{IN} = 25\text{V}$, $I_{LOAD} = 0.5\text{A}$ Circuit of <i>Figure 2</i>	12	11.76 12.24	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5\text{A} \leq I_{LOAD} \leq 3\text{A}$, $15\text{V} \leq V_{IN} \leq 40\text{V}$ Circuit of <i>Figure 2</i>	12	11.52/ 11.40 12.48/ 12.60	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5\text{A} \leq I_{LOAD} \leq 3\text{A}$, $15\text{V} \leq V_{IN} \leq 60\text{V}$ Circuit of <i>Figure 2</i>	12	11.52/ 11.40 12.54/ 12.66	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 15\text{V}$, $I_{LOAD} = 3\text{A}$	88		%

LM2576-15, LM2576HV-15

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-15 LM2576HV-15		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{OUT}	Output Voltage	$V_{IN} = 25\text{V}$, $I_{LOAD} = 0.5\text{A}$ Circuit of <i>Figure 2</i>	15	14.70 15.30	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5\text{A} \leq I_{LOAD} \leq 3\text{A}$, $18\text{V} \leq V_{IN} \leq 40\text{V}$ Circuit of <i>Figure 2</i>	15	14.40/ 14.25 15.60/ 15.75	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5\text{A} \leq I_{LOAD} \leq 3\text{A}$, $18\text{V} \leq V_{IN} \leq 60\text{V}$ Circuit of <i>Figure 2</i>	15	14.40/ 14.25 15.68/ 15.83	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 18\text{V}$, $I_{LOAD} = 3\text{A}$	88		%

LM2576-ADJ, LM2576HV-ADJ

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-ADJ LM2576HV-ADJ		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit <i>Figure 2</i>					
V_{OUT}	Feedback Voltage	$V_{IN} = 12\text{V}$, $I_{LOAD} = 0.5\text{A}$ $V_{OUT} = 5\text{V}$, Circuit of <i>Figure 2</i>	1.230	1.217 1.243	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576	$0.5\text{A} \leq I_{LOAD} \leq 3\text{A}$, $8\text{V} \leq V_{IN} \leq 40\text{V}$ $V_{OUT} = 5\text{V}$, Circuit of <i>Figure 2</i>	1.230	1.193/ 1.180 1.267/ 1.280	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576HV	$0.5\text{A} \leq I_{LOAD} \leq 3\text{A}$, $8\text{V} \leq V_{IN} \leq 60\text{V}$ $V_{OUT} = 5\text{V}$, Circuit of <i>Figure 2</i>	1.230	1.193/ 1.180 1.273/ 1.286	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12\text{V}$, $I_{LOAD} = 3\text{A}$, $V_{OUT} = 5\text{V}$	77		%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, $V_{IN} = 12\text{V}$ for the 3.3V, 5V, and Adjustable version, $V_{IN} = 25\text{V}$ for the 12V version, and $V_{IN} = 30\text{V}$ for the 15V version. $I_{LOAD} = 500\text{mA}$.

Symbol	Parameter	Conditions	LM2576-XX LM2576HV-XX		Units (Limits)
			Typ	Limit (Note 2)	
DEVICE PARAMETERS					
I_b	Feedback Bias Current	$V_{OUT} = 5\text{V}$ (Adjustable Version Only)	50	100/ 500	nA
f_o	Oscillator Frequency	(Note 10)	52	47/ 42 58/ 63	kHz kHz (Min) kHz (Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 3\text{A}$ (Note 4)	1.4	1.8/ 2.0	V V(Max)
DC	Max Duty Cycle (ON)	(Note 5)	98	93	% %(Min)
I_{CL}	Current Limit	(Notes 4 and 10)	5.8	4.2/ 3.5 6.9/ 7.5	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 6 and 7) Output = 0V Output = -1V Output = -1V	7.5	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 6)	5	10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{\text{ON}}/\text{OFF}$ Pin = 5V (OFF)	50	200	μA $\mu\text{A}(\text{Max})$
θ_{JA} θ_{JA} θ_{JC}	Thermal Resistance	T Package, Junction to Ambient (Note 8) T Package, Junction to Ambient (Note 9) T Package, Junction to Case	65 45 2		$^\circ\text{C}/\text{W}$
$\overline{\text{ON}}/\text{OFF}$ CONTROL Test Circuit <i>Figure 2</i>					
V_{IH}	$\overline{\text{ON}}/\text{OFF}$ Pin Logic Input Level	$V_{OUT} = 0\text{V}$	1.4	2.2/ 2.4	V(Min)
V_{IL}		$V_{OUT} = \text{Nominal Output Voltage}$	1.2	1.0/ 0.8	V(Max)
I_{IH}	$\overline{\text{ON}}/\text{OFF}$ Pin Input Current	$\overline{\text{ON}}/\text{OFF}$ Pin = 5V (OFF)	12	30	μA $\mu\text{A}(\text{Max})$
I_{IL}		$\overline{\text{ON}}/\text{OFF}$ Pin = 0V (ON)	0	10	μA $\mu\text{A}(\text{Max})$

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2576/LM2576HV is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 4: Output pin sourcing current. No diode, inductor or capacitor connected to output.

Note 5: Feedback pin removed from output and connected to 0V.

Note 6: Feedback pin removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

Note 7: $V_{IN} = 40\text{V}$ (60V for high voltage version).

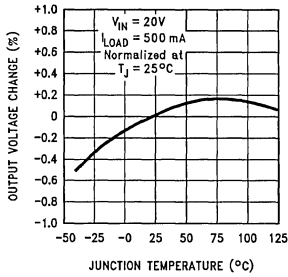
Note 8: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with $\frac{1}{2}$ inch leads in a socket, or on a PC board with minimum copper area.

Note 9: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with $\frac{1}{4}$ inch leads soldered to a PC board containing approximately 4 square inches of copper area surrounding the leads.

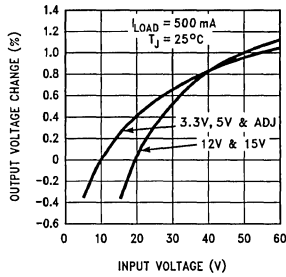
Note 10: The oscillator frequency reduces to approximately 11 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

Typical Performance Characteristics (Circuit of Figure 2)

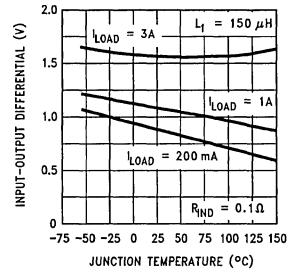
Normalized Output Voltage



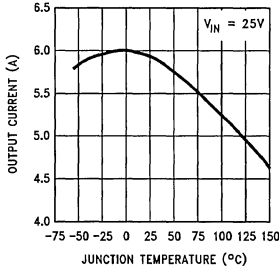
Line Regulation



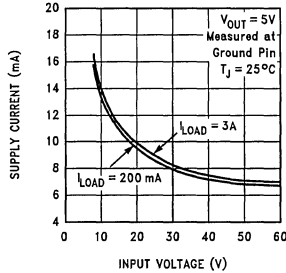
Dropout Voltage



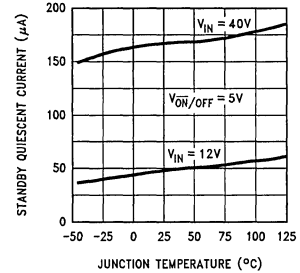
Current Limit



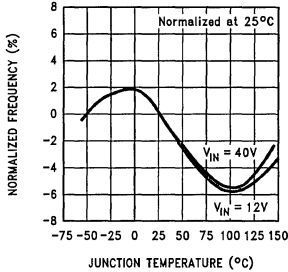
Supply Current



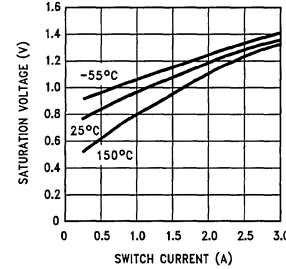
Standby Quiescent Current



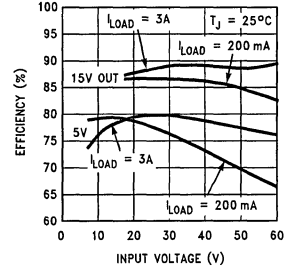
Oscillator Frequency



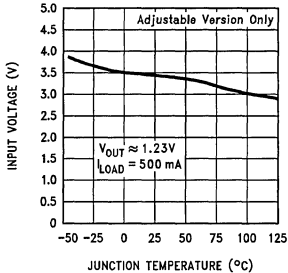
Switch Saturation Voltage



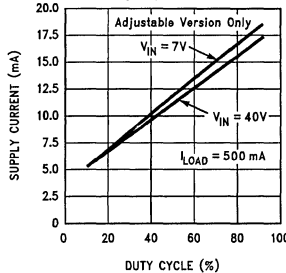
Efficiency



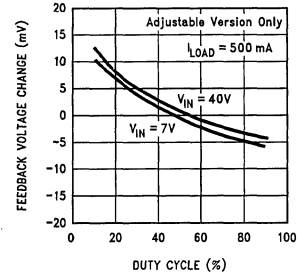
Minimum Operating Voltage



Supply Current vs Duty Cycle

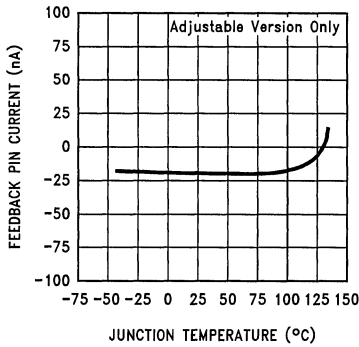


Feedback Voltage vs Duty Cycle



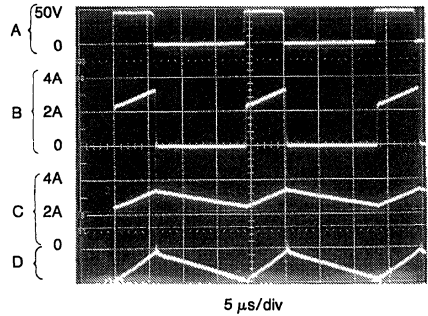
Typical Performance Characteristics (Circuit of Figure 2) (Continued)

Feedback Pin Current



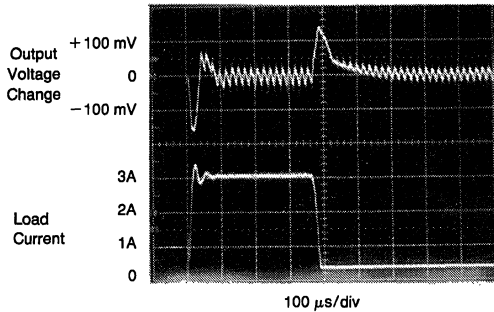
TL/H/11476-4

Switching Waveforms



TL/H/11476-6

Load Transient Response



TL/H/11476-5

$V_{OUT} = 15V$

A: Output Pin Voltage, 50V/div

B: Inductor Current, 0.2 A/div

C: Inductor Current, 2A/div

D: Output Ripple Voltage, 50 mV/div,

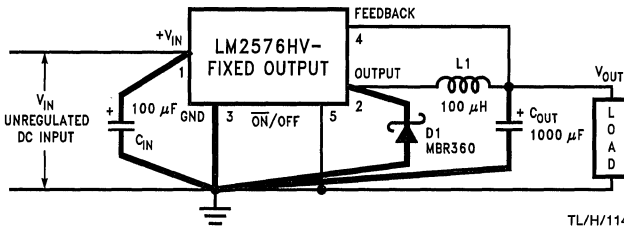
AC-Coupled

Horizontal Time Base: 5 μ s/div

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Test Circuit and Layout Guidelines

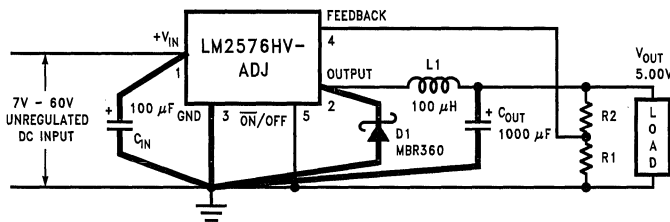
Fixed Output Voltage Versions



TL/H/11476-7

- C_{IN} — 100 μ F, 75V, Aluminum Electrolytic
- C_{OUT} — 1000 μ F, 25V, Aluminum Electrolytic
- D1 — Schottky, MBR360
- L1 — 100 μ H, Pulse Eng. PE-92108
- R1 — 2k, 0.1%
- R2 — 6.12k, 0.1%

Adjustable Output Voltage Version



TL/H/11476-8

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right)$$

$$R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right)$$

where $V_{REF} = 1.23V$, R1 between 1k and 5k.

FIGURE 2

LM2576 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
<p>Given:</p> <p>V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) $V_{IN(Max)}$ = Maximum Input Voltage $I_{LOAD(Max)}$ = Maximum Load Current</p> <p>1. Inductor Selection (L1)</p> <p>A. Select the correct Inductor value selection guide from <i>Figures 3, 4, 5, or 6</i>. (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version.</p> <p>B. From the inductor value selection guide, identify the inductance region intersected by $V_{IN(Max)}$ and $I_{LOAD(Max)}$, and note the inductor code for that region.</p> <p>C. Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in <i>Figure 3</i>. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of $1.15 \times I_{LOAD}$. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.</p> <p>2. Output Capacitor Selection (C_{OUT})</p> <p>A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 μF and 470 μF is recommended.</p> <p>B. The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended.</p> <p>Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.</p> <p>3. Catch Diode Selection (D1)</p> <p>A. The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output condition.</p> <p>B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.</p> <p>4. Input Capacitor (C_{IN})</p> <p>An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.</p>	<p>Given:</p> <p>V_{OUT} = 5V $V_{IN(Max)}$ = 15V $I_{LOAD(Max)}$ = 3A</p> <p>1. Inductor Selection (L1)</p> <p>A. Use the selection guide shown in <i>Figure 4</i>.</p> <p>B. From the selection guide, the inductance area intersected by the 15V line and 3A line is L100.</p> <p>C. Inductor value required is 100 μH. From the table in <i>Figure 3</i>. Choose AIE 415-0930, Pulse Engineering PE92108, or Renco RL2444.</p> <p>2. Output Capacitor Selection (C_{OUT})</p> <p>A. C_{OUT} = 680 μF to 2000 μF standard aluminum electrolytic.</p> <p>B. Capacitor voltage rating = 20V.</p> <p>3. Catch Diode Selection (D1)</p> <p>A. For this example, a 3A current rating is adequate.</p> <p>B. Use a 20V 1N5823 or SR302 Schottky diode, or any of the suggested fast-recovery diodes shown in <i>Figure 8</i>.</p> <p>4. Input Capacitor (C_{IN})</p> <p>A 100 μF, 25V aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.</p>

LM2576 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

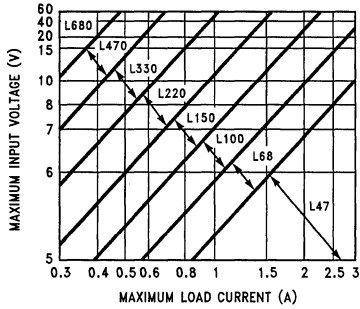


FIGURE 3. LM2576(HV)-3.3

TL/H/11476-9

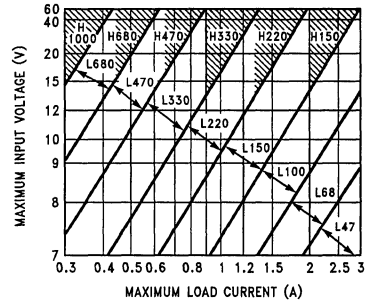


FIGURE 4. LM2576(HV)-5.0

TL/H/11476-10

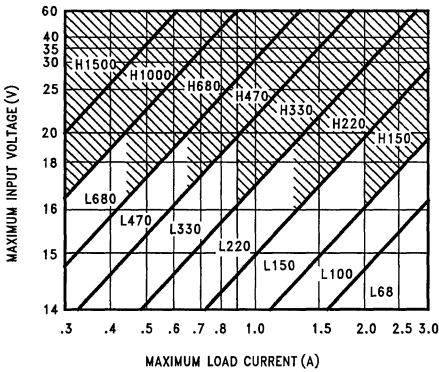


FIGURE 5. LM2576(HV)-12

TL/H/11476-11

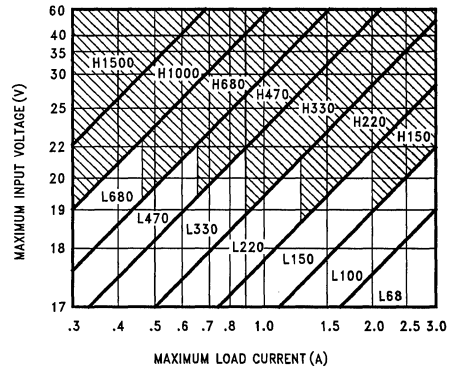


FIGURE 6. LM2576(HV)-15

TL/H/11476-12

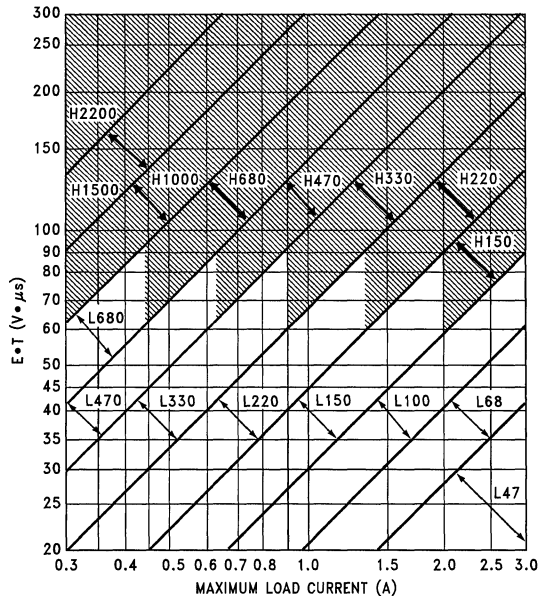


FIGURE 7. LM2576(HV)-ADJ

TL/H/11476-13

LM2576 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
<p>Given:</p> <p>V_{OUT} = Regulated Output Voltage $V_{IN(Max)}$ = Maximum Input Voltage $I_{LOAD(Max)}$ = Maximum Load Current F = Switching Frequency (<i>Fixed at 52 kHz</i>)</p> <p>1. Programming Output Voltage (Selecting R_1 and R_2, as shown in Figure 2)</p> <p>Use the following formula to select the appropriate resistor values.</p> $V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) \quad \text{where } V_{REF} = 1.23V$ <p>R_1 can be between 1k and 5k. (<i>For best temperature coefficient and stability with time, use 1% metal film resistors</i>)</p> $R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right)$ <p>2. Inductor Selection (L1)</p> <p>A. Calculate the inductor Volt • microsecond constant, $E \bullet T$ ($V \bullet \mu s$), from the following formula:</p> $E \bullet T = (V_{IN} - V_{OUT}) \frac{V_{OUT}}{V_{IN}} \frac{1000}{F \text{ (in kHz)}} (V \bullet \mu s)$ <p>B. Use the $E \bullet T$ value from the previous formula and match it with the $E \bullet T$ number on the vertical axis of the Inductor Value Selection Guide shown in <i>Figure 7</i>.</p> <p>C. On the horizontal axis, select the maximum load current.</p> <p>D. Identify the inductance region intersected by the $E \bullet T$ value and the maximum load current value, and note the inductor code for that region.</p> <p>E. Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in <i>Figure 9</i>. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of $1.15 \times I_{LOAD}$. For additional inductor information, see the inductor section in the application hints section of this data sheet.</p> <p>3. Output Capacitor Selection (C_{OUT})</p> <p>A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:</p> $C_{OUT} \geq 13,300 \frac{V_{IN(Max)}}{V_{OUT} \bullet L(\mu H)} (\mu F)$ <p>The above formula yields capacitor values between 10 μF and 2200 μF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields.</p> <p>B. The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 10V regulator, a rating of at least 15V or more is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.</p>	<p>Given:</p> <p>$V_{OUT} = 10V$ $V_{IN(Max)} = 25V$ $I_{LOAD(Max)} = 3A$ $F = 52 \text{ kHz}$</p> <p>1. Programming Output Voltage (Selecting R_1 and R_2)</p> $V_{OUT} = 1.23 \left(1 + \frac{R_2}{R_1} \right) \quad \text{Select } R_1 = 1k$ $R_2 = R_1 \left(\frac{V_{OUT}}{V_{REF}} - 1 \right) = 1k \left(\frac{10V}{1.23V} - 1 \right)$ $R_2 = 1k (8.13 - 1) = 7.13k, \text{ closest 1\% value is 7.15k}$ <p>2. Inductor Selection (L1)</p> <p>A. Calculate $E \bullet T$ ($V \bullet \mu s$)</p> $E \bullet T = (25 - 10) \bullet \frac{10}{25} \bullet \frac{1000}{52} = 115 V \bullet \mu s$ <p>B. $E \bullet T = 115 V \bullet \mu s$ C. $I_{LOAD(Max)} = 3A$ D. Inductance Region = H150 E. Inductor Value = 150 μH <i>Choose from AIE part #415-0936 Pulse Engineering part #PE-531115, or Renco part #RL2445.</i></p> <p>3. Output Capacitor Selection (C_{OUT})</p> <p>A. $C_{OUT} > 13,300 \frac{25}{10 \bullet 150} = 22.2 \mu F$</p> <p>However, for acceptable output ripple voltage select</p> $C_{OUT} \geq 680 \mu F$ <p>$C_{OUT} = 680 \mu F$ electrolytic capacitor</p>

LM2576 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)

- 4. Catch Diode Selection (D₁)**
A. The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output. See diode selection guide in *Figure 8*.
B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.
- 5. Input Capacitor (C_{IN})**
 An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.

EXAMPLE (Adjustable Output Voltage Versions)

- 4. Catch Diode Selection (D₁)**
A. For this example, a 3.3A current rating is adequate.
B. Use a 30V 31DQ03 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 8*.
- 5. Input Capacitor (C_{IN})**
 A 100 μ F aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

V _R	Schottky		Fast Recovery	
	3A	4A-6A	3A	4A-6A
20V	1N5820 MBR320P SR302	1N5823	The following diodes are all rated to 100V 31DF1 HER302	The following diodes are all rated to 100V 50WF10 MUR410 HER602
30V	1N5821 MBR330 31DQ03 SR303	50WQ03 1N5824		
40V	1N5822 MBR340 31DQ04 SR304	MBR340 50WQ04 1N5825		
50V	MBR350 31DQ05 SR305	50WQ05		
60V	MBR360 DQ06 SR306	50WR06 50SQ060		

*To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line of switching regulators. **Switchers Made Simple** (Version 3.3) is available on a (3½") diskette for IBM compatible computers from a National Semiconductor sales office in your area.*

FIGURE 8. Diode Selection Guide

Inductor Code	Inductor Value	AIE (Note 1)	Pulse Eng. (Note 2)	Renco (Note 3)
L47	47 μ H	415-0932	PE-53112	RL2442
L68	68 μ H	415-0931	PE-92114	RL2443
L100	100 μ H	415-0930	PE-92108	RL2444
L150	150 μ H	415-0953	PE-53113	RL1954
L220	220 μ H	415-0922	PE-52626	RL1953
L330	330 μ H	415-0926	PE-52627	RL1952
L470	470 μ H	415-0927	PE-53114	RL1951
L680	680 μ H	415-0928	PE-52629	RL1950
H150	150 μ H	415-0936	PE-53115	RL2445
H220	220 μ H	430-0636	PE-53116	RL2446
H330	330 μ H	430-0635	PE-53117	RL2447
H470	470 μ H	430-0634	PE-53118	RL1961
H680	680 μ H	415-0935	PE-53119	RL1960
H1000	1000 μ H	415-0934	PE-53120	RL1959
H1500	1500 μ H	415-0933	PE-53121	RL1958
H2200	2200 μ H	415-0945	PE-53122	RL2448

Note 1: AIE Magnetics Division, Vernatron Corporation, Passive Components Group, (813) 347-2181, 2801 72nd Street North, St Petersburg, FL 33710.

Note 2: Pulse Engineering, (619) 674-8100, P.O. Box 12235, San Diego, CA 92112.

Note 3: Renco Electronics Incorporated, (516) 586-5566, 60 Jeffryn Blvd. East, Deer Park, NY 11729.

FIGURE 9. Inductor Selection by Manufacturer's Part Number

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 100 μF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below -25°C , the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{\text{ON}}}{T} \right) \times I_{\text{LOAD}}$$

$$\text{where } \frac{t_{\text{ON}}}{T} = \frac{V_{\text{OUT}}}{V_{\text{IN}}} \text{ for a buck regulator}$$

$$\text{and } \frac{t_{\text{ON}}}{T} = \frac{|V_{\text{OUT}}|}{|V_{\text{OUT}}| + V_{\text{IN}}} \text{ for a buck-boost regulator.}$$

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2576 (or any of the Simple Switcher family) can be used for both continuous and discontinuous modes of operation.

The inductor value selection guides in *Figure 3* through *Figure 7* were designed for buck regulator designs of the continuous inductor current type. When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current will be approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit operates in the continuous mode (inductor current always flowing), but under light load conditions, the circuit will be forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 300 mA) it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software *Switchers Made Simple* will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toroid, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include ferrite pot core construction for AIE, powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This will cause the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2576 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (220 μF –1000 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

$$\text{Output Ripple Voltage} = (\Delta I_{\text{IND}}) (\text{ESR of } C_{\text{OUT}})$$

Application Hints (Continued)

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.03Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2576 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable**. See *Figure 8* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 μ H & 100 μ F) can be added to the output (as shown in *Figure 15*) to further reduce the amount of output ripple and transients. A $10\times$ reduction in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2576 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2576 to avoid picking up unwanted noise. Avoid using resistors greater than 100 k Ω because of the increased chance of noise pickup.

ON/OFF INPUT

For normal operation, the $\overline{\text{ON/OFF}}$ pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON/OFF}}$ pin can be safely pulled up to $+V_{\text{IN}}$ without a resistor in series with it. The $\overline{\text{ON/OFF}}$ pin should not be left open.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 2*). For the 5-lead TO-220 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, only a small heat sink is required to keep the LM2576 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (125°C for the LM2576). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperatures should be selected.
4. LM2576 package thermal resistances θ_{JA} and θ_{JC} .

Total power dissipated by the LM2576 can be estimated as follows:

$$P_D = (V_{\text{IN}})I_Q + (V_O/V_{\text{IN}})I_{\text{LOAD}}(V_{\text{SAT}})$$

where I_Q (quiescent current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D) (\theta_{\text{JA}})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D) (\theta_{\text{JC}} + \theta_{\text{interface}} + \theta_{\text{Heat sink}})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

Included on the **Switcher Made Simple** design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulators junction temperature below the maximum operating temperature.

Additional Applications

INVERTING REGULATOR

Figure 10 shows a LM2576-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to -12V.

For an input voltage of 12V or more, the maximum available output current in this configuration is approximately 700 mA. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 0.6A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 μ H and 220 μ H, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD}(V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN}|V_O|}{V_{IN} + |V_O|} \times \frac{1}{2L_1 f_{OSC}}$$

Where $f_{OSC} = 52$ kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

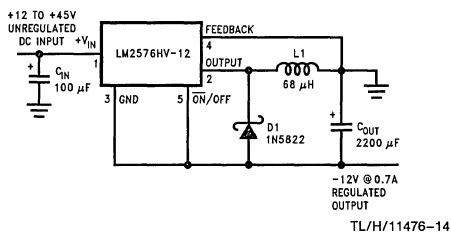


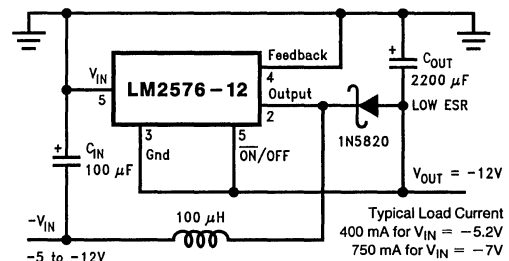
FIGURE 10. Inverting Buck-Boost Develops -12V

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a -12V output, the maximum input voltage for the LM2576 is +28V, or +48V for the LM2576HV.

The *Switchers Made Simple* (version 3.0) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in Figure 11 accepts an input voltage ranging from -5V to -12V and provides a regulated -12V output. Input voltages greater than -12V will cause the output to rise above -12V, but will not damage the regulator.



Note: Heat sink may be required.

TL/H/11476-15

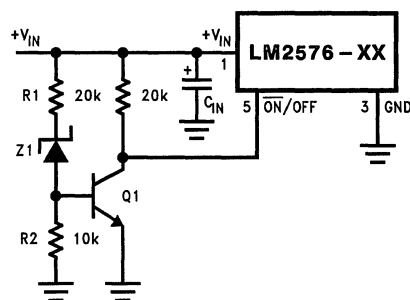
FIGURE 11. Negative Boost

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in Figure 12, while Figure 13 shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

$$V_{TH} \approx V_{Z1} + 2V_{BE}(Q1)$$

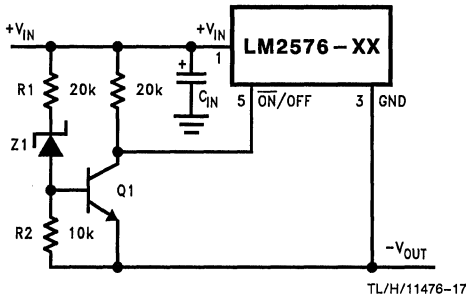


Note: Complete circuit not shown.

TL/H/11476-16

FIGURE 12. Undervoltage Lockout for Buck Circuit

Additional Applications (Continued)



Note: Complete circuit not shown (see Figure 10).

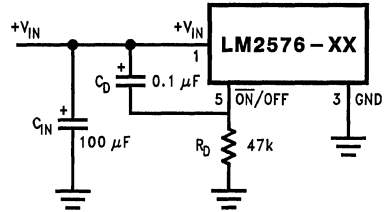
FIGURE 13. Undervoltage Lockout for Buck-Boost Circuit

DELAYED STARTUP

The $\overline{\text{ON/OFF}}$ pin can be used to provide a delayed startup feature as shown in Figure 14. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the $\overline{\text{ON/OFF}}$ pin.

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

A 3A power supply that features an adjustable output voltage is shown in Figure 15. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.



Note: Complete circuit not shown.

FIGURE 14. Delayed Startup

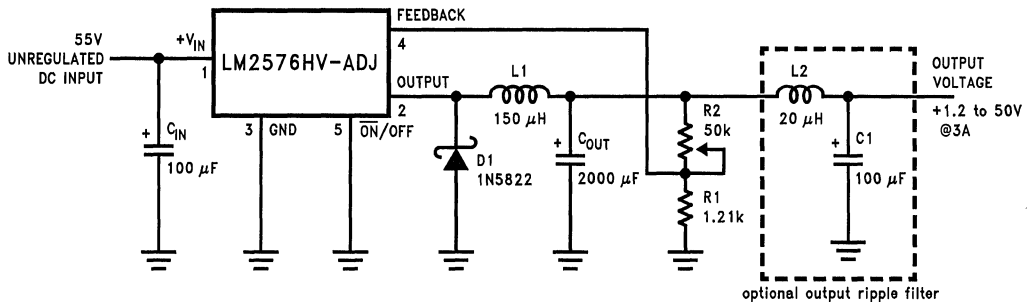


FIGURE 15. 1.2V to 55V Adjustable 3A Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

$$\text{for buck regulator} \quad D = \frac{t_{\text{ON}}}{T} = \frac{V_{\text{OUT}}}{V_{\text{IN}}}$$

$$\text{for buck-boost regulator} \quad D = \frac{t_{\text{ON}}}{T} = \frac{|V_{\text{O}}|}{|V_{\text{O}}| + V_{\text{IN}}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2576 switch is OFF.

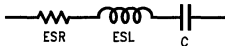
EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{IN}}} = \frac{P_{\text{OUT}}}{P_{\text{OUT}} + P_{\text{LOSS}}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see *Figure 16*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.



TL/H/11476-20

FIGURE 16. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 μF –1000 μF range have 0.5 Ω to 0.1 Ω ESR. Higher-grade capacitors ("low-ESR", "high-frequency", or "low-inductance") in the 100 μF –1000 μF range generally have ESR of less than 0.15 Ω .

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see *Figure 16*). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2576 when in the standby mode ($\overline{\text{ON}}$ /OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

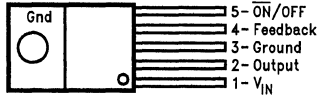
OPERATING VOLT MICROSECOND CONSTANT ($E \cdot T_{\text{op}}$)

The product (in Volt $\cdot\mu\text{s}$) of the voltage applied to the inductor and the time the voltage is applied. This $E \cdot T_{\text{op}}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

Connection Diagrams

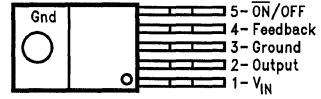
(XX indicates output voltage option. See ordering information table for complete part number.)

Straight Leads
5-Lead TO-220 (T)
Top View



TL/11476-21

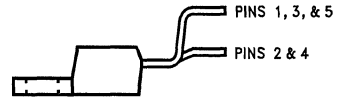
Bent, Staggered Leads
5-Lead TO-220 (T)
Top View



TL/11476-22

LM2576T-XX or LM2576HVT-XX
NS Package Number T05A

Side View



TL/11476-23

LM2576T-XX Flow LB03
or LM2576HVT-XX Flow LB03
NS Package Number T05D

Ordering Information

Package Type	NSC Package Number	Standard Voltage Rating (40V)	High Voltage Rating (60V)	Temperature Range
5-Lead TO-220 Straight Leads	T05A	LM2576T-3.3 LM2576T-5.0 LM2576T-12 LM2576T-15 LM2576T-ADJ	LM2576HVT-3.3 LM2576HVT-5.0 LM2576HVT-12 LM2576HVT-15 LM2576HVT-ADJ	-40°C ≤ T _J ≤ +125°C
5-Lead TO-220 Bent and Staggered Leads	T05D	LM2576T-3.3 Flow LB03 LM2576T-5.0 Flow LB03 LM2576T-12 Flow LB03 LM2576T-15 Flow LB03 LM2576T-ADJ Flow LB03	LM2576HVT-3.3 Flow LB03 LM2576HVT-5.0 Flow LB03 LM2576HVT-12 Flow LB03 LM2576HVT-15 Flow LB03 LM2576HVT-ADJ Flow LB03	

LM1577/LM2577 Series SIMPLE SWITCHER™ Step-Up Voltage Regulator

General Description

The LM1577/LM2577 are monolithic integrated circuits that provide all of the power and control functions for step-up (boost), flyback, and forward converter switching regulators. The device is available in three different output voltage versions: 12V, 15V, and adjustable.

Requiring a minimum number of external components, these regulators are cost effective, and simple to use. Listed in this data sheet are a family of standard inductors and flyback transformers designed to work with these switching regulators.

Included on the chip is a 3.0A NPN switch and its associated protection circuitry, consisting of current and thermal limiting, and undervoltage lockout. Other features include a 52 kHz fixed-frequency oscillator that requires no external components, a soft start mode to reduce in-rush current during start-up, and current mode control for improved rejection of input voltage and output load transients.

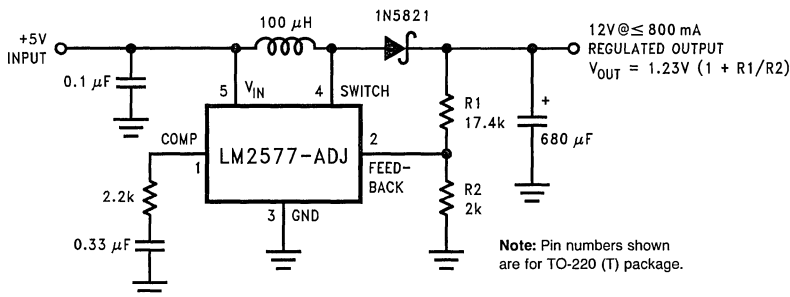
Features

- Requires few external components
- NPN output switches 3.0A, can stand off 65V
- Wide input voltage range: 3.5V to 40V
- Current-mode operation for improved transient response, line regulation, and current limit
- 52 kHz internal oscillator
- Soft-start function reduces in-rush current during start-up
- Output switch protected by current limit, under-voltage lockout, and thermal shutdown

Typical Applications

- Simple boost regulator
- Flyback and forward regulators
- Multiple-output regulator

Typical Application



TL/H/11468-1

Ordering Information

Package Type	NSC Package Drawing	Order Number	Temperature Range
5-Lead TO-220, Straight Leads	T05A	LM2577T-12, LM2577T-15, or LM2577T-ADJ	-40°C ≤ T _J ≤ +125°C
5-Lead TO-220 Bent, Staggered Leads	T05D	LM2577T-12 Flow LB03, LM2577T-15 Flow LB03, or LM2577T-ADJ Flow LB03	
16-Pin Molded DIP	N16A	LM2577N-12, LM2577N-15, or LM2577N-ADJ	
24-Pin Surface Mount	M24B	LM2577M-12, LM2577M-15, or LM2577M-ADJ	
4-Pin TO-3	K04A	LM1577K-12/883, LM1577K-15/883, or LM1577K-ADJ/883	-55°C ≤ T _J ≤ +150°C

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	45V
Output Switch Voltage	65V
Output Switch Current (Note 2)	6.0A
Power Dissipation	Internally Limited
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C
Minimum ESD Rating (C = 100 pF, R = 1.5 kΩ)	2 kV

Operating Ratings

Supply Voltage	$3.5V \leq V_{IN} \leq 40V$
Output Switch Voltage	$0V \leq V_{SWITCH} \leq 60V$
Output Switch Current	$I_{SWITCH} \leq 3.0A$
Junction Temperature Range	
LM1577	$-55^{\circ}C \leq T_J \leq +150^{\circ}C$
LM2577	$-40^{\circ}C \leq T_J \leq +125^{\circ}C$

Electrical Characteristics—LM1577-12, LM2577-12

Specifications with standard type face are for $T_J = 25^{\circ}C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5V$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-12 Limit (Notes 3, 4)	LM2577-12 Limit (Note 5)	Units (Limits)
SYSTEM PARAMETERS Circuit of Figure 1 (Note 6)						
V_{OUT}	Output Voltage	$V_{IN} = 5V$ to 10V $I_{LOAD} = 100$ mA to 800 mA (Note 3)	12.0	11.60/ 11.40 12.40/ 12.60	11.60/ 11.40 12.40/ 12.60	V V(min) V(max)
$\frac{\Delta V_{OUT}}{\Delta V_{IN}}$	Line Regulation	$V_{IN} = 3.5V$ to 10V $I_{LOAD} = 300$ mA	20	50/ 100	50/ 100	mV mV(max)
$\frac{\Delta V_{OUT}}{\Delta I_{LOAD}}$	Load Regulation	$V_{IN} = 5V$ $I_{LOAD} = 100$ mA to 800 mA	20	50/ 100	50/ 100	mV mV(max)
η	Efficiency	$V_{IN} = 5V$, $I_{LOAD} = 800$ mA	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK} = 14V$ (Switch Off)	7.5	10.0/ 14.0	10.0/ 14.0	mA mA(max)
		$I_{SWITCH} = 2.0A$ $V_{COMP} = 2.0V$ (Max Duty Cycle)	25	50/ 85	50/ 85	mA mA(max)
V_{UV}	Input Supply Undervoltage Lockout	$I_{SWITCH} = 100$ mA	2.90	2.70/ 2.65 3.10/ 3.15	2.70/ 2.65 3.10/ 3.15	V V(min) V(max)
f_O	Oscillator Frequency	Measured at Switch Pin $I_{SWITCH} = 100$ mA	52	48/ 42 56/ 62	48/ 42 56/ 62	kHz kHz(min) kHz(max)
V_{REF}	Output Reference Voltage	Measured at Feedback Pin $V_{IN} = 3.5V$ to 40V $V_{COMP} = 1.0V$	12	11.76/ 11.64 12.24/ 12.36	11.76/ 11.64 12.24/ 12.36	V V(min) V(max)
$\frac{\Delta V_{REF}}{\Delta V_{IN}}$	Output Reference Voltage Line Regulator	$V_{IN} = 3.5V$ to 40V	7			mV
R_{FB}	Feedback Pin Input Resistance		9.7			kΩ
G_M	Error Amp Transconductance	$I_{COMP} = -30$ μA to +30 μA $V_{COMP} = 1.0V$	370	225/ 145 515/ 615	225/ 145 515/ 615	μmho μmho(min) μmho(max)
A_{VOL}	Error Amp Voltage Gain	$V_{COMP} = 1.1V$ to 1.9V $R_{COMP} = 1.0$ MΩ (Note 7)	80	50/ 25	50/ 25	V/V V/V(min)

Electrical Characteristics—LM1577-12, LM2577-12 (Continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-12 Limit (Notes 3, 4)	LM2577-12 Limit (Note 5)	Units (Limits)
DEVICE PARAMETERS (Continued)						
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK} = 10.0\text{V}$	2.4	2.2/ 2.0	2.2/ 2.0	V V(min)
		Lower Limit $V_{FEEDBACK} = 15.0\text{V}$	0.3	0.40/ 0.55	0.40/ 0.55	V V(max)
	Error Amplifier Output Current	$V_{FEEDBACK} = 10.0\text{V}$ to 15.0V $V_{COMP} = 1.0\text{V}$	± 200	$\pm 130/\pm \mathbf{90}$ $\pm 300/\pm \mathbf{400}$	$\pm 130/\pm \mathbf{90}$ $\pm 300/\pm \mathbf{400}$	μA $\mu\text{A}(\text{min})$ $\mu\text{A}(\text{max})$
I_{SS}	Soft Start Current	$V_{FEEDBACK} = 10.0\text{V}$ $V_{COMP} = 0\text{V}$	5.0	2.5/ 1.5 7.5/ 9.5	2.5/ 1.5 7.5/ 9.5	μA $\mu\text{A}(\text{min})$ $\mu\text{A}(\text{max})$
D	Maximum Duty Cycle	$V_{COMP} = 1.5\text{V}$ $I_{SWITCH} = 100\text{mA}$	95	93/ 90	93/ 90	% %(min)
$\frac{\Delta I_{SWITCH}}{\Delta V_{COMP}}$	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{SWITCH} = 65\text{V}$ $V_{FEEDBACK} = 15\text{V}$ (Switch Off)	10	300/ 600	300/ 600	μA $\mu\text{A}(\text{max})$
V_{SAT}	Switch Saturation Voltage	$I_{SWITCH} = 2.0\text{A}$ $V_{COMP} = 2.0\text{V}$ (Max Duty Cycle)	0.5	0.7/ 0.9	0.7/ 0.9	V V(max)
	NPN Switch Current Limit		4.5	3.7/ 3.0 5.3/ 6.0	3.7/ 3.0 5.3/ 6.0	A A(min) A(max)

Electrical Characteristics—LM1577-15, LM2577-15

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, and $I_{\text{SWITCH}} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-15 Limit (Notes 3, 4)	LM2577-15 Limit (Note 5)	Units (Limits)
SYSTEM PARAMETERS Circuit of Figure 2 (Note 6)						
V_{OUT}	Output Voltage	$V_{\text{IN}} = 5\text{V to } 12\text{V}$ $I_{\text{LOAD}} = 100\text{ mA to } 600\text{ mA}$ (Note 3)	15.0	14.50/ 14.25 15.50/ 15.75	14.50/ 14.25 15.50/ 15.75	V V(min) V(max)
$\frac{\Delta V_{\text{OUT}}}{V_{\text{IN}}}$	Line Regulation	$V_{\text{IN}} = 3.5\text{V to } 12\text{V}$ $I_{\text{LOAD}} = 300\text{ mA}$	20	50/ 100	50/ 100	mV mV(max)
$\frac{\Delta V_{\text{OUT}}}{\Delta I_{\text{LOAD}}}$	Load Regulation	$V_{\text{IN}} = 5\text{V}$ $I_{\text{LOAD}} = 100\text{ mA to } 600\text{ mA}$	20	50/ 100	50/ 100	mV mV(max)
η	Efficiency	$V_{\text{IN}} = 5\text{V}$, $I_{\text{LOAD}} = 600\text{ mA}$	80			%
DEVICE PARAMETERS						
I_{S}	Input Supply Current	$V_{\text{FEEDBACK}} = 18.0\text{V}$ (Switch Off)	7.5	10.0/ 14.0	10.0/ 14.0	mA mA(max)
		$I_{\text{SWITCH}} = 2.0\text{A}$ $V_{\text{COMP}} = 2.0\text{V}$ (Max Duty Cycle)	25	50/ 85	50/ 85	mA mA(max)
V_{UV}	Input Supply Undervoltage Lockout	$I_{\text{SWITCH}} = 100\text{ mA}$	2.90	2.70/ 2.65 3.10/ 3.15	2.70/ 2.65 3.10/ 3.15	V V(min) V(max)
f_{O}	Oscillator Frequency	Measured at Switch Pin $I_{\text{SWITCH}} = 100\text{ mA}$	52	48/ 42 56/ 62	48/ 42 56/ 62	kHz kHz(min) kHz(max)
V_{REF}	Output Reference Voltage	Measured at Feedback Pin $V_{\text{IN}} = 3.5\text{V to } 40\text{V}$ $V_{\text{COMP}} = 1.0\text{V}$	15	14.70/ 14.55 15.30/ 15.45	14.70/ 14.55 15.30/ 15.45	V V(min) V(max)
$\frac{\Delta V_{\text{REF}}}{\Delta V_{\text{IN}}}$	Output Reference Voltage Line Regulation	$V_{\text{IN}} = 3.5\text{V to } 40\text{V}$	10			mV
R_{FB}	Feedback Pin Input Voltage Line Regulator		12.2			k Ω
G_{M}	Error Amp Transconductance	$I_{\text{COMP}} = -30\ \mu\text{A to } +30\ \mu\text{A}$ $V_{\text{COMP}} = 1.0\text{V}$	300	170/ 110 420/ 500	170/ 110 420/ 500	μmho $\mu\text{mho}(\text{min})$ $\mu\text{mho}(\text{max})$
A_{VOL}	Error Amp Voltage Gain	$V_{\text{COMP}} = 1.1\text{V to } 1.9\text{V}$ $R_{\text{COMP}} = 1.0\ \text{M}\Omega$ (Note 7)	65	40/ 20	40/ 20	V/V V/V(min)

Electrical Characteristics—LM1577-15, LM2577-15 (Continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-15 Limit (Notes 3, 4)	LM2577-15 Limit (Note 5)	Units (Limits)
DEVICE PARAMETERS (Continued)						
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK} = 12.0\text{V}$	2.4	2.2/ 2.0	2.2/ 2.0	V V(min)
		Lower Limit $V_{FEEDBACK} = 18.0\text{V}$	0.3	0.4/ 0.55	0.40/ 0.55	V V(max)
	Error Amp Output Current	$V_{FEEDBACK} = 12.0\text{V}$ to 18.0V $V_{COMP} = 1.0\text{V}$	± 200	$\pm 130/\pm 90$ $\pm 300/\pm 400$	$\pm 130/\pm 90$ $\pm 300/\pm 400$	μA $\mu\text{A}(\text{min})$ $\mu\text{A}(\text{max})$
I_{SS}	Soft Start Current	$V_{FEEDBACK} = 12.0\text{V}$ $V_{COMP} = 0\text{V}$	5.0	2.5/ 1.5 7.5/ 9.5	2.5/ 1.5 7.5/ 9.5	μA $\mu\text{A}(\text{min})$ $\mu\text{A}(\text{max})$
D	Maximum Duty Cycle	$V_{COMP} = 1.5\text{V}$ $I_{SWITCH} = 100\text{mA}$	95	93/ 90	93/ 90	% %(min)
$\frac{\Delta I_{SWITCH}}{\Delta V_{COMP}}$	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{SWITCH} = 65\text{V}$ $V_{FEEDBACK} = 18.0\text{V}$ (Switch Off)	10	300/ 600	300/ 600	μA $\mu\text{A}(\text{max})$
V_{SAT}	Switch Saturation Voltage	$I_{SWITCH} = 2.0\text{A}$ $V_{COMP} = 2.0\text{V}$ (Max Duty Cycle)	0.5	0.7/ 0.9	0.7/ 0.9	V V(max)
	NPN Switch Current Limit	$V_{COMP} = 2.0\text{V}$	4.3	3.7/ 3.0 5.3/ 6.0	3.7/ 3.0 5.3/ 6.0	A A(min) A(max)

Electrical Characteristics—LM1577-ADJ, LM2577-ADJ

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, $V_{FEEDBACK} = V_{REF}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-ADJ Limit (Notes 3, 4)	LM2577-ADJ Limit (Note 5)	Units (Limits)
SYSTEM PARAMETERS Circuit of <i>Figure 3</i> (Note 6)						
V_{OUT}	Output Voltage	$V_{IN} = 5\text{V to }10\text{V}$ $I_{LOAD} = 100\text{ mA to }800\text{ mA}$ (Note 3)	12.0	11.60/ 11.40 12.40/ 12.60	11.60/ 11.40 12.40/ 12.60	V V(min) V(max)
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation	$V_{IN} = 3.5\text{V to }10\text{V}$ $I_{LOAD} = 300\text{ mA}$	20	50/ 100	50/ 100	mV mV(max)
$\Delta V_{OUT}/\Delta I_{LOAD}$	Load Regulation	$V_{IN} = 5\text{V}$ $I_{LOAD} = 100\text{ mA to }800\text{ mA}$	20	50/ 100	50/ 100	mV mV(max)
η	Efficiency	$V_{IN} = 5\text{V}$, $I_{LOAD} = 800\text{ mA}$	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK} = 1.5\text{V}$ (Switch Off)	7.5	10.0/ 14.0	10.0/ 14.0	mA mA(max)
		$I_{SWITCH} = 2.0\text{A}$ $V_{COMP} = 2.0\text{V}$ (Max Duty Cycle)	25	50/ 85	50/ 85	mA mA(max)
V_{UV}	Input Supply Undervoltage Lockout	$I_{SWITCH} = 100\text{ mA}$	2.90	2.70/ 2.65 3.10/ 3.15	2.70/ 2.65 3.10/ 3.15	V V(min) V(max)
f_O	Oscillator Frequency	Measured at Switch Pin $I_{SWITCH} = 100\text{ mA}$	52	48/ 42 56/ 62	48/ 42 56/ 62	kHz kHz(min) kHz(max)
V_{REF}	Reference Voltage	Measured at Feedback Pin $V_{IN} = 3.5\text{V to }40\text{V}$ $V_{COMP} = 1.0\text{V}$	1.230	1.214/ 1.206 1.246/ 1.254	1.214/ 1.206 1.246/ 1.254	V V(min) V(max)
$\Delta V_{REF}/\Delta V_{IN}$	Reference Voltage Line Regulation	$V_{IN} = 3.5\text{V to }40\text{V}$	0.5			mV
I_B	Error Amp Input Bias Current	$V_{COMP} = 1.0\text{V}$	100	300/ 800	300/ 800	nA nA(max)
G_M	Error Amp Transconductance	$I_{COMP} = -30\ \mu\text{A to }+30\ \mu\text{A}$ $V_{COMP} = 1.0\text{V}$	3700	2400/ 1600 4800/ 5800	2400/ 1600 4800/ 5800	μmho μmho (min) μmho (max)
A_{VOL}	Error Amp Voltage Gain	$V_{COMP} = 1.1\text{V to }1.9\text{V}$ $R_{COMP} = 1.0\text{ M}\Omega$ (Note 7)	800	500/ 250	500/ 250	V/V V/V(min)
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK} = 1.0\text{V}$	2.4	2.2/ 2.0	2.2/ 2.0	V V(min)
		Lower Limit $V_{FEEDBACK} = 1.5\text{V}$	0.3	0.40/ 0.55	0.40/ 0.55	V V(max)

Electrical Characteristics—LM1577-ADJ, LM2577-ADJ (Continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full Operating Temperature Range. Unless otherwise specified, $V_{IN} = 5\text{V}$, $V_{FEEDBACK} = V_{REF}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-ADJ Limit (Notes 3, 4)	LM2577-ADJ Limit (Note 5)	Units (Limits)
DEVICE PARAMETERS (Continued)						
	Error Amp Output Current	$V_{FEEDBACK} = 1.0\text{V to }1.5\text{V}$ $V_{COMP} = 1.0\text{V}$	± 200	$\pm 130/\pm \mathbf{90}$ $\pm 300/\pm \mathbf{400}$	$\pm 130/\pm \mathbf{90}$ $\pm 300/\pm \mathbf{400}$	μA $\mu\text{A}(\text{min})$ $\mu\text{A}(\text{max})$
I_{SS}	Soft Start Current	$V_{FEEDBACK} = 1.0\text{V}$ $V_{COMP} = 0\text{V}$	5.0	2.5/ 1.5 7.5/ 9.5	2.5/ 1.5 7.5/ 9.5	μA $\mu\text{A}(\text{min})$ $\mu\text{A}(\text{max})$
D	Maximum Duty Cycle	$V_{COMP} = 1.5\text{V}$ $I_{SWITCH} = 100\text{ mA}$	95	93/ 90	93/ 90	% %(min)
$\Delta I_{SWITCH}/$ ΔV_{COMP}	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{SWITCH} = 65\text{V}$ $V_{FEEDBACK} = 1.5\text{V (Switch Off)}$	10	300/ 600	300/ 600	μA $\mu\text{A}(\text{max})$
V_{SAT}	Switch Saturation Voltage	$I_{SWITCH} = 2.0\text{A}$ $V_{COMP} = 2.0\text{V (Max Duty Cycle)}$	0.5	0.7/ 0.9	0.7/ 0.9	V V(max)
	NPN Switch Current Limit	$V_{COMP} = 2.0\text{V}$	4.3	3.7/ 3.0 5.3/ 6.0	3.7/ 3.0 5.3/ 6.0	A A(min) A(max)

THERMAL PARAMETERS (All Versions)

Symbol	Parameter	Conditions	Typical	LM1577-ADJ Limit (Notes 3, 4)	LM2577-ADJ Limit (Note 5)	Units (Limits)
θ_{JA} θ_{JC}	Thermal Resistance	K Package, Junction to Ambient	35			$^\circ\text{C/W}$
		K Package, Junction to Case	1.5			
θ_{JA} θ_{JC}		T Package, Junction to Ambient	65			
		T Package, Junction to Case	2			
θ_{JA}		N Package, Junction to Ambient (Note 8)	85			
θ_{JA}		M Package, Junction to Ambient (Note 8)	100			

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions the device is intended to be functional, but device parameter specifications may not be guaranteed under these conditions. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Due to timing considerations of the LM1577/LM2577 current limit circuit, output current cannot be internally limited when the LM1577/LM2577 is used as a step-up regulator. To prevent damage to the switch, its current must be externally limited to 6.0A. However, output current is internally limited when the LM1577/LM2577 is used as a flyback or forward converter regulator in accordance to the Application Hints.

Note 3: All limits guaranteed at room temperature (standard type face) and at temperature extremes (**boldface type**). All limits are used to calculate Outgoing Quality Level, and are 100% production tested.

Note 4: A military RETS electrical test specification is available on request. At the time of printing, the LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 RETS specifications complied fully with the **boldface** limits in these columns. The LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 may also be procured to Standard Military Drawing specifications.

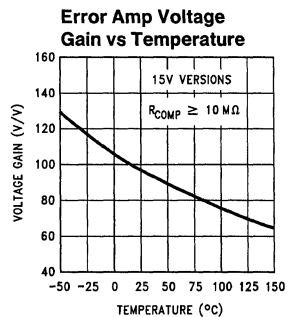
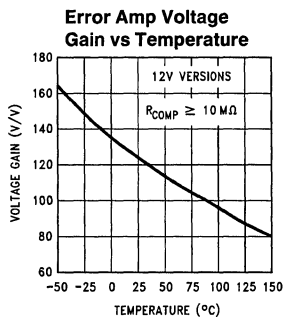
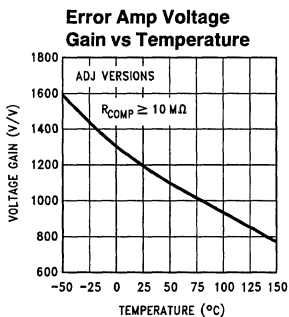
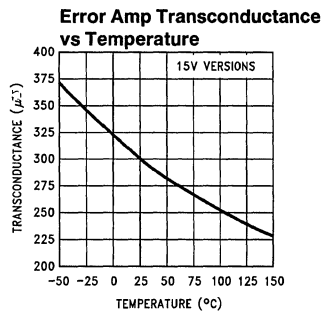
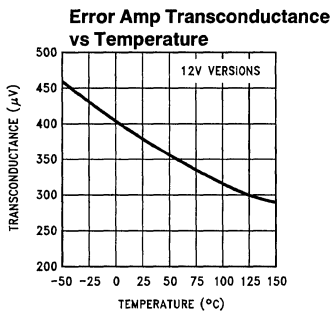
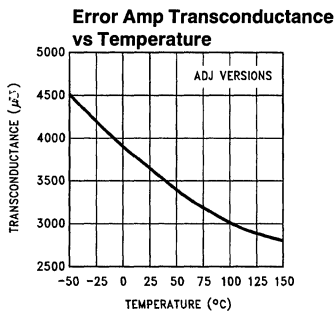
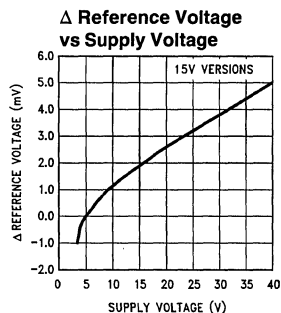
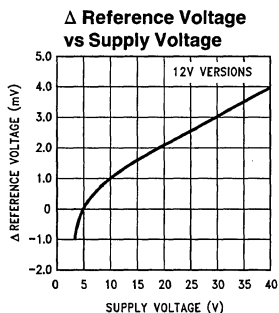
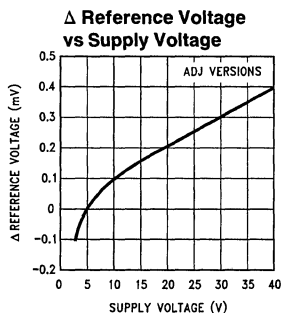
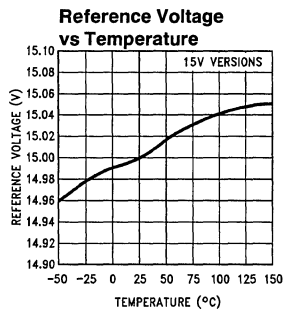
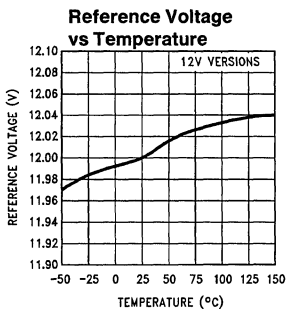
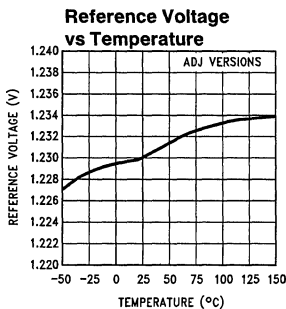
Note 5: All limits guaranteed at room temperature (standard type face) and at temperature extremes (**boldface type**). All room temperature limits are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 6: External components such as the diode, inductor, input and output capacitors can affect switching regulator performance. When the LM1577/LM2577 is used as shown in the Test Circuit, system performance will be as specified by the system parameters.

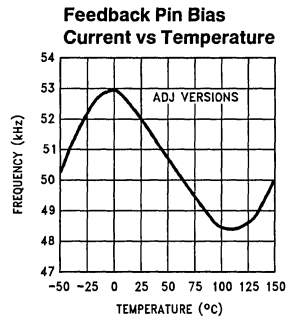
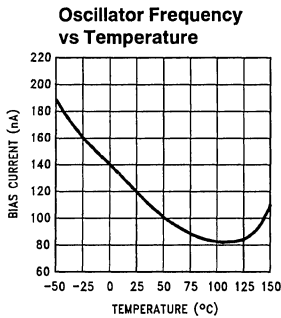
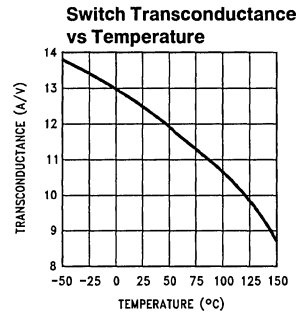
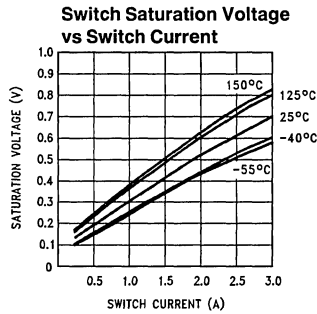
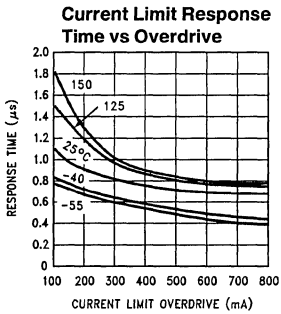
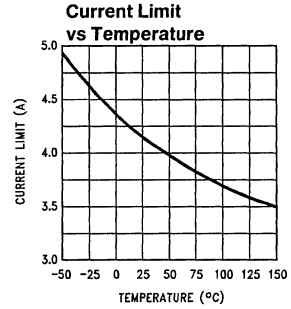
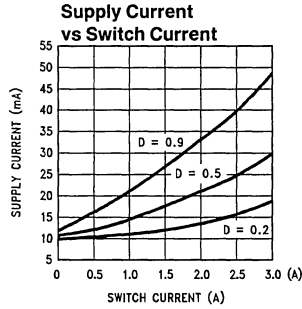
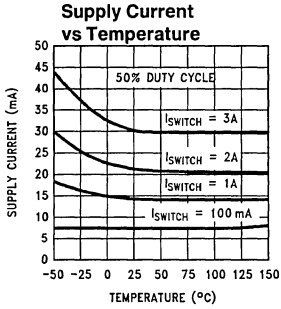
Note 7: A 1.0 M Ω resistor is connected to the compensation pin (which is the error amplifier's output) to ensure accuracy in measuring A_{VOL} . In actual applications, this pin's load resistance should be $\geq 10\text{ M}\Omega$, resulting in A_{VOL} that is typically twice the guaranteed minimum limit.

Note 8: Junction to ambient thermal resistance with approximately 1 square inch of pc board copper surrounding the leads. Additional copper area will lower thermal resistance further. See thermal model in "Switchers Made Simple" software.

Typical Performance Characteristics



Typical Performance Characteristics (Continued)



TL/H/11468-3

Connection Diagrams

**Straight Leads
5-Lead TO-220 (T)**

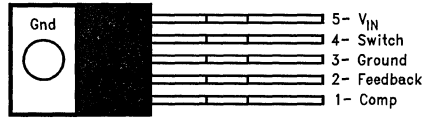


TL/H/11468-4

Top View

Order Number LM2577T-12, LM2577T-15,
or LM2577T-ADJ
See NS Package Number T05A

**Bent, Staggered Leads
5-Lead TO-220 (T)**

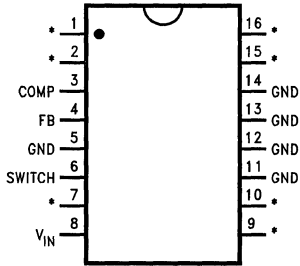


TL/H/11468-5

Top View

Order Number LM2577T-12 Flow LB03, LM2577T-15
Flow LB03, or LM2577T-ADJ Flow LB03
See NS Package Number T05D

16-Lead DIP (N)

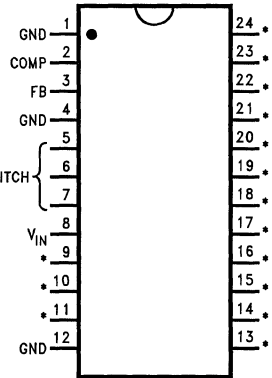


*No internal
Connection
TL/H/11468-6

Top View

Order Number LM2577N-12, LM2577N-15,
or LM2577N-ADJ
See NS Package Number N16A

24-Lead Surface Mount (M)

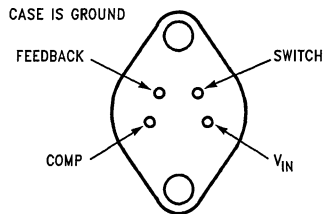


*No internal
Connection
TL/H/11468-7

Top View

Order Number LM2577M-12, LM2577M-15,
or LM2577M-ADJ
See NS Package Number M24B

4-Lead TO-3 (K)



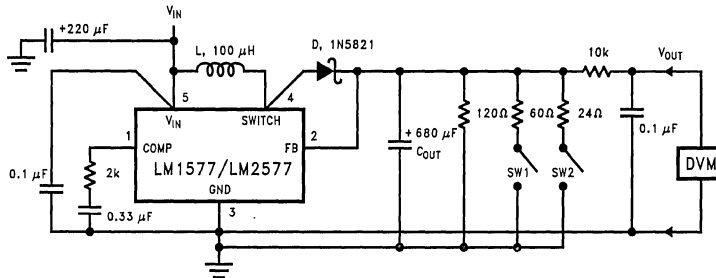
TL/H/11468-8

Bottom View

Order Number LM1577K-12/883, LM1577K-15/883, or LM1577K-ADJ/883
See NS Package Number K04A

Test Circuits

LM1577-12, LM2577-12



L = 415-0930 (AIE)
D = any manufacturer

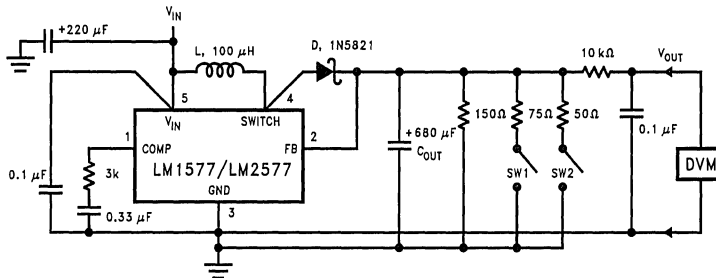
C_{OUT} = Sprague Type 673D
Electrolytic 680 μF, 20V

Note: Pin numbers shown are for TO-220 (T) package

TL/H/11468-30

FIGURE 1. Circuit Used to Specify System Parameters for 12V Versions

LM1577-15, LM2577-15



L = 415-0930 (AIE)
D = any manufacturer

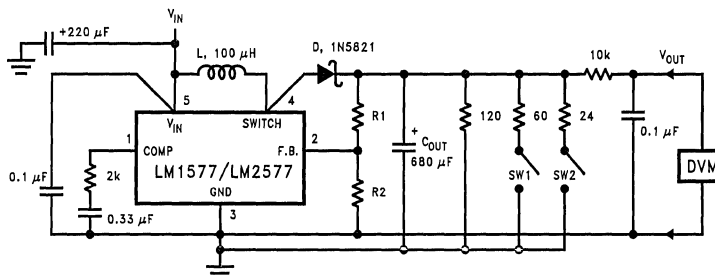
C_{OUT} = Sprague Type 673D
Electrolytic 680 μF, 20V

Note: Pin numbers shown are for TO-220 (T) package

TL/H/11468-86

FIGURE 2. Circuit Used to Specify System Parameters for 15V Versions

LM1577-ADJ, LM2577-ADJ



L = 415-0930 (AIE)
D = any manufacturer

C_{OUT} = Sprague Type 673D
Electrolytic 680 μF, 20V

R1 = 48.7k in series with 511Ω (1%)
R2 = 5.62k (1%)

TL/H/11468-9

FIGURE 3. Circuit Used to Specify System Parameters for ADJ Versions

Application Hints

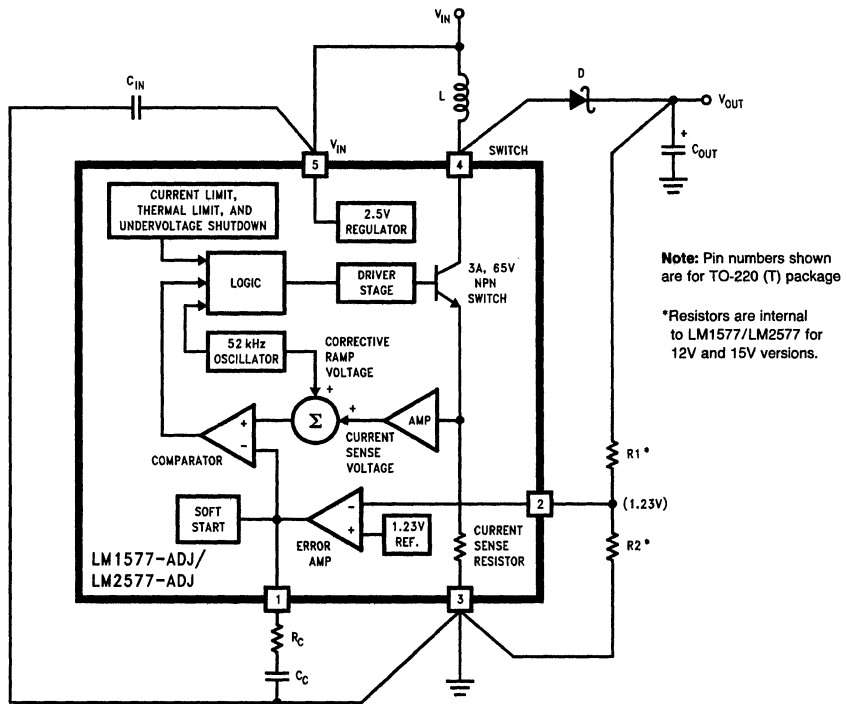


FIGURE 4. LM1577/LM2577 Block Diagram and Boost Regulator Application

TL/H/11468-10

STEP-UP (BOOST) REGULATOR

Figure 4 shows the LM1577-ADJ/LM2577-ADJ used as a Step-Up Regulator. This is a switching regulator used for producing an output voltage greater than the input supply voltage. The LM1577-12/LM2577-12 and LM1577-15/LM2577-15 can also be used for step-up regulators with 12V or 15V outputs (respectively), by tying the feedback pin directly to the regulator output.

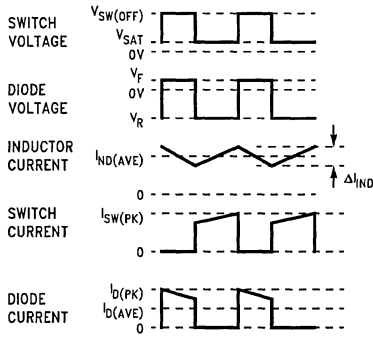
A basic explanation of how it works is as follows. The LM1577/LM2577 turns its output switch on and off at a frequency of 52 kHz, and this creates energy in the inductor (L). When the NPN switch turns on, the inductor current charges up at a rate of V_{IN}/L , storing current in the inductor.

When the switch turns off, the lower end of the inductor flies above V_{IN} , discharging its current through diode (D) into the output capacitor (C_{OUT}) at a rate of $(V_{OUT} - V_{IN})/L$. Thus, energy stored in the inductor during the switch on time is transferred to the output during the switch off time. The output voltage is controlled by the amount of energy transferred which, in turn, is controlled by modulating the peak inductor current. This is done by feeding back a portion of the output voltage to the error amp, which amplifies the difference between the feedback voltage and a 1.230V reference. The error amp output voltage is compared to a voltage proportional to the switch current (i.e., inductor current during the switch on time).

Application Hints (Continued)

The comparator terminates the switch on time when the two voltages are equal, thereby controlling the peak switch current to maintain a constant output voltage.

Voltage and current waveforms for this circuit are shown in *Figure 5*, and formulas for calculating them are given in *Figure 6*.



TL/H/11468-11

FIGURE 5. Step-Up Regulator Waveforms

Duty Cycle	D	$\frac{V_{OUT} + V_F - V_{IN}}{V_{OUT} + V_F - V_{SAT}} \approx \frac{V_{OUT} - V_{IN}}{V_{OUT}}$
Average Inductor Current	$I_{IND(AVE)}$	$\frac{I_{LOAD}}{1 - D}$
Inductor Current Ripple	ΔI_{IND}	$\frac{V_{IN} - V_{SAT}}{L} \frac{D}{52,000}$
Peak Inductor Current	$I_{IND(PK)}$	$\frac{I_{LOAD}}{1 - D} + \frac{\Delta I_{IND}}{2}$
Peak Switch Current	$I_{SW(PK)}$	$\frac{I_{LOAD}}{1 - D} + \frac{\Delta I_{IND}}{2}$
Switch Voltage When Off	$V_{SW(OFF)}$	$V_{OUT} + V_F$
Diode Reverse Voltage	V_R	$V_{OUT} - V_{SAT}$
Average Diode Current	$I_{D(AVE)}$	I_{LOAD}
Peak Diode Current	$I_{D(PK)}$	$\frac{I_{LOAD}}{1 - D} + \frac{\Delta I_{IND}}{2}$
Power Dissipation of LM1577/2577	P_D	$0.25\Omega \left(\frac{I_{LOAD}}{1 - D} \right)^2 D + \frac{I_{LOAD} D V_{IN}}{50(1 - D)}$

V_F = Forward Biased Diode Voltage

I_{LOAD} = Output Load Current

FIGURE 6. Step-Up Regulator Formulas

STEP-UP REGULATOR DESIGN PROCEDURE

The following design procedure can be used to select the appropriate external components for the circuit in *Figure 4*, based on these system requirements.

Given:

$V_{IN(min)}$ = Minimum input supply voltage

V_{OUT} = Regulated output voltage

$I_{LOAD(max)}$ = Maximum output load current

Before proceeding any further, determine if the LM1577/LM2577 can provide these values of V_{OUT} and $I_{LOAD(max)}$ when operating with the minimum value of V_{IN} . The upper limits for V_{OUT} and $I_{LOAD(max)}$ are given by the following equations.

$$V_{OUT} \leq 60V$$

$$\text{and } V_{OUT} \leq 10 \times V_{IN(min)}$$

$$I_{LOAD(max)} \leq \frac{2.1A \times V_{IN(min)}}{V_{OUT}}$$

These limits must be greater than or equal to the values specified in this application.

1. Inductor Selection (L)

A. Voltage Options:

1. For 12V or 15V output

From *Figure 7a* (for 12V output) or *Figure 7b* (for 15V output), identify inductor code for region indicated by $V_{IN(min)}$ and $I_{LOAD(max)}$. The shaded region indicates conditions for which the LM1577/LM2577 output switch would be operating beyond its switch current rating. The minimum operating voltage for the LM1577/LM2577 is 3.5V.

From here, *proceed to step C*.

2. For Adjustable version

Preliminary calculations:

The inductor selection is based on the calculation of the following three parameters:

$D_{(max)}$, the maximum switch duty cycle ($0 \leq D \leq 0.9$):

$$D_{(max)} = \frac{V_{OUT} + V_F - V_{IN(min)}}{V_{OUT} + V_F - 0.6V}$$

where $V_F = 0.5V$ for Schottky diodes and $0.8V$ for fast recovery diodes (typically);

$E \cdot T$, the product of volts \times time that charges the inductor:

$$E \cdot T = \frac{D_{(max)} (V_{IN(min)} - 0.6V) 10^6}{52,000 \text{ Hz}} \quad (V \cdot \mu s)$$

$I_{IND,DC}$, the average inductor current under full load;

$$I_{IND,DC} = \frac{1.05 \times I_{LOAD(max)}}{1 - D_{(max)}}$$

B. Identify Inductor Value:

1. From *Figure 7c*, identify the inductor code for the region indicated by the intersection of $E \cdot T$ and $I_{IND,DC}$. This code gives the inductor value in microhenries. The L or H prefix signifies whether the inductor is rated for a maximum $E \cdot T$ of $90 V \cdot \mu s$ (L) or $250 V \cdot \mu s$ (H).

2. If $D < 0.85$, go on to step C. If $D \geq 0.85$, then calculate the minimum inductance needed to ensure the switching regulator's stability:

$$L_{MIN} = \frac{6.4 (V_{IN(min)} - 0.6V) (2D_{(max)} - 1)}{1 - D_{(max)}} \quad (\mu H)$$

If L_{MIN} is smaller than the inductor value found in step B1, go on to step C. Otherwise, the inductor value found in step B1 is too low; an appropriate inductor code should be obtained from the graph as follows:

1. Find the lowest value inductor that is greater than L_{MIN} .
2. Find where $E \cdot T$ intersects this inductor value to determine if it has an L or H prefix. If $E \cdot T$ intersects both the L and H regions, select the inductor with an H prefix.

Application Hints (Continued)

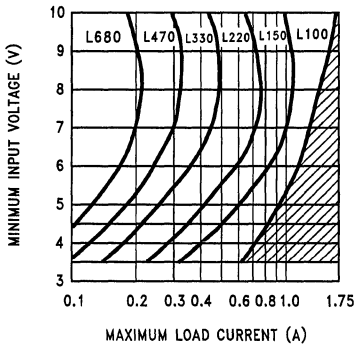


FIGURE 7a. LM2577-12 Inductor Selection Guide

TL/H/11468-27

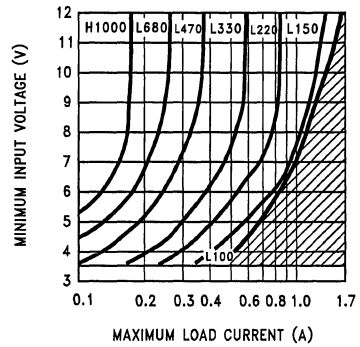


FIGURE 7b. LM2577-15 Inductor Selection Guide

TL/H/11468-28

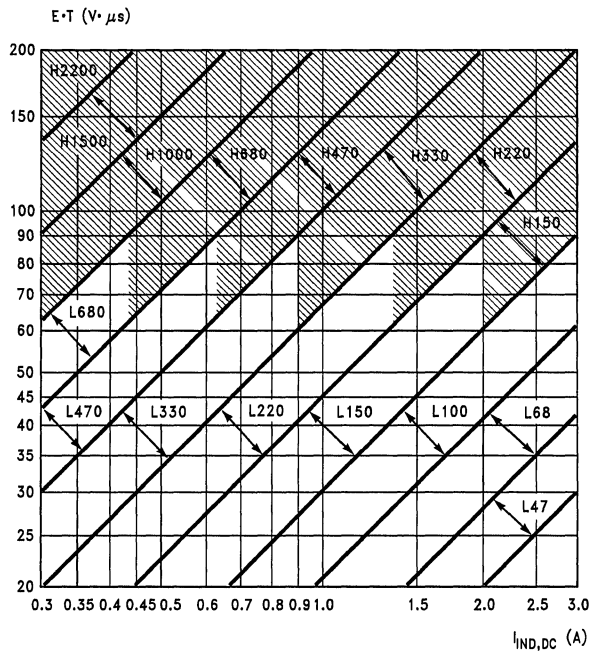


FIGURE 7c. LM1577-ADJ/LM2577-ADJ Inductor Selection Graph

TL/H/11468-12

Note:

These charts assume that the inductor ripple current is approximately 20% to 30% of the average inductor current (when the regulator is under full load). Greater ripple current causes higher peak switch currents and greater output ripple voltage; lower ripple current is achieved with larger-value inductors. The factor of 20 to 30% is chosen as a convenient balance between the two extremes.

Application Hints (Continued)

C. *Select an inductor* from the table of *Figure 8* which cross-references the inductor codes to the part numbers of three different manufacturers. Complete specifications for these inductors are available from the respective manufacturers. The inductors listed in this table have the following characteristics:

AIE: ferrite, pot-core inductors; Benefits of this type are low electro-magnetic interference (EMI), small physical size, and very low power dissipation (core loss). Be careful not to operate these inductors too far beyond their maximum ratings for $E \cdot T$ and peak current, as this will saturate the core.

Pulse: powdered iron, toroid core inductors; Benefits are low EMI and ability to withstand $E \cdot T$ and peak current above rated value better than ferrite cores.

Renco: ferrite, bobbin-core inductors; Benefits are low cost and best ability to withstand $E \cdot T$ and peak current above rated value. Be aware that these inductors generate more EMI than the other types, and this may interfere with signals sensitive to noise.

Inductor Code	Manufacturer's Part Number		
	AIE	Pulse	Renco
L47	415-0932	PE-53112	RL2442
L68	415-0931	PE-92114	RL2443
L100	415-0930	PE-92108	RL2444
L150	415-0953	PE-53113	RL1954
L220	415-0922	PE-52626	RL1953
L330	415-0926	PE-52627	RL1952
L470	415-0927	PE-53114	RL1951
L680	415-0928	PE-52629	RL1950
H150	415-0936	PE-53115	RL2445
H220	430-0636	PE-53116	RL2446
H330	430-0635	PE-53117	RL2447
H470	430-0634	PE-53118	RL1961
H680	415-0935	PE-53119	RL1960
H1000	415-0934	PE-53120	RL1959
H1500	415-0933	PE-53121	RL1958
H2200	415-0945	PE-53122	RL2448

AIE Magnetics, div. Vernitron Corp., (813) 347-2181
2801 72nd Street North, St. Petersburg, FL 33710
Pulse Engineering, (619) 268-2400
P.O. Box 12235, San Diego, CA 92112
Renco Electronics Inc., (516) 586-5566
60 Jeffry Blvd. East, Deer Park, NY 11729

FIGURE 8. Table of Standardized Inductors and Manufacturer's Part Numbers

2. Compensation Network (R_C , C_C) and Output Capacitor (C_{OUT}) Selection

R_C and C_C form a pole-zero compensation network that stabilizes the regulator. The values of R_C and C_C are mainly dependant on the regulator voltage gain, $I_{LOAD(max)}$, L and C_{OUT} . The following procedure calculates values for R_C , C_C , and C_{OUT} that ensure regulator stability. Be aware that this procedure doesn't necessarily result in R_C and C_C that provide optimum compensation. In order to guarantee optimum compensation, one of the standard procedures for testing loop stability must be used, such as measuring V_{OUT} transient response when pulsing I_{LOAD} . (See *Figure 13*.)

A. *First, calculate the maximum value for R_C*

$$R_C \leq \frac{750 \times I_{LOAD(max)} \times V_{OUT}^2}{V_{IN(min)}^2}$$

Select a resistor less than or equal to this value, and it should also be no greater than 3 k Ω .

B. *Calculate the minimum value for C_{OUT}* using the following two equations.

$$C_{OUT} \geq \frac{0.19 \times L \times R_C \times I_{LOAD(max)}}{V_{IN(min)} \times V_{OUT}}$$

and

$$C_{OUT} \geq \frac{V_{IN(min)} \times R_C \times (V_{IN(min)} + (3.74 \times 10^5 \times L))}{487,800 \times V_{OUT}^3}$$

The larger of these two values is the minimum value that ensures stability.

C. *Calculate the minimum value of C_C*

$$C_C \geq \frac{58.5 \times V_{OUT}^2 \times C_{OUT}}{R_C^2 \times V_{IN(min)}}$$

The compensation capacitor is also part of the soft start circuitry. When power to the regulator is turned on, the switch duty cycle is allowed to rise at a rate controlled by this capacitor (with no control on the duty cycle, it would immediately rise to 90%, drawing huge currents from the input power supply). In order to operate properly, the soft start circuit requires $C_C \geq 0.22 \mu\text{F}$.

The value of the output filter capacitor is normally large enough to require the use of aluminum electrolytic capacitors. *Figure 9* lists several different types that are recommended for switching regulators, and the following parameters are used to select the proper capacitor.

Working Voltage (WVDC): Choose a capacitor with a working voltage at least 20% higher than the regulator output voltage.

Ripple Current: This is the maximum RMS value of current that charges the capacitor during each switching cycle. For step-up and flyback regulators, the formula for ripple current is

$$I_{RIPPLE(RMS)} = \frac{I_{LOAD(max)} \times D_{(max)}}{1 - D_{(max)}}$$

Choose a capacitor that is rated at least 50% higher than this value at 52 kHz.

Equivalent Series Resistance (ESR): This is the primary cause of output ripple voltage, and it also affects the values of R_C and C_C needed to stabilize the regulator. As a result, the preceding calculations for C_C and R_C are only valid if ESR doesn't exceed the maximum value specified by the following equations.

$$ESR \leq \frac{0.01 \times 15V}{I_{RIPPLE(P-P)}} \text{ and } \leq \frac{8.7 \times (10) - 3 \times V_{IN}}{I_{LOAD(max)}}$$

where

$$I_{RIPPLE(P-P)} = \frac{1.15 \times I_{LOAD(max)}}{1 - D_{(max)}}$$

Select a capacitor with ESR, at 52 kHz, that is less than or equal to the lower value calculated. Most electrolytic capacitors specify ESR at 120 Hz which is 15% to 30% higher than at 52 kHz. Also, be aware that ESR increases by a factor of 2 when operating at -20°C .

Application Hints (Continued)

In general, low values of ESR are achieved by using large value capacitors ($C \geq 470 \mu\text{F}$), and capacitors with high WVDC, or by paralleling smaller-value capacitors.

3. Output Voltage Selection (R1 and R2)

This section is for applications using the LM1577-ADJ/LM2577-ADJ. Skip this section if the LM1577-12/LM2577-12 or LM1577-15/LM2577-15 is being used.

With the LM1577-ADJ/LM2577-ADJ, the output voltage is given by

$$V_{\text{OUT}} = 1.23\text{V} (1 + R1/R2)$$

Resistors R1 and R2 divide the output down so it can be compared with the LM1577-ADJ/LM2577-ADJ internal 1.23V reference. For a given desired output voltage V_{OUT} , select R1 and R2 so that

$$\frac{R1}{R2} = \frac{V_{\text{OUT}}}{1.23\text{V}} - 1$$

4. Input Capacitor Selection (C_{IN})

The switching action in the step-up regulator causes a triangular ripple current to be drawn from the supply source. This in turn causes noise to appear on the supply voltage. For proper operation of the LM1577, the input voltage should be decoupled. Bypassing the Input Voltage pin directly to

Cornell Dublier—Types 239, 250, 251, UFT, 300, or 350

P.O. Box 128, Pickens, SC 29671
(803) 878-6311

Nichicon—Types PF, PX, or PZ

927 East Parkway, Schaumburg, IL 60173
(708) 843-7500

Sprague—Types 672D, 673D, or 674D

Box 1, Sprague Road, Lansing, NC 28643
(919) 384-2551

United Chemi-Con—Types LX, SXF, or SXJ

9801 West Higgins Road, Rosemont, IL 60018
(708) 696-2000

FIGURE 9. Aluminum Electrolytic Capacitors Recommended for Switching Regulators

ground with a good quality, low ESR, 0.1 μF capacitor (leads as short as possible) is normally sufficient.

If the LM1577 is located far from the supply source filter capacitors, an additional large electrolytic capacitor (e.g. 47 μF) is often required.

5. Diode Selection (D)

The switching diode used in the boost regulator must withstand a reverse voltage equal to the circuit output voltage, and must conduct the peak output current of the LM2577. A suitable diode must have a minimum reverse breakdown voltage greater than the circuit output voltage, and should be rated for average and peak current greater than $I_{\text{LOAD(max)}}$ and $I_{\text{D(pk)}}$. Schottky barrier diodes are often favored for use in switching regulators. Their low forward voltage drop allows higher regulator efficiency than if a (less expensive) fast recovery diode was used. See *Figure 10* for recommended part numbers and voltage ratings of 1A and 3A diodes.

V_{OUT} (max)	Schottky		Fast Recovery	
	1A	3A	1A	3A
20V	1N5817 MBR120P	1N5820 MBR320P		
30V	1N5818 MBR130P 11DQ03	1N5821 MBR330P 31DQ03		
40V	1N5819 MBR140P 11DQ04	1N5822 MBR340P 31DQ04		
50V	MBR150 11DQ05	MBR350 31DQ05	1N4933 MUR105	
100V			1N4934 HER102 MUR110 10DL1	MR851 30DL1 MR831 HER302

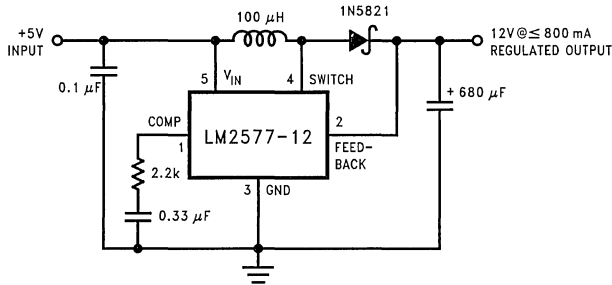
FIGURE 10. Diode Selection Chart

Application Hints (Continued)

BOOST REGULATOR CIRCUIT EXAMPLE

By adding a few external components (as shown in *Figure 11*), the LM2577 can be used to produce a regulated output voltage that is greater than the applied input voltage. Typi-

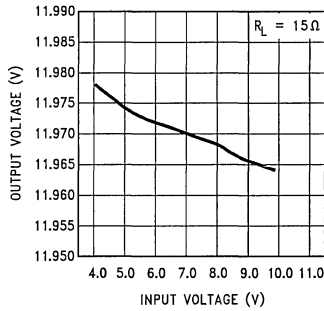
cal performance of this regulator is shown in *Figures 12* and *13*. The switching waveforms observed during the operation of this circuit are shown in *Figure 14*.



TL/H/11468-13

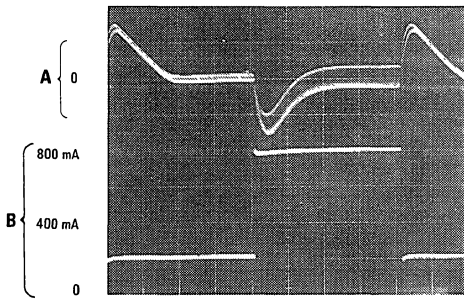
Note: Pin numbers shown are for TO-220 (T) package.

FIGURE 11. Step-up Regulator Delivers 12V from a 5V Input



TL/H/11468-14

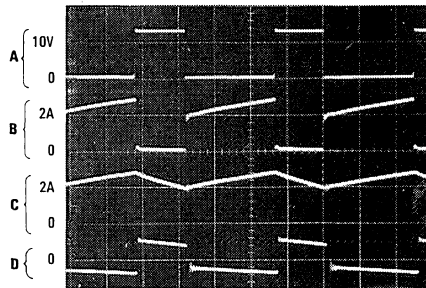
FIGURE 12. Line Regulation (Typical) of Step-Up Regulator of Figure 11



TL/H/11468-15

FIGURE 13. Load Transient Response of Step-Up Regulator of Figure 11

A: Output Voltage Change, 100 mV/div. (AC-coupled)
 B: Load current, 0.2 A/div
 Horizontal: 5 ms/div



TL/H/11468-16

FIGURE 14. Switching Waveforms of Step-Up Regulator of Figure 11

A: Switch pin voltage, 10 V/div
 B: Switch pin current, 2 A/div
 C: Inductor current, 2 A/div
 D: Output ripple voltage, 100 mV/div (AC-coupled)
 Horizontal: 5 μs/div

Application Hints (Continued)

FLYBACK REGULATOR

A Flyback regulator can produce single or multiple output voltages that are lower or greater than the input supply voltage. Figure 15 shows the LM1577/LM2577 used as a flyback regulator with positive and negative regulated outputs. Its operation is similar to a step-up regulator, except the output switch controls the primary current of a flyback transformer. Note that the primary and secondary windings are out of phase, so no current flows through secondary when current flows through the primary. This allows the primary to charge up the transformer core when the switch is on. When the switch turns off, the core discharges by sending current through the secondary, and this produces voltage at the outputs. The output voltages are controlled by adjusting the peak primary current, as described in the step-up regulator section.

Voltage and current waveforms for this circuit are shown in Figure 16, and formulas for calculating them are given in Figure 17.

FLYBACK REGULATOR DESIGN PROCEDURE

1. Transformer Selection

A family of standardized flyback transformers is available for creating flyback regulators that produce dual output voltages, from $\pm 10V$ to $\pm 15V$, as shown in Figure 15. Figure 18 lists these transformers with the input voltage, output voltages and maximum load current they are designed for.

2. Compensation Network (C_C , R_C) and Output Capacitor (C_{OUT}) Selection

As explained in the Step-Up Regulator Design Procedure, C_C , R_C and C_{OUT} must be selected as a group. The following procedure is for a dual output flyback regulator with equal turns ratios for each secondary (i.e., both output voltages have the same magnitude). The equations can be used for a single output regulator by changing $\Sigma I_{LOAD(max)}$ to $I_{LOAD(max)}$ in the following equations.

A. First, calculate the maximum value for R_C .

$$R_C \leq \frac{750 \times \Sigma I_{LOAD(max)} \times (15V + V_{IN(min)}N)^2}{V_{IN(min)}^2}$$

Where $\Sigma I_{LOAD(max)}$ is the sum of the load current (magnitude) required from both outputs. Select a resistor less than or equal to this value, and no greater than $3 k\Omega$.

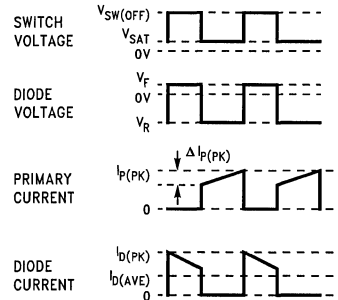
B. Calculate the minimum value for ΣC_{OUT} (sum of C_{OUT} at both outputs) using the following two equations.

$$C_{OUT} \geq \frac{0.19 \times R_C \times L_P \times \Sigma I_{LOAD(max)}}{15V \times V_{IN(min)}}$$

and

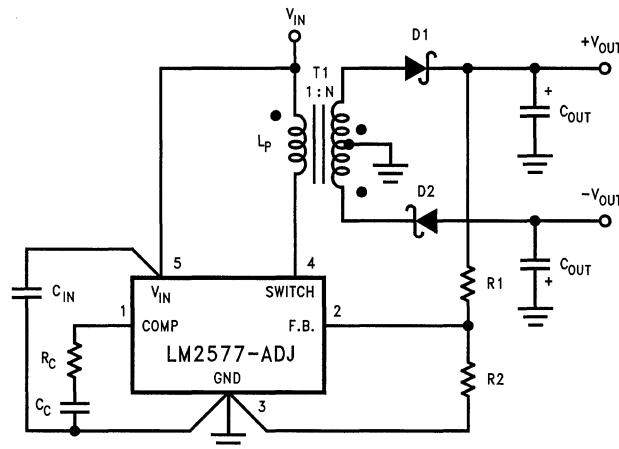
$$C_{OUT} \geq \frac{V_{IN(min)} \times R_C \times N^2 \times (V_{IN(min)} + (3.74 \times 10^5 \times L_P))}{487,800 \times (15V)^2 \times (15V + V_{IN(min)} \times N)}$$

The larger of these two values must be used to ensure regulator stability.



TL/H/11468-17

FIGURE 16. Flyback Regulator Waveforms



T1 = Pulse Engineering, PE-65300

D1, D2 = 1N5821

TL/H/11468-18

FIGURE 15. LM1577-ADJ/LM2577-ADJ Flyback Regulator with \pm Outputs

Application Hints (Continued)

Duty Cycle	D	$\frac{V_{OUT} + V_F}{N(V_{IN} - V_{SAT}) + V_{OUT} + V_F} \approx \frac{V_{OUT}}{N(V_{IN}) + V_{OUT}}$
Primary Current Variation	ΔI_P	$\frac{D(V_{IN} - V_{SAT})}{L_P \times 52,000}$
Peak Primary Current	$I_{P(PK)}$	$\frac{N}{\eta} \times \frac{\Sigma I_{LOAD}}{1 - D} + \frac{\Delta I_{PK}}{2}$
Switch Voltage when Off	$V_{SW(OFF)}$	$V_{IN} + \frac{V_{OUT} + V_F}{N}$
Diode Reverse Voltage	V_R	$V_{OUT} + N(V_{IN} - V_{SAT})$
Average Diode Current	$I_{D(AVE)}$	I_{LOAD}
Peak Diode Current	$I_{D(PK)}$	$\frac{I_{LOAD}}{1 - D} + \frac{\Delta I_{IND}}{2}$
Short Circuit Diode Current		$\approx \frac{6A}{N}$
Power Dissipation of LM1577/LM2577	P_D	$0.25\Omega \left(\frac{N \Sigma I_{LOAD}}{1 - D} \right)^2 + \frac{N I_{LOAD} D}{50(1 - D)} V_{IN}$

N = Transformer Turns Ratio = $\frac{\text{number of secondary turns}}{\text{number of primary turns}}$

η = Transformer Efficiency (typically 0.95)

$\Sigma I_{LOAD} = |I_{LOAD}| + |-I_{LOAD}|$

FIGURE 17. Flyback Regulator Formulas

C. Calculate the minimum value of C_C

$$C_C \geq \frac{58.5 \times C_{OUT} \times V_{OUT} \times (V_{OUT} + (V_{IN(min)} \times N))}{R_C^2 \times V_{IN(min)} \times N}$$

D. Calculate the maximum ESR of the + V_{OUT} and - V_{OUT} output capacitors in parallel.

$$ESR_+ \parallel ESR_- \leq \frac{8.7 \times 10^{-3} \times V_{IN(min)} \times V_{OUT} \times N}{\Sigma I_{LOAD(max)} \times (V_{OUT} + (V_{IN(min)} \times N))}$$

This formula can also be used to calculate the maximum ESR of a single output regulator.

At this point, refer to this same section in the **Step-Up Regulator Design Procedure** for more information regarding the selection of C_{OUT} .

Application Hints (Continued)

3. Output Voltage Selection

This section is for applications using the LM1577-ADJ/LM2577-ADJ. Skip this section if the LM1577-12/LM2577-12 or LM1577-15/LM2577-15 is being used.

With the LM1577-ADJ/LM2577-ADJ, the output voltage is given by

$$V_{OUT} = 1.23V (1 + R1/R2)$$

Resistors R1 and R2 divide the output voltage down so it can be compared with the LM1577-ADJ/LM2577-ADJ internal 1.23V reference. For a desired output voltage V_{OUT} , select R1 and R2 so that

$$\frac{R1}{R2} = \frac{V_{OUT}}{1.23V} - 1$$

4. Diode Selection

The switching diode in a flyback converter must withstand the reverse voltage specified by the following equation.

$$V_R = V_{OUT} + \frac{V_{IN}}{N}$$

A suitable diode must have a reverse voltage rating greater than this. In addition it must be rated for more than the average and peak diode currents listed in *Figure 17*.

5. Input Capacitor Selection

The primary of a flyback transformer draws discontinuous pulses of current from the input supply. As a result, a fly-

Transformer Type	Input Voltage	Dual Output Voltage	Maximum Output Current
1 $L_P = 100 \mu\text{H}$ $N = 1$	5V	$\pm 10\text{V}$	325 mA
	5V	$\pm 12\text{V}$	275 mA
	5V	$\pm 15\text{V}$	225 mA
2 $L_P = 200 \mu\text{H}$ $N = 0.5$	10V	$\pm 10\text{V}$	700 mA
	10V	$\pm 12\text{V}$	575 mA
	10V	$\pm 15\text{V}$	500 mA
	12V	$\pm 10\text{V}$	800 mA
	12V	$\pm 12\text{V}$	700 mA
	12V	$\pm 15\text{V}$	575 mA
3 $L_P = 250 \mu\text{H}$ $N = 0.5$	15V	$\pm 10\text{V}$	900 mA
	15V	$\pm 12\text{V}$	825 mA
	15V	$\pm 15\text{V}$	700 mA

Transformer Type	Manufacturers' Part Numbers		
	AIE	Pulse	Renco
1	326-0637	PE-65300	RL-2580
2	330-0202	PE-65301	RL-2581
3	330-0203	PE-65302	RL-2582

FIGURE 18. Flyback Transformer Selection Guide

back regulator generates more noise at the input supply than a step-up regulator, and this requires a larger bypass capacitor to decouple the LM1577/LM2577 V_{IN} pin from this noise. For most applications, a low ESR, 1.0 μF cap will be sufficient, if it is connected very close to the V_{IN} and Ground pins.

In addition to this bypass cap, a larger capacitor ($\geq 47 \mu\text{F}$) should be used where the flyback transformer connects to the input supply. This will attenuate noise which may interfere with other circuits connected to the same input supply voltage.

6. Snubber Circuit

A "snubber" circuit is required when operating from input voltages greater than 10V, or when using a transformer with $L_P \geq 200 \mu\text{H}$. This circuit clamps a voltage spike from the transformer primary that occurs immediately after the output switch turns off. Without it, the switch voltage may exceed the 65V maximum rating. As shown in *Figure 19*, the snubber consists of a fast recovery diode, and a parallel RC. The RC values are selected for switch clamp voltage (V_{CLAMP}) that is 5V to 10V greater than $V_{SW(OFF)}$. Use the following equations to calculate R and C;

$$C \geq \frac{0.02 \times L_P \times I_{P(PK)}^2}{(V_{CLAMP})^2 - (V_{SW(OFF)})^2}$$

$$R \leq \left(\frac{V_{CLAMP} + V_{SW(OFF)} - V_{IN}}{2} \right)^2 \times \left(\frac{19.2 \times 10^{-4}}{L_P \times I_{P(PK)}^2} \right)$$

Power dissipation (and power rating) of the resistor is;

$$P = \left(\frac{V_{CLAMP} + V_{SW(OFF)} - V_{IN}}{2} \right)^2 / R$$

The fast recovery diode must have a reverse voltage rating greater than V_{CLAMP} .

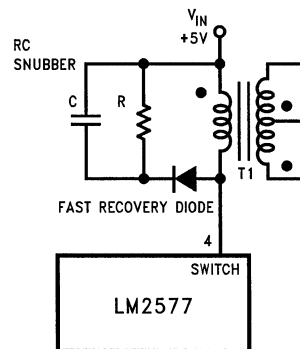


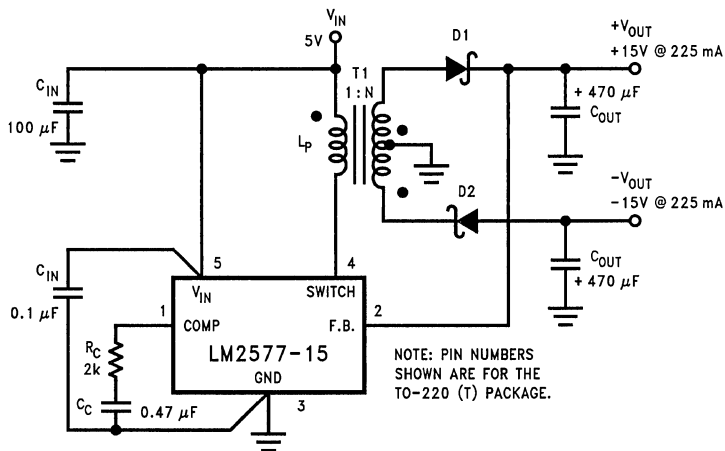
FIGURE 19. Snubber Circuit

TL/H/11468-19

Application Hints (Continued)

FLYBACK REGULATOR CIRCUIT EXAMPLE

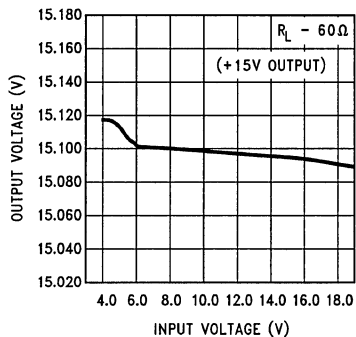
The circuit of *Figure 20* produces $\pm 15V$ (at 225 mA each) from a single 5V input. The output regulation of this circuit is shown in *Figures 21* and *22*, while the load transient response is shown in *Figures 23* and *24*. Switching waveforms seen in this circuit are shown in *Figure 25*.



TL/H/11468-20

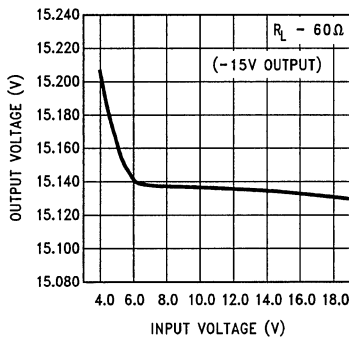
T1 = Pulse Engineering, PE-65300
D1, D2 = 1N5821

FIGURE 20. Flyback Regulator Easily Provides Dual Outputs



TL/H/11468-21

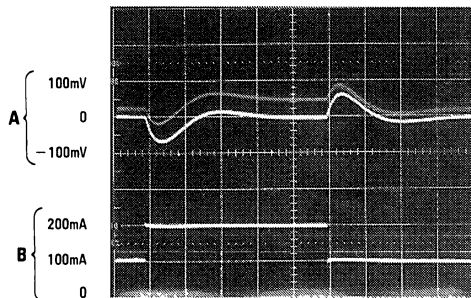
FIGURE 21. Line Regulation (Typical) of Flyback Regulator of Figure 20, +15V Output



TL/H/11468-22

FIGURE 22. Line Regulation (Typical) of Flyback Regulator of Figure 20, -15V Output

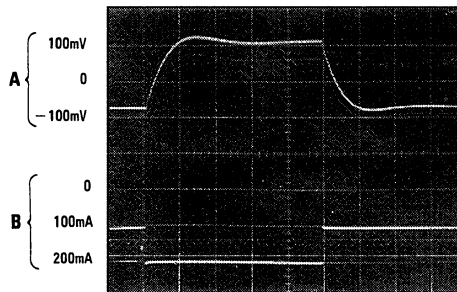
Application Hints (Continued)



TL/H/11468-23

FIGURE 23. Load Transient Response of Flyback Regulator of Figure 20, +15V Output

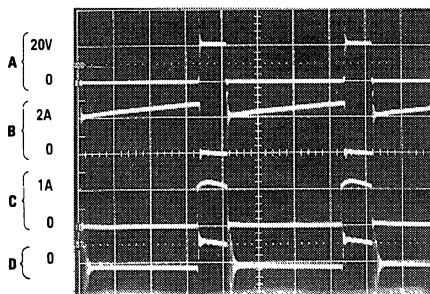
- A: Output Voltage Change, 100 mV/div
 - B: Output Current, 100 mA/div
- Horizontal: 10 ms/div



TL/H/11468-24

FIGURE 24. Load Transient Response of Flyback Regulator of Figure 20, -15V Output

- A: Output Voltage Change, 100 mV/div
 - B: Output Current, 100 mA/div
- Horizontal: 10 ms/div



TL/H/11468-25

FIGURE 25. Switching Waveforms of Flyback Regulator of Figure 20, Each Output Loaded with 60Ω

- A: Switch pin voltage, 20 V/div
 - B: Primary current, 2 A/div
 - C: +15V Secondary current, 1 A/div
 - D: +15V Output ripple voltage, 100 mV/div
- Horizontal: 5 μs/div

LM1578A/LM2578A/LM3578A Switching Regulator

General Description

The LM1578A is a switching regulator which can easily be set up for such DC-to-DC voltage conversion circuits as the buck, boost, and inverting configurations. The LM1578A features a unique comparator input stage which not only has separate pins for both the inverting and non-inverting inputs, but also provides an internal 1.0V reference to each input, thereby simplifying circuit design and p.c. board layout. The output can switch up to 750 mA and has output pins for its collector and emitter to promote design flexibility. An external current limit terminal may be referenced to either the ground or the V_{in} terminal, depending upon the application. In addition, the LM1578A has an on board oscillator, which sets the switching frequency with a single external capacitor from <1 Hz to 100 kHz (typical).

The LM1578A is an improved version of the LM1578, offering higher maximum ratings for the total supply voltage and output transistor emitter and collector voltages.

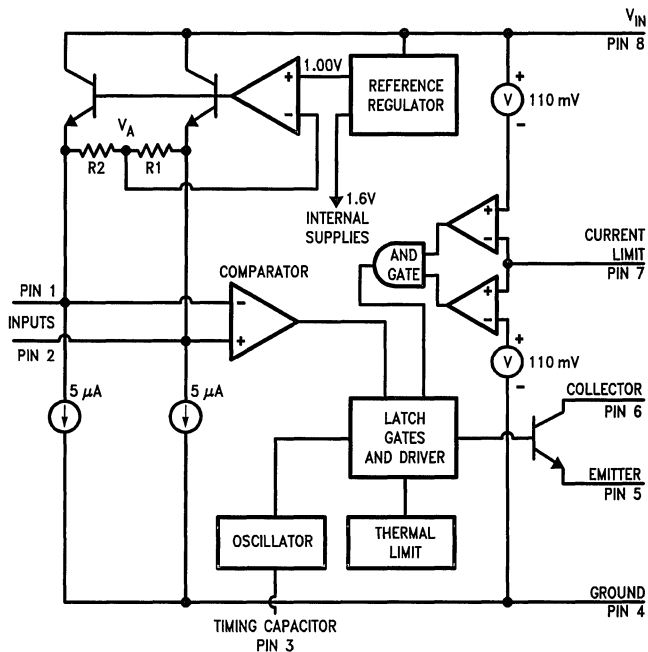
Features

- Inverting and non-inverting feedback inputs
- 1.0V reference at inputs
- Operates from supply voltages of 2V to 40V
- Output current up to 750 mA, saturation less than 0.9V
- Current limit and thermal shut down
- Duty cycle up to 90%

Applications

- Switching regulators in buck, boost, inverting, and single-ended transformer configurations
- Motor speed control
- Lamp flasher

Functional Diagram



TL/H/8711-1

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage	50V
Collector Output to Ground	-0.3V to +50V
Emitter Output to Ground (Note 2)	-1V to +50V
Power Dissipation (Note 3)	Internally limited
Output Current	750 mA
Storage Temperature	-65°C to +150°C
Lead Temperature (soldering, 10 seconds)	260°C

Maximum Junction Temperature	150°C
ESD Tolerance (Note 4)	2 kV

Operating Ratings

Ambient Temperature Range	
LM1578A	-55°C ≤ T _A ≤ +125°C
LM2578A	-40°C ≤ T _A ≤ +85°C
LM3578A	0°C ≤ T _A ≤ +70°C
Junction Temperature Range	
LM1578A	-55°C ≤ T _J ≤ +150°C
LM2578A	-40°C ≤ T _J ≤ +125°C
LM3578A	0°C ≤ T _J ≤ +125°C

Electrical Characteristics

These specifications apply for 2V ≤ V_{IN} ≤ 40V (2.2V ≤ V_{IN} ≤ 40V for T_J ≤ -25°C), timing capacitor C_T = 3900 pF, and 25% ≤ duty cycle ≤ 75%, unless otherwise specified. Values in standard typeface are for T_J = 25°C; values in **boldface type** apply for operation over the specified operating junction temperature range.

Symbol	Parameter	Conditions	Typical (Note 5)	LM1578A Limit (Notes 6, 11)	LM2578A/ LM3578A Limit (Note 7)	Units
OSCILLATOR						
f _{osc}	Frequency		20	22.4 17.6	24 16	kHz kHz (max) kHz (min)
Δf _{OSC} /ΔT	Frequency Drift with Temperature		-0.13			%/°C
	Amplitude		550			mV _{p-p}
REFERENCE/COMPARATOR (Note 8)						
V _R	Input Reference Voltage	I ₁ = I ₂ = 0 mA and I ₁ = I ₂ = 1 mA ±1% (Note 9)	1.0	1.035/ 1.050 0.965/ 0.950	1.050/ 1.070 0.950/ 0.930	V V (max) V (min)
ΔV _R /ΔV _{IN}	Input Reference Voltage Line Regulation	I ₁ = I ₂ = 0 mA and I ₁ = I ₂ = 1 mA ±1% (Note 9)	0.003	0.01/ 0.02	0.01/ 0.02	%/V %/V (max)
I _{INV}	Inverting Input Current	I ₁ = I ₂ = 0 mA, duty cycle = 25%	0.5			μA
	Level Shift Accuracy	Level Shift Current = 1 mA	1.0	5/8	10/13	% % (max)
ΔV _R /Δt	Input Reference Voltage Long Term Stability		100			ppm/1000h
OUTPUT						
V _C (sat)	Collector Saturation Voltage	I _C = 750 mA pulsed, Emitter grounded	0.7	0.85/ 1.2	0.90/ 1.0	V V (max)
V _E (sat)	Emitter Saturation Voltage	I _O = 80 mA pulsed, V _{IN} = V _C = 40V	1.4	1.6/ 2.1	1.7/ 2.0	V V (max)
I _{CES}	Collector Leakage Current	V _{IN} = V _{CE} = 40V, Emitter grounded, Output OFF	0.1	50/ 100	200/ 250	μA μA (max)
BV _{CEO(SUS)}	Collector-Emitter Sustaining Voltage	I _{SUST} = 0.2A (pulsed), V _{IN} = 0	60	50	50	V V (min)

Electrical Characteristics (Continued)

Symbol	Parameter	Conditions	Typical (Note 5)	LM1578A Limit (Note 6)	LM2578A/ LM3578A Limit (Note 7)	Units
CURRENT LIMIT						
V_{CL}	Sense Voltage Shutdown Level	Referred to V_{IN} or Ground (Note 10)	110	95 140	80 160	mV mV (min) mV (max)
$\Delta V_{CL}/\Delta T$	Sense Voltage Temperature Drift		0.3			%/°C
I_{CL}	Sense Bias Current	Referred to V_{IN} Referred to ground	4.0 0.4			μ A μ A
DEVICE POWER CONSUMPTION						
I_S	Supply Current	Output OFF, $V_E = 0V$	2.0	3.0/ 3.3	3.5/ 4.0	mA mA (max)
		Output ON, $I_C = 750$ mA pulsed, $V_E = 0V$	14			mA

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: For $T_J \geq 100^\circ\text{C}$, the Emitter pin voltage should not be driven more than 0.6V below ground (see Application Information).

Note 3: At elevated temperatures, devices must be derated based on package thermal resistance. The device in the TO-99 package must be derated at $150^\circ\text{C}/\text{W}$, junction to ambient, or $45^\circ\text{C}/\text{W}$, junction to case. The device in the 8-pin DIP must be derated at $95^\circ\text{C}/\text{W}$, junction to ambient. The device in the surface-mount package must be derated at $150^\circ\text{C}/\text{W}$, junction-to-ambient.

Note 4: Human body model, 1.5 k Ω in series with 100 pF.

Note 5: Typical values are for $T_J = 25^\circ\text{C}$ and represent the most likely parametric norm.

Note 6: All limits guaranteed and 100% production tested at room temperature (standard type face) and at **temperature extremes (bold type face)**. All limits are used to calculate Average Outgoing Quality Level (AOQL).

Note 7: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. Room temperature limits are 100% production tested. Limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate AOQL.

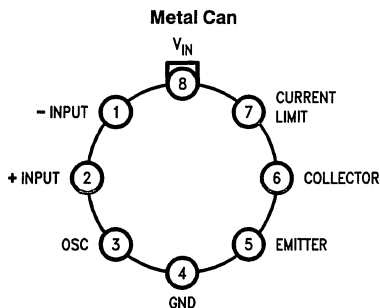
Note 8: Input terminals are protected from accidental shorts to ground but if external voltages higher than the reference voltage are applied, excessive current will flow and should be limited to less than 5 mA.

Note 9: I_1 and I_2 are the external sink currents at the inputs (refer to Test Circuit).

Note 10: Connection of a 10 k Ω resistor from pin 1 to pin 4 will drive the duty cycle to its maximum, typically 90%. Applying the minimum Current Limit Sense Voltage to pin 7 will not reduce the duty cycle to less than 50%. Applying the maximum Current Limit Sense Voltage to pin 7 is certain to reduce the duty cycle below 50%. Increasing this voltage by 15 mV may be required to reduce the duty cycle to 0%, when the Collector output swing is 40V or greater (see Ground-Referenced Current Limit Sense Voltage typical curve).

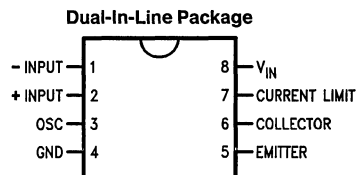
Note 11: A military RETS specification is available on request. At the time of printing, the LM1578A RETS spec complied with the **boldface** limits in this column. The LM1578AH may also be procured as a Standard Military Drawing.

Connection Diagram and Ordering Information



TL/H/8711-28

Order Number **LM1578AH, LM1578AH/883, LM2578AH or LM3578AH**
See NS Package Number **H08C**

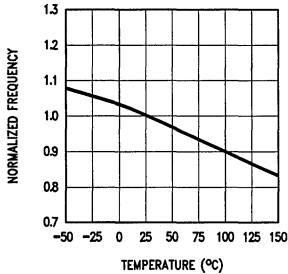


TL/H/8711-29

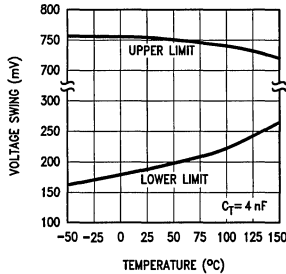
Order Number **LM3578AM, LM2578AN or LM3578AN**
See NS Package Number **M08A or N08E**

Typical Performance Characteristics

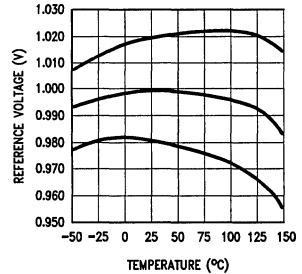
Oscillator Frequency Change with Temperature



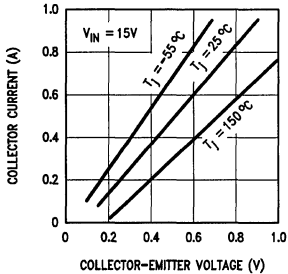
Oscillator Voltage Swing



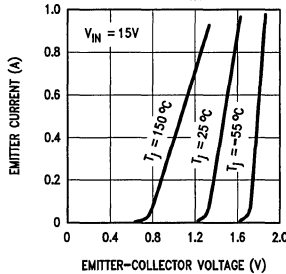
Input Reference Voltage Drift with Temperature



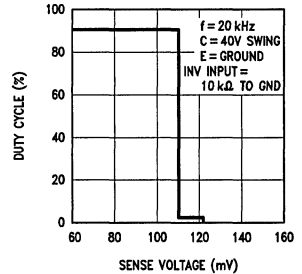
Collector Saturation Voltage (Sinking Current, Emitter Grounded)



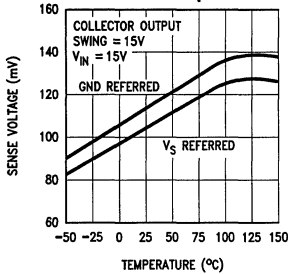
Emitter Saturation Voltage (Sourcing Current, Collector at V_IN)



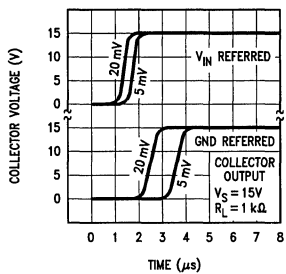
Ground Referred Current Limit Sense Voltage



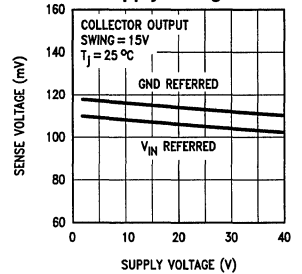
Current Limit Sense Voltage Drift with Temperature



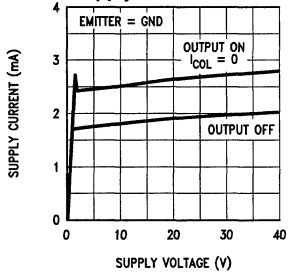
Current Limit Response Time for Various Over Drives



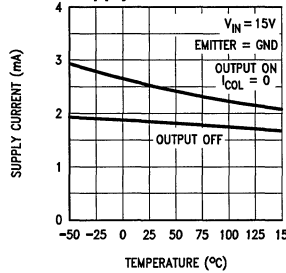
Current Limit Sense Voltage vs Supply Voltage



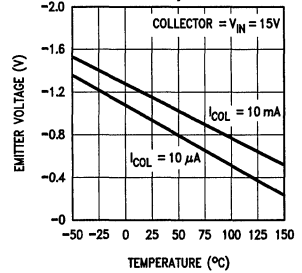
Supply Current



Supply Current



Collector Current with Emitter Output Below Ground



Test Circuit*

Parameter tests can be made using the test circuit shown. Select the desired V_{in} , collector voltage and duty cycle with adjustable power supplies. A digital volt meter with an input resistance greater than 100 M Ω should be used to measure the following:

Input Reference Voltage to Ground; S1 in either position.

Level Shift Accuracy (%) = $(T_{p3}(V)/1V) \times 100\%$; S1 at $I_1 = I_2 = 1 \text{ mA}$

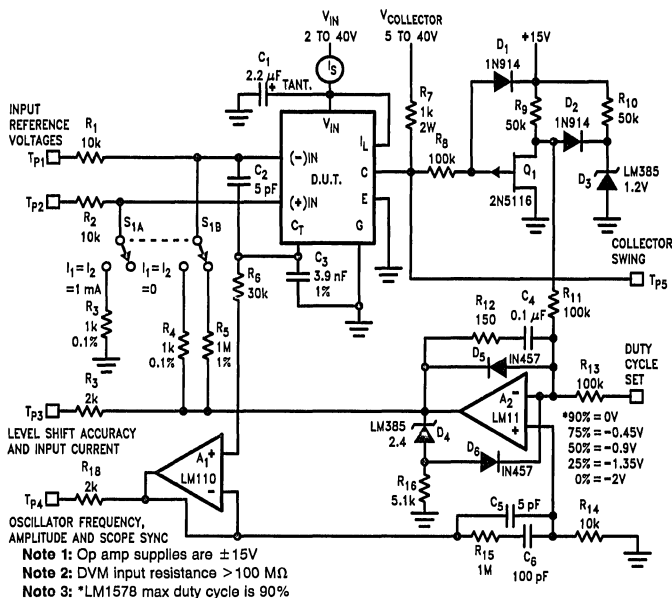
Input Current (mA) = $(1V - T_{p3}(V))/1 \text{ M}\Omega$; S1 at $I_1 = I_2 = 0 \text{ mA}$.

Oscillator parameters can be measured at T_{p4} using a frequency counter or an oscilloscope.

The Current Limit Sense Voltage is measured by connecting an adjustable 0-to-1V floating power supply in series with the current limit terminal and referring it to either the ground or the V_{in} terminal. Set the duty cycle to 90% and monitor test point T_{p5} while adjusting the floating power supply voltage until the LM1578A's duty cycle just reaches 0%. This voltage is the Current Limit Sense Voltage.

The Supply Current should be measured with the duty cycle at 0% and S1 in the $I_1 = I_2 = 0 \text{ mA}$ position.

*LM1578A specifications are measured using automated test equipment. This circuit is provided for the customer's convenience when checking parameters. Due to possible variations in testing conditions, the measured values from these testing procedures may not match those of the factory.



Definition of Terms

Input Reference Voltage: The voltage (referred to ground) that must be applied to either the inverting or non-inverting input to cause the regulator switch to change state (ON or OFF).

Input Reference Current: The current that must be drawn from either the inverting or non-inverting input to cause the regulator switch to change state (ON or OFF).

Input Level Shift Accuracy: This specification determines the output voltage tolerance of a regulator whose output control depends on drawing equal currents from the inverting and non-inverting inputs (see the Inverting Regulator of Figure 21, and the RS-232 Line Driver Power Supply of Figure 23).

Level Shift Accuracy is tested by using two equal-value resistors to draw current from the inverting and non-inverting input terminals, then measuring the percentage difference in the voltages across the resistors that produces a controlled duty cycle at the switch output.

Collector Saturation Voltage: With the inverting input terminal grounded thru a 10 k Ω resistor and the output transistor's emitter connected to ground, the Collector Saturation Voltage is the collector-to-emitter voltage for a given collector current.

Emitter Saturation Voltage: With the inverting input terminal grounded thru a 10 k Ω resistor and the output transistor's collector connected to V_{in} , the Emitter Saturation Voltage is the collector-to-emitter voltage for a given emitter current.

Collector Emitter Sustaining Voltage: The collector-emitter breakdown voltage of the output transistor, measured at a specified current.

Current Limit Sense Voltage: The voltage at the Current Limit pin, referred to either the supply or the ground terminal, which (via logic circuitry) will cause the output transistor to turn OFF and resets cycle-by-cycle at the oscillator frequency.

Definition of Terms (Continued)

Current Limit Sense Current: The bias current for the Current Limit terminal with the applied voltage equal to the Current Limit Sense Voltage.

Supply Current: The IC power supply current, excluding the current drawn through the output transistor, with the oscillator operating.

Functional Description

The LM1578A is a pulse-width modulator designed for use as a switching regulator controller. It may also be used in other applications which require controlled pulse-width voltage drive.

A control signal, usually representing output voltage, fed into the LM1578A's comparator is compared with an internally-generated reference. The resulting error signal and the oscillator's output are fed to a logic network which determines when the output transistor will be turned ON or OFF. The following is a brief description of the subsections of the LM1578A.

COMPARATOR INPUT STAGE

The LM1578A's comparator input stage is unique in that both the inverting and non-inverting inputs are available to the user, and both contain a 1.0V reference. This is accomplished as follows: A 1.0V reference is fed into a modified voltage follower circuit (see FUNCTIONAL DIAGRAM). When both input pins are open, no current flows through R1 and R2. Thus, both inputs to the comparator will have the potential of the 1.0V reference, V_A . When one input, for example the non-inverting input, is pulled ΔV away from V_A , a current of $\Delta V/R1$ will flow through R1. This same current flows through R2, and the comparator sees a total voltage of $2\Delta V$ between its inputs. The high gain of the system, through feedback, will correct for this imbalance and return both inputs to the 1.0V level.

This unusual comparator input stage increases circuit flexibility, while minimizing the total number of external components required for a voltage regulator system. The inverting switching regulator configuration, for example, can be set up without having to use an external op amp for feedback polarity reversal (see TYPICAL APPLICATIONS).

OSCILLATOR

The LM1578A provides an on-board oscillator which can be adjusted up to 100 kHz. Its frequency is set by a single external capacitor, C_1 , as shown in Figure 1, and follows the equation

$$f_{OSC} = 8 \times 10^{-5} / C_1$$

The oscillator provides a blanking pulse to limit maximum duty cycle to 90%, and a reset pulse to the internal circuitry.

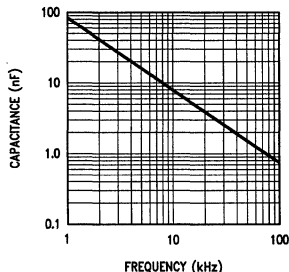


FIGURE 1. Value of Timing Capacitor vs Oscillator Frequency

TL/H/8711-4

OUTPUT TRANSISTOR

The output transistor is capable of delivering up to 750 mA with a saturation voltage of less than 0.9V. (see *Collector Saturation Voltage* and *Emitter Saturation Voltage* curves).

The emitter must not be pulled more than 1V below ground (this limit is 0.6V for $T_J \geq 100^\circ\text{C}$). Because of this limit, an external transistor must be used to develop negative output voltages (see the Inverting Regulator Typical Application). Other configurations may need protection against violation of this limit (see the Emitter Output section of the Applications Information).

CURRENT LIMIT

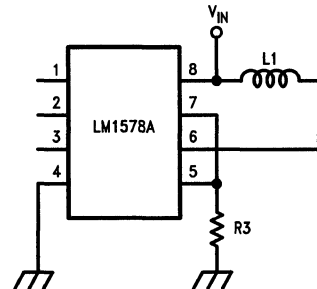
The LM1578A's current limit may be referenced to either the ground or the V_{IN} pins, and operates on a cycle-by-cycle basis.

The current limit section consists of two comparators: one with its non-inverting input referenced to a voltage 110 mV below V_{IN} , the other with its inverting input referenced 110 mV above ground (see FUNCTIONAL DIAGRAM). The current limit is activated whenever the current limit terminal is pulled 110 mV away from either V_{IN} or ground.

Applications Information

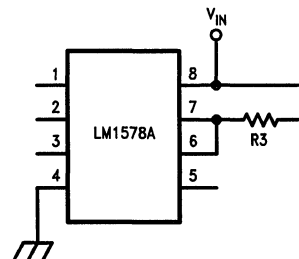
CURRENT LIMIT

As mentioned in the functional description, the current limit terminal may be referenced to either the V_{IN} or the ground terminal. Resistor R3 converts the current to be sensed into a voltage for current limit detection.



TL/H/8711-15

FIGURE 2. Current Limit, Ground Referred



TL/H/8711-16

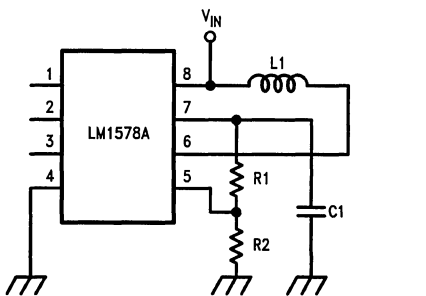
FIGURE 3. Current Limit, V_{IN} Referred

Applications Information (Continued)

CURRENT LIMIT TRANSIENT SUPPRESSION

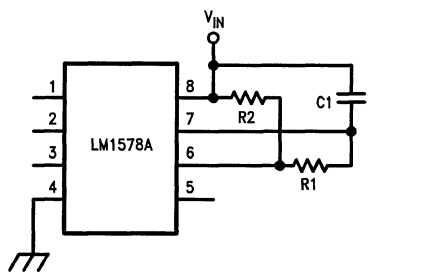
When noise spikes and switching transients interfere with proper current limit operation, R1 and C1 act together as a low pass filter to control the current limit circuitry's response time.

Because the sense current of the current limit terminal varies according to where it is referenced, R1 should be less than 2 kΩ when referenced to ground, and less than 100Ω when referenced to V_{in}.



TL/H/8711-17

FIGURE 4. Current Limit Transient Suppressor, Ground Referred

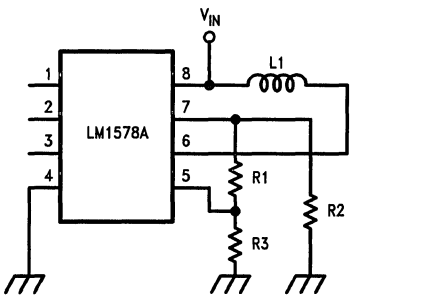


TL/H/8711-18

FIGURE 5. Current Limit Transient Suppressor, V_{in} Referred

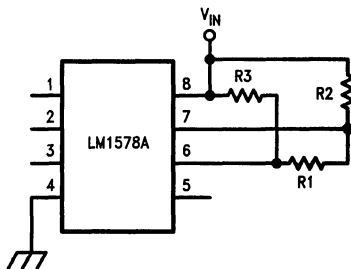
C.L. SENSE VOLTAGE MULTIPLICATION

When a larger sense resistor value is desired, the voltage divider network, consisting of R1 and R2, may be used. This effectively multiplies the sense voltage by (1 + R1/R2). Also, R1 can be replaced by a diode to increase current limit sense voltage to about 800 mV (diode V_f + 110 mV).



TL/H/8711-19

FIGURE 6. Current Limit Sense Voltage Multiplication, Ground Referred

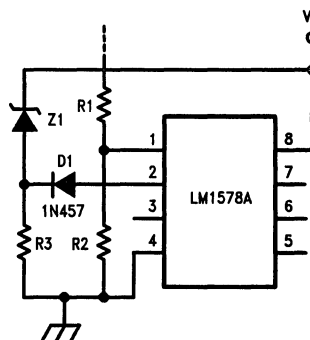


TL/H/8711-20

FIGURE 7. Current Limit Sense Voltage Multiplication, V_{in} Referred

UNDER-VOLTAGE LOCKOUT

Under-voltage lockout is accomplished with few external components. When V_{in} becomes lower than the zener breakdown voltage, the output transistor is turned off. This occurs because diode D1 will then become forward biased, allowing resistor R3 to sink a greater current from the non-inverting input than is sunk by the parallel combination of R1 and R2 at the inverting terminal. R3 should be one-fifth of the value of R1 and R2 in parallel.



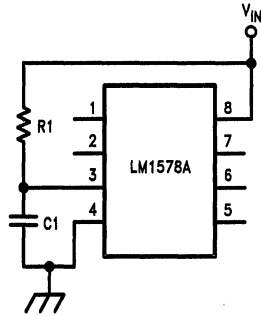
TL/H/8711-22

FIGURE 8. Under-Voltage Lockout

MAXIMUM DUTY CYCLE LIMITING

The maximum duty cycle can be externally limited by adjusting the charge to discharge ratio of the oscillator capacitor with a single external resistor. Typical values are 50 μA for the charge current, 450 μA for the discharge current, and a voltage swing from 200 mV to 750 mV. Therefore, R1 is selected for the desired charging and discharging slopes and C1 is readjusted to set the oscillator frequency.

Applications Information (Continued)



TL/H/8711-21

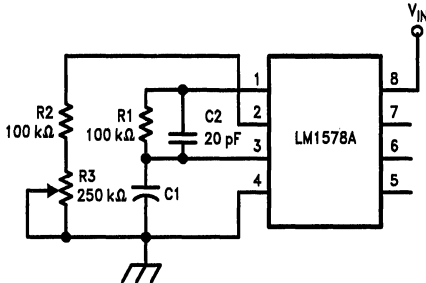
FIGURE 9. Maximum Duty Cycle Limiting

DUTY CYCLE ADJUSTMENT

When manual or mechanical selection of the output transistor's duty cycle is needed, the circuit shown below may be used. The output will turn on with the beginning of each oscillator cycle and turn off when the current sunk by R2 and R3 from the non-inverting terminal becomes greater than the current sunk from the inverting terminal.

With the resistor values as shown, R3 can be used to adjust the duty cycle from 0% to 90%.

When the sum of R2 and R3 is twice the value of R1, the duty cycle will be about 50%. C1 may be a large electrolytic capacitor to lower the oscillator frequency below 1 Hz.

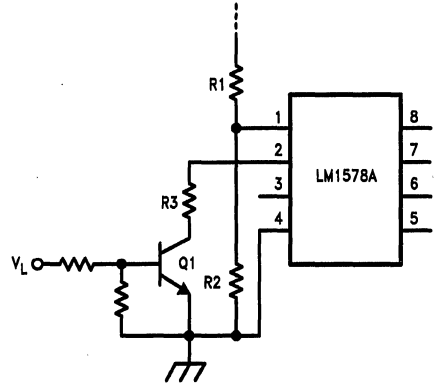


TL/H/8711-23

FIGURE 10. Duty Cycle Adjustment

REMOTE SHUTDOWN

The LM1578A may be remotely shutdown by sinking a greater current from the non-inverting input than from the inverting input. This may be accomplished by selecting resistor R3 to be approximately one-half the value of R1 and R2 in parallel.



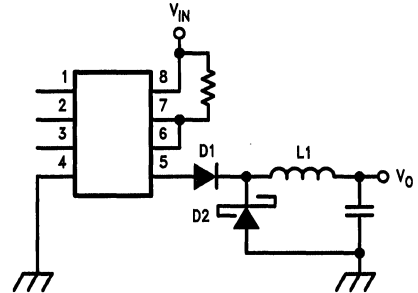
TL/H/8711-24

FIGURE 11. Shutdown Occurs when V_L is High

EMITTER OUTPUT

When the LM1578A output transistor is in the OFF state, if the Emitter output swings below the ground pin voltage, the output transistor will turn ON because its base is clamped near ground. The *Collector Current with Emitter Output Below Ground* curve shows the amount of Collector current drawn in this mode, vs temperature and Emitter voltage. When the Collector-Emitter voltage is high, this current will cause high power dissipation in the output transistor and should be avoided.

This situation can occur in the high-current high-voltage buck application if the Emitter output is used and the catch diode's forward voltage drop is greater than 0.6V. A fast-recovery diode can be added in series with the Emitter output to counter the forward voltage drop of the catch diode (see Figure 2). For better efficiency of a high output current buck regulator, an external PNP transistor should be used as shown in Figure 16.



TL/H/8711-30

FIGURE 12. D1 Prevents Output Transistor from Improperly Turning ON due to D2's Forward Voltage

Applications Information (Continued)

SYNCHRONIZING DEVICES

When several devices are to be operated at once, their oscillators may be synchronized by the application of an external signal. This drive signal should be a pulse waveform with a minimum pulse width of $2 \mu\text{s}$, and an amplitude from 1.5V to 2.0V. The signal source must be capable of 1.) driving capacitive loads and 2.) delivering up to $500 \mu\text{A}$ for each LM1578A.

Capacitors C1 thru CN are to be selected for a 20% slower frequency than the synchronization frequency.

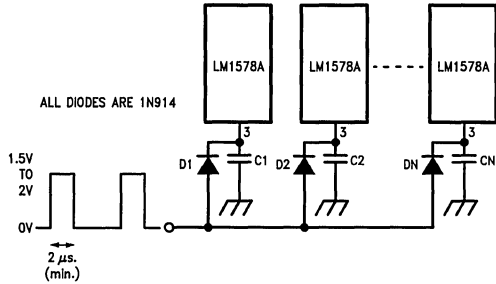


FIGURE 13. Synchronizing Devices

TL/H/8711-25

Typical Applications

The LM1578A may be operated in either the continuous or the discontinuous conduction mode. The following applications (except for the Buck-Boost Regulator) are designed for continuous conduction operation. That is, the inductor current is not allowed to fall to zero. This mode of operation has higher efficiency and lower EMI characteristics than the discontinuous mode.

BUCK REGULATOR

The buck configuration is used to step an input voltage down to a lower level. Transistor Q1 in Figure 14 chops the input DC voltage into a squarewave. This squarewave is then converted back into a DC voltage of lower magnitude by the low pass filter consisting of L1 and C1. The duty cycle, D, of the squarewave relates the output voltage to the input voltage by the following equation:

$$V_{out} = D \times V_{in} = V_{in} \times (t_{on}) / (t_{on} + t_{off})$$

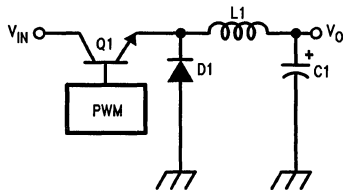


FIGURE 14. Basic Buck Regulator

TL/H/8711-5

Figure 15 is a 15V to 5V buck regulator with an output current, I_o , of 350 mA. The circuit becomes discontinuous at 20% of $I_{o(max)}$, has 10 mV of output voltage ripple, an efficiency of 75%, a load regulation of 30 mV (70 mA to 350 mA) and a line regulation of 10 mV ($12 \leq V_{in} \leq 18V$).

Component values are selected as follows:

$$R1 = (V_o - 1) \times R2 \text{ where } R2 = 10 \text{ k}\Omega$$

$$R3 = V / I_{sw(max)}$$

$$R3 = 0.15\Omega$$

where:

V is the current limit sense voltage, 0.11V

$I_{sw(max)}$ is the maximum allowable current thru the output transistor.

L1 is the inductor and may be found from the inductance calculation chart (Figure 16) as follows:

$$\text{Given } V_{in} = 15V \quad V_o = 5V$$

$$I_{o(max)} = 350 \text{ mA} \quad f_{osc} = 50 \text{ kHz}$$

Discontinuous at 20% of $I_{o(max)}$.

Note that since the circuit will become discontinuous at 20% of $I_{o(max)}$, the load current must not be allowed to fall below 70 mA.

Step 1: Calculate the maximum DC current through the inductor, $I_{L(max)}$. The necessary equations are indicated at the top of the chart and show that $I_{L(max)} = I_{o(max)}$ for the buck configuration. Thus, $I_{L(max)} = 350 \text{ mA}$.

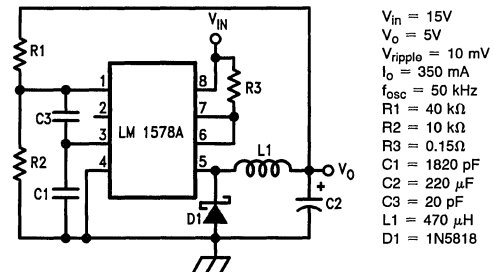
Step 2: Calculate the inductor Volts-sec product, E-T_{OP}, according to the equations given from the chart. For the Buck:

$$E-T_{op} = (V_{in} - V_o) (V_o / V_{in}) (1000 / f_{osc})$$

$$= (15 - 5) (5 / 15) (1000 / 50)$$

$$= 66V\text{-}\mu\text{s}$$

with the oscillator frequency, f_{osc} , expressed in kHz.



$V_{in} = 15V$
 $V_o = 5V$
 $V_{ripple} = 10 \text{ mV}$
 $I_o = 350 \text{ mA}$
 $f_{osc} = 50 \text{ kHz}$
 $R1 = 40 \text{ k}\Omega$
 $R2 = 10 \text{ k}\Omega$
 $R3 = 0.15\Omega$
 $C1 = 1820 \text{ pF}$
 $C2 = 220 \mu\text{F}$
 $C3 = 20 \text{ pF}$
 $L1 = 470 \mu\text{H}$
 $D1 = 1N5818$

TL/H/8711-6

FIGURE 15. Buck or Step-Down Regulator

Step 3: Using the graph with axis labeled "Discontinuous At % I_{OUT} " and " $I_{L(max, DC)}$ " find the point where the desired maximum inductor current, $I_{L(max, DC)}$ intercepts the desired discontinuity percentage.

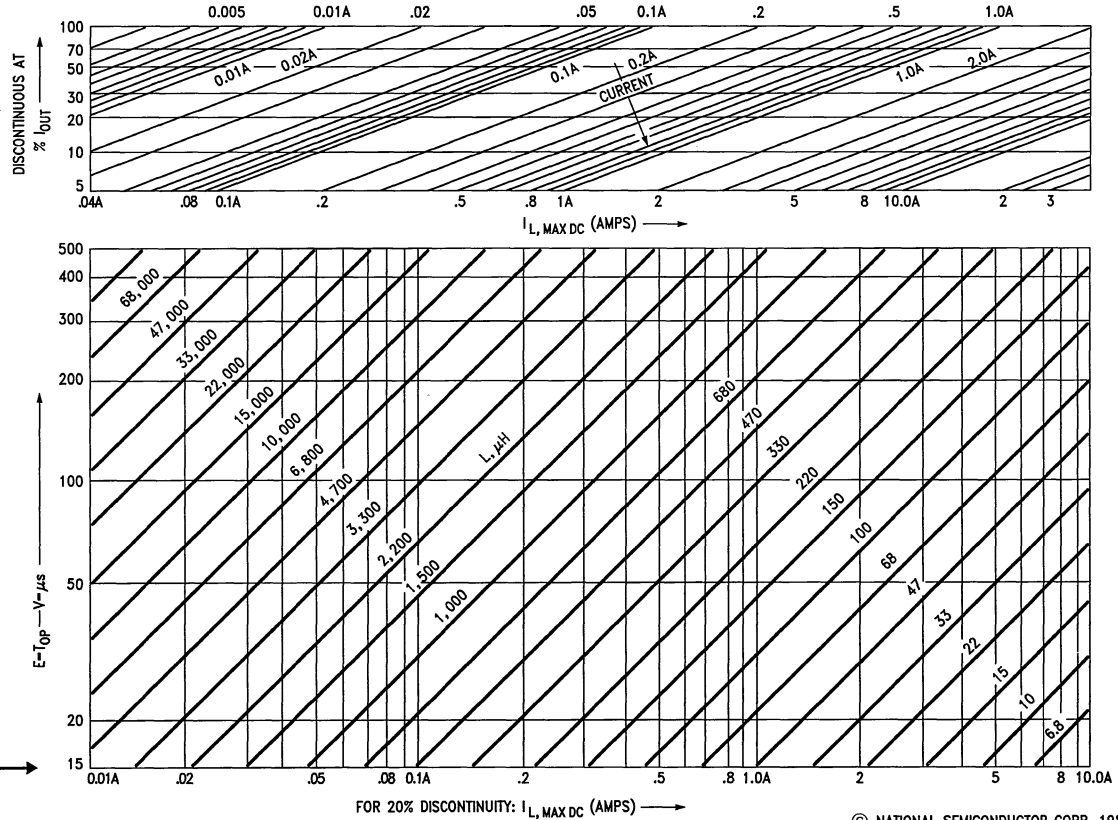
In this example, the point of interest is where the 0.35A line intersects with the 20% line. This is nearly the midpoint of the horizontal axis.

Step 4: This last step is merely the translation of the point found in Step 3 to the graph directly below it. This is accomplished by moving straight down the page to the point which intercepts the desired E-T_{OP}. For this example, E-T_{OP} is 66V- μs and the desired inductor value is 470 μH . Since this example was for 20% discontinuity, the bottom chart could have been used directly, as noted in step 3 of the chart instructions.

HOW TO USE THIS CHART

- ① CALCULATE $I_{L, MAX DC}$ HERE
- ② CALCULATE $E-T_{OP}$ HERE
- ③ ENTER REQUIRED % DISCONTINUITY $\Delta I_L \cdot 100\%$ = $2I_{L, MAX DC}$ HERE IF "20%" PROCEED TO ⑦
- ④ PROCEED HORIZONTALLY TO $I_{L, MAX DC}$ FROM ①
- ⑤ FROM $I_{L, MAX DC}$ PROCEED VERTICALLY TO $E-T_{OP}$ FROM ②
- ⑥ READ INDUCTANCE VALUE AT $E-T_{OP}$ FOR $I_{L, MAX DC}$
- ⑦ READ $I_{L, MAX DC}$ FROM ① HERE
- ⑧ READ INDUCTANCE VALUE AT $E-T_{OP}$ FOR $I_{L, MAX DC}$

BUCK	BOOST	INVERT	
$I_L = I_{LOAD}$	$I_L = I_{LOAD} \frac{V_0}{V_{IN}}$	$I_L = I_{LOAD} \cdot \frac{V_{IN} + V_{O1} }{V_{IN}}$	I_L
$(V_{IN} - V_0) \cdot \frac{V_0}{V_{IN}} \cdot \frac{1000}{F, kHz}$	$(V_0 - V_{IN}) \cdot \frac{V_{IN}}{V_0} \cdot \frac{1000}{F, kHz}$	$V_{IN} \cdot \frac{ V_{O1} }{V_{IN} + V_{O1} } \cdot \frac{1000}{F, kHz}$	$E-T_{OP}$



FOR 20% DISCONTINUITY: $I_{L, MAX DC}$ (AMPS) →

© NATIONAL SEMICONDUCTOR CORP. 1988

FIGURE 16. DC/DC Inductance Calculator

Typical Applications (Continued)

For a full line of standard inductor values, contact Pulse Engineering (San Diego, Calif.) regarding their PE526XX series, or A. I. E. Magnetics (Nashville, Tenn.).

A more precise inductance value may be calculated for the Buck, Boost and Inverting Regulators as follows:

BUCK

$$L = V_o (V_{in} - V_o) / (\Delta I_L V_{in} f_{osc})$$

BOOST

$$L = V_{in} (V_o - V_{in}) / (\Delta I_L f_{osc} V_o)$$

INVERT

$$L = V_{in} |V_o| / [\Delta I_L (V_{in} + |V_o|) f_{osc}]$$

where ΔI_L is the current ripple through the inductor. ΔI_L is usually chosen based on the minimum load current expected of the circuit. For the buck regulator, since the inductor current I_L equals the load current I_o ,

$$\Delta I_L = 2 \cdot I_o(\min)$$

$\Delta I_L = 140$ mA for this circuit. ΔI_L can also be interpreted as

$$\Delta I_L = 2 \cdot (\text{Discontinuity Factor}) \cdot I_L$$

where the Discontinuity Factor is the ratio of the minimum load current to the maximum load current. For this example, the Discontinuity Factor is 0.2.

The remainder of the components of *Figure 15* are chosen as follows:

C1 is the timing capacitor found in *Figure 1*.

$$C2 \geq V_o (V_{in} - V_o) / (8f_{osc} 2V_{in} V_{ripple} L)$$

where V_{ripple} is the peak-to-peak output voltage ripple.

C3 is necessary for continuous operation and is generally in the 10 pF to 30 pF range.

D1 should be a Schottky type diode, such as the 1N5818 or 1N5819.

BUCK WITH BOOSTED OUTPUT CURRENT

For applications requiring a large output current, an external transistor may be used as shown in *Figure 17*. This circuit steps a 15V supply down to 5V with 1.5A of output current. The output ripple is 50 mV, with an efficiency of 80%, a load regulation of 40 mV (150 mA to 1.5A), and a line regulation of 20 mV ($12V \leq V_{in} \leq 18V$).

Component values are selected as outlined for the buck regulator with a discontinuity factor of 10%, with the addition of R4 and R5:

$$R4 = 10V_{BE1} B_f / I_p$$

$$R5 = (V_{in} - V - V_{BE1} - V_{sat}) B_f / (I_{L(\max, DC)} + I_{R4})$$

where:

V_{BE1} is the V_{BE} of transistor Q1.

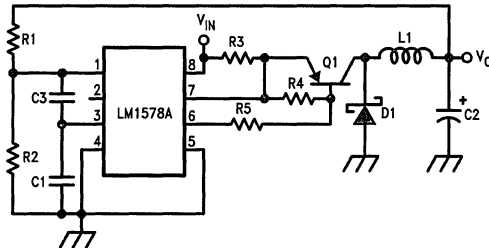
V_{sat} is the saturation voltage of the LM1578A output transistor.

V is the current limit sense voltage.

B_f is the forced current gain of transistor Q1 ($B_f = 30$ for *Figure 17*).

$$I_{R4} = V_{BE1} / R4$$

$$I_p = I_{L(\max, DC)} + 0.5\Delta I_L$$



$V_{in} = 15V$	$R4 = 200\Omega$
$V_o = 5V$	$R5 = 330\Omega$
$V_{ripple} = 50$ mV	$C1 = 1820$ pF
$I_o = 1.5A$	$C2 = 330$ μ F
$f_{osc} = 50$ kHz	$C3 = 20$ pF
$R1 = 40$ k Ω	$L1 = 220$ μ H
$R2 = 10$ k Ω	$D1 = 1N5819$
$R3 = 0.05\Omega$	$Q1 = D45$

TL/H/8711-8

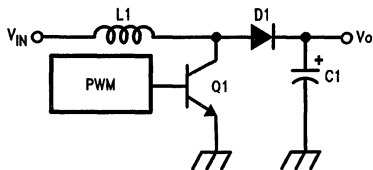
FIGURE 17. Buck Converter with Boosted Output Current

Typical Applications (Continued)

BOOST REGULATOR

The boost regulator converts a low input voltage into a higher output voltage. The basic configuration is shown in *Figure 18*. Energy is stored in the inductor while the transistor is on and then transferred with the input voltage to the output capacitor for filtering when the transistor is off. Thus,

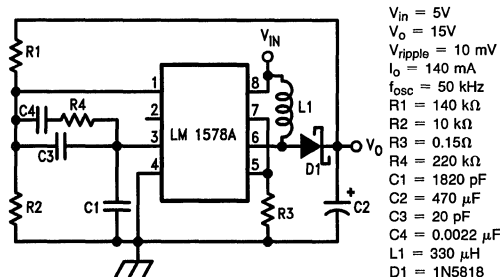
$$V_o = V_{in} + V_{in}(t_{on}/t_{off})$$



TL/H/8711-9

FIGURE 18. Basic Boost Regulator

The circuit of *Figure 19* converts a 5V supply into a 15V supply with 150 mA of output current, a load regulation of 14 mV (30 mA to 140 mA), and a line regulation of 35 mV ($4.5V \leq V_{in} \leq 8.5V$).



- $V_{in} = 5V$
- $V_o = 15V$
- $V_{ripple} = 10mV$
- $I_o = 140mA$
- $f_{osc} = 50kHz$
- $R1 = 140k\Omega$
- $R2 = 10k\Omega$
- $R3 = 0.15\Omega$
- $R4 = 220k\Omega$
- $C1 = 1820pF$
- $C2 = 470\mu F$
- $C3 = 20pF$
- $C4 = 0.0022\mu F$
- $L1 = 330\mu H$
- $D1 = 1N5818$

TL/H/8711-11

FIGURE 19. Boost or Step-Up Regulator

$$R1 = (V_o - 1) R2 \text{ where } R2 = 10k\Omega$$

$$R3 = V / (I_{L(max, DC)} + 0.5 \Delta I_L)$$

where:

$$\Delta I_L = 2(I_{LOAD(min)})(V_o/V_{in})$$

ΔI_L is 200 mA in this example.

R4, C3 and C4 are necessary for continuous operation and are typically 220 k Ω , 20 pF, and 0.0022 μ F respectively.

C1 is the timing capacitor found in *Figure 1*.

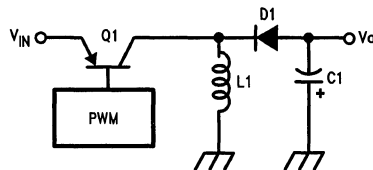
$$C2 \geq I_o (V_o - V_{in}) / (f_{osc} V_o V_{ripple})$$

D1 is a Schottky type diode such as a 1N5818 or 1N5819.

L1 is found as described in the buck converter section, using the inductance chart for *Figure 16* for the boost configuration and 20% discontinuity.

INVERTING REGULATOR

Figure 20 shows the basic configuration for an inverting regulator. The input voltage is of a positive polarity, but the output is negative. The output may be less than, equal to, or greater in magnitude than the input. The relationship between the magnitude of the input voltage and the output voltage is $V_o = V_{in} \times (t_{on}/t_{off})$.



TL/H/8711-10

FIGURE 20. Basic Inverting Regulator

Figure 21 shows an LM1578A configured as a 5V to -15V polarity inverter with an output current of 300 mA, a load regulation of 44 mV (60 mA to 300 mA) and a line regulation of 50 mV ($4.5V \leq V_{in} \leq 8.5V$).

$$R1 = (|V_o| + 1) R2 \text{ where } R2 = 10k\Omega$$

$$R3 = V / (I_{L(max, DC)} + 0.5 \Delta I_L)$$

$$R4 = 10V_{BE1}B_f / (I_{L(max, DC)} + 0.5 \Delta I_L)$$

where:

V , V_{BE1} , V_{sat} , and B_f are defined in the "Buck Converter with Boosted Output Current" section.

$$\Delta I_L = 2(I_{LOAD(min)})(V_{in} + |V_o|) / V_{IN}$$

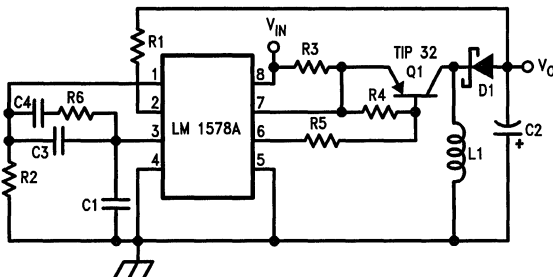
R5 is defined in the "Buck with Boosted Output Current" section.

R6 serves the same purpose as R4 in the Boost Regulator circuit and is typically 220 k Ω .

C1, C3 and C4 are defined in the "Boost Regulator" section.

$$C2 \geq I_o |V_o| / [f_{osc} (|V_o| + V_{in}) V_{ripple}]$$

L1 is found as outlined in the section on buck converters, using the inductance chart for *Figure 16* for the inverting configuration and 20% discontinuity.



- $V_{in} = 5V$
- $V_o = -15V$
- $V_{ripple} = 5mV$
- $I_o = 300mA, I_{min} = 60mA$
- $f_{osc} = 50kHz$
- $R1 = 160k\Omega, R2 = 10k\Omega$
- $R3 = 0.01\Omega, R4 = 190\Omega$
- $R5 = 82\Omega, R6 = 220k\Omega$
- $C1 = 1820pF$
- $C2 = 1000\mu F$
- $C3 = 20pF$
- $C4 = 0.0022\mu F$
- $L1 = 150\mu H$
- $D1 = 1N5818$

TL/H/8711-12

FIGURE 21. Inverting Regulator

Typical Applications (Continued)

BUCK-BOOST REGULATOR

The Buck-Boost Regulator, shown in *Figure 22*, may step a voltage up or down, depending upon whether or not the desired output voltage is greater or less than the input voltage. In this case, the output voltage is 12V with an input voltage from 9V to 15V. The circuit exhibits an efficiency of 75%, with a load regulation of 60 mV (10 mA to 100 mA) and a line regulation of 52 mV.

$$R1 = (V_o - 1) R2 \text{ where } R2 = 10 \text{ k}\Omega$$

$$R3 = V_o / 75A$$

R4, C1, C3 and C4 are defined in the "Boost Regulator" section.

D1 and D2 are Schottky type diodes such as the 1N5818 or 1N5819.

$$C2 \geq \frac{(I_o / V_{\text{ripple}}) (V_o + 2V_d)}{[f_{\text{osc}} (V_{\text{in}} + V_o + 2V_d - V_{\text{sat}} - V_{\text{sat1}})]}$$

where:

V_d is the forward voltage drop of the diodes.

V_{sat} is the saturation voltage of the LM1578A output transistor.

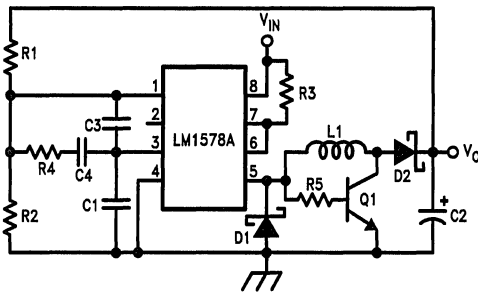
V_{sat1} is the saturation voltage of transistor Q1.

$$L1 \geq (V_{\text{in}} - V_{\text{sat}} - V_{\text{sat1}}) (t_{\text{on}} / I_p)$$

where:

$$t_{\text{on}} = \frac{(1/f_{\text{osc}}) (V_o + 2V_d)}{(V_o + V_{\text{in}} + 2V_d - V_{\text{sat}} - V_{\text{sat1}})}$$

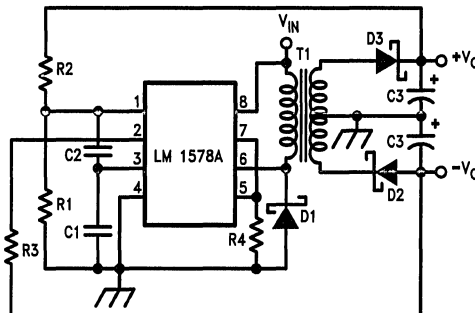
$$I_p = \frac{2I_o (V_{\text{in}} + V_o + 2V_d - V_{\text{sat}} - V_{\text{sat1}})}{(V_{\text{in}} - V_{\text{sat}} - V_{\text{sat1}})}$$



TL/H/8711-13

FIGURE 22. Buck-Boost Regulator

$9V \leq V_{\text{in}} \leq 15V$	$R5 = 270$
$V_o = 12V$	$C1 = 1820 \text{ pF}$
$I_o = 100 \text{ mA}$	$C2 = 220 \text{ }\mu\text{F}$
$V_{\text{ripple}} = 50 \text{ mV}$	$C3 = 20 \text{ pF}$
$f_{\text{osc}} = 50 \text{ kHz}$	$C4 = 0.0022 \text{ }\mu\text{F}$
$R1 = 110 \text{ k}$	$L1 = 220 \text{ }\mu\text{H}$
$R2 = 10 \text{ k}$	$D1, D2 = 1N5819$
$R3 = 0.15$	$Q1 = D44$
$R4 = 220 \text{ k}$	



TL/H/8711-14

FIGURE 23. RS-232 Line Driver Power Supply

$V_{\text{in}} = 5V$
$V_o = \pm 12V$
$I_o = \pm 40 \text{ mA}$
$f_{\text{osc}} = 80 \text{ kHz}$
$R1 = 10 \text{ k}\Omega$
$R2 = 240 \text{ k}\Omega$
$R3 = 240 \text{ k}\Omega$
$R4 = 0.15 \Omega$
$C1 = 820 \text{ pF}$
$C2 = 10 \text{ pF}$
$C3 = 220 \text{ }\mu\text{F}$
$D1, D2, D3 = 1N5819$
$T1 = PE-64287$

Typical Applications (Continued)

Capacitor C1 sets the oscillator frequency and is selected from *Figure 1*.

Capacitor C2 serves as a compensation capacitor for synchronous operation and a value of 10 to 50 pF should be sufficient for most applications.

A minimum value for an ideal output capacitor C3, could be calculated as $C = I_o \times t / \Delta V$ where I_o is the load current, t is the transistor on time (typically $0.4/f_{osc}$), and ΔV is the peak-to-peak output voltage ripple. A larger output capacitor than this theoretical value should be used since electrolytics have poor high frequency performance. Experience has shown that a value from 5 to 10 times the calculated value should be used.

For good efficiency, the diodes must have a low forward voltage drop and be fast switching. 1N5819 Schottky diodes work well.

Transformer selection should be picked for an output transistor "on" time of $0.4/f_{osc}$, and a primary inductance high enough to prevent the output transistor switch from ramping higher than the transistor's rating of 750 mA. Pulse Engineering (San Diego, Calif.) and Renco Electronics, Inc. (Deer Park, N.Y.) can provide further assistance in selecting the proper transformer for a specific application need. The transformer used in *Figure 23* was a Pulse Engineering PE-64287.

LM78S40

Universal Switching Regulator Subsystem

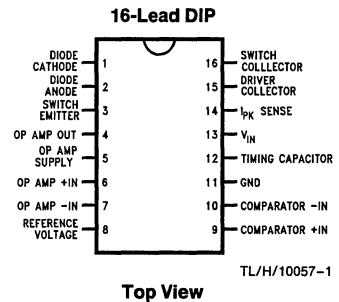
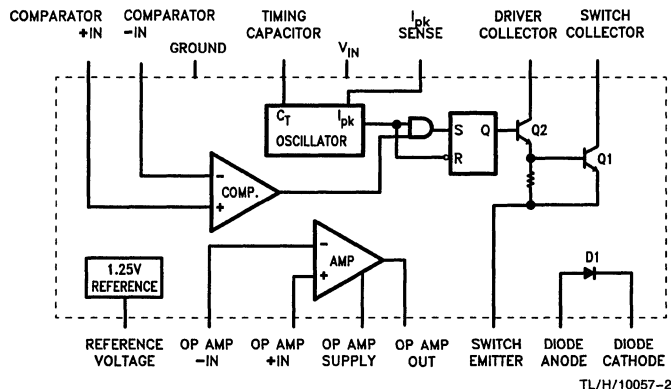
General Description

The LM78S40 is a monolithic regulator subsystem consisting of all the active building blocks necessary for switching regulator systems. The device consists of a temperature compensated voltage reference, a duty-cycle controllable oscillator with an active current limit circuit, an error amplifier, high current, high voltage output switch, a power diode and an uncommitted operational amplifier. The device can drive external NPN or PNP transistors when currents in excess of 1.5A or voltages in excess of 40V are required. The device can be used for step-down, step-up or inverting switching regulators as well as for series pass regulators. It features wide supply voltage range, low standby power dissipation, high efficiency and low drift. It is useful for any stand-alone, low part count switching system and works extremely well in battery operated systems.

Features

- Step-up, step-down or inverting switching regulators
- Output adjustable from 1.25V to 40V
- Peak currents to 1.5A without external transistors
- Operation from 2.5V to 40V input
- Low standby current drain
- 80 dB line and load regulation
- High gain, high current, independent op amp
- Pulse width modulation with no double pulsing

Block and Connection Diagrams



Ordering Information

Part Number	NS Package	Temperature Range
LM78S40J LM78S40J/883	J16A Ceramic DIP J16A Ceramic DIP	-55°C to +125°C
LM78S40N	N16E Molded DIP	-40°C to +125°C
LM78S40CJ LM78S40CN	J16A Ceramic DIP N16E Molded DIP	0°C to +70°C

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	
Ceramic DIP	-65°C to +175°C
Molded DIP	-65°C to +150°C
Operating Temperature Range	
Extended (LM78S40J)	-55°C to +125°C
Industrial (LM78S40N)	-40°C to +125°C
Commercial (LM78S40CN)	0°C to +70°C
Lead Temperature	
Ceramic DiP (Soldering, 60 sec.)	300°C
Molded DIP (Soldering, 10 sec.)	265°C
Internal Power Dissipation (Notes 1, 2)	
16L-Ceramic DIP	1.50W
16L-Molded DIP	1.04W
Input Voltage from V_{IN} to GND	40V
Input Voltage from V^+ (Op Amp) to GND	40V

Common Mode Input Range (Comparator and Op Amp)	-0.3 to V^+
Differential Input Voltage (Note 3)	$\pm 30V$
Output Short Circuit Duration (Op Amp)	Continuous
Current from V_{REF}	10 mA
Voltage from Switch Collectors to GND	40V
Voltage from Switch Emitters to GND	40V
Voltage from Switch Collectors to Emitter	40V
Voltage from Power Diode to GND	40V
Reverse Power Diode Voltage	40V
Current through Power Switch	1.5A
Current through Power Diode	1.5A
ESD Susceptibility	(to be determined)

LM78S40

Electrical Characteristics

T_A = Operating temperature range, $V_{IN} = 5.0V$, V^+ (Op Amp) = 5.0V, unless otherwise specified. (Note 4)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
GENERAL CHARACTERISTICS						
I_{CC}	Supply Current (Op Amp Disconnected)	$V_{IN} = 5.0V$		1.8	3.5	mA
		$V_{IN} = 40V$		2.3	5.0	mA
I_{CC}	Supply Current (Op Amp Connected)	$V_{IN} = 5.0V$			4.0	mA
		$V_{IN} = 40V$			5.5	mA
REFERENCE SECTION						
V_{REF}	Reference Voltage	$I_{REF} = 1.0 \text{ mA}$ Extend $-55^\circ\text{C} < T_A < +125^\circ\text{C}$, Comm $0 < T_A < +70^\circ\text{C}$, Indus $-40^\circ\text{C} < T_A < +85^\circ\text{C}$	1.180	1.245	1.310	V
$V_{R \text{ LINE}}$	Reference Voltage Line Regulation	$V_{IN} = 3.0V$ to $V_{IN} = 40V$, $I_{REF} = 1.0 \text{ mA}$, $T_A = 25^\circ\text{C}$		0.04	0.2	mV/V
$V_{R \text{ LOAD}}$	Reference Voltage Load Regulation	$I_{REF} = 1.0 \text{ mA}$ to $I_{REF} = 10 \text{ mA}$, $T_A = 25^\circ\text{C}$		0.2	0.5	mV/mA
OSCILLATOR SECTION						
I_{CHG}	Charging Current	$V_{IN} = 5.0V$, $T_A = 25^\circ\text{C}$	20		50	μA
I_{CHG}	Charging Current	$V_{IN} = 40V$, $T_A = 25^\circ\text{C}$	20		70	μA
I_{DISCHG}	Discharge Current	$V_{IN} = 5.0V$, $T_A = 25^\circ\text{C}$	150		250	μA
I_{DISCHG}	Discharge Current	$V_{IN} = 40V$, $T_A = 25^\circ\text{C}$	150		350	μA
V_{OSC}	Oscillator Voltage Swing	$V_{IN} = 5.0V$, $T_A = 25^\circ\text{C}$		0.5		V
t_{on}/t_{off}	Ratio of Charge/ Discharge Time			6.0		$\mu\text{s}/\mu\text{s}$

LM78S40

Electrical Characteristics (Continued)

T_A = Operating Temperature Range, V_{IN} = 5.0V, V^+ (Op Amp) = 5.0V, unless otherwise specified. (Note 4)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
CURRENT LIMIT SECTION						
V_{CLS}	Current Limit Sense Voltage	$T_A = 25^\circ\text{C}$	250		350	mV
OUTPUT SWITCH SECTION						
V_{SAT1}	Output Saturation Voltage 1	$I_{SW} = 1.0\text{A}$ (Figure 1)		1.1	1.3	V
V_{SAT2}	Output Saturation Voltage 2	$I_{SW} = 1.0\text{A}$ (Figure 2)		0.45	0.7	V
h_{FE}	Output Transistor Current Gain	$I_C = 1.0\text{A}$, $V_{CE} = 5.0\text{V}$, $T_A = 25^\circ\text{C}$		70		
I_L	Output Leakage Current	$V_O = 40\text{V}$, $T_A = 25^\circ\text{C}$		10		nA
POWER DIODE						
V_{FD}	Forward Voltage Drop	$I_D = 1.0\text{A}$		1.25	1.5	V
I_{DR}	Diode Leakage Current	$V_D = 40\text{V}$, $T_A = 25^\circ\text{C}$		10		nA
COMPARATOR						
V_{IO}	Input Offset Voltage	$V_{CM} = V_{REF}$		1.5	15	mV
I_{IB}	Input Bias Current	$V_{CM} = V_{REF}$		35	200	nA
I_{IO}	Input Offset Current	$V_{CM} = V_{REF}$		5.0	75	nA
V_{CM}	Common Mode Voltage Range	$T_A = 25^\circ\text{C}$	0		$V_{IN}-2$	V
PSRR	Power Supply Rejection Ratio	$V_{IN} = 3.0\text{V to } 40\text{V}$, $T_A = 25^\circ\text{C}$	70	96		dB
OPERATIONAL AMPLIFIER						
V_{IO}	Input Offset Voltage	$V_{CM} = 2.5\text{V}$		4.0	15	mV
I_{IB}	Input Bias Current	$V_{CM} = 2.5\text{V}$		30	200	nA
I_{IO}	Input Offset Current	$V_{CM} = 2.5\text{V}$		5.0	75	nA
A_{VS}^+	Voltage Gain ⁺	$R_L = 2.0\text{ k}\Omega$ to GND; $V_O = 1.0\text{V to } 2.5\text{V}$, $T_A = 25^\circ\text{C}$	25	250		V/mV
A_{VS}^-	Voltage Gain ⁻	$R_L = 2.0\text{ k}\Omega$ to V^+ (Op Amp) $V_O = 1.0\text{V to } 2.5\text{V}$, $T_A = 25^\circ\text{C}$	25	250		V/mV
V_{CM}	Common Mode Voltage Range	$T_A = 25^\circ\text{C}$	0		$V_{CC} - 2$	V
CMR	Common Mode Rejection	$V_{CM} = 0\text{V to } 3.0\text{V}$, $T_A = 25^\circ\text{C}$	76	100		dB
PSRR	Power Supply Rejection Ratio	V^+ (Op Amp) = $3.0\text{V to } 40\text{V}$, $T_A = 25^\circ\text{C}$	76	100		dB
I_{O}^+	Output Source Current	$T_A = 25^\circ\text{C}$		75	150	mA
I_{O}^-	Output Sink Current	$T_A = 25^\circ\text{C}$		10	35	mA
SR	Slew Rate	$T_A = 25^\circ\text{C}$		0.6		V/ μs
V_{OL}	Output Voltage LOW	$I_L = -5.0\text{ mA}$, $T_A = 25^\circ\text{C}$			1.0	V
V_{OH}	Output Voltage High	$I_L = 50\text{ mA}$, $T_A = 25^\circ\text{C}$	V^+ (Op Amp) - 3V			V

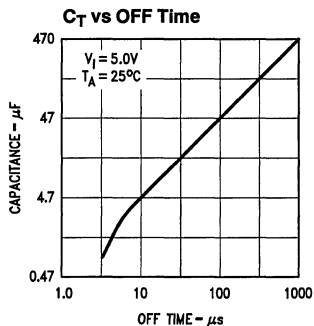
Note 1: $T_{J\text{ Max}} = 150^\circ\text{C}$ for the Molded DIP, and 175°C for the Ceramic DIP.

Note 2: Ratings apply to ambient temperature at 25°C . Above this temperature, derate the 16L-Ceramic DIP at $10\text{ mW}/^\circ\text{C}$, and the 16L-Molded DIP at $8.3\text{ mW}/^\circ\text{C}$.

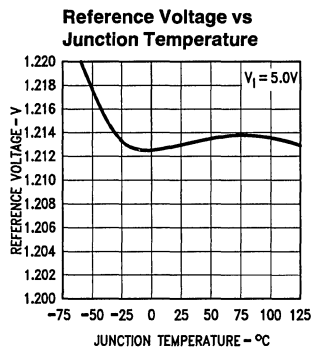
Note 3: For supply voltages less than 30V, the absolute maximum voltage is equal to the supply voltage.

Note 4: A military RETS specification is available on request. At the time of printing, the LM78S40 RETS specification complied with the Min and Max limits in this table. The LM78S40J may also be procured as a Standard Military Drawing.

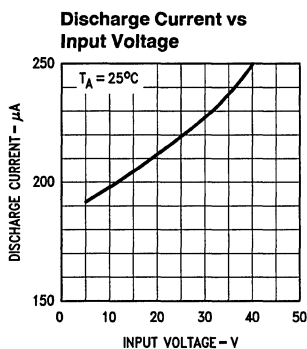
Typical Performance Characteristics



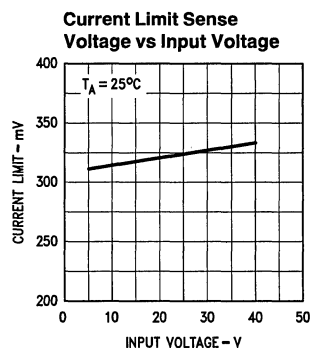
TL/H/10057-6



TL/H/10057-7



TL/H/10057-8



TL/H/10057-9

Design Formulas

Characteristic	Step-Down	Step-Up	Inverting	Units
$\frac{t_{on}}{t_{off}}$	$\frac{V_O + V_D}{V_I - V_{SAT} - V_O}$	$\frac{V_O + V_D - V_I}{V_I - V_{SAT}}$	$\frac{ V_O + V_D}{V_I - V_{SAT}}$	
$(t_{on} + t_{off}) \text{ Max}$	$\frac{1}{f_{Min}}$	$\frac{1}{f_{Min}}$	$\frac{1}{f_{MIN}}$	μs
C_T	$4 \times 10^{-5} t_{on}$	$4 \times 10^{-5} t_{on}$	$4 \times 10^{-5} t_{on}$	μF
I_{pk}	$2 I_{O \text{ Max}}$	$2 I_{O \text{ Max}} \cdot \frac{t_{on} + t_{off}}{t_{off}}$	$2 I_{O \text{ Max}} \cdot \frac{t_{on} + t_{off}}{t_{off}}$	A
L_{Min}	$\left(\frac{V_I - V_{SAT} - V_O}{I_{pk}} \right) t_{on \text{ Max}}$	$\left(\frac{V_I - V_{SAT}}{I_{pk}} \right) t_{on \text{ Max}}$	$\left(\frac{V_I - V_{SAT}}{I_{pk}} \right) t_{on \text{ Max}}$	μH
R_{SC}	$0.33/I_{pk}$	$0.33/I_{pk}$	$0.33/I_{pk}$	Ω
C_O	$\frac{I_{pk} (t_{on} + t_{off})}{8 V_{ripple}}$	$\approx \frac{I_O}{V_{ripple}} \cdot t_{on}$	$\approx \frac{I_O}{V_{ripple}} \cdot t_{on}$	μF

Note: V_{SAT} = Saturation voltage of the switching element.

V_D = Forward voltage of the flyback diode.

Functional Description

SWITCHING FREQUENCY CONTROL

The LM78S40 is a variable frequency, variable duty cycle device. The initial switching frequency is set by the timing capacitor. (Oscillator frequency is set by a single external capacitor. Oscillator frequency may be varied over a range of 100 Hz to 100 kHz). The initial duty cycle is 6:1. This switching frequency and duty cycle can be modified by two mechanisms—the current limit circuitry (I_{pk} sense) and the comparator.

The comparator modifies the OFF time. When the output voltage is correct, the comparator output is in the HIGH state and has no effect on the circuit operation. If the output voltage is too high then the comparator output goes LOW. In the LOW state the comparator inhibits the turn-on of the output stage switching transistors. As long as the comparator is LOW the system is in OFF time. As the output current rises the OFF time decreases. As the output current nears its maximum the OFF time approaches its minimum value. The comparator can inhibit several ON cycles, one ON cycle or any portion of an ON cycle. Once the ON cycle has begun the comparator cannot inhibit until the beginning of the next ON cycle.

The current limit modifies the ON time. The current limit is activated when a 300 mV potential appears between lead 13 (V_{CC}) and lead 14 (I_{pk}). This potential is intended to result when designed for peak current flows through R_{SC} . When the peak current is reached the current limit is turned on. The current limit circuitry provides for a quick end to ON time and the immediate start of OFF time.

Generally the oscillator is free running but the current limit action tends to reset the timing cycle.

Increasing load results in more current limited ON time and less OFF time. The switching frequency increases with load current.

USING THE INTERNAL REFERENCE, DIODE, AND SWITCH

The internal 1.245V reference (pin 8) must be bypassed, with 0.1 μ F directly to the ground pin (pin 11) of the LM78S40, to assure its stability.

V_{FD} is the forward voltage drop across the internal power diode. It is listed on the data sheet as 1.25V typical, 1.5V maximum. If an external diode is used, then its own forward voltage drop must be used for V_{FD} .

V_{SAT} is the voltage across the switch element (output transistors Q1 and Q2) when the switch is closed or ON. This is listed on the data sheet as Output Saturation Voltage.

“Output saturation voltage 1” is defined as the switching element voltage for Q2 and Q1 in the Darlington configuration with collectors tied together. This applies to *Figure 1*, the step down mode.

“Output saturation voltage 2” is the switching element voltage for Q1 only when used as a transistor switch. This applies to *Figure 2*, the step up mode.

For the inverting mode, *Figure 3*, the saturation voltage of the external transistor should be used for V_{SAT} .

Typical Applications

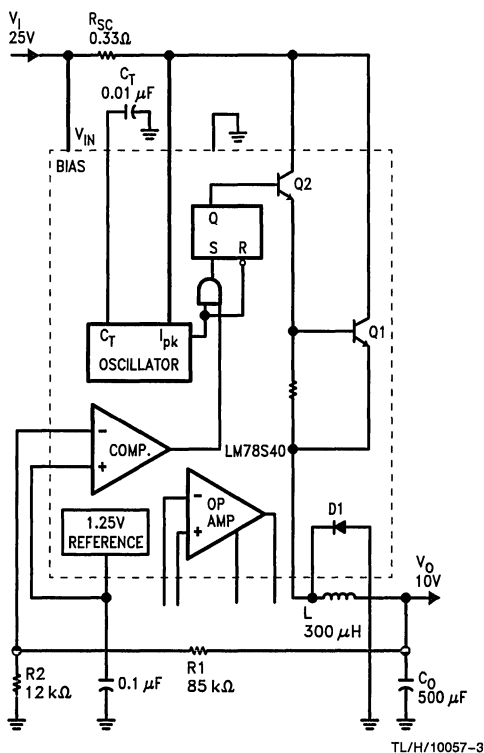


FIGURE 1. Typical Step-Down Regulator and Operational Performance ($T_A = 25^\circ\text{C}$)

Characteristic	Condition	Typical Value
Output Voltage	$I_O = 200 \text{ mA}$	10V
Line Regulation	$20\text{V} \leq V_I \leq 30\text{V}$	1.5 mV
Load Regulation	$5.0 \text{ mA} \leq I_O$ $I_O \leq 300 \text{ mA}$	3.0 mV
Max Output Current	$V_O = 9.5\text{V}$	500 mA
Output Ripple	$I_O = 200 \text{ mA}$	50 mV
Efficiency	$I_O = 200 \text{ mA}$	74%
Standby Current	$I_O = 200 \text{ mA}$	2.8 mA

Note A: For $I_O \geq 200 \text{ mA}$ use external diode to limit on-chip power dissipation.

Typical Applications (Continued)

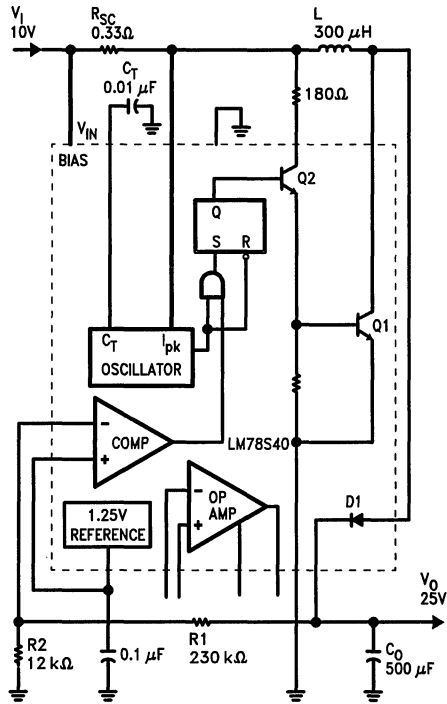


FIGURE 2. Typical Step-Up Regulator and Operational Performance ($T_A = 25^\circ\text{C}$)

TL/H/10057-4

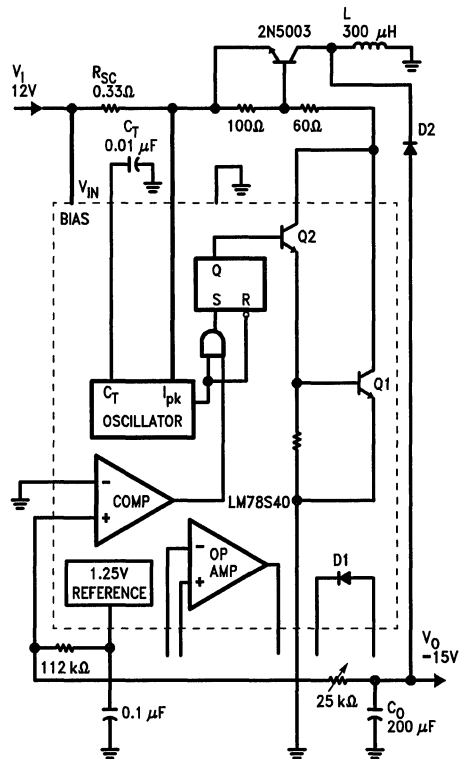


FIGURE 3. Typical Inverting Regulator and Operational Performance ($T_A = 25^\circ\text{C}$)

TL/H/10057-5

Characteristic	Condition	Typical Value
Output Voltage	$I_O = 50\text{ mA}$	25V
Line Regulation	$5.0\text{V} \leq V_I \leq 15\text{V}$	4.0 mV
Load Regulation	$5.0\text{ mA} \leq I_O$ $I_O \leq 100\text{ mA}$	2.0 mV
Max Output Current	$V_O = 23.75\text{V}$	160 mA
Output Ripple	$I_O = 50\text{ mA}$	30 mV
Efficiency	$I_O = 50\text{ mA}$	79%
Standby Current	$I_O = 50\text{ mA}$	2.6 mA

Characteristic	Condition	Typical Value
Output Voltage	$I_O = 100\text{ mA}$	-15V
Line Regulation	$8.0\text{V} \leq V_I \leq 18\text{V}$	5.0 mV
Load Regulation	$5.0\text{ mA} \leq I_O$ $I_O \leq 150\text{ mA}$	3.0 mV
Max Output Current	$V_O = 14.25\text{V}$	160 mA
Output Ripple	$I_O = 100\text{ mA}$	20 mV
Efficiency	$I_O = 100\text{ mA}$	70%
Standby Current	$I_O = 100\text{ mA}$	2.3 mA

Typical Applications (Continued)

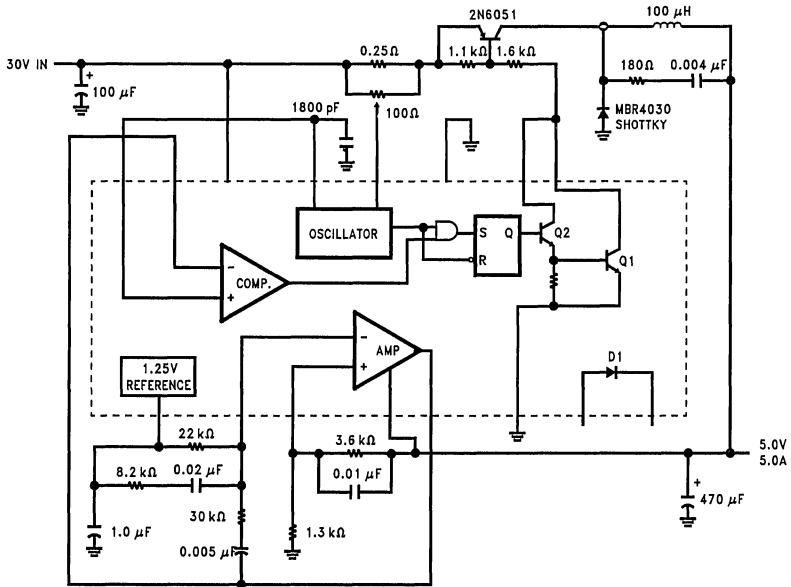


FIGURE 4. Pulse Width Modulated Step-Down Regulator ($f_{osc} = 20 \text{ kHz}$)

TL/H/10057-10



LMC7660 Switched Capacitor Voltage Converter

General Description

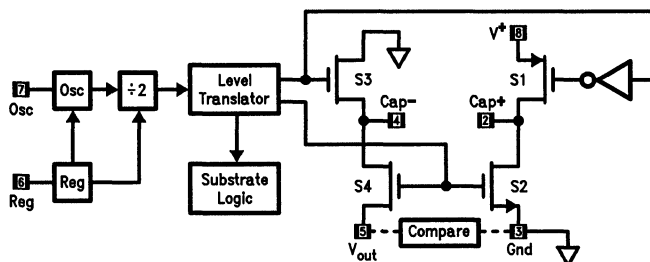
The LMC7660 is a CMOS voltage converter capable of converting a positive voltage in the range of +1.5V to +10V to the corresponding negative voltage of -1.5V to -10V. The LMC7660 is a pin-for-pin replacement for the industry-standard 7660. The converter features: operation over full temperature and voltage range without need for an external diode, low quiescent current, and high power efficiency.

The LMC7660 uses its built-in oscillator to switch 4 power MOS switches and charge two inexpensive electrolytic capacitors.

Features

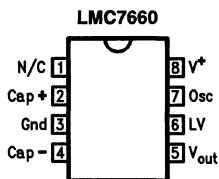
- Operation over full temperature and voltage range without an external diode
- Low supply current, 200 μ A max
- Pin-for-pin replacement for the 7660
- Wide operating range 1.5V to 10V
- 97% Voltage Conversion Efficiency
- 95% Power Conversion Efficiency
- Easy to use, only 2 external components
- Extended temperature range

Block Diagram



TL/H/9136-1

Pin Configuration



TL/H/9136-2

Ordering Information

LMC7660MJ $-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ LMC7660IN $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	10.5V
Input Voltage on Pin 6, 7 (Note 2)	-0.3V to (V ⁺ + 0.3V) for V ⁺ < 5.5V (V ⁺ - 5.5V) to (V ⁺ + 0.3V) for V ⁺ > 5.5V
Current into Pin 6 (Note 2)	20 μ A
Output Short Circuit Duration (V ⁺ \leq 5.5V)	Continuous

	Package	
	J	N
Power Dissipation (Note 3)	0.9W	1.4W
T _j Max (Note 3)	150°C	150°C
θ_{ja} (Note 3)	140°C/W	90°C/W
Storage Temp. Range	-65°C \leq T \leq 150°C	
Lead Temp. (Soldering, 5 sec)	260°C	260°C
ESD Tolerance (Note 8)	\pm 2000V	

Electrical Characteristics (Note 4)

Symbol	Parameter	Conditions	Typ	LMC7660MJ	LMC7660IN		Units Limits
				Tested Limit (Note 5)	Tested Limit (Note 5)	Design Limit (Note 6)	
I _s	Supply Current	R _L = ∞	120	200 400	200	400	μ A max
V ⁺ _H	Supply Voltage Range High (Note 7)	R _L = 10 k Ω , Pin 6 Open Voltage Efficiency \geq 90%	3 to 10	3 to 10	3 to 10	3 to 10	V
V ⁺ _L	Supply Voltage Range Low	R _L = 10 k Ω , Pin 6 to Gnd. Voltage Efficiency \geq 90%	1.5 to 3.5	1.5 to 3.5	1.5 to 3.5	1.5 to 3.5	V
R _{out}	Output Source Resistance	I _L = 20 mA	55	100 150	100	120	Ω max
		V = 2V, I _L = 3 mA Pin 6 Short to Gnd.	110	200 300	200	300	Ω max
F _{osc}	Oscillator Frequency		10				kHz
P _{eff}	Power Efficiency	R _L = 5 k Ω	97	95 90	95	90	% min
V _{o eff}	Voltage Conversion Efficiency	R _L = ∞	99.9	97 95	97	95	% min
I _{osc}	Oscillator Sink or Source Current	Pin 7 = Gnd. or V ⁺	3				μ A

Note 1: Absolute Maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 4 for conditions.

Note 2: Connecting any input terminal to voltages greater than V⁺ or less than ground may cause destructive latchup. It is recommended that no inputs from sources operating from external supplies be applied prior to "power-up" of the LMC7660.

Note 3: For operation at elevated temperature, these devices must be derated based on a thermal resistance of θ_{ja} and T_j max, T_j = T_A + θ_{ja} P_D.

Note 4: Boldface numbers apply at temperature extremes. All other numbers apply at T_A = 25°C, V⁺ = 5V, C_{osc} = 0, and apply for the LMC7660 unless otherwise specified. Test circuit is shown in Figure 1.

Note 5: Guaranteed and 100% production tested.

Note 6: Guaranteed over the operating temperature range (but not 100% tested). These limits are not used to calculate outgoing quality levels.

Note 7: The LMC7660 can operate without an external diode over the full temperature and voltage range. The LMC7660 can also be used with the external diode Dx, when replacing previous 7660 designs.

Note 8: The test circuit consists of the human body model of 100 pF in series with 1500 Ω .

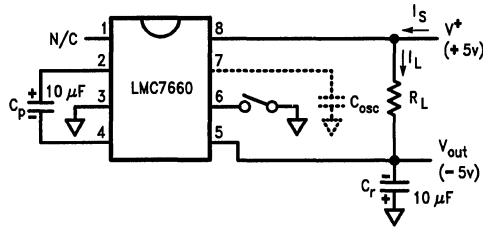
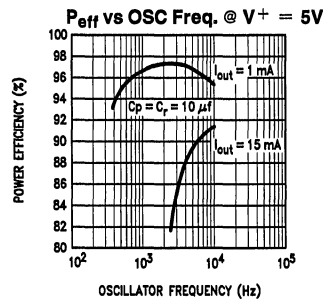
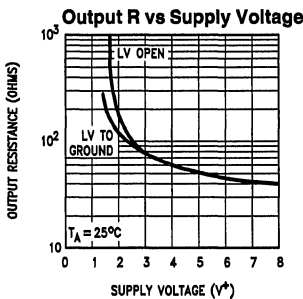
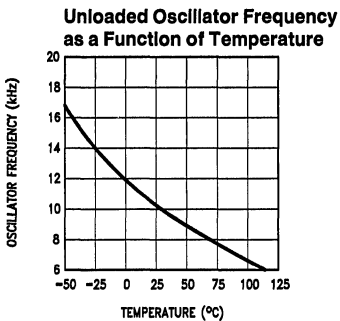
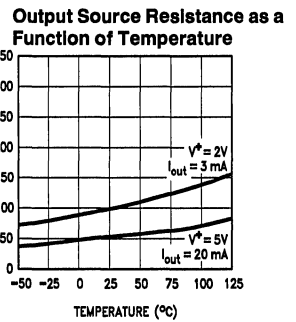
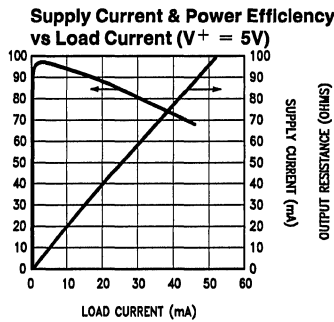
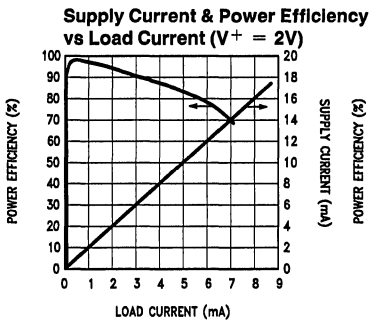
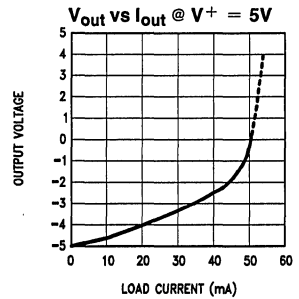
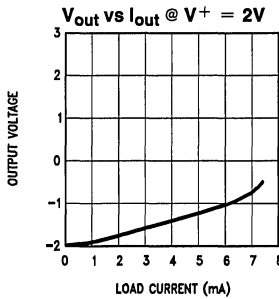
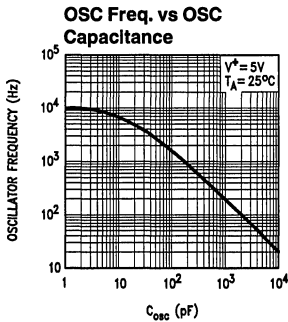


FIGURE 1. LMC7660 Test Circuit

TL/H/9136-5

Typical Performance Characteristics



TL/H/9136-4

CIRCUIT DESCRIPTION

The LMC7660 contains four large CMOS switches which are switched in a sequence to provide supply inversion $V_{out} = -V_{in}$. Energy transfer and storage are provided by two inexpensive electrolytic capacitors. *Figure 2* shows how the LMC7660 can be used to generate $-V^+$ from V^+ . When switches S1 and S3 are closed, C_p charges to the supply voltage V^+ . During this time interval, switches S2 and S4 are open. After C_p charges to V^+ , S1 and S3 are opened, S2 and S4 are then closed. By connecting S2 to ground, C_p develops a voltage $-V^+/2$ on C_r . After a number of cycles C_r will be pumped to exactly $-V^+$. This transfer will be exact assuming no load on C_r , and no loss in the switches.

In the circuit of *Figure 2*, S1 is a P-channel device and S2, S3, and S4 are N-channel devices. Because the output is biased below ground, it is important that the p^- wells of S3 and S4 never become forward biased with respect to either their sources or drains. A substrate logic circuit guarantees that these p^- wells are always held at the proper voltage. Under all conditions S4 p^- well must be at the lowest potential in the circuit. To switch off S4, a level translator generates $V_{GS4} = 0V$, and this is accomplished by biasing the level translator from the S4 p^- well.

An internal RC oscillator and $\div 2$ circuit provide timing signals to the level translator. The built-in regulator biases the oscillator and divider to reduce power dissipation on high supply voltage. The regulator becomes active at about $V^+ = 6.5V$. Low voltage operation can be improved if the LV pin is shorted to ground for $V^+ \leq 3.5V$. For $V^+ \geq 3.5V$, the LV pin must be left open to prevent damage to the part.

POWER EFFICIENCY AND RIPPLE

It is theoretically possible to approach 100% efficiency if the following conditions are met:

- 1) The drive circuitry consumes little power.
- 2) The power switches are matched and have low R_{on} .
- 3) The impedance of the reservoir and pump capacitors are negligibly small at the pumping frequency.

The LMC7660 closely approaches 1 and 2 above. By using a large pump capacitor C_p , the charge removed while supplying the reservoir capacitor is small compared to C_p 's total charge. Small removed charge means small changes in the pump capacitor voltage, and thus small energy loss and high efficiency. The energy loss by C_p is:

$$E = \frac{1}{2} C_p (V_1^2 - V_2^2)$$

By using a large reservoir capacitor, the output ripple can be reduced to an acceptable level. For example, if the load current is 5 mA and the accepted ripple is 200 mV, then the reservoir capacitor can omit approximately be calculated from:

$$I_s = C_r \frac{dv}{dt}$$

$$\sim C_r \times \frac{V_{\text{ripple p-p}}}{4/F_{\text{osc}}} \quad C_r = \frac{0.5 \text{ mA}}{0.5V/ms} = 10 \mu\text{F}$$

PRECAUTIONS

- 1) Do not exceed the maximum supply voltage or junction temperature.
- 2) Do not short pin 6 (LV terminal) to ground for supply voltages greater than 3.5V.
- 3) Do not short circuit the output to V^+ .
- 4) External electrolytic capacitors C_r and C_p should have their polarities connected as shown in *Figure 1*.

REPLACING PREVIOUS 7660 DESIGNS

To prevent destructive latchup, previous 7660 designs require a diode in series with the output when operated at elevated temperature or supply voltage. Although this prevented the latchup problem of these designs, it lowered the available output voltage and increased the output series resistance.

The National LMC7660 has been designed to solve the inherent latch problem. The LCM7660 can operate over the

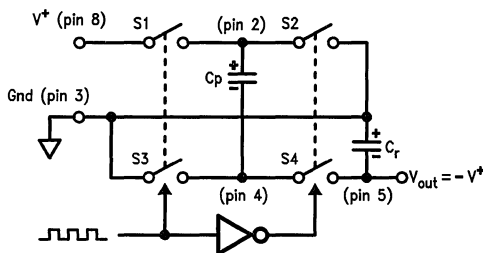


FIGURE 2. Idealized Voltage Converter

TL/H/9136-6

entire supply voltage and temperature range without the need for an output diode. When replacing existing designs, the LMC7660 can be operated with diode D_x.

Typical Applications

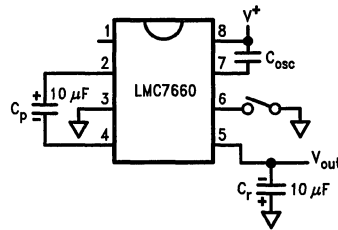
Changing Oscillator Frequency

It is possible to dramatically reduce the quiescent operating current of the LMC7660 by lowering the oscillator frequency. The oscillator frequency can be lowered from a nominal 10 kHz to several hundred hertz, by adding a slow-down capacitor C_{osc} (Figure 3). As shown in the Typical Performance Curves the supply current can be lowered to the 10 μ A range. This low current drain can be extremely useful when

used in μ Power and battery back-up equipment. It must be understood that the lower operating frequency and supply current cause an increased impedance of C_r and C_p . The increased impedance, due to a lower switching rate, can be offset by raising C_r and C_p until ripple and load current requirements are met.

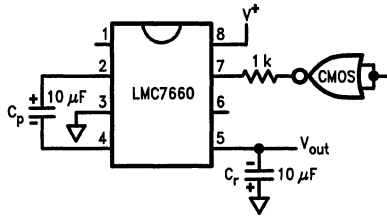
Synchronizing to an External Clock

Figure 4 shows an LMC7660 synchronized to an external clock. The CMOS gate overrides the internal oscillator when it is necessary to switch faster or reduce power supply interference. The external clock still passes through the $\div 2$ circuit in the 7660, so the pumping frequency will be $\frac{1}{2}$ the external clock frequency.



TL/H/9136-7

FIGURE 3. Reduce Supply Current by Lowering Oscillator Frequency



TL/H/9136-8

FIGURE 4. Synchronizing to an External Clock

Typical Applications (Continued)

Lowering Output Impedance

Paralleling two or more LMC7660's lowers output impedance. Each device must have its own pumping capacitor C_p , but the reservoir capacitor C_r is shared as depicted in *Figure 5*. The composite output resistance is:

$$R_{out} = \frac{R_{out \text{ of one LMC7660}}}{\text{Number of devices}}$$

Increasing Output Voltage

Stacking the LMC7660s is an easy way to produce a greater negative voltage. It should be noted that the input

current required for each stage is twice the load current on that stage as shown in *Figure 6A*. The effective output resistance is approximately the sum of the individual R_{out} values, and so only a few levels of multiplication can be used.

It is possible to generate $-15V$ from $+5V$ by connecting the second 7660's pin 8 to $+5V$ instead of ground as shown in *Figure 6B*. Note that the second 7660 sees a full 20V and the input supply should not be increased beyond $+5V$.

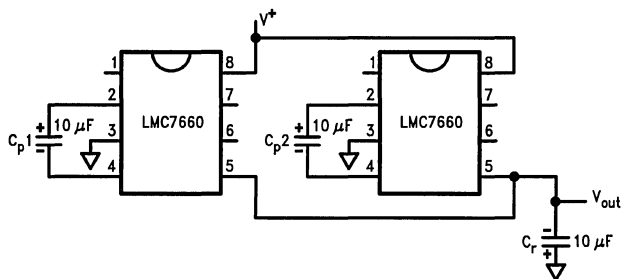


FIGURE 5. Lowering Output Resistance by Paralleling Devices

TL/H/9136-9

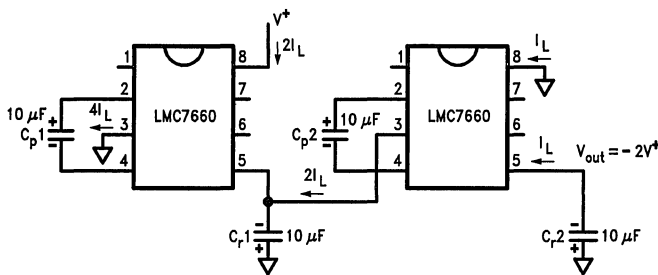


FIGURE 6A. Higher Voltage by Cascade

TL/H/9136-10

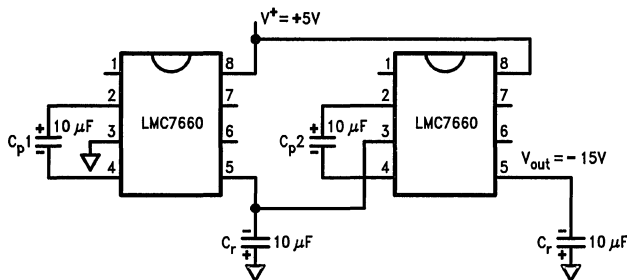


FIGURE 6B. Getting $-15V$ from $+5V$

TL/H/9136-11

Typical Applications (Continued)

Split V^+ In Half

Figure 7 is one of the more interesting applications for the LMC7660. The circuit can be used as a precision voltage divider (for very light loads), alternately it is used to generate a $\frac{1}{2}$ supply point in battery applications. In the $\frac{1}{2}$ cycle when S1 and S3 are closed, the supply voltage divides across the capacitors in a conventional way proportional to their value. In the $\frac{1}{2}$ cycle when S2 and S4 are closed, the capacitors switch from a series connection to a parallel connection. This forces the capacitors to have the same voltage; the charge redistributes to maintain precisely $V^+ / 2$, across C_p and C_r . In this application all devices are only $V^+ / 2$, and the supply voltage can be raised to 20V giving exactly 10V at V_{out} .

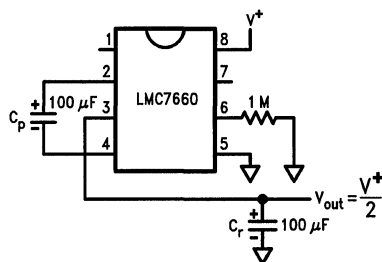


FIGURE 7. Split V^+ in Half

TL/H/9136-12

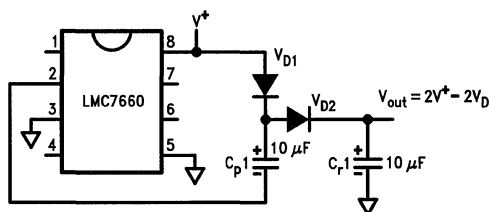


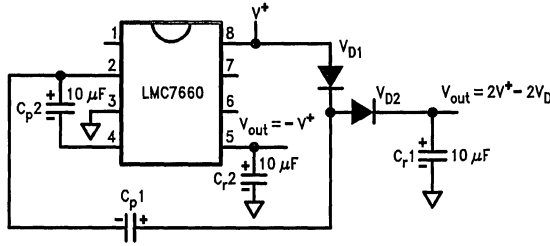
FIGURE 8. Positive Voltage Multiplier

TL/H/9136-13

Getting Up . . . and Down

The LMC7660 can also be used as a positive voltage multiplier. This application, shown in Figure 8, requires 2 additional diodes. During the first $\frac{1}{2}$ cycle S2 charges C_p1 through D1; D2 is reverse biased. In the next $\frac{1}{2}$ cycle S2 is open and S1 is closed. Since C_p1 is charged to $V^+ - V_{D1}$ and is referenced to V^+ through S1, the junction of D1 and D2 is at $V^+ + (V^+ - V_{D1})$. D1 is reverse biased in this interval. This application uses only two of the four switches in the 7660. The other two switches can be put to use in performing a negative conversion at the same time as shown in Figure 9. In the $\frac{1}{2}$ cycle that D1 is charging C_p1 , C_p2 is connected from ground to $-V_{out}$ via S2 and S4, and C_r2 is storing C_p2 's charge. In the interval that S1 and S3 are closed, C_p1 pumps the junction of D1 and D2 above V^+ , while C_p2 is refreshed from V^+ .

Typical Applications (Continued)



TL/H/9136-14

FIGURE 9. Combined Negative Converter and Positive Multiplier

Thermometer Spans 180°C

Using the combined negative and positive multiplier of *Figure 10* with an LM35 it is possible to make a μ Power thermometer that spans a 180°C temperature range. The LM35 temperature sensor has an output sensitivity of 10 mV/°C, while drawing only 50 μ A of quiescent current. In order for the LM35 to measure negative temperatures, a pull down to a negative voltage is required. *Figure 10* shows a thermometer circuit for measuring temperatures from -55°C to +125°C and requiring only two 1.5V cells. End of battery life can be extended by replacing the up converter diodes with Schottky's.

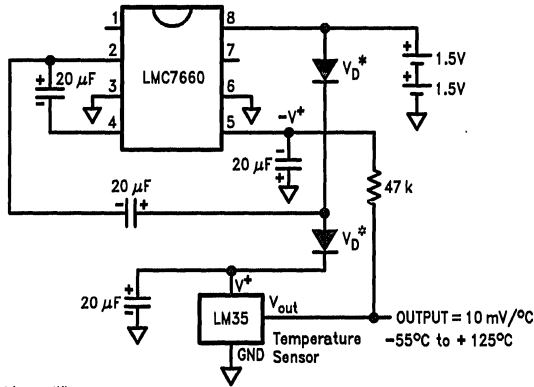
Regulating -Vout

It is possible to regulate the output of the LMC7660 and still maintain μ Power performance. This is done by enclosing

the LMC7660 in a loop with a LP2951. The circuit of *Figure 11* will regulate V_{out} to -5V for $I_L = 10$ mA, and $V_{in} = 6V$. For $V_{in} > 7V$, the output stays in regulation up to $I_L = 25$ mA. The error flag on pin 5 of the LP2951 sets low when the regulated output at pin 4 drops by about 5%. The LP2951 can be shutdown by taking pin 3 high; the LMC7660 can be shutdown by shorting pin 7 and pin 8.

The LP2951 can be reconfigured to an adjustable type regulator, which means the LMC7660 can give a regulated output from -2.0V to -10V dependent on the resistor ratios R1 and R2, as shown in *Figure 12*, $V_{ref} = 1.235V$:

$$V_{out} = V_{ref} \left(1 + \frac{R1}{R2} \right)$$



*For lower voltage operation, use Schottky rectifiers

TL/H/9136-15

FIGURE 10. μ Power Thermometer Spans 180°C, and Pulls Only 150 μ A

Typical Applications (Continued)

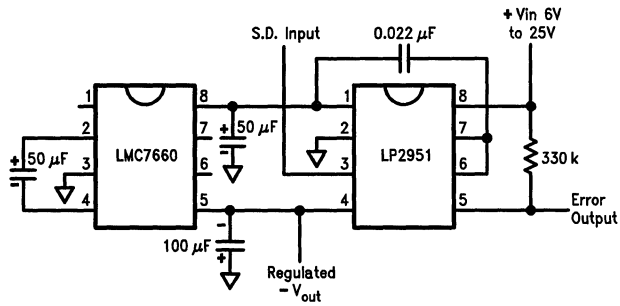
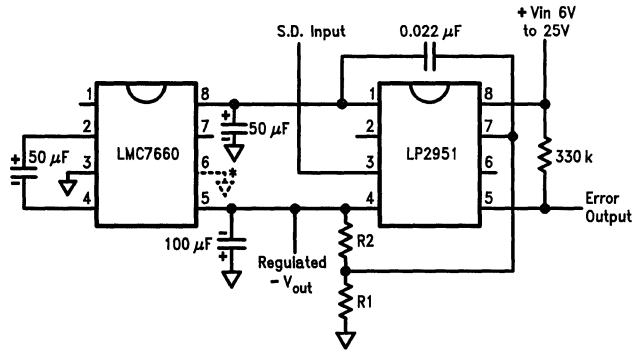


FIGURE 11. Regulated -5V with 200 μA Standby Current

TL/H/9136-16



$$V_{out} = V_{ref} \left(1 + \frac{R1}{R2} \right)$$

$$V_{ref} = 1.235V$$

*Low voltage operation

FIGURE 12. LMC7660 and LP2951 Make a Negative Adjustable Regulator

TL/H/9136-17



Section 4
Motion Control



Section 4 Contents

Motion Control and Motor Drive Selection Guide	4-3
LM12L 80W Operational Amplifier	4-4
LM621 Brushless Motor Commutator	4-17
LM628/LM629 Precision Motion Controllers	4-28
LM18293 Four Channel Push-Pull Driver	4-49
LM18298 Dual Full-Bridge Driver	4-55
LMD18200 3A, 55VH-Bridge	4-61
LMD18201 3A, 55VH-Bridge	4-70

Motion Control and Motor Drive Selection Guide

Motor Drive Circuits—Bridges

Device	Description	Output Current (A)	Max Input Voltage (V)	Operating Temperature (T _J)	Package Availability	Page No.
LM18200	DMOS H-Bridge with Internal Current Sense	3	55	-40°C to +125°C	11-Lead TO-220	4-61
LM18201	DMOS H-Bridge	3	55	-40°C to +125°C	11-Lead TO-220	4-70
LM18293	4-Channel Push-Pull Driver	1/Channel	36	-40°C to +125°C	16-Lead DIP	4-49
LM18298	Dual H-Bridge	2/Bridge	46	-40°C to +150°C	15-Lead TO-220	4-55

Motor Drive Circuits—Linear

Device	Description	Output Current (A)	Max Supply Voltage (V)	Operating Temperature (T _C)	Package Availability	Page No.
LM12	Monolithic Power Op-Amp	±10	±30	-55°C to +125°C	4-Lead TO-3	4-4

Brushless DC Motor Commutator

Device	Features	Operating Temperature (T _A)	Package Availability	Page No.
LM621	Compatible with 3-Phase and 4-Phase Brushless DC Motors, Interfaces Directly to Hall Sensors and PWM Sign and Magnitude Signals, Adjustable Dead Time Generator	-40°C to +85°C	18-Lead DIP	4-17

Precision Motion Control Processor

Device	Features	Operating Temperature (T _A)	Max Clock Speed (MHz)	Package Availability	Page No.
LM628	32-Bit Position, Velocity, and Acceleration Registers; Position and Velocity Modes; 16-Bit PID Filter with Programmable Coefficients; 8- or 12-Bit DAC Output Data; Quadrature Incremental Encoder Interface; 8-Bit Asynchronous Host Interface	-40°C to +85°C	6 or 8	28-Lead DIP	4-28
LM629	Same Features as LM628, but with 8-Bit PWM Sign/Magnitude Output Data	-40°C to +85°C	6 or 8	28-Lead DIP	4-28



LM12 (L) 80W Operational Amplifier

General Description

The LM12 is a power op amp capable of driving $\pm 25V$ at $\pm 10A$ while operating from $\pm 30V$ supplies. The monolithic IC can deliver 80W of sine wave power into a 4Ω load with 0.01% distortion. Power bandwidth is 60 kHz. Further, a peak dissipation capability of 800W allows it to handle reactive loads such as transducers, actuators or small motors without derating. Important features include:

- input protection
- controlled turn on
- thermal limiting
- overvoltage shutdown
- output-current limiting
- dynamic safe-area protection

The IC delivers $\pm 10A$ output current at any output voltage yet is completely protected against overloads, including shorts to the supplies. The dynamic safe-area protection is provided by instantaneous peak-temperature limiting within the power transistor array.

The turn-on characteristics are controlled by keeping the output open-circuited until the total supply voltage reaches 14V. The output is also opened as the case temperature

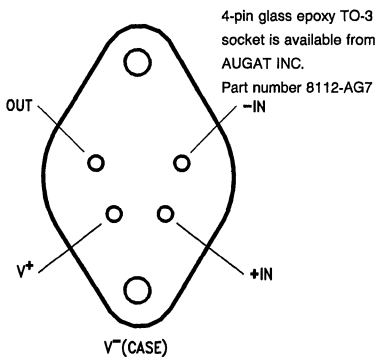
exceeds $150^{\circ}C$ or as the supply voltage approaches the BV_{CEO} of the output transistors. The IC withstands overvoltages to 80V.

This monolithic op amp is compensated for unity-gain feedback, with a small-signal bandwidth of 700 kHz. Slew rate is $9V/\mu s$, even as a follower. Distortion and capacitive-load stability rival that of the best designs using complementary output transistors. Further, the IC withstands large differential input voltages and is well behaved should the common-mode range be exceeded.

The LM12 establishes that monolithic ICs can deliver considerable output power without resorting to complex switching schemes. Devices can be paralleled or bridged for even greater output capability. Applications include operational power supplies, high-voltage regulators, high-quality audio amplifiers, tape-head positioners, x-y plotters or other servo-control systems.

The LM12 is supplied in a four-lead, TO-3 package with V^- on the case. A gold-eutectic die-attach to a molybdenum interface is used to avoid thermal fatigue problems. The LM12 is specified for either military or commercial temperature range.

Connection Diagram

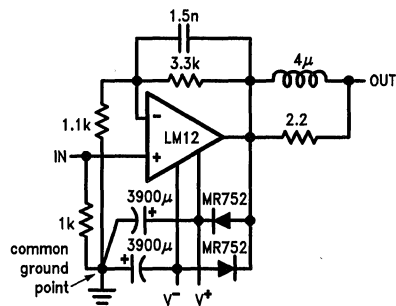


TL/H/8704-1

Bottom View

Order Number LM12LK or LM12CLK
See NS Package Number K04A

Typical Application*



TL/H/8704-2

*Low distortion (0.01%) audio amplifier

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage (Note 1)	80V
Input Voltage	(Note 2)
Output Current	Internally Limited

Junction Temperature	(Note 3)
Storage Temperature Range	-65°C to 150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Operating Ratings

Total Supply Voltage	15V to 60V
----------------------	------------

Electrical Characteristics (Note 4)

Parameter	Conditions	Typ 25°C	LM12L	LM12CL	Units
			Limits	Limits	
Input Offset Voltage	$\pm 10V \leq V_S \leq \pm 0.5 V_{MAX}$, $V_{CM} = 0$	2	7/ 15	15/ 20	mV (max)
Input Bias Current	$V^- + 4V \leq V_{CM} \leq V^+ - 2V$	0.15	0.3/ 1.0	0.7/ 1.0	μ A (max)
Input Offset Current	$V^- + 4V \leq V_{CM} \leq V^+ - 2V$	0.03	0.1/ 0.3	0.2/ 0.3	μ A (max)
Common Mode Rejection	$V^- + 4V \leq V_{CM} \leq V^+ - 2V$	86	75/ 70	70/ 65	dB (min)
Power Supply Rejection	$V^+ = 0.5 V_{MAX}$, $-6V \geq V^- \geq -0.5 V_{MAX}$ $V^- = -0.5 V_{MAX}$, $6V \leq V^+ \leq 0.5 V_{MAX}$	90	75/ 70	70/ 65	dB (min)
		110	80/ 75	75/ 70	dB (min)
Output Saturation Threshold	$t_{ON} = 1$ ms, $\Delta V_{IN} = 5$ (10) mV, $I_{OUT} = 1A$ 8A 10A	1.8	2.2/ 2.5	2.2/ 2.5	V (max)
		4	5/ 7	5/ 7	V (max)
		5	8		V (max)
Large Signal Voltage Gain	$t_{ON} = 2$ ms, $V_{SAT} = 2V$, $I_{OUT} = 0$ $V_{SAT} = 8V$, $R_L = 4\Omega$	100	50/ 30	30/ 20	V/mV (min)
		50	20/ 15	15/ 10	V/mV (min)
Thermal Gradient Feedback	$P_{DISS} = 50W$, $t_{ON} = 65$ ms	30	50	100	μ V/W (max)
Output-Current Limit	$t_{ON} = 10$ ms, $V_{DISS} = 10V$ $t_{ON} = 100$ ms, $V_{DISS} = 58V$	13	16	16	A (max)
		1.5	1.0/ 0.6	0.9/ 0.6	A (min)
		1.5	1.7	1.7	A (max)
Power Dissipation Rating	$t_{ON} = 100$ ms, $V_{DISS} = 20V$ $V_{DISS} = 58V$	100	90/ 40	80/ 55	W (min)
		80	58/ 35	52/ 35	W (min)
DC Thermal Resistance	(Note 5) $V_{DISS} = 20V$ $V_{DISS} = 58V$	2.3	2.6	2.9	°C/W (max)
		2.7	4.0	4.5	°C/W (max)
AC Thermal Resistance	(Note 5)	1.6	1.9	2.1	°C/W (max)
Supply Current	$V_{OUT} = 0$, $I_{OUT} = 0$	60	80/ 90	120/ 140	mA (max)

Note 1: These are non-operating limits (over-voltage shut down); operating limits are as in Note 4. With inductive loads or output shorts, other restrictions described in applications section apply.

Note 2: Neither input should exceed the supply voltage by more than 50 volts nor should the voltage between one input and any other terminal exceed 60 volts.

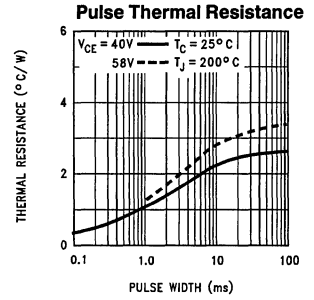
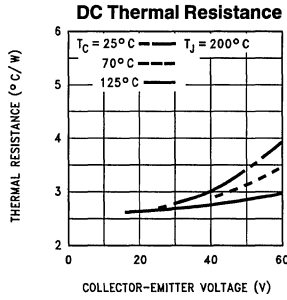
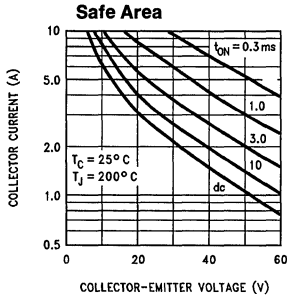
Note 3: Operating junction temperature is internally limited near 225°C within the power transistor and 160°C for the control circuitry.

Note 4: The supply voltage is $\pm 30V$ ($V_{MAX} = 60V$), unless otherwise specified. The voltage across the conducting output transistor (supply to output) is V_{DISS} and internal power dissipation is P_{DISS} . Temperature range is $-55^\circ C \leq T_C \leq 125^\circ C$ for the LM12L and $0^\circ C \leq T_C \leq 70^\circ C$ for LM12CL, where T_C is the case temperature. Standard typeface indicates limits at 25°C while **boldface type refers to limits or special conditions over full temperature range.** With no heat sink, the package will heat at a rate of 35°C/sec per 100W of internal dissipation.

Note 5: This thermal resistance is based upon a peak temperature of 200°C in the center of the power transistor and a case temperature of 25°C measured at the center of the package bottom. The maximum junction temperature of the control circuitry can be estimated based upon a dc thermal resistance of 0.9°C/W or an ac thermal resistance of 0.6°C/W for any operating voltage.

Although the output and supply leads are resistant to electrostatic discharges from handling, the input leads are not. The part should be treated accordingly.

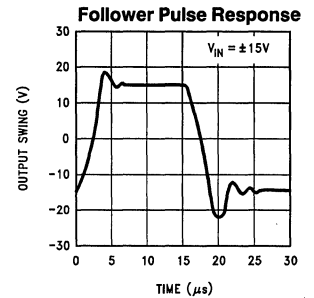
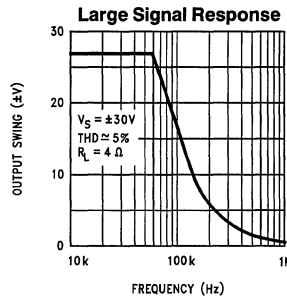
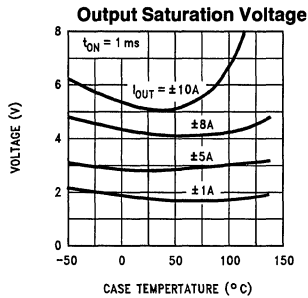
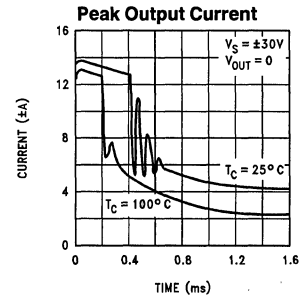
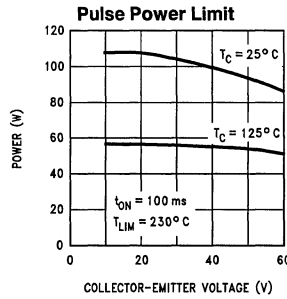
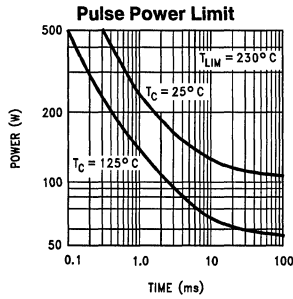
Output-Transistor Ratings (guaranteed)[†]



TL/H/8704-3

[†]LM12L. The power ratings of the LM12CL are 10-percent less at 20V and 15-percent less at 60V, with a corresponding increase in thermal resistance and decrease in safe area current.

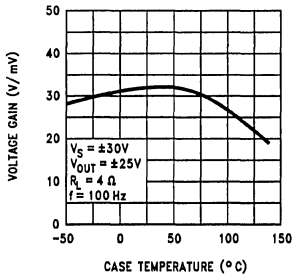
Typical Performance Characteristics



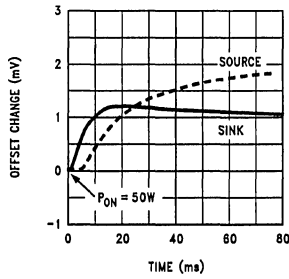
TL/H/8704-4

Typical Performance Characteristics (Continued)

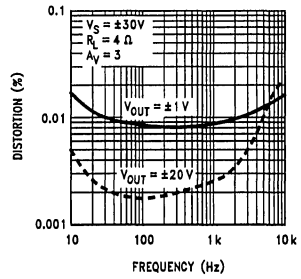
Large Signal Gain



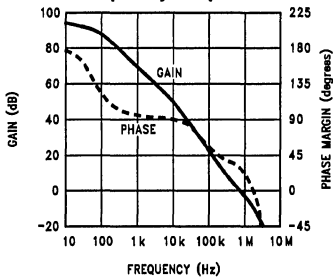
Thermal Response



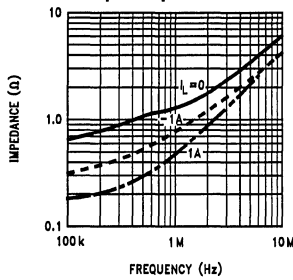
Total Harmonic Distortion



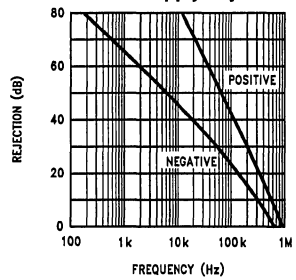
Frequency Response



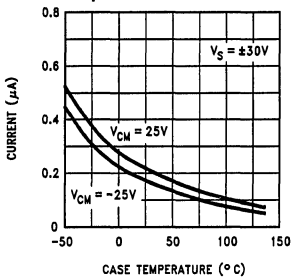
Output Impedance



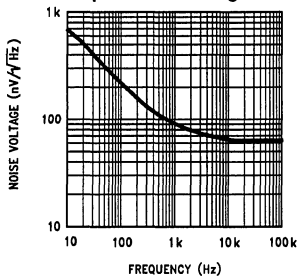
Power Supply Rejection



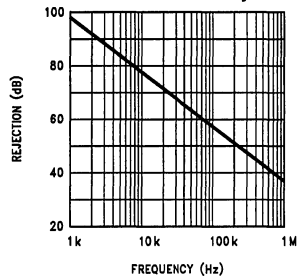
Input Bias Current



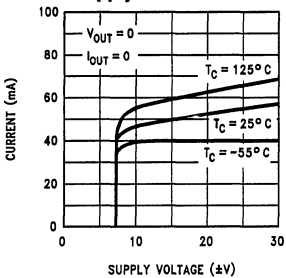
Input Noise Voltage



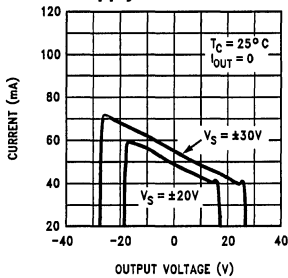
Common Mode Rejection



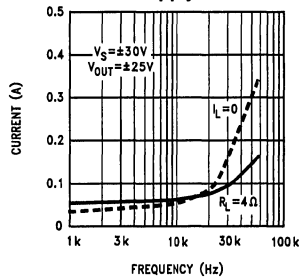
Supply Current



Supply Current



Cross-Supply Current



TL/H/8704-5

Application Information

GENERAL

Twenty five years ago the operational amplifier was a specialized design tool used primarily for analog computation. However, the availability of low cost IC op amps in the late 1960's prompted their use in rather mundane applications, replacing a few discrete components. Once a few basic principles are mastered, op amps can be used to give exceptionally good results in a wide range of applications while minimizing both cost and design effort.

The availability of a monolithic power op amp now promises to extend these advantages to high-power designs. Some conventional applications are given here to illustrate op amp design principles as they relate to power circuitry. The inevitable fall in prices, as the economies of volume production are realized, will prompt their use in applications that might now seem trivial. Replacing single power transistors with an op amp will become economical because of improved performance, simplification of attendant circuitry, vastly improved fault protection, greater reliability and the reduction of design time.

Power op amps introduce new factors into the design equation. With current transients above 10A, both the inductance and resistance of wire interconnects become important in a number of ways. Further, power ratings are a crucial factor in determining performance. But the power capability of the IC cannot be realized unless it is properly mounted to an adequate heat sink. Thus, thermal design is of major importance with power op amps.

This application summary starts off by identifying the origin of strange problems observed while using the LM12 in a wide variety of designs with all sorts of fault conditions. A few simple precautions will eliminate these problems. **One would do well to read the section on supply bypassing, lead inductance, output clamp diodes, ground loops and reactive loading before doing any experimentation. Should there be problems with erratic operation, blow-outs, excessive distortion or oscillation, another look at these sections is in order.**

The management and protection circuitry can also affect operation. Should the total supply voltage exceed ratings or drop below 15–20V, the op amp shuts off completely. Case temperatures above 150°C also cause shut down until the temperature drops to 145°C. This may take several seconds, depending on the thermal system. Activation of the dynamic safe-area protection causes both the main feedback loop to lose control and a reduction in output power, with possible oscillations. In ac applications, the dynamic protection will cause waveform distortion. Since the LM12 is well protected against thermal overloads, the suggestions for determining power dissipation and heat sink requirements are presented last.

SUPPLY BYPASSING

All op amps should have their supply leads bypassed with low-inductance capacitors having short leads and located close to the package terminals to avoid spurious oscillation problems. Power op amps require larger bypass capacitors. The LM12 is stable with good-quality electrolytic bypass capacitors greater than 20 μ F. Other considerations may require larger capacitors.

The current in the supply leads is a rectified component of the load current. If adequate bypassing is not provided, this distorted signal can be fed back into internal circuitry. Low distortion at high frequencies requires that the supplies be bypassed with 470 μ F or more, at the package terminals.

LEAD INDUCTANCE

With ordinary op amps, lead-inductance problems are usually restricted to supply bypassing. Power op amps are also sensitive to inductance in the output lead, particularly with heavy capacitive loading. Feedback to the input should be taken directly from the output terminal, minimizing common inductance with the load. Sensing to a remote load must be accompanied by a high-frequency feedback path directly from the output terminal. Lead inductance can also cause voltage surges on the supplies. With long leads to the power source, energy stored in the lead inductance when the output is shorted can be dumped back into the supply bypass capacitors when the short is removed. The magnitude of this transient is reduced by increasing the size of the bypass capacitor near the IC. With 20 μ F local bypass, these voltage surges are important only if the lead length exceeds a couple feet ($> 1 \mu$ H lead inductance). Twisting together the supply and ground leads minimizes the effect.

GROUND LOOPS

With fast, high-current circuitry, all sorts of problems can arise from improper grounding. In general, difficulties can be avoided by returning all grounds separately to a common point. Sometimes this is impractical. When compromising, special attention should be paid to the ground returns for the supply bypasses, load and input signal. Ground planes also help to provide proper grounding.

Many problems unrelated to system performance can be traced to the grounding of line-operated test equipment used for system checkout. Hidden paths are particularly difficult to sort out when several pieces of test equipment are used but can be minimized by using current probes or the new isolated oscilloscope pre-amplifiers. Eliminating any direct ground connection between the signal generator and the oscilloscope synchronization input solves one common problem.

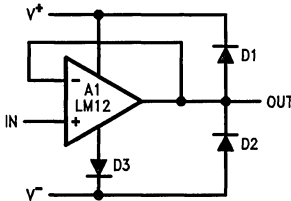
OUTPUT CLAMP DIODES

When a push-pull amplifier goes into power limit while driving an inductive load, the stored energy in the load inductance can drive the output outside the supplies. Although the LM12 has internal clamp diodes that can handle several amperes for a few milliseconds, extreme conditions can cause destruction of the IC. The internal clamp diodes are imperfect in that about half the clamp current flows into the supply to which the output is clamped while the other half flows across the supplies. Therefore, the use of external diodes to clamp the output to the power supplies is strongly recommended. This is particularly important with higher supply voltages.

Experience has demonstrated that hard-wire shorting the output to the supplies can induce random failures if these external clamp diodes are not used and the supply voltages are above ± 20 V. Therefore it is prudent to use output-

Application Information (Continued)

clamp diodes even when the load is not particularly inductive. This also applies to experimental setups in that blow-outs have been observed when diodes were not used. In packaged equipment, it may be possible to eliminate these diodes, providing that fault conditions can be controlled.



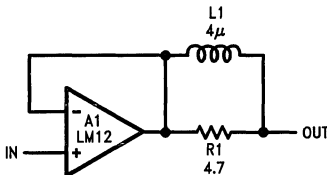
TL/H/8704-6

Heat sinking of the clamp diodes is usually unimportant in that they only clamp current transients. Forward drop with 15A fault transients is of greater concern. Usually, these transients die out rapidly. The clamp to the negative supply can have somewhat reduced effectiveness under worst case conditions should the forward drop exceed 1.0V. Mounting this diode to the power op amp heat sink improves the situation. Although the need has only been demonstrated with some motor loads, including a third diode (D3 above) will eliminate any concern about the clamp diodes. This diode, however, must be capable of dissipating continuous power as determined by the negative supply current of the op amp.

REACTIVE LOADING

The LM12 is normally stable with resistive, inductive or smaller capacitive loads. Larger capacitive loads interact with the open-loop output resistance (about 1Ω) to reduce the phase margin of the feedback loop, ultimately causing oscillation. The critical capacitance depends upon the feedback applied around the amplifier; a unity-gain follower can handle about $0.01\mu\text{F}$, while more than $1\mu\text{F}$ does not cause problems if the loop gain is ten. With loop gains greater than unity, a speedup capacitor across the feedback resistor will aid stability. In all cases, the op amp will behave predictably only if the supplies are properly bypassed, ground loops are controlled and high-frequency feedback is derived directly from the output terminal, as recommended earlier.

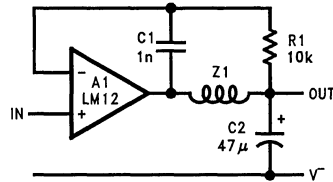
So-called capacitive loads are not always capacitive. A high-Q capacitor in combination with long leads can present a series-resonant load to the op amp. In practice, this is not usually a problem; but the situation should be kept in mind.



TL/H/8704-7

Large capacitive loads (including series-resonant) can be accommodated by isolating the feedback amplifier from the load as shown above. The inductor gives low output impedance at lower frequencies while providing an isolating impedance at high frequencies. The resistor kills the Q of series resonant circuits formed by capacitive loads. A low inductance, carbon-composition resistor is recommended. Optimum values of L and R depend upon the feedback gain

and expected nature of the load, but are not critical. A $4\mu\text{H}$ inductor is obtained with 14 turns of number 18 wire, close spaced, around a one-inch-diameter form.



TL/H/8704-8

The LM12 can be made stable for all loads with a large capacitor on the output, as shown above. This compensation gives the lowest possible closed-loop output impedance at high frequencies and the best load-transient response. It is appropriate for such applications as voltage regulators.

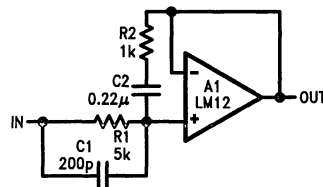
A feedback capacitor, C_1 , is connected directly to the output pin of the IC. The output capacitor, C_2 , is connected at the output terminal with short leads. Single-point grounding to avoid dc and ac ground loops is advised.

The impedance, Z_1 , is the wire connecting the op amp output to the load capacitor. About 3-inches of number-18 wire (70 nH) gives good stability and 18-inches (400 nH) begins to degrade load-transient response. The minimum load capacitance is $47\mu\text{F}$, if a solid-tantalum capacitor with an equivalent series resistance (ESR) of 0.1Ω is used. Electrolytic capacitors work as well, although capacitance may have to be increased to $200\mu\text{F}$ to bring ESR below 0.1Ω .

Loop stability is not the only concern when op amps are operated with reactive loads. With time-varying signals, power dissipation can also increase markedly. This is particularly true with the combination of capacitive loads and high-frequency excitation.

INPUT COMPENSATION

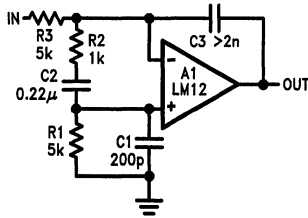
The LM12 is prone to low-amplitude oscillation bursts coming out of saturation if the high-frequency loop gain is near unity. The voltage follower connection is most susceptible. This glitching can be eliminated at the expense of small-signal bandwidth using input compensation. Input compensation can also be used in combination with LR load isolation to improve capacitive load stability.



TL/H/8704-9

An example of a voltage follower with input compensation is shown here. The R_2C_2 combination across the input works with R_1 to reduce feedback at high frequencies without greatly affecting response below 100 kHz. A lead capacitor, C_1 , improves phase margin at the unity-gain crossover frequency. Proper operation requires that the output impedance of the circuitry driving the follower be well under $1\text{ k}\Omega$ at frequencies up to a few hundred kilohertz.

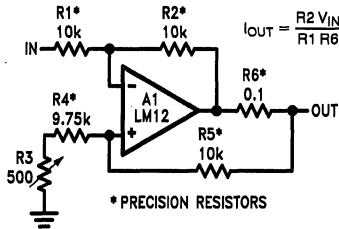
Application Information (Continued)



TL/H/8704-10

Extending input compensation to the integrator connection is shown here. Both the follower and this integrator will handle 1 μ F capacitive loading without LR output isolation.

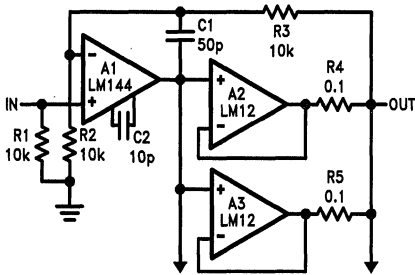
CURRENT DRIVE



TL/H/8704-11

This circuit provides an output current proportional to the input voltage. Current drive is sometimes preferred for servo motors because it aids in stabilizing the servo loop by reducing phase lag caused by motor inductance. In applications requiring high output resistance, such as operational power supplies running in the current mode, matching of the feedback resistors to 0.01% is required. Alternately, an adjustable resistor can be used for trimming.

PARALLEL OPERATION

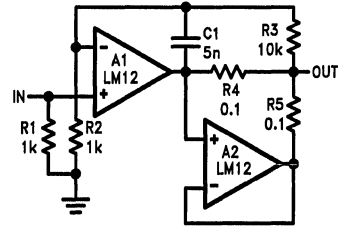


TL/H/8704-12

Output drive beyond the capability of one power amplifier can be provided as shown here. The power op amps are wired as followers and connected in parallel with the outputs coupled through equalization resistors. A standard, high-voltage op amp is used to provide voltage gain. Overall feedback compensates for the voltage dropped across the equalization resistors.

With parallel operation, there may be an increase in unloaded supply current related to the offset voltage across the

equalization resistors. More output buffers, with individual equalization resistors, may be added to meet even higher drive requirements.

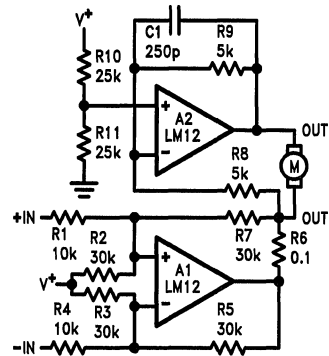


TL/H/8704-13

This connection allows increased output capability without requiring a separate control amplifier. The output buffer, A₂, provides load current through R₅ equal to that supplied by the main amplifier, A₁, through R₄. Again, more output buffers can be added.

Current sharing among paralleled amplifiers can be affected by gain error as the power-bandwidth limit is approached. In the first circuit, the operating current increase will depend upon the matching of high-frequency characteristics. In the second circuit, however, the entire input error of A₂ appears across R₄ and R₅. The supply current increase can cause power limiting to be activated as the slew limit is approached. This will not damage the LM12. It can be avoided in both cases by connecting A₁ as an inverting amplifier and restricting bandwidth with C₁.

SINGLE-SUPPLY OPERATION



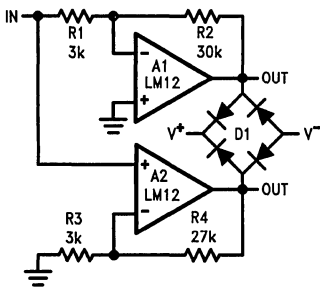
TL/H/8704-14

Although op amps are usually operated from dual supplies, single-supply operation is practical. This bridge amplifier supplies bi-directional current drive to a servo motor while operating from a single positive supply. The output is easily converted to voltage drive by shorting R₆ and connecting R₇ to the output of A₂, rather than A₁.

Either input may be grounded, with bi-directional drive provided to the other. It is also possible to connect one input to a positive reference, with the input signal varying about this voltage. If the reference voltage is above 5V, R₂ and R₃ are not required.

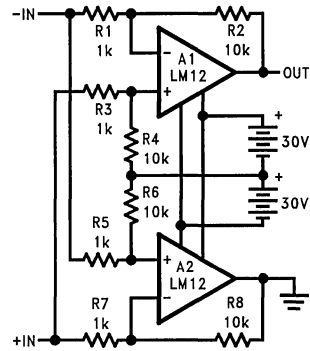
Application Information (Continued)

HIGH VOLTAGE AMPLIFIERS



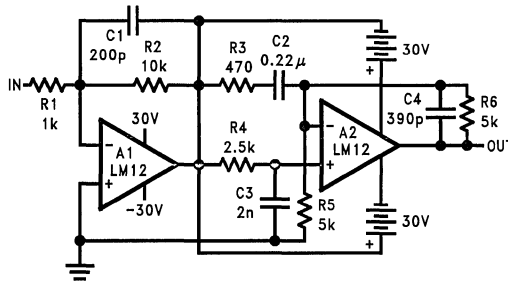
TL/H/8704-15

The voltage swing delivered to the load can be doubled by using the bridge connection shown here. Output clamping to the supplies can be provided by using a bridge-rectifier assembly.



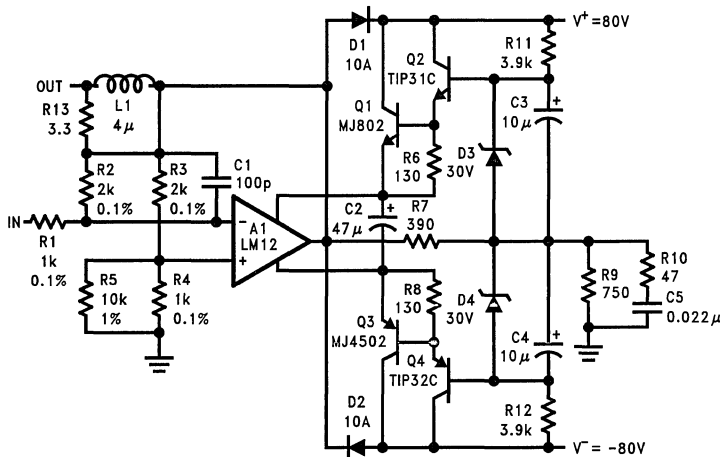
TL/H/8704-16

One limitation of the standard bridge connection is that the load cannot be returned to ground. This can be circumvented by operating the bridge with floating supplies, as shown above. For single-ended drive, either input can be grounded.



TL/H/8704-17

This circuit shows how two amplifiers can be cascaded to double output swing. The advantage over the bridge is that the output can be increased with any number of stages, although separate supplies are required for each.

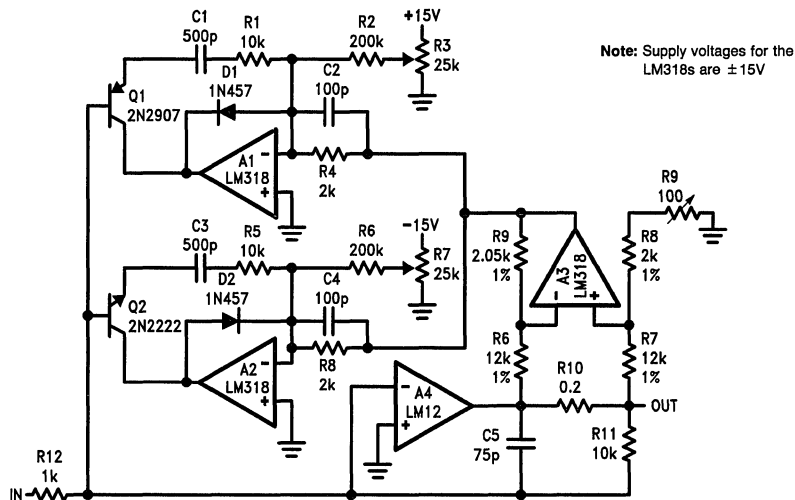


TL/H/8704-18

Discrete transistors can be used to increase output drive to $\pm 70\text{V}$ at $\pm 10\text{A}$ as shown above. With proper thermal design, the IC will provide safe-area protection for the external transistors. Voltage gain is about thirty.

Application Information (Continued)

OPERATIONAL POWER SUPPLY

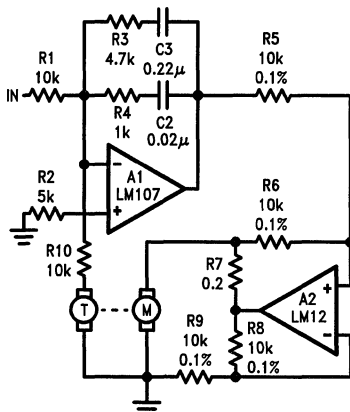


TL/H/8704-19

External current limit can be provided for a power op amp as shown above. The positive and negative current limits can be set precisely and independently. Fast response is assured by D_1 and D_2 . Adjustment range can be set down to zero with potentiometers R_3 and R_7 . Alternately, the limit can be programmed from a voltage supplied to R_2 and R_6 . This is the set up required for an operational power supply or voltage-programmable power source.

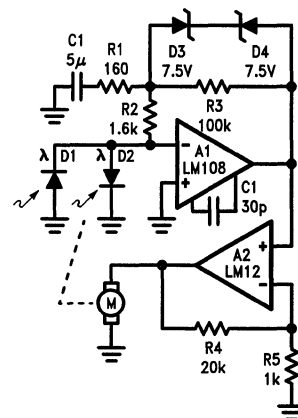
SERVO AMPLIFIERS

When making servo systems with a power op amp, there is a temptation to use it for frequency shaping to stabilize the servo loop. Sometimes this works; other times there are better ways; and occasionally it just doesn't fly. Usually it's a matter of how quickly and to what accuracy the servo must stabilize.



TL/H/8704-20

This motor/tachometer servo gives an output speed proportional to input voltage. A low-level op amp is used for frequency shaping while the power op amp provides current drive to the motor. Current drive eliminates loop phase shift due to motor inductance and makes high-performance servos easier to stabilize.

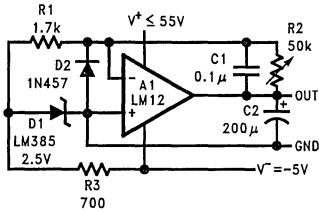


TL/H/8704-21

This position servo uses an op amp to develop the rate signal electrically instead of using a tachometer. In high-performance servos, rate signals must be developed with large error signals well beyond saturation of the motor drive. Using a separate op amp with a feedback clamp allows the rate signal to be developed properly with position errors more than an order of magnitude beyond the loop-saturation level as long as the photodiode sensors are positioned with this in mind.

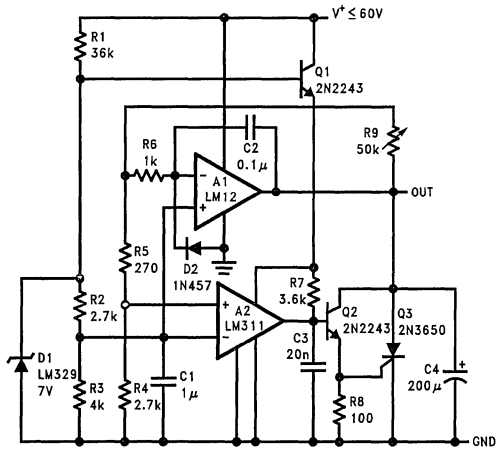
Application Information (Continued)

VOLTAGE REGULATORS



TL/H/8704-22

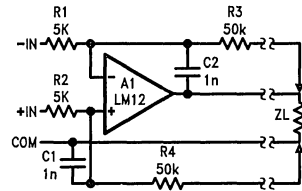
An op amp can be used as a positive or negative regulator. Unlike most regulators, it can sink current to absorb energy dumped back into the output. This positive regulator has a 0–50V output range.



TL/H/8704-23

Dual supplies are not required to use an op amp as a voltage regulator if zero output is not required. This 4V to 50V regulator operates from a single supply. Should the op amp not be able to absorb enough energy to control an overvoltage condition, a SCR will crowbar the output.

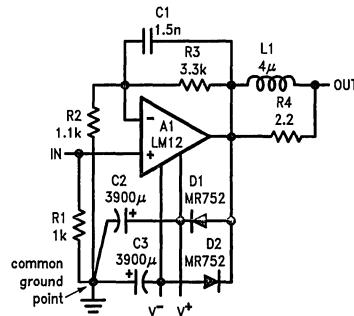
REMOTE SENSING



TL/H/8704-24

Remote sensing as shown above allows the op amp to correct for dc drops in cables connecting the load. Even so, cable drop will affect transient response. Degradation can be minimized by using twisted, heavy-gauge wires on the output line. Normally, common and one input are connected together at the sending end.

AUDIO AMPLIFIERS



TL/H/8704-25

A power amplifier suitable for use in high-quality audio equipment is shown above. Harmonic distortion is about 0.01-percent. Intermodulation distortion (60 Hz/7 kHz, 4:1) measured 0.015-percent. Transient response and saturation recovery are clean, and the 9 V/ μ s slew rate of the LM12 virtually eliminates transient intermodulation distortion. Using separate amplifiers to drive low- and high-frequency speakers gets rid of high-level crossover networks and attenuators. Further, it prevents clipping on the low-frequency channel from distorting the high frequencies.

Application Information (Continued)

DETERMINING MAXIMUM DISSIPATION

It is a simple matter to establish power requirements for an op amp driving a resistive load at frequencies well below 10 Hz. Maximum dissipation occurs when the output is at one-half the supply voltage with high-line conditions. The individual output transistors must be rated to handle this power continuously at the maximum expected case temperature. The power rating is limited by the maximum junction temperature as determined by

$$T_J = T_C + P_{DISS} \theta_{JC}$$

where T_C is the case temperature as measured at the center of the package bottom, P_{DISS} is the maximum power dissipation and θ_{JC} is the thermal resistance at the operating voltage of the output transistor. Recommended maximum junction temperatures are 200°C within the power transistor and 150°C for the control circuitry.

If there is ripple on the supply bus, it is valid to use the average value in worst-case calculations as long as the peak rating of the power transistor is not exceeded at the ripple peak. With 120 Hz ripple, this is 1.5 times the continuous power rating.

Dissipation requirements are not so easily established with time varying output signals, especially with reactive loads. Both peak and continuous dissipation ratings must be taken into account, and these depend on the signal waveform as well as load characteristics.

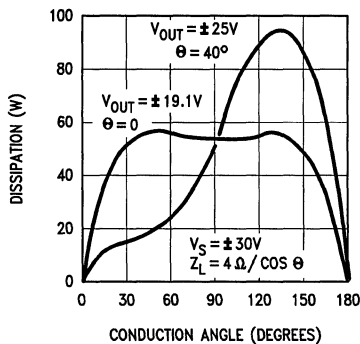
With a sine wave output, analysis is fairly straightforward. With supply voltages of $\pm V_S$, the maximum average power dissipation of both output transistors is

$$P_{MAX} = \frac{2V_S^2}{\pi^2 Z_L \cos \theta}, \quad \theta < 40^\circ;$$

and

$$P_{MAX} = \frac{V_S^2}{2Z_L} \left[\frac{4}{L\pi} - \cos \theta \right], \quad \theta \geq 40^\circ,$$

where Z_L is the magnitude of the load impedance and θ its phase angle. Maximum average dissipation occurs below maximum output swing for $\theta < 40^\circ$.



TL/H/8704-26

The instantaneous power dissipation over the conducting half cycle of one output transistor is shown here. Power dissipation is near zero on the other half cycle. The output level is that resulting in maximum peak and average dissipation. Plots are given for a resistive and a series RL load. The latter is representative of a 4Ω loudspeaker operating below resonance and would be the worst case condition in most

audio applications. The peak dissipation of each transistor is about four times average. In ac applications, power capability is often limited by the peak ratings of the power transistor.

The pulse thermal resistance of the LM12 is specified for constant power pulse duration. Establishing an exact equivalency between constant-power pulses and those encountered in practice is not easy. However, for sine waves, reasonable estimates can be made at any frequency by assuming a constant power pulse amplitude given by:

$$P_{PK} \approx \frac{V_S^2}{2Z_L} \left[1 - \cos(\phi - \theta) \right],$$

where $\phi = 60^\circ$ and θ is the absolute value of the phase angle of Z_L . Equivalent pulse width is $t_{ON} \approx 0.4\tau$ for $\theta = 0$ and $t_{ON} \approx 0.2\tau$ for $\theta \geq 20^\circ$, where τ is the period of the output waveform.

DISSIPATION DRIVING MOTORS

A motor with a locked rotor looks like an inductance in series with a resistance, for purposes of determining driver dissipation. With slow-response servos, the maximum signal amplitude at frequencies where motor inductance is significant can be so small that motor inductance does not have to be taken into account. If this is the case, the motor can be treated as a simple, resistive load as long as the rotor speed is low enough that the back emf is small by comparison to the supply voltage of the driver transistor.

A permanent-magnet motor can build up a back emf that is equal to the output swing of the op amp driving it. Reversing this motor from full speed requires the output drive transistor to operate, initially, along a loadline based upon the motor resistance and total supply voltage. Worst case, this loadline will have to be within the continuous dissipation rating of the drive transistor; but system dynamics may permit taking advantage of the higher pulse ratings. Motor inductance can cause added stress if system response is fast.

Shunt- and series-wound motors can generate back emf's that are considerably more than the total supply voltage, resulting in even higher peak dissipation than a permanent-magnet motor having the same locked-rotor resistance.

VOLTAGE REGULATOR DISSIPATION

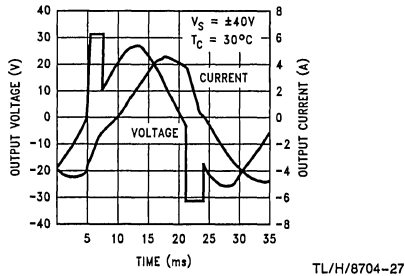
The pass transistor dissipation of a voltage regulator is easily determined in the operating mode. Maximum continuous dissipation occurs with high line voltage and maximum load current. As discussed earlier, ripple voltage can be averaged if peak ratings are not exceeded; however, a higher average voltage will be required to insure that the pass transistor does not saturate at the ripple minimum.

Conditions during start-up can be more complex. If the input voltage increases slowly such that the regulator does not go into current limit charging output capacitance, there are no problems. If not, load capacitance and load characteristics must be taken into account. This is also the case if automatic restart is required in recovering from overloads.

Automatic restart or start-up with fast-rising input voltages cannot be guaranteed unless the continuous dissipation rating of the pass transistor is adequate to supply the load current continuously at all voltages below the regulated output voltage. In this regard, the LM12 performs much better than IC regulators using foldback current limit, especially with high-line input voltage above 20V.

Application Information (Continued)

POWER LIMITING



Should the power ratings of the LM12 be exceeded, dynamic safe-area protection is activated. Waveforms with this power limiting are shown for the LM12 driving $\pm 26V$ at 30 Hz into 3Ω in series with 24 mH ($\theta = 45^\circ$). With an inductive load, the output clamps to the supplies in power limit, as above. With resistive loads, the output voltage drops in limit. Behavior with more complex RCL loads is between these extremes.

Secondary thermal limit is activated should the case temperature exceed $150^\circ C$. This thermal limit shuts down the IC completely (open output) until the case temperature drops to about $145^\circ C$. Recovery may take several seconds.

POWER SUPPLIES

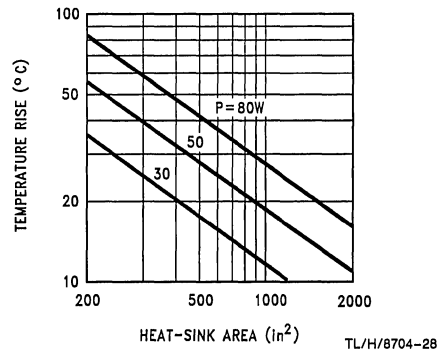
Power op amps do not require regulated supplies. However, the worst-case output power is determined by the low-line supply voltage in the ripple trough. The worst-case power dissipation is established by the average supply voltage with high-line conditions. The loss in power output that can be guaranteed is the square of the ratio of these two voltages. Relatively simple off-line switching power supplies can provide voltage conversion, line isolation and 5-percent regulation while reducing size and weight.

The regulation against ripple and line variations can provide a substantial increase in the power output that can be guaranteed under worst-case conditions. In addition, switching power supplies can convert low-voltage power sources such as automotive batteries up to regulated, dual, high-voltage supplies optimized for powering power op amps.

HEAT SINKING

A semiconductor manufacturer has no control over heat sink design. Temperature rating can only be based upon case temperature as measured at the center of the package bottom. With power pulses of longer duration than 100 ms,

case temperature is almost entirely dependent on heat sink design and the mounting of the IC to the heat sink.



The design of heat sink is beyond the scope of this work. Convection-cooled heat sinks are available commercially, and their manufacturers should be consulted for ratings. The preceding figure is a rough guide for temperature rise as a function of fin area (both sides) available for convection cooling.

Proper mounting of the IC is required to minimize the thermal drop between the package and the heat sink. The heat sink must also have enough metal under the package to conduct heat from the center of the package bottom to the fins without excessive temperature drop.

A thermal grease such as Wakefield type 120 or Thermalloy Thermacote should be used when mounting the package to the heat sink. Without this compound, thermal resistance will be no better than $0.5^\circ C/W$, and probably much worse. With the compound, thermal resistance will be $0.2^\circ C/W$ or less, assuming under 0.005 inch combined flatness runout for the package and heat sink. Proper torquing of the mounting bolts is important. Four to six inch-pounds is recommended.

Should it be necessary to isolate V^- from the heat sink, an insulating washer is required. Hard washers like beryllium oxide, anodized aluminum and mica require the use of thermal compound on both faces. Two-mil mica washers are most common, giving about $0.4^\circ C/W$ interface resistance with the compound. Silicone-rubber washers are also available. A $0.5^\circ C/W$ thermal resistance is claimed without thermal compound. Experience has shown that these rubber washers deteriorate and must be replaced should the IC be dismounted.

"Isostrate" insulating pads for four-lead TO-3 packages are available from Power Devices, Inc. Thermal grease is not required, and the insulators should not be reused.

Definition of Terms

Input offset voltage: The absolute value of the voltage between the input terminals with the output voltage and current at zero.

Input bias current: The absolute value of the average of the two input currents with the output voltage and current at zero.

Input offset current: The absolute value of the difference in the two input currents with the output voltage and current at zero.

Common-mode rejection: The ratio of the input voltage range to the change in offset voltage between the extremes.

Supply-voltage rejection: The ratio of the specified supply-voltage change to the change in offset voltage between the extremes.

Output saturation threshold: The output swing limit for a specified input drive beyond that required for zero output. It is measured with respect to the supply to which the output is swinging.

Large signal voltage gain: The ratio of the output voltage swing to the differential input voltage required to drive the output from zero to either swing limit. The output swing limit is the supply voltage less a specified quasi-saturation voltage. A pulse of short enough duration to minimize thermal effects is used as a measurement signal.

Thermal gradient feedback: The input offset voltage change caused by thermal gradients generated by heating of the output transistors, but not the package. This effect is delayed by several milliseconds and results in increased gain error below 100 Hz.

Output-current limit: The output current with a fixed output voltage and a large input overdrive. The limiting current drops with time once the protection circuitry is activated.

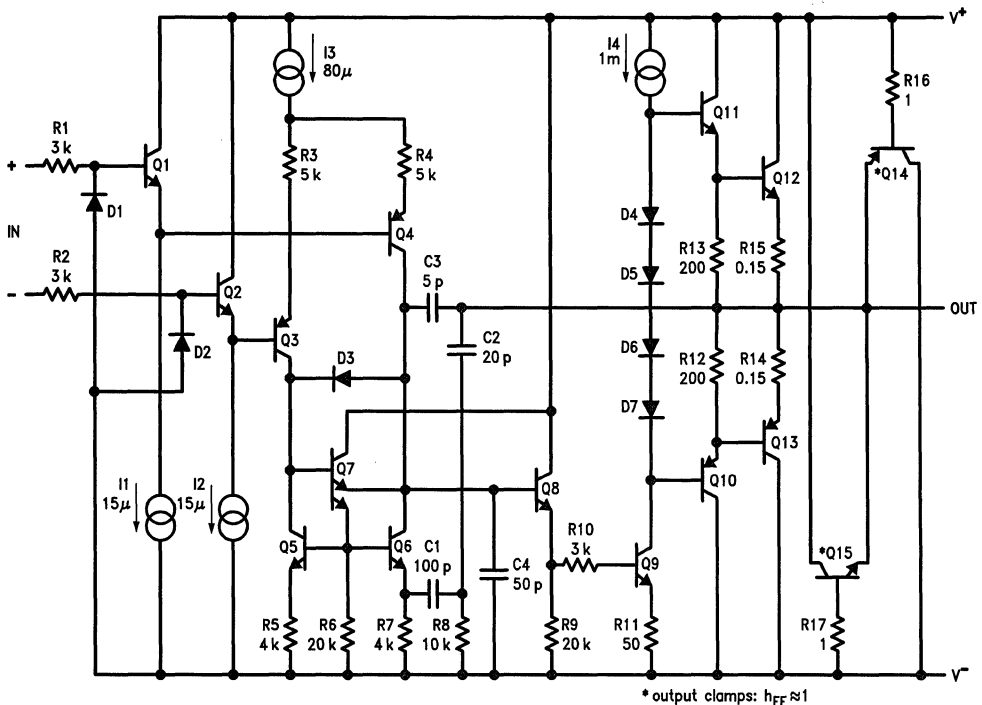
Power dissipation rating: The power that can be dissipated for a specified time interval without activating the protection circuitry. For time intervals in excess of 100 ms, dissipation capability is determined by heat sinking of the IC package rather than by the IC itself.

Thermal resistance: The peak, junction-temperature rise, per unit of internal power dissipation, above the case temperature as measured at the center of the package bottom.

The dc thermal resistance applies when one output transistor is operating continuously. The ac thermal resistance applies with the output transistors conducting alternately at a high enough frequency that the peak capability of neither transistor is exceeded.

Supply current: The current required from the power source to operate the amplifier with the output voltage and current at zero.

Equivalent Schematic (excluding active protection circuitry)



TL/H/8704-29

LM621 Brushless Motor Commutator

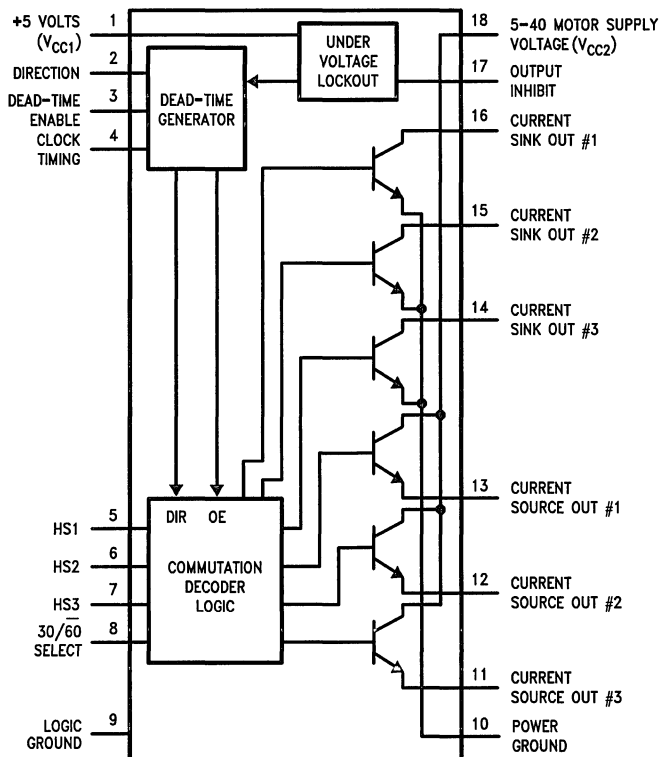
General Description

The LM621 is a bipolar IC designed for commutation of brushless DC motors. The part is compatible with both three- and four-phase motors. It can directly drive the power switching devices used to drive the motor. The LM621 provides an adjustable dead-time circuit to eliminate "shoot-through" current spiking in the power switching circuitry. Operation is from a 5V supply, but output swings of up to 40V are accommodated. The part is packaged in an 18-pin, dual-in-line package.

Features

- Adjustable dead-time feature eliminates current spiking
- On-chip clock oscillator for dead-time feature
- Outputs drive bipolar power devices (up to 35 mA base current) or MOSFET power devices
- Compatible with three- and four-phase motors . . .
 - Bipolar drive to delta- or Y-wound motors
 - Unipolar drive to center-tapped Y-wound motors
 - Supports 30- and 60-degree shaft position sensor placements for three-phase motors
 - Supports 90-degree sensor placement for four-phase motors
- Directly interfaces to pulse-width modulator output(s) via OUTPUT INHIBIT (PWM magnitude) and DIRECTION (PWM sign) inputs
- Direct interface to Hall sensors
- Outputs are current limited
- Undervoltage lockout

Connection Diagram



Order Number LM621N
 See NS Package Number N18A

TL/H/8679-1

Absolute Maximum Ratings (See Notes)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

V _{CC1}	+7V
V _{CC2}	+45V
Logic Inputs (Note 1)	V _{CC1} + 0.5V, -0.5V
Logic Input Clamp Current	20 mA
Output Voltages	+45V, -0.5V
Output Currents	Internally current limited

Operating Ambient Temperature Range LM621	-40°C to +85°C
Storage Temperature Range	-65°C to +150°C
Junction Temperature	150°C
ESD Susceptibility (Note 10)	2000V
Lead Temperature, N pkg. (Soldering, 4 sec.)	260°C

Electrical Characteristics (See Notes)

Parameter	Conditions	Typ	Tested Limits	Design Limits	Units
DECODER SECTION					
High Level Input Voltage HS1, HS2, HS3: 30/ $\overline{60}$ SELECT:			2.0 2.0	2.0 2.0	V min V min
High Level Input Current HS1, HS2, HS3: 30/ $\overline{60}$ SELECT:	V _{IH} = V _{CC1} V _{IH} = V _{CC1}		100 120	200 240	μ A max μ A max
Low Level Input Voltage HS1, HS3 and HS2 HS1, HS3 and HS2 30/ $\overline{60}$ Select	30/ $\overline{60}$ = 5V 30/ $\overline{60}$ = 0V H _{S1} = H _{S3} = 5V		0.6 0.6 0.6	0.4 0.4 0.4	V max V max V _{max}
Low Level Input Current HS1 and HS3: HS2: 30/ $\overline{60}$ SELECT	V _{IL} = 0.35V V _{IL} = 0.4V V _{IL} = 0.0V		-400 -100 -700	-600 -200 -1000	μ A max μ A max μ A max
Input Clamp Voltage (Pins 2, 3, 5, 6, 7, 8, 17)	I _{in} = 1 mA I _{in} = -1 mA	(V _{CC1} + 0.7) (-0.6)			V V
Output Leakage Current Sinking Outputs Sourcing Outputs	Outputs Off V _{CC2} = 40V, V _{OUT} = 40V V _{OUT} = 0V	0.2 -0.2		1.0 -1.0	μ A μ A
Short-Circuit Current Sinking Outputs Sourcing Outputs	V _{CC2} = 10V, V _{OUT} = 10V V _{OUT} = 0V	50 -50	35 -35		mA min mA min
V _{sat} (sinking) V _{drop} (sourcing) = (V _{CC2} - V _{OUT})	I = 20 mA I = -20 mA	0.83 1.7		1.00 2.00	V max V max
Output Rise Time	(sourcing) C _L < 10 pF	50			ns
Output Fall Time	(sinking) C _L ≤ 10 pF	50			ns
Propagation Delay (Hall Input to Output)	Dead-Time Off	200			ns

Electrical Characteristics (See Notes) (Continued)

Parameter	Conditions	Typ	Tested Limits	Design Limits	Units
DEAD-TIME SECTION					
High Level Input Voltage DIRECTION: OUTPUT INHIBIT: DEAD-TIME ENABLE:	Pin 3 = 0V Pin 17 = 0V		2.0 2.0 2.0	2.0 2.0 2.0	V min V min V min
High Level Input Current DIRECTION: OUTPUT INHIBIT: DEAD-TIME ENABLE:	$V_{in} = 5V$ Pin 3 = 0V		100 60 200	150 100 300	μA max μA max μA max
Low Level Input Voltage DIRECTION: OUTPUT INHIBIT: DEAD-TIME ENABLE:	Pin 3 = 0V		0.6 0.6 0.3	0.4 0.4 0.2	V max V max V max
Low Level Input Current DIRECTION: OUTPUT INHIBIT: DEAD-TIME ENABLE:	$V_{in} = 0.6V$ $V_{in} = 0.6V$ $V_{in} = 0V$		-100 -60 -200	- 150 - 100 - 300	μA max μA max μA max
Propagation Delays (Inputs to Outputs) OUTPUT INHIBIT DIRECTION	Dead-Time Off, (Pin 3 = 0V)	200 200			ns ns
Minimum Clock Period, T_{CLK} (Notes 3, 11)	$R = 11\text{ k}\Omega$, $R_1 = 1\text{ k}$ $C = 200\text{ pF}$	1.8			μs
Clock Accuracy $f = 100\text{ kHz}$ (Note 11)	$R = 30\text{ k}$, $R_1 = 1\text{ k}$ $C = 420\text{ pF}$	± 3			%
Minimum Dead-Time Minimum Dead-Time	Dead-Time Off Dead-Time On	15 2			ns T_{CLK}
COMPLETE CIRCUIT					
Total Current Drains I_{CC1} I_{CC1} I_{CC2} I_{CC2}	Outputs Off $V_{CC2} = 40V$	15 3	10 22 2 6	30 9	mA min mA max mA min mA max
Undervoltage Lockout V_{CC1}		3.6	3.0		V_{MAX}

Note 1. Unless otherwise noted ambient temperature (T_A) = 25°C.

Note 2. Unless otherwise noted: $V_{CC1} = +5.0V$, "recommended operating range $V_{CC} = 4.5V$ to $5.5V$ " $V_{CC2} = +10.0V$, ambient temperature = 25°C.

Note 3. The clock period is typically $T_{CLK} = (0.756 \times 10^{-3}) (R + 1) C$, where T_{CLK} is in μs , R is in $\text{k}\Omega$, and C is pF . Also see selection graph in Typical Characteristics for determining values of R and C . Note that the value of R should be no less than 11 $\text{k}\Omega$ and C no less than 200 pF .

Note 4. Tested limits are guaranteed and 100% production tested.

Note 5. Design limits are guaranteed (but not 100% production tested) at the indicated temperature and supply voltages. These limits are not used to calculate outgoing quality levels.

Note 6. Specifications in **boldface** apply over junction temperature range of -40°C to $+85^\circ\text{C}$.

Note 7. Typical Thermal Resistances θ_{JA} (see Note 8):

N pkg, board mounted	110°C/W
N pkg, socketed	118°C/W

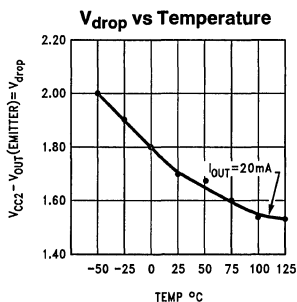
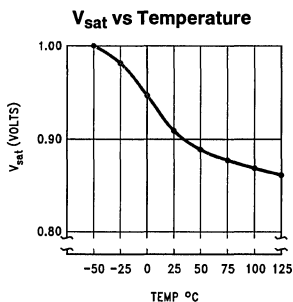
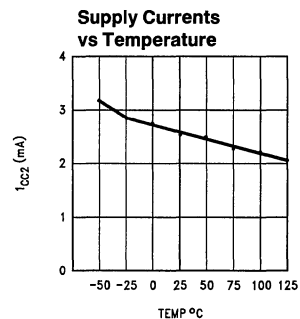
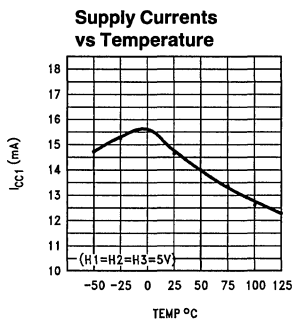
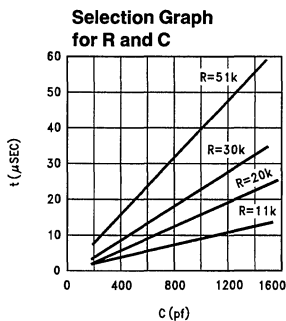
Note 8. Package thermal resistance indicates the ability of the package to dissipate heat generated on the die. Given ambient temperature and power dissipation, the thermal resistance parameter can be used to determine the approximate operating junction temperature. Operating junction temperature directly effects product performance and reliability.

Note 9. This part specifically does not have thermal shutdown protection to avoid safety problems related to an unintentional restart due to thermal time constant variations. Care should be taken to prevent excessive power dissipation on the die.

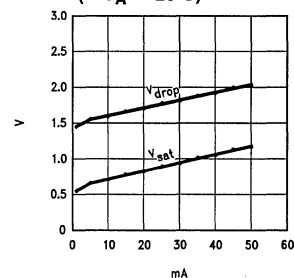
Note 10: Human body model, 100 pF , discharged through a 1500 Ω resistor.

Note 11: $R_1 = 0$ for $C \geq 620\text{ pF}$.

Typical Performance Characteristics



Typ. V_{sat} vs I_{out} sink
Typ. V_{drop} vs I_{out} source
(@ $T_A = 25^{\circ}$ C)



TL/H/8679-2

Description of Inputs and Outputs

Pin 1: V_{CC1} (+5V). The logic and clock power supply pin.

Pin 2: DIRECTION. This input determines the direction of rotation of the motor; ie., clockwise vs. counterclockwise. See truth table.

Pin 3: DEAD-TIME ENABLE. This input enables or disables the dead-time feature. Connecting +5V to pin 3 enables dead-time, and grounding pin 3 disables it. Pin 3 should not be allowed to float.

Pin 4: CLOCK TIMING. An RC network connected between this pin and ground sets the period of the clock oscillator, which determines the amount of dead-time. See Figure 2 and text.

Pins 5 thru 7: HS1, HS2, and HS3 (Hall-sensor inputs). These inputs receive the rotor-position sensor inputs from the motor. Three-phase motors provide all three signals; four phase motors provide only two, one of which is connected to both HS2 and HS3.

Pin 8: 30/60 SELECT. This input is used to select the required decoding for three-phase motors; ie, either "30-degree" (+5V) or "60-degree" (ground). Connect pin 8 to +5V when using a four-phase motor.

Pin 9: LOGIC GROUND. Ground for the logic power supply.

Pin 10: POWER GROUND. Ground for the output buffer supply.

Pins 11 thru 13: SOURCE OUTPUTS. The three current-sourcing outputs which drive the external power devices that drive the motor.

Pins 14 thru 16: SINK OUTPUTS. The three current-sinking outputs which drive the external power devices that drive the motor.

Pin 17: OUTPUT INHIBIT. This input disables the LM621 outputs. It is typically driven by the magnitude signal from an external sign/magnitude PWM generator. Pin 17 = +5V = outputs off.

Pin 18: V_{CC2} (+5 to +40V). This is the supply for the collectors of the three current-sourcing outputs (pins 11 thru 13). When driving MOSFET power devices, pin 18 may be connected to a voltage source of up to +40V to achieve sufficient output swing for the gate. When driving bipolar power devices, pin 18 should be connected to +5V to minimize on-chip power dissipation. Undervoltage lockout automatically shuts down all outputs if the V_{CC1} supply is too low. All outputs will be off if V_{CC1} falls below the undervoltage lockout voltage.

Functional Description

The commutation decoder receives Hall-sensor inputs HS1, HS2, and HS3 and a 30/60 SELECT input. This block decodes the gray-code sequence to the required motor-drive sequence.

The dead-time generator monitors the DIRECTION input and inhibits the outputs (pins 11 thru 16) for a time sufficient to prevent current-spiking in the external power switches when the direction is reversed.

The six chip outputs drive external power switching devices which drive the motor. Three outputs source current; the remaining three sink current. The output transistors provide up to 50 mA outputs for driving devices, or up to 40V output swings for driving MOSFETs. The LM621 logic is powered from 5V.

The undervoltage lockout section monitors the V_{CC} supply and if the voltage is not sufficient to permit reliable logic operation, the outputs are shutdown.

Three-Phase Motor Commutation

There are two popular conventions for establishing the relative phasing of rotor-position signals for three-phase motors. While usually referred to as 30-degree and 60-degree sensor placements, this terminology refers to mechanical degrees of sensor placement, not electrical degrees. The electrical angular resolution is the required 60 degrees in both cases. The phasing differences can be noted by comparing the sequences of HS1 through HS3 entries in Table I,

LM621 Commutation Decoder Truth Table, which shows both the 30- and 60-degree phasings (and the 90-degree phasing for four-phase motors) and their required decoder logic truth tables, respectively. Table I shows the phasing (or codes) of the Hall-effect sensors for each 60-degree (electrical) position range of the rotor, and correlates these data to the commutator sink and source outputs required to drive the power switches. These phasings are common to several motor manufacturers. The 60-degree phasing is preferred to 30-degree phasing because the all-zeros and all-ones codes are not generated. The 60-degree phasing is more failsafe because the all-zeros and all-ones codes could be inadvertently generated by things like disconnected or shorted sensors.

Because the above terminology is not used consistently among all motor manufacturers, Table II, Alternative Sensor-phasing Names, will hopefully clarify some of the differences. Table II shows a different 60-degree phasing, and 120-, 240-, and 300-degree phasings. Comparison with Table I will show that these four phasings are essentially shifted and/or reversed-order versions of those used with the LM621.

Figure 1 shows the waveforms associated with the commutation decoder logic for a motor which has 60-degree rotor-position phasing, along with the generated motor-drive waveforms. As can be seen in the drawing, Hall-effect sensor signals HS1 through HS3 are separated by 60 electrical degrees, which is the required angular resolution for three-phase motors.

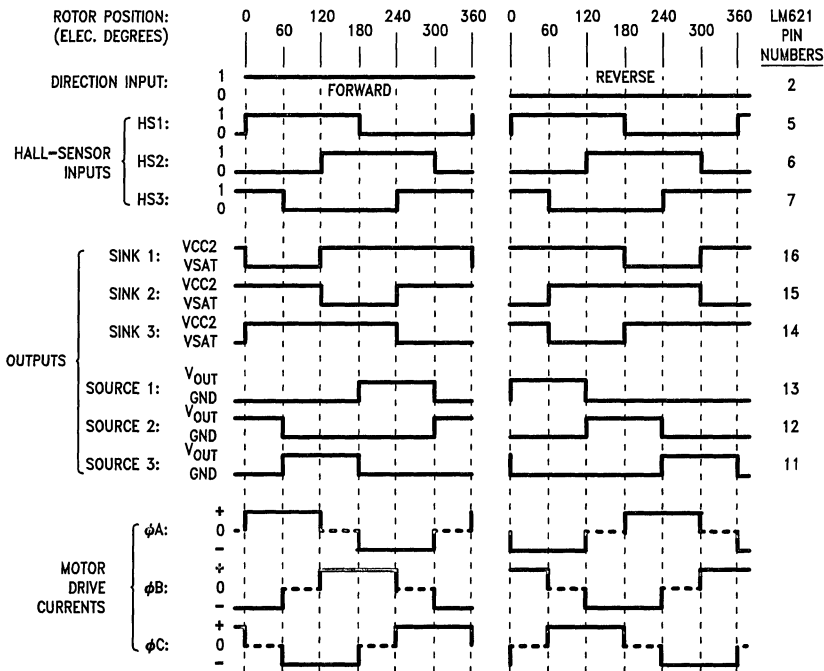


FIGURE 1. Commutation Waveforms for 60-degree Phasing

TL/H/8679-6

Three-Phase Motor Commutation (Continued)

TABLE I. LM621 Commutation Decoder Truth Table

Sensor Phasing	Position Range	Sensor Inputs			Sink Outputs			Source Outputs		
		HS1	HS2	HS3	1	2	3	1	2	3
30 deg	0–60	0	0	0	ON	off	off	off	ON	off
	60–120	0	0	1	ON	off	off	off	off	ON
	120–180	0	1	1	off	ON	off	off	off	ON
	180–240	1	1	1	off	ON	off	ON	off	off
	240–300	1	1	0	off	off	ON	ON	off	off
	300–360	1	0	0	off	off	ON	off	ON	off
60 deg	0–60	1	0	1	ON	off	off	off	ON	off
	60–120	1	0	0	ON	off	off	off	off	ON
	120–180	1	1	0	off	ON	off	off	off	ON
	180–240	0	1	0	off	ON	off	ON	off	off
	240–300	0	1	1	off	off	ON	ON	off	off
	300–360	0	0	1	off	off	ON	off	ON	off
90 deg	0–90	0	1	HS2	off	na	off	off	na	ON
	90–180	0	0	HS2	ON	na	off	off	na	off
	180–270	1	0	HS2	off	na	ON	off	na	off
	270–360	1	1	HS2	off	na	off	ON	na	off
Pin Numbers:		5	6	7	16	15	14	13	12	11

Note 1: The above outputs are generated when the Direction input, pin 2, is logic high. For reverse rotation (pin 2 logic low), the above sink and source output states become exchanged.

Note 2: For four-phase motors sink and source outputs number two (pins 15 and 12) are not used; hence the "na" (not applicable) in the appropriate columns above. *Figure 6* shows how the required sink and source outputs for four-phase motors are derived.

TABLE II. Alternative Sensor-Phasing Names

Alternate Phasing	Position Range	Sensor Inputs			Corresponding LM621 Position Range and/or Comments
		HS1	HS2	HS3	
"60 deg"	0–60	0	0	0	Same as 30-degree phasing, but in reverse order; i.e., only change is relative direction.
	60–120	1	0	0	
	120–180	1	1	0	
	180–240	1	1	1	
	240–300	0	1	1	
	300–360	0	0	1	
"120 deg"	0–60	0	0	1	Same as 60-degree phasing, but with shifted order of position ranges; i.e., only change is relative phasing of sensor signals.
	60–120	1	0	1	
	120–180	1	0	0	
	180–240	1	1	0	
	240–300	0	1	0	
	300–360	0	1	1	
"240 deg"	0–60	0	1	0	Same comment as above for "120 deg" phasing.
	60–120	1	1	0	
	120–180	1	0	0	
	180–240	1	0	1	
	240–300	0	0	1	
	300–360	0	1	1	
"300 deg"	0–60	0	1	1	Same as 30-degree phasing, but with shifted order of position ranges, i.e., only change is relative phasing of sensor signals.
	60–120	1	1	1	
	120–180	1	1	0	
	180–240	1	0	0	
	240–300	0	0	0	
	300–360	0	0	1	

Four-Phase Motor Commutation

Four-phase motors use a 90-degree (quadrature) rotor-position sensor phasing. This phasing scheme is also shown in Table I. LM621 Commutation Decoder Truth Table. As shown in Table I, the 90-degree phasing has only two rotor-

position-sensor signals, HS1 and HS2. When using the LM621 to run a four-phase motor the HS2 signal is connected to both the HS2 and HS3 chip inputs.

Dead-Time Feature

The DEAD-TIME ENABLE input is used to enable this feature (by connecting +5V to pin 3). The reason for providing this feature is that the external power switches are usually totem-pole structures. Since these structures switch heavy currents, if either totem-pole device is not completely turned off when its complementary device turns on, heavy "shoot-through" current spiking will occur. This situation occurs when the motor DIRECTION input changes (when all output drive polarities reverse), at which time device turn-off delay can cause the undesired current spiking.

Figure 2 shows the logic of the dead-time generator. The dead-time generator includes an RC oscillator to generate a required clock. Pin 4 (CLOCK TIMING) is used to connect an external RC network to set the frequency of this oscillator. The clock frequency should be adjusted so that two periods of oscillation just slightly exceed the worst-case turn-off time of the power switching devices. As shown by

the graph in Typical Performance Characteristics, the time of one clock period (in μs) is approximately $(0.756 \times 10^{-3}) (R + 1) C$, where R is in $k\Omega$ and C is in pF; the period can be measured with an oscilloscope at pin 4. The dead-time generator function monitors the DIRECTION input for changes, synchronizes the direction changes with the internal clock, and inhibits the chip outputs for two clock periods.

Flip-flops FF1 through FF3 form a three-bit, shift-register delay line, the input of which is the DIRECTION input. The flip-flops are the only elements clocked by the internal clock generator. The shift register outputs must all have the same state in order to enable gate G1 or G2, one of which must be enabled to enable the chip outputs. As soon as a direction change input is sensed at the output of FF1, gates G1 and G2 will be disabled, thereby disabling the drive to the power switches for a time equal to two clock periods.

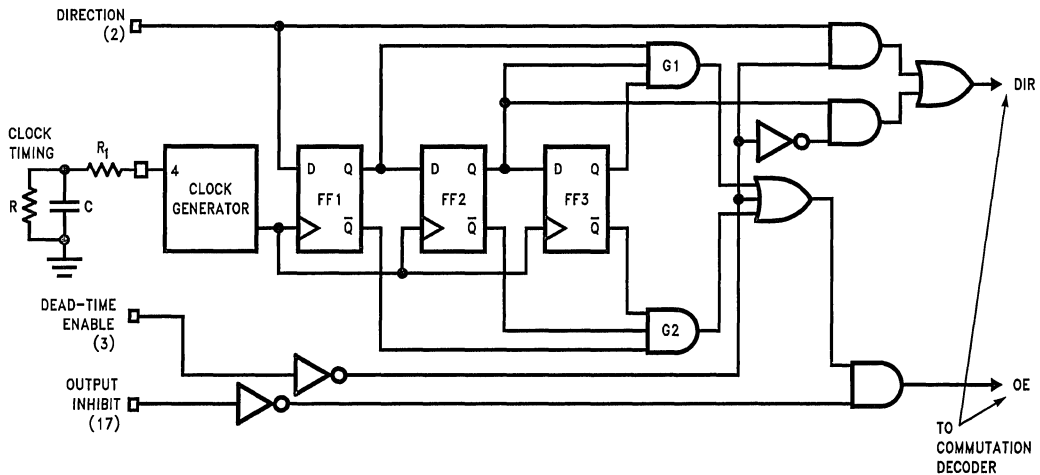


FIGURE 2. Dead-Time Generator Logic Diagram

TL/H/8679-7

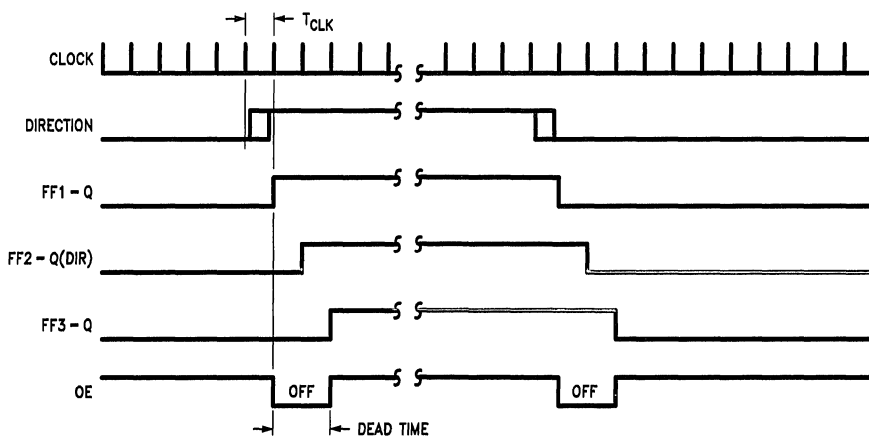


FIGURE 3. Dead-Time Generator Waveforms

TL/H/8679-8

Dead-Time Feature (Continued)

Dead-time is defined as the time the outputs are blanked off (to prevent shoot-through currents) after a direction change input. See *Figure 3*. It can be seen that the dead-time is two clock periods. Since the dead-time scheme introduces delay into the system feedback control loop, which could impact system performance or stability, it is important that the dead-time be kept to a minimum. From *Figure 3* it can be seen that the time between a direction change signal and the initiation of output blanking can vary up to one clock period due to asynchronous nature of the clock and the direction signal.

Typical Applications

THREE-PHASE EXAMPLES

Figure 4 is a typical LM621 application. This circuitry is for use with a three-phase motor having 30-degree sensor phasing, as indicated by connection of the 30/60 SELECT input, pin 8, to a logic "1" (+5V). The same connection of the DEAD-TIME ENABLE input, pin 3, enables this feature. Typical power switches and a simple implementation of an

overcurrent sensing circuit are also detailed in *Figure 4*. This application example assumes a device turn-off time of about $4.8 \mu\text{s}$ maximum, as evidenced by the choice of R and C. See Typical Performance Characteristics. The choice of RC should be made such that two periods are at least equal to the maximum device turn-off time.

The choice of the value for R_{LIMIT} (the resistors which couple the LM621 outputs to the power switches) depends on the input current requirements of the power switching devices. These resistors should be chosen to provide only the amount of current needed by the device inputs, up to 50 mA (typical). The resistors minimize the dissipation incurred by the LM621. Although *Figure 4* shows the 5–40V supply (pin 18) connected to the motor supply voltage, this was done only to emphasize the ability of the part to provide up to 40V output swings. For the bipolar power switches shown, connecting pin 18 to a 5V supply would reduce on-chip power dissipation. Driving FET power switches, however, may require connecting pin 18 to a higher voltage. *Figure 5* is the three-phase application built with MOSFET power-switching components. Note that since the output V_{drop} (sourcing) is at least 1.5V, V_{CC2} can be chosen to avoid overdriving the MOSFET gates.

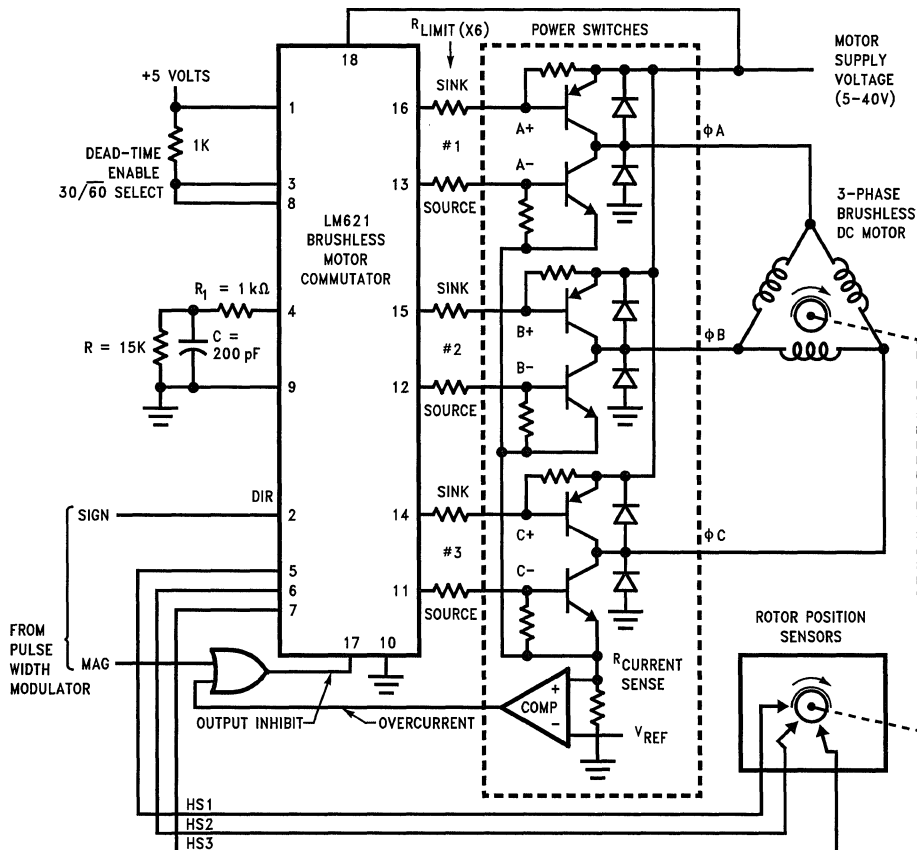


FIGURE 4. Commutation of Three-Phase Motor (Bipolar Switches)

TL/H/8879-9

Typical Applications (Continued)

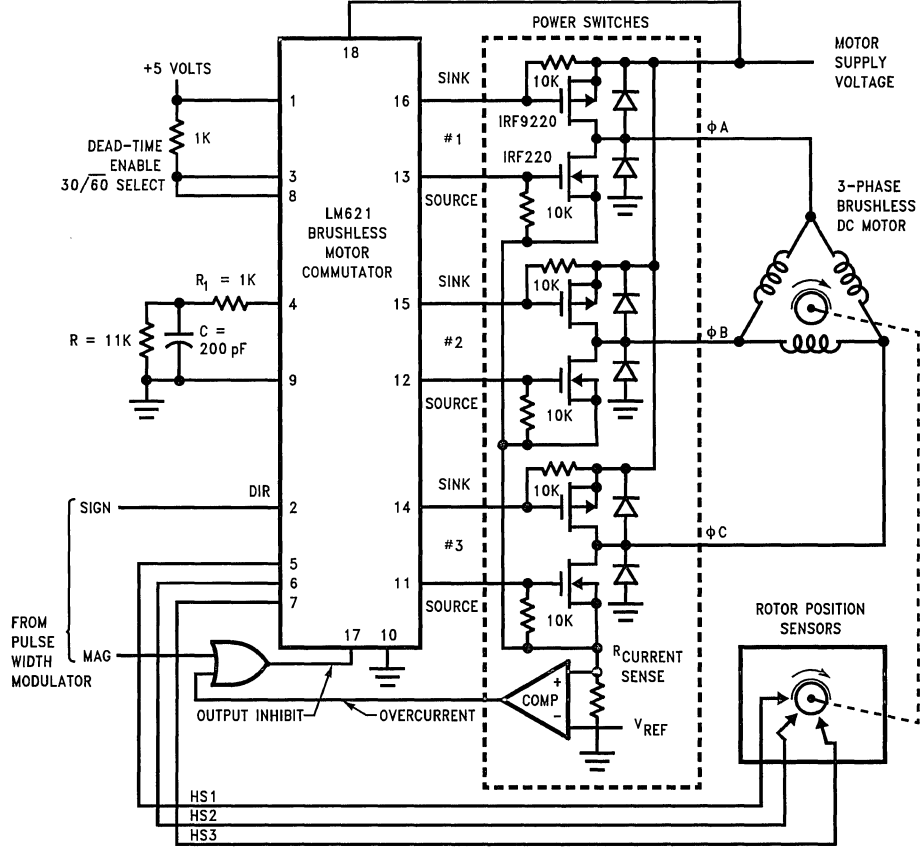


FIGURE 5. Commutation of Three-Phase Motor (MOSFET Switches)

TL/H/6679-10

Typical Applications (Continued)

FOUR-PHASE EXAMPLE

Figure 6 is typical of the circuitry used to commutate a four-phase motor using the LM621. This application is seen to differ from the three-phase application example in that the LM621 outputs are utilized differently. Four-phase motors require four-phase power switches, which in turn require the commutator to provide four current-sinking outputs and four current sourcing outputs. The 18-pin package of the LM621 facilitates only three sinking and three sourcing outputs. The schematic shows the 30/60 SELECT input in the 30-degree select state (pin 8 high) and rotor-position sensor inputs HS2 and HS3 connected together. This connection truncates the number of possible rotor-position input states to four, which is consistent with the 90-degree quadrature rotor-position signals provided by four-phase motors. With the LM621 outputs connected as shown, this approach provides the needed power-switch drive signals for a four-phase motor. Note that only four of the six LM621 outputs

(SINK #1 and #3, and SOURCE #1 and #3) are used directly, and that these are also inverted to form the remaining four. SINK #2 and SOURCE #2 outputs are not used.

HALF-WAVE DRIVE EXAMPLE

The previous applications examples involved delta-configured motor windings and full-wave operation of the motor. The application shown in Figure 7 differs in that it features half-wave operation of a motor with the windings in a Y-configuration. This approach is suitable for automotive and other applications where only low-voltage power supplies are conveniently available. The advantage of this power-switching scheme is that there is only one switch-voltage drop in series with the motor winding, thereby conserving more of the available voltage for application to the motor winding. Half-wave operation provides only unidirectional current to the windings; in contrast to the bidirectional currents applied by the previous full-wave examples.

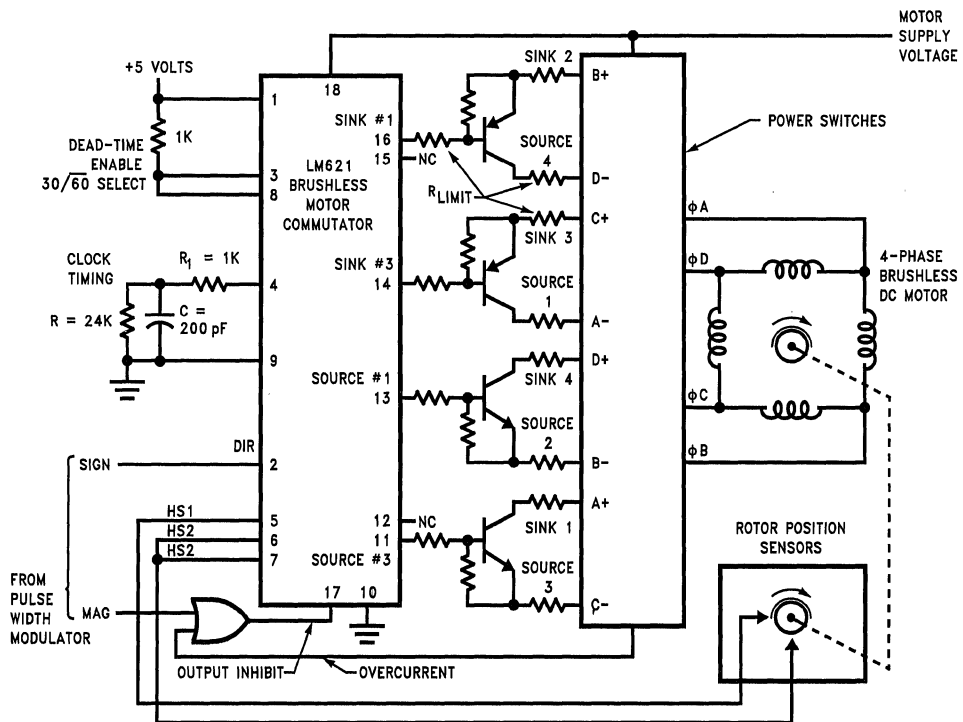


FIGURE 6. Commutation of Four-Phase Motor

TL/H/8679-11

Typical Applications (Continued)

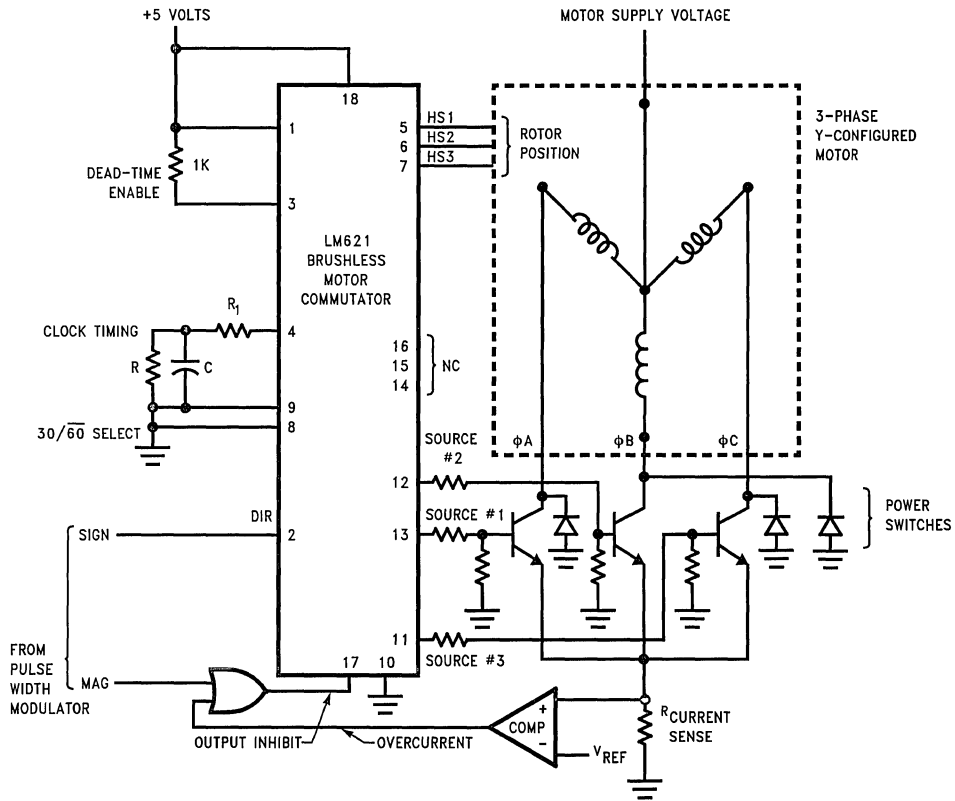


FIGURE 7. Half-Wave Drive of Y-Configured Motor

TL/H/8679-12



LM628/LM629 Precision Motion Controller

General Description

The LM628/LM629 are dedicated motion-control processors designed for use with a variety of DC and brushless DC servo motors, and other servomechanisms which provide a quadrature incremental position feedback signal. The parts perform the intensive, real-time computational tasks required for high performance digital motion control. The host control software interface is facilitated by a high-level command set. The LM628 has an 8-bit output which can drive either an 8-bit or a 12-bit DAC. The components required to build a servo system are reduced to the DC motor/actuator, an incremental encoder, a DAC, a power amplifier, and the LM628. An LM629-based system is similar, except that it provides an 8-bit PWM output for directly driving H-switches. The parts are fabricated in NMOS and packaged in a 28-pin dual in-line package, and are offered in both 6 MHz and 8 MHz maximum frequency versions. The suffixes -6 and -8, respectively, are used to designate version. They incorporate an SDA core processor and cells designed by SDA.

Features

- 32-bit position, velocity, and acceleration registers
- Programmable digital PID filter with 16-bit coefficients
- Programmable derivative sampling interval
- 8- or 12-bit DAC output data (LM628)
- 8-bit sign-magnitude PWM output data (LM629)
- Internal trapezoidal velocity profile generator
- Velocity, target position, and filter parameters may be changed during motion
- Position and velocity modes of operation
- Real-time programmable host interrupts
- 8-bit parallel asynchronous host interface
- Quadrature incremental encoder interface with index pulse input

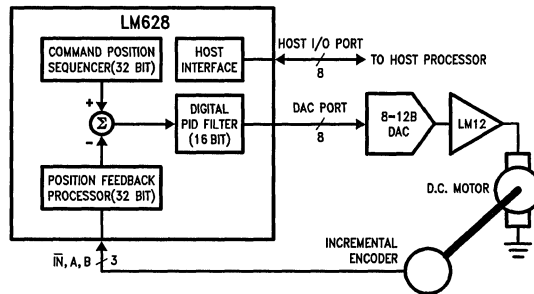
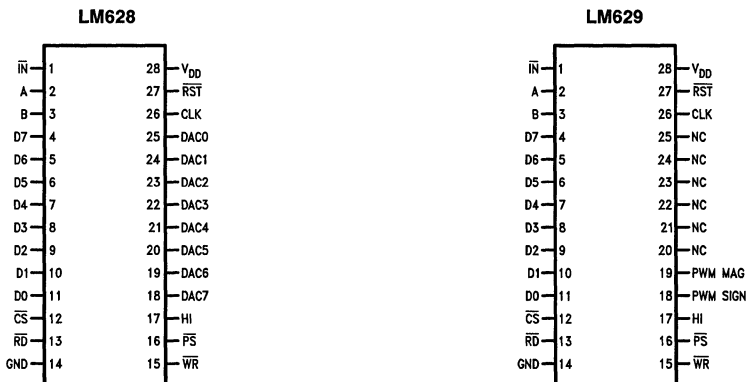


FIGURE 1. Typical System Block Diagram

TL/H/9219-1

Connection Diagrams



TL/H/9219-2

TL/H/9219-3

Order Number LM628N-6, LM628N-8, LM629N-6 or LM629N-8
See NS Package Number N28B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Voltage at Any Pin with Respect to GND (Pin 14)	-0.3V to +7.0V
Ambient Storage Temperature	-65°C to +150°C
Lead Temperature (Soldering, 4 sec.)	260°C
Maximum Power Dissipation	550 mW
ESD Tolerance (C _{ZAP} = 120 pF, R _{ZAP} = 1.5k)	2000V

Operating Ratings

Temperature Range	-40°C < T _A < +85°C
Clock Frequency:	
LM628N-6, LM629N-6	1.0 MHz < f _{CLK} < 6.0 MHz
LM628N-8, LM629N-8	1.0 MHz < f _{CLK} < 8.0 MHz
V _{DD} Range	4.5V < V _{DD} < 5.5V

DC Electrical Characteristics (V_{DD} and T_A per Operating Ratings; f_{CLK} = 6 MHz)

Symbol	Parameter	Conditions	Tested Limits		Units
			Min	Max	
I _{DD}	Supply Current	Outputs Open		100	mA

INPUT VOLTAGES

V _{IH}	Logic 1 Input Voltage		2.0		V
V _{IL}	Logic 0 Input Voltage			0.8	V
I _{IN}	Input Currents	0 ≤ V _{IN} ≤ V _{DD}	-10	10	μA

OUTPUT VOLTAGES

V _{OH}	Logic 1	I _{OH} = -1.6 mA	2.4		V
V _{OL}	Logic 0	I _{OL} = 1.6 mA		0.4	V
I _{OUT}	TRI-STATE® Output Leakage Current	0 ≤ V _{OUT} ≤ V _{DD}	-10	10	μA

AC Electrical Characteristics

(V_{DD} and T_A per Operating Ratings; f_{CLK} = 6 MHz; C_{LOAD} = 50 pF; Input Test Signal t_r = t_f = 10 ns)

Timing Interval	T#	Tested Limits		Units
		Min	Max	

ENCODER AND INDEX TIMING (See Figure 2)

Motor-Phase Pulse Width	T1	$\frac{16}{f_{CLK}}$		μs
Dwell-Time per State	T2	$\frac{8}{f_{CLK}}$		μs
Index Pulse Setup and Hold (Relative to A and B Low)	T3	0		μs

CLOCK AND RESET TIMING (See Figure 3)

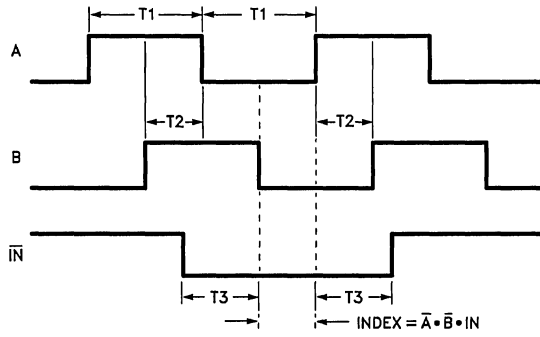
Clock Pulse Width	LM628N-6 or LM629N-6	T4	78	ns
	LM628N-8 or LM629N-8	T4	57	ns
Clock Period	LM628N-6 or LM629N-6	T5	166	ns
	LM628N-8 or LM629N-8	T5	125	ns
Reset Pulse Width	T6	$\frac{8}{f_{CLK}}$		μs

AC Electrical Characteristics (Continued)(V_{DD} and T_A per Operating Ratings; f_{CLK} = 6 MHz; C_{LOAD} = 50 pF; Input Test Signal t_r = t_f = 10 ns)

Timing Interval	T#	Tested Limits		Units
		Min	Max	
STATUS BYTE READ TIMING (See Figure 4)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Read Data Access Time	T10		180	ns
Read Data Hold Time	T11	0		ns
\overline{RD} High to Hi-Z Time	T12		180	ns
COMMAND BYTE WRITE TIMING (See Figure 5)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Busy Bit Delay	T13		(Note 2)	ns
\overline{WR} Pulse Width	T14	100		ns
Write Data Setup Time	T15	50		ns
Write Data Hold Time	T16	120		ns
DATA WORD READ TIMING (See Figure 6)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Read Data Access Time	T10		180	ns
Read Data Hold Time	T11	0		ns
\overline{RD} High to Hi-Z Time	T12		180	ns
Busy Bit Delay	T13		(Note 2)	ns
Read Recovery Time	T17	120		ns
DATA WORD WRITE TIMING (See Figure 7)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Busy Bit Delay	T13		(Note 2)	ns
\overline{WR} Pulse Width	T14	100		ns
Write Data Setup Time	T15	50		ns
Write Data Hold Time	T16	120		ns
Write Recovery Time	T18	120		ns

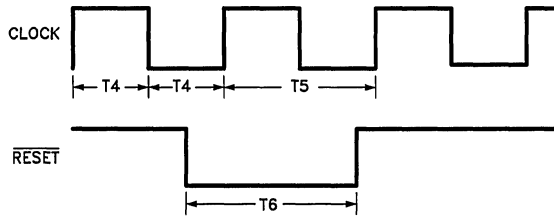
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond the above Operating Ratings.

Note 2: In order to read the busy bit, the status byte must first be read. The time required to read the busy bit far exceeds the time the chip requires to set the busy bit. It is, therefore, impossible to test actual busy bit delay. The busy bit is guaranteed to be valid as soon as the user is able to read it.



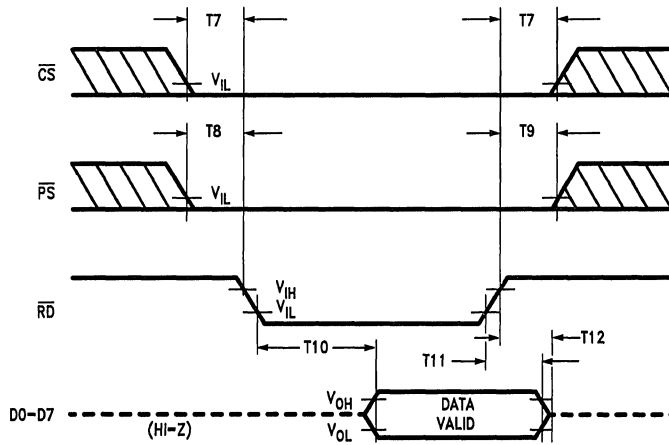
TL/H/9219-4

FIGURE 2. Quadrature Encoder Input Timing



TL/H/9219-5

FIGURE 3. Clock and Reset Timing



TL/H/9219-6

FIGURE 4. Status Byte Read Timing

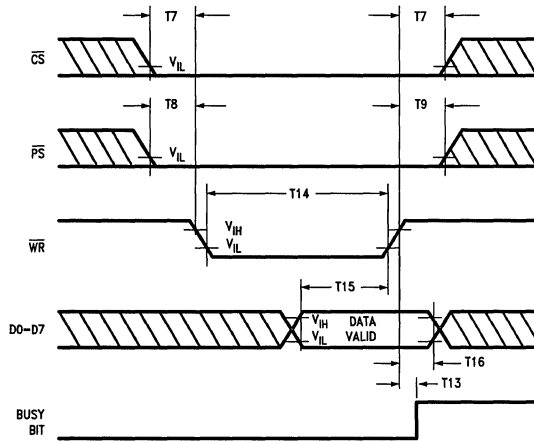


FIGURE 5. Command Byte Write Timing

TL/H/9219-7

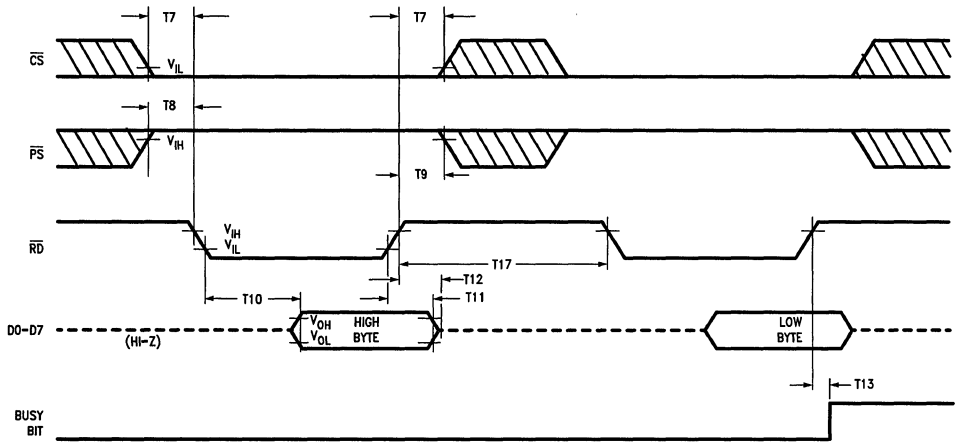


FIGURE 6. Data Word Read Timing

TL/H/9219-8

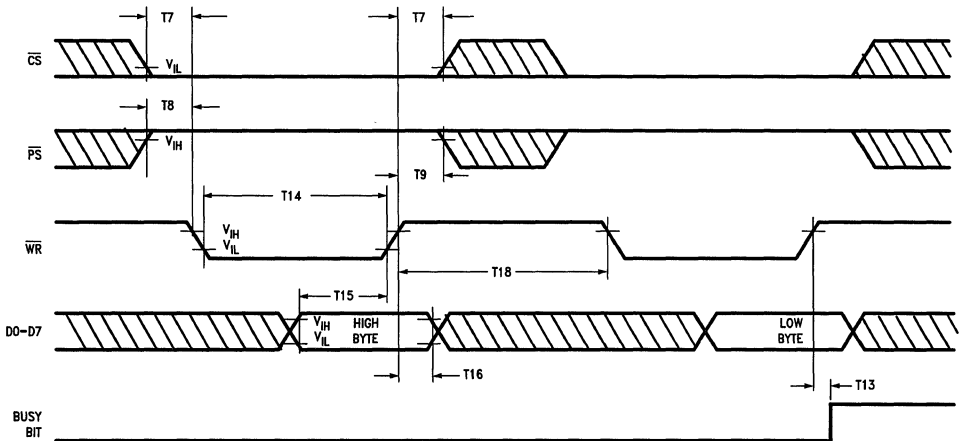


FIGURE 7. Data Word Write Timing

TL/H/9219-9

Pinout Description (See Connection Diagrams)

Pin 1, Index (\overline{IN}) Input: Receives optional index pulse from the encoder. Must be tied high if not used. The index position is read when Pins 1, 2, and 3 are low.

Pins 2 and 3, Encoder Signal (A, B) Inputs: Receive the two-phase quadrature signals provided by the incremental encoder. When the motor is rotating in the positive ("forward") direction, the signal at Pin 2 leads the signal at Pin 3 by 90 degrees. Note that the signals at Pins 2 and 3 must remain at each encoder state (See *Figure 9*) for a minimum of 8 clock periods in order to be recognized. Because of a four-to-one resolution advantage gained by the method of decoding the quadrature encoder signals, this corresponds to a maximum encoder-state capture rate of 1.0 MHz ($f_{CLK} = 8.0$ MHz) or 750 kHz ($f_{CLK} = 6.0$ MHz). For other clock frequencies the encoder signals must also remain at each state a minimum of 8 clock periods.

Pins 4 to 11, Host I/O Port (D0 to D7): Bi-directional data port which connects to host computer/processor. Used for writing commands and data to the LM628, and for reading the status byte and data from the LM628, as controlled by \overline{CS} (Pin 12), \overline{PS} (Pin 16), \overline{RD} (Pin 13), and \overline{WR} (Pin 15).

Pin 12, Chip Select (\overline{CS}) Input: Used to select the LM628 for writing and reading operations.

Pin 13, Read (\overline{RD}) Input: Used to read status and data.

Pin 14, Ground (GND): Power-supply return pin.

Pin 15, Write (\overline{WR}) Input: Used to write commands and data.

Pin 16, Port Select (\overline{PS}) Input: Used to select command or data port. Selects command port when low, data port when high. The following modes are controlled by Pin 16:

1. Commands are written to the command port (Pin 16 low),
2. Status byte is read from command port (Pin 16 low), and
3. Data is written and read via the data port (Pin 16 high).

Pin 17, Host Interrupt (HI) Output: This active-high signal alerts the host (via a host interrupt service routine) that an interrupt condition has occurred.

Pins 18 to 25, DAC Port (DAC0 to DAC7): Output port which is used in three different modes:

1. LM628 (8-bit output mode): Outputs latched data to the DAC. The MSB is Pin 18 and the LSB is Pin 25.

2. LM628 (12-bit output mode): Outputs two, multiplexed 6-bit words. The less-significant word is output first. The MSB is on Pin 18 and the LSB is on Pin 23. Pin 24 is used to demultiplex the words; Pin 24 is low for the less-significant word. The positive-going edge of the signal on Pin 25 is used to strobe the output data. *Figure 8* shows the timing of the multiplexed signals.

3. LM629 (sign/magnitude outputs): Outputs a PWM sign signal on Pin 18, and a PWM magnitude signal on Pin 19. Pins 20 to 25 are not used in the LM629. *Figure 11* shows the PWM output signal format.

Pin 26, Clock (CLK) Input: Receives system clock.

Pin 27, Reset (\overline{RST}) Input: Active-low, positive-edge triggered, resets the LM628 to the internal conditions shown below. Note that the reset pulse must be logic low for a minimum of 8 clock periods. Reset does the following:

1. Filter coefficient and trajectory parameters are zeroed.
2. Sets position error threshold to maximum value (7FFF hex), and effectively executes command LPEI.
3. The SBPA/SBPR interrupt is masked (disabled).
4. The five other interrupts are unmasked (enabled).
5. Initializes current position to zero, or "home" position.
6. Sets derivative sampling interval to $2048/f_{CLK}$ or $256 \mu s$ for an 8.0 MHz clock.
7. DAC port outputs 800 hex to "zero" a 12-bit DAC and then reverts to 80 hex to "zero" an 8-bit DAC.

Immediately after releasing the reset pin from the LM628, the status port should read '00'. If the reset is successfully completed, the status word will change to hex '84' or 'C4' within 1.5 ms. If the status word has not changed from hex '00' to '84' or 'C4' within 1.5 ms, perform another reset and repeat the above steps. To be certain that the reset was properly performed, execute a **RSTI** command. If the chip has reset properly, the status byte will change from hex '84' or 'C4' to hex '80' or 'C0'. If this does not occur, perform another reset and repeat the above steps.

Pin 28, Supply Voltage (V_{DD}): Power supply voltage (+5V).

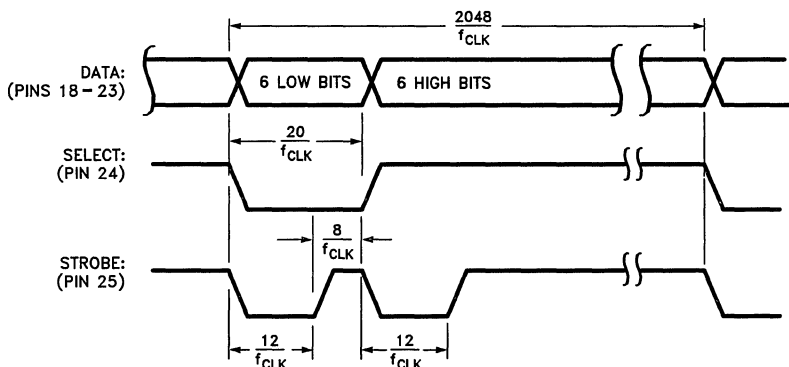


FIGURE 8. 12-Bit Multiplexed Output Timing

TL/H/9219-10

Theory of Operation

INTRODUCTION

The typical system block diagram (See *Figure 1*) illustrates a servo system built using the LM628. The host processor communicates with the LM628 through an I/O port to facilitate programming a trapezoidal velocity profile and a digital compensation filter. The DAC output interfaces to an external digital-to-analog converter to produce the signal that is power amplified and applied to the motor. An incremental encoder provides feedback for closing the position servo loop. The trapezoidal velocity profile generator calculates the required trajectory for either position or velocity mode of operation. In operation, the LM628 subtracts the actual position (feedback position) from the desired position (profile generator position), and the resulting position error is processed by the digital filter to drive the motor to the desired position. Table I provides a brief summary of specifications offered by the LM628/LM629:

POSITION FEEDBACK INTERFACE

The LM628 interfaces to a motor via an incremental encoder. Three inputs are provided: two quadrature signal inputs,

and an index pulse input. The quadrature signals are used to keep track of the absolute position of the motor. Each time a logic transition occurs at one of the quadrature inputs, the LM628 internal position register is incremented or decremented accordingly. This provides four times the resolution over the number of lines provided by the encoder. See *Figure 9*. Each of the encoder signal inputs is synchronized with the LM628 clock.

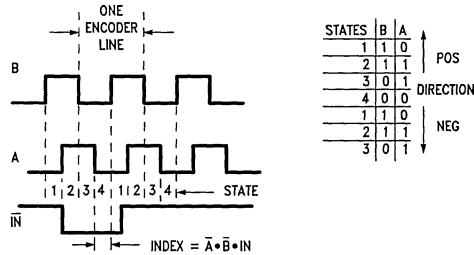
The optional index pulse output provided by some encoders assumes the logic-low state once per revolution. If the LM628 is so programmed by the user, it will record the absolute motor position in a dedicated register (the index register) at the time when all three encoder inputs are logic low.

If the encoder does not provide an index output, the LM628 index input can also be used to record the home position of the motor. In this case, typically, the motor will close a switch which is arranged to cause a logic-low level at the index input, and the LM628 will record motor position in the index register and alert (interrupt) the host processor. Permanently grounding the index input will cause the LM628 to malfunction.

TABLE I. System Specifications Summary

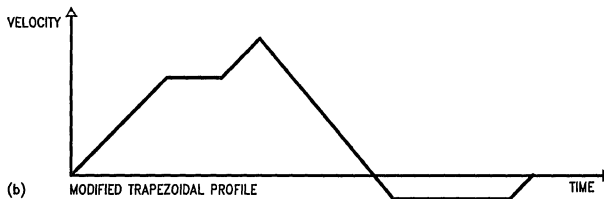
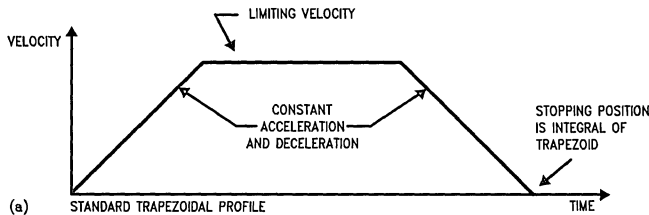
Position Range	–1,073,741,824 to 1,073,741,823 counts
Velocity Range	0 to 1,073,741,823/2 ¹⁶ counts/sample; ie, 0 to 16,383 counts/sample, with a resolution of 1/2 ¹⁶ counts/sample
Acceleration Range	0 to 1,073,741,823/2 ¹⁶ counts/sample/sample; ie, 0 to 16,383 counts/sample/sample, with a resolution of 1/2 ¹⁶ counts/sample/sample
Motor Drive Output	LM628: 8-bit parallel output to DAC, or 12-bit multiplexed output to DAC LM629: 8-bit PWM sign/magnitude signals
Operating Modes	Position and Velocity
Feedback Device	Incremental Encoder (quadrature signals; support for index pulse)
Control Algorithm	Proportional Integral Derivative (PID) (plus programmable integration limit)
Sample Intervals	Derivative Term: Programmable from 2048/f _{CLK} to (2048 * 256)/f _{CLK} in steps of 2048/f _{CLK} (256 to 65,536 μs for an 8.0 MHz clock). Proportional and Integral: 2048/f _{CLK}

Theory of Operation (Continued)



TL/H/9219-11

FIGURE 9. Quadrature Encoder Signals



TL/H/9219-12

FIGURE 10. Typical Velocity Profiles

VELOCITY PROFILE (TRAJECTORY) GENERATION

The trapezoidal velocity profile generator computes the desired position of the motor versus time. In the position mode of operation, the host processor specifies acceleration, maximum velocity, and final position. The LM628 uses this information to affect the move by accelerating as specified until the maximum velocity is reached or until deceleration must begin to stop at the specified final position. The deceleration rate is equal to the acceleration rate. At any time during the move the maximum velocity and/or the target position may be changed, and the motor will accelerate or decelerate accordingly. Figure 10 illustrates two typical trapezoidal velocity profiles. Figure 10 (a) shows a simple trapezoid, while Figure 10 (b) is an example of what the trajectory looks like when velocity and position are changed at different times during the move.

When operating in the velocity mode, the motor accelerates to the specified velocity at the specified acceleration rate and maintains the specified velocity until commanded to stop. The velocity is maintained by advancing the desired position at a constant rate. If there are disturbances to the motion during velocity mode operation, the long-time average velocity remains constant. If the motor is unable to maintain the specified velocity (which could be caused by a locked rotor, for example), the desired position will continue to be increased, resulting in a very large position error. If this

condition goes undetected, and the impeding force on the motor is subsequently released, the motor could reach a very high velocity in order to catch up to the desired position (which is still advancing as specified). This condition is easily detected; see commands LPEI and LPES.

All trajectory parameters are 32-bit values. Position is a signed quantity. Acceleration and velocity are specified as 16-bit, positive-only integers having 16-bit fractions. The integer portion of velocity specifies how many counts per sampling interval the motor will traverse. The fractional portion designates an additional fractional count per sampling interval. Although the position resolution of the LM628 is limited to integer counts, the fractional counts provide increased average velocity resolution. Acceleration is treated in the same manner. Each sampling interval the commanded acceleration value is added to the current desired velocity to generate a new desired velocity (unless the command velocity has been reached).

One determines the trajectory parameters for a desired move as follows. If, for example, one has a 500-line shaft encoder, desires that the motor accelerate at one revolution per second per second until it is moving at 600 rpm, and then decelerate to a stop at a position exactly 100 revolutions from the start, one would calculate the trajectory parameters as follows:

Theory of Operation (Continued)

```

let P = target position (units = encoder counts)
let R = encoder lines * 4 (system resolution)
then R = 500 * 4 = 2000
and P = 2000 * desired number of revolutions
    P = 2000 * 100 revs = 200,000 counts (value to load)
    P (coding) = 00030D40 (hex code written to LM628)

let V = velocity (units = counts/sample)
let T = sample time (seconds) = 341 μs (with 6 MHz clock)
let C = conversion factor = 1 minute/60 seconds
then V = R * T * C * desired rpm
and V = 2000 * 341E-6 * 1/60 * 600 rpm
    V = 6.82 counts/sample
    V (scaled) = 6.82 * 65,536 = 446,955.52
    V (rounded) = 446,956 (value to load)
    V (coding) = 0006D1EC (hex code written to LM628)

let A = acceleration (units = counts/sample/sample)
A = R * T * T * desired acceleration (rev/sec/sec)
then A = 2000 * 341E-6 * 341E-6 * 1 rev/sec/sec
and A = 2.33E-4 counts/sample/sample
    A (scaled) = 2.33E-4 * 65,536 = 15.24
    A (rounded) = 15 (value to load)
    A (coding) = 0000000F (hex code written to LM628)

```

The above position, velocity, and acceleration values must be converted to binary codes to be loaded into the LM628. The values shown for velocity and acceleration must be multiplied by 65,536 (as shown) to adjust for the required integer/fraction format of the input data. Note that after scaling the velocity and acceleration values, literal fractional data cannot be loaded; the data must be rounded and converted to binary. The factor of four increase in system resolution is due to the method used to decode the quadrature encoder signals, see *Figure 9*.

PID COMPENSATION FILTER

The LM628 uses a digital Proportional Integral Derivative (PID) filter to compensate the control loop. The motor is held at the desired position by applying a restoring force to the motor that is proportional to the position error, plus the integral of the error, plus the derivative of the error. The following discrete-time equation illustrates the control performed by the LM628:

$$u(n) = k_p * e(n) + k_i \sum_{N=0}^n e(n) + k_d [e(n') - e(n' - 1)] \quad (\text{Eq. 1})$$

where $u(n)$ is the motor control signal output at sample time n , $e(n)$ is the position error at sample time n , n' indicates sampling at the derivative sampling rate, and k_p , k_i , and k_d are the discrete-time filter parameters loaded by the users.

The first term, the proportional term, provides a restoring force proportional to the position error, just as does a spring obeying Hooke's law. The second term, the integration term, provides a restoring force that grows with time, and thus ensures that the static position error is zero. If there is

a constant torque loading, the motor will still be able to achieve zero position error.

The third term, the derivative term, provides a force proportional to the rate of change of position error. It acts just like viscous damping in a damped spring and mass system (like a shock absorber in an automobile). The sampling interval associated with the derivative term is user-selectable; this capability enables the LM628 to control a wider range of inertial loads (system mechanical time constants) by providing a better approximation of the continuous derivative. In general, longer sampling intervals are useful for low-velocity operations.

In operation, the filter algorithm receives a 16-bit error signal from the loop summing-junction. The error signal is saturated at 16 bits to ensure predictable behavior. In addition to being multiplied by filter coefficient k_p , the error signal is added to an accumulation of previous errors (to form the integral signal) and, at a rate determined by the chosen *derivative* sampling interval, the previous error is subtracted from it (to form the derivative signal). All filter multiplications are 16-bit operations; only the bottom 16 bits of the product are used.

The integral signal is maintained to 24 bits, but only the top 16 bits are used. This scaling technique results in a more usable (less sensitive) range of coefficient k_i values. The 16 bits are right-shifted eight positions and multiplied by filter coefficient k_i to form the term which contributes to the motor control output. The absolute magnitude of this product is compared to coefficient k_i , and the lesser, appropriately signed magnitude then contributes to the motor control signal.

The derivative signal is multiplied by coefficient k_d each *derivative* sampling interval. This product contributes to the motor control output *every* sample interval, independent of the user-chosen *derivative* sampling interval.

The k_p , limited k_i , and k_d product terms are summed to form a 16-bit quantity. Depending on the output mode (wordsize), either the top 8 or top 12 bits become the motor control output signal.

LM628 READING AND WRITING OPERATIONS

The host processor writes commands to the LM628 via the host I/O port when Port Select (\overline{PS}) input (Pin 16) is logic low. The desired command code is applied to the parallel port line and the Write (\overline{WR}) input (Pin 15) is strobed. The command byte is latched into the LM628 on the rising edge of the \overline{WR} input. When writing command bytes it is necessary to first read the status byte and check the state of a flag called the "busy bit" (Bit 0). If the busy bit is logic high, no command write may take place. The busy bit is never high longer than 100 μ s, and typically falls within 15 μ s to 25 μ s.

The host processor reads the LM628 status byte in a similar manner: by strobing the Read (\overline{RD}) input (Pin 13) when \overline{PS} (Pin 16) is low; status information remains valid as long as \overline{RD} is low.

Writing and reading data to/from the LM628 (as opposed to writing commands and reading status) are done with \overline{PS} (Pin 16) logic high. These writes and reads are always an integral number (from one to seven) of two-byte words, with the first byte of each word being the more significant. Each byte requires a write (\overline{WR}) or read (\overline{RD}) strobe. When transferring data words (byte-pairs), it is necessary to first read the status byte and check the state of the busy bit. When the

Theory of Operation (Continued)

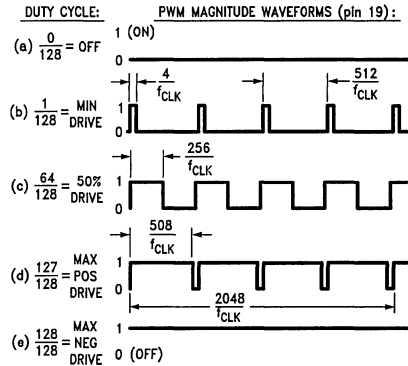
busy bit is logic low, the user may then sequentially transfer both bytes comprising a data word, but the busy bit must again be checked and found to be low before attempting to transfer the next byte pair (when transferring multiple words). Data transfers are accomplished via LM628-internal interrupts (which are not nested); the busy bit informs the host processor when the LM628 may not be interrupted for data transfer (or a command byte). If a command is written when the busy bit is high, the command will be ignored.

The busy bit goes high immediately after writing a command byte, or reading or writing a second byte of data (See Figures 5 thru 7).

MOTOR OUTPUTS

The LM628 DAC output port can be configured to provide either a latched eight-bit parallel output or a multiplexed 12-bit output. The 8-bit output can be directly connected to a flow-through (non-input-latching) D/A converter; the 12-bit output can be easily demultiplexed using an external 6-bit latch and an input-latching 12-bit D/A converter. The DAC output data is offset-binary coded; the 8-bit code for zero is 80 hex and the 12-bit code for zero is 800 hex. Values less than these cause a negative torque to be applied to the motor and, conversely, larger values cause positive motor torque. The LM628, when configured for 12-bit output, provides signals which control the demultiplexing process. See Figure 8 for details.

The LM629 provides 8-bit, sign and magnitude PWM output signals for directly driving switch-mode motor-drive amplifiers. Figure 11 shows the format of the PWM magnitude output signal.



TL/H/9219-13

Note: Sign output (pin 18) not shown

FIGURE 11. PWM Output Signal Format

TABLE II. LM628 User Command Set

Command	Type	Description	Hex	Data Bytes	Note
RESET	Initialize	Reset LM628	00	0	1
PORT8	Initialize	Select 8-Bit Output	05	0	2
PORT12	Initialize	Select 12-Bit Output	06	0	2
DFH	Initialize	Define Home	02	0	1
SIP	Interrupt	Set Index Position	03	0	1
LPEI	Interrupt	Interrupt on Error	1B	2	1
LPES	Interrupt	Stop on Error	1A	2	1
SBPA	Interrupt	Set Breakpoint, Absolute	20	4	1
SBPR	Interrupt	Set Breakpoint, Relative	21	4	1
MSKI	Interrupt	Mask Interrupts	1C	2	1
RSTI	Interrupt	Reset Interrupts	1D	2	1
LFIL	Filter	Load Filter Parameters	1E	2 to 10	1
UDF	Filter	Update Filter	04	0	1
LTRJ	Trajectory	Load Trajectory	1F	2 to 14	1
STT	Trajectory	Start Motion	01	0	3
RDSTAT	Report	Read Status Byte	None	1	1, 4
RDSIGS	Report	Read Signals Register	0C	2	1
RDIP	Report	Read Index Position	09	4	1
RDDP	Report	Read Desired Position	08	4	1
RDRP	Report	Read Real Position	0A	4	1
RDDV	Report	Read Desired Velocity	07	4	1
RDRV	Report	Read Real Velocity	0B	2	1
RDSUM	Report	Read Integration Sum	0D	2	1

Note 1: Commands may be executed "On the Fly" during motion.

Note 2: Commands not applicable to execution during motion.

Note 3: Command may be executed during motion if acceleration parameter was not changed.

Note 4: Command needs no code because the command port status-byte read is totally supported by hardware.

User Command Set

GENERAL

The following paragraphs describe the user command set of the LM628. Some of the commands can be issued alone and some require a supporting data structure. As examples, the command STT (STaRT motion) does not require additional data; command LFLI (Load FILter parameters) requires additional data (derivative-term sampling interval and/or filter parameters).

Commands are categorized by function: initialization, interrupt control, filter control, trajectory control, and data reporting. The commands are listed in Table II and described in the following paragraphs. Along with each command name is its command-byte code, the number of accompanying data bytes that are to be written (or read), and a comment as to whether the command is executable during motion.

Initialization Commands

The following four LM628 user commands are used primarily to initialize the system for use.

RESET COMMAND: RESET the LM628

Command Code: 00 Hex
Data Bytes: None
Executable During Motion: Yes

This command (and the hardware reset input, Pin 27) results in setting the following data items to zero: filter coefficients and their input buffers, trajectory parameters and their input buffers, and the motor control output. A zero motor control output is a half-scale, offset-binary code: (80 hex for the 8-bit output mode; 800 hex for 12-bit mode). During reset, the DAC port outputs 800 hex to "zero" a 12-bit DAC and reverts to 80 hex to "zero" an 8-bit DAC. The command also clears five of the six interrupt masks (only the SBPA/SBPR interrupt is masked), sets the output port size to 8 bits, and defines the current absolute position as home. Reset, which may be executed at any time, will be completed in less than 1.5 ms. Also see commands PORT8 and PORT12.

PORT8 COMMAND: Set Output PORT Size to 8 Bits

Command Code: 05 Hex
Data Bytes: None
Executable During Motion: Not Applicable

The default output port size of the LM628 is 8 bits; so the PORT8 command need not be executed when using an 8-bit DAC. This command must not be executed when using a 12-bit converter; it will result in erratic, unpredictable motor behavior. The 8-bit output port size is the required selection when using the LM629, the PWM-output version of the LM628.

PORT12 COMMAND: Set Output PORT Size to 12 Bits

Command Code: 06 Hex
Data Bytes: None
Executable During Motion: Not Applicable

When a 12-bit DAC is used, command PORT12 should be issued very early in the initialization process. Because use of this command is determined by system hardware, there is only one foreseen reason to execute it later: if the RESET command is issued (because an 8-bit output would then be selected as the default) command PORT12 should be im-

mediately executed. This command must not be issued when using an 8-bit converter or the LM629, the PWM-output version of the LM628.

DFH COMMAND: DeFINE Home

Command Code: 02 Hex
Data Bytes: None
Executable During Motion: Yes

This command declares the current position as "home", or absolute position 0 (Zero). If DFH is executed during motion it will not affect the stopping position of the on-going move unless command STT is also executed.

Interrupt Control Commands

The following seven LM628 user commands are associated with conditions which can be used to interrupt the host computer. In order for any of the potential interrupt conditions to actually interrupt the host via Pin 17, the corresponding bit in the interrupt mask data associated with command MSKI must have been set to logic high (the non-masked state).

The identity of all interrupts is made known to the host via reading and parsing the status byte. Even if all interrupts are masked off via command MSKI, the state of each condition is still reflected in the status byte. This feature facilitates polling the LM628 for status information, as opposed to interrupt driven operation.

SIP COMMAND: Set Index Position

Command Code: 03 Hex
Data Bytes: None
Executable During Motion: Yes

After this command is executed, the absolute position which corresponds to the occurrence of the next index pulse input will be recorded in the index register, and bit 3 of the status byte will be set to logic high. The position is recorded when both encoder-phase inputs and the index pulse input are logic low. This register can then be read by the user (see description for command RDIP) to facilitate aligning the definition of home position (see description of command DFH) with an index pulse. The user can also arrange to have the LM628 interrupt the host to signify that an index pulse has occurred. See the descriptions for commands MSKI and RSTI.

LPEI COMMAND: Load Position Error for Interrupt

Command Code: 1B Hex
Data Bytes: Two
Data Range: 0000 to 7FFF Hex
Executable During Motion: Yes

An excessive position error (the output of the loop summing junction) can indicate a serious system problem; e.g., a stalled rotor. Instruction LPEI allows the user to input a threshold for position error detection. Error detection occurs when the absolute magnitude of the position error exceeds the threshold, which results in bit 5 of the status byte being set to logic high. If it is desired to also stop (turn off) the motor upon detecting excessive position error, see command LPES, below. The first byte of threshold data written with command LPEI is the more significant. The user can have the LM628 interrupt the host to signify that an excessive position error has occurred. See the descriptions for commands MSKI and RSTI.

Interrupt Control Commands (Continued)

LPES COMMAND: Load Position Error for Stopping

Command Code: 1A Hex
 Data Bytes: Two
 Data Range: 0000 to 7FFF Hex
 Executable During Motion: Yes

Instruction LPES is essentially the same as command LPEI above, but adds the feature of turning off the motor upon detecting excessive position error. The motor drive is not actually switched off, it is set to half-scale, the offset-binary code for zero. As with command LPEI, bit 5 of the status byte is also set to logic high. The first byte of threshold data written with command LPES is the more significant. The user can have the LM628 interrupt the host to signify that an excessive position error has occurred. See the descriptions for commands MSKI and RSTI.

SBPA COMMAND:

Command Code: 20 Hex
 Data Bytes: Four
 Data Range: C0000000 to 3FFFFFFF Hex
 Executable During Motion: Yes

This command enables the user to set a breakpoint in terms of absolute position. Bit 6 of the status byte is set to logic high when the breakpoint position is reached. This condition is useful for signaling trajectory and/or filter parameter updates. The user can also arrange to have the LM628 interrupt the host to signify that a breakpoint position has been reached. See the descriptions for commands MSKI and RSTI.

SBPR COMMAND:

Command Code: 21 Hex
 Data Bytes: Four
 Data Range: See Text
 Executable During Motion: Yes

This command enables the user to set a breakpoint in terms of relative position. As with command SBPA, bit 6 of the status byte is set to logic high when the breakpoint position (relative to the current commanded target position) is reached. The relative breakpoint input value must be such that when this value is added to the target position the result remains within the absolute position range of the system (C0000000 to 3FFFFFFF hex). This condition is useful for signaling trajectory and/or filter parameter updates. The user can also arrange to have the LM628 interrupt the host to signify that a breakpoint position has been reached. See the descriptions for commands MSKI and RSTI.

MSKI COMMAND: MaSK Interrupts

Command Code: 1C Hex
 Data Bytes: Two
 Data Range: See Text
 Executable During Motion: Yes

The MSKI command lets the user determine which potential interrupt condition(s) will interrupt the host. Bits 1 through 6 of the status byte are indicators of the six conditions which are candidates for host interrupt(s). When interrupted, the host then reads the status byte to learn which condition(s) occurred. Note that the MSKI command is immediately followed by two data bytes. Bits 1 through 6 of the second (less significant) byte written determine the masked/unmasked status of each potential interrupt. Any zero(s) in this

6-bit field will mask the corresponding interrupt(s); any one(s) enable the interrupt(s). Other bits comprising the two bytes have no effect. The mask controls only the host interrupt process; reading the status byte will still reflect the actual conditions independent of the mask byte. See Table III.

TABLE III. Mask and Reset Bit Allocations for Interrupts

Bit Position	Function
Bits 15 thru 7	Not Used
Bit 6	Breakpoint Interrupt
Bit 5	Position-Error Interrupt
Bit 4	Wrap-Around Interrupt
Bit 3	Index-Pulse Interrupt
Bit 2	Trajectory-Complete Interrupt
Bit 1	Command-Error Interrupt
Bit 0	Not Used

RSTI COMMAND: ReSeT Interrupts

Command Code: 1D Hex
 Data Bytes: Two
 Data Range: See Text
 Executable During Motion: Yes

When one of the potential interrupt conditions of Table III occurs, command RSTI is used to reset the corresponding interrupt flag bit in the status byte. The host may reset one or all flag bits. Resetting them one at a time allows the host to service them one at a time according to a priority programmed by the user. As in the MSKI command, bits 1 through 6 of the second (less significant) byte correspond to the potential interrupt conditions shown in Table III. Also see description of RDSTAT command. Any zero(s) in this 6-bit field reset the corresponding interrupt(s). The remaining bits have no effect.

Filter Control Commands

The following two LM628 user commands are used for setting the derivative-term sampling interval, for adjusting the filter parameters as required to tune the system, and to control the timing of these system changes.

LFIL COMMAND: Load FILter Parameters

Command Code: 1E Hex
 Data Bytes: Two to Ten
 Data Ranges . . .
 Filter Control Word: See Text
 Filter Coefficients: 0000 to 7FFF Hex (Pos Only)
 Integration Limit: 0000 to 7FFF Hex (Pos Only)
 Executable During Motion: Yes

The filter parameters (coefficients) which are written to the LM628 to control loop compensation are: kp, ki, kd, and il (integration limit). The integration limit (il) constrains the contribution of the integration term

$$\left[k_i \sum_{N=0}^n e(n) \right]$$

(see Eq. 1) to values equal to or less than a user-defined maximum value; this capability minimizes integral or reset "wind-up" (an overshooting effect of the integral action). The positive-only input value is compared to the absolute

Filter Control Commands (Continued)

magnitude of the integration term; when the magnitude of integration term value exceeds it, the il value (with appropriate sign) is substituted for the integration term value.

The derivative-term sampling interval is also programmable via this command. After writing the command code, the first two data bytes that are written specify the derivative-term sampling interval and which of the four filter parameters is/are to be written via any forthcoming data bytes. The first byte written is the more significant. Thus the two data bytes constitute a filter control word that informs the LM628 as to the nature and number of any following data bytes. See Table IV.

TABLE IV. Filter Control word Bit Allocation

Bit Position	Function
Bit 15	Derivative Sampling Interval Bit 7
Bit 14	Derivative Sampling Interval Bit 6
Bit 13	Derivative Sampling Interval Bit 5
Bit 12	Derivative Sampling Interval Bit 4
Bit 11	Derivative Sampling Interval Bit 3
Bit 10	Derivative Sampling Interval Bit 2
Bit 9	Derivative Sampling Interval Bit 1
Bit 8	Derivative Sampling Interval Bit 0
Bit 7	Not Used
Bit 6	Not Used
Bit 5	Not Used
Bit 4	Not Used
Bit 3	Loading kp Data
Bit 2	Loading ki Data
Bit 1	Loading kd Data
Bit 0	Loading il Data

Bits 8 through 15 select the derivative-term sampling interval. See Table V. The user must locally save and restore these bits during successive writes of the filter control word. Bits 4 through 7 of the filter control word are not used.

Bits 0 to 3 inform the LM628 as to whether any or all of the filter parameters are about to be written. The user may choose to update any or all (or none) of the filter parameters. Those chosen for updating are so indicated by logic one(s) in the corresponding bit position(s) of the filter control word.

TABLE V. Derivative-Term Sampling Interval Selection Codes

	Bit Position								Selected Derivative Sampling Interval
	15	14	13	12	11	10	9	8	
	0	0	0	0	0	0	0	0	256 μ s
	0	0	0	0	0	0	0	1	512 μ s
	0	0	0	0	0	0	1	0	768 μ s
	0	0	0	0	0	0	1	1	1024 μ s, etc . . .
thru	1	1	1	1	1	1	1	1	65,536 μ s

Note: Sampling intervals shown are when using an 8.0 MHz clock. The 256 corresponds to 2048/8 MHz; sample intervals must be scaled for other clock frequencies.

The data bytes specified by and immediately following the filter control word are written in pairs to comprise 16-bit words. The order of sending the data words to the LM628 corresponds to the descending order shown in the above description of the filter control word; i.e., beginning with kp, then ki, kd and il. The first byte of each word is the more-significant byte. Prior to writing a word (byte pair) it is necessary to check the busy bit in the status byte for readiness. The required data is written to the primary buffers of a double-buffered scheme by the above described operations; it is not transferred to the secondary (working) registers until the UDF command is executed. This fact can be used advantageously; the user can input numerous data ahead of their actual use. This simple pipeline effect can relieve potential host computer data communications bottlenecks, and facilitates easier synchronization of multiple-axis controls.

UDF COMMAND: UpDate Filter

Command Code: 04 Hex
Data Bytes: None
Executable During Motion: Yes

The UDF command is used to update the filter parameters, the specifics of which have been programmed via the LFIL command. Any or all parameters (derivative-term sampling interval, kp, ki, kd, and/or il) may be changed by the appropriate command(s), but command UDF must be executed to affect the change in filter tuning. Filter updating is synchronized with the calculations to eliminate erratic or spurious behavior.

Trajectory Control Commands

The following two LM628 user commands are used for setting the trajectory control parameters (position, velocity, acceleration), mode of operation (position or velocity), and direction (velocity mode only) as required to describe a desired motion or to select the mode of a manually directed stop, and to control the timing of these system changes.

LTRJ COMMAND: Load TRAJectory Parameters

Command Code: 1F Hex
Data Bytes: Two to Fourteen
Data Ranges . . .
Trajectory Control Word: See Text
Position: C0000000 to 3FFFFFFF Hex
Velocity: 00000000 to 3FFFFFFF Hex (Pos Only)
Acceleration: 00000000 to 3FFFFFFF Hex (Pos Only)

Executable During Motion: Conditionally, See Text

Trajectory Control Commands (Continued)

The trajectory control parameters which are written to the LM628 to control motion are: acceleration, velocity, and position. In addition, indications as to whether these three parameters are to be considered as absolute or relative inputs, selection of velocity mode and direction, and manual stopping mode selection and execution are programmable via this command. After writing the command code, the first two data bytes that are written specify which parameter(s) is/are being changed. The first byte written is the more significant. Thus the two data bytes constitute a trajectory control word that informs the LM628 as to the nature and number of any following data bytes. See Table VI.

TABLE VI. Trajectory Control Word Bit Allocation

Bit Position	Function
Bit 15	Not Used
Bit 14	Not Used
Bit 13	Not Used
Bit 12	Forward Direction (Velocity Mode Only)
Bit 11	Velocity Mode
Bit 10	Stop Smoothly (Decelerate as Programmed)
Bit 9	Stop Abruptly (Maximum Deceleration)
Bit 8	Turn Off Motor (Output Zero Drive)
Bit 7	Not Used
Bit 6	Not Used
Bit 5	Acceleration Will Be Loaded
Bit 4	Acceleration Data Is Relative
Bit 3	Velocity Will Be Loaded
Bit 2	Velocity Data Is Relative
Bit 1	Position Will Be Loaded
Bit 0	Position Data Is Relative

Bit 12 determines the motor direction when in the velocity mode. A logic one indicates forward direction. This bit has no effect when in position mode.

Bit 11 determines whether the LM628 operates in velocity mode (Bit 11 logic one) or position mode (Bit 11 logic zero).

Bits 8 through 10 are used to select the method of *manually stopping* the motor. These bits are *not* provided for one to merely specify the desired *mode* of stopping, in position mode operations, normal stopping is always smooth and occurs automatically at the end of the specified trajectory. Under exceptional circumstances it may be desired to manually intervene with the trajectory generation process to affect a *premature stop*. In velocity mode operations, however, the normal means of stopping *is* via bits 8 through 10 (usually bit 10). Bit 8 is set to logic one to stop the motor by turning off motor drive output (outputting the appropriate offset-binary code to apply zero drive to the motor); bit 9 is set to one to stop the motor abruptly (at maximum available acceleration, by setting the target position equal to the current position); and bit 10 is set to one to stop the motor smoothly by using the current user-programmed acceleration value. Bits 8 through 10 are to be used *exclusively*; only one bit should be a logic one at any time.

Bits 0 through 5 inform the LM628 as to whether any or all of the trajectory controlling parameters are about to be written, and whether the data should be interpreted as absolute or relative. The user may choose to update any or all (or

none) of the trajectory parameters. Those chosen for updating are so indicated by logic one(s) in the corresponding bit position(s). Any parameter may be changed while the motor is in motion; however, if acceleration is changed then the next STT command must not be issued until the LM628 has completed the current move or has been manually stopped.

The data bytes specified by and immediately following the trajectory control word are written in pairs which comprise 16-bit words. Each data item (parameter) requires two 16-bit words; the word and byte order is most-to-least significant. The order of sending the parameters to the LM628 corresponds to the descending order shown in the above description of the trajectory control word; i.e., beginning with acceleration, then velocity, and finally position.

Acceleration and velocity are 32 bits, positive only, but range only from 0 (00000000 hex) to $[2^{30}] - 1$ (3FFFFFFF hex). The bottom 16 bits of both acceleration and velocity are scaled as fractional data; therefore, the least-significant integer data bit for these parameters is bit 16 (where the bits are numbered 0 through 31). To determine the coding for a given velocity, for example, one multiplies the desired velocity (in counts per sample interval) times 65,536 and converts the result to binary. The units of acceleration are counts per sample per sample. The value loaded for acceleration must not exceed the value loaded for velocity. Position is a signed, 32-bit integer, but ranges only from $-[2^{30}]$ (C0000000 hex) to $[2^{30}] - 1$ (3FFFFFFF Hex).

The required data is written to the primary buffers of a double-buffered scheme by the above described operations; it is not transferred to the secondary (working) registers until the STT command is executed. This fact can be used advantageously; the user can input numerous data ahead of their actual use. This simple pipeline effect can relieve potential host computer data communications bottlenecks, and facilitates easier synchronization of multiple-axis controls.

STT COMMAND: STaRT Motion Control

Command Code: 01 Hex
 Data Bytes: None
 Executable During Motion: Yes, if acceleration has not been changed

The STT command is used to execute the desired trajectory, the specifics of which have been programmed via the LTRJ command. Synchronization of multi-axis control (to within one sample interval) can be arranged by loading the required trajectory parameters for each (and every) axis and then simultaneously issuing a single STT command to all axes. This command may be executed at any time, unless the acceleration value has been changed and a trajectory has not been completed or the motor has not been manually stopped. If STT is issued during motion and acceleration has been changed, a command error interrupt will be generated and the command will be ignored.

Data Reporting Commands

The following seven LM628 user commands are used to obtain data from various registers in the LM628. Status, position, and velocity information are reported. With the exception of RDSTAT, the data is read from the LM628 data port after first writing the corresponding command to the command port.

Data Reporting Commands (Continued)

RDSTAT COMMAND: Read STATUS Byte

Command Code: None
 Byte Read: One
 Data Range: See Text
 Executable During Motion: Yes

The RDSTAT command is really not a command, but is listed with the other commands because it is used very frequently to control communications with the host computer. There is no identification code; it is directly supported by the hardware and may be executed at any time. The single-byte status read is selected by placing CS, PS and RD at logic zero. See Table VII.

TABLE VII. Status Byte Bit Allocation

Bit Position	Function
Bit 7	Motor Off
Bit 6	Breakpoint Reached [Interrupt]
Bit 5	Excessive Position Error [Interrupt]
Bit 4	Wraparound Occurred [Interrupt]
Bit 3	Index Pulse Observed [Interrupt]
Bit 2	Trajectory Complete [Interrupt]
Bit 1	Command Error [Interrupt]
Bit 0	Busy Bit

Bit 7, the motor-off flag, is set to logic one when the motor drive output is off (at the half-scale, offset-binary code for zero). The motor is turned off by any of the following conditions: power-up reset, command RESET, excessive position error (if command LPES had been executed), or when command LTRJ is used to manually stop the motor via turning the motor off. Note that when bit 7 is set in conjunction with command LTRJ for producing a manual, motor-off stop, the actual setting of bit 7 does not occur until command STT is issued to affect the stop. Bit 7 is cleared by command STT, except as described in the previous sentence.

Bit 6, the breakpoint-reached interrupt flag, is set to logic one when the position breakpoint loaded via command SBPA or SBPR has been exceeded. The flag is functional independent of the host interrupt mask status. Bit 6 is cleared via command RST1.

Bit 5, the excessive-position-error interrupt flag, is set to logic one when a position-error interrupt condition exists. This occurs when the error threshold loaded via command LPEI or LPES has been exceeded. The flag is functional independent of the host interrupt mask status. Bit 5 is cleared via command RST1.

Bit 4, the wraparound interrupt flag, is set to logic one when a numerical "wraparound" has occurred. To "wraparound" means to exceed the position address space of the LM628, which could occur during velocity mode operation. If a wrap-around has occurred, then position information will be in error and this interrupt helps the user to ensure position data integrity. The flag is functional independent of the host interrupt mask status. Bit 4 is cleared via command RST1.

Bit 3, the index-pulse acquired interrupt flag, is set to logic one when an index pulse has occurred (if command SIP had been executed) and indicates that the index position register has been updated. The flag is functional independent of the host interrupt mask status. Bit 3 is cleared by command RST1.

Bit 2, the trajectory complete interrupt flag, is set to logic one when the trajectory programmed by the LTRJ command and initiated by the STT command has been completed. Because of overshoot or a limiting condition (such as commanding the velocity to be higher than the motor can achieve), the motor may not yet be at the final commanded position. This bit is the logical OR of bits 7 and 10 of the Signals Register, see command RDSIGS below. The flag functions independently of the host interrupt mask status. Bit 2 is cleared via command RST1.

Bit 1, the command-error interrupt flag, is set to logic one when the user attempts to read data when a write was appropriate (or vice versa). The flag is functional independent of the host interrupt mask status. Bit 1 is cleared via command RST1.

Bit 0, the busy flag, is frequently tested by the user (via the host computer program) to determine the busy/ready status prior to writing and reading any data. Such writes and reads may be executed only when bit 0 is logic zero (not busy). Any command or data writes when the busy bit is high will be ignored. Any data reads when the busy bit is high will read the current contents of the I/O port buffers, not the data expected by the host. Such reads or writes (with the busy bit high) will not generate a command-error interrupt.

RDSIGS COMMAND: Read SIGNALS Register

Command Code: 0C Hex
 Bytes Read: Two
 Data Range: See Text
 Executable During Motion: Yes

The LM628 internal "signals" register may be read using this command. The first byte read is the more significant. The less significant byte of this register (with the exception of bit 0) duplicates the status byte. See Table VIII.

TABLE VIII. Signals Register Bit Allocation

Bit Position	Function
Bit 15	Host Interrupt
Bit 14	Acceleration Loaded (But Not Updated)
Bit 13	UDF Executed (But Filter Not yet Updated)
Bit 12	Forward Direction
Bit 11	Velocity Mode
Bit 10	On Target
Bit 9	Turn Off upon Excessive Position Error
Bit 8	Eight-Bit Output Mode
Bit 7	Motor Off
Bit 6	Breakpoint Reached [Interrupt]
Bit 5	Excessive Position Error [Interrupt]
Bit 4	Wraparound Occurred [Interrupt]
Bit 3	Index Pulse Acquired [Interrupt]
Bit 2	Trajectory Complete [Interrupt]
Bit 1	Command Error [Interrupt]
Bit 0	Acquire Next Index (SIP Executed)

Bit 15, the host interrupt flag, is set to logic one when the host interrupt output (Pin 17) is logic one. Pin 17 is set to logic one when any of the six host interrupt conditions occur (if the corresponding interrupt has not been masked). Bit 15 (and Pin 17) are cleared via command RST1.

Bit 14, the acceleration-loaded flag, is set to logic one when acceleration data is written to the LM628. Bit 14 is cleared by the STT command.

Data Reporting Commands (Continued)

Bit 13, the UDF-executed flag, is set to logic one when the UDF command is executed. Because bit 13 is cleared at the end of the sampling interval in which it has been set, this signal is very short-lived and probably not very profitable for monitoring.

Bit 12, the forward direction flag, is meaningful only when the LM628 is in velocity mode. The bit is set to logic one to indicate that the desired direction of motion is "forward"; zero indicates "reverse" direction. Bit 12 is set and cleared via command LTRJ. The actual setting and clearing of bit 12 does not occur until command STT is executed.

Bit 11, the velocity mode flag, is set to logic one to indicate that the user has selected (via command LTRJ) velocity mode. Bit 11 is cleared when position mode is selected (via command LTRJ). The actual setting and clearing of bit 11 does not occur until command STT is executed.

Bit 10, the on-target flag, is set to logic one when the trajectory generator has completed its functions for the last-issued STT command. Bit 10 is cleared by the next STT command.

Bit 9, the turn-off on-error flag, is set to logic one when command LPES is executed. Bit 9 is cleared by command LPEI.

Bit 8, the 8-bit output flag, is set to logic one when the LM628 is reset, or when command PORT8 is executed. Bit 8 is cleared by command PORT12.

Bits 0 through 7 replicate the status byte (see Table VII), with the exception of bit 0. Bit 0, the acquire next index flag, is set to logic one when command SIP is executed; it then remains set until the next index pulse occurs.

RDIP COMMAND: Read Index Position

Command Code: 09 Hex
 Bytes Read: Four
 Data Range: C0000000 to 3FFFFFFF Hex
 Executable During Motion: Yes

This command reads the position recorded in the index register. Reading the index register can be part of a system error checking scheme. Whenever the SIP command is executed, the new index position minus the old index position, divided by the incremental encoder resolution (encoder lines times four), should always be an integral number. The RDIP command facilitates acquiring these data for host-based calculations. The command can also be used to identify/verify home or some other special position. The bytes are read in most-to-least significant order.

RDDP COMMAND: Read Desired Position

Command Code: 08 Hex
 Bytes Read: Four
 Data Range: C0000000 to 3FFFFFFF Hex
 Executable During Motion: Yes

This command reads the instantaneous desired (current *temporal*) position output of the profile generator. This is the "setpoint" input to the position-loop summing junction. The bytes are read in most-to-least significant order.

RDRP COMMAND: Read Real Position

Command Code: 0A Hex
 Bytes Read: Four
 Data Range: C0000000 to 3FFFFFFF Hex
 Executable During Motion: Yes

This command reads the current actual position of the motor. This is the feedback input to the loop summing junction. The bytes are read in most-to-least significant order.

RDDV COMMAND: Read Desired Velocity

Command Code: 07 Hex
 Bytes Read: Four
 Data Range: C0000001 to 3FFFFFFF
 Executable During Motion: Yes

This command reads the integer and fractional portions of the instantaneous desired (current *temporal*) velocity, as used to generate the desired position profile. The bytes are read in most-to-least significant order. The value read is properly scaled for numerical comparison with the user-supplied (commanded) velocity; however, because the two least-significant bytes represent *fractional* velocity, only the two most-significant bytes are appropriate for comparison with the data obtained via command RDRV (see below). Also note that, although the velocity *input* data is constrained to positive numbers (see command LTRJ), the data returned by command RDDV represents a *signed* quantity where negative numbers represent operation in the reverse direction.

RDRV COMMAND: Read Real Velocity

Command Code: 0B Hex
 Bytes Read: Two
 Data Range: C000 to 3FFF Hex, See Text
 Executable During Motion: Yes

This command reads the *integer* portion of the instantaneous actual velocity of the motor. The internally maintained fractional portion of velocity is not reported because the reported data is derived by reading the incremental encoder, which produces only integer data. For comparison with the result obtained by executing command RDDV (or the user-supplied input value), the value returned by command RDRV must be multiplied by 2^{16} (shifted left 16 bit positions). Also, as with command RDDV above, data returned by command RDRV is a *signed* quantity, with negative values representing reverse-direction motion.

RDSUM COMMAND: Read Integration-Term SUMmation Value

Command Code: 0D Hex
 Bytes Read: Two
 Data Range: 00000 Hex to \pm the Current Value of the Integration Limit
 Executable During Motion: Yes

This command reads the value to which the integration term has accumulated. The ability to read this value may be helpful in initially or adaptively tuning the system.

Typical Applications

Programming LM628 Host Handshaking (Interrupts)

A few words regarding the LM628 host handshaking will be helpful to the system programmer. As indicated in various portions of the above text, the LM628 handshakes with the host computer in two ways: via the host interrupt output (Pin 17), or via polling the status byte for "interrupt" conditions. When the hardwired interrupt is used, the status byte is also read and parsed to determine which of six possible conditions caused the interrupt.

Typical Applications (Continued)

When using the hardwired interrupt it is very important that the host interrupt service routine does not interfere with a command sequence which might have been in progress when the interrupt occurred. If the host interrupt service routine were to issue a command to the LM628 while it is in the middle of an ongoing command sequence, the ongoing command will be aborted (which could be detrimental to the application).

Two approaches exist for avoiding this problem. If one is using hardwired interrupts, they should be disabled at the host prior to issuing any LM628 command sequence, and re-enabled after each command sequence. The second approach is to avoid hardwired interrupts and poll the LM628 status byte for "interrupt" status. The status byte always reflects the interrupt-condition status, independent of whether or not the interrupts have been masked.

Typical Host Computer/Processor Interface

The LM628 is interfaced with the host computer/processor via an 8-bit parallel bus. *Figure 12* shows such an interface and a minimum system configuration.

As shown in *Figure 12*, the LM628 interfaces with the host data, address and control lines. The address lines are decoded to generate the LM628 \overline{CS} input; the host address LSB directly drives the LM628 \overline{PS} input. *Figure 12* also shows an 8-bit DAC and an LM12 Power Op Amp interfaced to the LM628.

LM628 and High Performance Controller (HPC) Interface

Figure 13 shows the LM628 interfaced to a National HPC High Performance Controller. The delay and logic associated with the \overline{WR} line is used to effectively increase the write-data hold time of the HPC (as seen at the LM628) by causing the \overline{WR} pulse to rise early. Note that the HPC CK2 output provides the clock for the LM628. The 74LS245 is used to decrease the read-data hold time, which is necessary when interfacing to fast host busses.

Interfacing a 12-Bit DAC

Figure 14 illustrates use of a 12-bit DAC with the LM628. The 74LS378 hex gated-D flip-flop and an inverter demultiplex the 12-bit output. DAC offset must be adjusted to minimize DAC linearity and monotonicity errors. Two methods exist for making this adjustment. If the DAC1210 has been socketed, remove it and temporarily connect a 15 k Ω resistor between Pins 11 and 13 of the DAC socket (Pins 2 and 6 of the LF356) and adjust the 25 k Ω potentiometer for 0V at Pin 6 of the LF356.

If the DAC is not removable, the second method of adjustment requires that the DAC1210 inputs be presented an all-zeros code. This can be arranged by commanding the appropriate move via the LM628, but with no feedback from the system encoder. When the all-zeros code is present, adjust the pot for 0V at Pin 6 of the LF356.

A Monolithic Linear Drive Using LM12 Power Op Amp

Figure 15 shows a motor-drive amplifier built using the LM12 Power Operational Amplifier. This circuit is very simple and can deliver up to 8A at 30V (using the LM12L/LM12CL). Resistors R1 and R2 should be chosen to set the gain to provide maximum output voltage consistent with maximum input voltage. This example provides a gain of 2.2, which allows for amplifier output saturation at $\pm 22V$ with a $\pm 10V$ input, assuming power supply voltages of $\pm 30V$. The amplifier gain should not be higher than necessary because the system is non-linear when saturated, and because gain should be controlled by the LM628. The LM12 can also be configured as a current driver, see 1987 Linear Databook, Vol. 1, p. 2-280.

Typical PWM Motor Drive Interfaces

Figure 16 shows an LM18298 dual full-bridge driver interfaced to the LM629 PWM outputs to provide a switch-mode power amplifier for driving small brush/commutator motors. *Figure 17* shows an LM621 brushless motor commutator interfaced to the LM629 PWM outputs and a discrete device switch-mode power amplifier for driving brushless DC motors.

Incremental Encoder Interface

The incremental (position feedback) encoder interface consists of three lines: Phase A (Pin 2), Phase B (Pin 3), and Index (Pin 1). The index pulse output is not available on some encoders. The LM628 will work with both encoder types, but commands SIP and RDIP will not be meaningful without an index pulse (or alternative input for this input . . . be sure to tie Pin 1 high if not used).

Some consideration is merited relative to use in high Gaussian-noise environments. If noise is added to the encoder inputs (either or both inputs) and is such that it is not sustained until the next encoder transition, the LM628 decoder logic will reject it. Noise that mimics quadrature counts or persists through encoder transitions must be eliminated by appropriate EMI design.

Simple digital "filtering" schemes merely reduce susceptibility to noise (there will always be noise pulses longer than the filter can eliminate). Further, any noise filtering scheme reduces decoder bandwidth. In the LM628 it was decided (since simple filtering does not eliminate the noise problem) to not include a noise filter in favor of offering maximum possible decoder bandwidth. Attempting to drive encoder signals too long a distance with simple TTL lines can also be a source of "noise" in the form of signal degradation (poor risetime and/or ringing). This can also cause a system to lose positional integrity. Probably the most effective countermeasure to noise induction can be had by using balanced-line drivers and receivers on the encoder inputs. *Figure 18* shows circuitry using the DS26LS31 and DS26LS32.

Typical Applications (Continued)

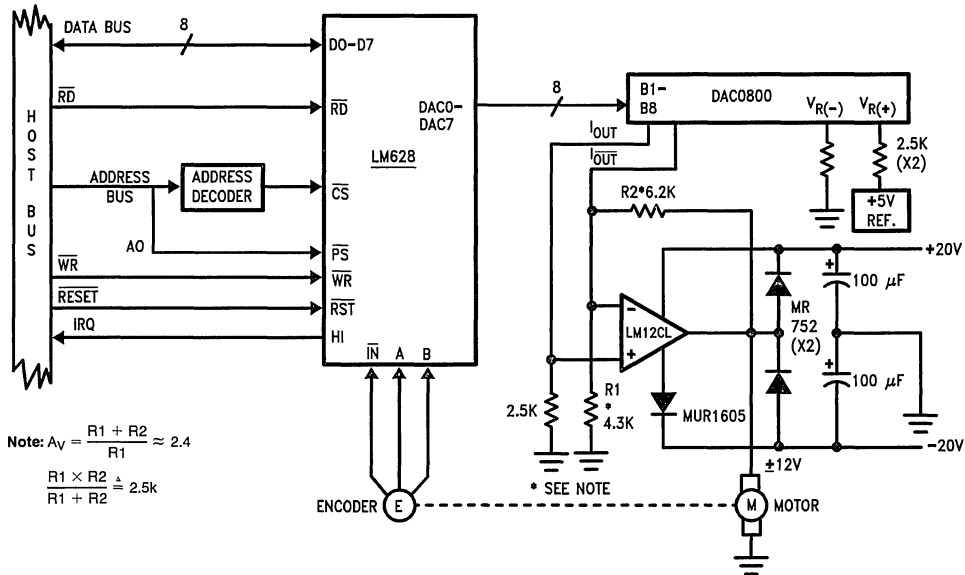


FIGURE 12. Host Interface and Minimum System Configuration

TL/H/9219-14

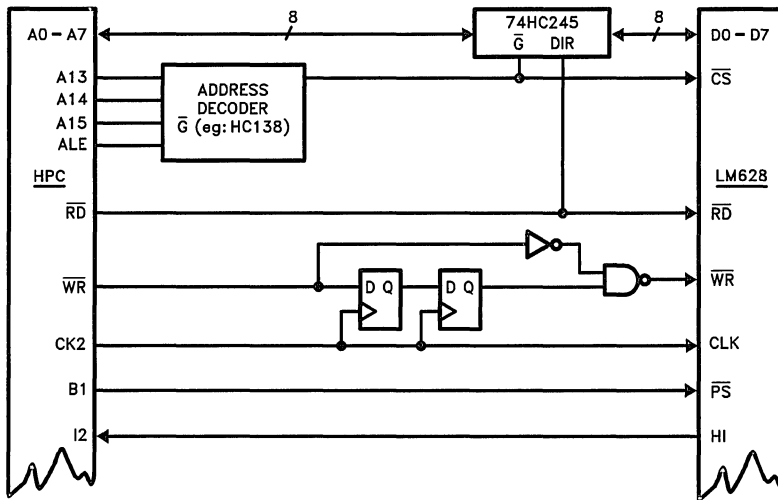
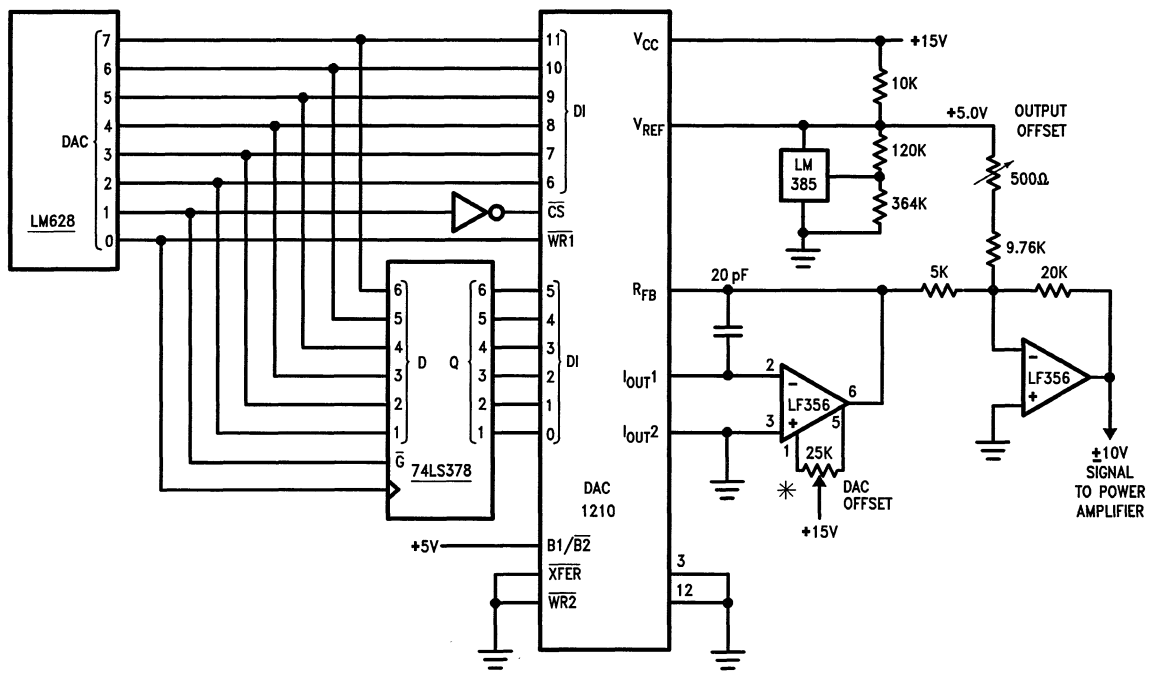


FIGURE 13. LM628 and HPC Interface

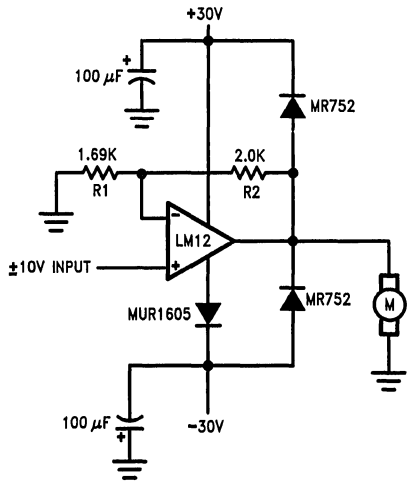
TL/H/9219-15



*DAC offset must be adjusted to minimize DAC linearity and monotonicity errors. See text.

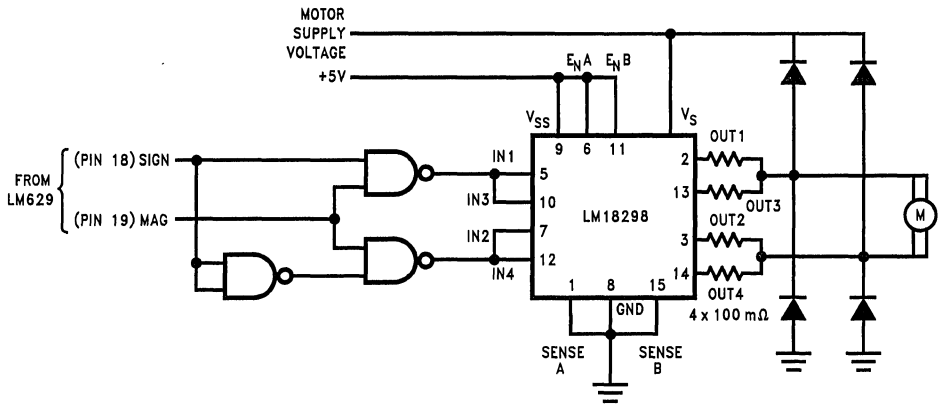
FIGURE 14. Interfacing a 12-Bit DAC and LM628

Typical Applications (Continued)



TL/H/9219-17

FIGURE 15. Driving a Motor with the LM12 Power Op Amp



TL/H/9219-18

FIGURE 16. PWM Drive for Brush/Commutator Motors

LM18293 Four Channel Push-Pull Driver

General Description

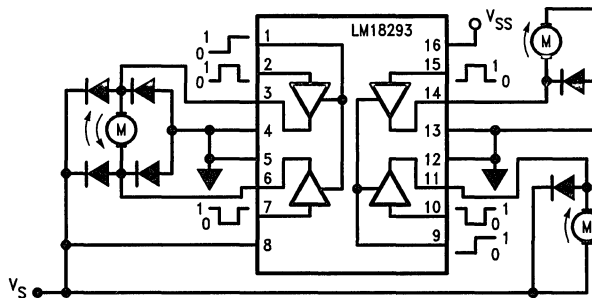
The LM18293 is designed to drive DC loads up to one amp. Typical applications include driving such inductive loads as solenoids, relays and stepper motors along with driving switching power transistors and use as a buffer for low level logic signals. The four inputs accept standard TTL and DTL levels for ease of interfacing. Two enable pins are provided that also accept the standard TTL and DTL levels. Each enable controls 2 channels and when an enable pin is disabled (tied low), the corresponding outputs are forced to the TRI-STATE® condition. If the enable pins are not connected (i.e., floating), the circuit will function as if it has been enabled. Separate pins are provided for the main power supply (pin 8), and the logic supply (pin 16). This allows a lower voltage to be used to bias up the logic resulting in reduced power dissipation. The chip is packaged in a specially de-

signed 16 pin power DIP. The 4 center pins of this package are tied together and form the die paddle inside the package. This provides much better heat sinking capability than most other DIP packages available. The device is capable of operating at voltages up to 36 volts.

Features

- 1A output current capability per channel
- Pin for pin replacement for L293B
- Special 16 pin power DIP package
- 36 volt operation
- Internal thermal overload protection
- Logical "0" input voltage up to 1.5 volts results in high noise immunity

Typical Connection



TL/H/8706-1

FIGURE 1. Application circuit showing bidirectional and on/off control of a single DC motor using two outputs and unidirectional on/off function of two DC motors using a single output each.

Order Number LM18293N
NS Package Number N16A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Output Drive Supply Voltage (V_S)	36V
Logic Supply Voltage (V_{SS})	36V
Input Voltage (V_I)	7V
Enable Voltage (V_E)	7V

Peak Output Current (Non-Repetitive $t = 5$ ms)	2A
Junction Temperature (T_J)	+150°C
Thermal Resistance Junction to Case (θ_{JC})	14°C/W
Thermal Resistance Junction to Ambient (θ_{JA})	80°C/W
Internal Power Dissipation	Internally Limited
Operating Temperature Range	-40°C to +125°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Solder 10 seconds)	260°C

Electrical Characteristics

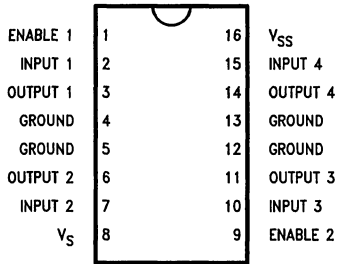
$V_S = 24V$, $V_{SS} = 5V$, $T = 25^\circ C$, $L = 0.4V$, $H = 3.5V$, each channel, unless otherwise noted

Symbol	Parameter	Conditions	Typical	Tested Limit (Note 1)	Design Limit (Note 2)	Units
V_S	Main Supply (Pin 8)	Maximum Supply Voltage		36		Vmax
V_{SS}	Logic Supply (Pin 16)	Minimum Logic Supply Voltage Maximum Logic Supply Voltage		4.5 36		Vmin Vmax
I_S	Total Quiescent Supply Current	$V_I = L$ $I_O = 0$ $V_E = H$ $V_I = H$ $I_O = 0$ $V_E = H$ $V_E = L$	2 16	6 24 4		mAmax mAmax mAmax
I_{SS}	Total Quiescent Logic Supply Current (pin 16)	$V_I = L$ $I_O = 0$ $V_E = H$ $V_I = H$ $I_O = 0$ $V_E = H$ $V_E = L$	44 16 16	60 22 24		mAmax mAmax mAmax
V_I	Input Voltage	Min Value of Low Max Value of Low Min Value of High Max Value of High ($V_{SS} \leq 7$) Max Value of High ($V_{SS} > 7$)		-0.3 1.5 2.3 V_{SS} 7		Vmin Vmax Vmin Vmax Vmax
I_I	Input Current	$V_I = L$ $V_I = H$	30	-10 100		μ Amax μ Amax
V_E	Enable Voltage (Pins 1, 9)	Min Value of Low Max Value of Low Min Value of High Max Value of High ($V_{SS} \leq 7$) Max Value of High ($V_{SS} > 7$)		-0.3 1.5 2.3 V_{SS} 7		Vmin Vmax Vmin Vmax Vmax
I_E	Enable Current	$V_E = L$ $V_E = H$	-30	-100 ± 10		μ Amax μ Amax
$V_{CE \text{ sat Top}}$	Source Saturation Voltage	$I_O = -1$ amp	1.4	1.8		Vmax
$V_{CE \text{ sat Bottom}}$	Sink Saturation Voltage	$I_O = 1$ amp	1.2	1.8		Vmax
t_r	Rise Time	10%–90% V_O	250			ns
t_f	Fall Time	90%–10% V_O	250			ns
t_{on}	Turn-On Delay	50% V_I to 50% V_O	450			ns
t_{off}	Turn-Off Delay	50% V_I to 50% V_O	200			ns

Note 1: Tested limits are guaranteed and 100% production tested.

Note 2: Design limits are guaranteed (but not 100% production tested) over the full supply and temperature range. These limits are not used to calculate outgoing quality levels.

Connection Diagram



Input/Output Truth Table

V _E (**)	V _I (Each Channel)	V _O
H	H	H
H	L	L
L	H	X (*)
L	L	X (*)

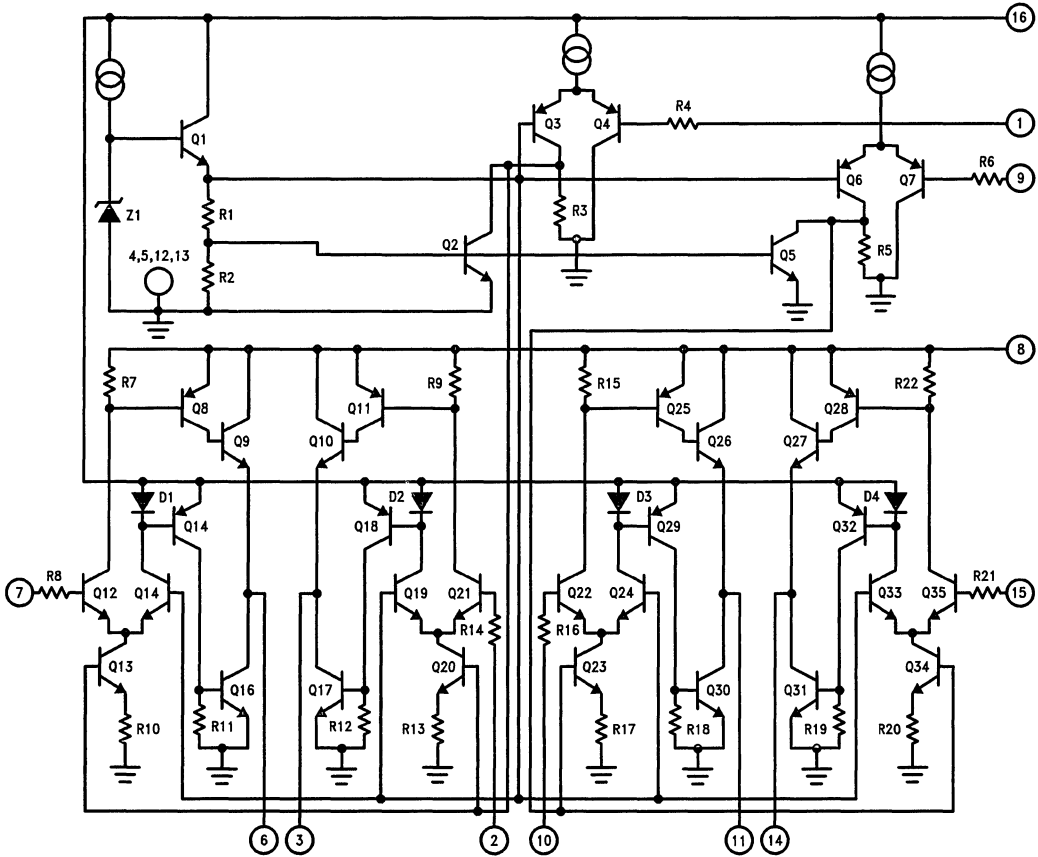
(*) High output impedance.

(**) Relative to the pertinent channel.

Enable 1 activates outputs 1 & 2
 Enable 2 activates outputs 3 & 4

TL/H/8706-2

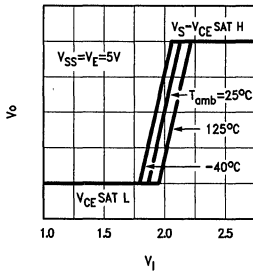
Simplified Schematic



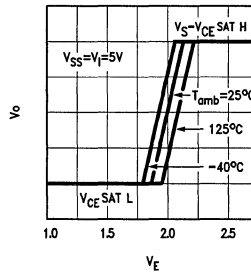
TL/H/8706-3

Typical Performance Characteristics V_S in all cases = 24V

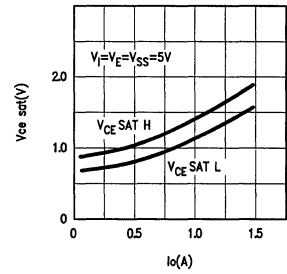
Output Voltage vs. Input Voltage



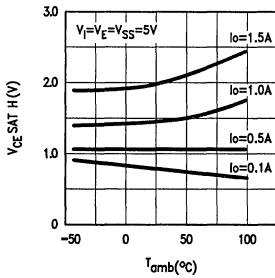
Output Voltage vs. Enable Voltage



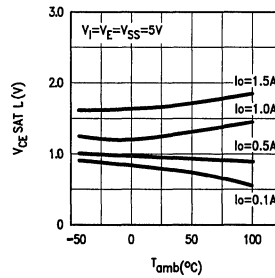
Saturation Voltage vs. Output Current



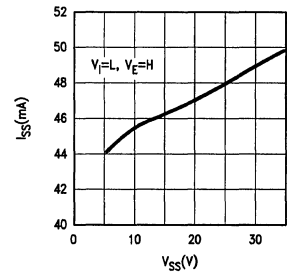
Source Saturation Voltage vs. Ambient Temperature



Sink Saturation Voltage vs. Ambient Temperature



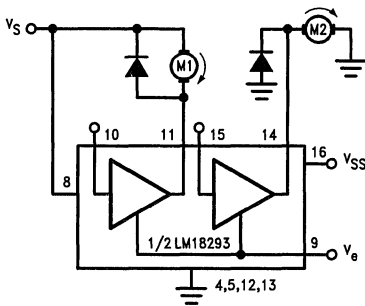
Quiescent Logic Supply Current vs. Logic Supply Voltage



TL/H/8706-4

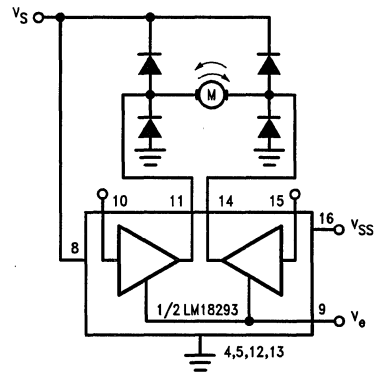
Typical Applications

DC motor controls (with connections to ground and to the supply voltages)



TL/H/8706-5

Bidirectional DC motor control



TL/H/8706-6

V_E	Pin 10	Pin 15	M1	M2
H	H	H	Fast Motor Stop	Run
H	H	L	Fast Motor Stop	Fast Motor Stop
H	L	H	Run	Run
H	L	L	Run	Fast Motor Stop
L	X	X	Free Running Motor Stop	Free Running Motor Stop

L = Low H = High X = Don't care

	Inputs	Function
$V_E = H$	Pin 10 = H Pin 15 = L	Turn CW
	Pin 10 = L Pin 15 = H	Turn CCW
	Pin 10 = Pin 15	Fast Motor Stop
$V_E = L$	Pin 10 = X Pin 15 = X	Free Running Motor Stop

L = Low H = High X = Don't care

Bipolar Stepping Motor Control

Step Sequencing Tables

Full Step *

V _{IN 1}	V _{IN 2}	Step
L	L	1
L	H	2
H	H	3
H	L	4
L	L	1

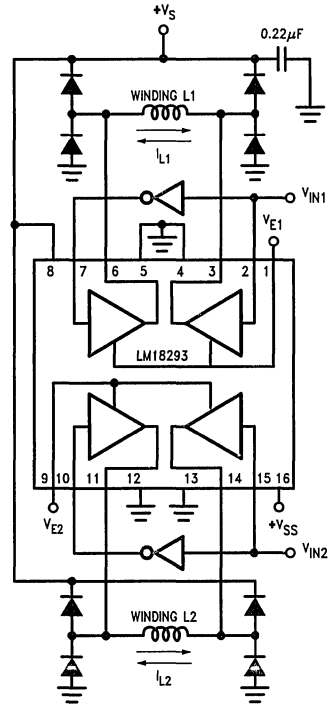
*V_{E 1} and V_{E 2} = H

Half Step

V _{E 1}	V _{E 2}	V _{IN 1}	V _{IN 2}	Step
H	L	L	X	1
H	H	L	L	2
L	H	X	L	3
H	H	H	L	4
H	L	H	X	5
H	H	H	H	6
L	H	X	H	7
H	H	L	H	8
H	L	L	X	1

H = High L = Low X = Don't care

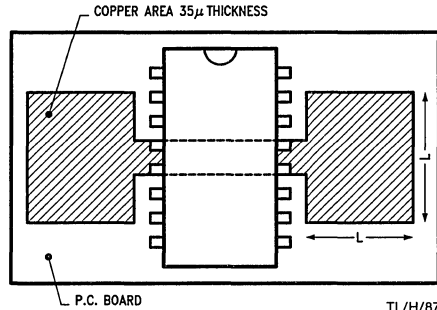
Motor Control Block Diagram



TL/H/8706-7

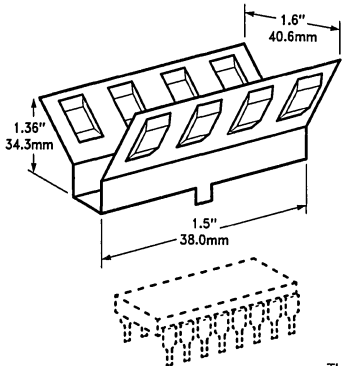
Mounting Instructions

The junction to ambient thermal resistance of the LM18293 can be reduced by soldering the ground pins to a suitable copper area of the printed circuit board or to an external heatsink. The graph below, which shows the maximum power dissipated and junction to ambient thermal resistance as a function of the side "l" of two equal square copper areas having a thickness of 35µ, illustrates this. In addition, it is possible to use an external heatsink (see illustration below). During soldering the pins temperature must not exceed 230°C and the soldering time must not be longer than 12 seconds. The external heatsink or printed circuit copper area must be connected to electrical ground.



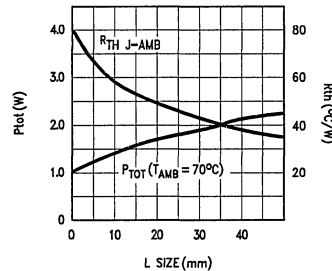
TL/H/8706-8

Staver External Heat-sink



TL/H/8706-10

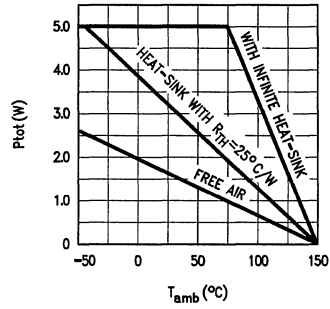
Maximum power dissipated and junction to ambient thermal resistance vs. size



TL/H/8706-9

Mounting Instructions (Continued)

**Maximum Allowable
Power Dissipation
vs Ambient Temperature**



TL/H/8706-11

LM18298 Dual Full-Bridge Driver

General Description

The LM18298 is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to gate the input control signals.

The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of a current sensing resistor. An additional supply input is provided to accommodate conventional logic supply voltages.

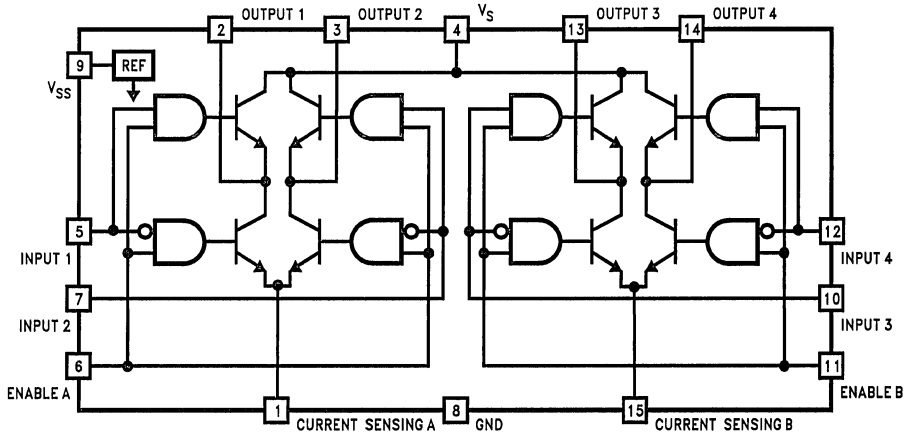
Features

- Power supply voltage up to 46V
- 2A output per channel
- Low saturation voltage
- Thermal shutdown protection
- Logical "0" input voltage up to 1.5V (High noise immunity)
- Pin for pin replacement for L298N

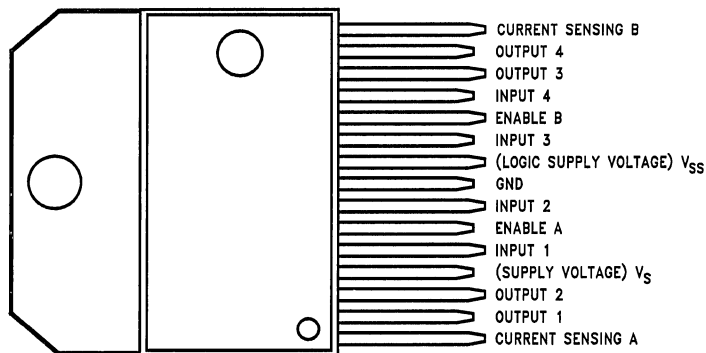
Applications

- DC and stepper motor drivers
- Relay and solenoid drivers

Block & Connection Diagrams



TL/H/9302-1



TL/H/9302-2

TO 220-15
 Order Number LM18298T
 NS Package Number TA15A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Main Supply (Pin 4)	50V
Logic Supply (Pin 9)	7V
Logic Inputs (Pins 5, 6, 7, 10, 11, 12)	-0.3 to 7V
Peak Output Current (Per Channel)	
Non-Repetitive ($t = 100 \mu\text{s}$)	3A
Repetitive (80% duty cycle, $t_{\text{ON}} = 10 \text{ ms}$)	2.5A
DC Operation	2A

Sense Voltage (Pins 1, 15)	-1 to +2.3V
Power Dissipation (Note 2)	25W
ESD Susceptibility (Note 3)	1 kV
Lead Temperature (Soldering, 10 seconds)	260°C
Storage Temperature Range	-65°C to +150°C

Operating Ratings

Junction Temperature Range (T_J)	-40°C to +150°C
Main Supply (Pin 4)	46V

Electrical Characteristics

$V_S = 42\text{V}$, $V_{SS} = 5\text{V}$, $I_O = 0\text{A}$, $T_J = 25^\circ\text{C}$, $L = 0\text{V}$, $H = 5\text{V}$, unless otherwise specified

Symbol	Parameter	Conditions	Typical (Note 4)	Limit (Note 5)	Units (Limits)
V_S	Main Supply Voltage (Pin 4)			$V_{SS} + 2.5$	V (min)
				46	V (max)
V_{SS}	Logic Supply Voltage (Pin 9)			4.5	V (min)
				7	V (max)
I_S	Main Supply Quiescent Current (Pin 4)	Enable = H, Input = L	9	22	mA (max)
		Enable = H, Input = H	32	70	
		Enable = L, Input = X		4	
I_{SS}	Logic Supply Quiescent Current (Pin 9)	Enable = H, Input = L	22	36	mA (max)
		Enable = H, Input = H	6	12	
		Enable = L, Input = X		6	
V_{IL}	Low Level Input Voltage (Pins 5, 7, 10, 12)			-0.3	V (min)
				1.5	V (max)
V_{IH}	High Level Input Voltage (Pins 5, 7, 10, 12)			2.3	V (min)
				V_{SS}	V (max)
I_{IL}	Low Level Input Current (Pins 5, 7, 10, 12)	Input = L		-10	μA (max)
I_{IH}	High Level Input Current (Pins 5, 7, 10, 12)	Input = H	30	100	μA (max)
V_{ENL}	Low Level Enable Voltage (Pins 6, 11)			-0.3	V (min)
				1.5	V (max)
V_{ENH}	High Level Enable Voltage (Pins 6, 11)			2.3	V (min)
				V_{SS}	V (max)
I_{ENL}	Low Level Enable Input Current (Pins 6, 11)	Enable = L		-10	μA (max)
I_{ENH}	High Level Enable Input Current (Pins 6, 11)	Enable = H	30	100	μA (max)

Electrical Characteristics (Continued)
 $V_S = 42V$, $V_{SS} = 5V$, $I_O = 0A$, $T_J = 25^\circ C$, unless otherwise specified

Symbol	Parameter	Conditions	Typical (Note 4)	Limit (Note 5)	Units (Limits)
$V_{CE\ sat\ (H)}$	Source Saturation Voltage (Pins 2, 3, 13, 14)	$I_O = 1A$	1.35	1.7	V (max)
		$I_O = 2A$	2.0	2.7	
$V_{CE\ sat\ (L)}$	Sink Saturation Voltage (Pins 2, 3, 13, 14)	$I_O = 1A$	1.2	1.6	V (max)
		$I_O = 2A$	1.7	2.3	
$V_{CE\ sat}$	Total Drop $V_{CE\ sat\ (H)} + V_{CE\ sat\ (L)}$	$I_O = 1A$		3.2	V (max)
		$I_O = 2A$		4.9	
V_{sense}	Sensing Voltage (Pins 1, 15)	$t \leq 50\ \mu s$		-1	V (min)
		Continuous		-0.5	
		Continuous		2	V (max)
T_1	Source Current Turn-Off Delay	0.5 Input to 0.9 I_O (Figure 2)	0.5		μs
T_2	Source Current Fall Time	0.9 I_O to 0.1 I_O (Figure 2)	0.15		μs
T_3	Source Current Turn-On Delay	0.5 Input to 0.1 I_O (Figure 2)	1.3		μs
T_4	Source Current Rise Time	0.1 I_O to 0.9 I_O (Figure 2)	0.85		μs
T_5	Sink Current Turn-Off Delay	0.5 Input to 0.9 I_O (Figure 3)	0.25		μs
T_6	Sink Current Fall Time	0.9 I_O to 0.1 I_O (Figure 3)	0.1		μs
T_7	Sink Current Turn-On Delay	0.5 Input to 0.1 I_O (Figure 3)	1.3		μs
T_8	Sink Current Rise Time	0.1 I_O to 0.9 I_O (Figure 3)	0.1		μs
f_C	Commutation Frequency	$I_O = 2A$	25		kHz

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

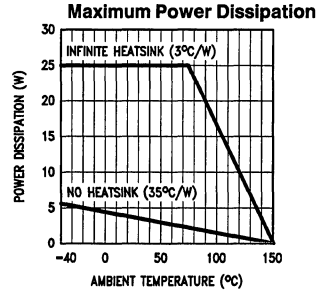
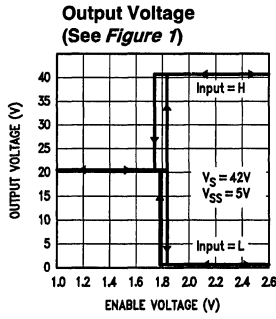
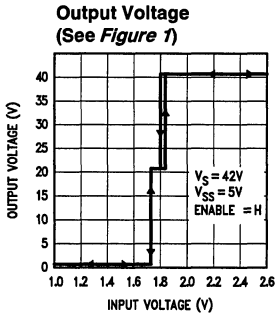
Note 2: The maximum power dissipation must be derated at elevated temperatures and is a function of $T_{J\ max}$, θ_{JC} , and T_C . The maximum allowable power dissipation at any temperature is $P_{D\ max} = (T_{J\ max} - T_C)/\theta_{JC}$ or the number given in the **Absolute Maximum Ratings**, whichever is lower. The typical junction-to-case thermal resistance (θ_{JC}) of the LM18298 is $3^\circ C/W$.

Note 3: Human body model, 100 pF discharged through a 1.5 k Ω resistor.

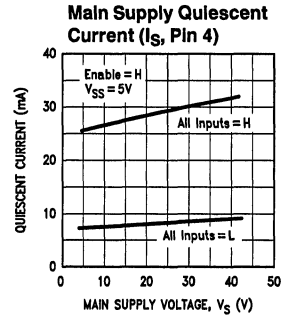
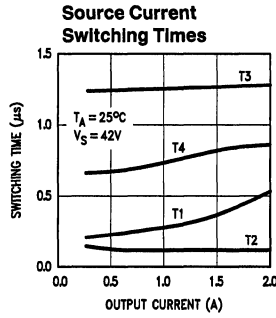
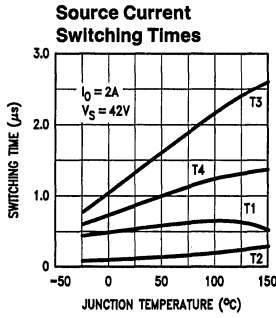
Note 4: Typicals are at $25^\circ C$ and represent the most likely parametric norm.

Note 5: Limits are guaranteed and 100% tested.

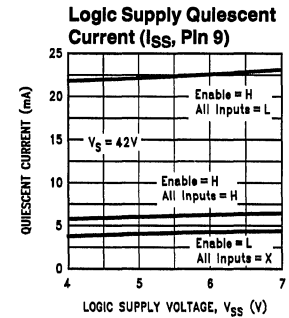
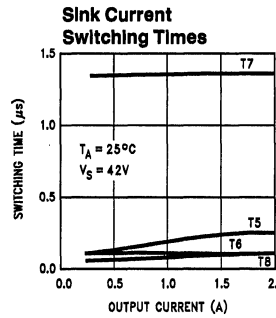
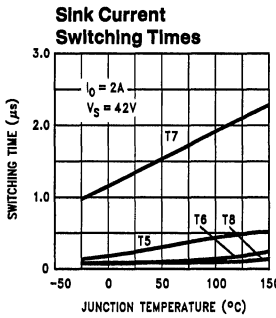
Typical Performance Characteristics



TL/H/9302-3

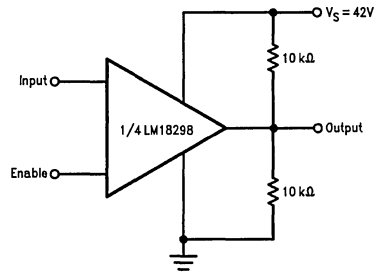


TL/H/9302-12



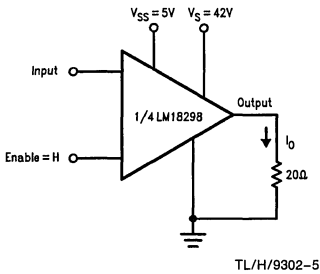
TL/H/9302-13

Test Circuits



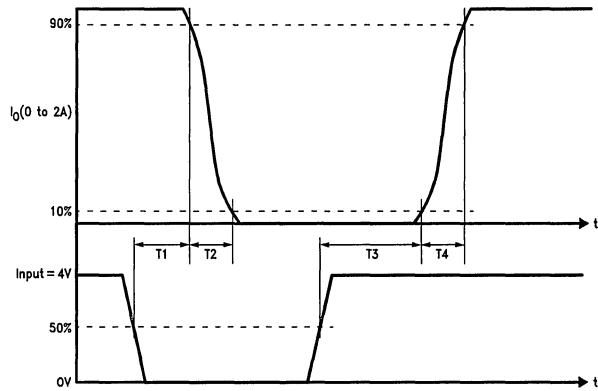
TL/H/9302-4

FIGURE 1. Input/Enable Threshold Test Circuit



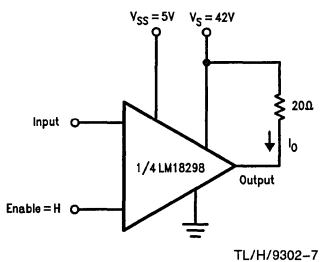
TL/H/9302-5

FIGURE 2(a). Source Current Switching Time Test Circuit



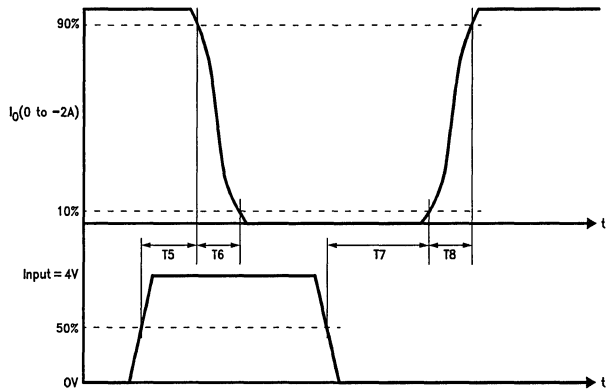
TL/H/9302-6

FIGURE 2(b). Source Current Switching Time Definitions



TL/H/9302-7

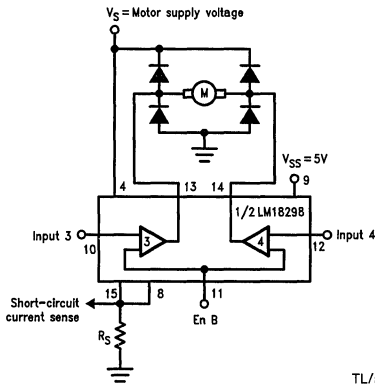
FIGURE 3(a). Sink Current Switching Time Test Circuit



TL/H/9302-8

FIGURE 3(b). Sink Current Switching Time Definitions

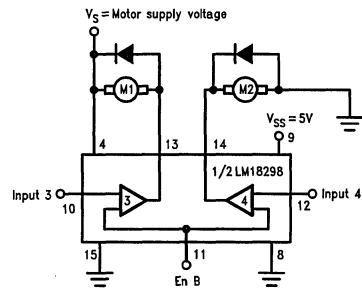
Applications Information



TL/H/9302-9

Enable B	Inputs	Motor Direction
H	Input 3 = H, Input 4 = L	Clockwise
	Input 3 = L, Input 4 = H	Counterclockwise
	Input 3 = Input 4	Dynamic Braking
L	Input 3 = X, Input 4 = Input 3	Coast to a Stop

L = Low H = High X = don't care
FIGURE 4. Bidirectional DC Motor Control



TL/H/9302-10

Enable B	Input 3	Motor 1	Input 4	Motor 2
H	H	Dynamic Braking	H	Run
H	L	Run	L	Dynamic Braking
L	X	Coast to a Stop	X	Coast to a Stop

L = Low H = High X = Don't Care
FIGURE 5. 2-Motor Controller (Using both High- and Low-Side Driver Modes)

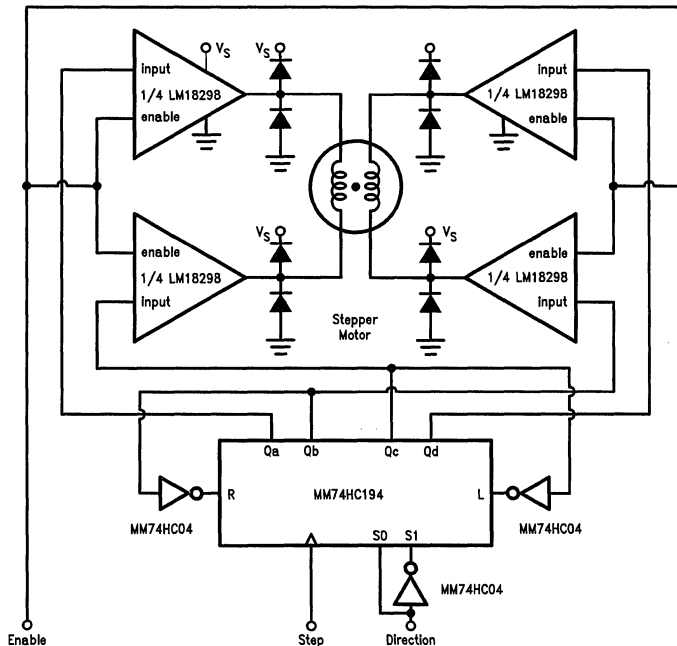


FIGURE 6. Two-Phase Bipolar Stepper Motor Control Circuit

TL/H/9302-11

CLAMP DIODES

When driving inductive loads, diodes are necessary to clamp spikes at the LM18298 outputs. Clamp diodes must have a recovery time of 200 ns or better and a forward drop

of 1.2V or less at the rated load current. Typical devices are the MB346 (Microsemi Corp., Santa Ana, CA), and the V331X (Varo Semiconductor Inc., Garland, TX).

LMD18200 3A, 55V H-Bridge

General Description

The LMD18200 is a 3A H-Bridge designed for motion control applications. The device is built using a multi-technology process which combines bipolar and CMOS control circuitry with DMOS power devices on the same monolithic structure. Ideal for driving DC and stepper motors; the LMD18200 accommodates peak output currents up to 6A. An innovative circuit which facilitates low-loss sensing of the output current has been implemented.

Features

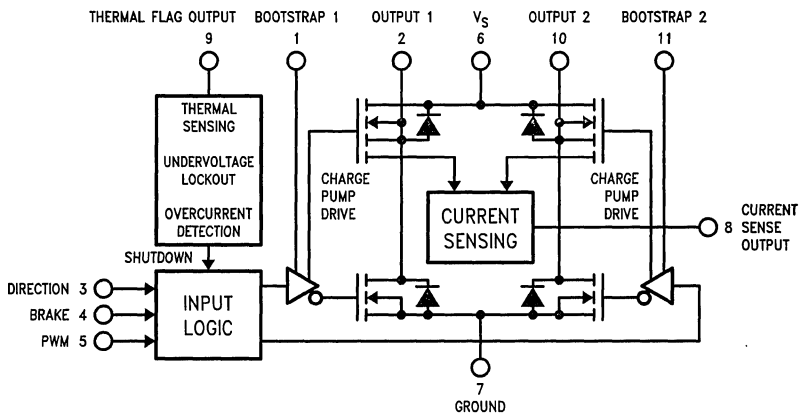
- Delivers up to 3A continuous output
- Operates at supply voltages up to 55V
- Low $R_{DS(ON)}$ typically 0.3 Ω per switch

- TTL and CMOS compatible inputs
- No "shoot-through" current
- Thermal warning flag output at 145°C
- Thermal shutdown (outputs off) at 170°C
- Internal clamp diodes
- Shorted load protection
- Internal charge pump with external bootstrap capability

Applications

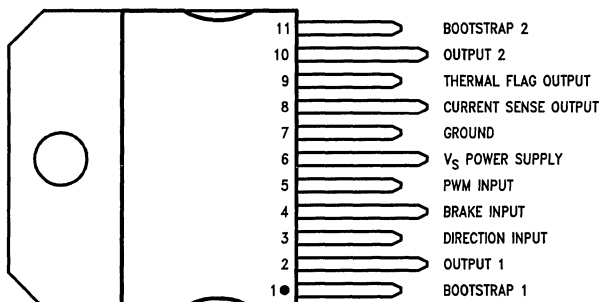
- DC and stepper motor drives
- Position and velocity servomechanisms
- Factory automation robots
- Numerically controlled machinery
- Computer printers and plotters

Functional Diagram



TL/H/10568-1

Connection Diagram and Ordering Information



MOUNTING TAB CONNECTED TO GROUND (PIN 7)

Top View

TL/H/10568-2

Order Number LMD18200T
See NS Package TA11B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage (V_S , Pin 6)	60V
Voltage at Pins 3, 4, 5, 8 and 9	12V
Voltage at Bootstrap Pins (Pins 1 and 11)	$V_{OUT} + 16V$
Peak Output Current (200 ms)	6A
Continuous Output Current (Note 2)	3A
Power Dissipation (Note 3)	25W

Power Dissipation ($T_A = 25^\circ\text{C}$, Free Air)	3W
Junction Temperature, $T_{J(\text{max})}$	150°C
ESD Susceptibility (Note 4)	1500V
Storage Temperature, T_{STG}	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Operating Ratings (Note 1)

Junction Temperature, T_J	-40°C to +125°C
V_S Supply Voltage	+12V to +55V

Electrical Characteristics

The following specifications apply for $V_S = 42V$, unless otherwise specified. **Boldface** limits apply over the entire operating temperature range, $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$, all other limits are for $T_A = T_J = 25^\circ\text{C}$. (Note 5)

Symbol	Parameter	Conditions	Typ	Limit	Units
$R_{DS(\text{ON})}$	Switch ON Resistance	Output Current = 3A (Note 6)	0.33	0.4/ 0.6	Ω (max)
$R_{DS(\text{ON})}$	Switch ON Resistance	Output Current = 6A (Note 6)	0.33	0.4/ 0.6	Ω (max)
V_{CLAMP}	Clamp Diode Forward Drop	Clamp Current = 3A (Note 6)	1.2	1.5	V (max)
V_{IL}	Logic Low Input Voltage	Pins 3, 4, 5		-0.1 0.8	V (min) V (max)
I_{IL}	Logic Low Input Current	$V_{IN} = -0.1V$, Pins = 3, 4, 5		-10	μA (max)
V_{IH}	Logic High Input Voltage	Pins 3, 4, 5		2 12	V (min) V (max)
I_{IH}	Logic High Input Current	$V_{IN} = 12V$, Pins = 3, 4, 5		10	μA (max)
	Current Sense Output	$I_{OUT} = 1A$ (Note 8)	377	325/ 300 425/ 450	μA (min) μA (max)
	Current Sense Linearity	$1A \leq I_{OUT} \leq 3A$ (Note 7)	± 6	± 9	%
	Undervoltage Lockout	Outputs turn OFF		9 11	V (min) V (max)
T_{JW}	Warning Flag Temperature	Pin 9 $\leq 0.8V$, $I_L = 2\text{mA}$	145		$^\circ\text{C}$
$V_F(\text{ON})$	Flag Output Saturation Voltage	$T_J = T_{JW}$, $I_L = 2\text{mA}$	0.15		V
$I_F(\text{OFF})$	Flag Output Leakage	$V_F = 12V$	0.2	10	μA (max)
T_{JSD}	Shutdown Temperature	Outputs Turn OFF	170		$^\circ\text{C}$
I_S	Quiescent Supply Current	All Logic Inputs Low	13	25	mA (max)
t_{Don}	Output Turn-On Delay Time	Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	300 300		ns ns
t_{on}	Output Turn-On Switching Time	Bootstrap Capacitor = 10 nF Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	100 80		ns ns
t_{Doff}	Output Turn-Off Delay Times	Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	200 200		ns ns
t_{off}	Output Turn-Off Switching Times	Bootstrap Capacitor = 10 nF Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	75 70		ns ns
t_{pw}	Minimum Input Pulse Width	Pins 3, 4 and 5	1		μs
t_{cpr}	Charge Pump Rise Time	No Bootstrap Capacitor	20		μs

Electrical Characteristics Notes

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: See Application Information for details regarding current limiting.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is a function of $T_{J(max)}$, θ_{JA} , and T_A . The maximum allowable power dissipation at any temperature is $P_{D(max)} = (T_{J(max)} - T_A)/\theta_{JA}$, or the number given in the Absolute Ratings, whichever is lower. The typical thermal resistance from junction to case (θ_{JC}) is 1.0°C/W and from junction to ambient (θ_{JA}) is 30°C/W . For guaranteed operation $T_{J(max)} = 125^\circ\text{C}$.

Note 4: Human-body model, 100 pF discharged through a 1.5 k Ω resistor. Except Bootstrap pins (pins 1 and 11) which are protected to 1000V of ESD.

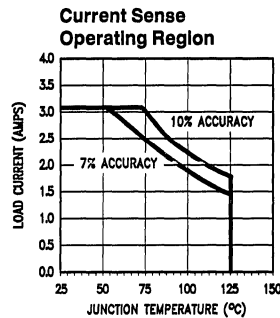
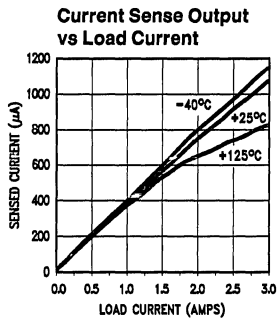
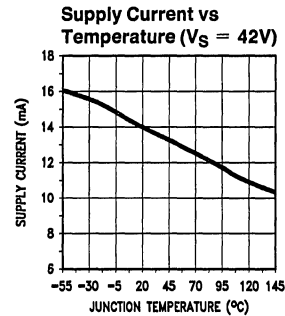
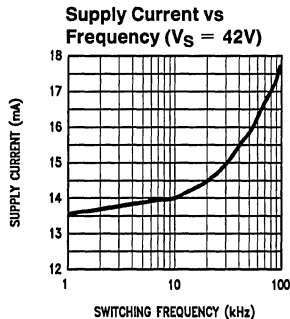
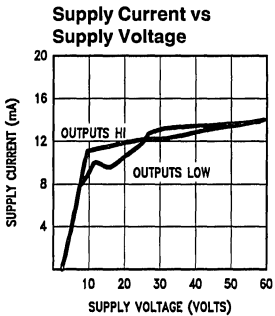
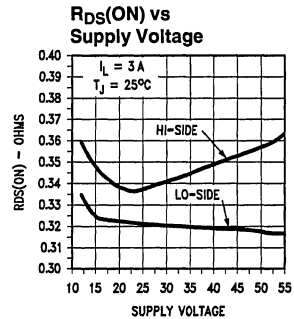
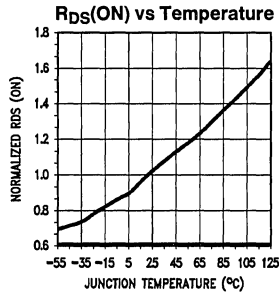
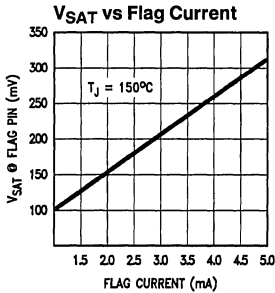
Note 5: All limits are 100% production tested at 25°C. Temperature extreme limits are guaranteed via correlation using accepted SQC (Statistical Quality Control) methods. All limits are used to calculate AOQL, (Average Outgoing Quality Level).

Note 6: Output currents are pulsed ($t_W < 2$ ms, Duty Cycle $< 5\%$).

Note 7: Regulation is calculated relative to the current sense output value with a 1A load.

Note 8: Selections for tighter tolerance are available. Contact factory.

Typical Performance Characteristics



TL/H/10588-3

Pinout Description (See Connection Diagram)

Pin 1, BOOTSTRAP 1 Input: Bootstrap capacitor pin for half H-bridge number 1. The recommended capacitor (10 nF) is connected between pins 1 and 2.

Pin 2, OUTPUT 1: Half H-bridge number 1 output.

Pin 3, DIRECTION Input: See Table I. This input controls the direction of current flow between OUTPUT 1 and OUTPUT 2 (pins 2 and 10) and, therefore, the direction of rotation of a motor load.

Pin 4, BRAKE Input: See Table I. This input is used to brake a motor by effectively shorting its terminals. When braking is desired, this input is taken to a logic high level and it is also necessary to apply logic high to PWM input, pin 5. The drivers that short the motor are determined by the logic level at the DIRECTION input (Pin 3): with Pin 3 logic high, both current sourcing output transistors are ON; with Pin 3 logic low, both current sinking output transistors are ON. All output transistors can be turned OFF by applying a logic high to Pin 4 and a logic low to PWM input Pin 5; in this case only a small bias current (approximately -1.5 mA) exists at each output pin.

Pin 5, PWM Input: See Table I. How this input (and DIRECTION input, Pin 3) is used is determined by the format of the PWM Signal.

Pin 6, V_S Power Supply

Pin 7, GROUND Connection: This pin is the ground return, and is internally connected to the mounting tab.

Pin 8, CURRENT SENSE Output: This pin provides the sourcing current sensing output signal, which is typically $377 \mu\text{A}/\text{A}$.

Pin 9, THERMAL FLAG Output: This pin provides the thermal warning flag output signal. Pin 9 becomes active-low at 145°C (junction temperature). However the chip will not shut itself down until 170°C is reached at the junction.

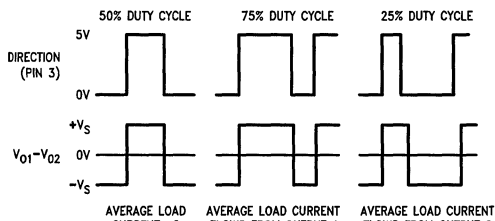
Pin 10, OUTPUT 2: Half H-bridge number 2 output.

Pin 11, BOOTSTRAP 2 Input: Bootstrap capacitor pin for Half H-bridge number 2. The recommended capacitor (10 nF) is connected between pins 10 and 11.

TABLE I. Logic Truth Table

PWM	Dir	Brake	Active Output Drivers
H	H	L	Source 1, Sink 2
H	L	L	Sink 1, Source 2
L	X	L	Source 1, Source 2
H	H	H	Source 1, Source 2
H	L	H	Sink 1, Sink 2
L	X	H	NONE

Locked Anti-Phase PWM Control



TL/H/10568-4

Application Information

TYPES OF PWM SIGNALS

The LMD18200 readily interfaces with different forms of PWM signals. Use of the part with two of the more popular forms of PWM is described in the following paragraphs.

Simple, locked anti-phase PWM consists of a single, variable duty-cycle signal in which is encoded both direction and amplitude information. A 50% duty-cycle PWM signal represents zero drive, since the net value of voltage (integrated over one period) delivered to the load is zero. For the LMD18200, the PWM signal drives the direction input (pin 3) and the PWM input (pin 5) is tied to logic high.

Sign/magnitude PWM consists of separate direction (sign) and amplitude (magnitude) signals. The (absolute) magnitude signal is duty-cycle modulated, and the absence of a pulse signal (a continuous logic low level) represents zero drive. Current delivered to the load is proportional to pulse width. For the LMD18200, the DIRECTION input (pin 3) is driven by the sign signal and the PWM input (pin 5) is driven by the magnitude signal.

USING THE CURRENT SENSE OUTPUT

The CURRENT SENSE output (pin 8) has a sensitivity of $377 \mu\text{A}$ per ampere of output current. For optimal accuracy and linearity of this signal, the value of voltage generating resistor between pin 8 and ground should be chosen to limit the maximum voltage developed at pin 8 to 5V, or less. The maximum voltage compliance is 12V.

It should be noted that the recirculating currents (free wheeling currents) are ignored by the current sense circuitry. Therefore, only the currents in the upper sourcing outputs are sensed.

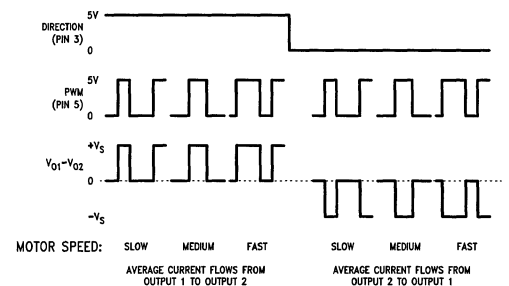
USING THE THERMAL WARNING FLAG

The THERMAL FLAG output (pin 9) is an open collector transistor. This permits a wired OR connection of thermal warning flag outputs from multiple LMD18200's, and allows the user to set the logic high level of the output signal swing to match system requirements. This output typically drives the interrupt input of a system controller. The interrupt service routine would then be designed to take appropriate steps, such as reducing load currents or initiating an orderly system shutdown. The maximum voltage compliance on the flag pin is 12V.

SUPPLY BYPASSING

During switching transitions the levels of fast current changes experienced may cause troublesome voltage transients across system stray inductance.

Sign/Magnitude PWM Control



TL/H/10568-5

Application Information (Continued)

It is normally necessary to bypass the supply rail with a high quality capacitor(s) connected as close as possible to the V_S Power Supply (Pin 6) and GROUND (Pin 7). A 1 μF high-frequency ceramic capacitor is recommended. Care should be taken to limit the transients on the supply pin below the Absolute Maximum Rating of the device. When operating the chip at supply voltages above 40V a voltage suppressor (transorb) such as P6KE62A is recommended from supply to ground. Typically the ceramic capacitor can be eliminated in the presence of the voltage suppressor. Note that when driving high load currents a greater amount of supply bypass capacitance (in general at least 100 μF per Amp of load current) is required to absorb the recirculating currents of the inductive loads.

CURRENT LIMITING

Current limiting protection circuitry has been incorporated into the design of the LMD18200. With any power device it is important to consider the effects of the substantial surge currents through the device that may occur as a result of shorted loads. The protection circuitry monitors this increase in current (the threshold is set to approximately 10 Amps) and shuts off the power device as quickly as possible in the event of an overload condition. In a typical motor driving application the most common overload faults are caused by shorted motor windings and locked rotors. Under these conditions the inductance of the motor (as well as any series inductance in the V_{CC} supply line) serves to reduce the magnitude of a current surge to a safe level for the LMD18200. Once the device is shut down, the control circuitry will periodically try to turn the power device back on. This feature allows the immediate return to normal operation in the event that the fault condition has been removed. While the fault remains however, the device will cycle in and out of thermal shutdown. This can create voltage transients on the V_{CC} supply line and therefore proper supply bypassing techniques are required.

The most severe condition for any power device is a direct, hard-wired ("screwdriver") long term short from an output to ground. This condition can generate a surge of current through the power device on the order of 15 Amps and require the die and package to dissipate up to 500 Watts of power for the short time required for the protection circuitry to shut off the power device. This energy can be destructive, particularly at higher operating voltages (>30V) so

some precautions are in order. Proper heat sink design is essential and it is normally necessary to heat sink the V_{CC} supply pin (pin 6) with 1 square inch of copper on the PCB.

INTERNAL CHARGE PUMP AND USE OF BOOTSTRAP CAPACITORS

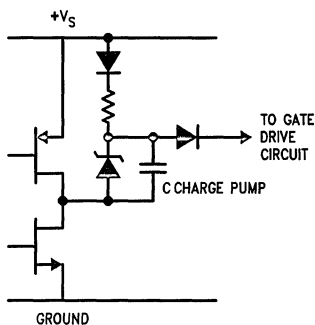
To turn on the high-side (sourcing) DMOS power devices, the gate of each device must be driven approximately 8V more positive than the supply voltage. To achieve this an internal charge pump is used to provide the gate drive voltage. As shown in *Figure 1*, an internal capacitor is alternately switched to ground and charged to about 14V, then switched to V supply thereby providing a gate drive voltage greater than V supply. This switching action is controlled by a continuously running internal 300 kHz oscillator. The rise time of this drive voltage is typically 20 μs which is suitable for operating frequencies up to 1 kHz.

For higher switching frequencies, the LMD18200 provides for the use of external bootstrap capacitors. The bootstrap principle is in essence a second charge pump whereby a large value capacitor is used which has enough energy to quickly charge the parasitic gate input capacitance of the power device resulting in much faster rise times. The switching action is accomplished by the power switches themselves (*Figure 2*). External 10 nF capacitors, connected from the outputs to the bootstrap pins of each high-side switch provide typically less than 100 ns rise times allowing switching frequencies up to 500 kHz.

INTERNAL PROTECTION DIODES

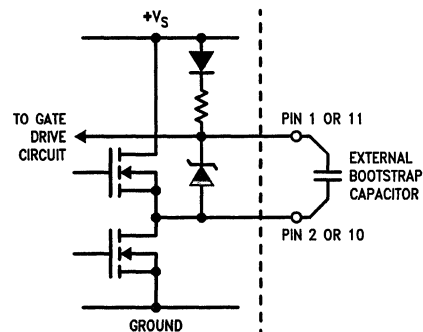
A major consideration when switching current through inductive loads is protection of the switching power devices from the large voltage transients that occur. Each of the four switches in the LMD18200 have a built-in protection diode to clamp transient voltages exceeding the positive supply or ground to a safe diode voltage drop across the switch.

The reverse recovery characteristics of these diodes, once the transient has subsided, is important. These diodes must come out of conduction quickly and the power switches must be able to conduct the additional reverse recovery current of the diodes. The reverse recovery time of the diodes protecting the sourcing power devices is typically only 70 ns with a reverse recovery current of 1A when tested with a full 6A of forward current through the diode. For the sinking devices the recovery time is typically 100 ns with 4A of reverse current under the same conditions.



TL/H/10568-6

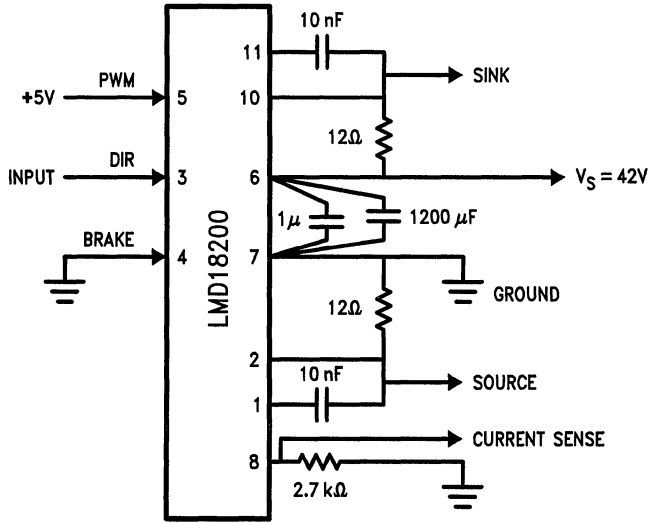
FIGURE 1. Internal Charge Pump Circuitry



TL/H/10568-7

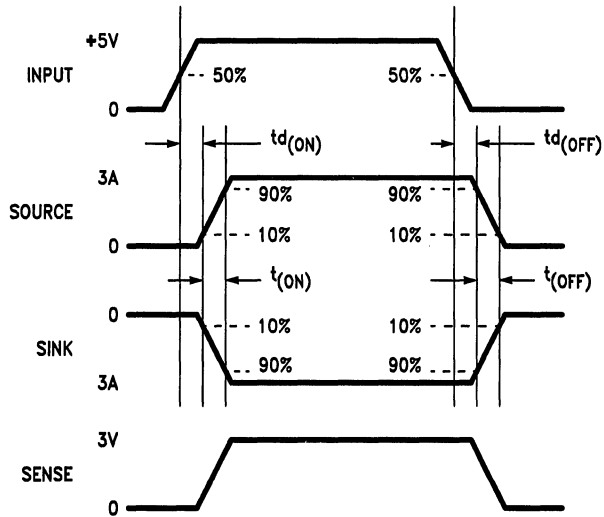
FIGURE 2. Bootstrap Circuitry

Test Circuit



TL/H/10568-8

Switching Time Definitions

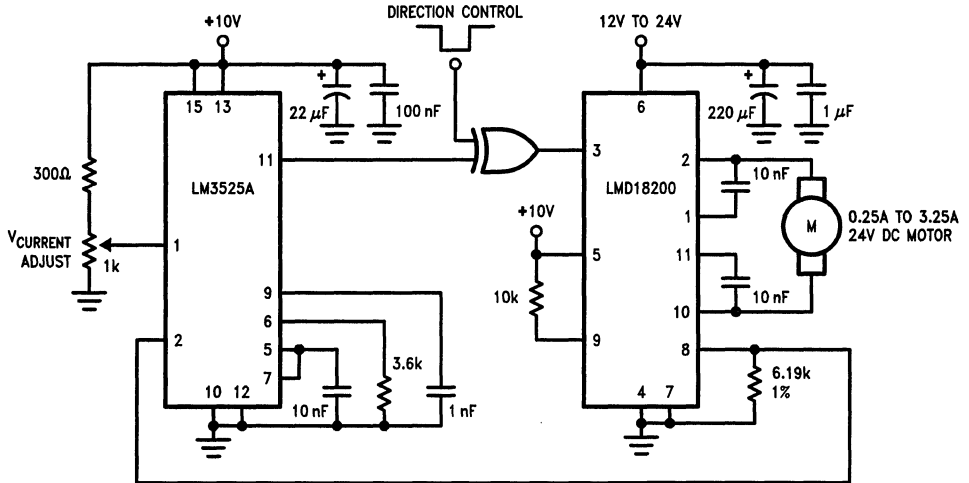


TL/H/10568-9

Typical Applications (Continued)

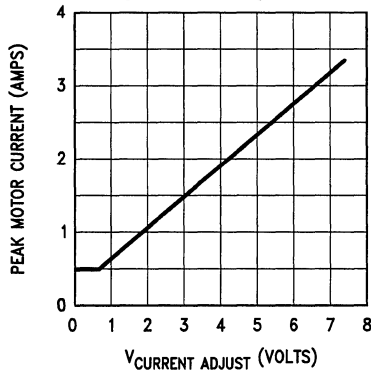
TORQUE REGULATION

Locked Anti-Phase Control of a brushed DC motor. Current sense output of the LMD18200 provides load sensing. The LM3525A is a general purpose PWM controller.



TL/H/10568-12

Peak Motor Current vs Adjustment Voltage

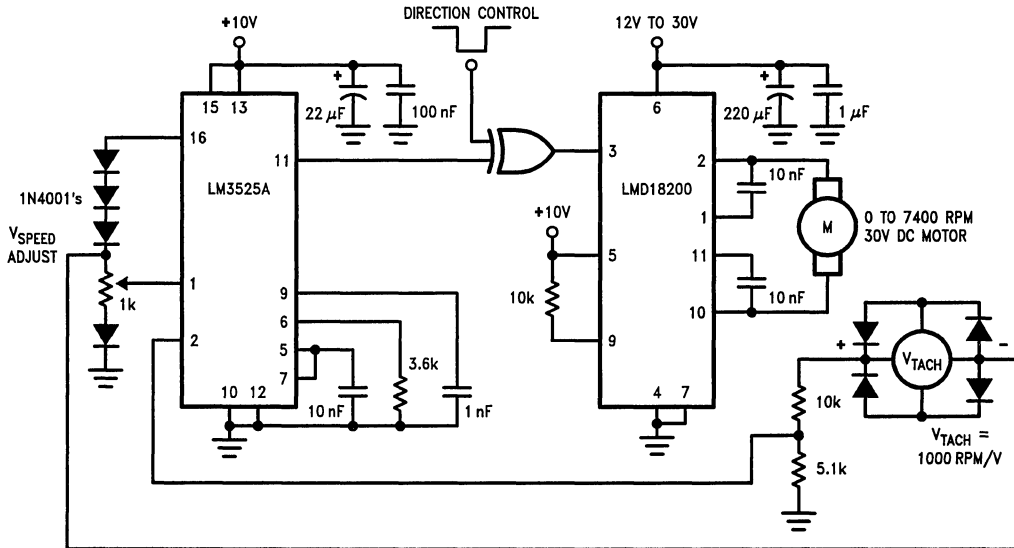


TL/H/10568-13

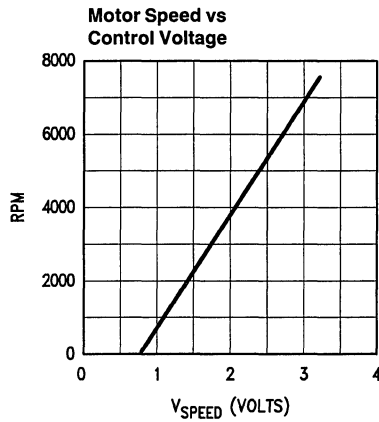
Typical Applications (Continued)

VELOCITY REGULATION

Utilizes tachometer output from the motor to sense motor speed for a locked anti-phase control loop.



TL/H/10568-14



TL/H/10568-15



LMD18201 3A, 55V H-Bridge

General Description

The LMD18201 is a 3A H-Bridge designed for motion control applications. The device is built using a multi-technology process which combines bipolar and CMOS control circuitry with DMOS power devices on the same monolithic structure. The H-Bridge configuration is ideal for driving DC and stepper motors. The LMD18201 accommodates peak output currents up to 6A. Current sensing can be achieved via a small sense resistor connected in series with the power ground lead. For current sensing without disturbing the path of current to the load, the LMD18200 is recommended.

Features

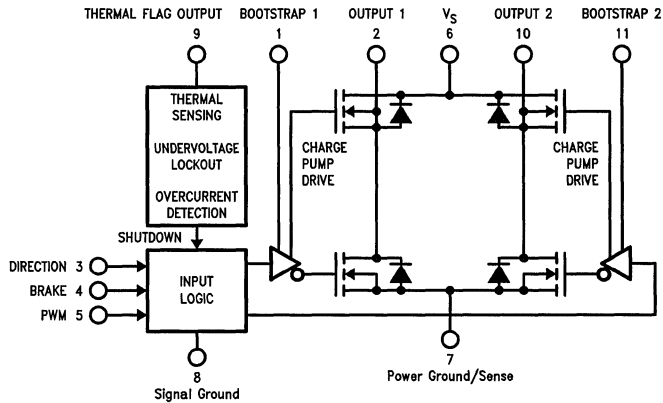
- Delivers up to 3A continuous output
- Operates at supply voltages up to 55V
- Low $R_{DS(ON)}$ typically 0.33Ω per switch

- TTL and CMOS compatible inputs
- No "shoot-through" current
- Thermal warning flag output at 145°C
- Thermal shutdown (outputs off) at 170°C
- Internal clamp diodes
- Shorted load protection
- Internal charge pump with external bootstrap capability

Applications

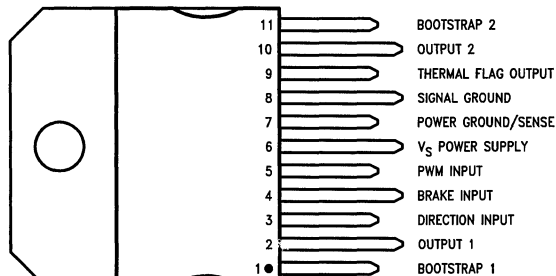
- DC and stepper motor drives
- Position and velocity servomechanisms
- Factory automation robots
- Numerically controlled machinery
- Computer printers and plotters

Functional Diagram



TL/H/10793-1

Connection Diagram and Ordering Information



— MOUNTING TAB CONNECTED TO GROUND (PIN 7)

Top View

TL/H/10793-2

Order Number LMD18201T
See NS Package Number TA11B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage (V_S , Pin 6)	60V
Voltage at Pins 3, 4, 5 and 9	12V
Voltage at Bootstrap Pins (Pins 1 and 11)	$V_{OUT} + 16V$
Peak Output Current (200 ms)	6A
Continuous Output Current (Note 2)	3A
Power Dissipation (Note 3)	25W
Sense Voltage (Pin 7 to Pin 8)	+0.5V to -1.0V

Power Dissipation ($T_A = 25^\circ\text{C}$, Free Air)	3W
Junction Temperature, $T_{J(\text{max})}$	150°C
ESD Susceptibility (Note 4)	1500V
Storage Temperature, T_{STG}	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Operating Ratings (Note 1)

Junction Temperature, T_J	-40°C to +125°C
V_S Supply Voltage	+12V to +55V

Electrical Characteristics

The following specifications apply for $V_S = 42V$, unless otherwise specified. **Boldface** limits apply over the entire operating temperature range, $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$, all other limits are for $T_A = T_J = 25^\circ\text{C}$. (Note 5)

Symbol	Parameter	Conditions	Typ	Limit	Units
$R_{DS(ON)}$	Switch ON Resistance	Output Current = 3A (Note 6)	0.33	0.4/0.6	Ω (max)
$R_{DS(ON)}$	Switch ON Resistance	Output Current = 6A (Note 6)	0.33	0.4/0.6	Ω (max)
V_{CLAMP}	Clamp Diode Forward Drop	Clamp Current = 3A (Note 6)	1.2	1.5	V (max)
V_{IL}	Logic Low Input Voltage	Pins 3, 4, 5		-0.1 0.8	V (min) V (max)
I_{IL}	Logic Low Input Current	$V_{IN} = -0.1V$, Pins = 3, 4, 5		-10	μA (max)
V_{IH}	Logic High Input Voltage	Pins 3, 4, 5		2 12	V (min) V (max)
I_{IL}	Logic High Input Current	$V_{IN} = 12V$, Pins = 3, 4, 5		10	μA (max)
	Undervoltage Lockout	Outputs Turn OFF		9 11	V (min) V (max)
T_{JW}	Warning Flag Temperature	Pin 9 $\leq 0.8V$, $I_L = 2\text{ mA}$	145		°C
$V_{F(ON)}$	Flag Output Saturation Voltage	$T_J = T_{JW}$, $I_L = 2\text{ mA}$	0.15		V
$I_{F(OFF)}$	Flag Output Leakage	$V_F = 12V$	0.2	10	μA (max)
T_{JSD}	Shutdown Temperature	Outputs Turn OFF	170		°C
I_S	Quiescent Supply Current	All Logic Inputs Low	13	25	mA (max)
$t_{D(ON)}$	Output Turn-On Delay Time	Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	300 300		ns ns
t_{ON}	Output Turn-On Switching Time	Bootstrap Capacitor = 10 nF Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	100 80		ns ns
$t_{D(OFF)}$	Output Turn-Off Delay Times	Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	200 200		ns ns
t_{OFF}	Output Turn-Off Switching Times	Bootstrap Capacitor = 10 nF Sourcing Outputs, $I_{OUT} = 3A$ Sinking Outputs, $I_{OUT} = 3A$	75 70		ns ns
t_{PW}	Minimum Input Pulse Width	Pins 3, 4 and 5	1		μs
t_{CPR}	Charge Pump Rise Time	No Bootstrap Capacitor	20		μs

Electrical Characteristics (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: See Application Information for details regarding current limiting.

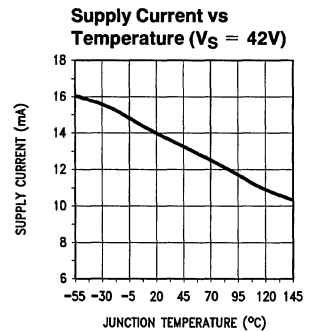
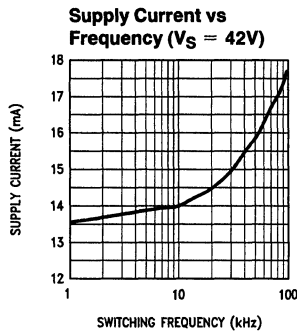
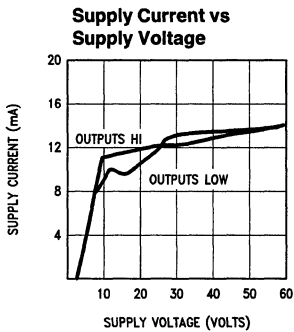
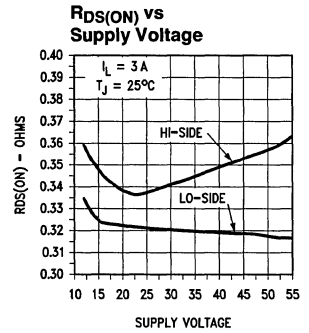
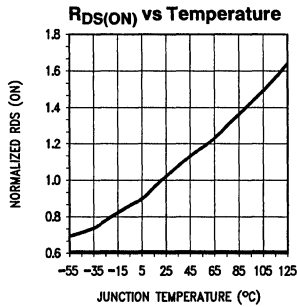
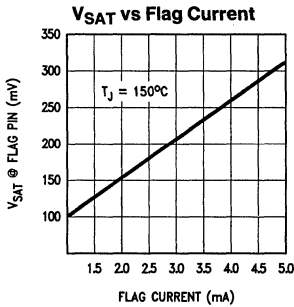
Note 3: The maximum power dissipation must be derated at elevated temperatures and is a function of $T_{J(max)}$, θ_{JA} , and T_A . The maximum allowable power dissipation at any temperature is $P_{D(max)} = (T_{J(max)} - T_A)/\theta_{JA}$, or the number given in the Absolute Ratings, whichever is lower. The typical thermal resistance from junction to case (θ_{JC}) is 1.0°C/W and from junction to ambient (θ_{JA}) is 30°C/W. For guaranteed operation $T_{J(max)} = 125^\circ\text{C}$.

Note 4: Human-body model, 100 pF discharged through a 1.5 kΩ resistor. Except Bootstrap pins (pins 1 and 11) which are protected to 1000V of ESD.

Note 5: All limits are 100% production tested at 25°C. Temperature extreme limits are guaranteed via correlation using accepted SQC (Statistical Quality Control) methods. All limits are used to calculate AOQL, (Average Outgoing Quality Level).

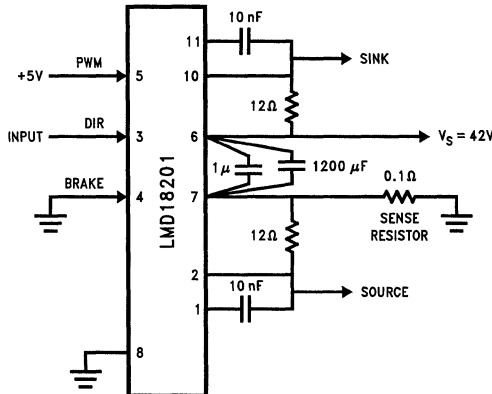
Note 6: Output currents are pulsed ($t_W < 2$ ms, Duty Cycle < 5%).

Typical Performance Characteristics



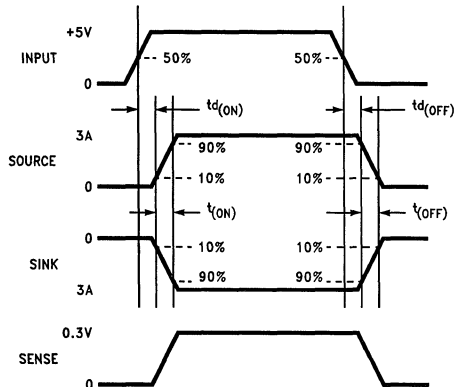
TL/H/10793-3

Test Circuit



TL/H/10793-8

Switching Time Definitions



TL/H/10793-9

Pinout Description (See Connection Diagram)

Pin 1, BOOTSTRAP 1 Input: Bootstrap capacitor pin for half H-Bridge number 1. The recommended capacitor (10 nF) is connected between pins 1 and 2.

Pin 2, OUTPUT 1: Half H-Bridge number 1 output.

Pin 3, DIRECTION Input: See Table I. This input controls the direction of current flow between OUTPUT 1 and OUTPUT 2 (pins 2 and 10) and, therefore, the direction of rotation of a motor load.

Pin 4, BRAKE Input: See Table I. This input is used to brake a motor by effectively shorting its terminals. When braking is desired, this input is taken to a logic high level and it is also necessary to apply logic high to PWM input, pin 5. The drivers that short the motor are determined by the logic level at the DIRECTION input (Pin 3): with Pin 3 logic high, both current sourcing output transistors are ON; with Pin 3 logic low, both current sinking output transistors are ON. All output transistors can be turned OFF by applying a logic high to Pin 4 and a logic low to PWM input Pin 5; in this case only a small bias current (approximately -1.5 mA) exists at each output pin.

Pin 5, PWM Input: See Table I. How this input (and DIRECTION input, Pin 3) is used is determined by the format of the PWM signal.

Pin 6, V_S Power Supply

Pin 7, POWER GROUND/SENSE Connection: This pin is the ground return for the power DMOS transistors of the H-Bridge. The current through the H-Bridge can be sensed by adding a small, 0.1Ω, sense resistor from this pin to the power supply ground.

Pin 8, SIGNAL GROUND: This is the ground return for the internal logic circuitry used to control the PWM switching of the H-Bridge.

Pin 9, THERMAL FLAG Output: This pin provides the thermal warning flag output signal. Pin 9 becomes active-low at 145°C (junction temperature). However the chip will not shut itself down until 170°C is reached at the junction.

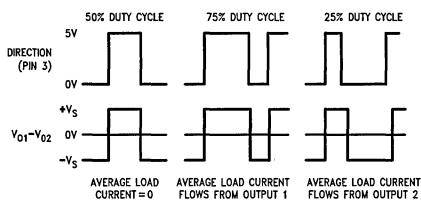
Pin 10, OUTPUT 2: Half H-Bridge number 2 output.

Pin 11, BOOTSTRAP 2 Input: Bootstrap capacitor pin for half H-Bridge number 2. The recommended capacitor (10 nF) is connected between pins 10 and 11.

TABLE I. Logic Truth Table

PWM	Dir	Brake	Active Output Drivers
H	H	L	Source 1, Sink 2
H	L	L	Sink 1, Source 2
L	X	L	Source 1, Source 2
H	H	H	Source 1, Source 2
H	L	H	Sink 1, Sink 2
L	X	H	NONE

Locked Anti-Phase PWM Control



TL/H/10793-4

Application Information

TYPES OF PWM SIGNALS

The LMD18201 readily interfaces with different forms of PWM signals. Use of the part with two of the more popular forms of PWM is described in the following paragraphs.

Simple, locked anti-phase PWM consists of a single, variable duty-cycle signal in which is encoded both direction and amplitude information. A 50% duty-cycle PWM signal represents zero drive, since the net value of voltage (integrated over one period) delivered to the load is zero. For the LMD18201, the PWM signal drives the direction input (pin 3) and the PWM input (pin 5) is tied to logic high.

Sign/magnitude PWM consists of separate direction (sign) and amplitude (magnitude) signals. The (absolute) magnitude signal is duty-cycle modulated, and the absence of a pulse signal (a continuous logic low level) represents zero drive. Current delivered to the load is proportional to pulse width. For the LMD18201, the DIRECTION input (pin 3) is driven by the sign signal and the PWM input (pin 5) is driven by the magnitude signal.

USING THE THERMAL WARNING FLAG

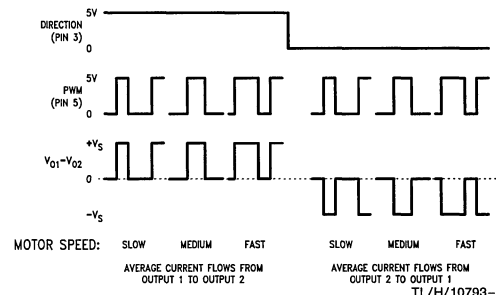
The THERMAL FLAG output (pin 9) is an open collector transistor. This permits a wired OR connection of thermal warning flag outputs from multiple LMD18201's, and allows the user to set the logic high level of the output signal swing to match system requirements. This output typically drives the interrupt input of a system controller. The interrupt service routine would then be designed to take appropriate steps, such as reducing load currents or initiating an orderly system shutdown. The maximum voltage compliance on the flag pin is 12V.

SUPPLY BYPASSING

During switching transitions the levels of fast current changes experienced may cause troublesome voltage transients across system stray inductances.

It is normally necessary to bypass the supply rail with a high quality capacitor(s) connected as close as possible to the V_S Power Supply (Pin 6) and POWER GROUND (Pin 7). A 1 μF high-frequency ceramic capacitor is recommended. Care should be taken to limit the transients on the supply pin below the Absolute Maximum Rating of the device. When operating the chip at supply voltages above 40V a voltage suppressor (transorb) such as P6KE62A is recommended from supply to ground. Typically the ceramic capacitor can be eliminated in the presence of the voltage suppressor. Note that when driving high load currents a greater amount of supply bypass capacitance (in general at least 100 μF per Amp of load current) is required to absorb the recirculating currents of the inductive loads.

Sign/Magnitude PWM Control



TL/H/10793-5

Application Information (Continued)

CURRENT LIMITING

Current limiting protection circuitry has been incorporated into the design of the LMD18201. With any power device it is important to consider the effects of the substantial surge currents through the device that may occur as a result of shorted loads. The protection circuitry monitors the current through the upper transistors and shuts off the power device as quickly as possible in the event of an overload condition (the threshold is set to approximately 10A). In a typical motor driving application the most common overload faults are caused by shorted motor windings and locked rotors. Under these conditions the inductance of the motor (as well as any series inductance in the V_{CC} supply line) serves to reduce the magnitude of a current surge to a safe level for the LMD18201. Once the device is shut down, the control circuitry will periodically try to turn the power device back on. This feature allows the immediate return to normal operation once the fault condition has been removed. While the fault remains however, the device will cycle in and out of thermal shutdown. This can create voltage transients on the V_{CC} supply line and therefore proper supply bypassing techniques are required.

The most severe condition for any power device is a direct, hard-wired ("screwdriver") long term short from an output to ground. This condition can generate a surge of current through the power device on the order of 15 Amps and require the die and package to dissipate up to 500W of power for the short time required for the protection circuitry to shut off the power device. This energy can be destructive, particularly at higher operating voltages (>30V) so some precautions are in order. Proper heat sink design is essential and it is normally necessary to heat sink the V_{CC} supply pin (pin 6) with 1 square inch of copper on the PC board.

INTERNAL CHARGE PUMP AND USE OF BOOTSTRAP CAPACITORS

To turn on the high-side (sourcing) DMOS power devices, the gate of each device must be driven approximately 8V more positive than the supply voltage. To achieve this an internal charge pump is used to provide the gate drive voltage. As shown in *Figure 1*, an internal capacitor is alternately switched to ground and charged to about 14V, then switched to V_S thereby providing a gate drive voltage greater than V_S . This switching action is controlled by a continuously running internal 300 kHz oscillator. The rise time of this drive voltage is typically 20 μ s which is suitable for operating frequencies up to 1 kHz.

For higher switching frequencies, the LMD18201 provides for the use of external bootstrap capacitors. The bootstrap principle is in essence a second charge pump whereby a large value capacitor is used which has enough energy to quickly charge the parasitic gate input capacitance of the power device resulting in much faster rise times. The switching action is accomplished by the power switches themselves (*Figure 2*). External 10 nF capacitors, connected from the outputs to the bootstrap pins of each high-side switch provide typically less than 100 ns rise times allowing switching frequencies up to 500 kHz.

INTERNAL PROTECTION DIODES

A major consideration when switching current through inductive loads is protection of the switching power devices from the large voltage transients that occur. Each of the four switches in the LMD18201 have a built-in protection diode to clamp transient voltages exceeding the positive supply or ground to a safe diode voltage drop across the switch.

The reverse recovery characteristics of these diodes, once the transient has subsided, is important. These diodes must come out of conduction quickly and the power switches must be able to conduct the additional reverse recovery current of the diodes. The reverse recovery time of the diodes protecting the sourcing power devices is typically only 70 ns with a reverse recovery current of 1A when tested with a full 3A of forward current through the diode. For the sinking devices the recovery time is typically 100 ns with 4A of reverse current under the same conditions.

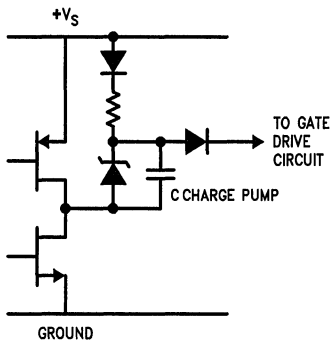


FIGURE 1. Internal Charge Pump Circuitry

TL/H/10793-6

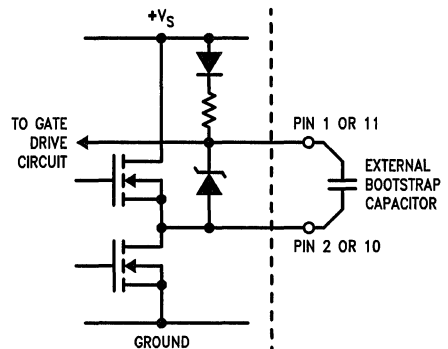


FIGURE 2. Bootstrap Circuitry

TL/H/10793-7

Typical Applications

BASIC MOTOR DRIVER

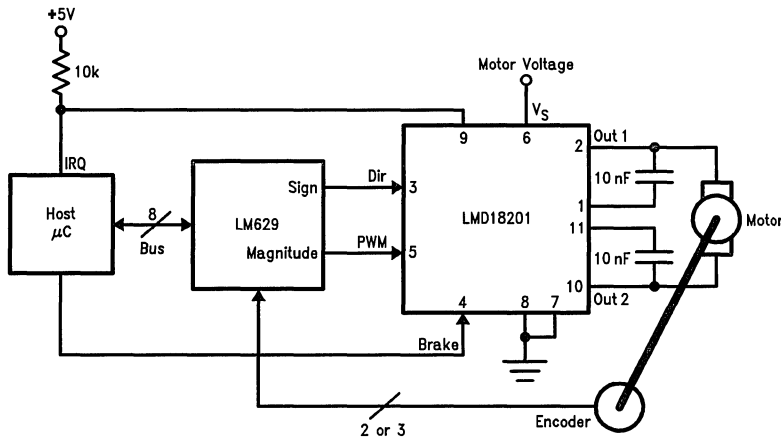
The LMD18201 can directly interface to any Sign/Magnitude PWM controller. The LM629 is a motion control processor that outputs a Sign/Magnitude PWM signal to coordinate either positional or velocity control of DC motors. The LMD18201 provides fully protected motor driver stage.

CURRENT SENSING

In many motor control applications it is desirable to sense and control the current through the motor. For these types of applications a companion product, the LMD18200, is also available. The LMD18200 is identical to the LMD18201 but has current sensing transistors that output a current directly proportional to the current conducted by the two upper DMOS power devices to a separate current sense pin. This technique does not require a low valued, power sense resistor and does not subtract from the available voltage drive to the motor.

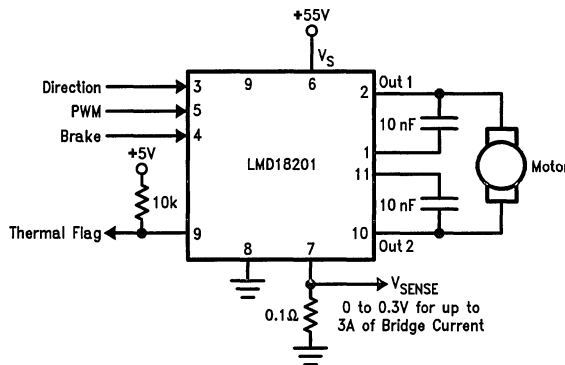
To sense the bridge current through the LMD18201 requires the addition of a small sense resistor between the power ground/sense pin (Pin 7) and the actual circuit ground. This resistor should have a value of 0.1Ω or less to stay within the allowable voltage compliance of the sense pin, particularly at higher operating current levels. The voltage between power ground/sense (Pin 7) and the signal ground (Pin 8) must stay within the range of $-1V$ to $+0.5V$. Internally there is approximately 25Ω between pins 7 and 8 and this resistance will slightly reduce the value of the external sense resistor. Approximately 70% of the quiescent supply current (10 mA) flows out of pin 7. This will cause a slight offset to the voltage across the sense resistor when the bridge is not conducting. During reverse recovery of the internal protection diodes the voltage compliance between pins 7 and 8 may be exceeded. The duration of these spikes however are only approximately 100 ns and do not have enough time or energy to disrupt the operation of the LMD18201.

Basic Motor Driver



TL/H/10793-10

Current Sensing



TL/H/10793-11



Section 5
Peripheral Drivers



Section 5 Contents

Peripheral Drivers—Introduction	5-3
Peripheral Drivers—Selection Guide	5-4
DP7310/DP8310/DP7311/DP8311 Octal Latched Peripheral Drivers	5-5
DS1631/DS3631/DS1632/DS3632/DS1633/DS3633/DS1634/DS3634 CMOS Dual Peripheral Drivers	5-12
DS2001/DS9665/DS2002/DS9666/DS2003/DS9667/DS2004/DS9668 High Current/Voltage Darlington Drivers	5-17
DS3654 Printer Solenoid Driver	5-22
DS3658 Quad High Current Peripheral Driver	5-26
DS3668 Quad Fault Protected Peripheral Driver	5-29
DS3669 Quad High Current Peripheral Driver	5-32
DS3680 Quad Negative Voltage Relay Driver	5-35
DS55451/2/3/4, DS75450/1/2/3/4 Series Dual Peripheral Drivers	5-38

Peripheral Drivers

Peripheral drivers is a broad definition given to interface power devices. The devices generally have open-collector output transistors that can switch hundreds of milliamps at high voltage and are driven by standard logic gates. They serve many applications including relay drivers, printer hammer drivers, lamp drivers, bus drivers, core memory drivers, voltage level translators, stepper motor drivers and solenoid drivers.

Unlike standard logic devices, peripheral drivers have many varied load situations depending on the application. This requires the design engineer to interpret device specifications in greater detail. Designers at National Semiconductor have incorporated many technically advanced and useful features into their broad line of peripheral driver devices.

Some of these features include:

- Short circuit protection at individual outputs
- Glitch-free power up/down
- Fall-safe operation
- Inductive fly-back protection
- Negative transient protection
- High input impedance for CMOS/NMOS compatibility

For further information on National Semiconductor's broad line of peripheral drivers, refer to the selection guide to follow and application note AN-213 in Appendix H.

PERIPHERAL DRIVERS SELECTION GUIDE

Device Number and Temperature Range		Drivers/Package	Logic Function (Driver On)	Input Compatibility (Logic)	Output High Voltage (V)	Latch-Up Voltage (Note 3) (V)	Output Low Voltage (V)	Output Low Current (mA)	Propagation Delay Typ (ns)	On Power Supply Current (mA)	Page No.
0°C to +70°C	-55°C to +125°C										
DP8310	DP7310	8	(Note 5)	TTL	30		0.5	100	40	152	5-5
DP8311	DP7311	8	(Note 6)	TTL	30		0.5	100	40	125	5-5
DS2001C		7	NAND	TTL	50		1.6	350	5000		5-17
DS9665C											5-17
DS2002C	DS2002M	7	NAND	PMOS	50		1.6	350	5000		5-17
DS9666C	DS9666M										5-17
DS2003C	DS2003M	7	NAND	TTL/CMOS	50		1.6	350	5000		5-17
DS9667C	DS9667M										5-17
DS2004C	DS2004M	7	NAND	CMOS/PMOS	50		1.6	350	5000		5-17
DS9668C	DS9668M										5-17
DS3631	DS1631	2	AND	CMOS	56	40	1.4	300	150	8	5-12
DS3632	DS1632	2	NAND	CMOS	56	40	1.4	300	150	8	5-12
DS3633	DS1633	2	OR	CMOS	56	40	1.4	300	150	8	5-12
DS3634	DS1634	2	NOR	CMOS	56	40	1.4	300	150	8	5-12
DS3654		10	(Note 2)	(Note 2)	(Note 1)	45	1.6	250	1000	70	5-22
DS3658		4	NAND	TTL/LS	70	35	0.7	600	2430	65	5-26
DS3668		4	NAND	TTL/LS	70	(Note 7)	1.5	600	2000	80	5-29
DS3669		4	AND	TTL/LS	70	35	0.7	600		65	5-32
DS3680		4	(Note 4)	TTL/CMOS	-2.1	-60	-60	-50	10,000	4.4	5-35
DS75450		2	AND	TTL	30	20	0.7	300	31	55	5-38
DS75451	DS55451	2	AND	TTL	30	20	0.7	300	31	55	5-38
DS75452	DS55452	2	NAND	TTL	30	20	0.7	300	31	55	5-38
DS75453	DS55453	2	OR	TTL	30	20	0.7	300	31	55	5-38
DS75454	DS55454	2	NOR	TTL	30	20	0.7	300	31	55	5-38

Note 1: The DS3654 contains an internal inductive fly-back clamp circuit connected from the output to ground. As an example, DS3654 driving a relay solenoid connected to 28V would clamp the output voltage fly-back transient at 50V caused by the solenoid's stored inductive current. This clamp protects the circuit output and quenches the fly-back.

Note 2: The DS3654 is a 10-bit shift register followed by 10 enabled drivers. The input circuit is equivalent to a 4k resistor to ground, and the logic input thresholds are 2.8V and 0.8V. The recommended power supply voltage is 7.5V to 9.5V. The circuit can be cascaded to be a 20 or 30-bit shift register.

Note 3: Latch-up voltage is the maximum voltage the output can sustain when switching an inductive load.

Note 4: DS3680 has a differential input circuit.

Note 5: DS8310 inverting, positive edge latching.

Note 6: DS8311 inverting, fall through latch.

Note 7: DS3668 35V, latch-up with output fault protection.



DP7310/DP8310/DP7311/DP8311 Octal Latched Peripheral Drivers

General Description

The DP7310/8310, DP7311/8311 Octal Latched Peripheral Drivers provide the function of latching eight bits of data with open collector outputs, each driving up to 100 mA DC with an operating voltage range of 30V. Both devices are designed for low input currents, high input/output voltages, and feature a power up clear (outputs off) function.

The DP7310/8310 are positive edge latching. Two active low write/enable inputs are available for convenient data bussing without external gating.

The DP7311/8311 are positive edge latches. The active low strobe input latches data or allows fall through operation when held at logic "0". The latches are cleared (outputs off) with a logic "0" on the clear pin.

Features

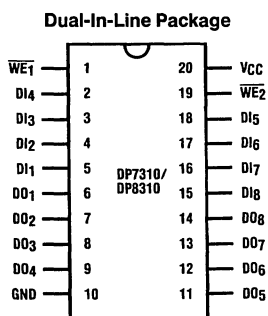
- High current, high voltage open collector outputs
- Low current, high voltage inputs

- All outputs simultaneously sink rated current "DC" with no thermal derating at maximum rated temperature
- Parallel latching or buffering
- Separate active low enables for easy data bussing
- Internal "glitch free" power up clear
- 10% V_{CC} tolerance

Applications

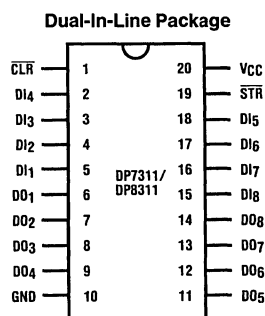
- High current high voltage drivers
- Relay drivers
- Lamp drivers
- LED drivers
- TRIAC drivers
- Solenoid drivers
- Stepper motor drivers
- Level translators
- Fiber-optic LED drivers

Connection Diagrams



Top View

TL/F/5246-1



Top View

TL/F/5246-2

Order Number DP7310J, DP7311J,
DP8310N or DP8311N
See NS Package Number J20A or N20A



Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7.0V
Input Voltage	35V
Output Voltage	35V
Maximum Power Dissipation* at 25°C	
Cavity Package	1821 mW
DP8310/DP8311	2005 mW
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 4 sec.)	260°C

*Derate cavity package 12.1 mW/°C above 25°C; derate molded package 16.0 mW/°C above 25°C.

Operating Conditions

	Min	Max	Units
Supply Voltage (V _{CC})	4.5	5.5	V
Temperature			
DP7310/DP7311	-55	+125	°C
DP8310/DP8311	0	+70	°C
Input Voltage		30	V
Output Voltage		30	V

DC Electrical Characteristics DP7310/DP8310, DP7311/DP8311 (Notes 2 and 3)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V _{IH}	Logical "1" Input Voltage		2.0			V
V _{IL}	Logical "0" Input Voltage				0.8	V
V _{OL}	Logical "0" Output Voltage	Data outputs latched to logical "0", V _{CC} = Min. I _{OL} = 75 mA I _{OL} = 100 mA		0.35	0.4 0.5	V V
I _{OH}	Logical "1" Output Current	Data outputs latched to logical "1", V _{CC} = Min. V _{OH} = 25V V _{OH} = 30V		2.5	500 250	μA μA
I _{IH}	Logical "1" Input Current	V _{IH} = 2.7V, V _{CC} = Max		0.1	25	μA
I _I	Input Current at Maximum Input Voltage	V _{IN} = 30V, V _{CC} = Max		1	250	μA
I _{IL}	Logical "0" Input Current	V _{IN} = 0.4V, V _{CC} = Max		-215	-300	μA
V _{clamp}	Input Clamp Voltage	I _{IN} = 12 mA		-0.8	-1.5	V
I _{CC0}	Supply Current, Outputs On	Data outputs latched to a logical "0". All inputs are at logical "1", V _{CC} = Max.		100 100 88 88	125 152 117 125	mA mA mA mA
I _{CC1}	Supply Current, Outputs Off	Data outputs latched to a logic "1". Other conditions same as I _{CC0} .		40 40 25 25	47 57 34 36	mA mA mA mA

AC Electrical Characteristics DP7310/DP8310: $V_{CC} = 4.5V$, $T_A = -55^{\circ}C$ to $+125^{\circ}C$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
t_{pd0}	High to Low Propagation Delay Write Enable Input to Output	(Figure 1)		40	120	ns
t_{pd1}	Low to High Propagation Delay Write Enable Input to Output	(Figure 1)		70	150	ns
t_{SETUP}	Minimum Set-Up Time Data in to Write Enable Input	$t_{HOLD} = 0$ ns (Figure 1)	45	20		ns
t_{pWH} , t_{pWL}	Minimum Write Enable Pulse Width	(Figure 1)	60	25		ns
t_{THL}	High to Low Output Transition Time	(Figure 1)		16	35	ns
t_{TLH}	Low to High Output Transition Time	(Figure 1)		38	70	ns
C_{IN}	"N" Package (Note 4)			5	15	pF

AC Electrical Characteristics DP7311/DP8311: $V_{CC} = 5V$, $T_A = 25^{\circ}C$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
t_{pd0}	High to Low Propagation Delay Data In to Output	(Figure 2)		30	60	ns
t_{pd1}	Low to High Propagation Delay Data to Output	(Figure 2)		70	100	ns
t_{SETUP}	Minimum Set-Up Time Data in to Strobe Input	$t_{HOLD} = 0$ ns (Figure 2)	0	-25		ns
t_{pWL}	Minimum Strobe Enable Pulse Width	(Figure 2)	60	35		ns
t_{pdC}	Propagation Delay Clear to Data Output	(Figure 2)		70	135	ns
t_{pWC}	Minimum Clear Input Pulse Width	(Figure 2)	60	25		ns
t_{THL}	High to Low Output Transition Time	(Figure 2)		20	35	ns
t_{TLH}	Low to High Output Transition Time	(Figure 2)		38	60	ns
C_{IN}	Input Capacitance—Any Input	(Note 4)		5	15	pF





Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. Except for "Operating Temperature Range" they are not meant to imply that the devices should be operated at these limits. The table of "Electrical Characteristics" provides conditions for actual device operation.

Note 2: Unless otherwise specified min/max limits apply across the $-55^{\circ}C$ to $+125^{\circ}C$ temperature range for the DP7310/DP7311 and across the $0^{\circ}C$ to $+70^{\circ}C$ for the DP8310/DP8311. All typical values are for $T_A = 25^{\circ}C$, $V_{CC} = 5V$.


Note 3: All currents into device pins shown as positive, out of device pins as negative, all voltages referenced to ground unless otherwise noted.

Note 4: Input capacitance is guaranteed by periodic testing. $f_{TEST} = 10$ kHz at 300 mV, $T_A = 25^{\circ}C$.

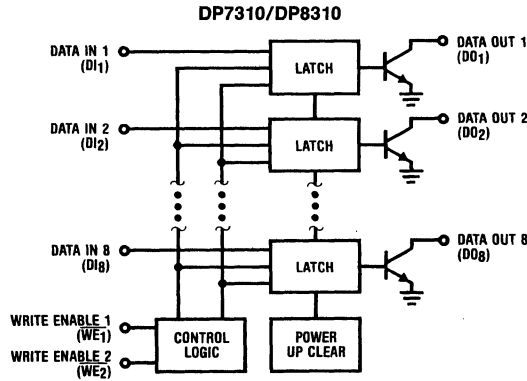
Logic Table

DP7310/DP8310			
Write Enable 1 \overline{WE}_1	Write Enable 2 \overline{WE}_2	Data Input DI ₁₋₈	Data Output DO ₁₋₈
0	0	X	Q
0		0	1
0		1	0
	0	0	1
	0	1	0
0	1	X	Q
1	0	X	Q
1	1	X	Q

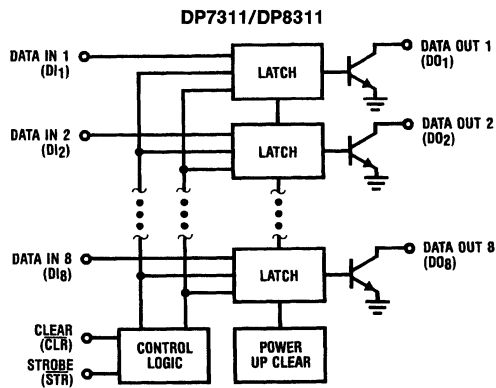
DP7311/DP8311			
Clear CLR	Strobe STR	Data Input DI ₁₋₈	Data Output DO ₁₋₈
1	1	X	Q
1	0	0	1
1	0	1	0
0	X	X	1

X = Don't Care
 1 = Outputs Off
 0 = Outputs On
 Q = Pre-existing Output
 = Positive Edge Transition

Block Diagrams

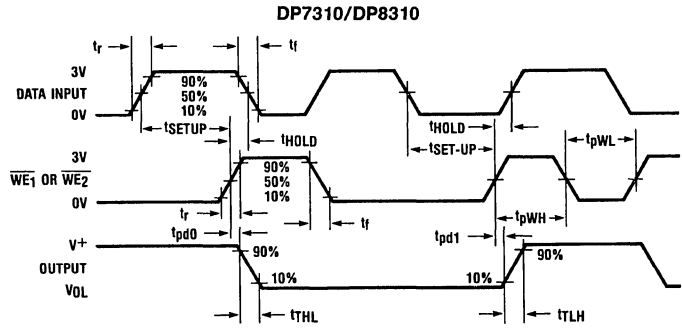


TL/F/5246-3

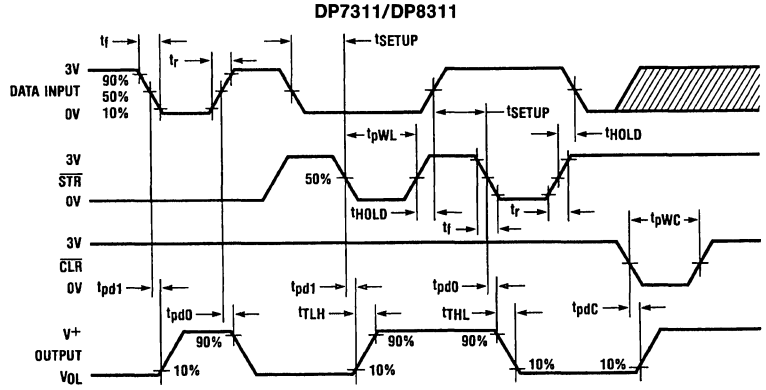


TL/F/5246-4

Switching Time Waveforms

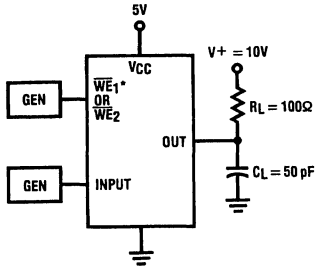


TL/F/5246-5



TL/F/5246-6

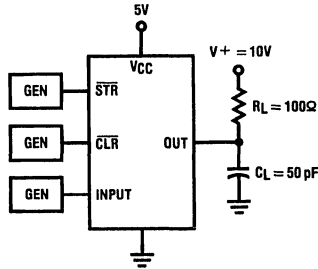
Switching Time Test Circuits



TL/F/5246-7

*WE₁ = 0V When the Input = WE₂

FIGURE 1. DP7310/DP8310



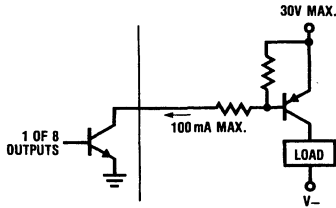
TL/F/5246-8

Pulse Generator Characteristics:
Z_O = 50Ω, $t_r = t_f = 5\text{ ns}$

FIGURE 2. DP7311/DP8311

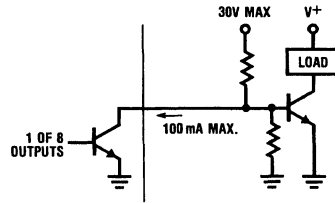
Typical Applications DP8310/11 Buffering High Current Device (Notes 1 and 2)

PNP High Current Driver



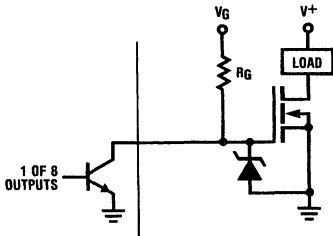
TL/F/5246-9

NPN High Current Driver



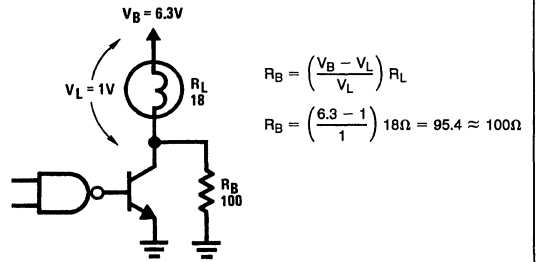
TL/F/5246-10

VMOS High Current Driver



TL/F/5246-11

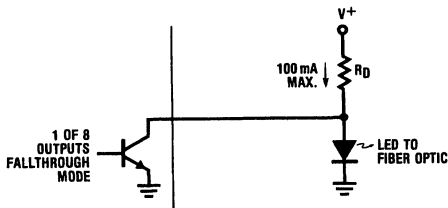
Circuit Used to Reduce Peak Transient Lamp Current



TL/F/5246-12

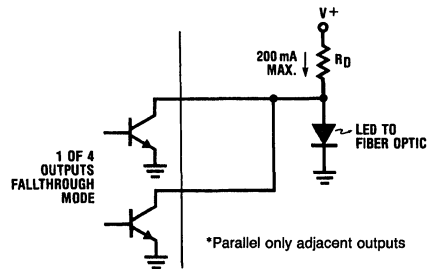
Eight Output/Four Output Fiber Optic LED Driver

DP8311 100 mA Drivers



TL/F/5246-13

DP8311 Parallel Outputs (200 mA) Drivers*

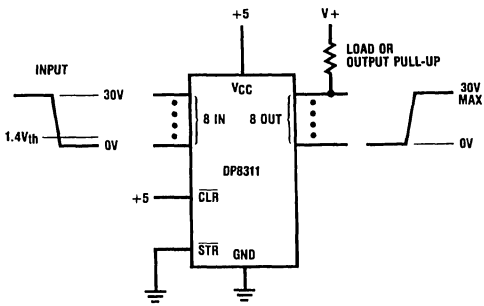


*Parallel only adjacent outputs

TL/F/5246-14

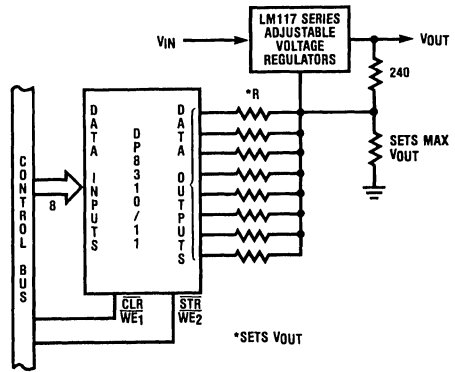
Typical Applications (Continued)

8-Bit Level Translator-Driver



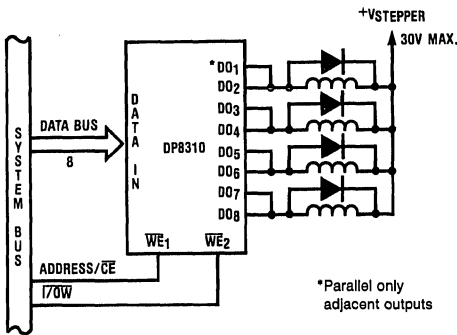
TL/F/5246-15

Digital Controlled 256 Level Power Supply from 1.2V to 30V



TL/F/5246-16

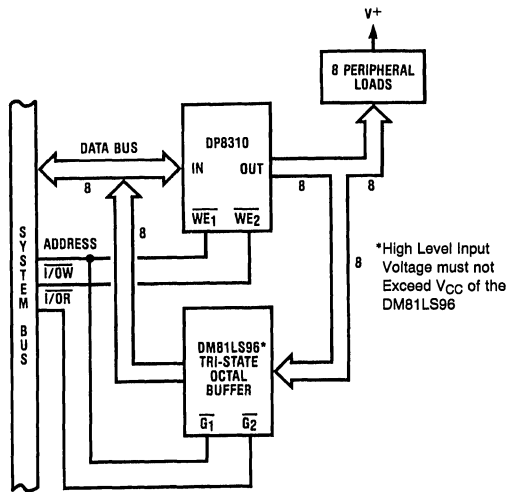
200 mA Drive for a 4 Phase Bifilar Stepper Motor



*Parallel only adjacent outputs

TL/F/5246-17

Reading the State of the Latched Peripherals



*High Level Input Voltage must not Exceed VCC of the DM81LS96

TL/F/5246-18

Note 1: Always use good VCC bypass and ground techniques to suppress transients caused by peripheral loads.

Note 2: Printed circuit board mounting is required if these devices are operated at maximum rated temperature and current (all outputs on DC).



DS1631/DS3631/DS1632/DS3632/DS1633/DS3633/ DS1634/DS3634 CMOS Dual Peripheral Drivers

General Description

The DS1631 series of dual peripheral drivers was designed to be a universal set of interface components for CMOS circuits.

Each circuit has CMOS compatible inputs with thresholds that track as a function of V_{CC} (approximately $\frac{1}{2} V_{CC}$). The inputs are PNP's providing the high impedance necessary for interfacing with CMOS.

Outputs have high voltage capability, minimum breakdown voltage is 56V at 250 μ A.

The outputs are Darlington connected transistors. This allows high current operation (300 mA max) at low internal V_{CC} current levels since base drive for the output transistor is obtained from the load in proportion to the required loading conditions. This is essential in order to minimize loading on the CMOS logic supply.

Typical $V_{CC} = 5V$ power is 28 mW with both outputs ON. V_{CC} operating range is 4.5V to 15V.

The circuit also features output transistor protection if the V_{CC} supply is lost by forcing the output into the high impedance OFF state with the same breakdown levels as when V_{CC} was applied.

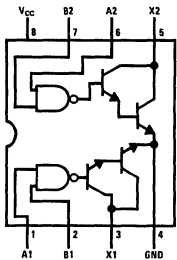
Pin-outs are the same as the respective logic functions found in the following popular series of circuits: DS75451, DS75461. This feature allows direct conversion of present systems to the MM74C CMOS family and DS1631 series circuits with great power savings.

The DS1631 series is also TTL compatible at $V_{CC} = 5V$.

Features

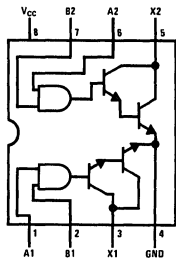
- CMOS compatible inputs
- High impedance inputs PNP's
- High output voltage breakdown 56V min
- High output current capability 300 mA max
- Same pin-outs and logic functions as DS75451 and DS75461 series circuits
- Low V_{CC} power dissipation (28 mW both outputs "ON" at 5V)

Connection Diagrams (Dual-In-Line and Metal Can Packages)



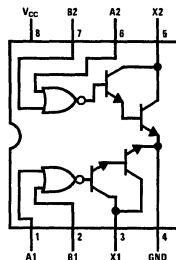
TL/F/5816-1

Top View
Order Number DS1631J-8
or DS3631N



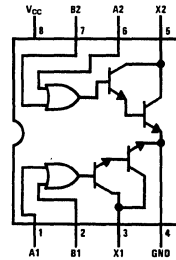
TL/F/5816-2

Top View
Order Number DS1632J-8
or DS3632N



TL/F/5816-3

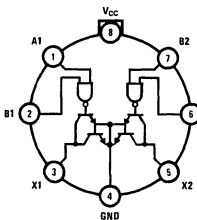
Top View
Order Number DS1633J-8
or DS3633N



TL/F/5816-4

Top View
Order Number DS1634J-8
or DS3634N

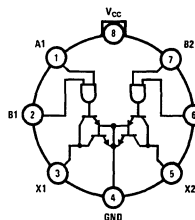
See NS Package Number J08A or N08E



TL/F/5816-5

Top View
(Pin 4 is electrically connected to the case.)

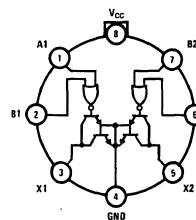
Order Number DS1631H



TL/F/5816-6

Top View
(Pin 4 is electrically connected to the case.)

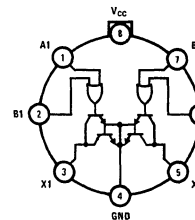
Order Number DS1632H



TL/F/5816-7

Top View
(Pin 4 is electrically connected to the case.)

Order Number DS1633H



TL/F/5816-8

Top View
(Pin 4 is electrically connected to the case.)

Order Number DS1634H

See NS Package Number H08C

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	16V
Voltage at Inputs	-0.3V to $V_{CC} + 0.3V$
Output Voltage	56V
Storage Temperature Range	-65°C to +150°C
Maximum Power Dissipation* at 25°C	
Cavity Package	1133 mW
Molded Package	1022 mW
TO-5 Package	787 mW
Lead Temperature (Soldering, 4 sec.)	260°C

*Derate cavity package 7.6 mW/°C above 25°C; derate molded package 8.2 mW/°C above 25°C; derate TO-5 package 5.2 mW/°C above 25°C.

Operating Conditions

	Min	Max	Units
Supply Voltage, V_{CC}			
DS1631/DS1632/DS1633/DS1634	4.5	15	V
DS3631/DS3632/DS3633/DS3634	4.75	15	V
Temperature, T_A			
DS1631/DS1632/DS1633/DS1634	-55	+125	°C
DS3631/DS3632/DS3633/DS3634	0	+70	°C

Electrical Characteristics (Notes 2 and 3)

Symbol	Parameter	Conditions	Min	Typ	Max	Units	
ALL CIRCUITS							
V_{IH}	Logical "1" Input Voltage	(Figure 1)	$V_{CC} = 5V$	3.5	2.5		V
			$V_{CC} = 10V$	8.0	5		V
			$V_{CC} = 15V$	12.5	7.5		V
V_{IL}	Logical "0" Input Voltage	(Figure 1)	$V_{CC} = 5V$		2.5	1.5	V
			$V_{CC} = 10V$		5.5	2.0	V
			$V_{CC} = 15V$		7.5	2.5	V
I_{IH}	Logical "1" Input Current	$V_{CC} = 15V, V_{IN} = 15V$, (Figure 2)		0.1	10	μA	
I_{IL}	Logical "0" Input Current	$V_{IN} = 0.4V$, (Figure 3)	$V_{CC} = 5V$		-50	-120	μA
			$V_{CC} = 15V$		-200	-360	μA
V_{OH}	Output Breakdown Voltage	$V_{CC} = 15V, I_{OH} = 250 \mu A$, (Figure 1)	56	65		V	
V_{OL}	Output Low Voltage	$V_{CC} = \text{Min}$, (Figure 1), DS1631, DS1632, DS1633, DS1634	$I_{OL} = 100 \text{ mA}$		0.85	1.1	V
			$I_{OL} = 300 \text{ mA}$		1.1	1.4	V
		$V_{CC} = \text{Min}$, (Figure 1), DS3631, DS3632, DS3633, DS3634	$I_{OL} = 100 \text{ mA}$		0.85	1.0	V
			$I_{OL} = 300 \text{ mA}$		1.1	1.3	V
DS1631/DS3631							
$I_{CC(0)}$	Supply Currents	$V_{IN} = 0V$, (Figure 4)	$V_{CC} = 5V$	Output Low	7	11	mA
			$V_{CC} = 15V$	Both Drivers	14	20	mA
$I_{CC(1)}$		(Figure 4)	$V_{CC} = 5V, V_{IN} = 5V$	Output High	2	3	mA
			$V_{CC} = 15V, V_{IN} = 15V$	Both Drivers	7.5	10	mA
t_{PD1}	Propagation to "1"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 \text{ pF}, R_L = 50\Omega, V_L = 10V$, (Figure 5)		500		ns	
t_{PD0}	Propagation to "0"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 \text{ pF}, R_L = 50\Omega, V_L = 10V$, (Figure 5)		750		ns	
DS1632/DS3632							
$I_{CC(0)}$	Supply Currents	(Figure 4)	$V_{CC} = 5V, V_{IN} = 5V$	Output Low	8	12	mA
			$V_{CC} = 15V, V_{IN} = 15V$		18	23	mA
$I_{CC(1)}$		$V_{IN} = 0V$, (Figure 4)	$V_{CC} = 5V$	Output High	2.5	3.5	mA
			$V_{CC} = 15V$		9	14	mA
t_{PD1}	Propagation to "1"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 \text{ pF}, R_L = 50\Omega, V_L = 10V$, (Figure 5)		500		ns	
t_{PD0}	Propagation to "0"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 \text{ pF}, R_L = 50\Omega, V_L = 10V$, (Figure 5)		750		ns	

Electrical Characteristics (Notes 2 and 3) (Continued)

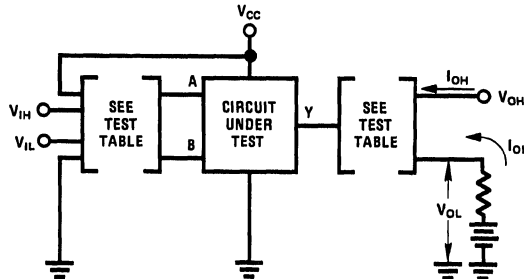
Symbol	Parameter	Conditions		Min	Typ	Max	Units
DS1633/DS3633							
$I_{CC(0)}$	Supply Currents	$V_{IN} = 0V$, (Figure 4)	$V_{CC} = 5V$	Output Low	7.5	12	mA
			$V_{CC} = 15V$		16	23	mA
$I_{CC(1)}$		(Figure 4)	$V_{CC} = 5V, V_{IN} = 5V$	Output High	2	4	mA
			$V_{CC} = 15V, V_{IN} = 15V$		7.2	15	mA
t_{PD1}	Propagation to "1"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 pF, R_L = 50\Omega, V_L = 10V$, (Figure 5)			500		ns
t_{PD0}	Propagation to "0"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 pF, R_L = 50\Omega, V_L = 10V$, (Figure 5)			750		ns
DS1634/DS3634							
$I_{CC(0)}$	Supply Currents	(Figure 4)	$V_{CC} = 5V, V_{IN} = 5V$	Output Low	7.5	12	mA
			$V_{CC} = 15V, V_{IN} = 15V$		18	23	mA
$I_{CC(1)}$		$V_{IN} = 0V$, (Figure 4)	$V_{CC} = 5V$	Output High	3	5	mA
			$V_{CC} = 15V$		11	18	mA
t_{PD1}	Propagation to "1"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 pF, R_L = 50\Omega, V_L = 10V$, (Figure 5)			500		ns
t_{PD0}	Propagation to "0"	$V_{CC} = 5V, T_A = 25^\circ C, C_L = 15 pF, R_L = 50\Omega, V_L = 10V$, (Figure 5)			750		ns

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. Except for "Operating Temperature Range" they are not meant to imply that the devices should be operated at these limits. The table of "Electrical Characteristics" provides conditions for actual device operation.

Note 2: Unless otherwise specified min/max limits apply across the $-55^\circ C$ to $+125^\circ C$ temperature range for the DS1631, DS1632, DS1633 and DS1634 and across the $0^\circ C$ to $+70^\circ C$ range for the DS3631, DS3632, DS3633 and DS3634. All typical values are for $T_A = 25^\circ C$.

Note 3: All currents into device pins shown as positive, out of device pins as negative, all voltages referenced to ground unless otherwise noted. All values shown as max or min on absolute value basis.

Test Circuits



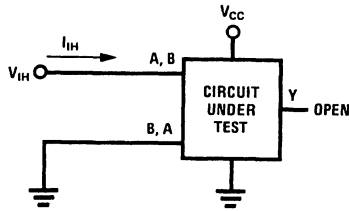
TL/F/5816-9

Circuit	Input Under Test	Other Input	Output	
			Apply	Measure
DS3631	V_{IH} V_{IL}	V_{IH} V_{CC}	I_{OH} I_{OL}	V_{OH} V_{OL}
DS3632	V_{IH} V_{IL}	V_{IH} V_{CC}	I_{OL} I_{OH}	V_{OL} V_{OH}
DS3633	V_{IH} V_{IL}	GND V_{IL}	I_{OH} I_{OL}	V_{OH} V_{OL}
DS3634	V_{IH} V_{IL}	GND V_{IL}	I_{OL} I_{OH}	V_{OL} V_{OH}

Note: Each input is tested separately.

FIGURE 1. V_{IH} , V_{IL} , V_{OH} , V_{OL}

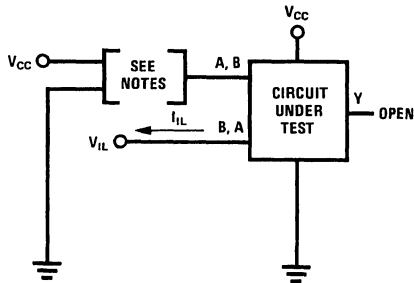
Test Circuits (Continued)



Each input is tested separately.

FIGURE 2. I_{IH}

TL/F/5816-10

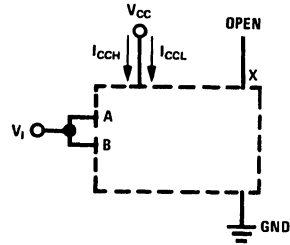


Note A: Each input is tested separately.

Note B: When testing DS1633 and DS1634 input not under test is grounded. For all other circuits it is at V_{CC} .

FIGURE 3. I_{IL}

TL/F/5816-11

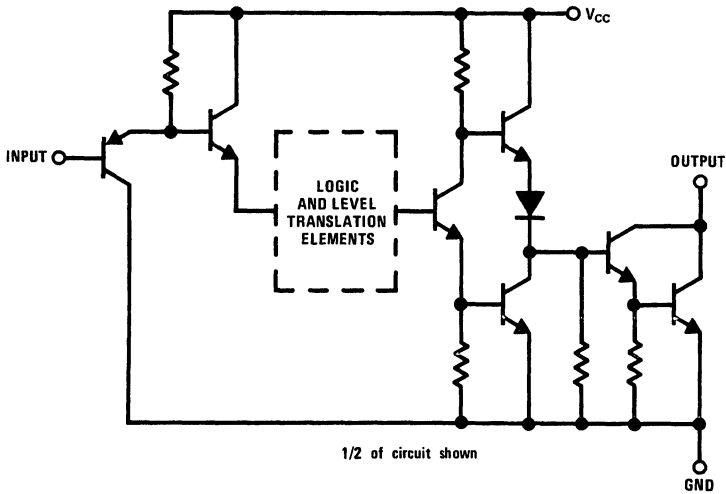


Both gates are tested simultaneously.

FIGURE 4. I_{CC} for AND and NAND Circuits

TL/F/5816-12

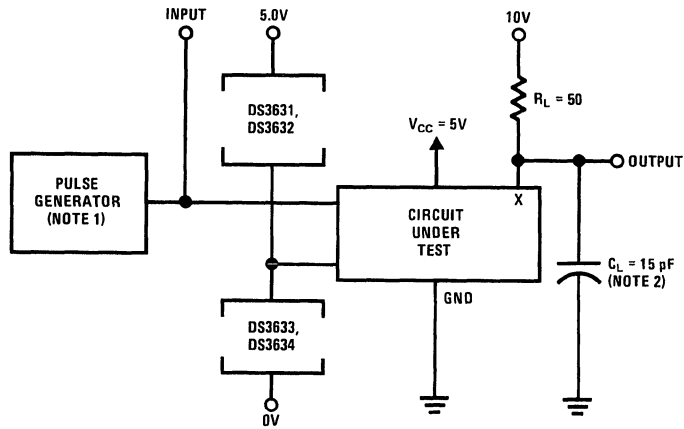
Schematic Diagram (Equivalent Circuit)



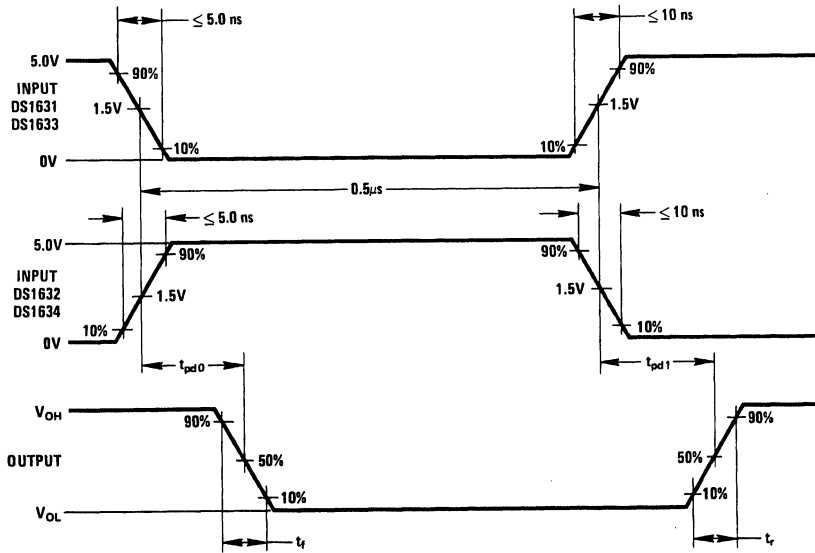
1/2 of circuit shown

TL/F/5816-15

Switching Time Waveforms



TL/F/5816-13



TL/F/5816-14

Note 1: The pulse generator has the following characteristics: PRR = 500 kHz, $Z_{OUT} \approx 50\Omega$

Note 2: C_L includes probe and jig capacitance

FIGURE 5. Switching Times



DS2001/DS9665/DS2002/DS9666 DS2003/DS9667/DS2004/DS9668 High Current/Voltage Darlington Drivers

General Description

The DS2001/DS9665/DS2002/DS9666/DS2003/DS9667/DS2004/DS9668 are comprised of seven high voltage, high current NPN Darlington transistor pairs. All units feature common emitter, open collector outputs. To maximize their effectiveness, these units contain suppression diodes for inductive loads and appropriate emitter base resistors for leakage.

The DS2001/DS9665 is a general purpose array which may be used with DTL, TTL, PMOS, CMOS, etc. Input current limiting is done by connecting an appropriate discrete resistor to each input.

The DS2002/DS9666 version does away with the need for any external discrete resistors, since each unit has a resistor and a Zener diode in series with the input. The DS2002/DS9666 was specifically designed for direct interface from PMOS logic (operating at supply voltages from 14V to 25V) to solenoids or relays.

The DS2003/DS9667 has a series base resistor to each Darlington pair, thus allowing operation directly with TTL or CMOS operating at supply voltages of 5.0V.

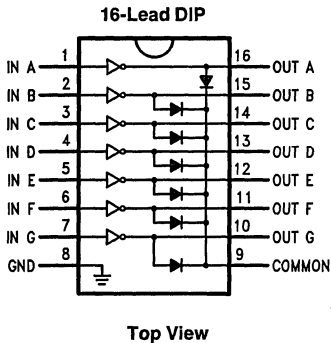
The DS2004/DS9668 has an appropriate input resistor to allow direct operation from CMOS or PMOS outputs operating from supply voltages of 6.0V to 15V.

The DS2001/DS9665/DS2002/DS9666/DS2003/DS9667/DS2004/DS9668 offer solutions to a great many interface needs, including solenoids, relays, lamps, small motors, and LEDs. Applications requiring sink currents beyond the capability of a single output may be accommodated by paralleling the outputs.

Features

- Seven high gain Darlington pairs
- High output voltage ($V_{CE} = 50V$)
- High output current ($I_C = 350\text{ mA}$)
- DTL, TTL, PMOS, CMOS compatible
- Suppression diodes for inductive loads
- Extended temperature range

Connection Diagram



TL/F/9647-1

Order Numbers

	J Package Number J16A	N Package Number N16E	M Package Number M16A
DS2001 DS9665	DS2001MJ DS2001TJ DS2001CJ DS9665MJ DS9665TJ DS9665CJ	DS2001TN DS2001CN DS9665TN DS9665CN	DS2001TM DS2001CM
DS2002 DS9666	DS2002MJ DS2002TJ DS2002CJ DS9666MJ DS9666TJ DS9666CJ	DS2002TN DS2002CN DS9666TN DS9666CN	DS2002TM DS2002CM
DS2003 DS9667	DS2003MJ DS2003TJ DS2003CJ DS9667MJ DS9667TJ DS9667CJ	DS2003TN DS2003CN DS9667TN DS9667CN	DS2003TM DS2003CM
DS2004 DS9668	DS2004MJ DS2004TJ DS2004CJ DS9668MJ DS9668TJ DS9668CJ	DS2004TN DS2004CN DS9668TN DS9668CN	DS2004TM DS2004CM

DS2001/DS9665/DS2002/DS9666/DS2003/DS9667/DS2004/DS9668



Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range

Ceramic DIP	-65°C to +175°C
Molded DIP	-65°C to +150°C

Operating Temperature Range

DS2001M/DS9665M	-55°C to +125°C
DS2002M/DS9666M	-55°C to +125°C
DS2003M/DS9667M	-55°C to +125°C
DS2004M/DS9668M	-55°C to +125°C
DS2001T/DS9665T	-40°C to +105°C
DS2002T/DS9666T	-40°C to +105°C
DS2003T/DS9667T	-40°C to +105°C
DS2004T/DS9668T	-40°C to +105°C

DS2001C/DS9665C	0°C to +85°C
DS2002C/DS9666C	0°C to +85°C
DS2003C/DS9667C	0°C to +85°C
DS2004C/DS9668C	0°C to +85°C

Lead Temperature

Ceramic DIP (Soldering, 60 seconds)	300°C
Molded DIP (Soldering, 10 seconds)	265°C

Maximum Power Dissipation* at 25°C

Cavity Package	2016 mW
Molded Package	1838 mW
S.O. Package	926 mW

*Derate cavity package 16.13 mW/°C above 25°C; derate molded DIP package 14.7 mW/°C above 25°C. Derate S.O. package 7.4 mW/°C.

Input Voltage	30V
Output Voltage	55V
Emitter-Base Voltage	6.0V
Continuous Collector Current	500 mA
Continuous Base Current	25 mA

Electrical Characteristics $T_A = 25^\circ\text{C}$, unless otherwise specified (Note 2)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
I_{CEX}	Output Leakage Current	$T_A = 85^\circ\text{C}$ for Commercial $V_{CE} = 50\text{V}$ (Figure 1a)			100	μA
		$V_{CE} = 50\text{V}, V_I = 6.0\text{V}$ (Figure 1b)	DS2002/DS9666		500	
		$V_{CE} = 50\text{V}, V_I = 1.0\text{V}$ (Figure 1b)	DS2004/DS9668		500	
$V_{CE(Sat)}$	Collector-Emitter Saturation Voltage	$I_C = 350\text{ mA}, I_B = 500\ \mu\text{A}$ (Figure 2) (Note 3)		1.25	1.6	V
		$I_C = 200\text{ mA}, I_B = 350\ \mu\text{A}$ (Figure 2)		1.1	1.3	
		$I_C = 100\text{ mA}, I_B = 250\ \mu\text{A}$ (Figure 2)		0.9	1.1	
$I_{I(ON)}$	Input Current	$V_I = 17\text{V}$ (Figure 3)	DS2002/DS9666	0.85	1.3	mA
		$V_I = 3.85\text{V}$ (Figure 3)	DS2003/DS9667	0.93	1.35	
		$V_I = 5.0\text{V}$ (Figure 3)	DS2004/DS9668	0.35	0.5	
		$V_I = 12\text{V}$ (Figure 3)		1.0	1.45	
$I_{I(OFF)}$	Input Current (Note 4)	$T_A = 85^\circ\text{C}$ for Commercial $I_C = 500\ \mu\text{A}$ (Figure 4)	50	100		μA
$V_{I(ON)}$	Input Voltage (Note 5)	$V_{CE} = 2.0\text{V}, I_C = 300\text{ mA}$ (Figure 5)	DS2002/DS9666		13	V
		$V_{CE} = 2.0\text{V}, I_C = 200\text{ mA}$ (Figure 5)	DS2003/DS9667		2.4	
		$V_{CE} = 2.0\text{V}, I_C = 250\text{ mA}$ (Figure 5)			2.7	
		$V_{CE} = 2.0\text{V}, I_C = 300\text{ mA}$ (Figure 5)			3.0	
		$V_{CE} = 2.0\text{V}, I_C = 125\text{ mA}$ (Figure 5)	DS2004/DS9668		5.0	
		$V_{CE} = 2.0\text{V}, I_C = 200\text{ mA}$ (Figure 5)			6.0	
		$V_{CE} = 2.0\text{V}, I_C = 275\text{ mA}$ (Figure 5)			7.0	
		$V_{CE} = 2.0\text{V}, I_C = 350\text{ mA}$ (Figure 5)			8.0	
h_{FE}	DC Forward Current Transfer Ratio	$V_{CE} = 2.0\text{V}, I_C = 350\text{ mA}$ (Figure 2)	DS2001/DS9665	1000		
C_I	Input Capacitance			15	30	pF
t_{PLH}	Turn-On Delay	$0.5 V_I$ to $0.5 V_O$			1.0	μs
t_{PHL}	Turn-Off Delay	$0.5 V_I$ to $0.5 V_O$			1.0	μs
I_R	Clamp Diode Leakage Current	$V_R = 50\text{V}$ (Figure 6)	$T_A = 25^\circ\text{C}$		50	μA
			$T_A = 85^\circ\text{C}$		100	μA
V_F	Clamp Diode Forward Voltage	$I_F = 350\text{ mA}$ (Figure 7)		1.7	2.0	V

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. They are not meant to imply that the devices should be operated at these limits. The tables of "Electrical Characteristics" provide conditions for actual device operation.

Note 2: All limits apply to the complete Darlington series except as specified for a single device type.

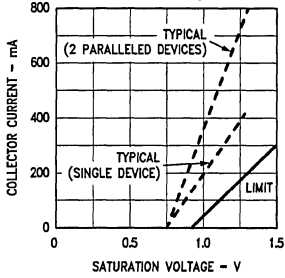
Note 3: Under normal operating conditions these units will sustain 350 mA per output with $V_{CE(Sat)} = 1.6\text{V}$ at 70°C with a pulse width of 20 ms and a duty cycle of 30%.

Note 4: The $I_{I(OFF)}$ current limit guaranteed against partial turn-on of the output.

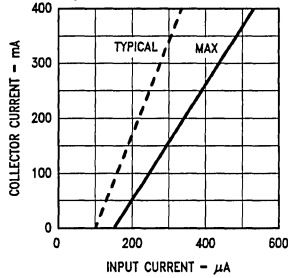
Note 5: The $V_{I(ON)}$ voltage limit guarantees a minimum output sink current per the specified test conditions.

Typical Performance Characteristics

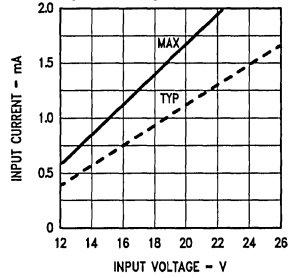
Collector Current vs Saturation Voltage



Collector Current vs Input Current

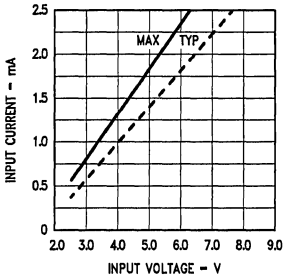


DS2002/DS9666 Input Current vs Input Voltage

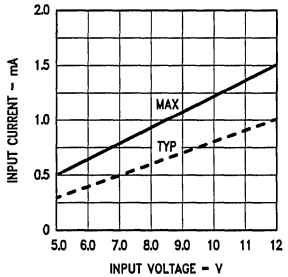


TL/F/9647-6

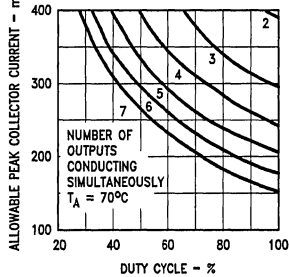
DS2003/DS9667 Input Current vs Input Voltage



DS2004/DS9668 Input Current vs Input Voltage

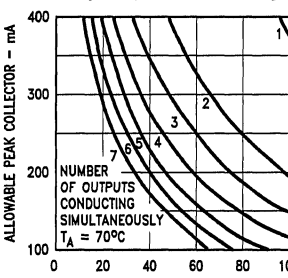


Peak Collector Current vs Duty Cycle and Number of Outputs (Molded Package)



TL/F/9647-18

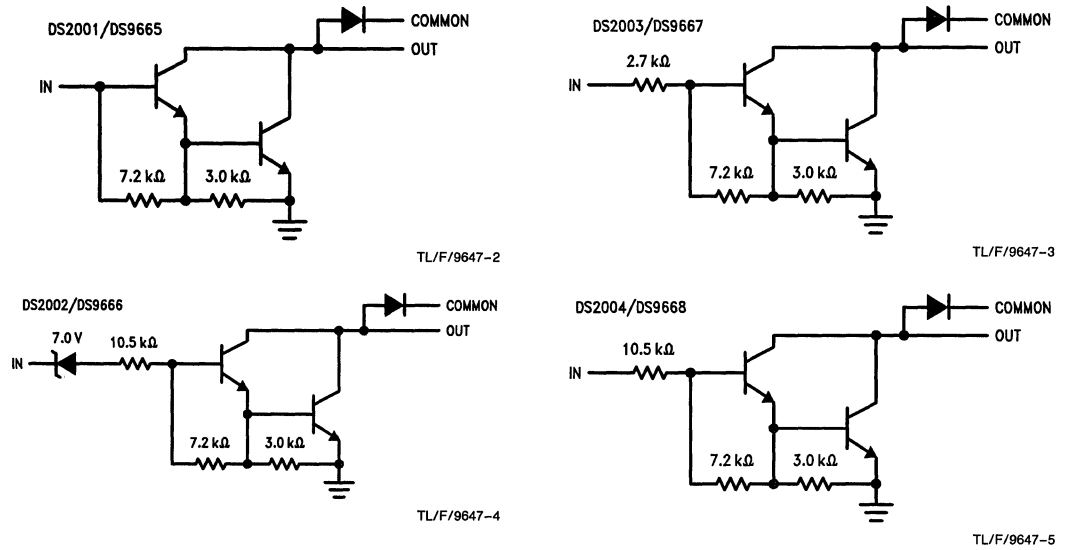
Peak Collector Current vs Duty Cycle and Number of Outputs (Ceramic Package)



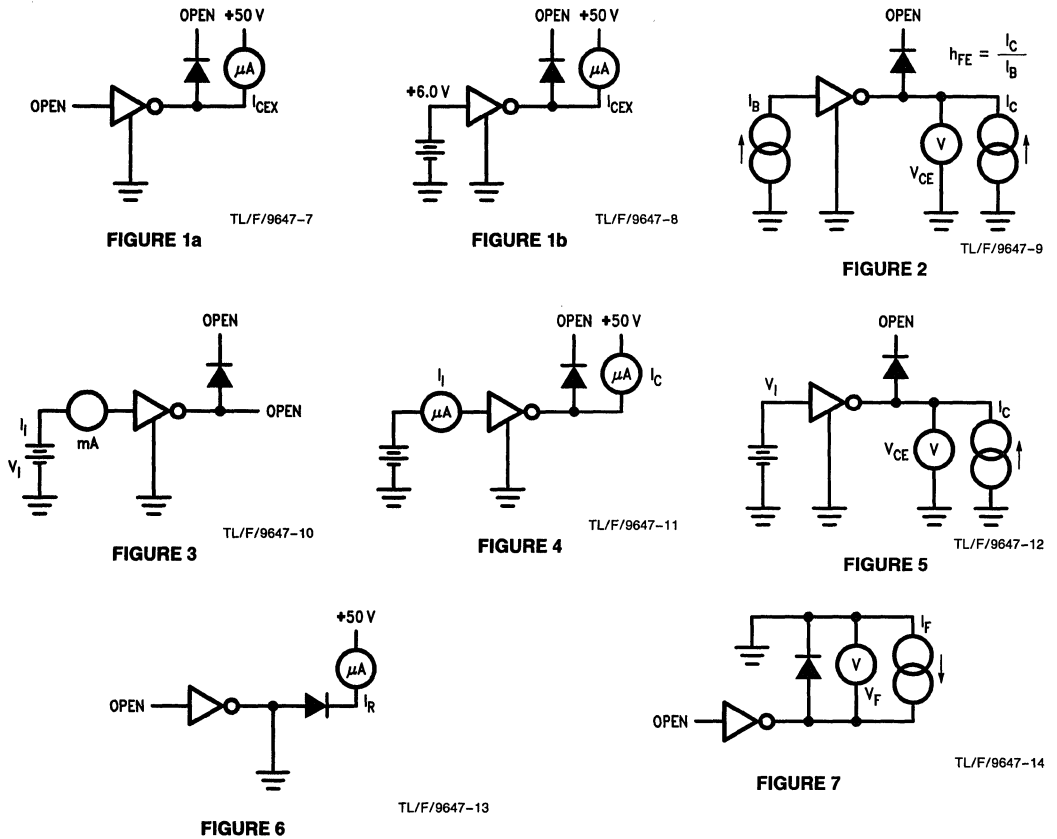
TL/F/9647-19

DS2001/DS96665/DS2002/DS9666/DS2003/DS9667/DS2004/DS9668

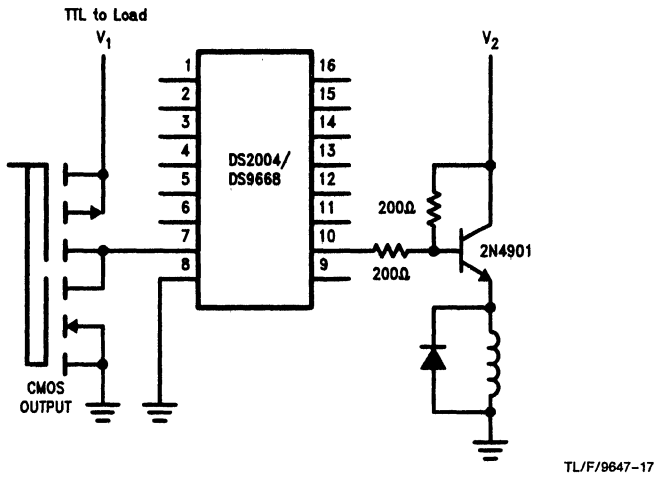
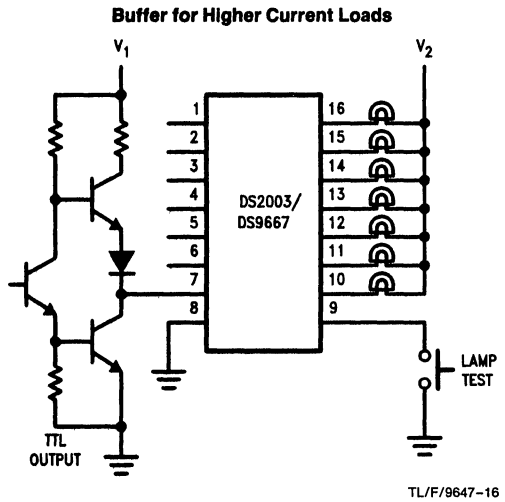
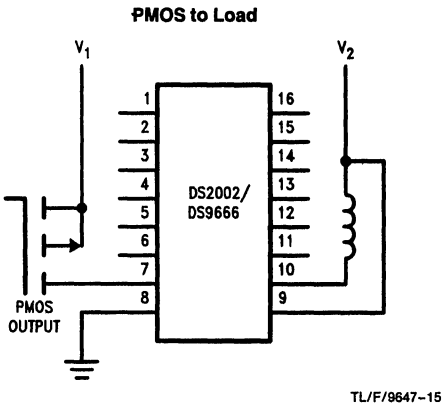
Equivalent Circuits



Test Circuits



Typical Applications



DS2001/DS9665/DS2002/DS9666/DS2003/DS9667/DS2004/DS9668



DS3654 Printer Solenoid Driver

General Description

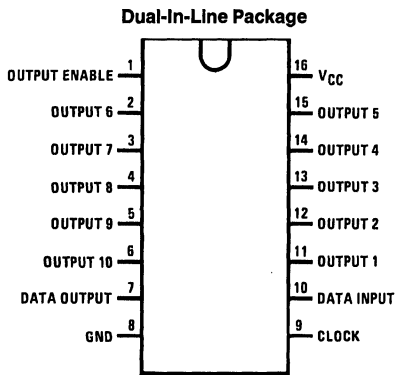
The DS3654 is a serial-to-parallel 10-bit shift register with a clock and data input, a data output from the tenth bit, and 10 open-collector clamped relay driver outputs suitable for driving printer solenoids.

Timing for the circuit is shown in *Figure 1*. Data input is sampled on the positive clock edge. Data output changes

on the negative clock edge, and is always active. Enable transfers data from the shift register to the open-collector outputs. Internal circuitry inhibits output enable for power supply voltage less than 6V.

Each output sinks 250 mA and is internally clamped to ground at 50V to dissipate energy stored in inductive loads.

Connection Diagram



TL/F/5817-1

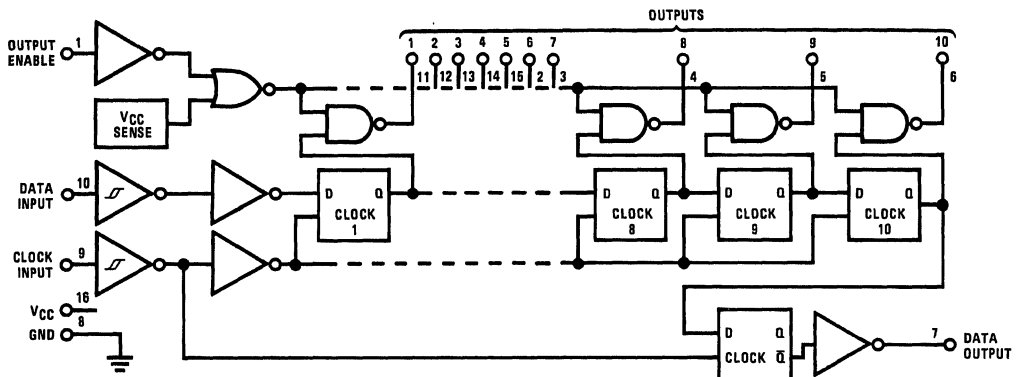
Top View

Order Number DS3654N
See NS Package Number N16E

Pin Descriptions

Pin No.	Function
1	Output Enable
2	Output 6
3	Output 7
4	Output 8
5	Output 9
6	Output 10
7	Data Output
8	Ground
9	Clock Input
10	Data Input
11	Output 1
12	Output 2
13	Output 3
14	Output 4
15	Output 5
16	VCC

Logic Diagram



TL/F/5817-2

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage, V_{CC}	9.5V Max
Input Voltage	-0.5V Min. 9.5V Max
Output Supply, V_{p-p}	45V Max
Storage Temperature Range	-65°C to +150°C
Output Current (Single Output)	0.4A
Ground Current	4.0A
Peak Power Dissipation $t < 10$ ms, Duty Cycle $< 5\%$	4.5W Max

Maximum Power Dissipation* at 25°C

Molded Package 1687 mW

Lead Temperature (Soldering, 4 seconds) 260°C

*Derate molded package 13.5 mW/°C above 25°C.

Operating Conditions

	Min	Max	Units
Supply Voltage (V_{CC})	7.5	9.5	V
Temperature (T_A)	0	+70	°C
Output Supply (V_{p-p})		40	V

Electrical Characteristics (Notes 2, 3 and 4) $V_{p-p} = 30V$ unless otherwise noted

Parameter	Conditions	Min	Typ	Max	Units
Logical "1" Input Voltage		2.6			V
Logical "0" Input Voltage				0.8	V
Logical "1" Output Voltage Clamp	$I_{CLAMP} = 0.1A, V_{EN} = 0V$	45	50	65	V
Logical "1" Output Current	$V_{OH} = 40V, V_{EN} = 0V$			1.0	mA
Logical "0" Output Voltage	$I_{OL} = 250$ mA, $V_{EN} = 2.6V$			1.6	V
Logical "1" Input Current					
Clock	$T_A = 70^\circ C, V_{CL} = 2.6V$	0.2	0.33		mA
Enable	$T_A = 70^\circ C, V_{EN} = 2.6V$	0.2	0.33		mA
Data	$T_A = 70^\circ C, V_D = 2.6V$	0.3	0.57		mA
Clock	$T_A = 0^\circ C, V_{CL} = 2.6V$		0.33	0.5	mA
Enable	$T_A = 0^\circ C, V_{EN} = 2.6V$		0.33	0.5	mA
Data	$T_A = 0^\circ C, V_D = 2.6V$		0.57	0.75	mA
Logical "0" Input Current					
Clock	$T_A = 70^\circ C, V_{CL} = 1V$		125		μA
Enable	$T_A = 70^\circ C, V_{EN} = 1V$		125		μA
Data	$T_A = 70^\circ C, V_D = 1V$		220		μA
Input Pull-Down Resistance					
Clock	$T_A = 25^\circ C, V_{CL} < V_{CC}$		8		k Ω
Enable	$T_A = 25^\circ C, V_{EN} < V_{CC}$		8		k Ω
Data	$T_A = 25^\circ C, V_D < V_{CC}$		4.5		k Ω
Supply Current (I_{CC})					
Outputs Disabled	$T_A \geq 25^\circ C, V_{EN} = 0V, V_{DO} = 0V,$ $V_{CC} = 9.5V$		27	40	mA
Outputs Enabled	$T_A \geq 25^\circ C, V_{EN} = 2.6V, I_{OL} = 250$ mA Each Bit		55	70	mA
Data Output Low (V_{DOL})	$V_D = 0V, I_{OL} = 0V$		0.01	0.5	V
Data Output High (V_{DOH})	$V_D = 2.6V, I_{OH} = -0.75$ mA	2.6	3.4		V
Data Output Pull-Down Resistance	$V_D = 0V, V_{DO} = 1V$		14		k Ω

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. They are not meant to imply that the devices should be operated at these limits. The tables of "Electrical Characteristics" provide conditions for actual device operation.

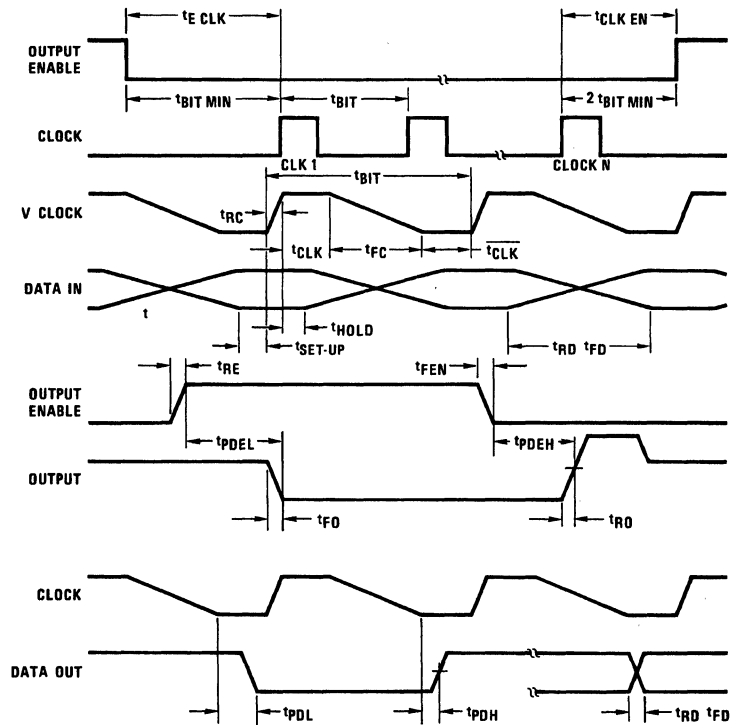
Note 2: Unless otherwise specified, min/max limits apply across the 0°C to +70°C temperature range and the 7.5V to 9.5V power supply range. All typical values given are for $V_{CC} = 8.5V$ and $T_A = 25^\circ C$.

Note 3: All currents into device pins are positive; all currents out of device pins are negative. All voltages are referenced to ground unless otherwise specified.

Note 4: Only one output at a time should be shorted.

Switching Characteristics 0°C to +70°C, $T_A = 25^\circ\text{C}$, nominal power supplies unless otherwise noted

Parameter	Conditions	Min	Typ	Max	Units	
Clk, Data and Enable Inputs	(Figure 1)					
t_{FC}	$t_{BIT} \geq 10 \mu\text{s}$			2.0	μs	
t_{RC}				2.0	μs	
t_{CLK}		2			μs	
$t_{\overline{CLK}}$		3.5			μs	
t_{HOLD}					1.0	μs
t_{SET-UP}					1.0	μs
$t_{RE}, t_{RD IN}$				1.0	μs	
$t_{FE}, t_{FD IN}$				5.0	μs	
Output 1-10	$V_{p-p} = 20\text{V}$ $R_L = 100\Omega, C_L < 100 \text{pF}$					
t_{RO}	$R_L = 100\Omega, C_L < 100 \text{pF}$		1.2		μs	
t_{FO}			1.2		μs	
t_{PDEH}			3.5		μs	
t_{PDEL}			3.0		μs	
Data Output	$R_L = 5 \text{k}\Omega, C_L \leq 10 \text{pF}$					
t_{PDH}, t_{PDL}			0.8	2.5	μs	
t_{RD}			0.4		μs	
t_{FD}			0.4		μs	
Clock to Enable Delay						
t_{CE}		$2 t_{BIT}$			μs	
Enable to Clock Delay		t_{BIT}			μs	

Switching Time Waveforms

FIGURE 1. Shift Timing

TL/F/5817-3

Definition of Terms

V_{p-p}: Output power supply voltage. The return for open-collector relay driver outputs.

t_{BIT}: Period of the incoming clock.

V_{CLK}: The voltage at the clock input.

t_{CLK}: The portion of t_{BIT} when V_{CLK} ≥ 2.6V

t_{CLK}: The portion of t_{BIT} when V_{CLK} ≤ 0.8V

t_{SET-UP}: The time prior to the end of t_{CLK} required to insure valid data at the shift register input for subsequent clock transitions.

t_{HOLD}: The time following the start of t_{CLK} required to transfer data within the shift register.



DS3658 Quad High Current Peripheral Driver

General Description

The DS3658 quad peripheral driver is designed for those applications where low operating power, high breakdown voltage, high output current and low output ON voltage are required. A unique input circuit combines TTL compatibility with high impedance. In fact, its extreme low input current allows it to be driven directly by a CMOS device.

The outputs are capable of sinking 600 mA each and offer a 70V breakdown. However, for inductive loads the output should be clamped to 35V or less to avoid latch-up during turn off (inductive fly back protection—refer AN-213). An on-chip clamp diode capable of handling 800 mA is provided at each output for this purpose. In addition, the DS3658 incorporates circuitry that guarantees glitch-free power up or down operation and a fail-safe feature which puts the output in a high impedance state when the input is open.

The molded package is specifically constructed to allow increased power dissipation over conventional packages. The four ground pins are directly connected to the device chip with a special copper lead frame. When the quad driver is soldered into a PC board, the power rating of the device improves significantly.

Applications

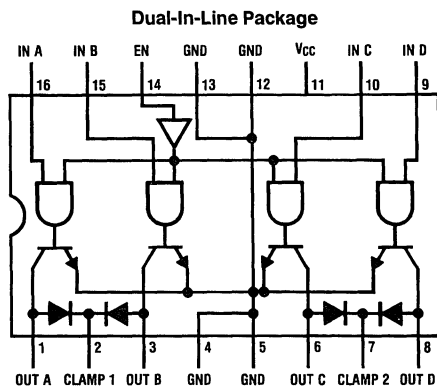
- Relay drivers
- Lamp drivers
- Solenoid drivers
- Hammer drivers
- Stepping motor drivers
- Triac drivers

- LED drivers
- High current, high voltage drivers
- Level translators
- Fiber optic LED drivers

Features

- Single saturated transistor outputs
- Low standby power, 10 mW typical
- High impedance TTL compatible inputs
- Outputs may be tied together for increased current capacity
- High output current
600 mA per output
2.4A per package
- No output latch-up at 35V
- Low output ON voltage (350 mV typ @ 600 mA)
- High breakdown voltage (70V)
- Open collector outputs
- Output clamp diodes for inductive fly back protection
- NPN inputs for minimal input currents (1 μ A typical)
- Low operating power
- Standard 5V power supply
- Power up/down protection
- Fail safe operation
- 2W power package
- Pin-for-pin compatible with SN75437

Connection Diagram



TL/F/5819-1

Order Number DS3658N
See NS Package Number N16E

Truth Table

IN	EN	OUT
H	H	L
L	H	Z
H	L	Z
L	L	Z

H = High state

L = Low state

Z = High impedance state

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7V
Input Voltage	15V
Output Voltage	70V
Output Current	1.5A
Continuous Power Dissipation @ 25°C Free-Air (Note 5)	2075 mW
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 4 sec.)	260°C

Operating Conditions

	Min	Max	Units
Supply Voltage	4.75	5.25	V
Ambient Temperature	0	70	°C

Electrical Characteristics (Notes 2 and 3)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{IH}	Input High Voltage		2.0			V
V_{IL}	Input Low Voltage				0.8	V
I_{IH}	Input High Current	$V_{IN} = 5.25V, V_{CC} = 5.25V$		1.0	10	μA
I_{IL}	Input Low Current	$V_{IN} = 0.4V$			± 10	μA
V_{IK}	Input Clamp Voltage	$I_I = -12 \text{ mA}$		-0.8	-1.5	V
V_{OL}	Output Low Voltage	$I_L = 300 \text{ mA}$		0.2	0.4	V
		$I_L = 600 \text{ mA}$ (Note 4)		0.35	0.7	V
I_{CEX}	Output Leakage Current	$V_{CE} = 70V, V_{IN} = 0.8V$			100	μA
V_F	Diode Forward Voltage	$I_F = 800 \text{ mA}$		1.0	1.6	V
I_R	Diode Leakage Current	$V_R = 70V$			100	μA
I_{CC}	Supply Current	All Inputs High		60	85	mA
		All Inputs Low		2	4	mA

Switching Characteristics (Note 2)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
t_{PHL}	Turn On Delay	$R_L = 60\Omega, V_L = 30V$		226	500	ns
t_{PLH}	Turn Off Delay	$R_L = 60\Omega, V_L = 30V$		2430	8000	ns

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. They are not meant to imply that the device should be operated at these limits. The table of "Electrical Characteristics" provides conditions for actual device operation.

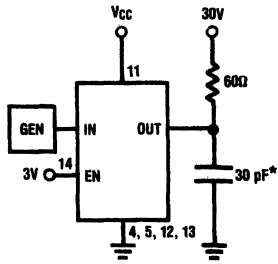
Note 2: Unless otherwise specified, min/max limits apply across the 0°C to +70°C temperature range and the 4.75V to 5.25V power supply range. All typical values are for $T_A = 25^\circ\text{C}$ and $V_{CC} = 5.0V$.

Note 3: All currents into device pins are shown as positive; all currents out of device pins are shown as negative; all voltages are referenced to ground, unless otherwise specified. All values shown as max or min are so classified on absolute value basis.

Note 4: All sections of this quad circuit may conduct rated current simultaneously; however, power dissipation averaged over a short interval of time must fall within specified continuous dissipation ratings.

Note 5: For operation over 25°C free-air temperature, derate linearly to 1328 mW @ 70°C @ the rate of 16.6 mW/°C.

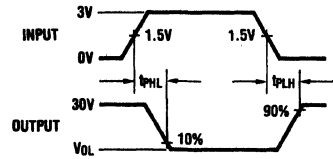
AC Test Circuit



TL/F/5819-2

*Includes probe and jig capacitance

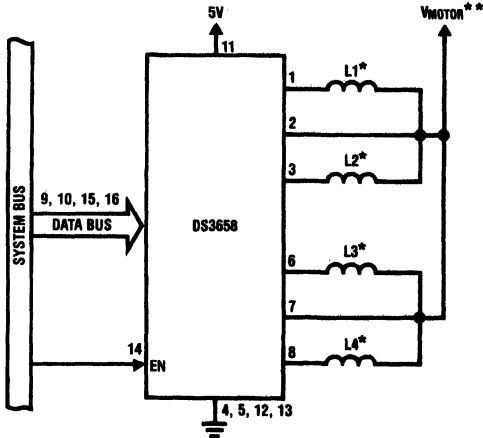
Switching Waveforms



TL/F/5819-3

Typical Applications

Stepping Motor Driver

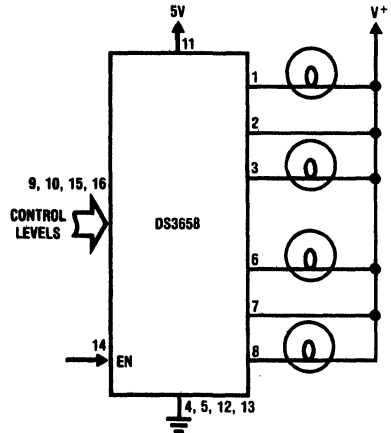


TL/F/5819-4

*L1, L2, L3, L4 are the windings of a bifilar stepping motor

**VMOTOR is the supply voltage of the motor

Lamp Driver



TL/F/5819-5



DS3668 Quad Fault Protected Peripheral Driver

General Description

The DS3668 quad peripheral driver is designed for those applications where low operating power, high breakdown voltage, high output current and low output ON voltage are required. Unlike most peripheral drivers available, a unique fault protection circuit is incorporated on each output. When the load current exceeds 1.0A (approximately) on any output for more than a built-in delay time, nominally 12 μ s, that output will be shut off by its protection circuitry with no effect on other outputs. This condition will prevail until that protection circuitry is reset by toggling the corresponding input or the enable pin low for at least 1.0 μ s. This built-in delay is provided to ensure that the protection circuitry is not triggered by turn-on surge currents associated with certain kinds of loads.

The DS3668's inputs combine TTL compatibility with high input impedance. In fact, its extreme low input current allows it to be driven directly by a MOS device. The outputs are capable of sinking 600 mA each and offer a 70V breakdown. However, for inductive loads the output should be clamped to 35V or less to avoid latch up during turn off (inductive fly-back protection — refer AN-213). An on-chip clamp diode capable of handling 800 mA is provided at each output for this purpose. In addition, the DS3668 incorporates circuitry that guarantees glitch-free power up or down operation and a fail-safe feature which puts the output in a high impedance state when the input is open.

The molded package is specifically constructed to allow increased power dissipation over conventional packages. The four ground pins are directly connected to the device chip with a special copper lead frame. When the quad driver is soldered into a PC board, the power rating of the device improves significantly.

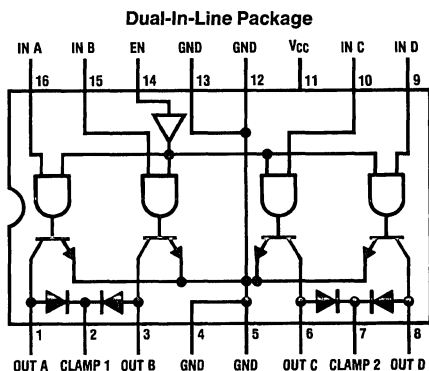
Applications

- Relay drivers
- Solenoid drivers
- Hammer drivers
- Stepping motor drivers
- Triac drivers
- LED drivers
- High current, high voltage drivers
- Level translators
- Fiber optic LED drivers

Features

- Output fault protection
- High impedance TTL compatible inputs
- High output current—600 mA per output
- No output latch-up at 35V
- Low output ON voltage (550 mV typ @ 600 mA)
- High breakdown voltage (70V)
- Open collector outputs
- Output clamp diodes for inductive fly-back protection
- NPN inputs for minimal input currents (1 μ A typical)
- Low operating power
- Standard 5V power supply
- Power up/down protection
- Fail-safe operation
- 2W power package
- Pin-for-pin compatible with SN75437

Connection Diagram



Top View

TL/F/5225-1

Truth Table

IN	EN	OUT
H	H	L
L	H	Z
H	L	Z
L	L	Z

H = High state

L = Low state

Z = High impedance state

Order Number DS3668N
See NS Package Number N16E

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7.0V
Input Voltage	15V
Output Voltage	70V
Continuous Power Dissipation @ 25°C Free-Air ⁽⁵⁾	2075 mW
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 4 seconds)	260

Operating Conditions

	Min	Max	Units
Supply Voltage	4.75	5.25	V
Ambient Temperature	0	70	°C

Electrical Characteristics (Notes 2 and 3)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V _{IH}	Input High Voltage		2.0			V
V _{IL}	Input Low Voltage				0.8	V
I _{IH}	Input High Current	V _{IN} = 5.25V, V _{CC} = 5.25V		1.0	20	μA
I _{IL}	Input Low Current	V _{IN} = 0.4V			±10	μA
V _{IK}	Input Clamp Voltage	I _I = -12 mA		-0.8	-1.5	V
V _{OL}	Output Low Voltage	I _L = 300 mA		0.2	0.7	V
		I _L = 600 mA (Note 4)		0.55	1.5	V
I _{CEX}	Output Leakage Current	V _{CE} = 70V, V _{IN} = 0.8V			100	μA
V _F	Diode Forward Voltage	I _F = 800 mA		1.2	1.6	V
I _R	Diode Leakage Current	V _R = 70V			100	μA
I _{CC}	Supply Current	All Inputs High		62	80	mA
		All Inputs Low		20		mA
I _{TH}	Protection Circuit Threshold Current			1	1.4	A

Switching Characteristics (Note 2)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
t _{PHL}	Turn On Delay	R _L = 60Ω, V _L = 30V		0.3	1.0	μs
t _{PLH}	Turn Off Delay	R _L = 60Ω, V _L = 30V		2	10.0	μs
t _{FZ}	Protection Enable Delay (after Detection of Fault)		6	12		μs
t _{RL}	Input Low Time for Protection Circuit Reset		1.0			μs

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. They are not meant to imply that the device should be operated at these limits. The table of "Electrical Characteristics" provides conditions for actual device operation.

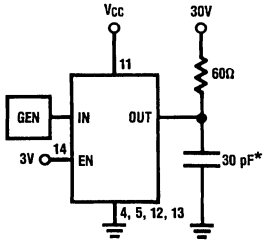
Note 2: Unless otherwise specified, min/max limits apply across the 0°C to +70°C temperature range and the 4.75V to 5.25V power supply range. All typical values are for T_A = 25°C and V_{CC} = 5.0V.

Note 3: All currents into device pins are shown as positive; all currents out of device pins are shown as negative; all voltages are referenced to ground, unless otherwise specified. All values shown as max or min are so classified on absolute value basis.

Note 4: All sections of this quad circuit may conduct rated current simultaneously; however, power dissipation averaged over a short interval of time must fall within specified continuous dissipation ratings.

Note 5: For operation over 25°C free-air temperature, derate linearly to 1328 mW @ 70°C @ the rate of 16.6 mW/°C.

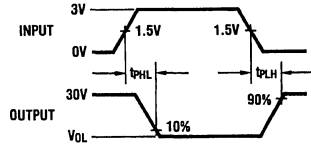
AC Test Circuit



TL/F/5225-2

*Includes probe and jig capacitance.

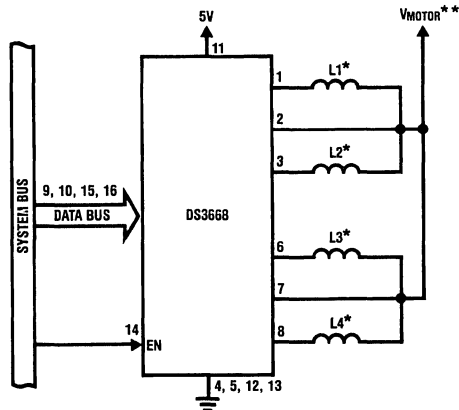
Switching Waveforms



TL/F/5225-3

Typical Application

Stepping Motor Driver

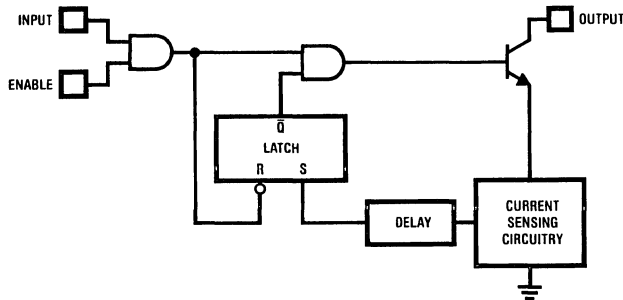


*L1, L2, L3, L4 are the windings of a bifilar stepping motor.

**VMOTOR is the supply voltage of the motor.

TL/F/5225-4

Protection Circuit Block Diagram



TL/F/5225-5



DS3669 Quad High Current Peripheral Driver

General Description

The DS3669 is a non-inverting quad peripheral driver similar to the DS3658. These drivers are designed for those applications where low operating power, high breakdown voltage, high output current and low output ON voltage are required. A unique input circuit combines TTL compatibility with high impedance. In fact, its extreme low input current allows it to be driven directly by a CMOS device.

The outputs are capable of sinking 600 mA each and offer a 70V breakdown. However, for inductive loads the output should be clamped to 35V or less to avoid latch-up during turn off (inductive fly back protection—refer AN-213). An on-chip clamp diode capable of handling 800 mA is provided at each output for this purpose. In addition, the DS3669 incorporates circuitry that guarantees glitch-free power up or down operation.

The molded package is specifically constructed to allow increased power dissipation over conventional packages. The four ground pins are directly connected to the device chip with a special copper lead frame. When the quad driver is soldered into a PC board, the power rating of the device improves significantly.

Applications

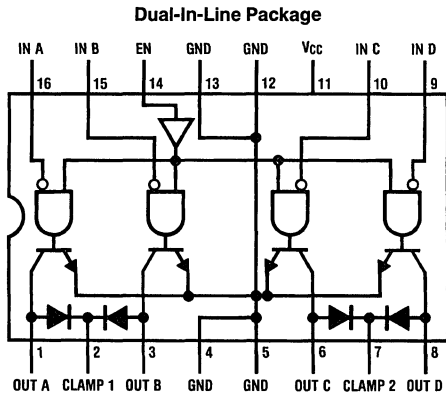
- Relay drivers
- Lamp drivers
- Solenoid drivers
- Hammer drivers

- Stepping motor drivers
- Triac drivers
- LED drivers
- High current, high voltage drivers
- Level translators
- Fiber optic LED drivers

Features

- Single saturated transistor outputs
- Low standby power, 10 mW typical
- High impedance TTL compatible inputs
- Outputs may be tied together for increased current capacity
- High output current
 - 600 mA per output
 - 2.4A per package
- No output latch-up at 35V
- Low output ON voltage (350 mV typ @600 mA)
- High breakdown voltage (70V)
- Open collector outputs
- Output clamp diodes for inductive fly back protection
- NPN inputs for minimal input currents (1 μ A typical)
- Low operating power
- Standard 5V power supply
- Power up/down protection
- 2W power package

Connection Diagram



Order Number DS3669N
See NS Package Number N16E

Truth Table

IN	EN	OUT
L	H	L
H	H	Z
L	L	Z
H	L	Z

H = High state
L = Low state
Z = High impedance state

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	7.0V
Input Voltage	15V
Output Voltage	70V
Output Current	1.5A

Continuous Power Dissipation
@25°C Free-Air (Note 5) 2075 mW

Storage Temperature Range -65°C to +150°C
Lead Temperature (Soldering, 4 seconds) 260°C

Operating Conditions

	Min	Max	Units
Supply Voltage	4.75	5.25	V
Ambient Temperature	0	70	°C

Electrical Characteristics (Notes 2 and 3)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{IH}	Input High Voltage		2.0			V
V_{IL}	Input Low Voltage				0.8	V
I_{IH}	Input High Current	$V_{IN} = 5.25V, V_{CC} = 5.25V$		1.0	10	μA
I_{IL}	Input Low Current	$V_{IN} = 0.4V$			± 10	μA
V_{IK}	Input Clamp Voltage	$I_I = -12\text{ mA}$		-0.8	-1.5	V
V_{OL}	Output Low Voltage	$I_L = 300\text{ mA}$		0.2	0.4	V
		$I_L = 600\text{ mA}$ (Note 4)		0.35	0.7	V
I_{CEX}	Output Leakage Current	$V_C = 70V, V_{IN} = 2V, V_{EN} = 0.8V$			100	μA
V_F	Diode Forward Voltage	$I_F = 800\text{ mA}$		1.0	1.6	V
I_R	Diode Leakage Current	$V_R = 70V$			100	μA
I_{CC}	Supply Current	All Inputs Low $EN = 2.0V$		60	85	mA
		All Inputs High		2	4	mA

Switching Characteristics (Note 2)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
t_{PHL}	Turn On Delay	$R_L = 60\Omega, V_L = 30V$		226	500	ns
t_{PLH}	Turn Off Delay	$R_L = 60\Omega, V_L = 30V$		2430	8000	ns

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. They are not meant to imply that the device should be operated at these limits. The table of "Electrical Characteristics" provides conditions for actual device operation.

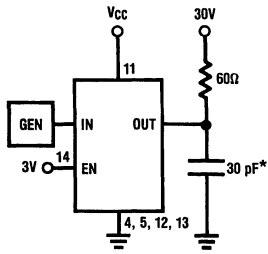
Note 2: Unless otherwise specified, min/max limits apply across the 0°C to +70°C temperature range and the 4.75V to 5.25V power supply range. All typical values are for $T_A = 25^\circ C$ and $V_{CC} = 5.0V$.

Note 3: All currents into device pins are shown as positive; all currents out of device pins are shown as negative; all voltages are referenced to ground, unless otherwise specified. All values shown as max or min are so classified on absolute value basis.

Note 4: All sections of this quad circuit may conduct rated current simultaneously; however, power dissipation averaged over a short interval of time must fall within specified continuous dissipation ratings.

Note 5: For operation over 25°C free-air temperature, derate linearly to 1328 mW @70°C @ the rate of 16.6 mW/°C.

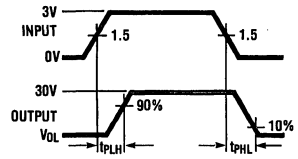
AC Test Circuit



TL/F/5820-2

*Includes probe and jig capacitance

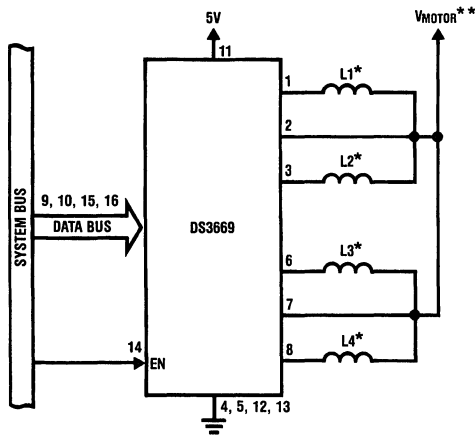
Switching Waveforms



TL/F/5820-3

Typical Applications

Stepping Motor Driver

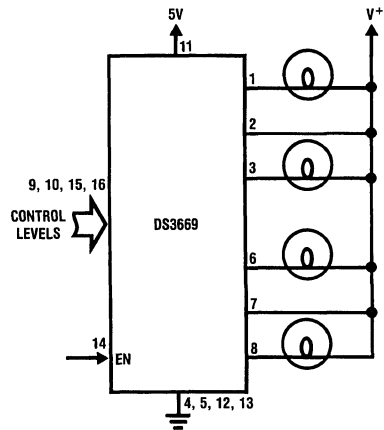


TL/F/5820-4

*L1, L2, L3, L4 are the windings of a bililar stepping motor.

**V_{MOTOR} is the supply voltage of the motor.

Lamp Driver



TL/F/5820-5

DS3680 Quad Negative Voltage Relay Driver

General Description

The DS3680 is a quad high voltage negative relay driver designed to operate over wide ranges of supply voltage, common-mode voltage, and ambient temperature, with 50 mA sink capability. These drivers are intended for switching the ground end of loads which are directly connected to the negative supply, such as in telephone relay systems.

Since there may be considerable noise and IR drop between logic ground and negative supply ground in many applications, these drivers are designed to operate with a high common-mode range ($\pm 20V$ referenced to negative supply ground). Each driver has a common-mode range separate from the other drivers in the package, which permits input signals from more than one element of the system.

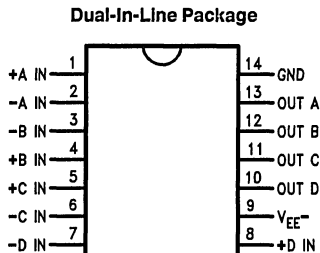
With low differential input current requirements (typically 100 μA), these drivers are compatible with TTL, LS and CMOS logic. Differential inputs permit either inverting or non-inverting operation.

The driver outputs incorporate transient suppression clamp networks, which eliminate the need for external networks when used in applications of switching inductive loads. A fail-safe feature is incorporated to insure that, if the +IN input or both inputs are open, the driver will be OFF.

Features

- $-10V$ to $-60V$ operation
- Quad 50 mA sink capability
- TTL/LS/COMS or voltage comparator input
- High input common-mode voltage range
- Very low input current
- Fail-safe disconnect feature
- Built-in output clamp diode

Connection Diagram

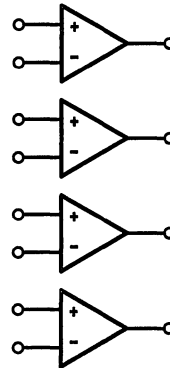


Top View

TL/F/5821-1

Order Number DS3680J, DS3680M or DS3680N
See NS Package Number J14A, M14A, N14A

Logic Diagram



TL/F/5821-2

Truth Table

Differential Inputs	Outputs
$V_{ID} \geq 2V$	On
$V_{ID} \leq 0.8V$	Off
Open	Off

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage (GND to V_{EE-} , and Any Pin)	-70V
Positive Input Voltage (Input to GND)	20V
Negative Input Voltage (Input to V_{EE-})	-5V
Differential Voltage (+ IN to -IN)	$\pm 20V$
Inductive Load	$L_L \leq 5h$ $I_L \leq 50 mA$
Output Current	-100 mA
Storage Temperature	-65°C to +150°C
Maximum Power Dissipation* at 25°C	
Cavity Package	1433 mW
Molded Dip Package	1398 mW
SO Package	1002 mW
Lead Temperature (Soldering, 4 seconds)	260°C

* Derate cavity package 9.6 mW/°C above 25°C; derate molded dip package 11.2 mW/°C above 25°C; derate SO package 8.02 mW/°C above 25°C.

Recommended Operating Conditions

	Min	Max	Units
Supply Voltage (GND to V_{EE-})	-10	-60	V
Input Voltage (Input to GND)	-20	20	V
Logic ON Voltage (+ IN)			
Referenced to -IN	2	20	V
Logic OFF Voltage (+ IN)			
Referenced to -IN	-20	0.8	V
Temperature Range	-25	+85	°C

Electrical Characteristics (Notes 2 and 3)

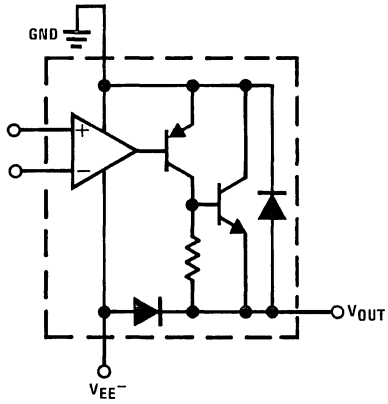
Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{IH}	Logic "1" Input Voltage		2.0	1.3		V
V_{IL}	Logic "0" Input Voltage			1.3	0.8	V
I_{INH}	Logic "1" Input Current	$V_{IN} = 2V$ $V_{IN} = 7V$		40 375	100 1000	μA μA
I_{INL}	Logic "0" Input Current	$V_{IN} = 0.4V$ $V_{IN} = -7V$		-0.01 -1	-5 -100	μA μA
V_{OL}	Output ON Voltage	$I_{OL} = 50 mA$		-1.6	-2.1	V
I_{OFF}	Output Leakage	$V_{OUT} = V_{EE-}$		-2	-100	μA
I_{FS}	Fail-Safe Output Leakage	$V_{OUT} = V_{EE-}$ (Inputs Open)		-2	-100	μA
I_{LC}	Output Clamp Leakage Current	$V_{OUT} = GND$		2	100	μA
V_C	Output Clamp Voltage	$I_{CLAMP} = -50 mA$ Referenced to V_{EE-}		-2	-1.2	V
V_P	Positive Output Clamp Voltage	$I_{CLAMP} = 50 mA$ Referenced to GND		0.9	1.2	V
$I_{EE(ON)}$	ON Supply Current	All Drivers ON		-2	-4.4	mA
$I_{EE(OFF)}$	OFF Supply Current	All Drivers OFF		-1	-100	μA
$t_{PD(ON)}$	Propagation Delay to Driver ON	$L = 1h, R_L = 1k,$ $V_{IN} = 3V$ Pulse		1	10	μs
$t_{PD(OFF)}$	Propagation Delay to Driver OFF	$L = 1h, R_L = 1k,$ $V_{IN} = 3V$ Pulse		1	10	μs

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. Except for "Operating Temperature Range", they are not meant to imply that the device should be operated at these limits. The table of "Electrical Characteristics" provides conditions for actual device operation.

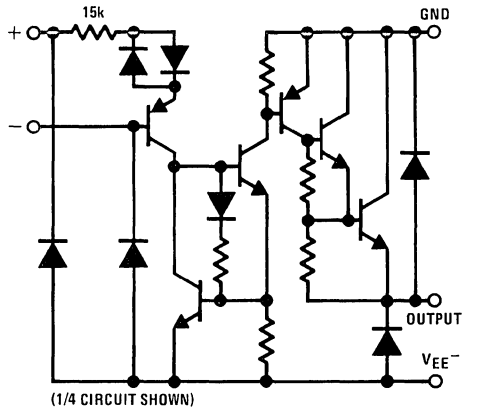
Note 2: Unless otherwise specified, the min/max limits of the table of "Electrical Characteristics" apply within the range of the table of "Operating Conditions". All typical values are given for $V_{EE-} = 52V$, and $T_A = 25^\circ C$.

Note 3: All current into device pins shown as positive, out of the device as negative. All voltages are referenced to ground unless otherwise noted.

Schematic Diagrams



TL/F/5821-3



TL/F/5821-4



DS55451/2/3/4, DS75450/1/2/3/4 Series Dual Peripheral Drivers

General Description

The DS75450 series of dual peripheral drivers is a family of versatile devices designed for use in systems that use TTL logic. Typical applications include high speed logic buffers, power drivers, relay drivers, lamp drivers, MOS drivers, bus drivers and memory drivers.

The DS75450 is a general purpose device featuring two standard Series 54/74 TTL gates and two uncommitted, high current, high voltage NPN transistors. The device offers the system designer the flexibility of tailoring the circuit to the application.

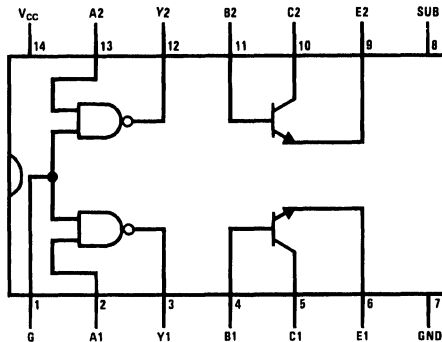
The DS55451/DS75451, DS55452/DS75452, DS55453/DS75453 and DS55454/DS75454 are dual peripheral AND, NAND, OR and NOR drivers, respectively, (positive logic)

with the output of the logic gates internally connected to the bases of the NPN output transistors.

Features

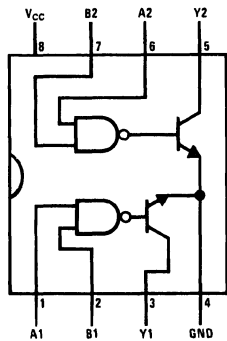
- 300 mA output current capability
- High voltage outputs
- No output latch-up at 20V
- High speed switching
- Choice of logic function
- TTL compatible diode-clamped inputs
- Standard supply voltages
- Replaces TI "A" and "B" series

Connection Diagrams (Dual-In-Line and Metal Can Packages)



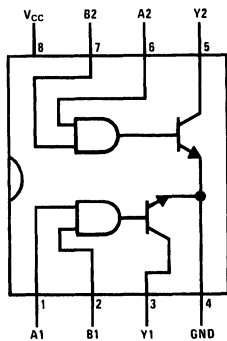
TL/F/5824-1

Top View
Order Number DS75450N
See NS Package Number N14A



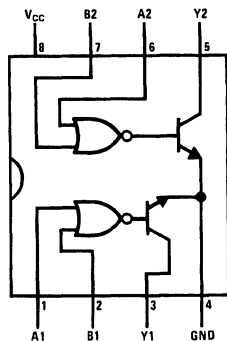
TL/F/5824-2

Top View
Order Number DS55451J-8,
DS75451M or DS75451N
See NS Package Numbers J08A, M08A* or N08E



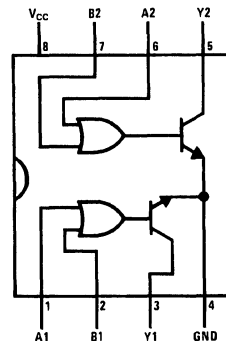
TL/F/5824-3

Top View
Order Number DS55452J-8,
DS75452M or DS75452N



TL/F/5824-4

Top View
Order Number DS55453J-8,
DS75453M or DS75453N



TL/F/5824-5

Top View
Order Number DS55454J-8,
DS75454M or DS75454N

*See Note 6 and Appendix E regarding S.O. package power dissipation constraints.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage, (V _{CC}) (Note 2)	7.0V
Input Voltage	5.5V
Inter-Emitter Voltage (Note 3)	5.5V
V _{CC} -to-Substrate Voltage DS75450	35V
Collector-to-Substrate Voltage DS75450	35V
Collector-Base Voltage DS75450	35V
Collector-Emitter Voltage (Note 4) DS75450	30V
Emitter-Base Voltage DS75450	5.0V
Output Voltage (Note 5) DS55451/DS75451, DS55452/DS75452, DS55453/DS75453, DS55454/DS75454	30V
Collector Current (Note 6) DS75450	300 mA
Output Current (Note 6) DS55451/DS75451, DS55452/DS75452, DS55453/DS75453, DS55454/DS75454	300 mA

DS75450 Maximum Power (Note 6)

Dissipation* at 25°C	
Cavity Package	1308 mW
Molded Package	1207 mW

DS75451/2/3/4 Maximum Power (Note 6)

Dissipation† at 25°C	
Cavity Package	1090 mW
Molded DIP Package	957 mW
TO-5 Package	760 mW
SO Package	632 mW

Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 4 sec.)	260°C

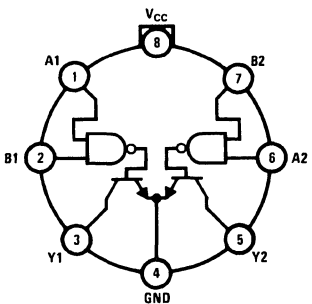
Operating Conditions (Note 7)

	Min	Max	Units
Supply Voltage, (V _{CC})			
DS5545X	4.5	5.5	V
DS7545X	4.75	5.25	V
Temperature, (T _A)			
DS5545X	-55	+125	°C
DS7545X	0	+70	°C

*Derate cavity package 8.7 mW/°C above 25°C; derate molded package 9.7 mW/°C above 25°C.

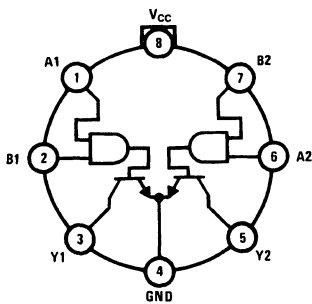
†Derate cavity package 7.3 mW/°C above 25°C; derate molded package 7.7 mW/°C above 25°C; derate TO-5 package 5.1 mW/°C above 25°C; derate SO package 7.56 mW/°C above 25°C.

Connection Diagrams (Dual-In-Line and Metal Can Packages) (Continued)



Top View TL/F/5824-6

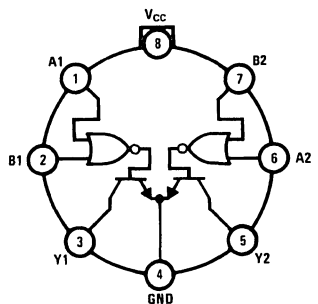
Order Number DS55451H



Top View TL/F/5824-7

Order Number DS55452H

(Pin 4 is in Electrical Contact with the Case)



Top View TL/F/5824-8

Order Number DS55453H

See NS Package Number H08C

Electrical Characteristics DS75450 (Notes 8 and 9)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
TTL GATES						
V _{IH}	High Level Input Voltage	(Figure 1)	2			V
V _{IL}	Low Level Input Voltage	(Figure 2)			0.8	V
V _I	Input Clamp Voltage	V _{CC} = Min, I _I = -12 mA, (Figure 3)			-1.5	V
V _{OH}	High Level Output Voltage	V _{CC} = Min, V _{IL} = 0.8V, I _{OH} = -400 μA, (Figure 2)	2.4	3.3		V
V _{OL}	Low Level Output Voltage	V _{CC} = Min, V _{IH} = 2V, I _{OL} = 16 mA (Figure 1)		0.22	0.4	V
I _I	Input Current at Maximum Input Voltage	V _{CC} = Max, V _I = 5.5V, (Figure 4)				
		Input A			1	mA
		Input G			2	mA

Electrical Characteristics DS75450 (Notes 8 and 9) (Continued)

Symbol	Parameter	Conditions		Min	Typ	Max	Units		
TTL GATES (Continued)									
I_{IH}	High Level Input Current	$V_{CC} = \text{Max}, V_I = 2.4\text{V},$ (Figure 4)		Input A		40	μA		
				Input G		80	μA		
I_{IL}	Low Level Input Current	$V_{CC} = \text{Max}, V_I = 0.4\text{V},$ (Figure 3)		Input A		-1.6	mA		
				Input G		-3.2	mA		
I_{OS}	Short Circuit Output Current	$V_{CC} = \text{Max},$ (Figure 5), (Note 10)		-18		-55	mA		
I_{OCH}	Supply Current	$V_{CC} = \text{Max}, V_I = 0\text{V},$ Outputs High, (Figure 6)			2	4	mA		
I_{OCL}	Supply Current	$V_{CC} = \text{Max}, V_I = 5\text{V},$ Outputs Low, (Figure 6)			6	11	mA		
OUTPUT TRANSISTORS									
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	$I_C = 100\ \mu\text{A}, I_E = 0\ \mu\text{A}$		35			V		
$V_{(BR)CER}$	Collector-Emitter Breakdown Voltage	$I_C = 100\ \mu\text{A}, R_{BE} = 500\ \Omega$		30			V		
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	$I_E = 100\ \mu\text{A}, I_C = 0\ \mu\text{A}$		5			V		
h_{FE}	Static Forward Current Transfer Ratio	$V_{CE} = 3\text{V},$ (Note 11)	$T_A = +25^\circ\text{C}$	$I_C = 100\ \text{mA}$		25			
				$I_C = 300\ \text{mA}$		30			
			$T_A = 0^\circ\text{C}$	$I_C = 100\ \text{mA}$		20			
				$I_C = 300\ \text{mA}$		25			
V_{BE}	Base-Emitter Voltage	(Note 11)		$I_B = 10\ \text{mA}, I_C = 100\ \text{mA}$		0.85	1	V	
				$I_B = 30\ \text{mA}, I_C = 300\ \text{mA}$		1.05	1.2	V	
$V_{CE(SAT)}$	Collector-Emitter Saturation Voltage	(Note 11)		$I_B = 10\ \text{mA}, I_C = 100\ \text{mA}$		0.25	0.4	V	
				$I_B = 30\ \text{mA}, I_C = 300\ \text{mA}$		0.5	0.7	V	

Electrical Characteristics (Continued)

DS55451/DS75451, DS55452/DS75452, DS55453/DS75453, DS55454/DS75454 (Notes 8 and 9)

Symbol	Parameter	Conditions		Min	Typ	Max	Units		
V_{IH}	High-Level Input Voltage	(Figure 7)		2			V		
V_{IL}	Low-Level Input Voltage					0.8	V		
V_I	Input Clamp Voltage	$V_{CC} = \text{Min}, I_I = -12\ \text{mA}$				-1.5	V		
V_{OL}	Low-Level Output Voltage	$V_{CC} = \text{Min},$ (Figure 7)	$V_{IL} = 0.8\text{V}$	$I_{OL} = 100\ \text{mA}$	DS55451, DS55453		0.25	0.5	V
					DS75451, DS75453		0.25	0.4	V
			$V_{IH} = 2\text{V}$	$I_{OL} = 300\ \text{mA}$	DS55451, DS55453		0.5	0.8	V
					DS75451, DS75453		0.5	0.7	V
		$I_{OH} = 100\ \text{mA}$	DS55452, DS55454	DS55452, DS55454		0.25	0.5	V	
				DS75452, DS75454		0.25	0.4	V	
			$I_{OL} = 300\ \text{mA}$	DS55452, DS55454		0.5	0.8	V	
				DS75452, DS75454		0.5	0.7	V	
I_{OH}	High-Level Output Current	$V_{CC} = \text{Min},$ (Figure 7)	$V_{OH} = 30\text{V}$	$V_{IH} = 2\text{V}$	DS55451, DS55453		300	μA	
					DS75451, DS75453		100	μA	
				$V_{IL} = 0.8\text{V}$	DS55452, DS55454		300	μA	
					DS75452, DS75454		100	μA	
I_I	Input Current at Maximum Input Voltage	$V_{CC} = \text{Max}, V_I = 5.5\text{V},$ (Figure 9)				1	mA		

Electrical Characteristics (Continued)

DS55451/DS75451, DS55452/DS75452, DS55453/DS75453, DS55454/DS75454 (Notes 8 and 9) (Continued)

Symbol	Parameter	Conditions		Min	Typ	Max	Units
I_{IH}	High-Level Input Current	$V_{CC} = \text{Max}, V_I = 2.4V, \text{(Figure 9)}$				40	μA
I_{IL}	Low-Level Input Current	$V_{CC} = \text{Max}, V_I = 0.4V, \text{(Figure 8)}$			-1	-1.6	mA
I_{CCH}	Supply Current, Outputs High	$V_{CC} = \text{Max}, \text{(Figure 10)}$	$V_I = 5V$	DS55451/DS75451	7	11	mA
			$V_I = 0V$	DS55452/DS75452	11	14	mA
			$V_I = 5V$	DS55453/DS75453	8	11	mA
			$V_I = 0V$	DS55454/DS75454	13	17	mA
I_{CCL}	Supply Current, Outputs Low	$V_{CC} = \text{Max}, \text{(Figure 10)}$	$V_I = 0V$	DS55451/DS75451	52	65	mA
			$V_I = 5V$	DS55452/DS75452	56	71	mA
			$V_I = 0V$	DS55453/DS75453	54	68	mA
			$V_I = 5V$	DS55454/DS75454	61	79	mA

Switching Characteristics DS75450 ($V_{CC} = 5V, T_A = 25^\circ C$)

Symbol	Parameter	Conditions		Min	Typ	Max	Units
t_{PLH}	Propagation Delay Time, Low-to-High Level Output	$C_L = 15 \text{ pF}$	$R_L = 400\Omega, \text{TTL Gates, (Figure 12)}$		12	22	ns
			$R_L = 50\Omega, I_C \approx 200 \text{ mA}, \text{Gates and Transistors Combined, (Figure 14)}$		20	30	ns
t_{PHL}	Propagation Delay Time, High-to-Low Level Output	$C_L = 15 \text{ pF}$	$R_L = 400\Omega, \text{TTL Gates, (Figure 12)}$		8	15	ns
			$R_L = 50\Omega, I_C \approx 200 \text{ mA}, \text{Gates and Transistors Combined, (Figure 14)}$		20	30	ns
t_{TLH}	Transition Time, Low-to-High Level Output	$C_L = 15 \text{ pF}, R_L = 50\Omega, I_C \approx 200 \text{ mA}, \text{Gates and Transistors Combined, (Figure 14)}$			7	12	ns
t_{THL}	Transition Time, High-to-Low Level Output	$C_L = 15 \text{ pF}, R_L = 50\Omega, I_C \approx 200 \text{ mA}, \text{Gates and Transistors Combined, (Figure 14)}$			9	15	ns
V_{OH}	High-Level Output Voltage after Switching	$V_S = 20V, I_C \approx 300 \text{ mA}, R_{BE} = 500\Omega, \text{(Figure 15)}$		$V_S - 6.5$			mV
t_D	Delay Time	$I_C = 200 \text{ mA}, I_{B(1)} = 20 \text{ mA},$			8	15	ns
t_R	Rise Time	$I_B = -40 \text{ mA}, V_{BE(OFF)} = -1V,$			12	20	ns
t_S	Storage Time	$C_L = 15 \text{ pF}, R_L = 50\Omega,$			7	15	ns
t_F	Full Time	$\text{(Figure 13), (Note 12)}$			6	15	ns

Switching Characteristics (Continued)DS55451/DS75451, DS55452/DS75452, DS55453/DS75453, DS55454/DS75454 ($V_{CC} = 5V, T_A = 25^\circ C$)

Symbol	Parameter	Conditions		Min	Typ	Max	Units
t_{PLH}	Propagation Delay Time, Low-to-High Level Output	$C_L = 15 \text{ pF}, R_L = 50\Omega,$	$I_O \approx 200 \text{ mA}, \text{(Figure 14)}$	DS55451/DS75451	18	25	ns
				DS55452/DS75452	26	35	ns
				DS55453/DS75453	18	25	ns
				DS55454/DS75454	27	35	ns
t_{PHL}	Propagation Delay Time, High-to-Low Level Output	$C_L = 15 \text{ pF}, R_L = 50\Omega,$	$I_O \approx 200 \text{ mA}, \text{(Figure 14)}$	DS55451/DS75451	18	25	ns
				DS55452/DS75452	24	35	ns
				DS55453/DS75453	16	25	ns
				DS55454/DS75454	24	35	ns
t_{TLH}	Transition Time, Low-to-High Level Output	$C_L = 15 \text{ pF}, R_L = 50\Omega, I_O \approx 200 \text{ mA}, \text{(Figure 14)}$			5	8	ns
t_{THL}	Transition Time, High-to-Low Level Output	$C_L = 15 \text{ pF}, R_L = 50\Omega, I_O \approx 200 \text{ mA}, \text{(Figure 14)}$			7	12	ns
V_{OH}	High-Level Output Voltage after Switching	$V_S = 20V, I_O \approx 300 \text{ mA}, \text{(Figure 15)}$		$V_S - 6.5$			mV

Switching Characteristics (Continued)

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. Except for "Operating Temperature Range" they are not meant to imply that the devices should be operated at these limits. The table of "Electrical Characteristics" provides conditions for actual device operation.

Note 2: Voltage values are with respect to network ground terminal unless otherwise specified.

Note 3: The voltage between two emitters of a multiple-emitter transistor.

Note 4: Value applies when the base-emitter resistance (R_{BE}) is equal to or less than 500Ω.

Note 5: The maximum voltage which should be applied to any output when it is in the "OFF" state.

Note 6: Both halves of these dual circuits may conduct rated current simultaneously; however, power dissipation averaged over a short time interval must fall within the continuous dissipation rating.

Note 7: For the DS75450, the substrate (pin 8) must always be at the most-negative device voltage for proper operation.

Note 8: Unless otherwise specified min/max limits apply across the -55°C to $+125^{\circ}\text{C}$ temperature range for the DS55450 series and across the 0°C to $+70^{\circ}\text{C}$ range for the DS75450 series. All typicals are given for $V_{CC} = +5\text{V}$ and $T_A = 25^{\circ}\text{C}$.

Note 9: All currents into device pins shown as positive, out of device pins as negative, all voltages referenced to ground unless otherwise noted. All values shown as max or min on absolute value basis.

Note 10: Only one output at a time should be shorted.

Note 11: These parameters must be measured using pulse techniques. $t_W = 300\ \mu\text{s}$, duty cycle $< 2\%$.

Note 12: Applies to output transistors only.

Truth Tables (H = high level, L = low level)

DS55451/DS75451

A	B	Y
L	L	L (ON State)
L	H	L (ON State)
H	L	L (ON State)
H	H	H (OFF State)

DS55453/DS75453

A	B	Y
L	L	L (ON State)
L	H	H (OFF State)
H	L	H (OFF State)
H	H	H (OFF State)

DS55452/DS75452

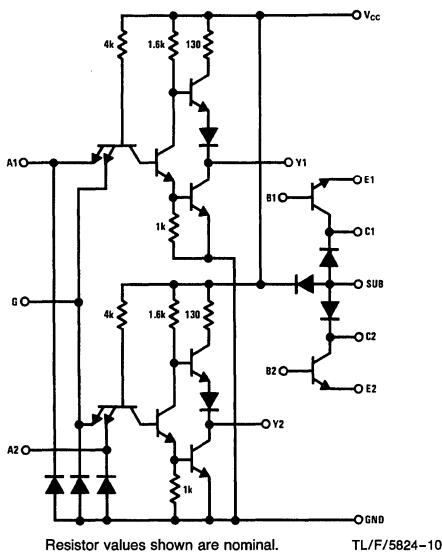
A	B	Y
L	L	H (OFF State)
L	H	H (OFF State)
H	L	H (OFF State)
H	H	L (ON State)

DS55454/DS75454

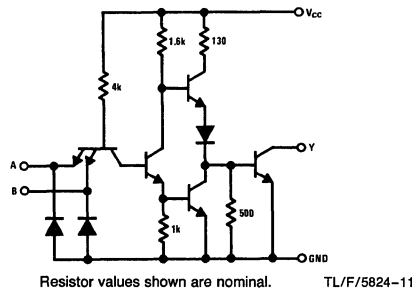
A	B	Y
L	L	H (OFF State)
L	H	L (ON State)
H	L	L (ON State)
H	H	L (ON State)

Schematic Diagrams

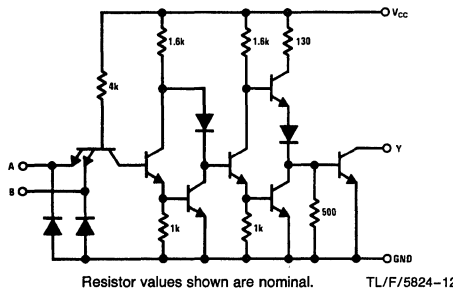
DS75450



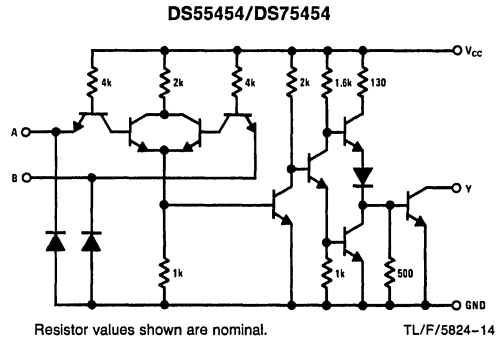
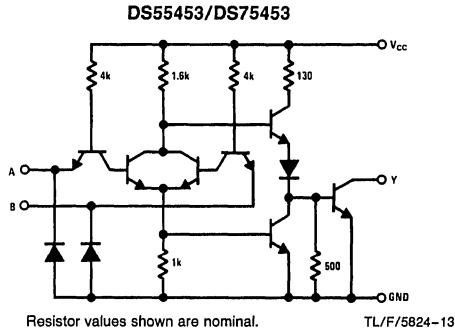
DS55451/DS75451



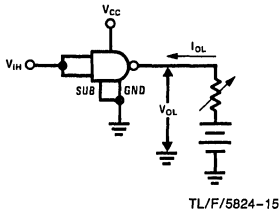
DS55452/DS75452



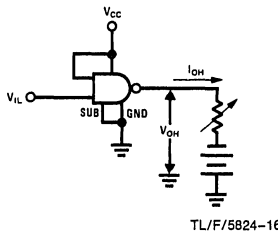
Schematic Diagrams (Continued)



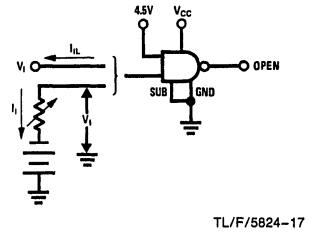
DC Test Circuits



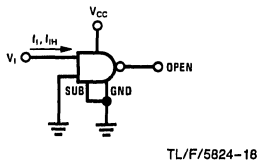
Both inputs are tested simultaneously.
FIGURE 1. V_{IH} , V_{OL}



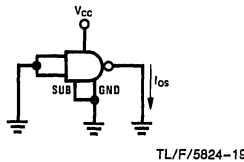
Each input is tested separately.
FIGURE 2. V_{IL} , V_{OH}



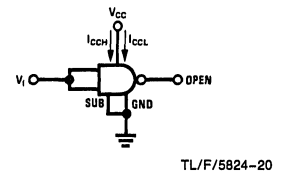
Each input is tested separately.
FIGURE 3. V_I , I_{IL}



Each input is tested separately.
FIGURE 4. I_i , I_{iH}



Each input is tested separately.
FIGURE 5. I_{os}



Both gates are tested simultaneously.
FIGURE 6. I_{CCH} , I_{CCL}

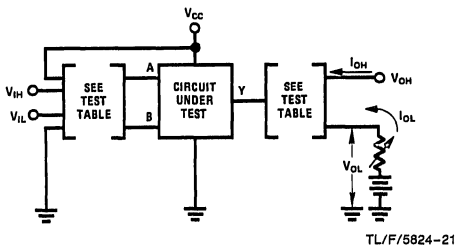
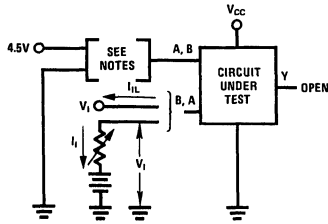


FIGURE 7. V_{IH} , V_{IL} , I_{OH} , V_{OL}

Circuit	Input Under Test	Other Input	Output	
			Apply	Measure
DS55451	V_{IH}	V_{IH}	V_{OH}	I_{OH}
	V_{IL}	V_{CC}	I_{OL}	V_{OL}
DS55452	V_{IH}	V_{IH}	I_{OL}	V_{OL}
	V_{IL}	V_{CC}	V_{OH}	I_{OH}
DS55453	V_{IH}	Gnd	V_{OH}	I_{OH}
	V_{IL}	V_{IL}	I_{OL}	V_{OH}
DS55454	V_{IH}	Gnd	I_{OL}	V_{OL}
	V_{IL}	V_{IL}	V_{OH}	I_{OH}

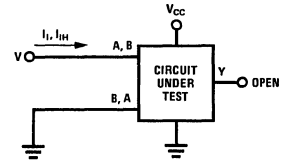
DC Test Circuits (Continued)



Note A: Each input is tested separately.
Note B: When testing DS55453/DS75453, DS55454/DS75454, input not under test is grounded.
 For all other circuits it is at 4.5V.

TL/F/5824-22

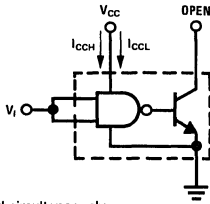
FIGURE 8. V_i, V_{iL}



Each input is tested separately.

TL/F/5824-23

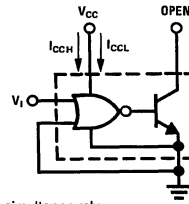
FIGURE 9. I_i, I_{iH}



Both gates are tested simultaneously.

TL/F/5824-24

FIGURE 10. I_{cCH}, I_{cCL} for AND, NAND Circuits

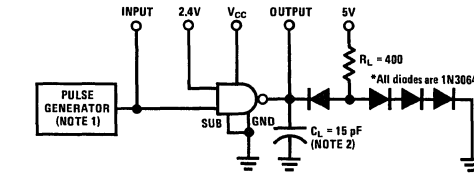


Both gates are tested simultaneously.

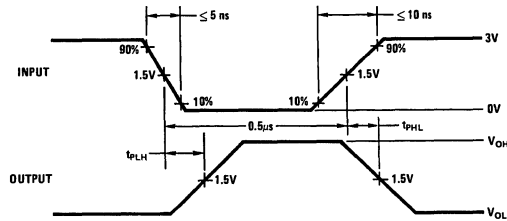
TL/F/5824-25

FIGURE 11. I_{cCH}, I_{cCL} for OR, NOR Circuits

AC Test Circuits and Switching Time Waveforms



TL/F/5824-26



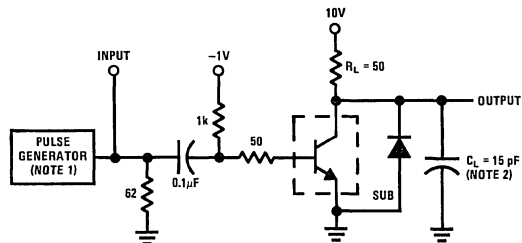
TL/F/5824-27

Note 1: The pulse generator has the following characteristics: PRR = 1 MHz, $Z_{OUT} \approx 50\Omega$.

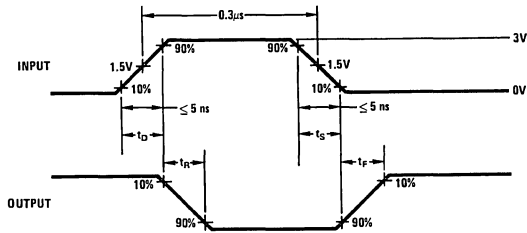
Note 2: C_c includes probe and jig capacitance.

FIGURE 12. Propagation Delay Times, Each Gate (DS75450 Only)

AC Test Circuits and Switching Time Waveforms (Continued)



TL/F/5824-28

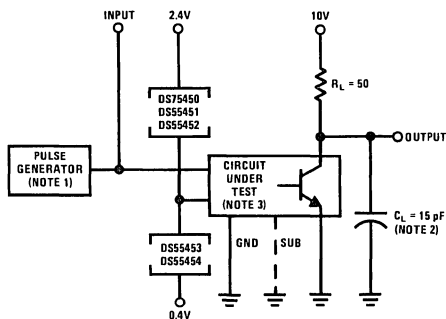


TL/F/5824-29

Note 1: The pulse generator has the following characteristics: duty cycle $\leq 1\%$, $Z_{OUT} \approx 50\Omega$.

Note 2: C_L includes probe and jig capacitance.

FIGURE 13. Switching Times, Each Transistor (DS75450 Only)

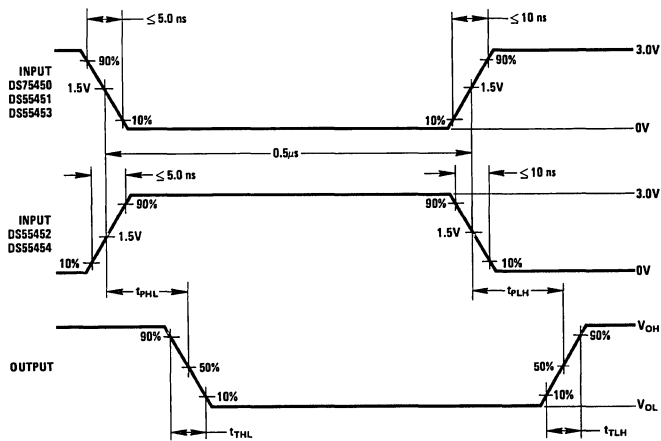


TL/F/5824-30

Note 1: The pulse generator has the following characteristics: PRR = 1.0 MHz, $Z_{OUT} \approx 50\Omega$.

Note 2: C_L includes probe and jig capacitance.

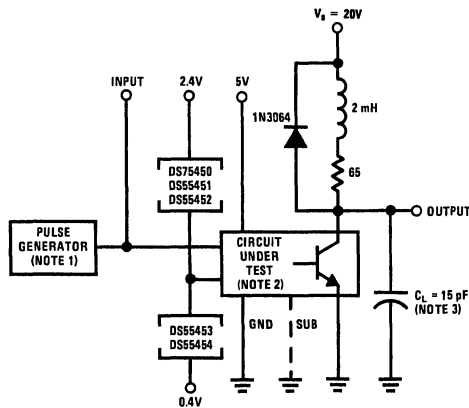
Note 3: When testing DS75450, connect output V to transistor base and ground the substrate terminal.



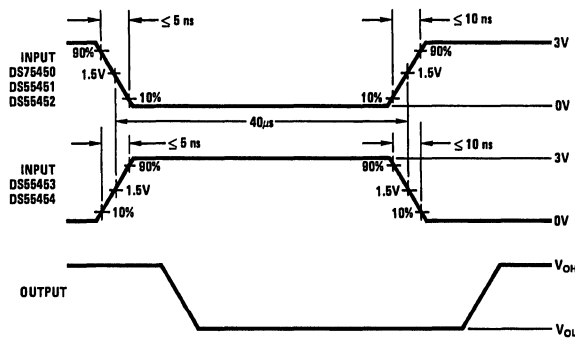
TL/F/5824-31

FIGURE 14. Switching Times of Complete Drivers

AC Test Circuits and Switching Time Waveforms (Continued)



TL/F/5824-32



Note 1: The pulse generator has the following characteristics: PRR = 12.5 kHz, $Z_{OUT} \approx 50\Omega$.

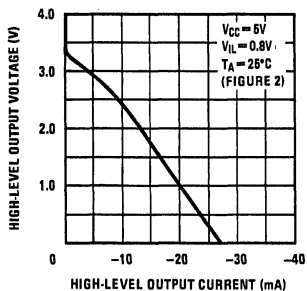
TL/F/5824-33

Note 2: When testing DS75450, connect output V to transistor base with a 600Ω resistor from there to ground and ground the substrate terminal.

Note 3: C_L includes probe and jig capacitance.

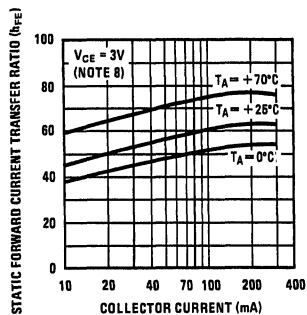
FIGURE 15. Latch-UP Test of Complete Drivers

Typical Performance Characteristics



TL/F/5824-34

FIGURE 16. DS75450 TTL Gate High-Level Output Voltage vs High-Level Output Current



TL/F/5824-35

FIGURE 17. DS75450 Transistor Static Forward Current Transfer Ratio vs Collector Current

Typical Performance Characteristics (Continued)

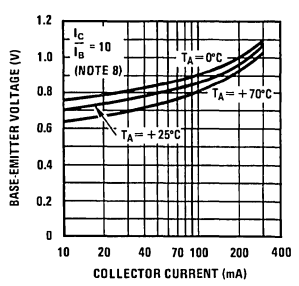


FIGURE 18. DS75450 Transistor Base-Emitter Voltage vs Collector Current

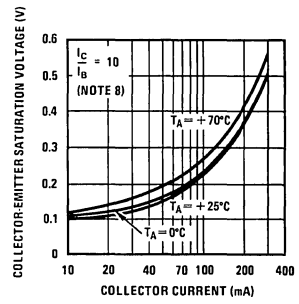


FIGURE 19. Transistor Collector-Emitter Saturation Voltage vs Collector Current

Typical Applications

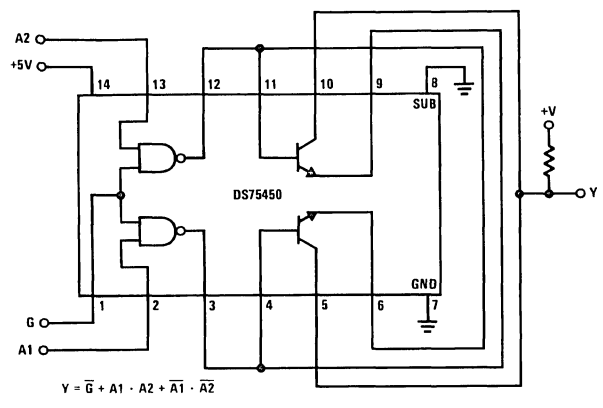


FIGURE 20. Gated Comparator

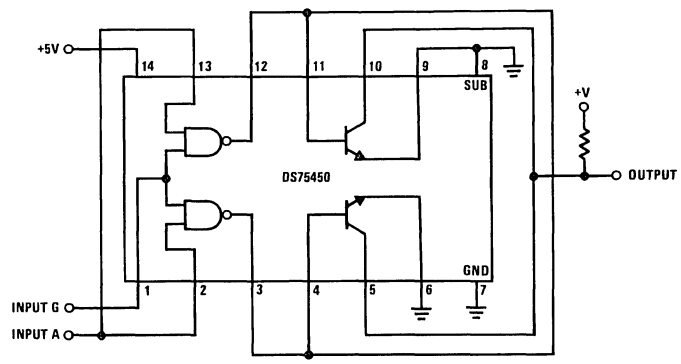
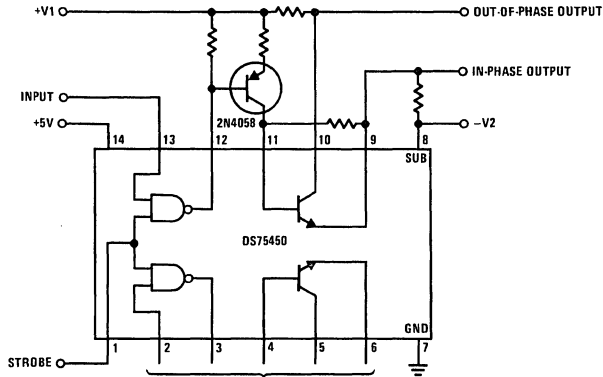


FIGURE 21. 500 mA Sink



Typical Applications (Continued)



This side can perform the same or another function.
FIGURE 22. Floating Switch

TL/F/5824-40

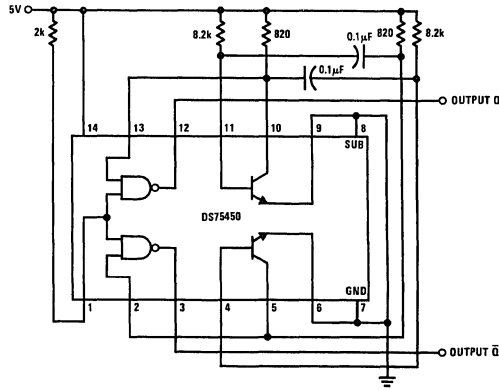


FIGURE 23. Square-Wave Generator

TL/F/5824-41

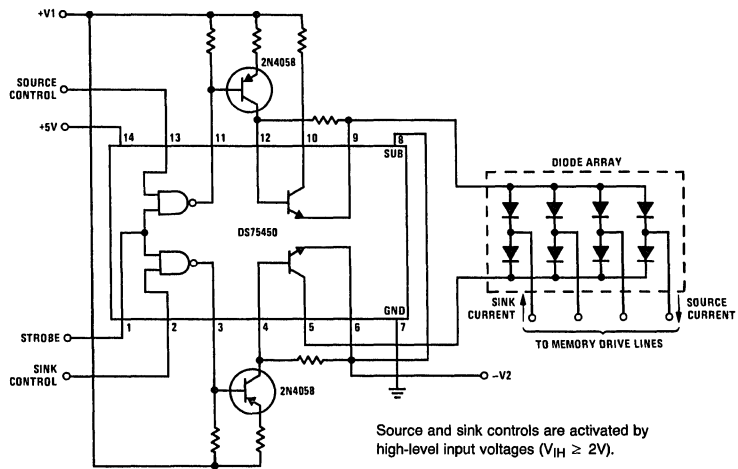


FIGURE 24. Core Memory Driver

TL/F/5824-42

Typical Applications (Continued)

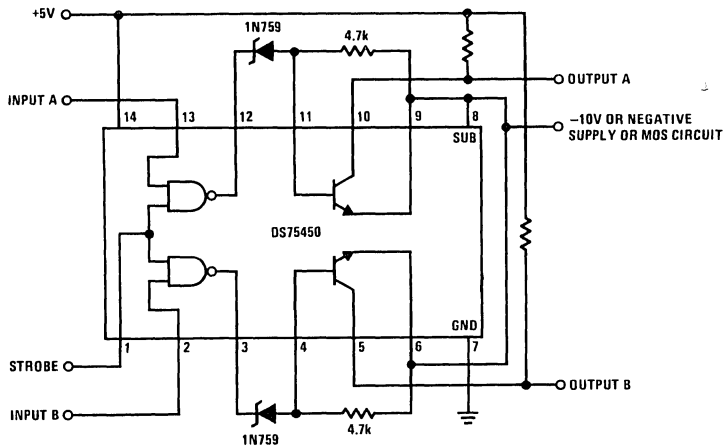


FIGURE 25. Dual TTL-to-MOS Driver

TL/F/5824-43

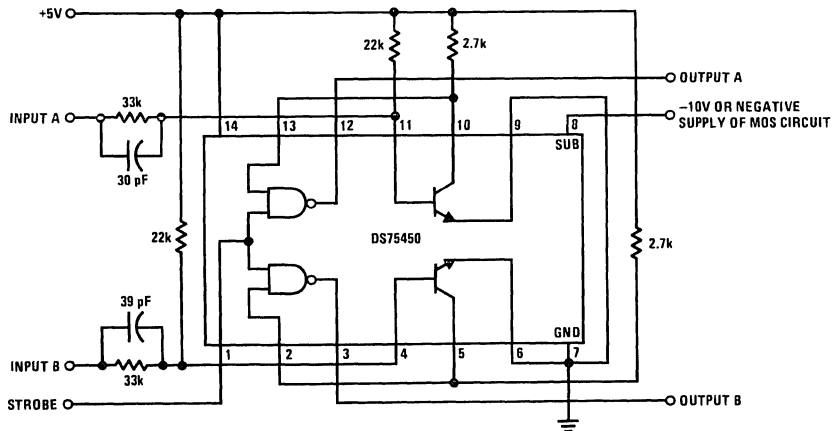
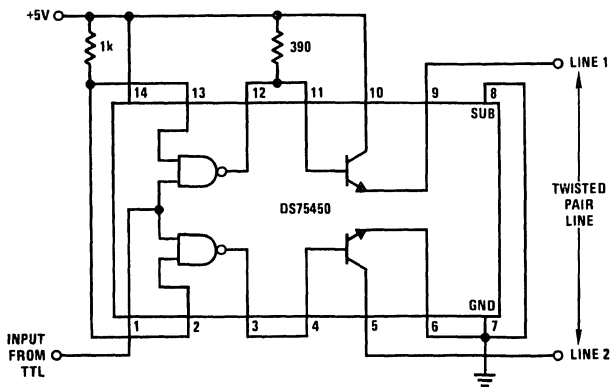


FIGURE 26. Dual MOS-to-TTL Driver

TL/F/5824-44



TL/F/5824-45

FIGURE 27. Balanced Line Driver

Termination is made at the receiving end as follows:
 Line 1 is terminated to ground through Z_0/Z ;
 Line 2 is terminated to +5V through Z_0/Z ;
 where Z_0 is the line impedance.

DS55451/DS55452/DS55453/DS55454/DS75450/DS75451/DS75452/DS75453/DS75454



Typical Applications (Continued)

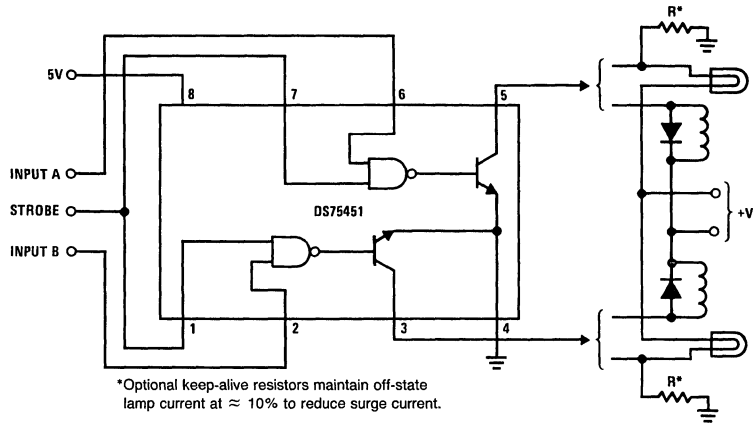


FIGURE 28. Dual Lamp or Relay Driver

TL/F/5824-46

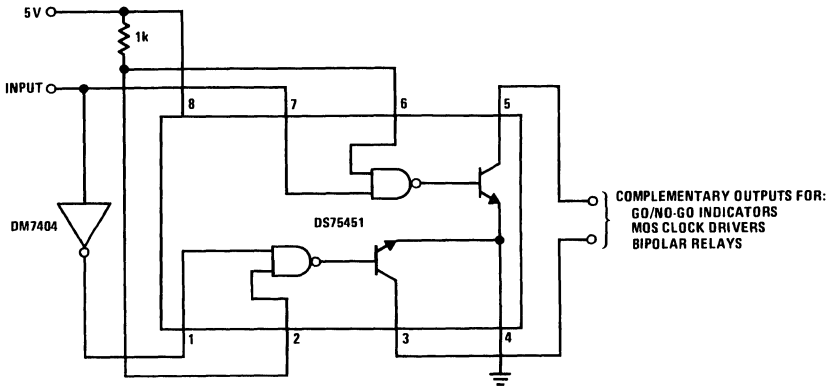


FIGURE 29. Complementary Driver

TL/F/5824-47

Typical Applications (Continued)

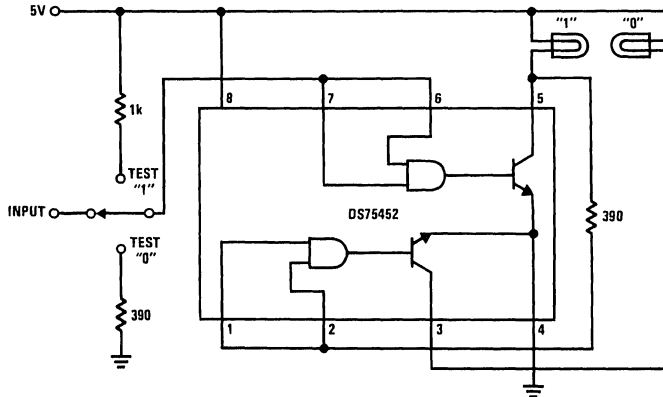
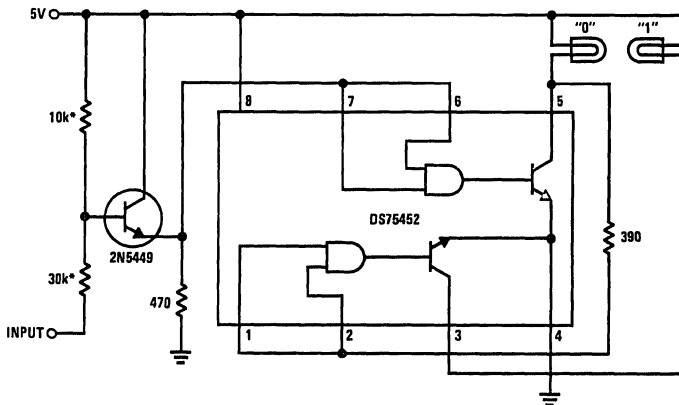


FIGURE 30. TTL or DTL Positive Logic-Level Detector

TL/F/5824-48



*The two input resistors must be adjusted for the level of MOS input.

FIGURE 31. MOS Negative Logic-Level Detector

TL/F/5824-49

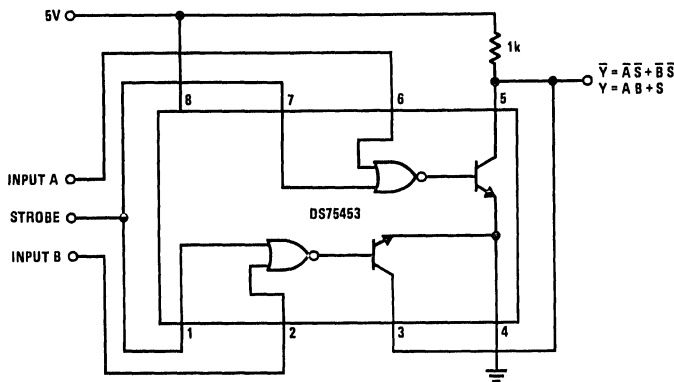
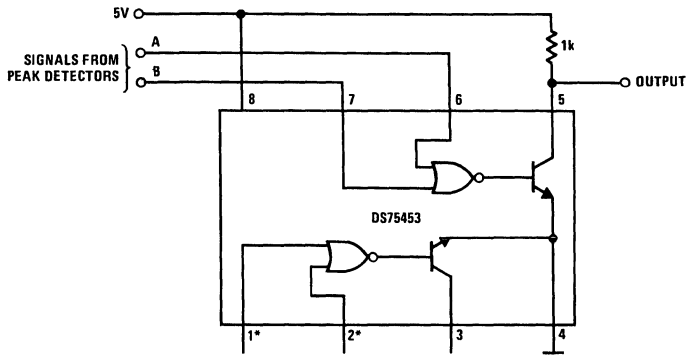


FIGURE 32. Logic Signal Comparator

TL/F/5824-50

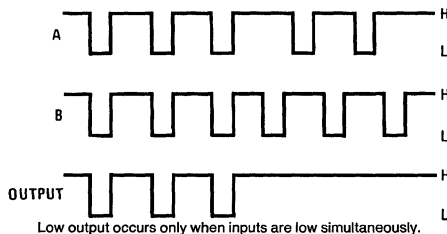
DS55451/DS55452/DS55453/DS55454/DS75450/DS75451/DS75452/DS75453/DS75454

Typical Applications (Continued)



*If inputs are unused, they should be connected to +5V through a 1k resistor.

TL/F/5824-51



Low output occurs only when inputs are low simultaneously.

TL/F/5824-52

FIGURE 33. In-Phase Detector

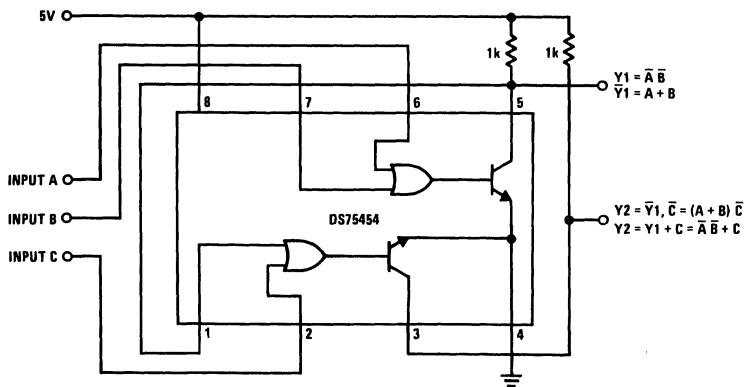


FIGURE 34. Multifunction Logic-Signal Comparator

TL/F/5824-53

Typical Applications (Continued)

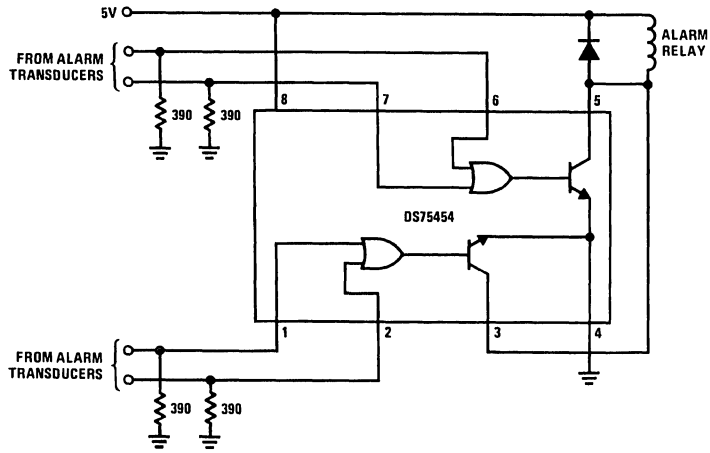


FIGURE 35. Alarm Detector

TL/F/5824-54

DS5545/1/DS55452/DS55453/DS55454/DS75450/DS75451/DS75452/DS75453/DS75454



Section 6
High Current Switches



Section 6 Contents

High Current Switch Selection Guide 6-3
LM1921 1 Amp Industrial Switch 6-4
LM1950 750 mA High Side Switch 6-9
LM1951 Solid State 1 Amp Switch 6-14
LMD18400 Quad High Side Driver 6-22

High Current Switch Selection Guide

Device	Drivers/ Package	Continuous Current	Peak Current	Input Voltage Range*	Diagnostics	Page No.
LM1921	1	1.0A	2.0A	4.5V to 26V	None	6-4
LM1950	1	750 mA	1.4A	4.75V to 26V	None	6-9
LM1951	1	1.0A	2.5A	4.5V to 26V	Error Flag	6-14
LMD18400	4	1.0A	3.0A	6V to 26V	Error Flag Thermal Shutdown Flag Data Output provides switch status feedback, output load fault conditions and thermal and overvoltage shutdown status.	6-22

*All devices incorporate Automotive transient protection.



LM1921 1 Amp Industrial Switch

General Description

The LM1921 Relay Driver incorporates an integrated power PNP transistor as the main driving element. The advantages of this over previous integrated circuits employing NPN power elements are several. Greater output voltages are available off the same supply for driving grounded loads; typically 4.5 volts for a 500 mA load from a 5.0 volt supply. The output can swing below ground potential up to 57 volts negative with respect to the positive power supply. This can be used to facilitate rapid decay times in inductive loads. Also, the IC is immune to negative supply voltages or transients. The inherent Safe Operating Area of the lateral PNP allows use of the IC as a bulb driver or for capacitive loads.

Familiar integrated circuit features such as short circuit protection and thermal shutdown are also provided. The input voltage threshold levels are designed to be TTL, CMOS, and LSTTL compatible over the entire operating temperature range. If several drivers are used in a system, their inputs and/or outputs may be combined and wired together if their supply voltages are also common.

Features

- 1 Amp output drive
- Load connected to ground
- Low input-output voltage differential
- +60 volt positive transient protection
- -50 volt negative transient protection
- Automotive reverse battery protection
- Short circuit proof
- Internal thermal overload protection
- Unclamped output for fast decay times
- TTL, LSTTL, CMOS compatible input
- Plastic TO-220 package
- 100% electrical burn-in

Applications

- Relays
- Solenoids
- Valves
- Motors
- Lamps
- Heaters

Typical Application Circuit

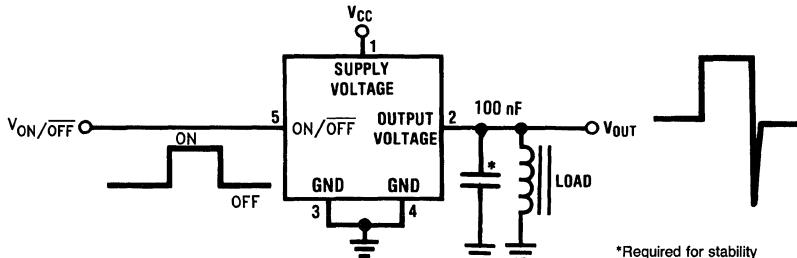
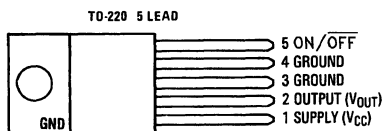


FIGURE 1. Test and Application Circuit

TL/H/5271-1

Connection Diagram



Front View

Order Number LM1921T

See NS Package Number T05A

TL/H/5271-2

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	
Operating Range	4.75V to 26V
Overvoltage Protection (100 ms)	-50V to +60V

Internal Power Dissipation	Internally Limited
Operating Temperature Range	-40°C to +125°C
Maximum Junction Temperature	150°C
Storage Temperature Range	-65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	230°C

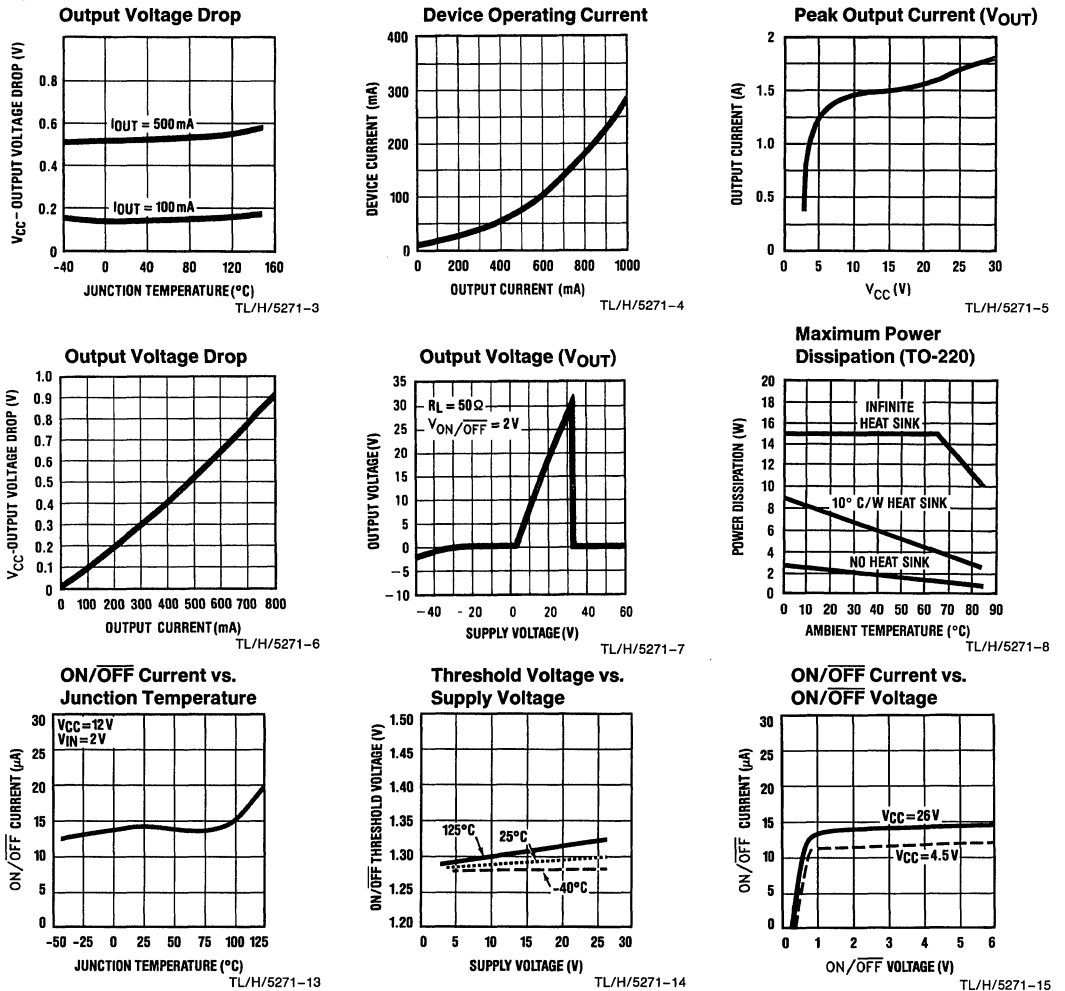
Electrical Characteristics ($V_{CC} = 12V$, $I_{OUT} = 500\text{ mA}$, $T_J = 25^\circ\text{C}$, $V_{ON/OFF} = 2V$, unless otherwise specified.)

Parameter	Conditions	Typ	Tested Limits (Note 1)		Design Limits (Note 2)		Units
			Min	Max	Min	Max	
Supply Voltage							
Operational			4.75	26	6	24	V
Survival			-15	60			V_{DC}
Transient	100 ms, 1% Duty Cycle		-50				V
Supply Current							
$V_{ON/OFF} = 0$		0.6				1.5	mA
$V_{ON/OFF} = 2V$							
	$I_{OUT} = 0\text{ mA}$	6		10			mA
	$I_{OUT} = 250\text{ mA}$	285		350			mA
	$I_{OUT} = 500\text{ mA}$	575		700			mA
	$I_{OUT} = 1\text{ A}$	1.3		1.5			A
Input to Output Voltage Drop	$I_{OUT} = 500\text{ mA}$ $I_{OUT} = 1\text{ A}$	0.5 1.0		0.8			V V
Short Circuit Current	$6V \leq V_{CC} \leq 24V$	1.4	1.0	2.0	.75	3.0	A A
Output Leakage Current	$V_{ON/OFF} = 0$	0.1				50	μA
ON/OFF Voltage Threshold	$6V \leq V_{CC} \leq 24V$	1.3	0.8	2.0	0.8	2.0	V V
ON/OFF Current		15	10	30			μA
Overvoltage Shutdown		32			26	36	V
Thermal Resistance							
junction-case	θ_{jc}	3					$^\circ\text{C}/\text{W}$
case-ambient	θ_{ca}	50					$^\circ\text{C}/\text{W}$
Inductive Clamp Output Voltage	$V_{ON/OFF} = 0$, $I_{OUT} = 100\text{ mA}$	-60			-120	-45	V
Fault Conditions							
Output Current							
ON/OFF Floating	Pin 5 Open	0.1				50	μA
Ground Floating	Pin 3 & Pin 4 Open	0.1				50	μA
Reverse Voltage	$V_{CC} = -15V$	-0.01			-1		mA
Reverse Transient	$V_{CC} = -50V$	-100					mA
Overvoltage	$V_{CC} = +60V$	0.01				1	mA
Supply Current	Pin 1 & Pin 2 Short, No load	10				40	mA

Note 1: Guaranteed and 100% production tested.

Note 2: Guaranteed, not necessarily 100% production tested. Not used to calculate outgoing AQL. Limits are for the temperature range of $-40^\circ\text{C} \leq T_J \leq 150^\circ\text{C}$.

Typical Performance Characteristics



Equivalent Block Diagram

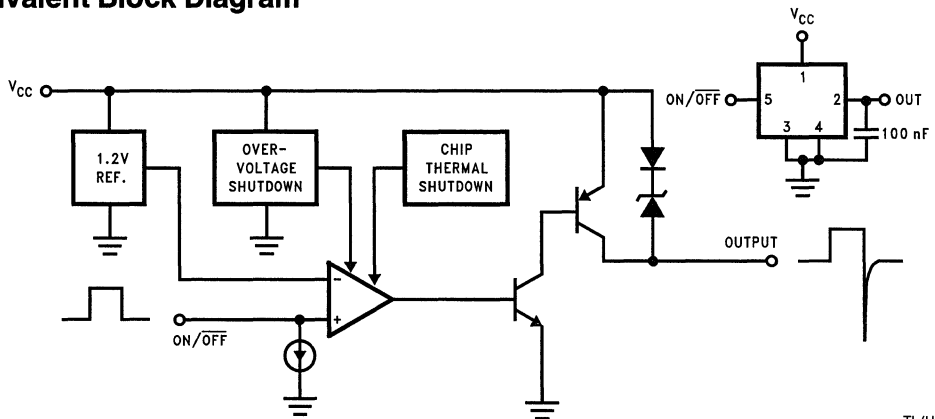
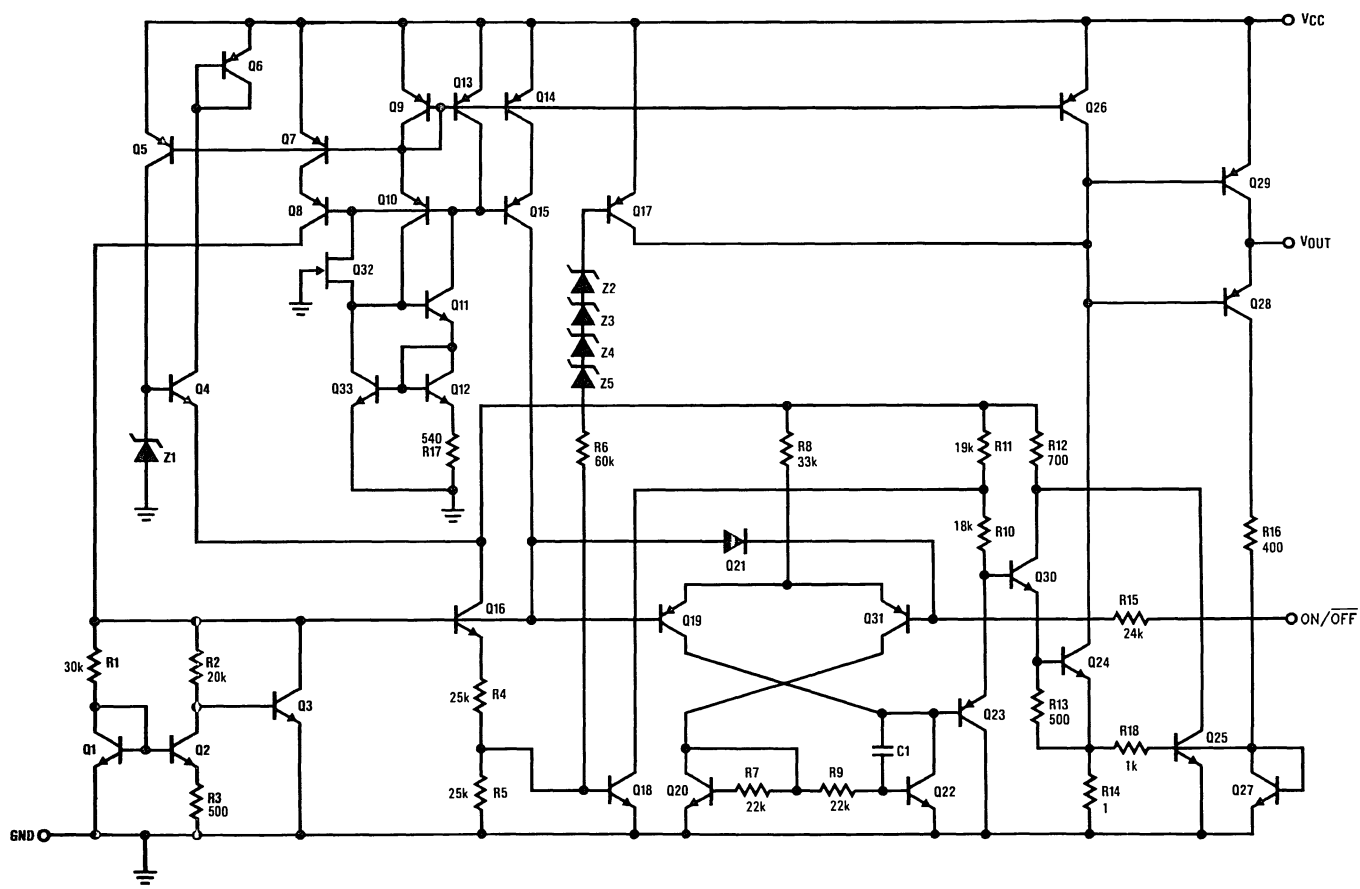


FIGURE 1

TL/H/5271-12

Circuit Schematic



TL/H/5271-9

6-7

Application Hints

HIGH CURRENT OUTPUT

The 1 Amp output is fault protected against overvoltage. If the supply voltage rises above approximately 30 volts, the output will automatically shut down. This protects the internal circuitry and enables the IC to survive higher voltage transients than would otherwise be expected. The 1921 will survive transients and DC voltages up to 60 volts on the supply. The output remains off during this time, independent of the state of the input logic voltage. This protects the load. The high current output is also protected against short circuits to either ground or supply voltage. Standard thermal shutdown circuits are employed to protect the 1921 from over heating.

FLYBACK RESPONSE

Since the 1921 is designed to drive inductive as well as any other type of load, inductive kickback can be expected whenever the output changes state from on to off (see waveforms on *Figure 1*). The driver output was left unclamped since it is often desirable in many systems to achieve a very rapid decay in the load current. In applications where this is not true, such as in *Figure 2*, a simple external diode clamp will suffice. In this application, the integrated current in the inductive load is controlled by varying the duty cycle of the input to the driver IC. This technique achieves response characteristics that are desirable for certain automotive transmission solenoids, for example.

For applications requiring a rapid controlled decay in the solenoid current, such as fuel injector drivers, an external zener and diode can be used as in *Figure 3*. The voltage rating of the zener should be such that it breaks down before the output of the LM1921. The minimum output breakdown voltage of the IC output is rated at -57 volts with respect to the supply voltage. Thus, on a 12 volt supply, the

combined zener and diode breakdown should be less than 45 volts.

The LM1921 can be used alone as a simple relay or solenoid driver where a rapid decay of the load current is desired, but the exact rate of decay is not critical to the system. If the output is unclamped as in *Figure 1*, and the load is inductive enough, the negative flyback transient will cause the output of the IC to breakdown and behave similarly to a zener clamp. Relying upon the IC breakdown is practical, and will not damage or degrade the IC in any way. There are two considerations that must be accounted for when the driver is operated in this mode. The IC breakdown voltage is process and lot dependent. Clamp voltages ranging from -60 to -120 volts (with respect to the supply voltage) will be encountered over time on different devices. This is not at all critical in most applications. An important consideration, however, is the additional heat dissipated in the IC as a result. This must be added to normal device dissipation when considering junction temperatures and heat sinking requirements. Worst case for the additional dissipation can be approximated as:

$$\text{Additional } P_D = I^2 \times L \times f \text{ (Watts)}$$

where: I = peak solenoid current (Amps)

L = solenoid inductance (Henries)

f = maximum frequency input signal (Hz)

For solenoids where the inductance is less than ten millihenries, the additional power dissipation can be ignored.

Overshoot, undershoot, and ringing can occur on certain loads. The simple solution is to lower the Q of the load by the addition of a resistor in parallel or series with the load. A value that draws one tenth of the current or DC voltage of the load is usually sufficient.

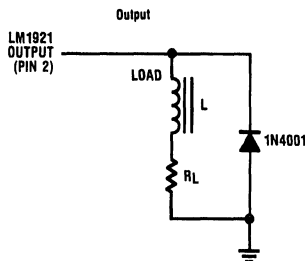


FIGURE 2. Diode Clamp

TL/H/5271-10

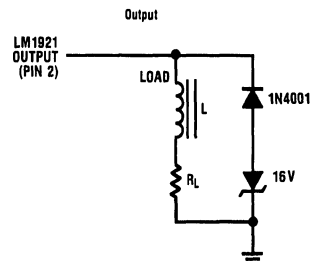


FIGURE 3

Zener clamp for rapid controlled current decay

TL/H/5271-11

LM1950 750 mA High Side Switch

General Description

The LM1950 is a high current, high side (PNP) power switch for driving ground referenced loads. Intended for industrial and automotive applications the LM1950 is guaranteed to deliver 750 mA continuous load current (with typically 1.4 Amps peak) and can withstand supply voltage transients up to +60V and -50V. When switched OFF the quiescent current drain from the input power supply is less than 100 μ A which can allow continuous connection to a battery power source.

The LM1950 will drive all types of resistive or reactive loads. To obtain a rapid decay time of the energy in inductive loads, the output is internally protected but not clamped and can swing below ground to at least 54V negative with respect to the input power supply voltage.

The ON/OFF input can be driven with standard 5V TTL or CMOS compatible logic levels independent of the V_{CC} supply voltage used. Built in protection features include short circuit protection, thermal shutdown, over-voltage shutdown to protect load circuits and protection against reverse polarity input connections. The LM1950 is available in a 5-lead power TO-220 package and specified over a wide -40°C to 125°C operating temperature range.

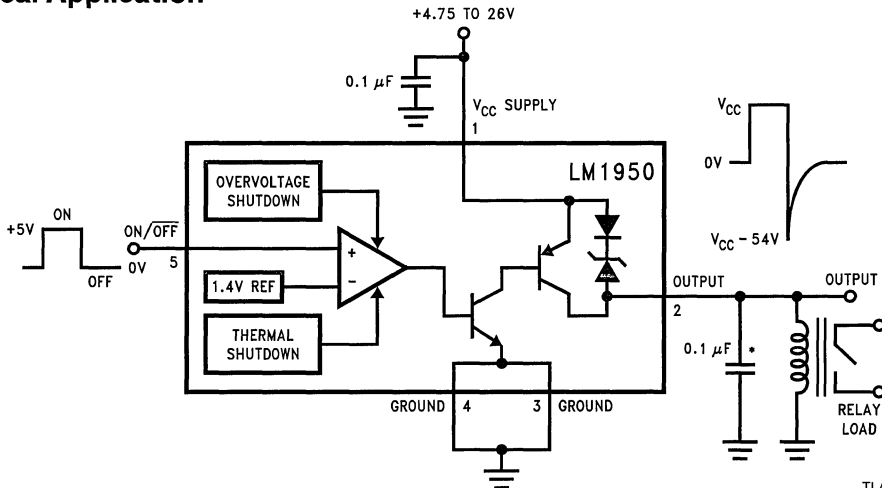
Features

- 750 mA continuous output drive current
- Less than 100 μ A quiescent current in OFF state
- Low input/output voltage drop
- +60V/-50V transient protection
- Drives resistive or reactive loads
- Unclamped output for fast inductive decay times
- Reverse battery protected
- Short circuit proof
- Overvoltage shutdown to protect loads
- TTL/CMOS compatible control input
- Thermal overload protection

Applications

- Relay driver
- Solenoid/Valve driver
- Lamp driver
- Load circuit switching
- Motor driver

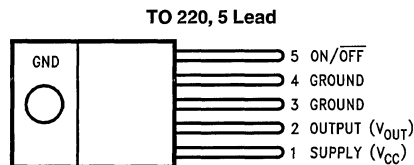
Typical Application



TL/H/11237-1

*Required for stability

Connection Diagram



TL/H/11237-2

Front View
 Order Number LM1950T
 See NS Package Number T05A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	
Continuous	26V
Transient ($\tau \leq 100$ ms)	-50V to +60V
Reverse Polarity (continuous)	-15V
On/Off Voltage	-0.3V to +6.0V
Power Dissipation	Internally Limited
Load Inductance	150 mH
Maximum Junction Temperature	150°C

Storage Temperature Range	-65°C to +150°C
Lead Temperature	
(Soldering, 10 seconds)	230°C
ESD Susceptibility (Note 2)	2000V

Operating Ratings (Note 1)

Temperature Range (T_A)	-40°C to +125°C
Supply Voltage Range	4.75V to 26V
Thermal Resistances:	
Junction to Case (θ_{j-c})	3°C/W
Case to Ambient (θ_{c-a})	50°C/W

Electrical Characteristics

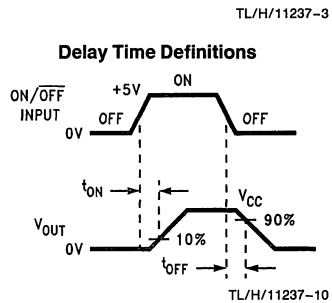
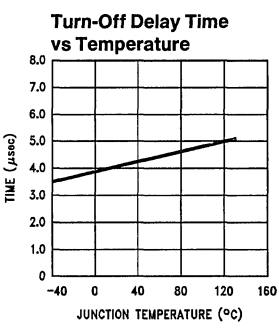
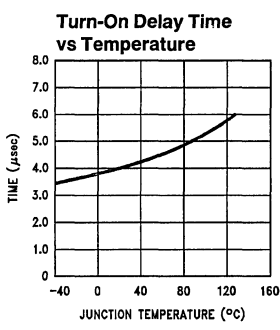
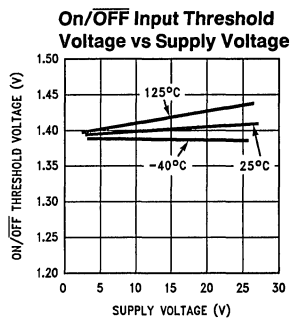
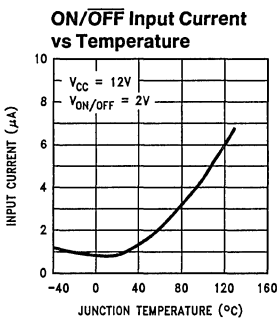
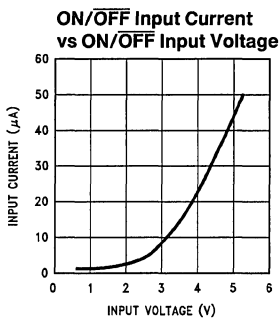
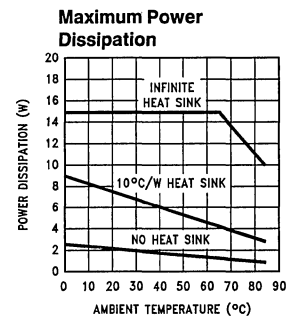
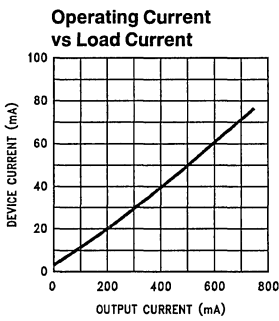
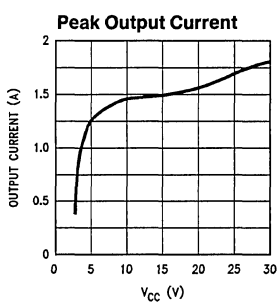
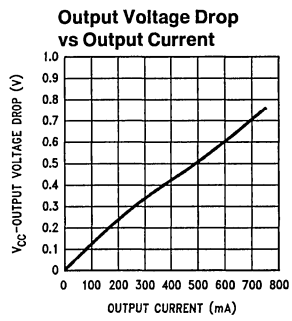
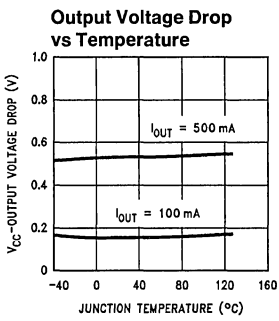
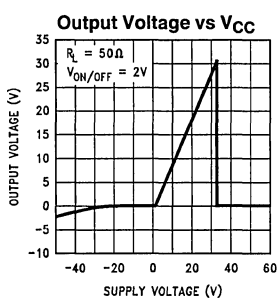
$V_{CC} = 14V$, $I_{OUT} = 150$ mA unless otherwise indicated. **Boldface** limits apply over the entire operating temperature range, $-40^\circ\text{C} \leq T_A \leq 125^\circ\text{C}$, all other specifications are for $T_A = T_J = 25^\circ\text{C}$

Parameter	Conditions	Typical	Limit	Units (Limit)
Supply Voltage				
Operational			4.75/ 4.75	V (Min)
Survival			26/ 26	V (Max)
Transient	$t = 1$ ms, $\tau = 100$ ms, 1% dutycycle		-15/- 15	V_{DC} (Min)
			60/ 60	V (Max)
			-50/- 50	V (Min)
Supply Current	$V_{ON/OFF} = 0.8V$	20	100/ 100	μA (Max)
	$V_{ON/OFF} = 2.0V$			
	$I_{OUT} = 0$ mA	5	10/ 10	mA (Max)
	$I_{OUT} = 250$ mA	275	350/ 350	mA (Max)
	$I_{OUT} = 500$ mA	550	700/ 700	mA (Max)
	$I_{OUT} = 750$ mA	825	950/ 950	mA (Max)
Input to Output	$I_{OUT} = 250$ mA	0.30	0.5/ 0.6	V (Max)
Voltage Drop	$I_{OUT} = 500$ mA	0.50	0.7/ 1.0	V (Max)
	$I_{OUT} = 750$ mA	0.75	1.1/ 1.4	V (Max)
Short Circuit Current		1.5	1.0/ 0.75	A (Min)
			2.0/ 2.0	A (Max)
Output Leakage Current	$V_{ON/OFF} = 0.8V$	10	50/ 50	μA (Max)
ON/OFF Input		1.4	0.8/ 0.8	V (Min)
Threshold Voltage			2.0/ 2.0	V (Max)
ON/OFF Input Current	$V_{ON/OFF} = 0.8V$	0.1	5/ 10	μA (Max)
	$V_{ON/OFF} = 2.0V$	1	10/ 20	μA (Max)
	$V_{ON/OFF} = 5.25V$	50	100/ 100	μA (Max)
Overvoltage Shutdown		33	27/ 27	V (Min)
Threshold			37/ 37	V (Max)
Inductive Clamp	$V_{ON/OFF} = 2V$ to 0.8V,	-45	-120/- 120	V (Max)
Output Voltage	$I_{OUT} = 100$ mA		-40/- 40	V (Min)
Output Turn-On Delay	$V_{ON/OFF} 0.8V$ to 2V	4.2	20	μs
Output Turn-Off Delay	$V_{ON/OFF} 2V$ to 0.8V	4.5	20	μs

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Human body model, 100 pF discharged through a 1.5 k Ω resistor.

Typical Performance Characteristics



TL/H/11237-11

TL/H/11237-12

TL/H/11237-3

TL/H/11237-10

Application Hints

HIGH CURRENT OUTPUT

The 750 mA output is fault protected against overvoltage. If the supply voltage rises above approximately 30V, the output will automatically shut down. This protects the internal circuitry and enables the IC to survive higher voltage transients than would otherwise be expected. The LM1950 will survive transients and DC voltages up to 60V on the supply. The output remains off during this time, independent of the state of the input logic voltage. This protects the load. The high current output is also protected against short circuits to either ground or supply voltage. Standard thermal shutdown circuits are employed to protect the LM1950 from over heating.

FLYBACK RESPONSE

Since the LM1950 is designed to drive inductive as well as any other type of load, inductive kickback can be expected whenever the output changes state from ON to OFF (See Waveform on *Figure 1*). The driver output was left unclamped since it is often desirable in many systems to achieve a very rapid decay in the load current. In applications where this is not true, such as in *Figure 2*, a simple external diode clamp will suffice. In this application, the integrated current in the inductive load is controlled by varying the duty cycle of the input to the drive IC. This technique achieves response characteristics that are desirable for certain automotive transmission solenoids, for example.

For applications requiring a rapid controlled decay in the solenoid current, such as fuel injector drivers, an external zener and diode can be used as in *Figure 3*. The voltage rating of the zener should be such that it breaks down before the output of the LM1950. The minimum output breakdown voltage of the IC output is rated at $-54V$ with respect to the supply voltage.

The LM1950 can be used alone as a simple relay or solenoid driver where a rapid decay of the load current is desired, but the exact rate of decay is not critical to the system. If the output is unclamped as in *Figure 1*, and the load is inductive enough, the negative flyback transient will cause the output of the IC to breakdown and behave similarly to a zener clamp. Relying upon the IC breakdown is practical and will not damage or degrade the IC in any way. There are two considerations that must be accounted for when the driver is operated in this mode. The IC breakdown voltage is process and lot dependent. Output clamp voltages ranging from $-40V$ to $-120V$ (with V_{CC} supply of 14V) will be encountered over time on different devices. This is not at all critical in most applications. An important consideration, however, is the additional heat dissipated in the IC as a result. This must be added to normal device dissipation when considering junction temperatures and heat sinking requirements. Worst case for the additional dissipation can be approximated as:

$$\text{Additional } P_D = I^2 \times L \times f \text{ (Watts)}$$

Where: I = Peak Solenoid Current (Amps)

L = Solenoid Inductance (Henries)

f = Maximum Frequency Input Signal (Hz)

For solenoids where the inductance is less than ten millihenries, the additional power dissipation can be ignored. Overshoot, undershoot, and ringing can occur on certain loads. The simple solution is to lower the Q of the load by the addition of a resistor in parallel or series with the load. A value that draws one tenth of the current or DC voltage of the load is usually sufficient.

For frequency stability of the switch, a 0.1 μF or larger output bypass capacitor is required.

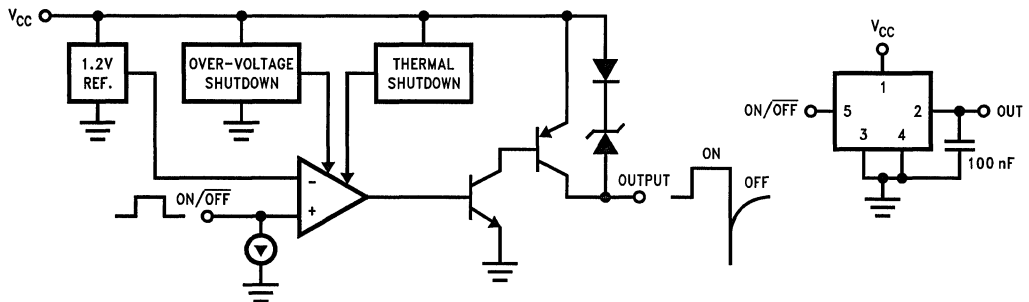


FIGURE 1

TL/H/11237-4

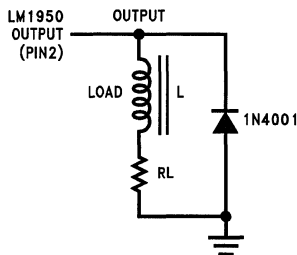


FIGURE 2. Diode Clamp

TL/H/11237-5

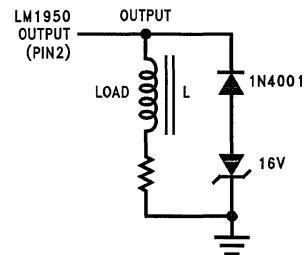
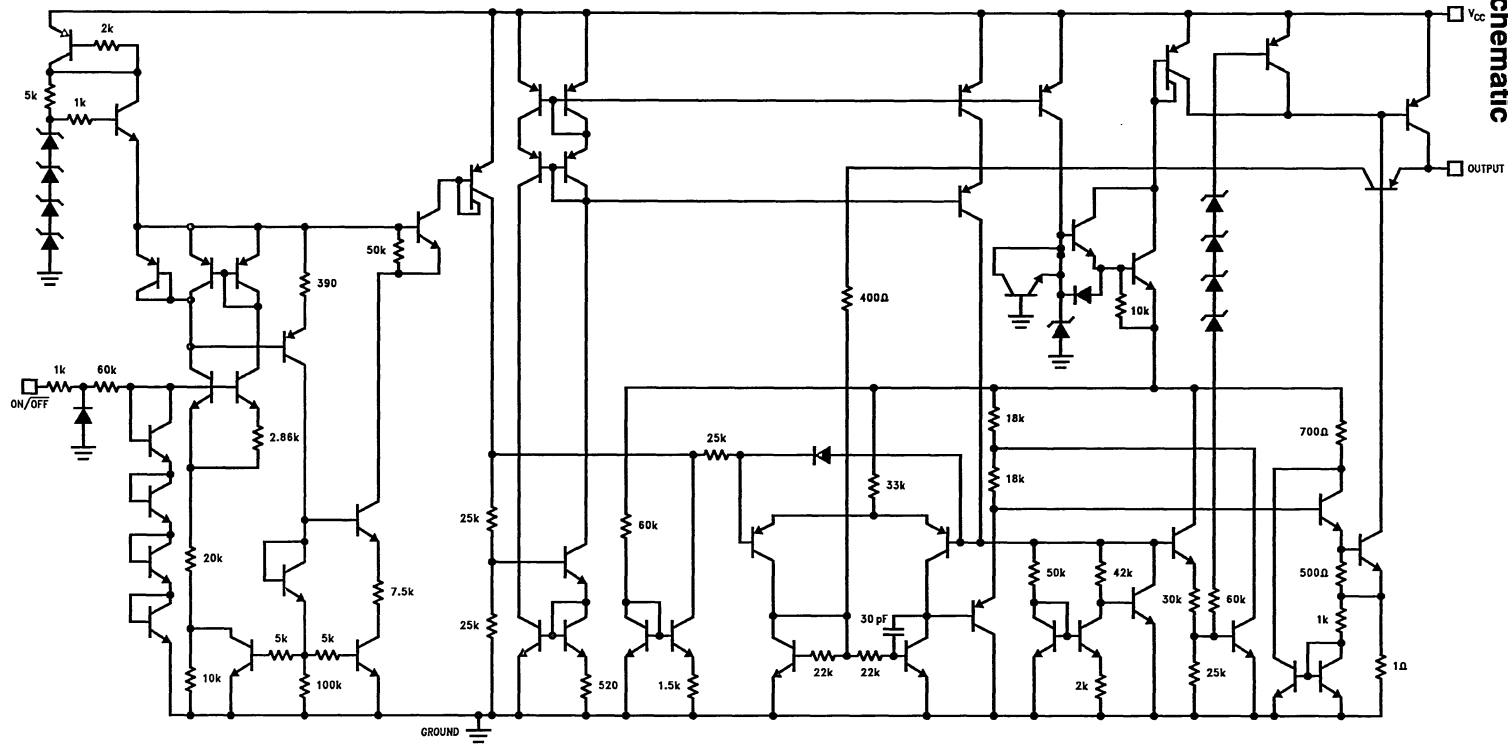


FIGURE 3. Zener Clamp for Rapid Controlled Current Decay

TL/H/11237-6

Circuit Schematic



6-13

TL/H/11237-9





LM1951 Solid State 1 Amp Switch

General Description

The LM1951 is a high current, high voltage, high side (PNP) switch with a built-in error detection circuit.

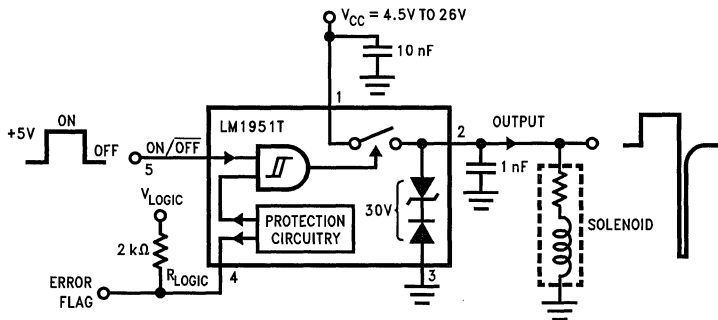
The LM1951 is guaranteed to deliver 1 Amp output current and is capable of withstanding up to $\pm 85\text{V}$ transients. The built-in error detection provides an error flag output under the following fault conditions: output short to ground or supply, open load, current limit, overvoltage or thermal shutdown. The LM1951 will drive all types of resistive or inductive loads. The output has a built-in negative voltage clamp ($\approx -30\text{V}$) to provide a quick energy discharge path for inductive loads. The LM1951 features TTL and CMOS compatible logic input with hysteresis. Switching times, both turn on and turn off, are $2\ \mu\text{s}$ ($C_{\text{load}} < 0.005\ \mu\text{F}$). In addition, its quiescent current in the OFF state is typically less than $0.1\ \mu\text{A}$ at room temperature and less than $10\ \mu\text{A}$ over the entire operating temperature and voltage range.

The LM1951 features make it well suited for industrial and automotive applications.

Features

- $0.1\ \mu\text{A}$ typical quiescent current (OFF state)
- 1 Amp output current guaranteed
- $\pm 85\text{V}$ transient protection
- Reverse voltage protection
- Negative output voltage clamp
- Error flag output
- Internal overvoltage shutdown
- Internal thermal shutdown
- Short circuit proof
- High speed switching (up to 50 kHz)
- Inductive or resistive loads
- Low ON resistance ($1\ \Omega$ maximum)
- TTL, CMOS compatible input with hysteresis
- Plastic TO-220 5-lead package
- ESD protected
- 4.5V to 26V operation

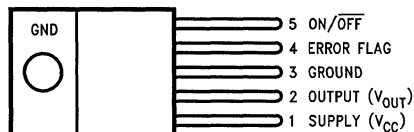
Typical Application Circuit and Connection Diagram



TL/H/9133-1

V_{IN}	Output
0	OFF
1	ON

TO-220, 5-Lead



TL/H/9133-2

Front View
Order Number LM1951T
See NS Package Number T05A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage

Operational Voltage	26 V _{DC}
Sustained Voltage	-40 V _{DC} ≥ V _{CC} ≤ 85 V _{DC}
Transient Voltage Protection	±85V
(τ = 100 ms, 1% Duty Cycle, R _S ≥ 10Ω)	
Pins 4, 5	26 V _{DC}

Power Dissipation (Note 1)	Internally Limited
Load Inductance	1H
Operating Temperature Range (T _A)	-40°C to +125°C
Maximum Junction Temperature	150°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C
ESD Tolerance (Note 4):	2000V

Electrical Characteristics

V_{CC} = 12V, I_{out} = 500 mA, C_{out} = 0.001 μF, T_A = 25°C unless otherwise specified

Parameter	Conditions	Typical	Tested Limit (Note 2)	Design Limit (Note 3)	Units		
Supply Voltage, V _{CC}	Operational Transient		4.5		V _{min}		
			26		V _{max}		
			-85		V		
			85		V		
Supply Current	I _{out} = 0 mA, V _{ON/OFF} = 0.8V	0.1	10	100	μA _{max}		
			I _{out} = 250 mA, V _{ON/OFF} = 2.0V	260	270	mA _{max}	
			I _{out} = 600 mA, V _{ON/OFF} = 2.0V	630	650	mA _{max}	
			I _{out} = 1A, V _{ON/OFF} = 2.0V	1.06	1.2	A _{max}	
Voltage Drop (V _{CC} - V _{OUT})	I _{out} = 600 mA, V _{ON/OFF} = 2.0V	400	600		mV _{max}		
					I _{out} = 1A, V _{ON/OFF} = 2.0V	0.7	1.0
Short Circuit Current	V _{OUT} = 0V, V _{ON/OFF} = 2V	1.3	1.0		A _{min}		
			2.5		A _{max}		
Input Threshold, Pin 5	4.5V ≤ V _{CC} ≤ 26V		Turn ON	1.4	2.0	2.0	V _{max}
			Turn OFF	1.2	0.8	0.8	V _{min}
Input Current, Pin 5	0.8V ≤ V _{ON/OFF} ≤ 5.5V	25	50		μA _{max}		
Output Clamp	I _{out} ≤ 600 mA	-30	-40		V _{min}		
			-24		V _{max}		
Delay Time	t _{d, ON} t _{d, OFF}	R _{load} = 20Ω, C _{load} = 0.001 μF	1	3		μS _{max}	
			1	3		μS _{max}	
Rise Time		1	3		μS _{max}		
Fall Time		1	3		μS _{max}		
Error Flag Characteristics:							
Output Voltage	Error Condition, Pin 4 Low, Sinking 10 mA	0.3	0.8		V _{max}		
Sink Current	Error Condition, Pin 4 = 0.3V	10	3		mA _{min}		
Output Leakage Current	No Error, Pin 4 = 26V	0.01	1		μA _{max}		
Response Time	V _{LOGIC} = 5V, R _{LOGIC} = 2 kΩ, C _{LOGIC} = 0 μF	1			μS		

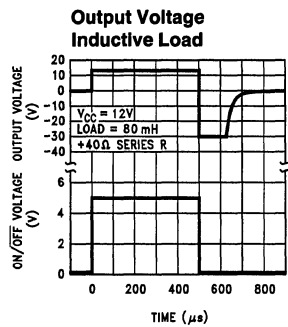
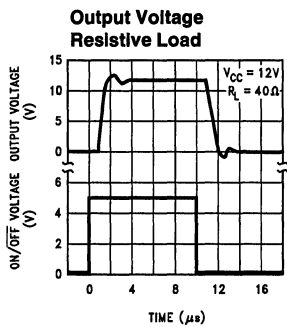
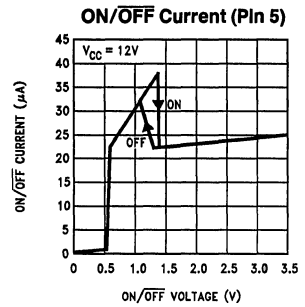
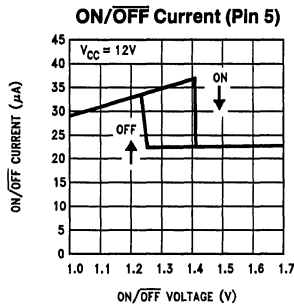
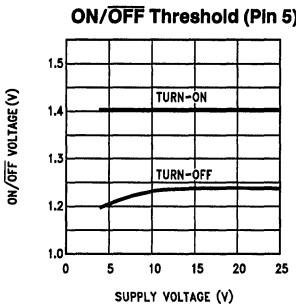
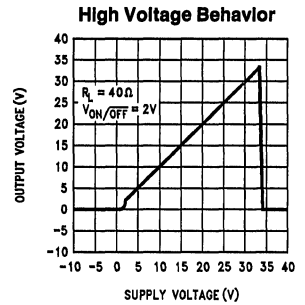
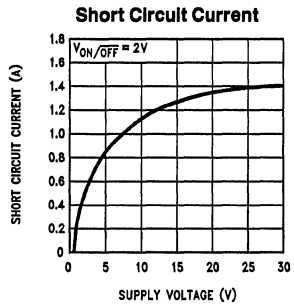
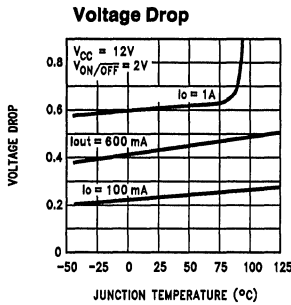
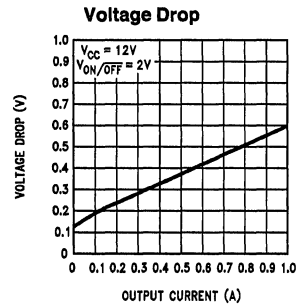
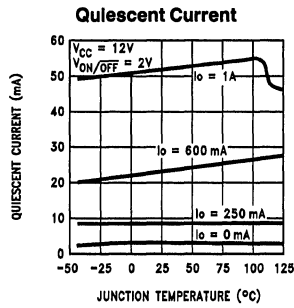
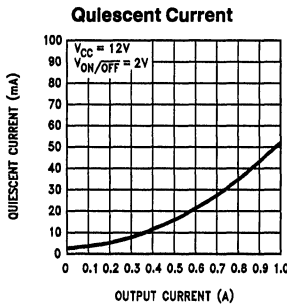
Note 1: Thermal resistance junction-to-case is 3°C/W. Thermal resistance case-to-ambient is 50°C/W.

Note 2: Tested Limits are guaranteed and 100% production tested.

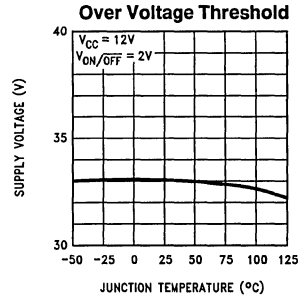
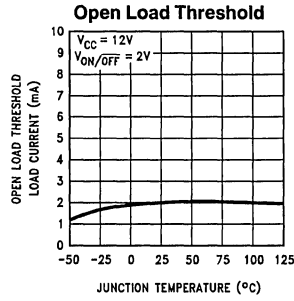
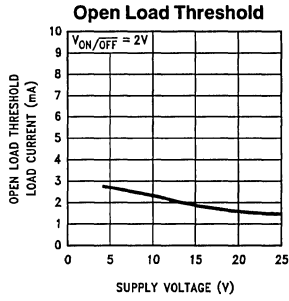
Note 3: Design Limits are guaranteed (but not 100% production tested) over the operating temperature and supply voltage range. These limits are not used to calculate outgoing quality levels.

Note 4: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Typical Performance Characteristics



Error Flag Output Characteristics



TL/H/9133-13

Truth Table

Fault Condition	V _{ON/OFF} *	V _{out}	Error Flag
Normal	L	L	H
	H	H	H
Overvoltage	L	L	L
	H	L	L
Thermal Shutdown	L	L	L
	H	L	L
V _{OUT} Short to GND	L	L	H
	H	L	L
V _{OUT} Short to V _{supply}	L	H	L
	H	H	L
Open Load	L	L	H
	H	H	L
Current Limit	L	L	H
	H	H	L

* L \approx 0 \leq V_{ON/OFF} \leq 0.8V H \approx 2V \leq V_{ON/OFF} \leq 26V

Typical Applications

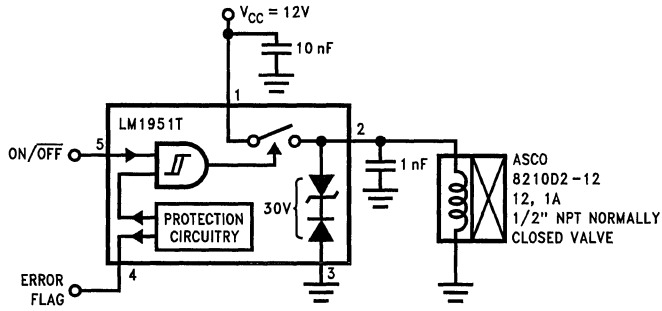


FIGURE 1. Solenoid Actuated Valve

TL/H/9133-4

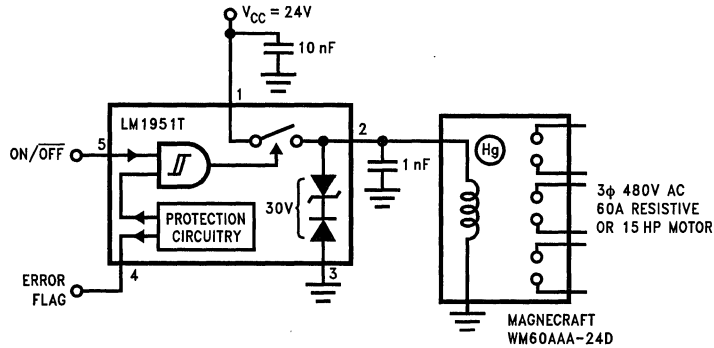
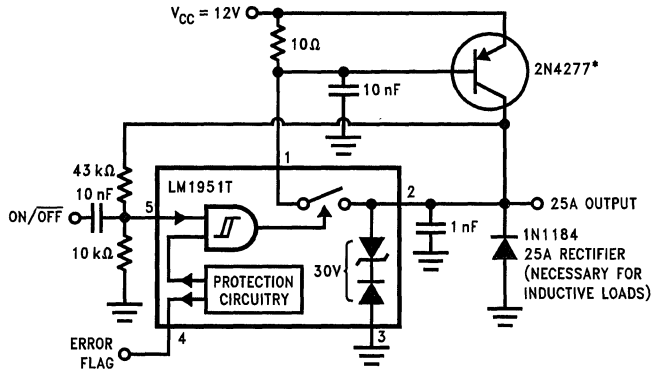


FIGURE 2. 60A 3-Phase Mercury Displacement Relay

TL/H/9133-5



*Available from Germanium Power Devices, Andover, MA, Tel. (617) 475-5982

FIGURE 3. 25A Switch with Short Circuit Foldback

TL/H/9133-6

Typical Applications (Continued)

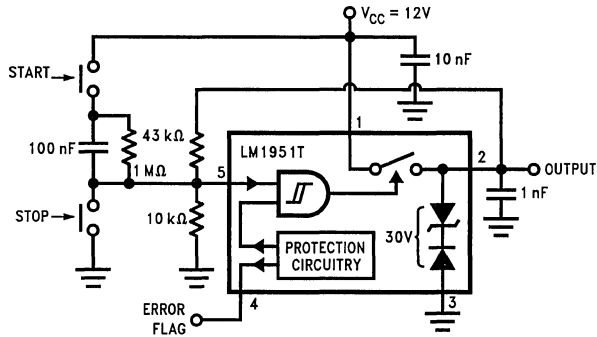


FIGURE 4. Latching Switch

TL/H/9133-7

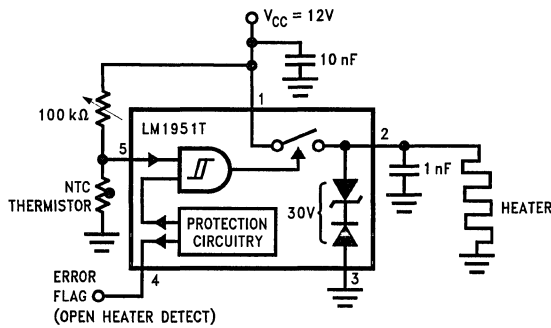


FIGURE 5. Temperature Controller with Hysteresis

TL/H/9133-8

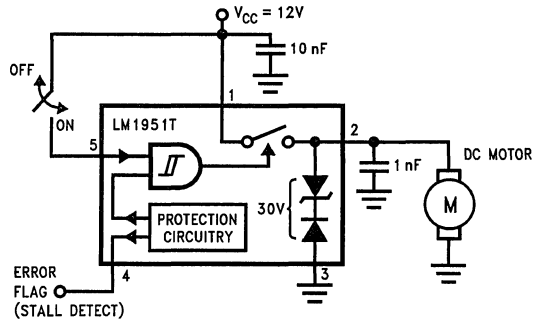


FIGURE 6. DC Motor Driver

TL/H/9133-9

Typical Applications (Continued)

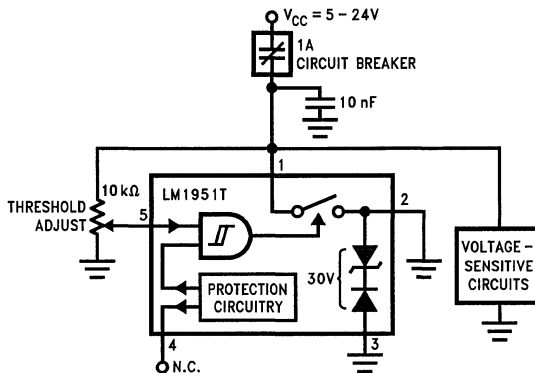


FIGURE 7. Over-Voltage Crowbar

TL/H/9133-10

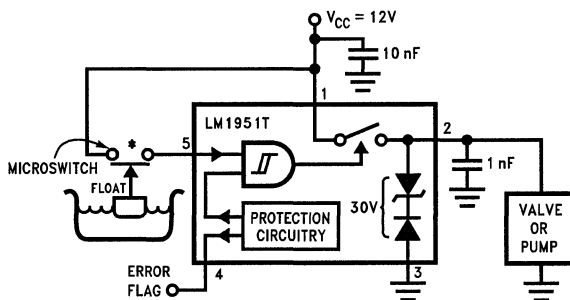


FIGURE 8. Fluid Level Controller

TL/H/9133-11

Operation	Switch Type
Empty	Normally Open
Fill	Normally Closed

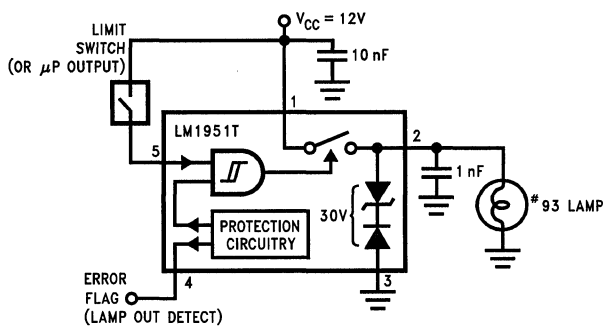


FIGURE 9. Indicator Lamp Driver

TL/H/9133-12

Application Hints

When inductive loads are turned OFF, they produce a negative voltage spike. The LM1951 contains a voltage clamp that limits these spikes to approximately -30V , thus an external clamp is not necessary in most applications.

Loads with an inductance of greater than 1H , driven to full output current, may damage the clamp simply by exceeding the power capabilities of the LM1951. An LM1951 can dissipate 25W continuous at 25°C ambient when mounted on a large heatsink. If the load current is limited to 800 mA , the sustained spike from an infinitely large inductance can be handled. Sustained spikes produced by higher currents and high inductances will exceed the 25W limit.

For inductances above 1H , care should be taken to see that the output current does not exceed a value that could damage the clamp. While 800 mA is acceptable for the device running at 25°C ambient on a heatsink, derate this current for smaller heatsinks or higher ambient temperatures to limit the junction temperature to 150°C . Alternatively, an external clamp or resonating capacitor can be added to handle any combination of load inductance, load current, and device temperature. This is especially important if the output current is boosted, such as the application shown in *Figure 3*. A peak power of 750W could be developed in the internal clamp if an inductive load is switched without external clamping.

Another case where the clamp's power capability may be exceeded is when driving a solenoid. The inductance of a solenoid is greatest when energized, with the plunger pulled in. As the plunger is pulled out of the solenoid, the inductance goes down. Under certain conditions of high solenoid inductance and fast mechanical time constants, the current may actually **Increase** when the solenoid is turned OFF. Since the energy stored in an inductor cannot change instantaneously, the current must increase to conserve energy when the inductance decreases. This condition is traced by observing the load current with a current probe and storage oscilloscope.

Load capacitances larger than 1 nF will slow rise and fall times. Inductive loads having a capacitive component larger than 1 nF will also exhibit overshoot. Furthermore, ringing

may be evident in a combination inductive/capacitive load, or in an inductive load with supply decoupling capacitors in the range of 100 nF to $1\text{ }\mu\text{F}$. For fast rise and fall times and minimum ringing with inductive loads, a supply decoupling capacitor of 10 nF and an output capacitor of 1 nF is recommended. These should be located as close to the IC pins as possible.

The error flag is an open collector output that pulls low under certain fault conditions. These errors include overvoltage ($V_{\text{CC}} > 26\text{V}$), overcurrent ($I_{\text{OUT}} > 1.3\text{A}$), undercurrent ($I_{\text{OUT}} < 2\text{ mA}$), output short circuit to ground, output short circuit to supply, and junction temperature greater than 150°C . By connecting a $2\text{ k}\Omega$ resistor from the error flag output to a 5V supply a logic output to a microprocessor is provided.

The error flag can give seemingly false indications in a number of situations. Slewing large capacitive loads ($> 100\text{ nF}$) can drive the LM1951 into temporary current limit, producing a momentary error indication. Incandescent lamps and DC motors require an inrush current that will also cause a temporary current limit and error indication. Large inductive loads ($> 50\text{ mH}$) initially appear as open circuits, falsing the error flag. The error flag pulses for about $1\text{ }\mu\text{s}$ when any load is turned ON since the output is initially at ground. In microprocessor systems these false indications are easily ignored in software. In discrete logic circuits utilizing a latch at the error flag output, some filtering may be required.

An internal current sink ($10\text{ }\mu\text{A}$ minimum) is connected to the input, pin 5. If this pin is left open it is guaranteed to pull low, switching the LM1951 OFF. This characteristic is important under certain fault conditions such as when the control line fails open circuit.

Although the input threshold has hysteresis, the switch points are derived from a very stable band-gap reference. In many applications, such as *Figures 5* and *7*, the LM1951 input can replace an external reference and comparator.

The input (pin 5) is clamped at -0.7V and includes a series resistance of approximately $30\text{ k}\Omega$. This pin tolerates negative inputs of up to 1 mA without affecting the performance of the chip.



LMD18400 Quad High Side Driver

General Description

The LMD18400 is a fully protected quad high side driver. It contains four common-drain DMOS N-channel power switches, each capable of switching a continuous 1 Amp load (>3 Amps transient) to a common positive power supply. The switches are fully protected from excessive voltage, current and temperature. An instantaneous power sensing circuit calculates the product of the voltage across and the current through each DMOS switch and limits the power to a safe level. The device can be disabled to produce a "sleep" condition reducing the supply current to less than 10 μ A. Separate ON/OFF control of each switch is provided through standard LSTTL/CMOS logic compatible inputs.

A MICROWIRE™ compatible serial data interface is built in to provide extensive diagnostic information. This information includes switch status readback, output load fault conditions and thermal and overvoltage shutdown status. There are also two direct-output error flags to provide an immediate indication of a general system fault and an indication of excessive operating temperature.

The LMD18400 is packaged in a special power dissipating leadframe that reduces the junction to case thermal resistance to approximately 20°C/W.

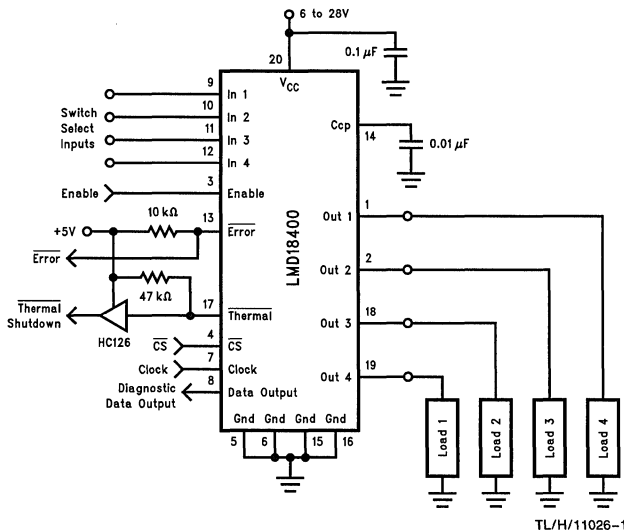
Features

- Four independent outputs with >3A peak, 1A continuous current capability
- 1.3 Ω maximum ON resistance over temperature
- True instantaneous power limit for each switch
- High survival voltage (60 V_{DC}, 80V transient)
- Shorted load (to ground and supply) protection
- Overvoltage shutdown at V_{CC} > 35V
- LS TTL/CMOS compatible logic inputs and outputs
- <10 μ A supply current in "sleep" mode
- -5V output clamp for discharging inductive loads
- Serial data interface for 11 diagnostic checks:
 - Switch ON/OFF status
 - Open or shorted load
 - Operating temperature
 - Excessive supply voltage
- Two direct-output error flags

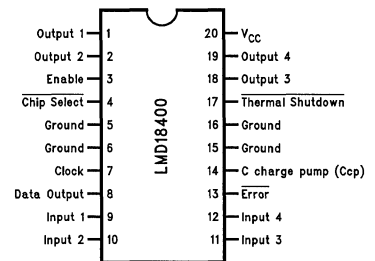
Applications

- Relay and solenoid drivers
- High impedance automotive fuel injector drivers
- Lamp drivers
- Power supply switching
- Motor drivers

Typical Application



Connection Diagram



Order Number LMD18400N
See NS Package Number N20A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Survival Voltage (Pin 20)	
Transient (t = 10 ms)	80V
Continuous	-0.5V to +60V
Output Transient Current (Each Switch)	3.75A
Output Transient Current (Total, All Switches)	6A
Output Steady State Current (Each Switch)	1A
Logic Input Voltage (Pins 3, 9, 10, 11, 12)	-0.3V to +16V
Logic Input Voltage (Pins 4, 7)	-0.3V to +6V

Error Flag Voltage	16V
ESD Susceptibility (Note 2)	2000V
Power Dissipation (Note 3)	5W
	Internally Limited
Junction Temperature (T_{JMax})	150°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 Sec.)	+260°C

Operating Ratings (Note 1)

Ambient Temperature Range (T_A)	-40°C to +125°C
Supply Voltage Range	6V to 28V

Electrical Characteristics $V_{CC} = 12V$, $C_{CP} = 0.01 \mu Fd$, unless otherwise indicated. **Boldface** limits apply over the entire operating temperature range, $-40^\circ C \leq T_A \leq +125^\circ C$, all other limits are for $T_A = T_J = +25^\circ C$.

Parameter	Conditions	Typical (Note 4)	Limit (Note 5)	Units (Limit)
DC CHARACTERISTICS				
Supply Current	Enable Input = 0V	0.04	10	μA (Max)
	Enable Input = 5V, Inputs = 0V	7.5	15	mA (Max)
	Enable Input = 5V, Inputs = 5V			
	Open Loads	7.5	15	mA (Max)
Output Leakage	Enable Input = 0V, Inputs = 0V (Pins 1, 2, 18, 19)	0.01	10	μA (Max)
Rds ON	$I_{OUT} = 1A$, (Note 6)	0.8	1.3	Ω (Max)
Short Circuit Current	$V_{CC} = 12V$, (Note 6)	1.2	0.8	A (Min)
	$V_{CC} = 6V$, (Note 6)	2.4		A
	$V_{CC} = 28V$, (Note 6)	0.6		A
Maximum Output Current	$V_{CC} - V_O = 4V$, (Note 6)	3.75		A
Load Error Threshold Voltage	Pins 1, 2, 18, 19	4.1		V
Open Load Detection Current	Pins 1, 2, 18, 19	150		μA
Negative Clamp Output Voltage	$I_O = 1A$, (Note 6)	-5		V
Overshoot Shutdown Threshold		35	40	V (Max)
Overshoot Shutdown Hysteresis		0.75		V
Error Output Leakage Current	$V_{Pin 13} = 12V$	0.001	10	μA (Max)
Thermal Warning Temperature	$V_{Pin 13} < 0.8V$	145		°C
Thermal Shutdown Temperature	$V_{Pin 17} < 0.8V$	170		°C

Electrical Characteristics $V_{CC} = 12V$, $C_{CP} = 0.01 \mu F$, unless otherwise indicated. **Boldface** limits apply over the entire operating temperature range, $-40^{\circ}C \leq T_A \leq +125^{\circ}C$, all other limits are for $T_A = T_J = +25^{\circ}C$. (Continued)

Parameter	Conditions	Typical (Note 4)	Limit (Note 5)	Units (Limit)
AC CHARACTERISTICS				
Switch Turn-On Delay ($t_{d(ON)}$)	Enable (Pin 3) = 5V, $I_{OUT} = 1A$	5	10	μs (Max)
Switch Turn-On Rise Time (t_{ON})	$I_{OUT} = 1A$	7	15	μs (Max)
Switch Turn-Off Delay ($t_{d(OFF)}$)	Enable (Pin 3) = 5V, $I_{OUT} = 1A$	0.5	2	μs (Max)
Switch Turn-Off Fall Time (t_{OFF})	$I_{OUT} = 1A$	0.15	1	μs (Max)
Enable Time (t_{EN})	Measured with Switch 1, Pin 9 = 5V	30	50	μs (Max)
Error Reporting Delay (t_{Error})	Enable (Pin 3) = 5V, Switch 1 Load Opened	75	150	μs (Max)
Data Setup Time (t_{DS})	$C_L = 30 pF$	200	500	ns (Min)
TRI-STATE® Control (t_{1H} , t_{OH})	Pin 8, Hi-Z Enable Time	2		μs
Data Clock Frequency		3	1	MHz (Max)
DIGITAL CHARACTERISTICS				
Logic "1" Input Voltage	Pins 3, 4, 7, 9, 10, 11, 12		2.0	V (Min)
Logic "0" Input Voltage	Pins 3, 4, 7, 9, 10, 11, 12		0.8	V (Max)
Logic "1" Input Current	Pins 4, 7	0.001	1	μA (Max)
Logic "0" Input Current	Pins 4, 7	-0.001	-1	μA (Max)
TRI-STATE Output Current	Pin 8, Pin 4 = 5V Pin 8 = 0V	0.05 -0.05	10 -10	μA (Max) μA (Max)
Enable Input Current	Pin 3 = 2.4V	12	25	μA (Max)
Channel Input Resistance	Pins 9, 10, 11, 12	75	25	k Ω (Min)
Error Output Sink Current	Pin 13 = 0.8V	4	1.6	mA (Min)
Logic "1" Output Voltage	Pin 8 $I_{OUT} = -360 \mu A$ $I_{OUT} = -10 \mu A$ $I_{OUT} = -10 \mu A$	4.4 5.1	2.4 4.5 5.5	V (Min) V (Min) V (Max)
Logic "0" Output Voltage	Pin 8 $I_{OUT} = 100 \mu A$		0.4	V (Max)
Thermal Shutdown Output Source Current	Pin 17 = 2.4V	5	3	μA (Min)
Thermal Shutdown Output Sink Current	Pin 17 = 0.8V	360	250	μA (Min)

Electrical Characteristics Notes

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Human body model; 100 pF discharge through a 1.5 kΩ resistor. All pins except pins 8 and 13 which are protected to 1000V and pins 1, 2, 18 and 19 which are protected to 500V.

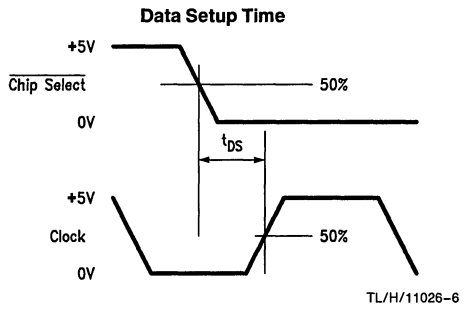
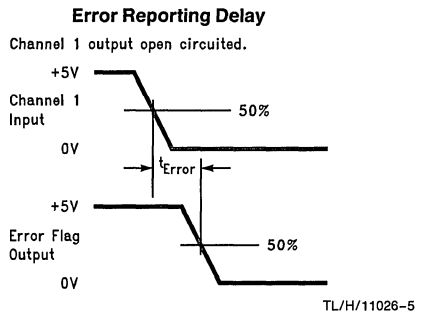
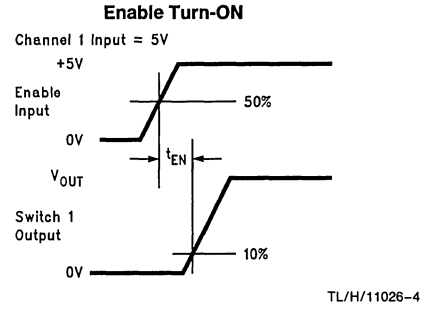
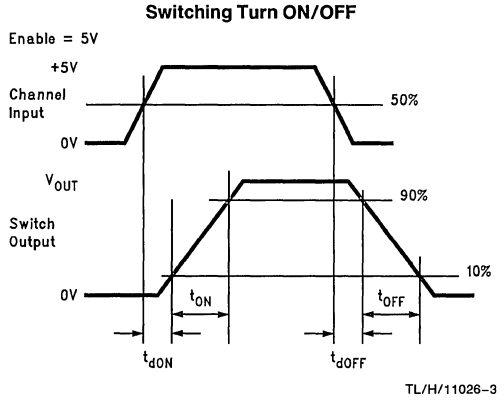
Note 3: The maximum power dissipation is a function of T_{JMax} , θ_{JA} , and T_A and is limited by thermal shutdown. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{JMax} - T_A) / \theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the device will eventually go into thermal shutdown. For the LMD18400 the junction-to-ambient thermal resistance, θ_{JA} , is 60°C/W. With sufficient heatsinking the maximum continuous power dissipation for the package will be, $I_{DCMax}^2 \times R_{ON(Max)} \times 4$ switches ($1A^2 \times 1.3\Omega \times 4 = 5.2W$).

Note 4: Typical values are at $T_J = +25^\circ C$ and represent the most likely parametric norm.

Note 5: All limits are 100% production tested at +25°C. Limits at temperature extremes are guaranteed through correlation and accepted Statistical Quality Control (SQC) methods.

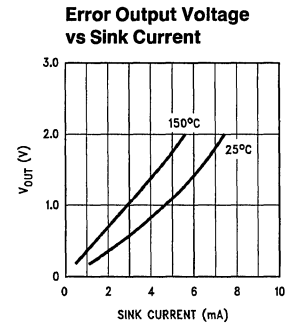
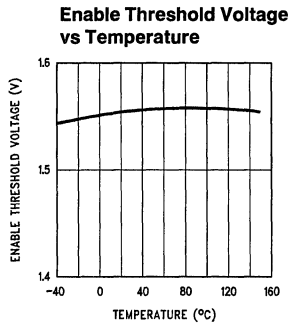
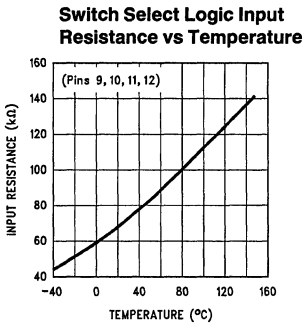
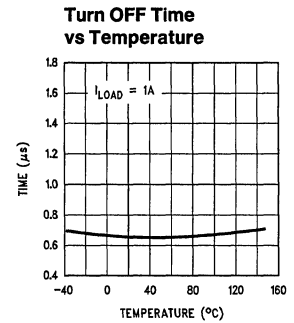
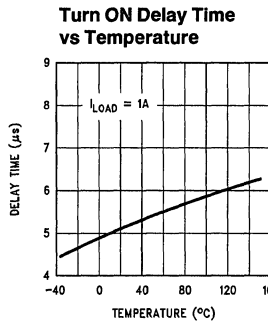
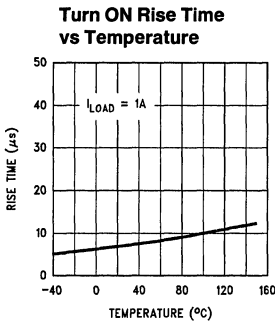
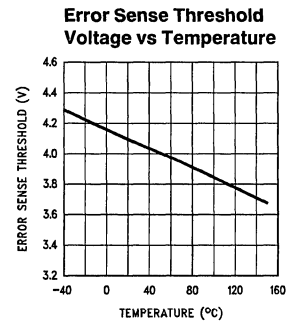
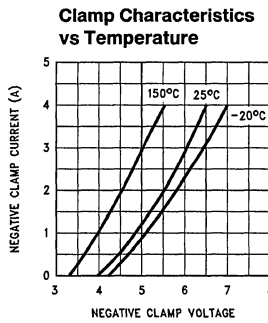
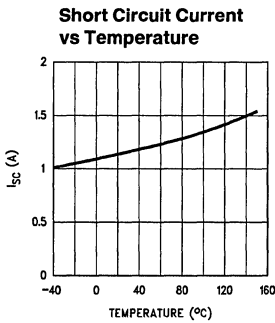
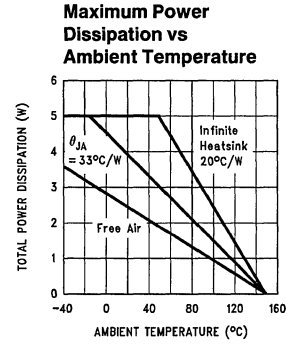
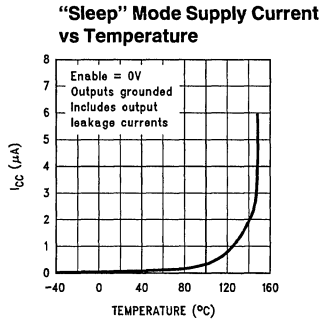
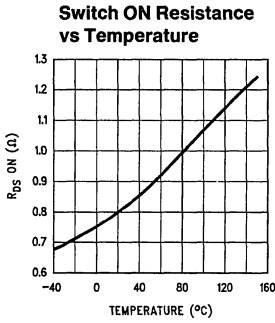
Note 6: Pulse Testing techniques used. Pulse width is < 5 ms with a duty cycle < 1 %.

Timing Specification Definitions

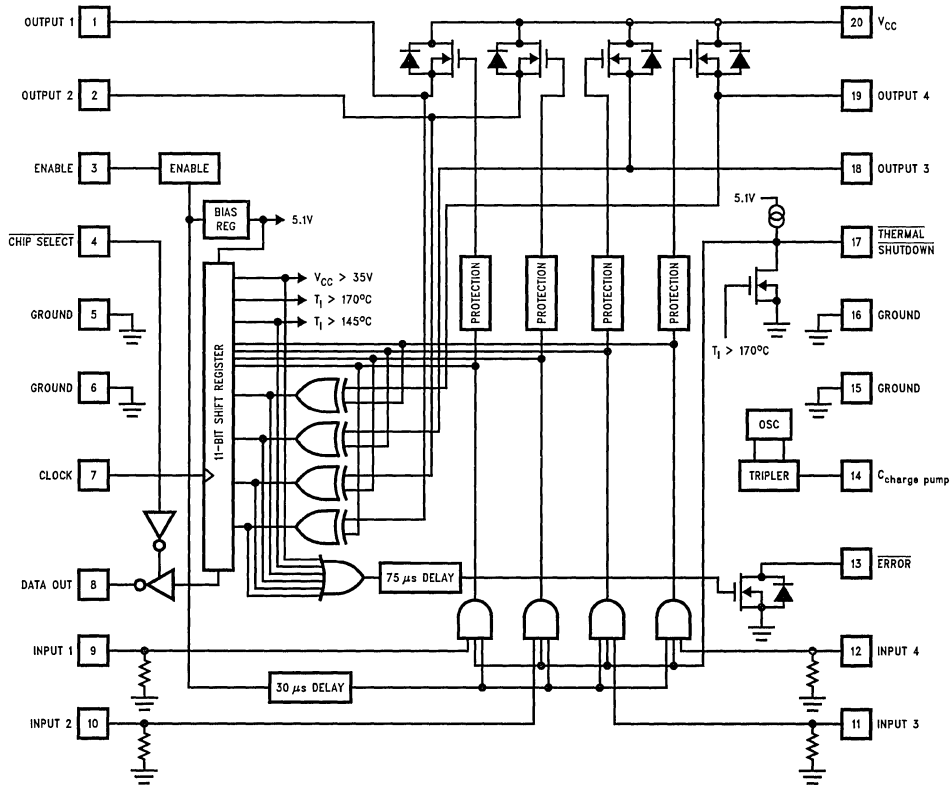


Typical Performance Characteristics

For all curves, $V_{CC} = 12V$, Temperature is the junction temperature unless otherwise noted.



Functional Block Diagram



TL/H/11026-8

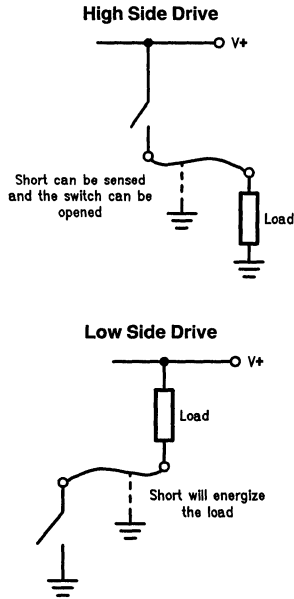
Truth Table

Enable Input (Pin 3)	Chip Select Input (Pin 4)	Switch Control Input (Pins 8, 9, 10, 11)	Error Output (Pin 13)	Thermal SD Output (Pin 17)	Conditions
0	X	X	0	0	"Sleep" Mode, $I_{Supply} < 10 \mu A$
1	X	0	1	1	Selected Switch is OFF
1	X	1	1	1	Selected Switch is ON, Normal Operation
1	X	0	0	1	Switch is OFF but: a. Load is Open Circuited, or b. Load is Shorted to V_{CC} , or c. $T_J > +145^\circ C$, or d. $V_{CC} > +35V$
1	X	1	0	1	Switch is ON, but: a. Load is Shorted to Ground, or b. Switch is in Power Limit, or c. $T_J > +145^\circ C$, or d. $V_{CC} > +35V$ and Switch is Actually OFF
1	X	1	0	0	$T_J > +170^\circ C$, All Switches are OFF
1	1	X	X	X	Data Output Pin is TRI-STATE
1	0	X	X	X	Data Output Pin is Enabled and Ready to Output Diagnostic Information

Applications Information

BASIC OPERATION

High-side drivers are used extensively in automotive and industrial applications to switch power to ground referred loads. The major advantage of using high-side drive, as opposed to low-side drive, is to protect the load from being energized in the event that the load drive wire is inadvertently shorted to ground as shown in *Figure 1*. A high-side driver can sense a shorted condition and open the power switch to disable the load and eliminate the excessive current drain on the power supply. The LMD18400 can control and protect up to four separate ground referenced loads.



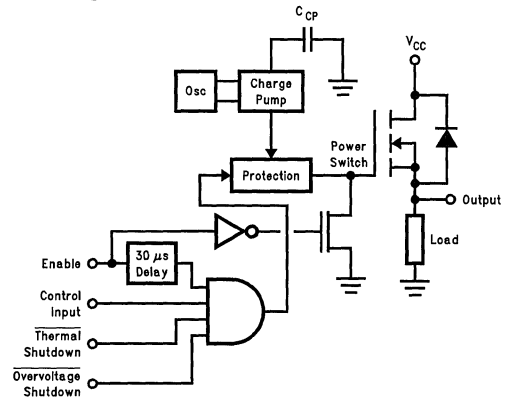
TL/H/11026-9

TL/H/11026-10

FIGURE 1. High-Side vs Low-Side Drive

The LMD18400 combines low voltage CMOS logic control circuitry with a high voltage DMOS process. Each DMOS power switch has an individual ON/OFF control input. When commanded ON, the output of the switch will connect the load to the V_{CC} supply through a maximum resistance of 1.3Ω (the ON resistance of the DMOS switch). The voltage applied to the load will depend upon the load current and the designed current capability of the LMD18400. When a switch is commanded OFF, the load will be disconnected from the supply except for a small leakage current of typically less than $0.01\ \mu\text{A}$.

The LMD18400 can be continually connected to a live power source, a car battery for example, while drawing less than $10\ \mu\text{A}$ from the power source when put into a "sleep" condition. This "sleep" mode is enacted by taking the Enable Input (pin 3) low. During this mode the supply current for the device is typically only $0.04\ \mu\text{A}$. Special low current consumption standby circuitry is used to hold the DMOS switches OFF to eliminate the possibility of supply voltage transients from turning on any of the loads (a common problem with MOS power devices). When in the "sleep" mode, all diagnostic and logic circuitry is inactive. When the Enable Input is taken to a logic 1, the switches become "armed" and ready to respond to their control input after a short, $30\ \mu\text{s}$, enable delay time. This delay interval prevents the switches from transient turn-on. *Figure 2* shows the switch control logic.



TL/H/11026-11

FIGURE 2. Control Logic for Each Power Switch

Each DMOS switch is turned ON when its gate is driven approximately 3.5V more positive than its source voltage. Because the source of the switch is the output terminal to the load it can be taken to a voltage very near the V_{CC} supply potential. To ensure that there is sufficient voltage available to drive the gates of the DMOS device a charge pump circuit is built in. This circuit is controlled by an internal $300\ \text{kHz}$ oscillator and using an external $10\ \text{nF}$ capacitor connected from pin 14 to ground generates a voltage that is approximately 20V greater than the V_{CC} supply voltage. This provides sufficient gate voltage drive for each of the switches which is applied under command of standard 5V logic input levels.

The turn-on time for each switch is approximately $12\ \mu\text{s}$ when driving a 1A load current. This relatively slow switching time is beneficial in minimizing electromagnetic interference (EMI) related problems created from switching high current levels.

Applications Information (Continued)

PROTECTION CIRCUITRY

The LMD18400 has extensive protection circuitry built in. With any power device, protection against excessive voltage, current and temperature conditions is essential. To achieve a "fail-safe" system implementation, the loads are deactivated automatically by the LMD18400 in the event of any detected overvoltage or over-temperature fault conditions.

Voltage Protection

The V_{CC} supply can range from $-0.5V$ to $+60 V_{DC}$ without any damage to the LMD18400. The CMOS logic circuitry is biased from an internal 5.1V regulator which protects these lower voltage transistors from the higher V_{CC} potentials. In order to protect the loads connected to the switch outputs however, an overvoltage shutdown circuit is employed. Should the V_{CC} potential exceed 35V all of the switches are turned OFF thereby disconnecting the loads. This 35V threshold has 750 mV of hysteresis to prevent potential oscillations.

Additionally, there is an undervoltage lockout feature built in. With V_{CC} less than 5V it becomes uncertain whether the logic circuitry can hold the switches in their commanded state. To avoid this uncertainty, all of the switches are turned OFF when V_{CC} drops below approximately 5V. *Figure 3* illustrates the shutoff of an output during a 0V to 80V V_{CC} supply transient.

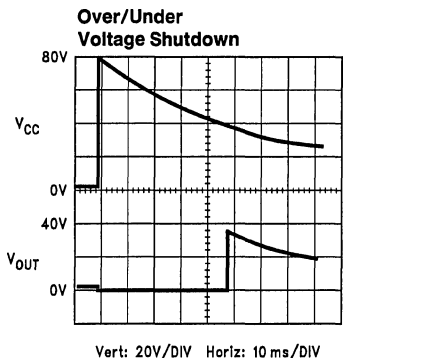
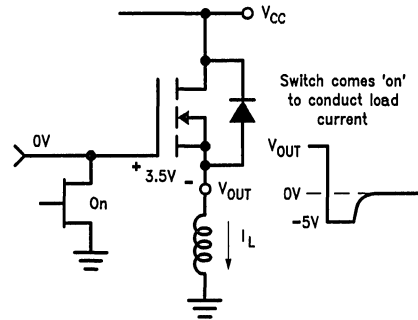


FIGURE 3. Overvoltage/Undervoltage Shutdown

The LMD18400 has been designed to drive all types of loads. When driving a ground referenced inductive load such as a relay or solenoid, the voltage across the load will reverse in polarity as the field in the inductor collapses when the power switch is turned OFF. This will pull the output pin of the LMD18400 below ground. This negative transient voltage is clamped at approximately $-5V$ to protect the IC. This clamping action is not done with diodes but rather the power DMOS switch turning back on momentarily to conduct the inductor current as it de-energizes as shown in *Figure 4*.



TL/H/11026-13

FIGURE 4. Turn-OFF Conditions with an Inductive Load

When the output inductance produces a negative voltage, the gate of the DMOS transistor is clamped at 0V. At $-3.5V$, the source of the power device is less than the gate by enough to cause the switch to turn ON again. During this negative transient condition the power limiting circuitry to protect the switch is disabled due to the gate being held at 0V. The maximum current during this clamping interval, which is equal to the steady state ON current through the inductor, should be kept less than 1A. Another concern during this interval has to do with the size of an inductive load and the amount of time required to de-energize it. With larger inductors it may be possible for the additional power dissipation to cause the die temperature to exceed the thermal shutdown limit. If this occurs all of the other switches will turn OFF momentarily (see section on Thermal Management).

Power Limiting

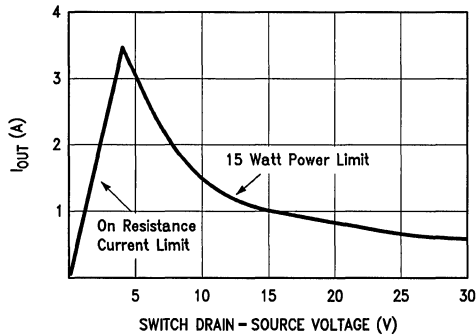
The LMD18400 utilizes a true instantaneous power limit circuit rather than simple current limiting to protect each switch. This provides a higher transient current capability while still maintaining a safe power dissipation level. The power dissipation in each switch (the product of the Drain-to-Source voltage and the output current, $V_{ds} \times I_{OUT}$) is con-

Applications Information (Continued)

tinually monitored and limited to 15W by varying the gate voltage and therefore the ON resistance of the switch. Basically the ON resistance will be as low as possible until 15W is being dissipated. To maintain 15W, the ON resistance increases to reduce the load current. This results in a decrease of the output voltage. For resistive loads, the output voltage when in power limit will be:

$$V_{OUT} \text{ (in Power Limit)} = \frac{V_{CC} - \sqrt{V_{CC}^2 - 60 R_L}}{2}$$

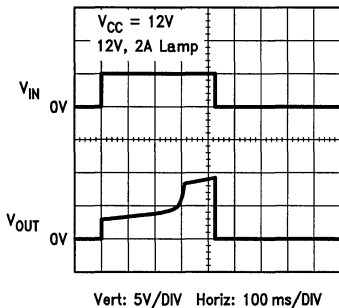
This provides a maximum transient current and drain-to-source voltage characteristic as shown in *Figure 5*.



TL/H/11026-14

FIGURE 5. Maximum Output Current with Instantaneous Power Limiting

Driving a Lamp



TL/H/11026-15

FIGURE 6. Soft Turn-On of a Lamp Load

The steady state current to the load is limited by the package power dissipation, ambient temperature and the ON resistance of the switch which has a positive temperature coefficient as shown in the Typical Performance Characteristics.

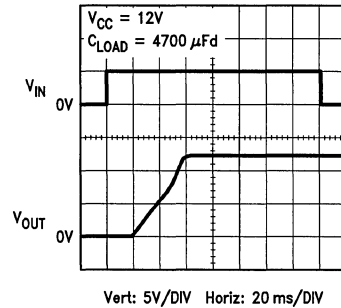
This dynamic current limiting of the switches is beneficial when driving lamp and large capacitive loads. Lamps require a large inrush current, on the order of 10 times the normal operating current, when first switched on with a cold filament. The LMD18400 will limit this initial current to the level where 15W is dissipated in the switch. As the filament warms up the voltage across the lamp increases thereby decreasing the voltage across the switch which permits more current to fully light the lamp. With limited inrush current the lifetime of a lamp load is increased significantly. *Figure 6* illustrates the soft turn-on of a lamp load.

The same principle of increasing output current as the voltage across the load increases allows large capacitive loads to be charged more quickly by an LMD18400 driver than as opposed to a driver with a fixed 1A current limit protection scheme. *Figure 7* shows the output response while driving a large capacitive load.

Thermal Protection

The die temperature of the LMD18400 is continually monitored. Should any conditions cause the die temperature to rise to $+170^{\circ}\text{C}$, all of the power switches are turned OFF automatically to reduce the power dissipation. It is important to realize that the thermal shutdown affects all four of the switches together. That is, if just one switch load is enough to heat the die to the thermal shutdown threshold, all of the other switches, regardless of their power dissipation conditions, will be switched OFF. All of the switches will be re-enabled when the die temperature has cooled to approximately $+160^{\circ}\text{C}$. Until the high temperature forcing conditions have been removed the switches will cycle ON and OFF thus maintaining an average die temperature of $+165^{\circ}\text{C}$. The LMD18400 will signal that excessive temperatures exist through several diagnostic output signals (see Diagnostics).

Driving a Large Capacitive Load



TL/H/11026-16

FIGURE 7. Driving a Large Capacitive Load

Applications Information (Continued)

DIAGNOSTICS

The LMD18400 has extensive circuit diagnostic information reporting capability. Use of this information can produce systems with intelligent feedback of switch status as well as load fault conditions for troubleshooting purposes. All of the diagnostic information is contained in an 11-bit word. This data can be clocked out of the LMD18400 in a serial fashion as shown in *Figure 8*. The shift register is parallel loaded with the diagnostic data whenever the Chip Select Input is at a Logic 1 and changes to the serial shift mode when Chip Select is taken to a Logic 0. The Data Output line (pin 8) is biased internally from a 5.1V regulator which sets the Logic 1 output voltage. This pin has low current sourcing capability so any load on this pin will reduce the Logic 1 output level which is guaranteed to be at least 2.4V with a 360 μ A load.

The data interface is MICROWIRE compatible in that data is clocked out of the LMD18400 on the falling edge of the clock, to be clocked into the controlling microprocessor on the rising edge. Any number of devices can share a common data output line because the data output pin is held in a high impedance (TRI-STATE) condition until the device is selected by taking its Chip Select Input low. Following Chip Select going low there is a short data setup time interval (500 ns Min) required. This is necessary to allow the first data bit of information to be established on the data output line prior to the first rising clock edge which will input the data bit into the controller. When all 11 bits of diagnostic data have been shifted out the data output goes to a Logic 1 level until the Chip Select line is returned high.

Figure 8 also indicates the significance of the diagnostic data bits. The first 4 bits indicate an output load error condi-

tion, one for each channel in succession (see Load Error Detection).

Bits 5 through 8 provide a readback of the commanded ON/OFF status of each switch.

A unique feature of the LMD18400 is that it provides an early warning of excessive operating temperature. Should the die temperature exceed +145°C, bit 9 will be set to a Logic 0. Acting on this information a system can be programmed to take corrective action, shutting OFF specific loads perhaps, while the LMD18400 is still operating normally (not yet in thermal shutdown). If this early warning is ignored and the device continues to rise in temperature, the thermal shutdown circuitry will come into action at a die temperature of +170°C. Should this occur bit 10 of the diagnostic data stream will be set to a Logic 0 indicating that the device is in thermal shutdown and all of the outputs have been shut OFF.

The final data bit, bit 11, indicates an overvoltage condition on the V_{CC} supply (V_{CC} is greater than 35V) and again indicates that all of the drivers are OFF.

The diagnostic data can be read periodically by a controller or only in the event of a general system error indication to determine the cause of any system problem. This general indication of a fault is provided by an Error Flag output (pin 13). This pin goes low whenever any type of error is detected. There is a built-in delay of approximately 75 μ s from the time an error is detected until pin 13 is taken low. This is to help mask short duration error conditions such as may be caused by driving highly capacitive loads (> 2 μ F). A lamp load may generate a shorted load error for several hundred milliseconds as it turns on which should be ignored.

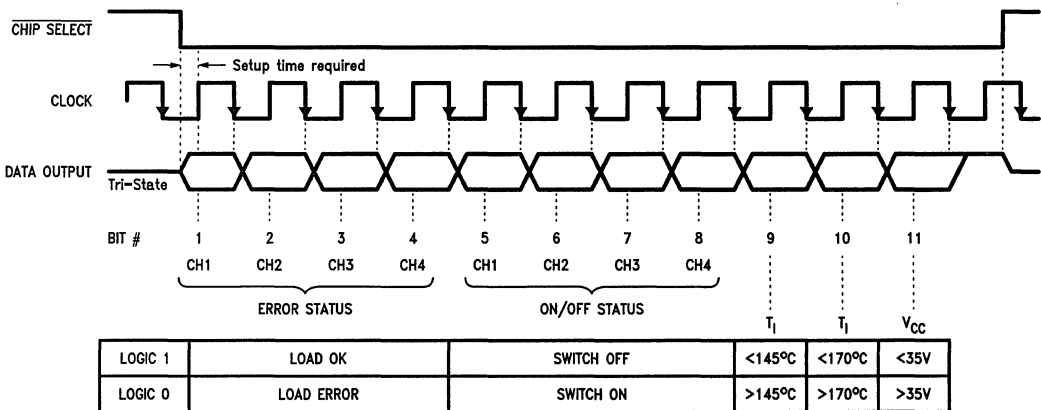


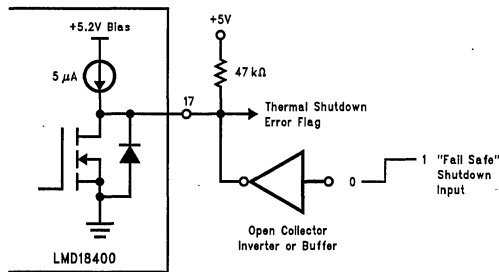
FIGURE 8. Serial Diagnostic Data Assignments

TL/H/11026-17

Applications Information (Continued)

The Error Flag output pin is an open drain transistor which requires a pull-up resistor to a positive voltage of up to 16V. Typically this pull-up is to the same 5V supply which is biasing the Enable input and any other external logic circuitry. The Error Flag pins of several LMD18400 packages can be connected together with just one pull-up resistor to provide an all-encompassing general system error indication. Upon detection of an error, each device could then be polled for diagnostic information to determine the source of the fault condition.

A second direct output error flag is for an indication of Thermal Shutdown (pin 17). This active low flag provides an immediate indication that the die temperature has reached +170°C and that the drive to all four switches has been removed. This output is pulled up to the internal 5.1V logic regulator through a small (5 μ A) current source so use of a buffer on this pin is recommended.



TL/H/11026-18

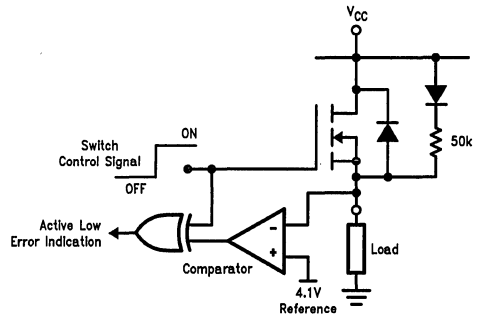
FIGURE 9. Thermal Shutdown Flag and Shutdown Input

A useful feature of pin 17 is that it can also be used as a shutdown input. Driving this pin low immediately switches all of the drivers OFF, just the same as if thermal shutdown temperatures has been reached, yet all of the control logic and diagnostic circuits remain active. This is useful in designing "fail-safe" systems where the loads can be disabled under any sort of externally detected system fault condition. The diagnostic logic however does not distinguish between normal thermal shutdown or the fact that pin 17 has been driven low. As such, various switch errors and an over-temperature indication will be reported in the diagnostic data stream.

Figure 9 illustrates the use of pin 17 as both an output thermal shutdown flag and as an input to shut down only the switches. Directly tying pin 17 to +5V will prevent the internal thermal shutdown circuitry from disabling the switches. For reliability purposes however this is not recommended as there will then be no limit to the maximum die temperature. Refer to the Truth Table for a summary of the action of these direct-output error flags.

LOAD ERROR DETECTION

An important feature of the LMD18400 is the ability to detect open or shorted load connections. Figure 10 illustrates the detection circuit used with each of the drivers.



TL/H/11026-19

FIGURE 10. Detection Circuitry for Open/Shorted Loads

A voltage comparator monitors the voltage to the load and compares it to a fixed 4.1V reference level. When a switch is OFF, the ground referenced load should have no voltage across it. Under this condition, an internal 50 k Ω resistor connected to V_{CC} will provide a small amount of current to the load. If the load resistance is large enough to create a voltage greater than 4.1V an Open Load Error will be indicated for that switch. The maximum load resistance that will not generate an Open Load Error when a switch is OFF can be found by:

$$R_{Max} = \frac{4.1V}{V_{CC} - 4.6V} \times 50 \text{ k}\Omega; \text{ for no Open Load Indication}$$

To make this Open Load Error threshold more sensitive, an external pull-up resistor can be added from the output to the V_{CC} supply.

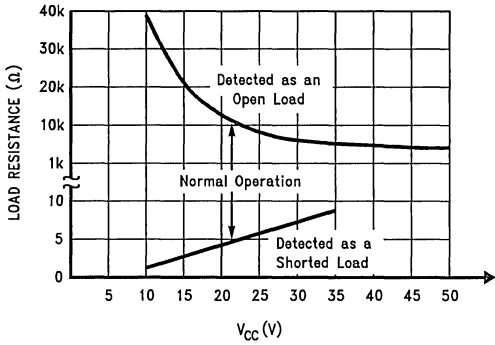
Also when a switch is commanded OFF, should the load be shorted to the V_{CC} supply, this same circuitry will again indicate an error.

When a switch is commanded ON, the load is expected to have a voltage across it that approaches the V_{CC} potential. If the output voltage is less than the 4.1V threshold an error will again be reported, indicating that the load is either shorted to ground or that the driver is in power limit and not able to pull the output voltage any closer to V_{CC} . The minimum load resistance that will not generate a Shorted Load Error when a switch is ON can be found by:

$$R_{Min} = \frac{4.1V (V_{CC} - 4.1V)}{15W}; \text{ for no Shorted Load Error}$$

Applications Information (Continued)

Figure 11 indicates the range of load resistance for normal operation, open load, and shorted load or power limit indication.

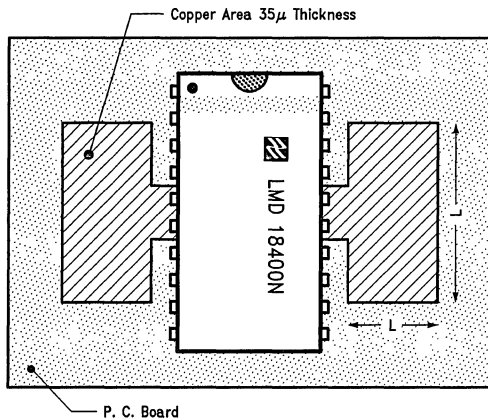


TL/H/11026-20

FIGURE 11. Load Resistance Detected as Errors

THERMAL MANAGEMENT

It is particularly important to consider the total amount of power being dissipated by all four switches in the LMD18400 at all times. Any combination of the switches driving loads will cause an increase in the die temperature. Should the die temperature reach the thermal shutdown threshold of +170°C, all of the switches will be disabled.



TL/H/11026-21

FIGURE 12. Recommended PC Board Layout to Reduce the Thermal Resistance from Junction-to-Ambient

Careful calculation of the worst case total power dissipation required at any point in time, together with providing sufficient heatsinking will prevent this from occurring.

The LMD18400 is packaged with a special leadframe that helps dissipate heat through the two ground pins on each side of the package. The thermal resistance from junction-to-case (θ_{JC}) for this package is approximately 20°C/W. The thermal resistance from junction-to-ambient (θ_{JA}), without any heatsinking, is approximately 60°C/W. Figure 12 illustrates how the copper foil of a printed circuit board can be designed to provide heatsinking and reduce the overall junction-to-ambient thermal resistance.

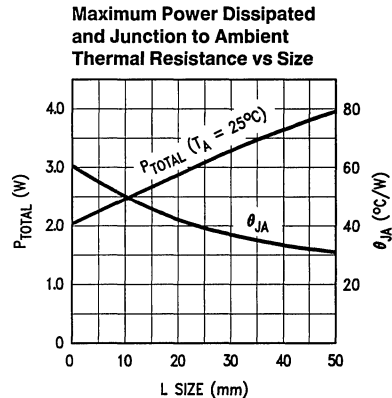
The power dissipation in each switch is equal to:

$$P_D (\text{Each Switch}) = I_{\text{Load}}^2 \times R_{\text{ON}} \quad \text{or} \quad \frac{(V_{\text{CC}} - V_{\text{OUT}})^2}{R_{\text{ON}}}$$

where R_{ON} is the ON resistance of the switch (1.3Ω maximum). These equations hold true until the power dissipation reaches the maximum limit of 15W. With resistive loads, the 15W power limit threshold will be reached when:

$$R_L \leq \frac{V_{\text{CC}}^2}{60W}$$

Inductive loads will create additional power dissipation when switched OFF. Figure 13 shows the idealized voltage and current waveforms for an inductive load.



TL/H/11026-22

Applications Information (Continued)

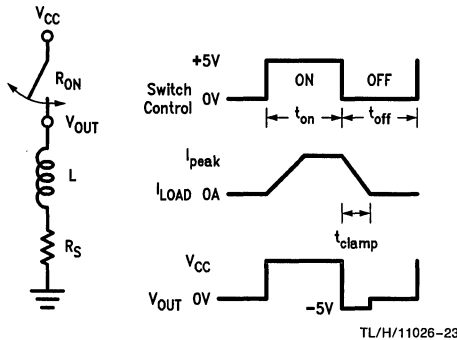


FIGURE 13. Switching an Inductive Load

When switched ON, the worst case power dissipation is:

$$P_{D(ON)} = I_{Peak}^2 \times R_{ON}; \text{ where } I_{Peak} = \frac{V_{CC}}{R_{ON} + R_S}$$

The steady-state ON current of the inductor should be kept less than 1A per power switch.

The additional power dissipation during turn-off, as the inductor is de-energized and the voltage across the inductor is clamped to $-5V$, can be found by:

$$P_{D(OFF)} = \frac{(V_{CC} + 5V) \times I_{Peak}}{2}$$

for the time interval, t_{Clamp} , which is the time required for the inductor current to fall to zero;

$$t_{Clamp} = \frac{I_{Peak} \times L}{5V}$$

The size of the inductor will determine the time duration for this additional power dissipation interval. Even though the peak current is kept less than 1A, the switch during this interval will see a voltage across it of $V_{CC} + 5V$ with no

power limit protection. If the inductor is too large, the time interval may be long enough to heat the die temperature to $+170^\circ C$ thereby shutting OFF all other loads on the package.

The total average power dissipation during a full ON/OFF switching cycle of an inductive load will be:

$$P_{D(tot)} = \left[I_{Peak}^2 R_{ON} t_{ON} + \frac{I_{Peak}^2 L (V_{CC} + 5V)}{10} \right] \frac{1}{t_{ON} + t_{OFF}}$$

Due to the common cut-off of all loads forced by thermal shutdown, the thermal time constants of the package become a concern. Figure 14 provides an indication of the time it takes to heat the die to thermal shutdown with a step increase in package power dissipation from an initial junction temperature of $+25^\circ C$. This data was measured using a PC board layout providing a thermal resistance from junction to ambient of approximately $35^\circ C/W$. Less heatsinking will, of course, result in faster thermal shutdown of the power switches.

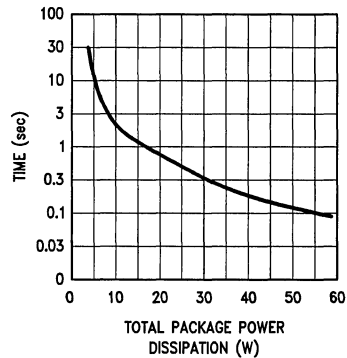
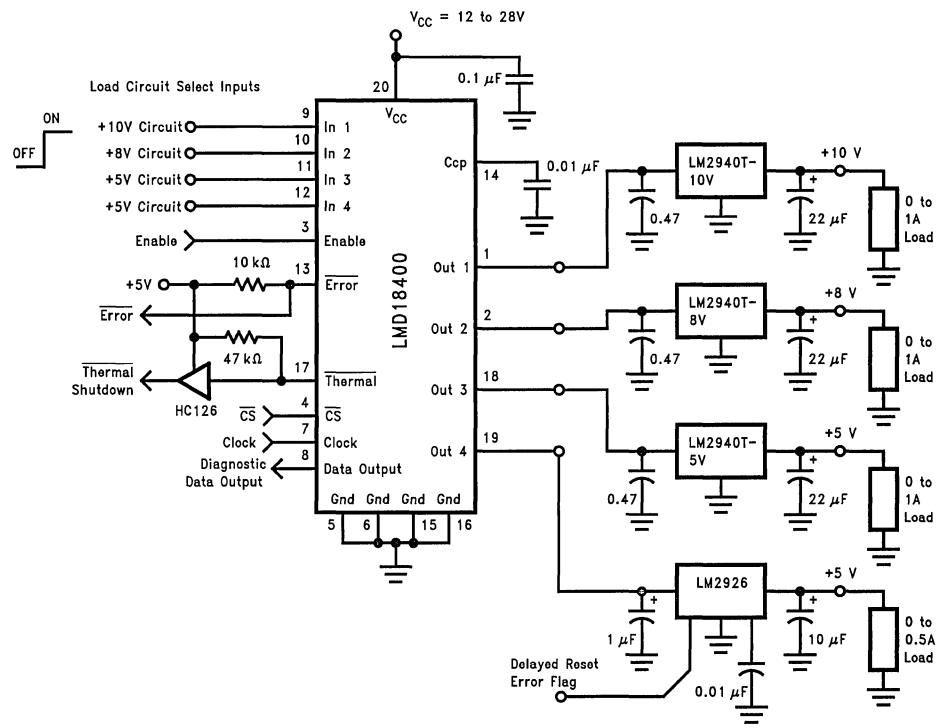


FIGURE 14. Approximate time required for the die to reach the $170^\circ C$ thermal shutdown point from $25^\circ C$ for different total package power dissipation levels.

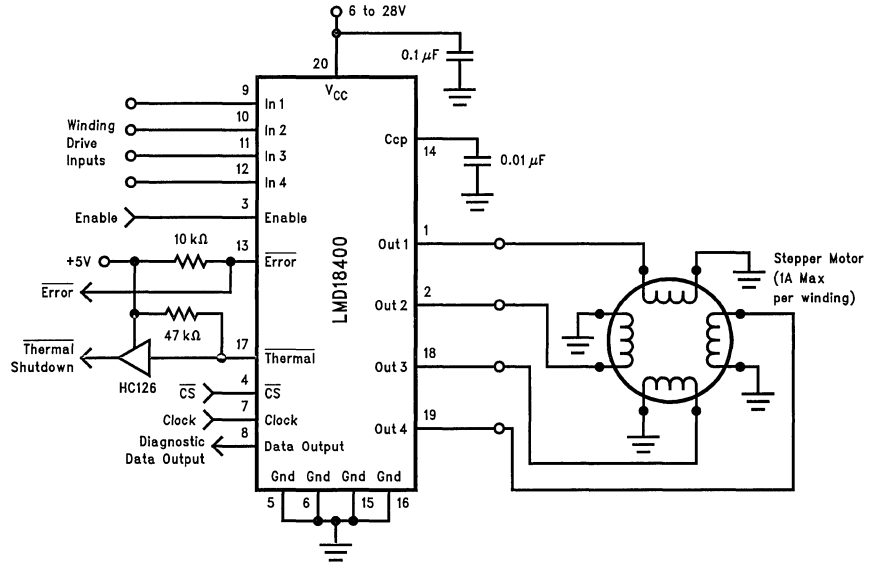
Applications

ON/OFF Switching of multiple voltage regulated circuit loads. Reset flag feedback from the LM2926 as shown connected to Output 4 can make the LMD18400 act as an electronic fuse for load faults.



TL/H/11026-25

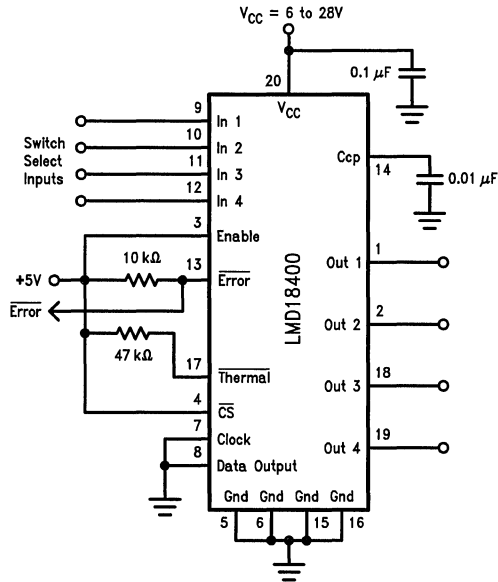
Unipolar Drive for a 4-Phase Stepper Motor



TL/H/11026-26

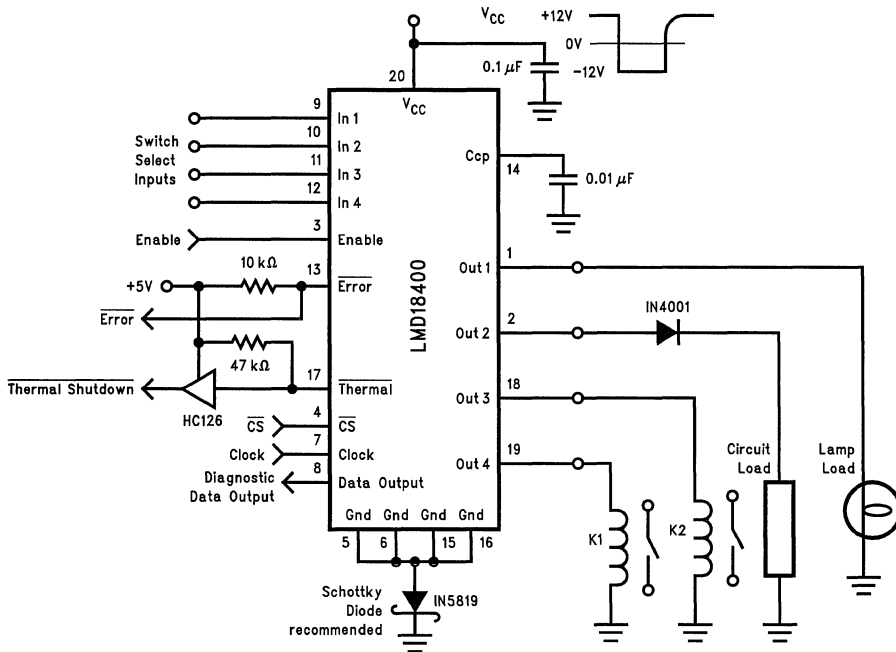
Applications (Continued)

Recommended Connection if No Diagnostics are Required



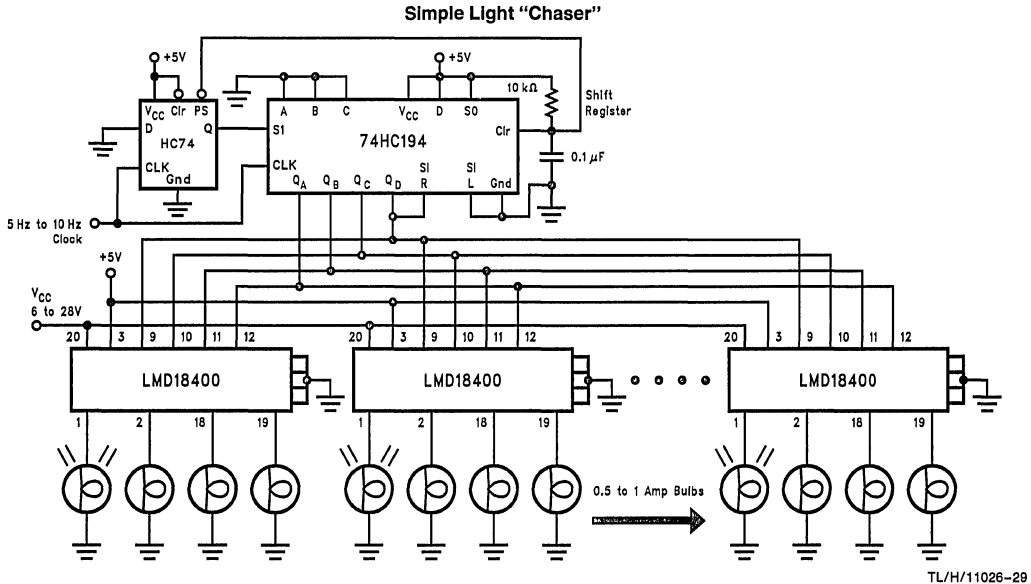
TL/H/11026-27

Simple protection of the LMD18400 against supply voltage reversal. Loads will be energized through the intrinsic diodes in parallel with the power switches. The Schottky diode will add approximately 0.2V to the logic input switching thresholds and the logic output low levels.

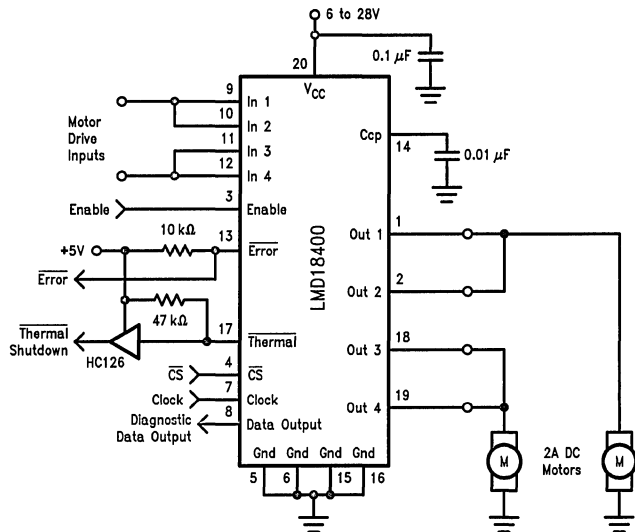


TL/H/11026-28

Applications (Continued)



Parallelling switches for higher current capability. Positive temperature coefficient of the switch ON resistance provides ballasting to evenly share the load current between the switches. Any combination of switches can be paralleled. Required peak load current will depend upon the motor load. Motor speed control can be provided by a PWM signal of up to 20 kHz applied to the motor drive input lines.





Section 7
Surface Mount



Section 7 Contents

Surface Mount	7-3
AN-450 Small Outline (SO) Package Surface Mounting Methods—Parameters and Their Effect on Product Reliability.....	7-23

Surface Mount

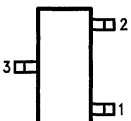
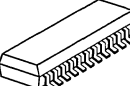
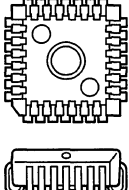

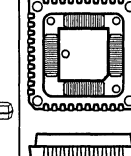
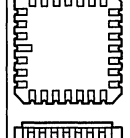

SURFACE MOUNT PACKAGING AT NATIONAL

To meet the growing demand for smaller packaging, National has developed a line of surface mount packages. Ranging in lead counts from 3 to 360, the package offerings are summarized in Table I.

Lead center spacing keeps shrinking with each new generation of surface mount package. Traditional packages (e.g.,

DIPs) have a 100 mil lead center spacing. Surface mount packages currently in production (e.g., SOT, SOIC, PCC, LCC, LDCC) have a 50 mil lead center spacing. Surface mount packages in production release (e.g., PQFP) have a 25 mil lead center spacing. Surface mount packages in development (e.g., TAPEPAK®) will have a lead center spacing of only 12–20 mils.

TABLE I. Surface Mount Packages from National

Package Type	Small Outline Transistor (SOT)	Small Outline IC (SOIC)	Plastic Chip Carrier (PCC)	Plastic Quad Flat Pack (PQFP)	TAPEPAK® (TP)	Leadless Chip Carrier (LCC) (LDCC)	Leaded Chip Carrier
							
Package Material	Plastic	Plastic	Plastic	Plastic	Plastic	Ceramic	Ceramic
Lead Bend	Gull Wing	Gull Wing	J-Bend	Gull Wing	Gull Wing	—	Gull Wing
Lead Center Spacing	50 Mils	50 Mils	50 Mils	25 Mils	20, 15, 12 Mils	50 Mils	50 Mils
Tape & Reel Option	Yes	Yes	Yes	tbd	tbd	No	No
Lead Counts	SOT-23 High Profile SOT-23 Low Profile	SO-8(*) SO-14(*) SO-14 Wide(*) SO-16(*) SO-16 Wide(*) SO-20(*) SO-24(*) SO-28(*)	PCC-20(*) PCC-28(*) PCC-44(*) PCC-68 PCC-84 PCC-124	PQFP-84 PQFP-100 PQFP-132 PQFP-196(*) PQFP-244	TP-40 (*) TP-68 TP-84 TP-132 TP-172 TP-220 TP-284 TP-360	LCC-18 LCC-20(*) LCC-28 LCC-32 LCC-44 (*) LCC-48 LCC-52 LCC-68 LCC-84 LCC-124	LDCC-44 LDCC-68 LDCC-84 LDCC-124

*In production (or planned) for linear products.

LINEAR PRODUCTS IN SURFACE MOUNT

Linear functions available in surface mount include:

- Op amps
- Comparators
- Regulators
- References
- Data conversion
- Industrial
- Consumer
- Automotive

A representative list of linear part numbers in surface mount is presented in Table III. Refer to the datasheet in the appropriate chapter of this databook for a complete description of the device. In addition, National has other products and is continually expanding the list of devices offered in surface mount. If the functions you need do not appear in Table III, contact the sales office or distributor branch nearest you for additional information.

Automated manufacturers can improve their cost savings by using Tape-and-Reel for surface mount devices. Simplified handling results because hundreds-to-thousands of semiconductors are carried on a single Tape-and-Reel pack (see ordering and shipping information—printed later in this section—for a comparison of devices/reel vs. devices/rail for those surface mount package types being used for linear products). With this higher device count per reel (when compared with less than a 100 devices per rail), pick-and-place machines have to be re-loaded less frequently and lower labor costs result.

With Tape-and-Reel, manufacturers save twice—once from using surface mount technology for automated PC board assembly and again from less device handling during shipment and machine set-up.

BOARD CONVERSION

Besides new designs, many manufacturers are converting existing printed circuit board designs to surface mount. The resulting PCB will be smaller, lighter and less expensive to manufacture; but there is one caveat—be careful about the thermal dissipation capability of the surface mount package.

Because the surface mount package is smaller than the traditional dual-in-line package, the surface mount package is not capable of conducting as much heat away as the DIP (i.e., the surface mount package has a higher thermal resistance—see Table II).

The silicon for most National devices can operate up to a 150°C junction temperature (check the datasheet for the rare exception). Like the DIP, the surface mount package can actually withstand an ambient temperature of up to 125°C (although a commercial temperature range device will only be specified for a max ambient temperature of 70°C and an industrial temperature range device will only be specified for a max ambient temperature of 85°C). See AN-336, "Understanding Integrated Circuit Package Power Capabilities", (reprinted in the appendix of each linear databook volume) for more information.

TABLE II: Surface Mount Package Thermal Resistance Range*

Package	Thermal Resistance** (θ_{JA} , °C/W)
SO-8	120–175
SO-14	100–140
SO-14 Wide	70–110
SO-16	90–130
SO-16 Wide	70–100
SO-20	60–90
SO-24	55–85
SO-28	TBD
PCC-20	70–100
PCC-28	60–90
PCC-44	40–60

*Actual thermal resistance for a particular device depends on die size. Refer to the datasheet for the actual θ_{JA} value.

**Test conditions: PCB mount (FR4 material), still air (room temperature), copper traces (150 × 20 × 10 mils).

Given a max junction temperature of 150°C and a maximum allowed ambient temperature, the surface mount device will be able to dissipate less power than the DIP device. This factor must be taken into account for new designs.

For board conversion, the DIP and surface mount devices would have to dissipate the same power. This means the surface mount circuit would have a lower maximum allowable ambient temperature than the DIP circuit. For DIP circuits where the maximum ambient temperature required is substantially lower than the maximum ambient temperature allowed, there may be enough margin for safe operation of the surface mount circuit with its lower maximum allowable ambient temperature. But where the maximum ambient temperature required of the DIP current is close to the maximum allowable ambient temperature, the lower maximum ambient temperature allowed for the surface mount circuit may fall below the maximum ambient temperature required. The circuit designer must be aware of this potential pitfall so that an appropriate work-around can be found to keep the surface mount package from being thermally overstressed in the application.

SURFACE MOUNT LITERATURE

National has published extensive literature on the subject of surface mount packaging. Engineers from packaging, quality, reliability, and surface mount applications have pooled their experience to provide you with practical hands-on knowledge about the construction and use of surface mount packages.

The applications note AN-450 "Surface Mounting Methods and their Effect on Product Reliability" is referenced on each SMD datasheet. In addition, "Wave Soldering of Surface Mount Components" is reprinted in this section for your information.

TABLE III. Linear Surface Mount Selected Device Listing

Amplifiers and Comparators

Part Number	Part Number
LF451CM	LMC6022IM
LF453CM	LMC6024IM
LM10CWM	LMC6032IM
LM10CLWM	LMC6034IM
LM318M	LMC6041IM
LM3080M	LMC6042IM
LM4250M	LMC6044IM
LM611CM	LMC6084IM
LM612IM	LMC6064IM
LM613CWM	LMC6061IM
LM614CWM	LMC6081IM
LM615WIM	LMC6062IM
LM6181IM	LMC6082IM
LM6218WIM	LMC6484IM
LM6321M	LMC6482IM
LM6361M	LPC660IM
LM6362M	LPC661IM
LM6364M	LPC662IM
LM6365M	
LMC660CM	
LMC662CM	

Peripheral Drivers

Part Number	Part Number
DS2001CM	DS2004TM
DS2001TM	DS3680M
DS2002CM	DS75451M
DS2002TM	DS75452M
DS2003CM	DS75453M
DS2003TM	DS75454M
DS2004CM	

Regulators and References

Part Number	Part Number
LM317LM	LM2577M—12
LM337LM	LM2577M—15
LM431ACM	LM2577M—ADJ
LM723CM	LM2578AM
LM2574M—3.3	LM2931AM—5.0
LM2574M—5.0	LM2931M—5.0
LM2574M—12	LM2931CM
LM2574M—15	LM2936M—5.0
LM2574M—ADJ	LM3524DM
LM2574HVM—3.3	LM3578AM
LM2574HVM—5.0	LM78L05ACM
LM2574HVM—12	LM78L12ACM
LM2574HVM—15	LM78L15ACM
LM2574HVM—ADJ	LM79L05ACM
LM2575M—5.0	LM79L12ACM
LM2575M—12	LM79L15ACM
LM2575M—15	LP2951ACM
LM2575M—ADJ	LP2951CM
LM2575HVM—5.0	LP2952AIM
LM2575HVM—12	LP2952IM
LM2575HVM—15	LP2953AIM
LM2575HVM—ADJ	LP2953IM

Data Acquisition Products

Part Number	Part Number
ADC08061/2/4/8	DAC0854
ADC08161/4/8	LM12454/8
ADC08031/2/4/8	LM34
ADC08131/4/8	LM35
ADC08231/4/8	LM4040
ADC0851/58	LM4041
ADC10061/2/4	LM4431
ADC10154/8	LMF100
ADC1034/8	LMF380
ADC10461/2/4	LMF40
ADC1061	LMF60
ADC10662/4	LMF90
ADC12030/2/4/8	

Industrial Functions

Part Number	Part Number
AH5012CM	LM13600M
LF13331M	LM13700M
LF13509M	LMC555CM
LF13333M	LM567CM
LM555CM	MF4CWM-50
LM556CM	MF4CWM-100
LM567CM	MF6CWM-50
LM1496M	MF10CCWM
LM2917M	MF6CWM-100
LM3046M	MF5CWM
LM3086M	LMC568CM
LM3146M	LMC567CM

Commercial and Automotive

Part Number	Part Number
LM386M-1	LM1851M
LM831M	LM1865M
LM832M	LM1877M
LM833M	LM1894M
LM837M	LM1882CM
LMC835V	LM1964V
LM1201M	LMC1982CIV
LM1204V	LMC1983CIV
	LM3361AM
	LM1881M
	LM3914V

A FINAL WORD

National is a world leader in the design and manufacture of surface mount components.

Because of design innovations such as perforated copper leadframes, our small outline package is as reliable as our DIP—the laws of physics would have meant that a straight “junior copy” of the DIP would have resulted in an “S.O.” package of lower reliability. You benefit from this equivalence of reliability. In addition, our ongoing vigilance at each step of the production process assures that the reliability we designed in stays in so that only devices of the highest quality and reliability are shipped to your factory.

Our surface mount applications lab at our headquarters site in Santa Clara, California continues to research (and publish) methods to make it even easier for you to use surface mount technology. Your problems are our problems.

When you think “Surface Mount”—think “National”!

Ordering and Shipping Information

When you order a surface mount semiconductor, it will be in one of the several available surface mount package types. Specifying the Tape-and-Reel method of shipment means that you will receive your devices in the following quantities per Tape-and-Reel pack: SMD devices can also be supplied in conventional conductive rails.

When ordering bulk S.O.—specify “M”.

When ordering S.O. Tape & Reel—specify “MX”.

Package	Package Designator	Max/Rail	Per Reel*
SO-8	M	100	2500
SO-14	M	50	2500
SO-14 Wide	WM	50	1000
SO-16	M	50	2500
SO-16 Wide	WM	50	1000
SO-20	M	40	1000
SO-24	M	30	1000
SO-28	M	26	1000
PCL-20	V	50	1000
PCL-28	V	40	1000
PCL-44	V	25	500
PQFP-196	VF	TBD	—
TP-40	TP	100	TBD
LCC-20	E	50	—
LCC-44	E	25	—

*Incremental ordering quantities. (National Semiconductor reserves the right to provide a smaller quantity of devices per Tape-and-Reel pack to preserve lot or date code integrity. See example below.)

Example: You order 5,000 LM324MXICs shipped in Tape-and-Reel.

- Case 1: All 5,000 devices have the same date code
 - You receive 2 SO-14 (Narrow) Tape-and-Reel packs, each having 2500 LM324M ICs
- Case 2: 3,000 devices have date code A and 2,000 devices have date code B
 - You receive 3 SO-14 (Narrow) Tape-and-Reel packs as follows:
 - Pack #1 has 2,500 LM324MXICs with date code A
 - Pack #2 has 500 LM324MXICs with date code A
 - Pack #3 has 2,000 LM324MXICs with date code B

Short-Form Procurement Specification

TAPE FORMAT

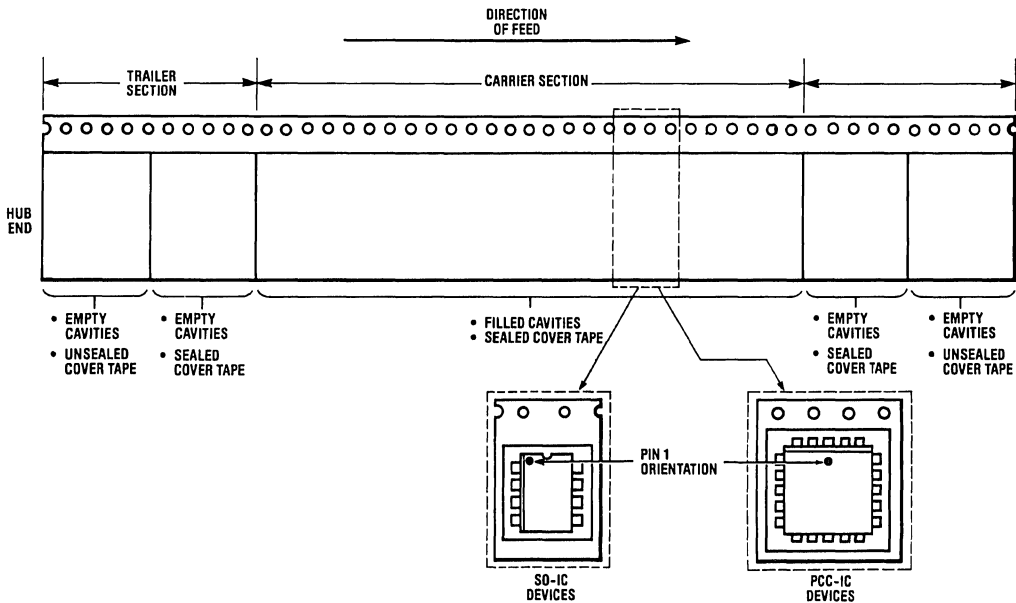
→ Direction of Feed

	Trailer (Hub End)*		Carrier*	Leader (Start End)*	
	Empty Cavities, min (Unsealed Cover Tape)	Empty Cavities, min (Sealed Cover Tape)		Empty Cavities, min (Sealed Cover Tape)	Empty Cavities, min (Unsealed Cover Tape)
Small Outline IC					
SO-8 (Narrow)	2	2	2500	5	5
SO-14 (Narrow)	2	2	2500	5	5
SO-14 (Wide)	2	2	1000	5	5
SO-16 (Narrow)	2	2	2500	5	5
SO-16 (Wide)	2	2	1000	5	5
SO-20 (Wide)	2	2	1000	5	5
SO-24 (Wide)	2	2	1000	5	5
SO-28 (Wide)	0	25	1000	42	0
Plastic Chip Carrier IC					
PCC-20	2	2	1000	5	5
PCC-28	2	2	750	5	5
PCC-44	2	2	500	5	5

*The following diagram identifies these sections of the tape and Pin #1 device orientation.

Short-Form Procurement Specification (Continued)

DEVICE ORIENTATION



TL/XX/0026-8

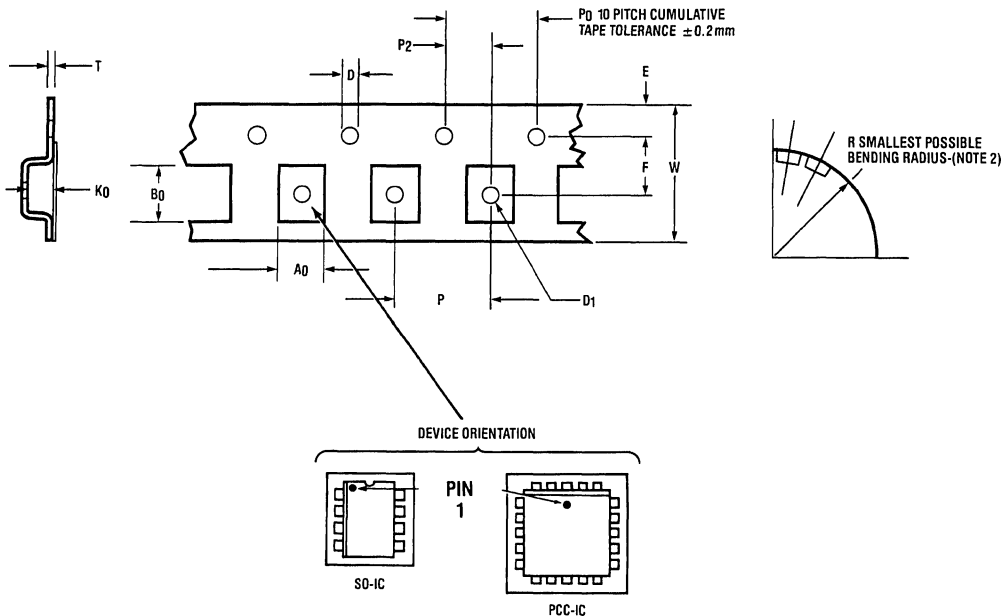
MATERIALS

- Cavity Tape: Conductive PVC (less than 10^5 Ohms/Sq)
- Cover Tape: Polyester
 - (1) Conductive cover available

• Reel:

- (1) Solid 80 pt fibreboard (standard)
- (2) Conductive fibreboard available
- (3) Conductive plastic (PVC) available

TAPE DIMENSIONS (24 Millimeter Tape or Less)



TL/XX/0026-9

Short-Form Procurement Specification (Continued)

	W	P	F	E	P ₂	P ₀	D	T	A ₀	B ₀	K ₀	D ₁	R
Small Outline IC													
SO-8 (Narrow)	12 ± .30	8.0 ± .10	5.5 ± .05	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	6.4 ± .10	5.2 ± .10	2.1 ± .10	1.55 ± .05	30
SO-14 (Narrow)	16 ± .30	8.0 ± .10	7.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	6.5 ± .10	9.0 ± .10	2.1 ± .10	1.55 ± .05	40
SO-14 (Wide)	16 ± .30	12.0 ± .10	7.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	10.9 ± .10	9.5 ± .10	3.0 ± .10	1.55 ± .05	40
SO-16 (Narrow)	16 ± .30	8.0 ± .10	7.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	6.5 ± .10	10.3 ± .10	2.1 ± .10	1.55 ± .05	40
SO-16 (Wide)	16 ± .30	12.0 ± .10	7.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	10.9 ± .10	10.76 ± .10	3.0 ± .10	1.55 ± .05	40
SO-20 (Wide)	24 ± .30	12.0 ± .10	11.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	10.9 ± .10	13.3 ± .10	3.0 ± .10	2.05 ± .05	50
SO-24 (Wide)	24 ± .30	12.0 ± .10	11.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	10.9 ± .10	15.85 ± .10	3.0 ± .10	2.05 ± .05	50
Plastic Chip Carrier IC													
PCC-20	16 ± .30	12.0 ± .10	7.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	9.3 ± .10	9.3 ± .10	4.9 ± .10	1.55 ± .05	40
PCC-28	24 ± .30	16.0 ± .10	11.5 ± .10	1.75 ± .10	2.0 ± .05	4.0 ± .10	1.55 ± .05	.30 ± .10	13.0 ± .10	13.0 ± .10	4.9 ± .10	2.05 ± .05	50

Note 1: A₀, B₀ and K₀ dimensions are measured 0.3 mm above the inside wall of the cavity bottom.

Note 2: Tape with components shall pass around a mandril radius R without damage.

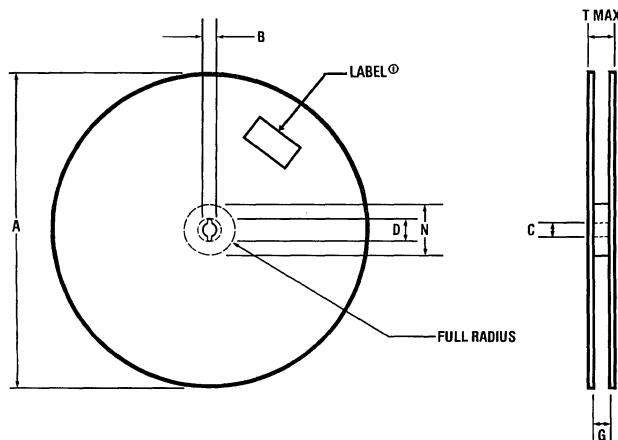
Note 3: Cavity tape material shall be PVC conductive (less than 10⁵ Ohms/Sq).

Note 4: Cover tape material shall be polyester (30–65 grams peel-back force).

Note 5: D₁ Dimension is centered within cavity.

Note 6: All dimensions are in millimeters.

REEL DIMENSIONS



START™ Surface Mount Tape and Reel

TL/XX/0026-10

Short-Form Procurement Specifications (Continued)

		A (Max)	B (Min)	C	D (Min)	N (Min)	G	T (Max)
12 mm Tape	SO-8 (Narrow)	$\frac{(13.00)}{(330)}$	$\frac{.059}{1.5}$	$\frac{.512 \pm .002}{13 \pm 0.05}$	$\frac{.795}{20.2}$	$\frac{1.969}{50}$	$\frac{0.488^{+.078}}{-0.000}$ $\frac{12.4^{+2}}{-0}$	$\frac{.724}{18.4}$
16 mm Tape	SO-14 (Narrow) SO-14 (Wide) SO-16 (Narrow) SO-16 (Wide) PCC-20	$\frac{(13.00)}{(330)}$	$\frac{.059}{1.5}$	$\frac{.512 \pm .002}{13 \pm 0.05}$	$\frac{.795}{20.2}$	$\frac{1.969}{50}$	$\frac{0.646^{+.078}}{-0.000}$ $\frac{16.4^{+2}}{-0}$	$\frac{.882}{22.4}$
24 mm Tape	SO-20 (Wide) SO-24 (Wide) PCC-28	$\frac{(13.00)}{(330)}$	$\frac{.059}{1.5}$	$\frac{.512 \pm .002}{13 \pm 0.05}$	$\frac{.795}{20.2}$	$\frac{1.969}{50}$	$\frac{0.960^{+.078}}{-0.000}$ $\frac{24.4^{+2}}{-0}$	$\frac{1.197}{30.4}$
32 mm Tape	PCC-44	$\frac{(13.00)}{(330)}$	$\frac{.059}{1.5}$	$\frac{.512 \pm .002}{13 \pm 0.05}$	$\frac{.795}{20.2}$	$\frac{1.969}{50}$	$\frac{1.276^{+.078}}{-0.000}$ $\frac{32.4^{+2}}{-0}$	$\frac{1.512}{38.4}$

Units: $\frac{\text{Inches}}{\text{Millimeters}}$

Material: Paperboard (Non-Flaking)

LABEL

Human and Machine Readable Label is provided on reel. A variable (C.P.I.) density code 39 is available. NSC STD label (7.6 C.P.I.)

FIELD

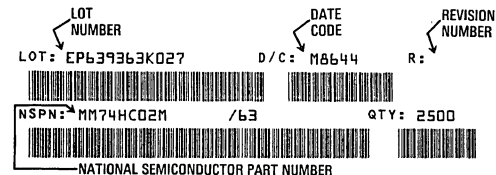
Lot Number

Date Code

Revision Level

National Part No. I.D.

Qty.

EXAMPLE

TL/XX/0026-11

Fields are separated by at least one blank space.

Future Tape-and-Reel packs will also include a smaller-size bar code label (high-density code 39) at the beginning of the tape. (This tape label is not available on current production.)

National Semiconductor will also offer additional labels containing information per your specific specification.

Wave Soldering of Surface Mount Components

ABSTRACT

In facing the upcoming surge of "surface mount technology", many manufacturers of printed circuit boards have taken steps to convert some portions of their boards to this new process. However, as the availability of surface mount components is still limited, may have taken to mixing the lead-inserted standard dual-in-line packages (DIPs) with the surface mounted devices (SMDs). Furthermore, to take advantage of using both sides of the board, surface-mounted components are generally adhered to the bottom side of the board while the top side is reserved for the conventional lead-inserted packages. If processed through a wave solder machine, the semiconductor components are now subjected to extra thermal stresses (now that the components are totally immersed into the molten solder).

A discussion of the effect of wave soldering on the reliability of plastic semiconductor packages follows. This is intended to highlight the limitations which should be understood in the use of wave soldering of surface mounted components.

ROLE OF WAVE-SOLDERING IN APPLICATION OF SMDs

The generally acceptable methods of soldering SMDs are vapor phase reflow soldering and IR reflow soldering, both requiring application of solder paste on PW boards prior to placement of the components. However, sentiment still exists for retaining the use of the old wave-soldering machine.

Wave Soldering of Surface Mount Components (Continued)

The reasons being:

- 1) Most PC Board Assembly houses already possess wave soldering equipment. Switching to another technology such as vapor phase soldering requires substantial investment in equipment and people.
- 2) Due to the limited number of devices that are surface mount components, it is necessary to mix both lead inserted components and surface mount components on the same board.
- 3) Some components such as relays and switches are made of materials which would not be able to survive the temperature exposure in a vapor phase or IR furnace.

PW BOARD ASSEMBLY PROCEDURES

There are two considerations in which through-hole ICs may be combined with surface mount components on the PW Board:

- a) Whether to mount ICs on one or both sides of the board.
- b) The sequence of soldering using Vapor Phase, IR or Wave Soldering singly or combination of two or more methods.

The various processes that may be employed are:

- A) Wave Solder before Vapor/IR reflow solder.
 1. Components on the same side of PW Board.
 - Lead insert standard DIPS onto PW Board Wave solder (conventional)
 - Wash and lead trim
 - Dispense solder paste on SMD pads
 - Pick and place SMDs onto PW Board
 - Bake
 - Vapor phase/IR reflow
 - Clean
 2. Components on opposite side of PW Board.
 - Lead insert standard DIPS onto PW Board
 - Wave Solder (conventional)
 - Clean and lead trim
 - Invert PW Board
 - Dispense solder paste on SMD pads
 - Dispense drop of adhesive on SMD sites (optional for smaller components)
 - Pick and place SMDs onto board
 - Bake/Cure
 - Invert board to rest on raised fixture
 - Vapor/IR reflow soldering
 - Clean
- B) Vapor/IR reflow solder then Wave Solder.
 1. Components on the same side of PW Board.
 - Solder paste screened on SMD side of Printed Wire Board
 - Pick and place SMDs
 - Bake
 - Vapor/IR reflow
 - Lead insert on same side as SMDs
 - Wave solder
 - Clean and trim underside of PCB

- C) Vapor/IR reflow only.
 1. Components on the same side of PW Board.
 - Trim and form standard DIPS in "gull wing" configuration
 - Solder paste screened on PW Board
 - Pick and place SMDs and DIPS
 - Bake
 - Vapor/IR reflow
 - Clean
 2. Components on opposite sides of PW Board.
 - Solder paste screened on SMD-side of Printed Wire Board
 - Adhesive dispensed at central location of each component
 - Pick and place SMDs
 - Bake
 - Solder paste screened on all pads on DIP-side or alternatively apply solder rings (performs) on leads
 - Lead insert DIPS
 - Vapor/IR reflow
 - Clean and lead trim
- D) Wave Soldering Only
 1. Components on opposite sides of PW Board.
 - Adhesive dispense on SMD side of PW Board
 - Pick and place SMDs
 - Cure adhesive
 - Lead insert top side with DIPS
 - Wave solder with SMDs down and into solder bath
 - Clean and lead trim

All of the above assembly procedures can be divided into three categories for I.C. Reliability considerations:

- 1) Components are subjected to both a vapor phase/IR heat cycle then followed by a wave-solder heat cycle or vice versa.
- 2) Components are subjected to only a vapor phase/IR heat cycle.
- 3) Components are subjected to wave-soldering only and SMDs are subjected to heat by immersion into a solder pot.

Of these three categories, the last is the most severe regarding heat treatment to a semiconductor device. However, note that semiconductor molded packages generally possess a coating of solder on their leads as a final finish for solderability and protection of base leadframe material. Most semiconductor manufacturers solder-plate the component leads, while others perform hot solder dip. In the latter case the packages may be subjected to total immersion into a hot solder bath under controlled conditions (manual operation) or be partially immersed while in a 'pallet' where automatic wave or DIP soldering processes are used. It is, therefore, possible to subject SMDs to solder heat under certain conditions and not cause catastrophic failures.

Wave Soldering of Surface Mount Components (Continued)

THERMAL CHARACTERISTICS OF MOLDED INTEGRATED CIRCUITS

Since Plastic DIPs and SMDs are encapsulated with a thermoset epoxy, the thermal characteristics of the material generally correspond to a TMA (Thermo-Mechanical Analysis) graph. The critical parameters are (a) its Linear thermal expansion characteristics and (b) its glass transition temperature after the epoxy has been fully cured. A typical TMA graph is illustrated in *Figure 1*. Note that the epoxy changes to a higher thermal expansion once it is subjected to temperatures exceeding its glass transition temperature. Metals (as used on lead frames, for example) do not have this characteristic and generally will have a consistent Linear thermal expansion over the same temperature range.

In any good reliable plastic package, the choice of lead frame material should be such to match its thermal expansion properties to that of the encapsulating epoxy. In the event that there is a mismatch between the two, stresses can build up at the interface of the epoxy and metal. There now exists a tendency for the epoxy to separate from the metal lead frame in a manner similar to that observed on bi-metallic thermal range.

In most cases when the packages are kept at temperatures below their glass transition, there is a small possibility of separation at the epoxy-metal interface. However, if the package is subjected to temperature above its glass-transition temperature, the epoxy will begin to expand much faster than the metal and the probability of separation is greatly increased.

CONVENTIONAL WAVE-SOLDERING

Most wave-soldering operations occur at temperatures between 240–260°C. Conventional epoxies for encapsulation have glass-transition temperature between 140–170°C. An I.C. directly exposed to these temperatures risks its long term functionality due to epoxy/metal separation.

Fortunately, there are factors that can reduce that element of risk:

- 1) The PW board has a certain amount of heat-sink effect and tends to shield the components from the temperature of the solder (if they were placed on the top side of the board). In actual measurements, DIPs achieve a temperature between 120–150°C in a 5-second pass over the solder. This accounts for the fact that DIPs mounted in the conventional manner are reliable.
- 2) In conventional soldering, only the tip of each lead in a DIP would experience the solder temperature because the epoxy and die are standing above the PW board and out of the solder bath.

EFFECT ON PACKAGE PERFORMANCE BY EPOXY-METAL SEPARATION

In wave soldering, it is necessary to use fluxes to assist the solderability of the components and PW boards. Some facilities may even process the boards and components through some form of acid cleaning prior to the soldering temperature. If separation occurs, the flux residues and acid residues (which may be present owing to inadequate cleaning) will be forced into the package mainly by capillary action as the residues move away from the solder heat source. Once the package is cooled, these contaminants are now trapped within the package and are available to diffuse with moisture from the epoxy over time. It should be noted that electrical tests performed immediately after soldering generally will give no indication of this potential problem. In any case, the end result will be corrosion of the chip metallization over time and premature failure of the device in the field.

VAPOR PHASE/IR REFLOW SOLDERING

In both vapor phase and IR reflow soldering, the risk of separation between epoxy/metal can also be high. Operating temperatures are 215°C (vapor phase) or 240°C (IR) and duration may also be longer (30 sec–60 sec). On the same theoretical basis, there should also be separation. However, in both these methods, solder paste is applied to the pads of the boards; no fluxes are used. Also, the devices are not immersed into the hot solder. This reduces the possibility of solder forcing itself into the epoxy-lead frame interface. Furthermore, in the vapor phase system, the soldering environment is "oxygen-free" and considered "contaminant free". Being so, it could be visualized that as far as reliability with respect to corrosion, both of these methods are advantageous over wave soldering.

BIAS MOISTURE TEST

A bias moisture test was designed to determine the effect on package performance. In this test, the packages are pressured in a stream chamber to accelerate penetration of moisture into the package. An electrical bias is applied on the device. Should there be any contaminants trapped within the package, the moisture will quickly form an electrolyte and cause the electrodes (which are the lead fingers), the gold wire and the aluminum bond-pads of the silicon device to corrode. The aluminum bond-pads, being the weakest link of the system, will generally be the first to fail.

This proprietary accelerated bias/moisture pressure-test is significant in relation to the life test condition at 85°C and

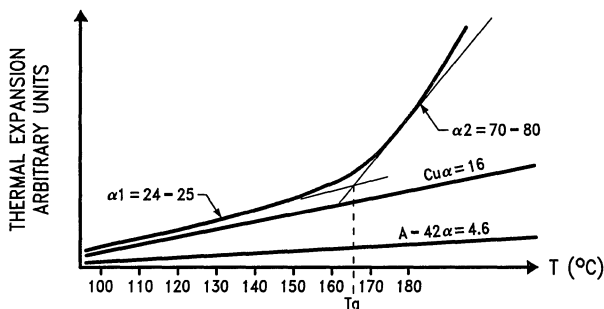


FIGURE 1. Thermal Expansion and Glass Transition Temperature

TL/XX/0026-12

Wave Soldering of Surface Mount Components (Continued)

85% relative humidity. Once cycle of approximately 100 hours has been shown to be equivalent to 2000 hours in the 85/85 condition. Should the packages start to fail within the first cycle in the test, it is anticipated that the boards with these components in the harsh operating environment (85°C/85% RH) will experience corrosion and eventual electrical failures within its first 2000 hours of operation.

Whether this is significant to a circuit board manufacturer will obviously be dependent on the products being manufactured and the workmanship or reliability standards. Generally in systems with a long warranty and containing many components, it is advisable both on a reputation and cost basis to have the most reliable parts available.

TEST RESULTS

The comparison of vapor phase and wave-soldering upon the reliability of molded Small-Outline packages was performed using the bias moisture test (see Table IV). It is clearly seen that vapor phase reflow soldering gave more consistent results. Wave-soldering results were based on manual operation giving variations in soldering parameters such as temperature and duration.

TABLE IV. Vapor Phase vs. Wave Solder

1. Vapor phase (60 sec. exposure @ 215°C)
= 9 failures/1723 samples
= 0.5% (average over 32 sample lots)
2. Wave solder (2 sec total immersion @ 260°C)
= 16 failures/1201 samples
= 1.3% (average over 27 sample lots)
Package: SO-14 lead
Test: Bias moisture test 85% R.H., 85°C for 2000 hours
Device: LM324M

In Table V we examine the tolerance of the Small-Outlined (SOIC) package to varying immersion time in a hot solder pot. SO-14 lead molded packages were subjected to the bias moisture test after being treated to the various soldering conditions and repeated four (4) times. End point was an electrical test after an equivalent of 4000 hours 85/85 test. Results were compared for packages by itself against packages which were surface-mounted onto a FR-4 printed wire board.

**TABLE V. Summary of Wave Solder Results
(85% R.H./85°C Bias Moisture Test, 2000 hours)
(# Failures/Total Tested)**

	Unmounted	Mounted
Control/Vapor Phase 15 sec @ 215°C	0/114	0/84
Solder Dip 2 sec @ 260°C	2/144 (1.4%)	0/85
Solder Dip 4 sec @ 260°C	—	0/83
Solder Dip 6 sec @ 260°C	13/248 (5.2%)	1/76 (1.3%)
Solder Dip 10 sec @ 260°C	14/127 (11.0%)	3/79 (3.8%)
Package: SO-14 lead		
Device: LM324M		

Since the package is of very small mass and experiences a rather sharp thermal shock followed by stresses created by the mismatch in expansion, the results show the package being susceptible to failures after being immersed in excess of 6 seconds in a solder pot. In the second case where the packages were mounted, the effect of severe temperature excursion was reduced. In the second case where the packages were mounted, the effect of severe temperature excursion was reduced. In any case, because of the repeated treatment, the package had failures when subjected in excess of 6 seconds immersion in hot solder. The safety margin is therefore recommended as maximum 4 seconds immersion. If packages were immersed longer than 4 seconds, there is a probable chance of finding some long term reliability failures even though the immediate electrical test data could be acceptable.

Finally, Table VI examines the bias moisture test performed on surface mount (SOIC) components manufactured by various semiconductor houses. End point was an electrical test after an equivalent of 6000 hours in a 85/85 test. Failures were analyzed and corrosion was checked for in each case to detect flaws in package integrity.

**TABLE VI. U.S. Manufacturers Integrated Circuits
Reliability in Various Solder Environments
(# Failure/Total Tested)**

Package SO-8	Vapor Phase 30 sec	Wave Solder 2 sec	Wave Solder 4 sec	Wave Solder 6 sec	Wave Solder 10 sec
Manuf A	8/30*	1/30*	0/30	12/30*	16/30*
Manuf B	2/30*	8/30*	2/30*	22/30*	20/30*
Manuf C	0/30	0/29	0/29	0/30	0/30
Manuf D	1/30*	0/30	12/30*	14/30*	2/30*
Manuf E	1/30**	0/30	0/30	0/30	0/30
Manuf F	0/30	0/30	0/30	0/30	0/30
Manuf G	0/30	0/30	0/30	0/30	0/30

*Corrosion-failures

**No Visual Defects—Non-corrosion failures

Test: Accelerated Bias Moisture Test; 85% R.H./85°C, 6000 equivalent hours.

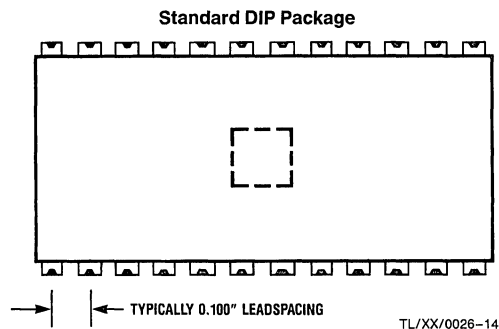
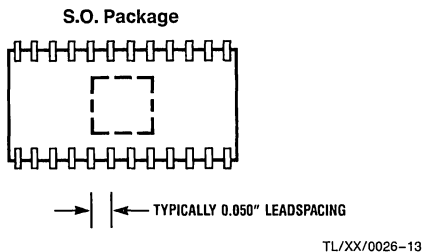
SUMMARY

Based on the results presented, it is noted that surface-mounted components are as reliable as standard molded DIP packages. Whereas DIPs were never processed by being totally immersed in a hot solder wave during printed circuit board soldering, surface mounted components such as SOICs (Small Outline) are expected to survive a total immersion in the hot solder in order to capitalize on maximum population on boards. Being constructed from a thermoset plastic of relatively low Tg compared to the soldering temperature, the ability of the package to survive is dependent on the time of immersion and also the cleanliness of material. The results indicate that one should limit the immersion time of package in the solder wave to a maximum of 4 seconds in order to truly duplicate the reliability of a DIP. As the package size is reduced, as in a SO-8 lead, the requirement becomes even more critical. This is shown by the various manufacturers' performance. Results indicate there is room for improvement since not all survived the hot solder immersion without compromise to lower reliability.

Small Outline (SO) Package Surface Mounting Methods—Parameters and Their Effect on Product Reliability

The SO (small outline) package has been developed to meet customer demand for ever-increasing miniaturization and component density.

COMPONENT SIZE COMPARISON



Because of its small size, reliability of the product assembled in SO packages needs to be carefully evaluated.

SO packages at National were internally qualified for production under the condition that they be of comparable reliability performance to a standard dual in line package under all accelerated environmental tests. *Figure A* is a summary of accelerated bias moisture test performance on 30V bipolar and 15V CMOS product assembled in SO and DIP (control) packages.

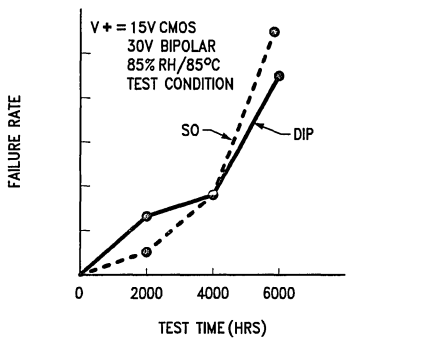


FIGURE A

In order to achieve reliability performance comparable to DIPs—SO packages are designed and built with materials and processes that effectively compensate for their small size.

All SO packages tested on 85%RA, 85°C were assembled on PC conversion boards using vapor-phase reflow soldering. With this approach we are able to measure the effect of surface mounting methods on reliability of the process. As illustrated in *Figure A* no significant difference was detected between the long term reliability performance of surface mounted S.O. packages and the DIP control product for up to 6000 hours of accelerated 85%/85°C testing.

SURFACE-MOUNT PROCESS FLOW

The standard process flowcharts for basic surface-mount operation and mixed-lead insertion/surface-mount operations, are illustrated on the following pages.

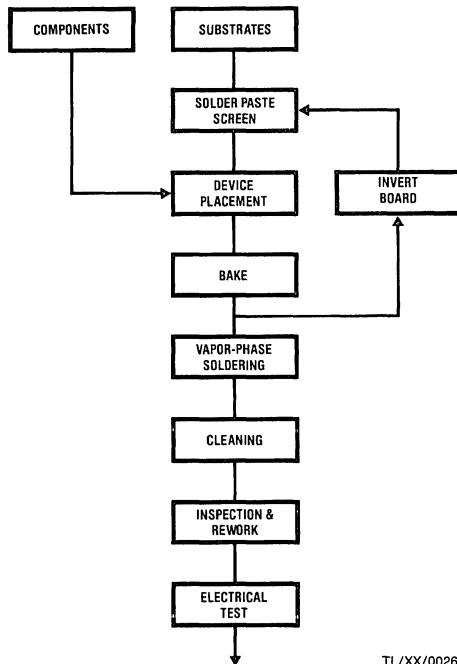
Usual variations encountered by users of SO packages are:

- Single-sided boards, surface-mounted components only.
- Single-sided boards, mixed-lead inserted and surface-mounted components.
- Double-sided boards, surface-mounted components only.
- Double-sided boards, mixed-lead inserted and surface-mounted components.

In consideration of these variations, it became necessary for users to utilize techniques involving wave soldering and adhesive applications, along with the commonly-used vapor-phase solder reflow soldering technique.

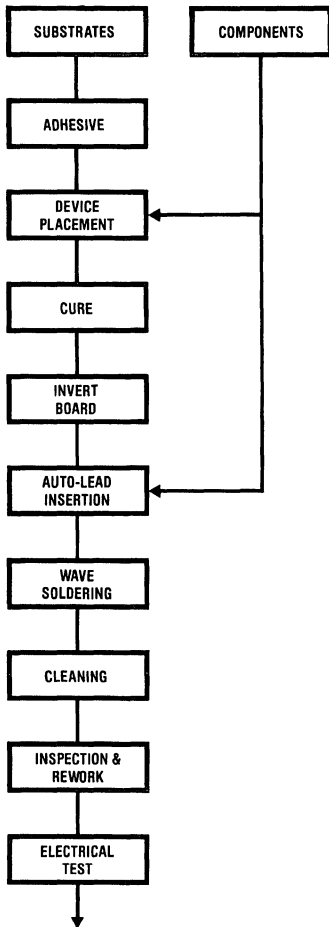
PRODUCTION FLOW

Basic Surface-Mount Production Flow



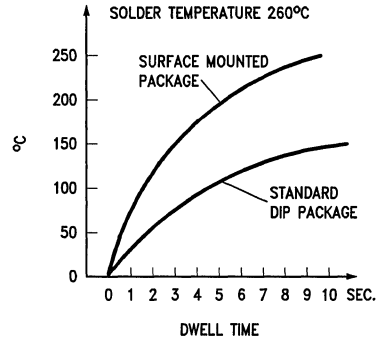
TL/XX/0026-16

Mixed Surface-Mount and Axial-Leaded Insertion Components Production Flow



TL/XX/0026-17

Thermal stress of the packages during surface-mounting processing is more severe than during standard DIP PC board mounting processes. *Figure B* illustrates package temperature versus wave soldering dwell time for surface mounted packages (components are immersed into the molten solder) and the standard DIP wave soldering process. (Only leads of the package are immersed into the molten solder).



TL/XX/0026-18

FIGURE B

For an ideal package, the thermal expansion rate of the encapsulant should match that of the leadframe material in order for the package to maintain mechanical integrity during the soldering process. Unfortunately, a perfect matchup of thermal expansion rates with most presently used packaging materials is scarce. The problem lies primarily with the epoxy compound.

Normally, thermal expansion rates for epoxy encapsulant and metal lead frame materials are linear and remain fairly close at temperatures approaching 160°C, *Figure C*. At lower temperatures the difference in expansion rate of the two materials is not great enough to cause interface separation. However, when the package reaches the glass-transition temperature (T_g) of epoxy (typically 160–165°C), the thermal expansion rate of the encapsulant increases sharply, and the material undergoes a transition into a plastic state. The epoxy begins to expand at a rate three times or more greater than the metal leadframe, causing a separation at the interface.

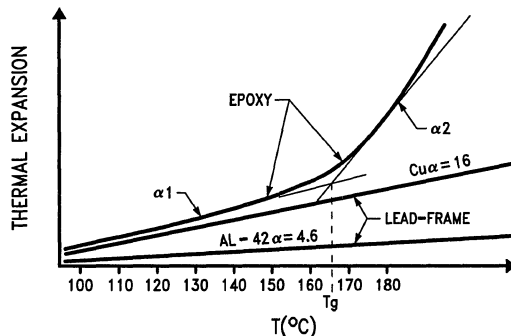


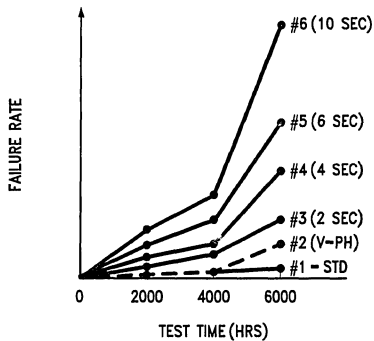
FIGURE C

TL/XX/0026-19

When this happens during a conventional wave soldering process using flux and acid cleaners, process residues and even solder can enter the cavity created by the separation and become entrapped when the material cools. These contaminants can eventually diffuse into the interior of the package, especially in the presence of moisture. The result is die contamination, excessive leakage, and even catastrophic failure. Unfortunately, electrical tests performed immediately following soldering may not detect potential flaws. Most soldering processes involve temperatures ranging up to 260°C, which far exceeds the glass-transition temperature of epoxy. Clearly, circuit boards containing SMD packages require tighter process controls than those used for boards populated solely by DIPs.

Figure D is a summary of accelerated bias moisture test performance on the 30V bipolar process.

- Group 1 — Standard DIP package
- Group 2 — SO packages vapor-phase reflow soldered on PC boards
- Group 3-6 SO packages wave soldered on PC boards
- Group 3 — dwell time 2 seconds
- 4 — dwell time 4 seconds
- 5 — dwell time 6 seconds
- 6 — dwell time 10 seconds



TL/XX/0026-20

FIGURE D

It is clear based on the data presented that SO packages soldered onto PC boards with the vapor phase reflow process have the best long term bias moisture performance and this is comparable to the performance of standard DIP packages. The key advantage of reflow soldering methods is the clean environment that minimized the potential for contamination of surface mounted packages, and is preferred for the surface-mount process.

When wave soldering is used to surface mount components on the board, the dwell time of the component under molten solder should be no more than 4 seconds, preferably under 2 seconds in order to prevent damage to the component. Non-Halide, or (organic acid) fluxes are highly recommended.

PICK AND PLACE

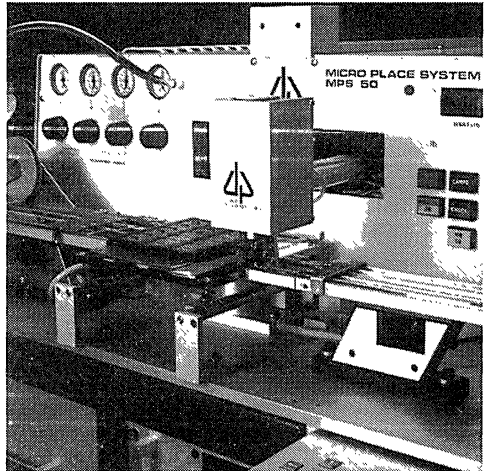
The choice of automatic (all generally programmable) pick-and-place machines to handle surface mounting has grown considerably, and their selection is based on individual needs and degree of sophistication.

The basic component-placement systems available are classified as:

- (a) In-line placement
 - Fixed placement stations
 - Boards indexed under head and respective components placed
- (b) Sequential placement
 - Either a X-Y moving table system or a θ , X-Y moving pickup system used
 - Individual components picked and placed onto boards
- (c) Simultaneous placement
 - Multiple pickup heads
 - Whole array of components placed onto the PCB at the same time
- (d) Sequential/simultaneous placement
 - X-Y moving table, multiple pickup heads system
 - Components placed on PCB by successive or simultaneous actuation of pickup heads

The SO package is treated almost the same as surface-mount, passive components requiring correct orientation in placement on the board.

Pick and Place Action



TL/XX/0026-21

BAKE

This is recommended, despite claims made by some solder paste suppliers that this step be omitted.

The functions of this step are:

- Holds down the solder globules during subsequent reflow soldering process and prevents expulsion of small solder balls.
- Acts as an adhesive to hold the components in place during handling between placement to reflow soldering.
- Holds components in position when a double-sided surface-mounted board is held upside down going into a vapor-phase reflow soldering operation.
- Removes solvents which might otherwise contaminate other equipment.
- Initiates activator cleaning of surfaces to be soldered.
- Prevents moisture absorption.

The process is moreover very simple. The usual schedule is about 20 minutes in a 65°C–95°C (dependent on solvent system of solder paste) oven with adequate venting. Longer bake time is not recommended due to the following reasons:

- The flux will degrade and affect the characteristics of the paste.
- Solder globules will begin to oxidize and cause solderability problems.
- The paste will creep and after reflow, may leave behind residues between traces which are difficult to remove and vulnerable to electro-migration problems.

REFLOW SOLDERING

There are various methods for reflowing the solder paste, namely:

- Hot air reflow
- Infrared heating (furnaces)
- Convectional oven heating
- Vapor-phase reflow soldering
- Laser soldering

For SO applications, hot air reflow/infrared furnace may be used for low-volume production or prototype work, but vapor-phase soldering reflow is more efficient for consistency and speed. Oven heating is not recommended because of "hot spots" in the oven and uneven melting may result. Laser soldering is more for specialized applications and requires a great amount of investment.

HOT GAS REFLOW/INFRARED HEATING

A hand-held or table-mount air blower (with appropriate orifice mask) can be used.

The boards are preheated to about 100°C and then subjected to an air jet at about 260°C. This is a slow process and results may be inconsistent due to various heat-sink properties of passive components.

Use of an infrared furnace is the next step to automating the concept, except that the heating is promoted by use of IR lamps or panels. The main objection to this method is that certain materials may heat up at different rates under IR radiation and may result in damage to these components (usually sockets and connectors). This could be minimized by using far-infrared (non-focused) system.

VAPOR-PHASE REFLOW SOLDERING

Currently the most popular and consistent method, vapor-phase soldering utilizes a fluorinert fluid with excellent heat-transfer properties to heat up components until the solder paste reflows. The maximum temperature is limited by the vapor temperature of the fluid.

The commonly used fluids (supplied by 3M Corp) are:

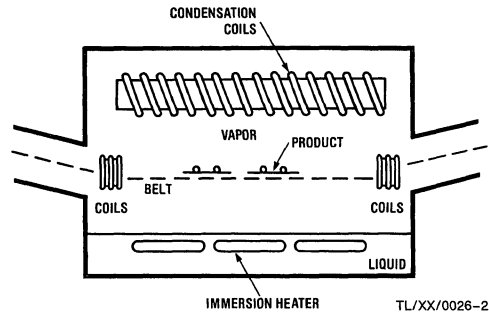
- FC-70, 215°C vapor (most applications) or FX-38
- FC-71, 253°C vapor (low-lead or tin-plate)

HTC, Concord, CA, manufactures equipment that utilizes this technique, with two options:

- Batch systems, where boards are lowered in a basket and subjected to the vapor from a tank of boiling fluid.
- In-line conveyORIZED systems, where boards are placed onto a continuous belt which transports them into a concealed tank where they are subjected to an environment of hot vapor.

Dwell time in the vapor is generally on the order of 15–30 seconds (depending on the mass of the boards and the loading density of boards on the belt).

In-Line ConveyORIZED Vapor-Phase Soldering



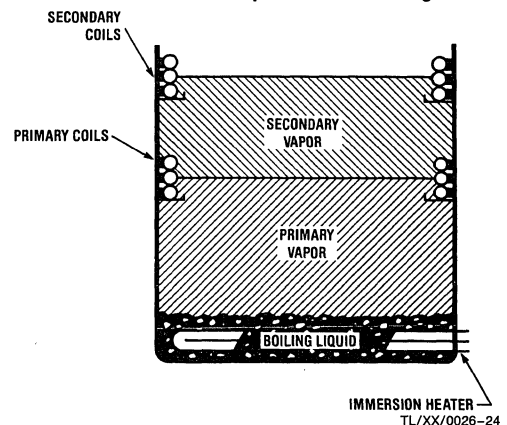
The question of thermal shock is asked frequently because of the relatively sharp increase in component temperature from room temperature to 215°C. SO packages mounted on representative boards have been tested and have shown little effect on the integrity of the packages. Various packages, such as cerdips, metal cans and TO-5 cans with glass seals, have also been tested.

Vapor-Phase Furnace

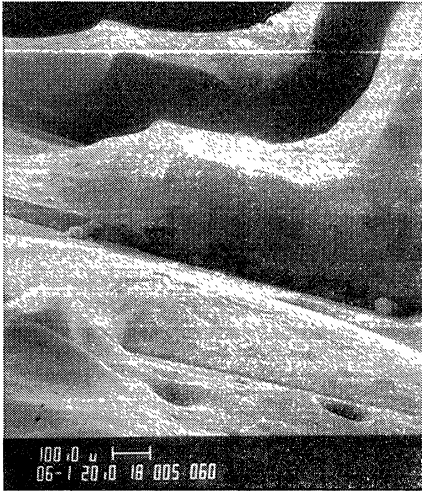


TL/XX/0026-23

Batch-Fed Production Vapor-Phase Soldering Unit

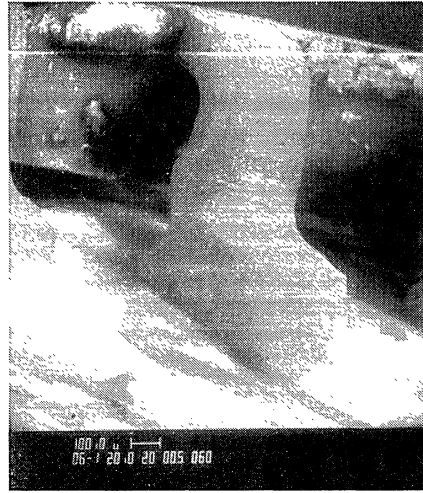


Solder Joints on a SO-14 Package on PCB



TL/XX/0026-25

Solder Joints on a SO-14 Package on PCB



TL/XX/0026-26

PRINTED CIRCUIT BOARD

The SO package is molded out of clean, thermoset plastic compound and has no particular compatibility problems with most printed circuit board substrates.

The package can be reliably mounted onto substrates such as:

- G10 or FR4 glass/resin
- FR5 glass/resin systems for high-temperature applications
- Polyimide boards, also high-temperature applications
- Ceramic substrates

General requirements for printed circuit boards are:

- Mounting pads should be solder-plated whenever applicable.
- Solder masks are commonly used to prevent solder bridging of fine lines during soldering.

The mask also protects circuits from processing chemical contamination and corrosion.

If coated over pre-tinned traces, residues may accumulate at the mask/trace interface during subsequent reflow, leading to possible reliability failures.

Recommended application of solder resist on bare, clean traces prior to coating exposed areas with solder.

General requirements for solder mask:

- Good pattern resolution.
- Complete coverage of circuit lines and resistance to flaking during soldering.
- Adhesion should be excellent on substrate material to keep off moisture and chemicals.
- Compatible with soldering and cleaning requirements.

SOLDER PASTE SCREEN PRINTING

With the initial choice of printed circuit lithographic design and substrate material, the first step in surface mounting is the application of solder paste.

The typical lithographic "footprints" for SO packages are illustrated below. Note that the 0.050" lead center-center spacing is not easily managed by commercially-available air pressure, hand-held dispensers.

Using a stainless-steel, wire-mesh screen stenciled with an emulsion image of the substrate pads is by far the most common and well-tried method. The paste is forced through the screen by a V-shaped plastic squeegee in a sweeping manner onto the board placed beneath the screen.

The setup for SO packages has no special requirement from that required by other surface-mounted, passive components. Recommended working specifications are:

- Use stainless-steel, wire-mesh screens, #80 or #120, wire diameter 2.6 mils. Rule of thumb: mesh opening should be approximately 2.5–5 times larger than the average particle size of paste material.
- Use squeegee of Durometer 70.
- Experimentation with squeegee travel speed is recommended, if available on machine used.
- Use solder paste of mesh 200–325.
- Emulsion thickness of 0.005" usually used to achieve a solder paste thickness (wet) of about 0.008" typical.
- Mesh pattern should be 90 degrees, square grid.
- Snap-off height of screen should not exceed $\frac{1}{8}$ ", to avoid damage to screens and minimize distortion.

SOLDER PASTE

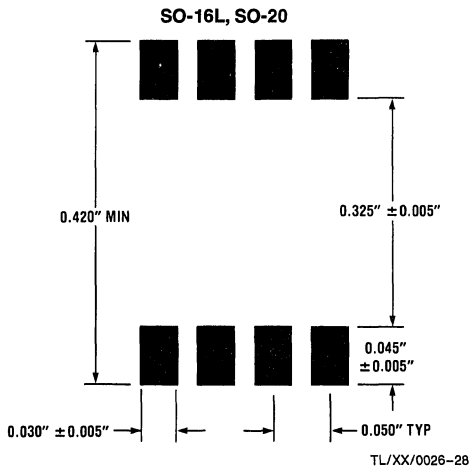
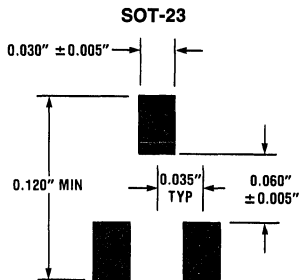
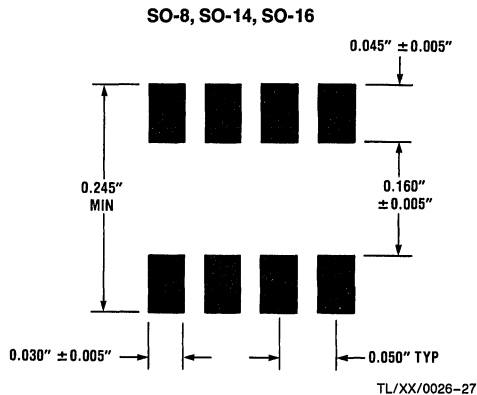
Selection of solder paste tends to be confusing, due to numerous formulations available from various manufacturers. In general, the following guidelines are sufficient to qualify a particular paste for production:

- Particle sizes (see photographs below). Mesh 325 (approximately 45 microns) should be used for general purposes, while larger (solder globules) particles are preferred for leadless components (LCC). The larger particles can easily be used for SO packages.

- Uniform particle distribution. Solder globules should be spherical in shape with uniform diameters and minimum amount of elongation (visual under 100/200 × magnification). Uneven distribution causes uneven melting and subsequent expulsion of smaller solder balls away from their proper sites.

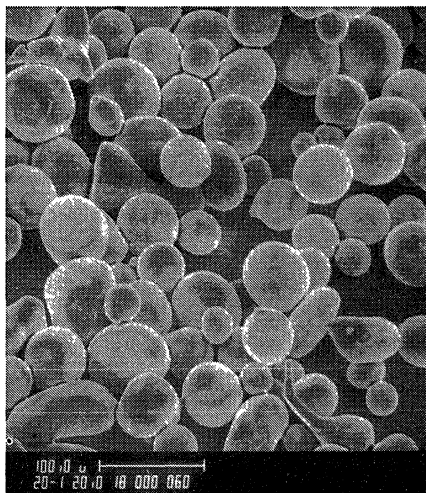
- Composition, generally 60/40 or 63/37 Sn/Pb. Use 62/36 Sn/Pb with 2% Ag in the presence of Au on the soldering area. This formulation reduces problems of metal leaching from soldering pads.
- RMA flux system usually used.
- Use paste with approximately 88–90% solids.

RECOMMENDED SOLDER PADS FOR SO PACKAGES



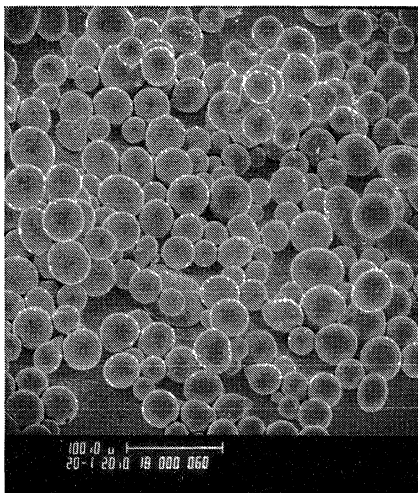
Comparison of Particle Size/Shape of Various Solder Pastes

200 × Alpha (62/36/2)



TL/XX/0026-30

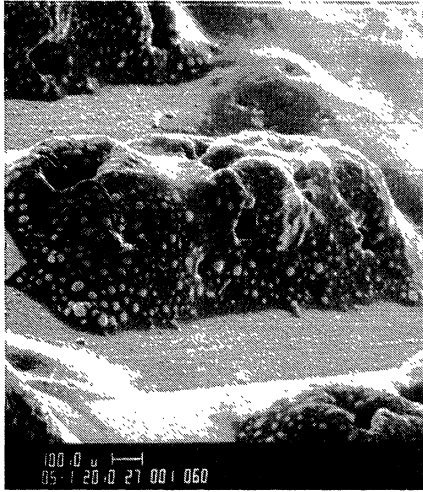
200 × Kester (63/37)



TL/XX/0026-31

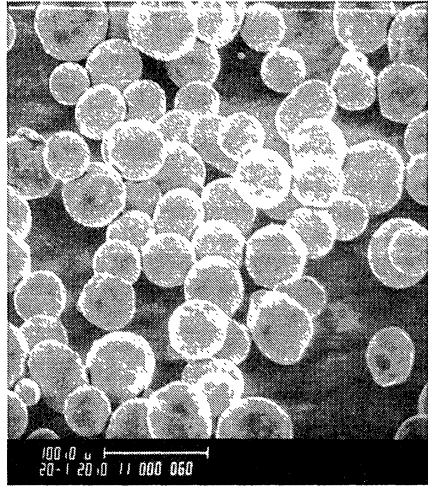
Comparison of Particle Size/Shape of Various Solder Pastes (Continued)

Solder Paste Screen on Pads



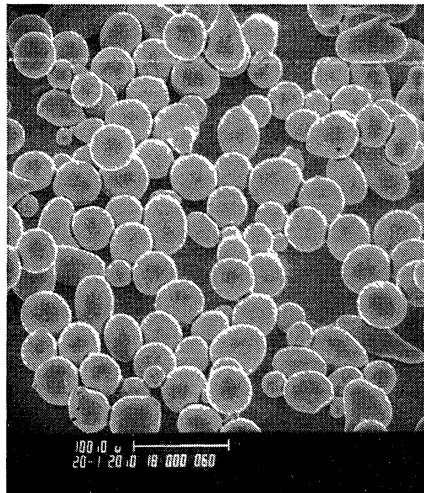
TL/XX/0026-32

200 × Fry Metal (63/37)



TL/XX/0026-33

200 ESL (63/37)



TL/XX/0026-34

CLEANING

The most critical process in surface mounting SO packages is in the cleaning cycle. The package is mounted very close to the surface of the substrate and has a tendency to collect residue left behind after reflow soldering.

Important considerations in cleaning are:

- Time between soldering and cleaning to be as short as possible. Residue should not be allowed to solidify on the substrate for long periods of time, making it difficult to dislodge.
- A low surface tension solvent (high penetration) should be employed. Solvents commercially available are:

Freon TMS (general purpose)
 Freon TE35/TP35 (cold-dip cleaning)
 Freon TES (general purpose)

It should also be noted that these solvents generally will leave the substrate surface hydrophobic (moisture repellent), which is desirable.

Prelete or 1,1,1-Trichloroethane
 Kester 5120/5121

- A defluxer system which allows the workpiece to be subjected to a solvent vapor, followed by a rinse in pure solvent and a high-pressure spray lance are the basic requirements for low-volume production.
- For volume production, a conveyORIZED, multiple hot solvent spray/jet system is recommended.
- Rosin, being a natural occurring material, is not readily soluble in solvents, and has long been a stumbling block to the cleaning process. In recent developments, synthetic flux (SA flux), which is readily soluble in Freon TMS solvent, has been developed. This should be explored where permissible.

The dangers of an inadequate cleaning cycle are:

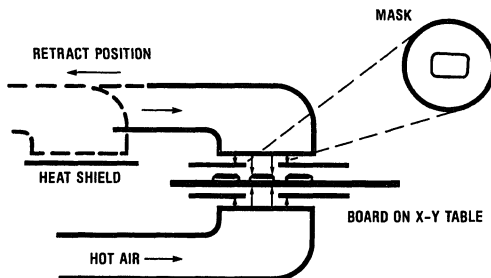
- Ion contamination, where ionic residue left on boards would cause corrosion to metallic components, affecting the performance of the board.
- Electro-migration, where ionic residue and moisture present on electrically-biased boards would cause dendritic growth between close spacing traces on the substrate, resulting in failures (shorts).

REWORK

Should there be a need to replace a component or re-align a previously disturbed component, a hot air system with appropriate orifice masking to protect surrounding components may be used.

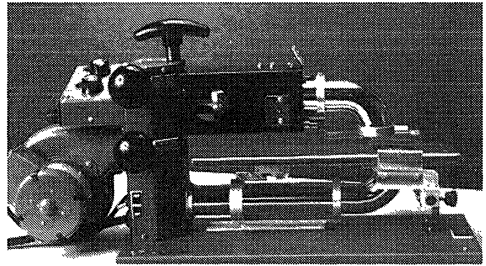
When rework is necessary in the field, specially-designed tweezers that thermally heat the component may be used to remove it from its site. The replacement can be fluxed at the

Hot-Air Solder Rework Station



TL/XX/0026-35

Hot-Air Rework Machine



TL/XX/0026-36

lead tips or, if necessary, solder paste can be dispensed onto the pads using a varimeter. After being placed into position, the solder is reflowed by a hot-air jet or even a standard soldering iron.

WAVE SOLDERING

In a case where lead insertions are made on the same board as surface-mounted components, there is a need to include a wave-soldering operation in the process flow.

Two options are used:

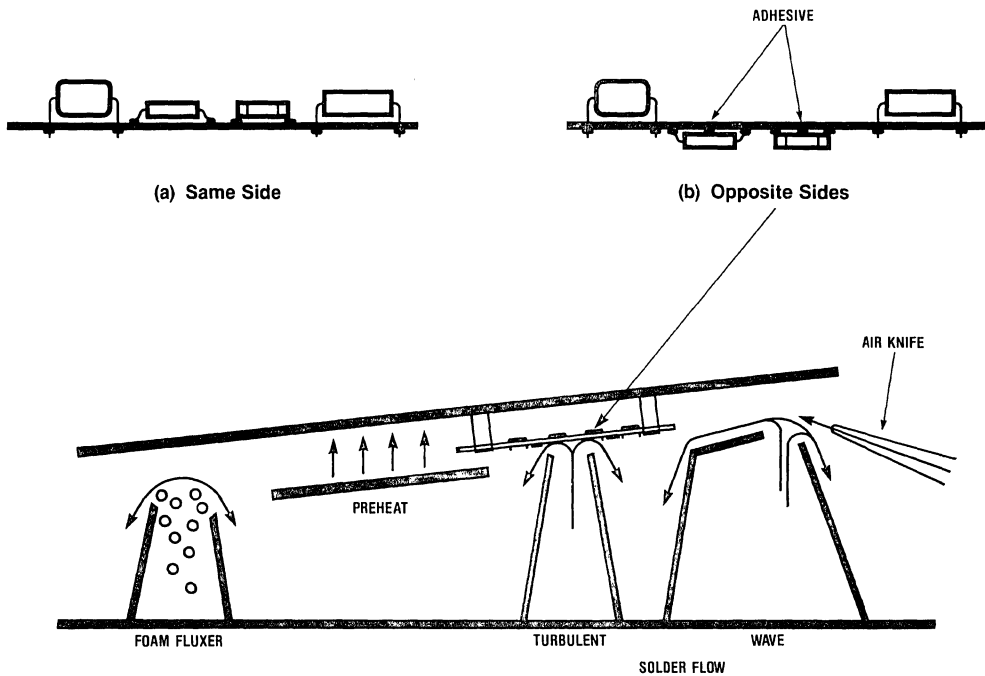
- Surface mounted components are placed and vapor phase reflowed before auto-insertion of remaining components. The board is carried over a standard wave-solder system and the underside of the board (only lead-inserted leads) soldered.
- Surface-mounted components are placed in position, but no solder paste is used. Instead, a drop of adhesive about 5 mils maximum in height with diameter not exceeding 25% width of the package is used to hold down the package. The adhesive is cured and then proceeded to auto-insertion on the reverse side of the board (surface-mounted side facing down). The assembly is then passed over a "dual wave" soldering system. Note that the surface-mounted components are immersed into the molten solder.

Lead trimming will pose a problem after soldering in the latter case, unless the leads of the insertion components are pre-trimmed or the board specially designed to localize certain areas for easy access to the trim blade.

The controls required for wave soldering are:

- Solder temperature to be 240–260°C. The dwell time of components under molten solder to be short (preferably kept under 2 seconds), to prevent damage to most components and semiconductor devices.
- RMA (Rosin Mildly Activated) flux or more aggressive OA (Organic Acid) flux are applied by either dipping or foam fluxing on boards prior to preheat and soldering. Cleaning procedures are also more difficult (aqueous, when OA flux is used), as the entire board has been treated by flux (unlike solder paste, which is more or less localized). Non-halide OA fluxes are highly recommended.
- Preheating of boards is essential to reduce thermal shock on components. Board should reach a temperature of about 100°C just before entering the solder wave.
- Due to the closer lead spacings (0.050" vs 0.100" for dual-in-line packages), bridging of traces by solder could occur. The reduced clearance between packages also causes "shadowing" of some areas, resulting in poor solder coverage. This is minimized by dual-wave solder systems.

Mixed Surface Mount and Lead Insertion



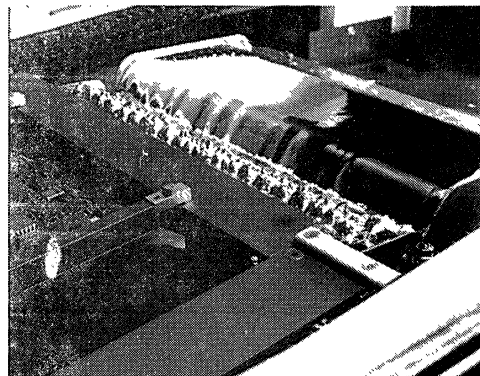
TL/XX/0026-37

A typical dual-wave system is illustrated below, showing the various stages employed. The first wave typically is in turbulence and given a transverse motion (across the motion of the board). This covers areas where "shadowing" occurs. A second wave (usually a broad wave) then proceeds to perform the standard soldering. The departing edge from the solder is such to reduce "icicles," and is still further reduced by an air knife placed close to the final soldering step. This air knife will blow off excess solder (still in the fluid stage) which would otherwise cause shorts (bridging) and solder bumps.

AQUEOUS CLEANING

- For volume production, a conveyerized system is often used with a heated recirculating spray wash (water temperature 130°C), a final spray rinse (water temperature 45–55°C), and a hot (120°C) air/air-knife drying section.
- For low-volume production, the above cleaning can be done manually, using several water rinses/tanks. Fast-drying solvents, like alcohols that are miscible with water, are sometimes used to help the drying process.
- Neutralizing agents which will react with the corrosive materials in the flux and produce material readily soluble in water may be used; the choice depends on the type of flux used.
- Final rinse water should be free from chemicals which are introduced to maintain the biological purity of the water. These materials, mostly chlorides, are detrimental to the assemblies cleaned because they introduce a fresh amount of ionizable material.

Dual Wave



TL/XX/0026-38

CONFORMAL COATING

Conformal coating is recommended for high-reliability PCBs to provide insulation resistance, as well as protection against contamination and degradation by moisture.

Requirements:

- Complete coating over components and solder joints.
- Thixotropic material which will not flow under the packages or fill voids, otherwise will introduce stress on solder joints on expansion.
- Compatibility and possess excellent adhesion with PCB material/components.
- Silicones are recommended where permissible in application.

SMD Lab Support

FUNCTIONS

Demonstration—Introduce first-time users to surface-mounting processes.

Service—Investigate problems experienced by users on surface mounting.

Reliability Builds—Assemble surface-mounted units for reliability data acquisition.

Techniques—Develop techniques for handling different materials and processes in surface mounting.

Equipment—In conjunction with equipment manufacturers, develop customized equipments to handle high density, new technology packages developed by National.

In-House Expertise—Availability of in-house expertise on semiconductor research/development to assist users on packaging queries.

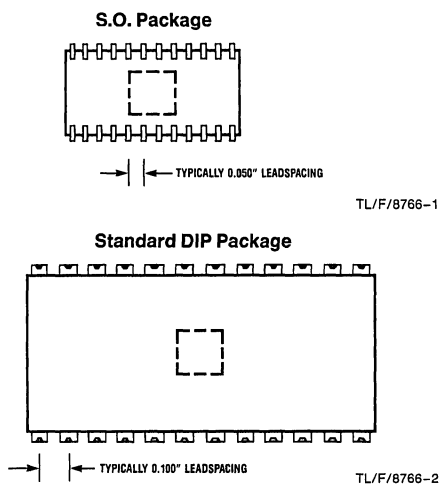


Small Outline (SO) Package Surface Mounting Methods-Parameters and Their Effect on Product Reliability

National Semiconductor
 Application Note 450
 Josip Huljev
 W. K. Boey

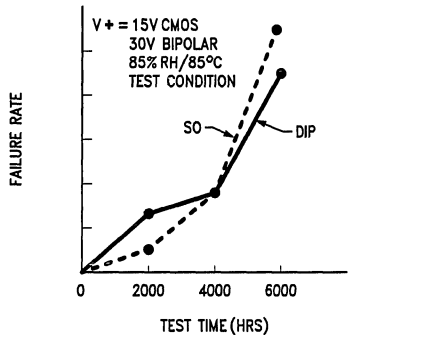
The SO (small outline) package has been developed to meet customer demand for ever-increasing miniaturization and component density.

COMPONENT SIZE COMPARISON



Because of its small size, reliability of the product assembled in SO packages needs to be carefully evaluated.

SO packages at National were internally qualified for production under the condition that they be of comparable reliability performance to a standard dual in line package under all accelerated environmental tests. *Figure A* is a summary of accelerated bias moisture test performance on 30V bipolar and 15V CMOS product assembled in SO and DIP (control) packages.



In order to achieve reliability performance comparable to DIPs—SO packages are designed and built with materials and processes that effectively compensate for their small size.

All SO packages tested on 85%RA, 85°C were assembled on PC conversion boards using vapor-phase reflow soldering. With this approach we are able to measure the effect of surface mounting methods on reliability of the process. As illustrated in *Figure A* no significant difference was detected between the long term reliability performance of surface mounted S.O. packages and the DIP control product for up to 6000 hours of accelerated 85%/85°C testing.

SURFACE-MOUNT PROCESS FLOW

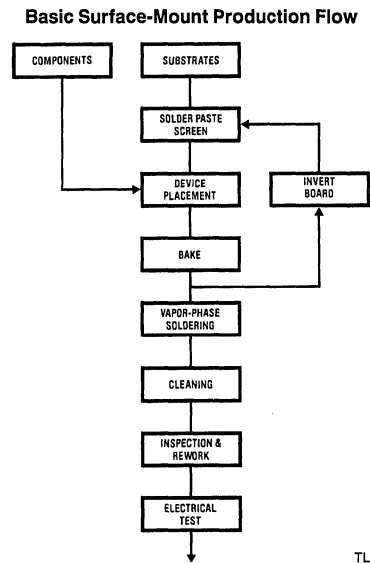
The standard process flowcharts for basic surface-mount operation and mixed-lead insertion/surface-mount operations, are illustrated on the following pages.

Usual variations encountered by users of SO packages are:

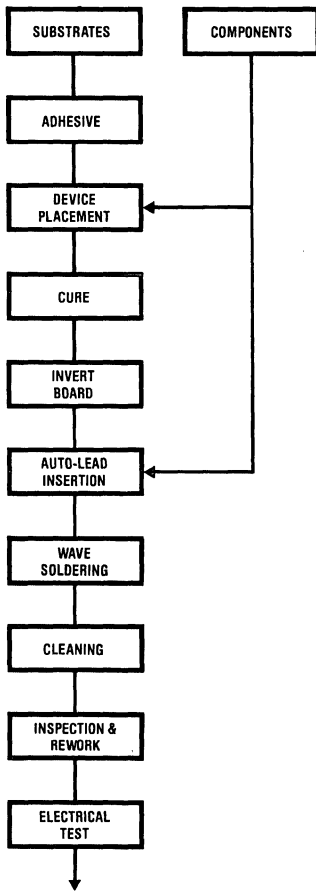
- Single-sided boards, surface-mounted components only.
- Single-sided boards, mixed-lead inserted and surface-mounted components.
- Double-sided boards, surface-mounted components only.
- Double-sided boards, mixed-lead inserted and surface-mounted components.

In consideration of these variations, it became necessary for users to utilize techniques involving wave soldering and adhesive applications, along with the commonly-used vapor-phase solder reflow technique.

PRODUCTION FLOW

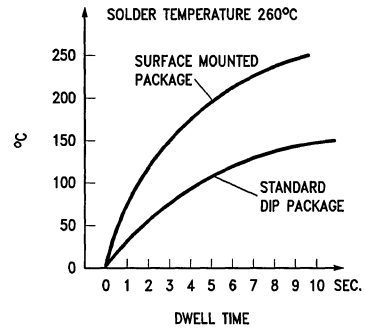


Mixed Surface-Mount and Axial-Leaded Insertion Components Production Flow



TL/F/8766-5

Thermal stress of the packages during surface-mounting processing is more severe than during standard DIP PC board mounting processes. *Figure B* illustrates package temperature versus wave soldering dwell time for surface mounted packages (components are immersed into the molten solder) and the standard DIP wave soldering process. (Only leads of the package are immersed into the molten solder).



TL/F/8766-6

FIGURE B

For an ideal package, the thermal expansion rate of the encapsulant should match that of the leadframe material in order for the package to maintain mechanical integrity during the soldering process. Unfortunately, a perfect matchup of thermal expansion rates with most presently used packaging materials is scarce. The problem lies primarily with the epoxy compound.

Normally, thermal expansion rates for epoxy encapsulant and metal lead frame materials are linear and remain fairly close at temperatures approaching 160°C, *Figure C*. At lower temperatures the difference in expansion rate of the two materials is not great enough to cause interface separation. However, when the package reaches the glass-transition temperature (T_g) of epoxy (typically 160–165°C), the thermal expansion rate of the encapsulant increases sharply, and the material undergoes a transition into a plastic state. The epoxy begins to expand at a rate three times or more greater than the metal leadframe, causing a separation at the interface.

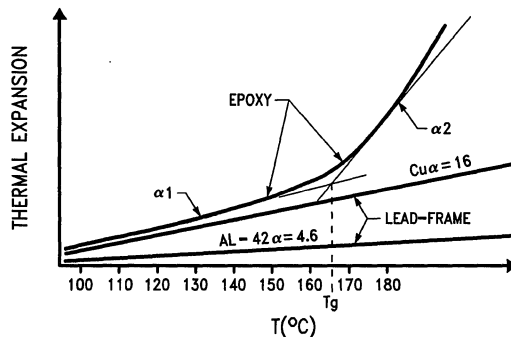


FIGURE C

TL/F/8766-26

When this happens during a conventional wave soldering process using flux and acid cleaners, process residues and even solder can enter the cavity created by the separation and become entrapped when the material cools. These contaminants can eventually diffuse into the interior of the package, especially in the presence of moisture. The result is die contamination, excessive leakage, and even catastrophic failure. Unfortunately, electrical tests performed immediately following soldering may not detect potential flaws. Most soldering processes involve temperatures ranging up to 260°C, which far exceeds the glass-transition temperature of epoxy. Clearly, circuit boards containing SMD packages require tighter process controls than those used for boards populated solely by DIPs.

Figure D is a summary of accelerated bias moisture test performance on the 30V bipolar process.

- Group 1 — Standard DIP package
- Group 2 — SO packages vapor-phase reflow soldered on PC boards
- Group 3-6 SO packages wave soldered on PC boards
- Group 3 — dwell time 2 seconds
- 4 — dwell time 4 seconds
- 5 — dwell time 6 seconds
- 6 — dwell time 10 seconds

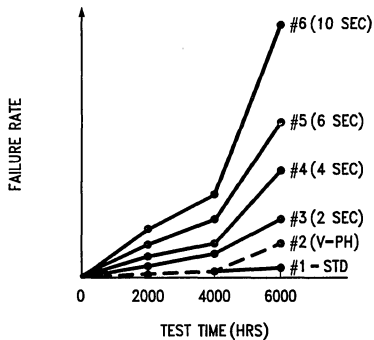


FIGURE D

TL/F/8766-7

It is clear based on the data presented that SO packages soldered onto PC boards with the vapor phase reflow process have the best long term bias moisture performance and this is comparable to the performance of standard DIP packages. The key advantage of reflow soldering methods is the clean environment that minimized the potential for contamination of surface mounted packages, and is preferred for the surface-mount process.

When wave soldering is used to surface mount components on the board, the dwell time of the component under molten solder should be no more than 4 seconds, preferably under 2 seconds in order to prevent damage to the component. Non-Halide, or (organic acid) fluxes are highly recommended.

PICK AND PLACE

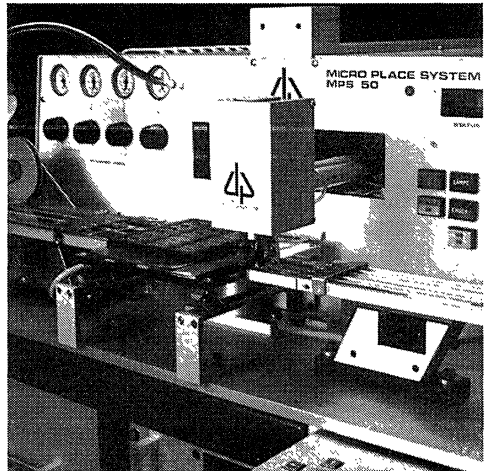
The choice of automatic (all generally programmable) pick-and-place machines to handle surface mounting has grown considerably, and their selection is based on individual needs and degree of sophistication.

The basic component-placement systems available are classified as:

- (a) In-line placement
 - Fixed placement stations
 - Boards indexed under head and respective components placed
- (b) Sequential placement
 - Either a X-Y moving table system or a θ , X-Y moving pickup system used
 - Individual components picked and placed onto boards
- (c) Simultaneous placement
 - Multiple pickup heads
 - Whole array of components placed onto the PCB at the same time
- (d) Sequential/simultaneous placement
 - X-Y moving table, multiple pickup heads system
 - Components placed on PCB by successive or simultaneous actuation of pickup heads

The SO package is treated almost the same as surface-mount, passive components requiring correct orientation in placement on the board.

Pick and Place Action



TL/F/8766-8

BAKE

This is recommended, despite claims made by some solder paste suppliers that this step be omitted.

The functions of this step are:

- Holds down the solder globules during subsequent reflow soldering process and prevents expulsion of small solder balls.
- Acts as an adhesive to hold the components in place during handling between placement to reflow soldering.
- Holds components in position when a double-sided surface-mounted board is held upside down going into a vapor-phase reflow soldering operation.
- Removes solvents which might otherwise contaminate other equipment.
- Initiates activator cleaning of surfaces to be soldered.
- Prevents moisture absorption.

The process is moreover very simple. The usual schedule is about 20 minutes in a 65°C–95°C (dependent on solvent system of solder paste) oven with adequate venting. Longer bake time is not recommended due to the following reasons:

- The flux will degrade and affect the characteristics of the paste.
- Solder globules will begin to oxidize and cause solderability problems.
- The paste will creep and after reflow, may leave behind residues between traces which are difficult to remove and vulnerable to electro-migration problems.

REFLOW SOLDERING

There are various methods for reflowing the solder paste, namely:

- Hot air reflow
- Infrared heating (furnaces)
- Convectional oven heating
- Vapor-phase reflow soldering
- Laser soldering

For SO applications, hot air reflow/infrared furnace may be used for low-volume production or prototype work, but vapor-phase soldering reflow is more efficient for consistency and speed. Oven heating is not recommended because of "hot spots" in the oven and uneven melting may result. Laser soldering is more for specialized applications and requires a great amount of investment.

HOT GAS REFLOW/INFRARED HEATING

A hand-held or table-mount air blower (with appropriate orifice mask) can be used.

The boards are preheated to about 100°C and then subjected to an air jet at about 260°C. This is a slow process and results may be inconsistent due to various heat-sink properties of passive components.

Use of an infrared furnace is the next step to automating the concept, except that the heating is promoted by use of IR lamps or panels. The main objection to this method is that certain materials may heat up at different rates under IR radiation and may result in damage to these components (usually sockets and connectors). This could be minimized by using far-infrared (non-focused) system.

VAPOR-PHASE REFLOW SOLDERING

Currently the most popular and consistent method, vapor-phase soldering utilizes a fluoroinert fluid with excellent heat-transfer properties to heat up components until the solder paste reflows. The maximum temperature is limited by the vapor temperature of the fluid.

The commonly used fluids (supplied by 3M Corp) are:

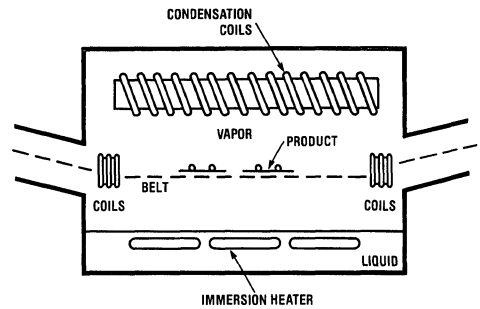
- FC-70, 215°C vapor (most applications) or FX-38
- FC-71, 253°C vapor (low-lead or tin-plate)

HTC, Concord, CA, manufactures equipment that utilizes this technique, with two options:

- Batch systems, where boards are lowered in a basket and subjected to the vapor from a tank of boiling fluid.
- In-line conveyorized systems, where boards are placed onto a continuous belt which transports them into a concealed tank where they are subjected to an environment of hot vapor.

Dwell time in the vapor is generally on the order of 15–30 seconds (depending on the mass of the boards and the loading density of boards on the belt).

In-Line Conveyorized Vapor-Phase Soldering



TL/F/8766-9

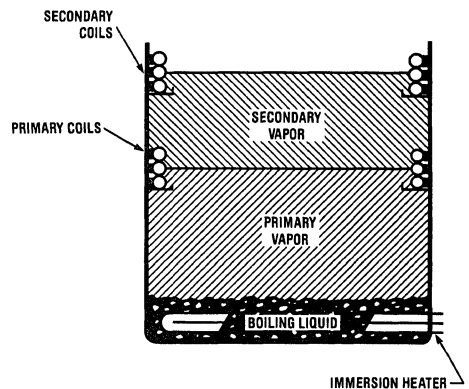
The question of thermal shock is asked frequently because of the relatively sharp increase in component temperature from room temperature to 215°C. SO packages mounted on representative boards have been tested and have shown little effect on the integrity of the packages. Various packages, such as cerdips, metal cans and TO-5 cans with glass seals, have also been tested.

Vapor-Phase Furnace



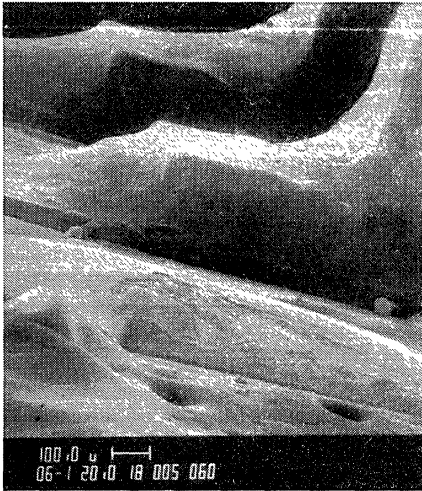
TL/F/8766-10

Batch-Fed Production Vapor-Phase Soldering Unit



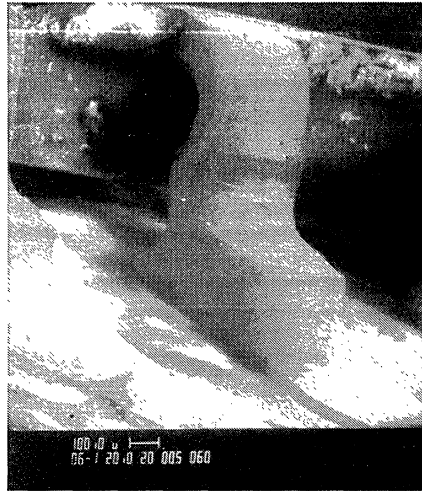
TL/F/8766-11

Solder Joints on a SO-14 Package on PCB



TL/F/8766-12

Solder Joints on a SO-14 Package on PCB



TL/F/8766-13

PRINTED CIRCUIT BOARD

The SO package is molded out of clean, thermoset plastic compound and has no particular compatibility problems with most printed circuit board substrates.

The package can be reliably mounted onto substrates such as:

- G10 or FR4 glass/resin
- FR5 glass/resin systems for high-temperature applications
- Polyimide boards, also high-temperature applications
- Ceramic substrates

General requirements for printed circuit boards are:

- Mounting pads should be solder-plated whenever applicable.
- Solder masks are commonly used to prevent solder bridging of fine lines during soldering.

The mask also protects circuits from processing chemical contamination and corrosion.

If coated over pre-tinned traces, residues may accumulate at the mask/trace interface during subsequent reflow, leading to possible reliability failures.

Recommended application of solder resist on bare, clean traces prior to coating exposed areas with solder.

General requirements for solder mask:

- Good pattern resolution.
- Complete coverage of circuit lines and resistance to flaking during soldering.
- Adhesion should be excellent on substrate material to keep off moisture and chemicals.
- Compatible with soldering and cleaning requirements.

SOLDER PASTE SCREEN PRINTING

With the initial choice of printed circuit lithographic design and substrate material, the first step in surface mounting is the application of solder paste.

The typical lithographic "footprints" for SO packages are illustrated below. Note that the 0.050" lead center-center spacing is not easily managed by commercially-available air pressure, hand-held dispensers.

Using a stainless-steel, wire-mesh screen stencilled with an emulsion image of the substrate pads is by far the most common and well-tried method. The paste is forced through the screen by a V-shaped plastic squeegee in a sweeping manner onto the board placed beneath the screen.

The setup for SO packages has no special requirement from that required by other surface-mounted, passive components. Recommended working specifications are:

- Use stainless-steel, wire-mesh screens, #80 or #120, wire diameter 2.6 mils. Rule of thumb: mesh opening should be approximately 2.5–5 times larger than the average particle size of paste material.
- Use squeegee of Durometer 70.
- Experimentation with squeegee travel speed is recommended, if available on machine used.
- Use solder paste of mesh 200–325.
- Emulsion thickness of 0.005" usually used to achieve a solder paste thickness (wet) of about 0.008" typical.
- Mesh pattern should be 90 degrees, square grid.
- Snap-off height of screen should not exceed $\frac{1}{8}$ ", to avoid damage to screens and minimize distortion.

SOLDER PASTE

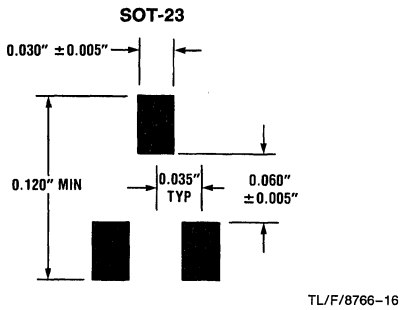
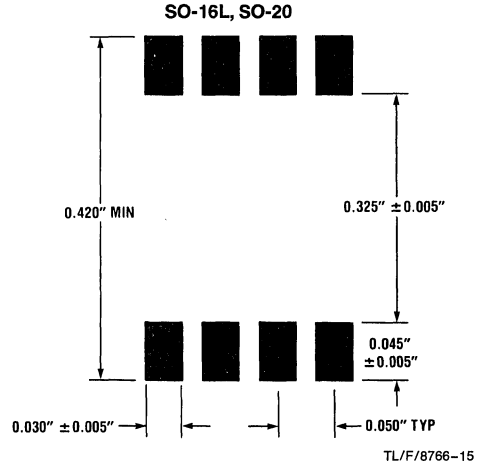
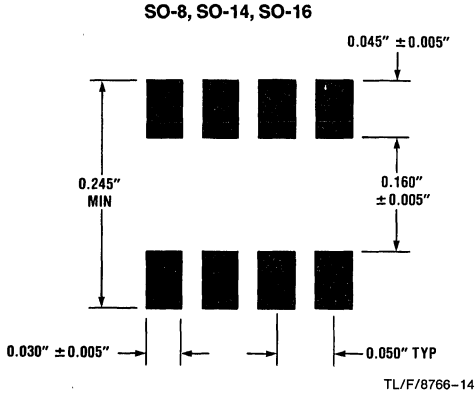
Selection of solder paste tends to be confusing, due to numerous formulations available from various manufacturers. In general, the following guidelines are sufficient to qualify a particular paste for production:

- Particle sizes (see photographs below). Mesh 325 (approximately 45 microns) should be used for general purposes, while larger (solder globules) particles are preferred for leadless components (LCC). The larger particles can easily be used for SO packages.

- Uniform particle distribution. Solder globules should be spherical in shape with uniform diameters and minimum amount of elongation (visual under 100/200 × magnification). Uneven distribution causes uneven melting and subsequent expulsion of smaller solder balls away from their proper sites.

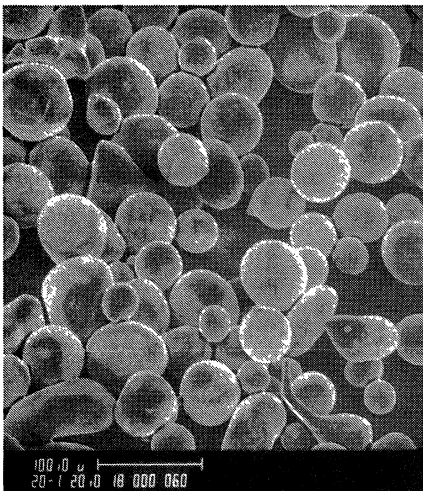
- Composition, generally 60/40 or 63/37 Sn/Pb. Use 62/36 Sn/Pb with 2% Ag in the presence of Au on the soldering area. This formulation reduces problems of metal leaching from soldering pads.
- RMA flux system usually used.
- Use paste with approximately 88–90% solids.

RECOMMENDED SOLDER PADS FOR SO PACKAGES



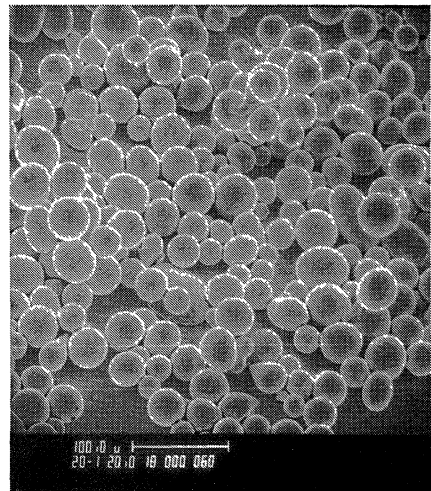
Comparison of Particle Size/Shape of Various Solder Pastes

200 × Alpha (62/36/2)



TL/F/8766-17

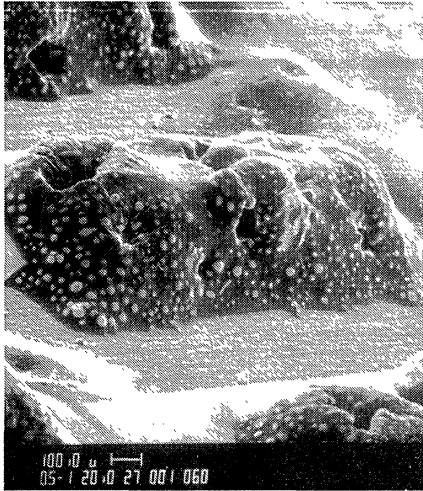
200 × Kester (63/37)



TL/F/8766-18

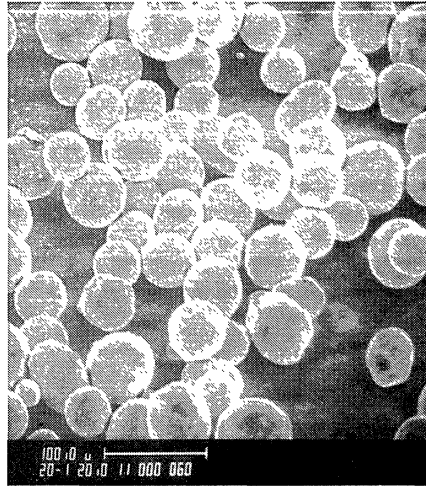
Comparison of Particle Size/Shape of Various Solder Pastes (Continued)

Solder Paste Screen on Pads



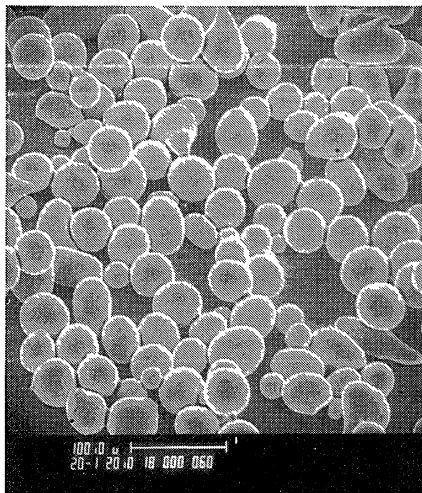
TL/F/8766-19

200 X Fry Metal (63/37)



TL/F/8766-20

200 ESL (63/37)



TL/F/8766-21

CLEANING

The most critical process in surface mounting SO packages is in the cleaning cycle. The package is mounted very close to the surface of the substrate and has a tendency to collect residue left behind after reflow soldering.

Important considerations in cleaning are:

- Time between soldering and cleaning to be as short as possible. Residue should not be allowed to solidify on the substrate for long periods of time, making it difficult to dislodge.
- A low surface tension solvent (high penetration) should be employed. Solvents commercially available are:

Freon TMS (general purpose)
 Freon TE35/TP35 (cold-dip cleaning)
 Freon TES (general purpose)

It should also be noted that these solvents generally will leave the substrate surface hydrophobic (moisture repellent), which is desirable.

Prelete or 1,1,1-Trichloroethane
 Kester 5120/5121

- A defluxer system which allows the workpiece to be subjected to a solvent vapor, followed by a rinse in pure solvent and a high-pressure spray lance are the basic requirements for low-volume production.
- For volume production, a conveyORIZED, multiple hot solvent spray/jet system is recommended.
- Rosin, being a natural occurring material, is not readily soluble in solvents, and has long been a stumbling block to the cleaning process. In recent developments, synthetic flux (SA flux), which is readily soluble in Freon TMS solvent, has been developed. This should be explored where permissible.

The dangers of an inadequate cleaning cycle are:

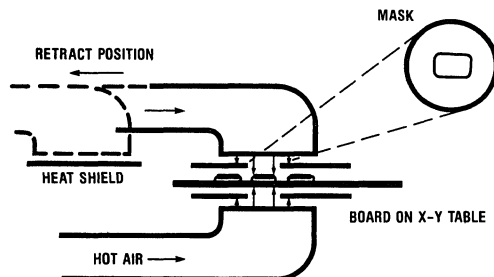
- Ion contamination, where ionic residue left on boards would cause corrosion to metallic components, affecting the performance of the board.
- Electro-migration, where ionic residue and moisture present on electrically-biased boards would cause dendritic growth between close spacing traces on the substrate, resulting in failures (shorts).

REWORK

Should there be a need to replace a component or re-align a previously disturbed component, a hot air system with appropriate orifice masking to protect surrounding components may be used.

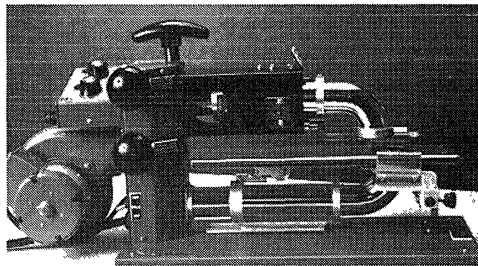
When rework is necessary in the field, specially-designed tweezers that thermally heat the component may be used to remove it from its site. The replacement can be fluxed at the

Hot-Air Solder Rework Station



TL/F/8766-22

Hot-Air Rework Machine



TL/F/8766-23

lead tips or, if necessary, solder paste can be dispensed onto the pads using a varimeter. After being placed into position, the solder is reflowed by a hot-air jet or even a standard soldering iron.

WAVE SOLDERING

In a case where lead insertions are made on the same board as surface-mounted components, there is a need to include a wave-soldering operation in the process flow.

Two options are used:

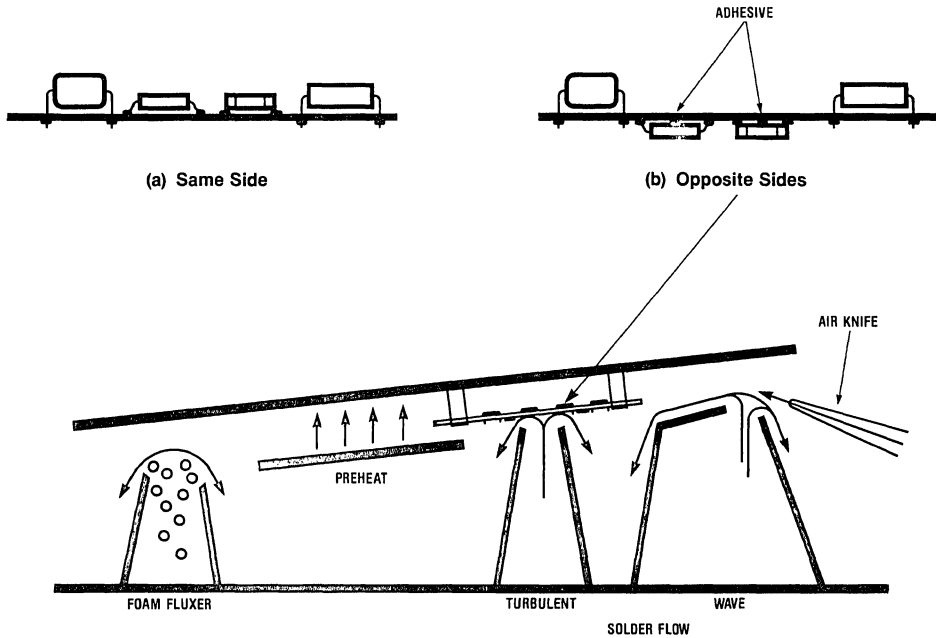
- Surface mounted components are placed and vapor phase reflowed before auto-insertion of remaining components. The board is carried over a standard wave-solder system and the underside of the board (only lead-inserted leads) soldered.
- Surface-mounted components are placed in position, but no solder paste is used. Instead, a drop of adhesive about 5 mils maximum in height with diameter not exceeding 25% width of the package is used to hold down the package. The adhesive is cured and then proceeded to auto-insertion on the reverse side of the board (surface-mounted side facing down). The assembly is then passed over a "dual wave" soldering system. Note that the surface-mounted components are immersed into the molten solder.

Lead trimming will pose a problem after soldering in the latter case, unless the leads of the insertion components are pre-trimmed or the board specially designed to localize certain areas for easy access to the trim blade.

The controls required for wave soldering are:

- Solder temperature to be 240–260°C. The dwell time of components under molten solder to be short (preferably kept under 2 seconds), to prevent damage to most components and semiconductor devices.
- RMA (Rosin Mildly Activated) flux or more aggressive OA (Organic Acid) flux are applied by either dipping or foam fluxing on boards prior to preheat and soldering. Cleaning procedures are also more difficult (aqueous, when OA flux is used), as the entire board has been treated by flux (unlike solder paste, which is more or less localized). Non-halide OA fluxes are highly recommended.
- Preheating of boards is essential to reduce thermal shock on components. Board should reach a temperature of about 100°C just before entering the solder wave.
- Due to the closer lead spacings (0.050" vs 0.100" for dual-in-line packages), bridging of traces by solder could occur. The reduced clearance between packages also causes "shadowing" of some areas, resulting in poor solder coverage. This is minimized by dual-wave solder systems.

Mixed Surface Mount and Lead Insertion

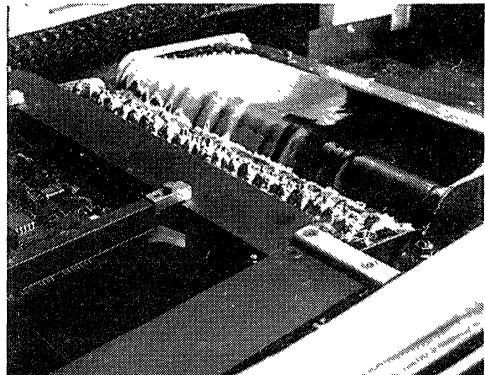


TL/F/8766-24

A typical dual-wave system is illustrated below, showing the various stages employed. The first wave typically is in turbulence and given a transverse motion (across the motion of the board). This covers areas where "shadowing" occurs. A second wave (usually a broad wave) then proceeds to perform the standard soldering. The departing edge from the solder is such to reduce "icicles," and is still further reduced by an air knife placed close to the final soldering step. This air knife will blow off excess solder (still in the fluid stage) which would otherwise cause shorts (bridging) and solder bumps.

AQUEOUS CLEANING

- For volume production, a conveyerized system is often used with a heated recirculating spray wash (water temperature 130°C), a final spray rinse (water temperature 45–55°C), and a hot (120°C) air/air-knife drying section.
- For low-volume production, the above cleaning can be done manually, using several water rinses/tanks. Fast-drying solvents, like alcohols that are miscible with water, are sometimes used to help the drying process.
- Neutralizing agents which will react with the corrosive materials in the flux and produce material readily soluble in water may be used; the choice depends on the type of flux used.
- Final rinse water should be free from chemicals which are introduced to maintain the biological purity of the water. These materials, mostly chlorides, are detrimental to the assemblies cleaned because they introduce a fresh amount of ionizable material.

Dual Wave

TL/F/8766-25

CONFORMAL COATING

Conformal coating is recommended for high-reliability PCBs to provide insulation resistance, as well as protection against contamination and degradation by moisture.

Requirements:

- Complete coating over components and solder joints.
- Thixotropic material which will not flow under the packages or fill voids, otherwise will introduce stress on solder joints on expansion.
- Compatibility and possess excellent adhesion with PCB material/components.
- Silicones are recommended where permissible in application.

SMD Lab Support

FUNCTIONS

Demonstration—Introduce first-time users to surface-mounting processes.

Service—Investigate problems experienced by users on surface mounting.

Reliability Builds—Assemble surface-mounted units for reliability data acquisition.

Techniques—Develop techniques for handling different materials and processes in surface mounting.

Equipment—In conjunction with equipment manufacturers, develop customized equipments to handle high density, new technology packages developed by National.

In-House Expertise—Availability of in-house expertise on semiconductor research/development to assist users on packaging queries.



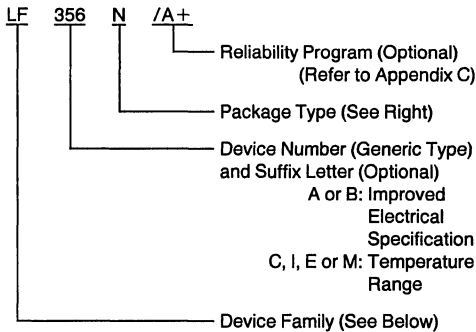
Section 8
**Appendices/
Physical Dimensions**



Section 8 Contents

Appendix A General Product Marking and Code Explanation	8-3
Appendix B Device/Application Literature Cross-Reference	8-4
Appendix C Summary of Commercial Reliability Programs	8-11
Appendix D Military Aerospace Programs from National Semiconductor	8-13
Appendix E Understanding Integrated Circuit Package Power Capabilities	8-22
Appendix F How to Get the Right Information from a Datasheet	8-27
Appendix G Obsolete Product Replacement Guide	8-31
Appendix H Safe Operating Areas for Peripheral Drivers	8-33
Physical Dimensions	8-41
Bookshelf	
Distributors	

Appendix A General Product Marking & Code Explanation

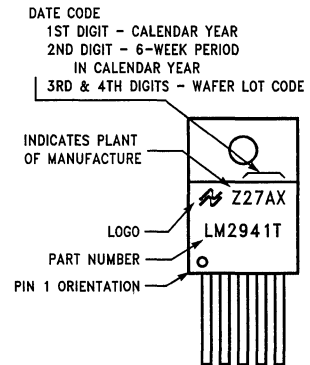
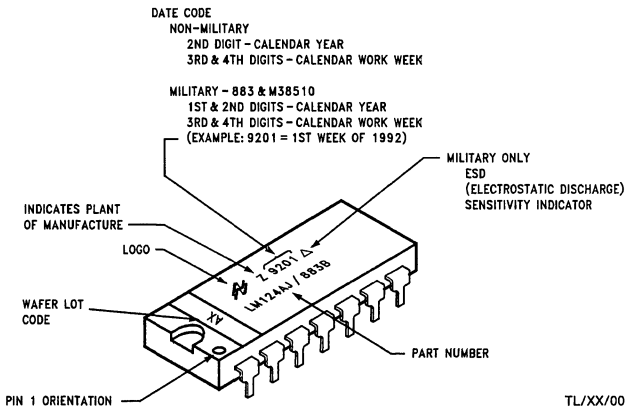


Device Family

ADC	Data Conversion
AF	Active Filter
AH	Analog Switch (Hybrid)
DAC	Data Conversion
DM	Digital (Monolithic)
HS	Hybrid
LF	Linear (Bifet)
LH	Linear (Hybrid)
LM	Linear (Monolithic)
LMC	Linear CMOS
LMD	Linear DMOS
LP	Linear (Low Power)
LPC	Linear CMOS (Low Power)
MF	Linear (Monolithic Filter)
LMF	Linear Monolithic Filter

Package Type

D	Glass/Metal DIP
E	Ceramic Leadless Chip Carrier (LCC)
F	Glass/Metal Flat Pak (1/4" x 1/4")
G	12 Lead TO-8 Metal Can (M/C)
H	Multi-Lead Metal Can (M/C)
H-05	4 Lead M/C (TO-5) } Shipped with Thermal Shield
H-46	4 Lead M/C (TO-46) }
J	Lo-Temp Ceramic DIP
J-8	8 Lead Ceramic DIP ("MiniDIP")
J-14	14 Lead Ceramic DIP (-14 used only when product is also available in -8 pkg).
K	TO-3 M/C in Steel, except LM309K which is shipped in Aluminum
KC	TO-3 M/C (Aluminum)
K Steel	TO-3 M/C (Steel)
M	Small Outline Package
M3	3-Lead Small Outline Package
N	Molded DIP (EPOXY B)
N-01	Molded DIP (Epoxy B) with Staggered Leads
N-8	8 Lead Molded DIP (Epoxy B) ("Mini-DIP")
N-14	14 Lead Molded DIP (Epoxy B) (-14 used only when product is also available in -8 pkg).
P	3 Lead TO-202 Power Pkg
Q	Cerdip with UV Window
T	3,5,11,15 & 23 Lead TO-220 PWR Pkg (Epoxy B)
V	Multi-lead Plastic Chip Carrier (PCC)
W	Lo-Temp Ceramic Flat Pak
WM	Wide Body Small Outline Package



TL/XX/0027-2

TL/XX/0027-3



Appendix B

Device/Application Literature Cross-Reference

Device Number	Application Literature
ADCXXXX.....	AN-156
ADC80	AN-360
ADC0801	AN-233, AN-271, AN-274, AN-280, AN-281, AN-294, LB-53
ADC0802	AN-233, AN-274, AN-280, AN-281, LB-53
ADC0803	AN-233, AN-274, AN-280, AN-281, LB-53
ADC08031	AN-460
ADC0804	AN-233, AN-274, AN-276, AN-280, AN-281, AN-301, AN-460, LB-53
ADC0805	AN-233, AN-274, AN-280, AN-281, LB-53
ADC0808	AN-247, AN-280, AN-281
ADC0809	AN-247, AN-280
ADC0816	AN-193, AN-247, AN-258, AN-280
ADC0817	AN-247, AN-258, AN-280
ADC0820	AN-237
ADC0831	AN-280, AN-281
ADC0832	AN-280, AN-281
ADC0833	AN-280, AN-281
ADC0834	AN-280, AN-281
ADC0838	AN-280, AN-281
ADC1001	AN-276, AN-280, AN-281
ADC1005	AN-280
ADC10461	AN-769
ADC10462	AN-769
ADC10464	AN-769
ADC10662	AN-769
ADC10664	AN-769
ADC1210	AN-245
ADC12441	AN-769
ADC12451	AN-769
ADC3501	AN-200, AN-202
ADC3511	AN-200
ADC3701	AN-200
ADC3711	AN-200
AH0014	AN-38
AH0019	AN-38
CD4016	AB-10
DACXXXX.....	AN-156
DAC0800	AN-693
DAC0830	AN-284
DAC0831	AN-271, AN-284
DAC0832	AN-271, AN-284
DAC1000	AN-271, AN-275, AN-277, AN-284
DAC1001	AN-271, AN-275, AN-277, AN-284
DAC1002	AN-271, AN-275, AN-277, AN-284

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
DAC1006	AN-271, AN-275, AN-277, AN-284
DAC1007	AN-271, AN-275, AN-277, AN-284
DAC1008	AN-271, AN-275, AN-277, AN-284
DAC1020	AN-263, AN-269, AN-2293, AN-294, AN-299
DAC1021	AN-269
DAC1022	AN-269
DAC1208	AN-271, AN-284
DAC1209	AN-271, AN-284
DAC1210	AN-271, AN-284
DAC1218	AN-293
DAC1219	AN-693
DAC1220	AN-253, AN-269
DAC1221	AN-269
DAC1222	AN-269
DAC1230	AN-284
DAC1231	AN-271, AN-284
DAC1232	AN-271, AN-284
DAC1280	AN-261, AN-263
DH0034	AN-253
DH0035	AN-49
Digitalizer	AN-252, LB-54
DM8890	Appendix B
DS8606	AN-381, AN-382
DS8608	AN-382
DT1058	AN-287
DT1060	AN-287
DTSW250E2	AN-287
DTSW250GI	AN-287
INS8070	AN-260
LF111	LB-39
LF155	AN-263, AN-447
LF198	AN-245, AN-294
LF311	AN-301
LF347	AN-256, AN-262, AN-263, AN-265, AN-266, AN-301, AN-344, AN-447, LB-44
LF351	AN-242, AN-263, AN-266, AN-271, AN-275, AN-293, AN-447, Appendix C
LF351A	AN-240
LF351B	Appendix D
LF353	AN-256, AN-258, AN-262, AN-263, AN-264, AN-266, AN-271, AN-285, AN-293, AN-447, LB-44, Appendix D
LF356	AN-253, AN-258, AN-260, AN-263, AN-266, AN-271, AN-272, AN-275, AN-293, AN-294, AN-295, AN-301, AN-447, AN-693
LF357	AN-263, AN-447, LB-42
LF398	AN-247, AN-258, AN-266, AN-294, AN-298, LB-45
LF400	AN-428, AN-447
LF411	AN-294, AN-301, AN-344, AN-447
LF412	AN-272, AN-299, AN-301, AN-344, AN-447
LF441	AN-301, AN-447
LF13006	AN-344
LF13007	AN-344
LF13331	AN-294, AN-447
LF13508	AN-289, AN-360, AN-447
LF13509	AN-289, AN-295, AN-447

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LH0002	AN-13, AN-63, AN-227, AN-244, AN-263, AN-272, AN-301
LH0005	AN-13
LH0022	AN-63, AN-75
LH0023	AN-245, AN-360
LH0024	AN-253
LH0032	AN-242, AN-244, AN-253
LH0033	AN-48, AN-115, AN-227, AN-253
LH0042	AN-63
LH0043	AN-245
LH0052	AN-63
LH0053	AN-245
LH0062	AN-75
LH0063	AN-227
LH0070	AN-301
LH0071	AN-245
LH0082	AN-244, AN-266
LH0086	AN-245, AN-360
LH0091	AN-180
LH0094	AN-301
LH0101	AN-261
LH1605	AN-343
LM10	AN-211, AN-247, AN-258, AN-271, AN-288, AN-299, AN-300, AN-460, AN-693
LM11	AN-241, AN-242, AN-260, AN-266, AN-271
LM12	AN-446, AN-693, AN-706
LM101	AN-4, AN-13, AN-20, AN-24, AN-75, LB-42, Appendix A
LM101A	AN-29, AN-30, AN-31, AN-79, AN-241 AN-711, LB-1, LB-2, LB-4, LB-8, LB-14, LB-16, LB-19, LB-28
LM102	AN-4, AN-13, AN-30, LB-1, LB-5, LB-6, LB-11
LM103	AN-110, LB-41
LM104	AN-21, LB-3, LB-7, LB-10, LB-40
LM105	AN-21, AN-23, AN-110, LB-3, LB-7, LB-10
LM106	AN-41, LB-6, LB-12
LM107	AN-20, AN-31, LB-1, LB-12, LB-19, Appendix A
LM108	AN-29, AN-30, AN-31, AN-63, AN-79, AN-211, AN-241, LB-14, LB-15, LB-21
LM108A	AN-260, LB-15, LB-19
LM109	AN-42, LB-15
LM109A	LB-15
LM110	LB-11, LB-42
LM111	AN-41, AN-103, LB-12, LB-16, LB-32, LB-39
LM112	AN-63, LB-19
LM113	AN-56, AN-110, LB-21, LB-24, LB-28, LB-37
LM117	AN-178, AN-181, AN-182, LB-46, LB-47
LM117HV	LB-46, LB-47
LM118	LB-17, LB-19, LB-21, LB-23, Appendix A
LM119	AN-115, LB-23
LM120	AN-182
LM121	AN-79, AN-104, AN-184, AN-260, LB-22
LM121A	LB-32
LM122	AN-97, LB-38
LM125	AN-82
LM126	AN-82

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LM129	AN-173, AN-178, AN-262, AN-266
LM131	AN-210, AN-460, Appendix D
LM131A	AN-210
LM134	LB-41, AN-460
LM135	AN-225, AN-262, AN-292, AN-298, AN-460
LM137	LB-46
LM137HV	LB-46
LM138	LB-46
LM139	AN-74
LM143	AN-127, AN-271
LM148	AN-260
LM150	LB-46
LM158	AN-116
LM160	AN-87
LM161	AN-87, AN-266
LM163	AN-295
LM194	AN-222, LB-21
LM195	AN-110
LM199	AN-161, AN-260, AN-360
LM199A	AN-161
LM211	LB-39
LM216A	LB-37
LM231	AN-210
LM231A	AN-210
LM235	AN-225
LM239	AN-74
LM258	AN-116
LM260	AN-87
LM261	AN-87
LM34	AN-460
LM35	AN-460
LM301A	AN-178, AN-181, AN-222
LM304	LB-40
LM308	AN-88, AN-184, AN-272, LB-22, LB-28, Appendix D
LM308A	AN-225, LB-24
LM309	AN-178, AN-182
LM311	AN-41, AN-103, AN-260, AN-263, AN-288, AN-294, AN-295, AN-307, LB-12, LB-16, LB-18, LB-39
LM313	AN-263
LM316	AN-258
LM317	AN-178, LB-35, LB-46
LM317H	LB-47
LM318	AN-115, AN-299, LB-21
LM319	AN-115, AN-271, AN-293
LM320	AN-288
LM321	LB-24
LM324	AN-88, AN-258, AN-274, AN-284, AN-301, LB-44, AB-25, Appendix C
LM329	AN-256, AN-263, AN-284, AN-295, AN-301
LM329B	AN-225
LM330	AN-301
LM331	AN-210, AN-240, AN-265, AN-278, AN-285, AN-311, LB-45, Appendix C, Appendix D
LM331A	AN-210, Appendix C

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LM334	AN-242, AN-256, AN-284
LM335	AN-225, AN-263, AN-295
LM336	AN-202, AN-247, AN-258
LM337	LB-46
LM338	LB-49, LB-51
LM339	AN-74, AN-245, AN-274
LM340	AN-103, AN-182
LM340L	AN-256
LM342	AN-288
LM346	AN-202, LB-54
LM348	AN-202, LB-42
LM349	LB-42
LM358	AN-116, AN-247, AN-271, AN-274, AN-284, AN-298, Appendix C
LM358A	Appendix D
LM359	AN-278, AB-24
LM360	AN-87
LM361	AN-87, AN-294
LM363	AN-271
LM380	AN-69, AN-146
LM381	AN-64, AN-104
LM382	AN-147
LM385	AN-242, AN-256, AN-301, AN-344, AN-460, AN-693, AN-777
LM386	LB-54
LM389	AN-256, AN-263, AN-264, AN-274
LM391	AN-272
LM392	AN-274, AN-286
LM393	AN-271, AN-274, AN-293, AN-694
LM394	AN-262, AN-263, AN-264, AN-271, AN-293, AN-299, AN-311, LB-52
LM395	AN-178, AN-181, AN-262, AN-263, AN-266, AN-301, AN-460, LB-28
LM399	AN-184
LM555	AN-694, AB-7
LM556	AB-7
LM565	AN-46, AN-146
LM566	AN-146
LM604	AN-460
LM628	AN-693, AN-706
LM629	AN-693, AN-694, AN-706
LM709	AN-24, AN-30
LM710	AN-41, LB-12
LM725	LB-22
LM741	AN-75, AN-79, LB-19, LB-22
LM832	AN-386, AN-390
LM833	AN-346
LM1036	AN-390
LM1310	AN-81
LM1458	AN-116
LM1524	AN-272, AN-288, AN-292, AN-293
LM1558	AN-116
LM1578A	AB-30
LM1807	Appendix B

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LM1808	Appendix B
LM1820	LB-29
LM1828	Appendix B
LM1830	AB-10
LM1845	Appendix B
LM1865	AN-382, AN-390
LM1894	AN-384, AN-386, AN-390
LM2577	AN-776, AN-777
LM2878	AN-147
LM2907	AN-162
LM2917	AN-162
LM2931	AB-12
LM2931CT	AB-11
LM3045	AN-286
LM3046	AN-146, AN-299
LM3064	Appendix B
LM3065	Appendix B
LM3070	Appendix B
LM3071	Appendix B
LM3089	AN-147
LM3524	AN-272, AN-288, AN-292, AN-293
LM3525A	AN-694
LM3578A	AB-30
LM3900	AN-72, AN-263, AN-274, AN-278, LB-20, AB-24
LM3909	AN-154
LM3911	LB-27, AN-460
LM3914	AN-460, LB-48, AB-25
LM3915	AN-386
LM3999	AN-161
LM4250	AN-88, LB-34
LM7800	AN-178
LM78L12	AN-146
LM78S40	AN-711
LMC555	AN-460
LMC835	AN-435
LMD18200	AN-694
LM18293	AN-706
LP324	AN-284
LP395	AN-460

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
MF10	AN-307
MM2716	LB-54
MM54104	AN-252, AN-287, LB-54
MM57110	AN-382
MM74C00	AN-88
MM74C02	AN-88
MM74C04	AN-88
MM74C948	AN-193
MM74LS138	LB-54
MM53200	AN-290
2N4339	AN-32

Appendix C

Summary of Commercial Reliability Programs

General

National Semiconductor Commercial Reliability Programs provide a broad range of off-the-shelf enhanced semiconductor products that supply an extra measure of quality and reliability needed in high-stress or difficult to service applications.

National's A+ and B+ programs allow each individual customer to:

- Minimize the need for incoming electrical inspection
- Eliminate the need and associated costs of using independent testing laboratories
- Reduction in infant mortality rate
- Reduction in reworked board costs
- Reduction in warranty and service costs

A+ Product Enhancement

The A+ Product Enhancement incorporates the benefits of the Multiple-Pass and Elevated Temperature along with "BURN-IN."

The A+ Program provides:

- 100% Temperature Cycling
- 100% Electrical Testing at Room and High Temperature
- 100% Burn-In Testing Combining Increased Temperature with Applied Voltage
- Acceptable Quality Levels Greater than Industry Norm

Typical A+ Flow is:

- SEM
- Assembly and Seal
- Four Hour 150°C Bake
- Five Temperature Cycles (0°C to +100°C)
- High Temperature Electrical Test
- Electrical Test
- Burn-In (160 hours at a minimum junction temperature of 125°C)
- DC Parametric and Function Tests
- Tightened Quality Control Inspection Plans

Note: Certain products may follow slightly different process flows dictated by specific capabilities and device characteristics, consult NSC.

P+ Product Enhancement

The P+ product enhancement program applies to power devices and offers an added advantage. P+ involves dynamic tests that screen out assembly related and silicon defects that can lead to infant mortality and/or reduce the survivability of the device under high stress conditions. This includes but is not limited to the following devices:

Device	Package Types					
	TO-3 K STEEL	TO-39 (H)	TO-220 (T)	TO-202 (P)	DIP (N)	SO (M)
LM12	X					
LM109/309	X	X				
LM117/317	X	X	X	X		
LM117HV/317HV	X	X				
LM120/320	X	X	X	X		
LM123/323	X					
LM133/333	X		X			
LM137/337	X	X	X	X		
LM137HV/337HV	X	X				
LM138/338	X		X			
LM140/340	X		X			
LM145/345	X					
LM150/350	X		X			
LM195/395	X	X	X	X		
LM196/396	X					
LM2930/2935/2984			X			
LM2937			X			
LM2940/2941			X			
LM2990/2991			X			
LM2575/2575HV			X		X	X
LM2576			X			
LM2577			X		X	X
LMD18200/18201			X			
LM18298			X			



Appendix D Military Aerospace Programs from National Semiconductor

This appendix is intended to provide a brief overview of military products available from National Semiconductor. For further information, refer to our 1987 Reliability Handbook.

National Semiconductor's Military/Aerospace Program is founded on dedication to excellence. National offers complete support across the broadest range of products with the widest selection of qualification levels and screening flows. These flows include:

Process Flows (Integrated Circuits)	Description
JAN S	QPL products processed to MIL-M-38510 Level S for space level applications.
JAN B	QPL products processed to MIL-M-38510 Level B for military applications.
SMD	Standard Military Drawing products processed to Level B with Table I Electricals controlled by DESC. (Formally called DESC Drawing.)
883	Products processed to MIL-STD-883 Level B for military applications.
MLP	Products processed on the Monitored Line (Program) developed by the Air Force for space level applications.
MIL S	Non-JAN products processed to Level S to negotiated electrical specifications for space level applications.
-MIL	Similar to MIL-STD-883 with exceptions noted on Certificate of Conformance.
MSP	Military Screening Program for initial release of advanced products.

- **MIL-M-38510:** The MIL-M-38510 Program, which is sometimes called the JAN IC Program, is administered by the Defense Electronics Supply Center (DESC). The purpose of this program is to provide the military community with standardized products that have been manufactured and screened to government-controlled specifications in government certified facilities. All 38510 manufacturers must be formally qualified and their products listed on DESC's Qualified Products List (QPL) before devices can be marked and shipped as JAN product.

There are two processing levels specified within MIL-M-38510: Class S and B. Class S is typically specified for space flight applications, while Class B is used for aircraft, naval and ground systems. National is a major supplier of both classes of devices. Screening requirements are outlined in Table III.

Tables I and II explain the JAN device marking system. Copies of MIL-M-38510, the QPL and other related documents may be obtained from:

Naval Publications and Forms Center
5801 Tabor Avenue
Philadelphia, PA 19120
(212) 697-2179

- **Standard Military Drawings (SMD):** SMD's are issued to provide standardized versions of devices which are not available as JAN product. MIL-STD-883 Class B screening is coupled with tightly controlled electrical specifications which have been written to allow a manufacturer to use his standard electrical tests. A current listing of National's SMD offerings can be obtained from our authorized distributors, sales offices or DESC. DESC is located in Dayton, Ohio.
- **MIL-STD-883:** Although originally intended to establish uniform test methods and procedures, MIL-STD-883 has also become the general specification for non-JAN military product. Revision D of this document defines the minimum requirements for a device to be marked and advertised as 883-compliant. Included are design and construction criteria, documentation controls, electrical and mechanical screening requirements, and quality control procedures. Details can be found in paragraph 1.2.1 of MIL-STD-883.

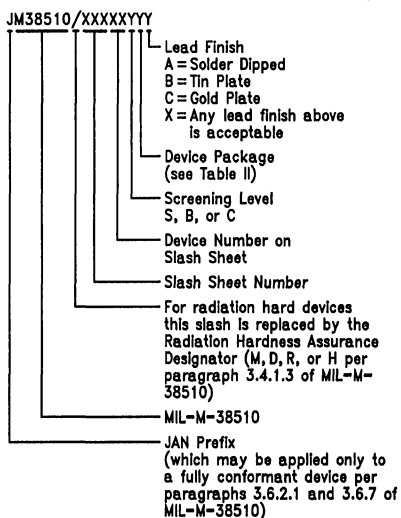
National offers both 883 Class B and 883 Class S product. The screening requirements for both classes of product are outlined in Table III.

As with SMDs a manufacturer is allowed to use his standard electrical tests provided that all critical parameters are tested. Also, the electrical test parameters, test conditions, test limits and test temperatures must be clearly documented. At National Semiconductor, this information is available via our Table I (formerly RETS, Reliability Electrical Test Specification Program). The Table I document is a complete description of the electrical tests performed and is controlled by our QA department. Individual copies are available upon request.

Some of National's products are produced on a flow similar to MIL-STD-883. These devices are screened to the same stringent requirements as 883 product, but are marked as -MIL; specific reasons for prevention of compliance are clearly defined in the Certificate of Conformance (C of C) shipped with the product.

- **Monitored Line Program (MLP):** is a non JAN Level S program developed by the Air Force. Monitored Line product usually provides the shortest cycle time, and is acceptable for application in several space level programs. Lockheed Missiles and Space Company in Sunnyvale, California, under an Air Force contract, provides "on-site" monitoring of product processing, and as appropriate, program management. Monitored Line orders generally do not allow "customizing", and most flows do not include quality conformance inspection. Drawing control is maintained by the Lockheed Company.
- **Military Screening Program (MSP):** National's Military Screening Program was developed to make screened versions of advanced products such as gate arrays and microprocessors available more quickly than is possible for JAN and 883 devices. Through this program, screened product is made available for prototypes and breadboards prior to or during the JAN or 883 qualification activities. MSP products receive the 100% screening of Table III, but are not subjected to Group C and D quality conformance testing. Other criteria such as electrical testing and temperature range will vary depending upon individual device status and capability.

TABLE I. The MIL-M-38510 Part Marking



TL/XX/0030-1

TABLE II. JAN Package Codes

38510 Package Designation	Microcircuit Industry Description
A	14-pin 1/4" x 1/4" (Metal) Flatpak
B	14-pin 3/16" x 1/4" (Metal) Flatpak
C	14-pin 1/4" x 3/4" Dual-In-Line
D	14-pin 1/4" x 3/8" (Ceramic) Flatpak
E	16-pin 1/4" x 7/8" Dual-In-Line
F	16-pin 1/4" x 3/8" (Metal or Ceramic) Flatpak
G	8-pin TO-99 Can or Header
H	10-pin 1/4" x 1/4" (Metal) Flatpak
I	10-pin TO-100 Can or Header
J	24-pin 1/2" x 1/4" Dual-In-Line
K	24-pin 3/8" x 5/8" Flatpak
L	24-pin 1/4" x 1 1/4" Dual-In-Line
M	12-pin TO-101 Can or Header
N	(Note 1)
P	8-pin 1/4" x 3/8" Dual-In-Line
Q	40-pin 3/16" x 2 1/16" Dual-In-Line
R	20-pin 1/4" x 1 1/16" Dual-In-Line
S	20-pin 1/4" x 1/2" Flatpak
T	(Note 1)
U	(Note 1)
V	18-pin 3/8" x 15/16" Dual-In-Line
W	22-pin 3/8" x 1 1/8" Dual-In-Line
X	(Note 1)
Y	(Note 1)
Z	(Note 1)
2	20-terminal 0.350" x 0.350" Chip Carrier
3	28-terminal 0.450" x 0.450" Chip Carrier

Note 1: These letters are assigned to packages by individual MIL-M-38510 detail specifications and may be assigned to different packages in different specifications.

TABLE III. 100% Screening Requirements

	Screen	Class S		Class B	
		Method	Reqmt	Method	Reqmt
1.	Wafer Lot Acceptance	5007	All Lots		
2.	Nondestructive Bond Pull (Note 14)	2023	100%		
3.	Internal Visual (Note 1)	2020, Condition A	100%	2010, Condition B	100%
4.	Stabilization Bake (Note 16)	1008, Condition C, Min 24 Hrs. Min	100%	1008, Condition C, Min 24 Hrs. Min	100%
5.	Temperature Cycling (Note 2)	1010, Condition C	100%	1010, Condition C	100%
6.	Constant Acceleration	2001, Condition E Min Y ₁ Orientation Only	100%	2001, Condition E Min Y ₁ Orientation Only	100%
7.	Visual Inspection (Note 3)		100%		100%
8.	Particle Impact Noise Detection (PIND)	2010, Condition A (Note 4)	100%		
9.	Serialization	(Note 5)	100%		
10.	Interim (Pre-Burn-In) Electrical Parameters	Per Applicable Device Specification (Note 13)	100%	Per Applicable Device Specification (Note 6)	

TABLE III. 100% Screening Requirements (Continued)

	Screen	Class S		Class B	
		Method	Reqmt	Method	Reqmt
11.	Burn-In Test	1015 240 Hrs. @ 125°C Min (Cond. F Not Allowed)	100%	1015 160 Hrs. @ 125°C Min	100%
12.	Interim (Post Burn-In) Electrical Parameters	Per Applicable Device Specification (Note 3)	100%		
13.	Reverse Bias Burn-In (Note 7)	1015; Test Condition A, C, 72 Hrs. @ 150°C Min (Cond. F Not Allowed)	100%		
14.	Interim (Post-Burn-In) Electrical Parameters	Per Applicable Device Specification (Note 13)	100%	Per Applicable Device Specification	100%
15.	PDA Calculation	5% Parametric (Note 14), 3% Functional	All Lots	5% Parametric (Note 14)	All Lots
16.	Final Electrical Test (Note 15) a) Static Tests 1) 25°C (Subgroup 1, Table I, 5005) 2) Max & Min Rated Operating Temp. (Subgroups 2, 3, Table I, 5005) b) Dynamic Tests or Functional Tests 1) 25°C (Subgroup 4 or 7) 2) Max and Min Rated Operating Temp. (Subgroups 5 and 6 or 8, Table I, 5005) c) Switching Tests 25°C (Subgroup 9, Table I, 5005)	Per Applicable Device Specification	100% 100% 100% 100%	Per Applicable Device Specification	100% 100% 100% 100%
17.	Seal Fine, Gross	1014	100% (Note 8)	1014	100% (Note 9)
18.	Radiographic (Note 10)	2012 Two Views	100%		
19.	Qualification or Quality Conformance Inspection Test Sample Selection	(Note 11)	Samp.	(Note 11)	Samp.
20.	External Visual (Note 12)	2009	100%		100%

Note 1: Unless otherwise specified, at the manufacturer's option, test samples for Group B, bond strength (Method 5005) may be randomly selected prior to or following internal visual (Method 5004), prior to sealing provided all other specification requirements are satisfied (e.g., bond strength requirements shall apply to each inspection lot, bond failures shall be counted even if the bond would have failed internal visual).

Note 2: For Class B devices, this test may be replaced with thermal shock Method 1011, Test Condition A, minimum.

Note 3: At the manufacturer's option, visual inspection for catastrophic failures may be conducted after each of the thermal/mechanical screens, after the sequence or after seal test. Catastrophic failures are defined as missing leads, broken packages, or lids off.

Note 4: The PIND test may be performed in any sequence after step 6 and prior to step 16. See MIL-M-38510, paragraph 4.6.3.

Note 5: Class S devices shall be serialized prior to interim electrical parameter measurements.

Note 6: When specified, all devices shall be tested for those parameters requiring delta calculations.

Note 7: Reverse bias burn-in is a requirement only when specified in the applicable device specification. The order of performing burn-in and reverse bias burn-in may be inverted.

Note 8: For Class S devices, the seal test may be performed in any sequence between step 16 and step 19, but it shall be performed after all shearing and forming operations on the terminals.

Note 9: For Class B devices, the fine and gross seal tests shall be performed separately or together in any sequence and order between step 6 and step 20 except that they shall be performed after all shearing and forming operations on the terminals. When 100% seal screen cannot be performed after shearing and forming (e.g., flatpaks and chip carriers) the seal screen shall be done 100% prior to these operations and a sample test (LTPD = 5) shall be performed on each inspection lot following these operations. If the sample fails, 100% rescreening shall be required.

Note 10: The radiographic screen may be performed in any sequence after step 9.

Note 11: Samples shall be selected for testing in accordance with the specific device class and lot requirements of Method 5005.

Note 12: External Visual shall be performed on the lot any time after step 19 and prior to shipment.

Note 13: Read and record is required at steps 10 and 12 only for those parameters for which post-burn-in delta measurements are specified. All parameters shall be read and recorded at step 14.

Note 14: The PDA shall apply to all subgroup 1 parameters at 25°C and all delta parameters.

Note 15: Only one view is required for flat packages and leadless chip carriers with leads on all four sides.

Note 16: May be performed at any time prior to step 10.

Military Analog Products Available from National Semiconductor				
Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
HIGH PERFORMANCE AMPLIFIERS AND BUFFERS				
LF147	D, J	Wide BW Quad JFET Op Amp	SMD/JAN	/11906
LF155	J, W, H	JFET Input Op Amp	883/JAN	/11401
LF155A	H	JFET Input Op Amp	883	—
LF156	J, W, H	JFET Input Op Amp	883/JAN	/11402
LF156A	H	JFET Input Op Amp	883	—
LF157	H	JFET Input Op Amp	883	—
LF157A	H	JFET Input Op Amp	883	—
LF411M	H, J	Low Offset, Low Drift JFET Input	883/JAN	/11904
LF412M	H, J	Low Offset, Low Drift JFET Input-Dual	883/JAN	/11905
LF441M	H	Low Power JFET Input	883	—
LF442M	H	Low Power JFET Input-Dual	883	—
LF444M	D	Low Power JFET Input-Quad	883	—
LH0002	H	Buffer Amp	883/MIL	7801301
LH0021	K	1.0 Amp Power Op Amp	883/SMD	85088
LH0024	H	High Slew Rate Op Amp	"-MIL"	—
LH0032	G	Ultra Fast FET-Input Op Amp	883/SMD	80013
LH0041	G	0.2 Amp Power Op Amp	883/SMD	85087
LH0061	K	0.5 Amp Wide Bandwidth Op Amp	"-MIL"	—
LH0101	K	Power Op Amp	883/SMD	85089
LH4118	G	Low Gain Wide Band RF Amp	"-MIL"	—
LH4161	H	Trimmed LM6161 VIP Amp	"-MIL"	—
LH4162	H	Dual LH4161	"-MIL"	—
LM10	H	Super-Block™ Micropower Op Amp/Ref	883/SMD	5962-87604
LM101A	J, H, W	General Purpose Op Amp	883/JAN	/10103
LM108A	J, H, W	Precision Op Amp	883/JAN	/10104
LM118	J, H, W	Fast Op Amp	883/JAN	/10107
LM124	J, E, W	Low Power Quad Op Amp	883/JAN	/11005
LM124A	J, W	Low Power Quad	883/JAN	/11006
LM146	J	Quad Programmable Op Amp	883	—
LM148	J, E, W	Quad 741 Op amp	883/JAN	/11001
LM158A	J, H	Low Power Dual Op Amp	883/SMD	5962-8771002
LM158	J, H	Low Power Dual Op Amp	883/SMD	5962-8771001
LM604AM	J	Super-Block 4 Channel Mux Amp	883/SMD	5962-89639
LM611AM	J	Super-Block Op Amp/Reference	883/SMD	TBD
LM613AM	J, E	Super-Block Dual Op Amp/Dual Comp/Ref	883/SMD	TBD
LM614AM	J	Super-Block Quad Op Amp/Ref	883/SMD	TBD
LM709A	H, J, W	General Purpose Op Amp	883/SMD	7800701
LM741	J, H, W	General Purpose Op Amp	883/JAN	/10101
LM747	J, H, W	General Purpose Dual Op Amp	883/JAN	/10102
LM6118	J, E	VIP Dual Op Amp	883/SMD	5962-91565
LM6121	H	VIP Buffer	883/SMD	5962-90812
LM6125	H	VIP Buffer with Error Flag	883/SMD	5962-90815
LM6161	J, E, W	VIP Op Amp (Unity Gain)	883/SMD	5962-89621
LM6164	J, E, W	VIP Op Amp ($A_V > 5$)	883/SMD	5962-89624
LM6165	J, E, W	VIP Op Amp ($A_V > 25$)	883/SMD	5962-89625
LM6162	J, E, W	VIP Op Amp ($A_V > 2, -1$)	883/SMD	5962-92165
LMC660AM	J	Low Power CMOS Quad Op Amp	883/SMD	TBD
LMC662AM	J	Low Power CMOS Dual Op Amp	883/SMD	TBD
LPC660AM	J	Micropower CMOS Quad Op Amp	883/SMD	TBD
LPC662AM	J	Micropower CMOS Dual Op Amp	883/SMD	TBD
OP07	H	Precision Op Amp	SMD/JAN	/13502

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
COMPARATORS				
LF111	H	Voltage Comparator	"-MIL"	—
LH2111	J, W	Dual Voltage Comparator	883/JAN	/10305
LM106	H, W	Voltage Comparator	883/SMD	8003701
LM111	J, H, E, W	Voltage Comparator	883/JAN	/10304
LM119	J, H, E, W	High Speed Dual Comparator	883/JAN	/10306
LM139	J, E, W	Quad Comparator	883/JAN	/11201
LM139A	J	Precision Quad Comparator	883/SMD	5962-87739
LM160	J, H	High Speed Differential Comparator	883/SMD	8767401
LM161	J, H	High Speed Differential Comparator	883/SMD	5962-87572
LM193A	J, H	Dual Comparator	883/JAN	/11202
LM612AM	J	Dual-Channel Comparator/Reference	883/SMD	TBD
LM613AM	J, E	Super-Block Dual Comparator/ Dual Op Amp/Adj Reference	883/SMD	TBD
LM615AM	J	Quad Comparator/Adjustable Reference	883/SMD	TBD
LM710A*	J, H, W	Voltage Comparator	883/JAN	/10301
LM711A*	J, H, W	Dual LM710	883/JAN	/10302
LM760	J, H	High Speed Differential Comparator	883/JAN	5962-87545
*Formerly manufactured by Fairchild Semiconductor as part numbers μ A710 and μ A711.				
LINEAR REGULATORS				
Positive Voltage Regulators				
LH0075	G	Precision Voltage Regulator	"-MIL"	—
LM105	H	Adjustable Voltage Regulator	883/SMD	5962-89588
LM109	H	5V Regulator, $I_o = 20$ mA	883/JAN	/10701BXA
LM109	K	5V Regulator, $I_o = 1$ A	883/JAN	/10701BYA
LM117	H, E, K	Adjustable Regulator	883/JAN	/11703, /11704
LM117A	H	Precision Adjustable Regulator, $I_o = 0.5$ A	883/SMD	7703405XA
LM117A	K	Precision Adjustable Regulator, $I_o = 1.5$ A	883/SMD	7703405YA
LM117HV	H	Adjustable Regulator, $I_o = 0.5$ A	883/SMD	7703402XA
LM117HV	K	Adjustable Regulator, $I_o = 1.5$ A	883/SMD	7703402YA
LM123	K	3A Voltage Regulator	883	—
LM138	K	5A Adjustable Regulator	"-MIL"	—
LM140H-5.0	H	0.5A Fixed 5V Regulator	883/JAN	/10702
LM140H-6.0	H	0.5A Fixed 6V Regulator	883	—
LM140H-8.0	H	0.5A Fixed 8V Regulator	883	—
LM140H-12	H	0.5A Fixed 12V Regulator	883/JAN	/10703
LM140H-15	H	0.5A Fixed 15V Regulator	883/JAN	/10704
LM140H-24	H	0.5A Fixed 24V Regulator	883	—
LM140AK-5.0	K	1.0A Fixed 5V Regulator	883	—
LM140AK-12	K	1.0A Fixed 12V Regulator	883	—
LM140AK-15	K	1.0A Fixed 15V Regulator	883	—
LM140K-5.0	K	1.0A Fixed 5V Regulator	883/JAN	/10706
LM140K-12	K	1.0A Fixed 12V Regulator	883/JAN	/10707
LM140K-15	K	1.0A Fixed 15V Regulator	883/JAN	/10708
LM140K-24	K	1.2A Fixed 24V Regulator	883/JAN	/10709
LM140LAH-5.0	H	100 mA Fixed 5V Regulator	883	—
LM140LAH-12	H	100 mA Fixed 12V Regulator	883	—
LM140LAH-15	H	100 mA Fixed 15V Regulator	883	—
LM150	K	3A Adjustable Power Regulator	883	—
LM2940K-5.0	K	5V Low Dropout Regulator	883/SMD	5962-89587
LM2940K-8.0	K	8V Low Dropout Regulator	883/SMD	5962-90883
LM2940K-12	K	12V Low Dropout Regulator	883/SMD	5962-90884
LM2940K-15	K	15V Low Dropout Regulator	883/SMD	5962-90885
LM2941K	K	Adjustable Low Dropout Regulator	883/SMD	TBD
LM723	H, J, E	Precision Adjustable Regulator	883/JAN	/10201
LM78MG	H	Adjustable Regulator	883	—
LP2951	H, E, J	Adjustable Micropower LDO	883/SMD	5962-38705
LP2953AM	J	250 mA Adj. Micropower LDO	883	—

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
LINEAR REGULATORS (Continued)				
Negative Voltage Regulators				
LH0076	G	Precision Programmable Regulator	“-MIL”	—
LM104	H	Precision Negative Regulator	883/SMD	5962-87605
LM120H-5.0	H	Fixed 0.5A Regulator, $V_{OUT} = -5V$	883/JAN	/11501
LM120H-8.0	H	Fixed 0.5A Regulator, $V_{OUT} = -8V$	883	—
LM120H-12	H	Fixed 0.5A Regulator, $V_{OUT} = -12V$	883/JAN	/11502
LM120H-15	H	Fixed 0.5A Regulator, $V_{OUT} = -15V$	883/JAN	/11503
LM120K-5.0	K	Fixed 1.0A Regulator, $V_{OUT} = -5V$	883/JAN	/11505
LM120K-12	K	Fixed 1.0A Regulator, $V_{OUT} = -12V$	883/JAN	/11506
LM120K-15	K	Fixed 1.0A Regulator, $V_{OUT} = -15V$	883/JAN	/11507
LM137A	H	Precision Adjustable Regulator	883/SMD	7703406XA
LM137A	K	Precision Adjustable Regulator	883/SMD	7703406YA
LM137	H, K	Adjustable Regulator	883/JAN	/11803, /11804
LM137HV	H	Adjustable (High Voltage) Regulator	883/SMD	7703404XA
LM137HV	K	Adjustable (High Voltage) Regulator	883/SMD	7703404YA
LM145K-5.0	K	Negative 3 Amp Regulator	883/SMD	5962-90645
LM145K-5.2	K	Negative 3 Amp Regulator	883	—
LM79MG	H	Adjustable Regulator	883	—
SWITCHING REGULATORS				
LM1575-5	K	Simple Switcher™ Step-Down, $V_{OUT} = 5V$	883/SMD	TBD
LM1575-12	K	Simple Switcher Step-Down, $V_{OUT} = 12V$	883/SMD	TBD
LM1575-15	K	Simple Switcher Step-Down, $V_{OUT} = 15V$	883/SMD	TBD
LM1575-ADJ	K	Simple Switcher Step-Down, Adj V_{OUT}	883/SMD	TBD
LM1575HV-5	K	Simple Switcher Step-Down, $V_{OUT} = 5V$	883/SMD	TBD
LM1575HV-12	K	Simple Switcher Step-Down, $V_{OUT} = 12V$	883/SMD	TBD
LM1575HV-15	K	Simple Switcher Step-Down, $V_{OUT} = 15V$	883/SMD	TBD
LM1575HV-ADJ	K	Simple Switcher Step-Down, Adj V_{OUT}	883/SMD	TBD
LM1577-12	K	Simple Switcher Step-Up, $V_{OUT} = 12V$	883/SMD	TBD
LM1577-15	K	Simple Switcher Step-Up, $V_{OUT} = 15V$	883/SMD	TBD
LM1577-ADJ	K	Simple Switcher Step-Up, Adj V_{OUT}	883/SMD	TBD
LM1578	H	750 mA Switching Regulator	883/SMD	5962-89586
LM78S40*	J	Universal Switching Regulator Subsystem	883/SMD	5962-88761
*Formerly manufactured by Fairchild Semiconductor as the μ A78S40DMQB.				
VOLTAGE REFERENCES				
LM103-3.0	H	Reference Diode, $BV = 3.0V$	883/SMD	7702806
LM103-3.3	H	Reference Diode, $BV = 3.3V$	883/SMD	7702807
LM103-3.6	H	Reference Diode, $BV = 3.6V$	883/SMD	7702808
LM103-3.9	H	Reference Diode, $BV = 3.9V$	883/SMD	7702809
LM113	H	Reference Diode with 5% Tolerance	883/SMD	5962-8671101
LM113-1	H	Reference Diode with 1% Tolerance	883/SMD	5962-8671102
LM113-2	H	Reference Diode with 2% Tolerance	883/SMD	5962-8671103
LM129A	H	Precision Reference, 10 ppm/°C Drift	883/SMD	5962-8992101XA
LM129B	H	Precision Reference, 20 ppm/°C Drift	883/SMD	5962-8992102XA
LM136A-2.5	H	2.5V Reference Diode, 1% V_{OUT} Tolerance	883	—
LM136A-5.0	H	5V Reference Diode, 1% V_{OUT} Tolerance	883/SMD	8418001
LM136-2.5	H	2.5V Reference Diode, 2% V_{OUT} Tolerance	883	—
LM136-5.0	H	5V Reference Diode, 2% V_{OUT} Tolerance	883	—

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
VOLTAGE REFERENCES (Continued)				
LM169	H	10V Precision Reference, Low Tempco 0.05% Tolerance	883/SMD	TBD
LM185	H, E	Adjustable Micropower Voltage Reference	883	—
LM185BXH2.5	H	2.5V Micropower Reference Diode, Ultralow Drift	883/SMD	5962-8759404
LM185BY	H	Adjustable Micropower Voltage Reference	883	—
LM185BYH1.2	H	1.2V Micropower Reference Diode, Low Drift	883/SMD	5962-8759405
LM185BYH2.5	H	2.5V Micropower Reference Diode, Low Drift	883/SMD	5962-8759406
LM185-1.2	H, E	1.2V Micropower Reference Diode, Low Drift	883/SMD	5962-8759401
LM185-2.5	H, E	2.5V Micropower Reference Diode, Low Drift	883/SMD	5962-8759402
LM199	H	Precision Reference, Low Tempco	883/SMD	5962-8856102
LM199A	H	Precision Reference, Ultralow Tempco	883/SMD	5962-8856101
LM199A-20	H	Precision Reference, Ultralow Tempco	883	—
LM611AM	J	Super-Block Op Amp/Reference	883/SMD	TBD
LM612AM	J	Super-Block Dual-Channel Comparator/Reference	883/SMD	TBD
LM613AM	J, E	Super-Block Dual Op Amp/DualComp/Dual Ref	883/SMD	TBD
LM614AM	J	Super-Block Quad Op Amp/Reference	883/SMD	TBD
LM615AM	J	Super-Block Quad Comparator/Reference	883/SMD	TBD
LH0070-0	H	Precision BCD Buffered Reference	"-MIL"	—
LH0070-1	H	Precision BCD Buffered Reference	"-MIL"	—
LH0070-2	H	Precision BCD Buffered Reference	"-MIL"	—
DATA ACQUISITION				
ADC08020L	J	8-Bit μ P-Compatible	883/SMD	5962-90966
ADC0851	J	8-Bit Analog Data Acquisition & Monitoring System	883/SMD	TBD
ADC0858	J	8-Bit Analog Data Acquisition & Monitoring System	883/SMD	TBD
ADC1241CM	J	12-Bit Plus Sign Self-Calibrating with Sample/Hold Function	883/SMD	TBD
ADC12441CM	J	Dynamically-Tested ADC1241	883/SMD	TBD
ADC1251CM	J	12-Bit Plus Sign Self-Calibrating with Sample/Hold Function	883/SMD	TBD
ADC12451CM	J	Dynamically-Tested ADC1251	883/SMD	TBD
ADC10061CM	J	10-Bit Multistep ADC	883/SMD	TBD
ADC10062CM	J	10-Bit Multistep ADC w/Dual Input Multiplexer	883/SMD	TBD
ADC10064CM	J	10-Bit Multistep ADC w/Quad Input Multiplexer	883/SMD	TBD
ADC08061CM	J	8-Bit Multistep ADC	883/SMD	TBD
ADC08062CM	J	8-Bit Multistep ADC w/Dual Input Multiplexer	883/SMD	TBD
ADC08064CM	J	8-Bit Multistep ADC w/Quad Input Multiplexer	883/SMD	TBD
ADC08068CM	J	8-Bit Multistep ADC w/Octal Input Multiplexer	883/SMD	TBD

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
DATA ACQUISITION SUPPORT				
Switched Capacitor Filters				
LMF60CMJ50	J	6th Order Butterworth Lowpass	883/SMD	5962-90967
LMF60CMJ100	J	6th Order Butterworth Lowpass	883/SMD	5962-90967
LMF90CM	J	4th Order Elliptic Notch	883/SMD	5962-90968
LMF100A	J, E	Dual 2nd Order General Purpose	883/SMD	TBD
Sample and Hold				
LF198	H	Monolithic Sample and Hold	SMD/JA	5962-87608 /12501

Note 1: D: Side-Brazed DIP

- E: Leadless Ceramic Chip Carrier
- G: Metal Can (TO-8)
- H: Metal Can (TO-39, TO-5, TO-99, TO-100)
- J: Ceramic DIP
- K: Metal Can (TO-3)
- W: Flatpak

Note 2: Process Flows

- JAN = JM38510, Level B
- SMD = Standard Military Drawing
- 883 = MIL-STD-883 Rev C
- MIL = Exceptions to 883C noted on Certificate of Conformance

Note 3: Please call your local sales office to determine price and availability of space-level products. All "LM" prefix products in this guide are available with space-level processing.





Appendix E

Understanding Integrated Circuit Package Power Capabilities

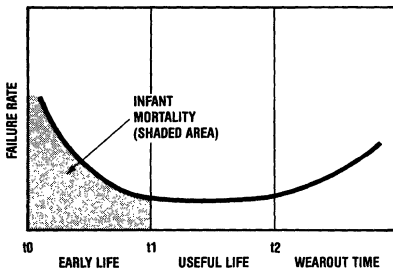
INTRODUCTION

The short and long term reliability of National Semiconductor's interface circuits, like any integrated circuit, is very dependent on its environmental condition. Beyond the mechanical/environmental factors, nothing has a greater influence on this reliability than the electrical and thermal stress seen by the integrated circuit. Both of these stress issues are specifically addressed on every interface circuit data sheet, under the headings of Absolute Maximum Ratings and Recommended Operating Conditions.

However, through application calls, it has become clear that electrical stress conditions are generally more understood than the thermal stress conditions. Understanding the importance of electrical stress should never be reduced, but clearly, a higher focus and understanding must be placed on thermal stress. Thermal stress and its application to interface circuits from National Semiconductor is the subject of this application note.

FACTORS AFFECTING DEVICE RELIABILITY

Figure 1 shows the well known "bathtub" curve plotting failure rate versus time. Similar to all system hardware (mechanical or electrical) the reliability of interface integrated circuits conform to this curve. The key issues associated with this curve are infant mortality, failure rate, and useful life.



TL/H/9312-1

FIGURE 1. Failure Rate vs Time

Infant mortality, the high failure rate from time t_0 to t_1 (early life), is greatly influenced by system stress conditions other than temperature, and can vary widely from one application to another. The main stress factors that contribute to infant mortality are electrical transients and noise, mechanical maltreatment and excessive temperatures. Most of these failures are discovered in device test, burn-in, card assembly and handling, and initial system test and operation. Although important, much literature is available on the subject of infant mortality in integrated circuits and is beyond the scope of this application note.

Failure rate is the number of devices that will be expected to fail in a given period of time (such as, per million hours). The mean time between failure (MTBF) is the average time (in hours) that will be expected to elapse after a unit has failed before the next unit failure will occur. These two primary "units of measure" for device reliability are inversely related:

$$\text{MTBF} = \frac{1}{\text{Failure Rate}}$$

Although the "bathtub" curve plots the overall failure rate versus time, the useful failure rate can be defined as the percentage of devices that fail per-unit-time during the flat portion of the curve. This area, called the useful life, extends between t_1 and t_2 or from the end of infant mortality to the onset of wearout. The useful life may be as short as several years but usually extends for decades if adequate design margins are used in the development of a system.

Many factors influence useful life including: pressure, mechanical stress, thermal cycling, and electrical stress. However, die temperature during the device's useful life plays an equally important role in triggering the onset of wearout.

FAILURE RATES vs TIME AND TEMPERATURE

The relationship between integrated circuit failure rates and time and temperature is a well established fact. The occurrence of these failures is a function which can be represented by the Arrhenius Model. Well validated and predominantly used for accelerated life testing of integrated circuits, the Arrhenius Model assumes the degradation of a performance parameter is linear with time and that MTBF is a function of temperature stress. The temperature dependence is an exponential function that defines the probability of occurrence. This results in a formula for expressing the lifetime or MTBF at a given temperature stress in relation to another MTBF at a different temperature. The ratio of these two MTBFs is called the acceleration factor F and is defined by the following equation:

$$F = \frac{X_1}{X_2} = \exp \left[\frac{E}{K} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \right]$$

Where: X_1 = Failure rate at junction temperature T_1

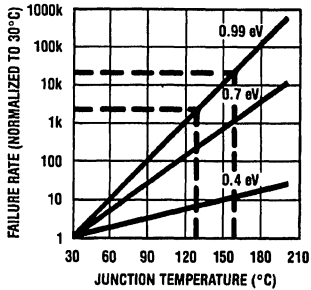
X_2 = Failure rate at junction temperature T_2

T = Junction temperature in degrees Kelvin

E = Thermal activation energy in electron volts (ev)

K = Boltzman's constant

However, the dramatic acceleration effect of junction temperature (chip temperature) on failure rate is illustrated in a plot of the above equation for three different activation energies in *Figure 2*. This graph clearly demonstrates the importance of the relationship of junction temperature to device failure rate. For example, using the 0.99 eV line, a 30° rise in junction temperature, say from 130°C to 160°C, results in a 10 to 1 increase in failure rate.



TL/H/9312-2

FIGURE 2. Failure Rate as a Function of Junction Temperature

DEVICE THERMAL CAPABILITIES

There are many factors which affect the thermal capability of an integrated circuit. To understand these we need to understand the predominant paths for heat to transfer out of the integrated circuit package. This is illustrated by *Figures 3 and 4*.

Figure 3 shows a cross-sectional view of an assembled integrated circuit mounted into a printed circuit board.

Figure 4 is a flow chart showing how the heat generated at the power source, the junctions of the integrated circuit

flows from the chip to the ultimate heat sink, the ambient environment. There are two predominant paths. The first is from the die to the die attach pad to the surrounding package material to the package lead frame to the printed circuit board and then to the ambient. The second path is from the package directly to the ambient air.

Improving the thermal characteristics of any stage in the flow chart of *Figure 4* will result in an improvement in device thermal characteristics. However, grouping all these characteristics into one equation determining the overall thermal capability of an integrated circuit/package/environmental condition is possible. The equation that expresses this relationship is:

$$T_J = T_A + P_D (\theta_{JA})$$

Where: T_J = Die junction temperature

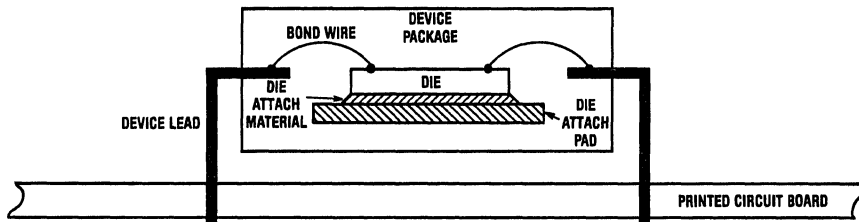
T_A = Ambient temperature in the vicinity device

P_D = Total power dissipation (in watts)

θ_{JA} = Thermal resistance junction-to-ambient

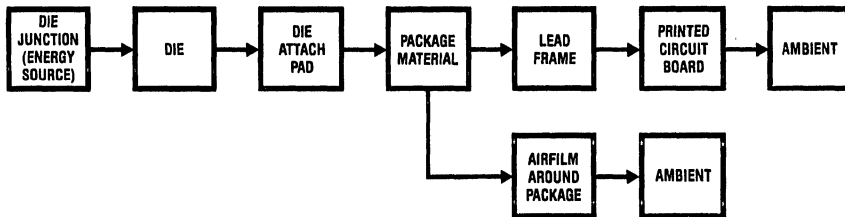
θ_{JA} , the thermal resistance from device junction-to-ambient temperature, is measured and specified by the manufacturers of integrated circuits. National Semiconductor utilizes special vehicles and methods to measure and monitor this parameter. All circuit data sheets specify the thermal characteristics and capabilities of the packages available for a given device under specific conditions—these package power ratings directly relate to thermal resistance junction-to-ambient or θ_{JA} .

Although National provides these thermal ratings, it is critical that the end user understand how to use these numbers to improve thermal characteristics in the development of his system using IC components.



TL/H/9312-3

FIGURE 3. Integrated Circuit Soldered Into a Printed Circuit Board (Cross-Sectional View)



TL/H/9312-4

FIGURE 4. Thermal Flow (Predominant Paths)

DETERMINING DEVICE OPERATING JUNCTION TEMPERATURE

From the above equation the method of determining actual worst-case device operating junction temperature becomes straightforward. Given a package thermal characteristic, θ_{JA} , worst-case ambient operating temperature, $T_A(\max)$, the only unknown parameter is device power dissipation, P_D . In calculating this parameter, the dissipation of the integrated circuit due to its own supply has to be considered, the dissipation within the package due to the external load must also be added. The power associated with the load in a dynamic (switching) situation must also be considered. For example, the power associated with an inductor or a capacitor in a static versus dynamic (say, 1 MHz) condition is significantly different.

The junction temperature of a device with a total package power of 600 mW at 70°C in a package with a thermal resistance of 63°C/W is 108°C.

$$T_J = 70^\circ\text{C} + (63^\circ\text{C}/\text{W}) \times (0.6\text{W}) = 108^\circ\text{C}$$

The next obvious question is, "how safe is 108°C?"

MAXIMUM ALLOWABLE JUNCTION TEMPERATURES

What is an acceptable maximum operating junction temperature is in itself somewhat of a difficult question to answer. Many companies have established their own standards based on corporate policy. However, the semiconductor industry has developed some defacto standards based on the device package type. These have been well accepted as numbers that relate to reasonable (acceptable) device lifetimes, thus failure rates.

National Semiconductor has adopted these industry-wide standards. For devices fabricated in a molded package, the maximum allowable junction temperature is 150°C. For these devices assembled in ceramic or cavity DIP packages, the maximum allowable junction temperature is 175°C. The numbers are different because of the differences in package types. The thermal strain associated with the die package interface in a cavity package is much less than that exhibited in a molded package where the integrated circuit chip is in direct contact with the package material.

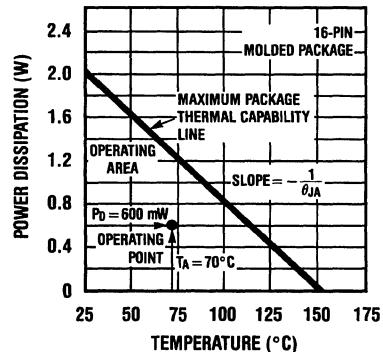
Let us use this new information and our thermal equation to construct a graph which displays the safe thermal (power) operating area for a given package type. Figure 5 is an example of such a graph. The end points of this graph are easily determined. For a 16-pin molded package, the maximum allowable temperature is 150°C; at this point no power dissipation is allowable. The power capability at 25°C is 1.98W as given by the following calculation:

$$P_D @ 25^\circ\text{C} = \frac{T_J(\max) - T_A}{\theta_{JA}} = \frac{150^\circ\text{C} - 25^\circ\text{C}}{63^\circ\text{C}/\text{W}} = 1.98\text{W}$$

The slope of the straight line between these two points is minus the inversion of the thermal resistance. This is referred to as the derating factor.

$$\text{Derating Factor} = -\frac{1}{\theta_{JA}}$$

As mentioned, Figure 5 is a plot of the safe thermal operating area for a device in a 16-pin molded DIP. As long as the intersection of a vertical line defining the maximum ambient temperature (70°C in our previous example) and maximum device package power (600 mW) remains below the maximum package thermal capability line the junction temperature will remain below 150°C—the limit for a molded package. If the intersection of ambient temperature and package power falls on this line, the maximum junction temperature will be 150°C. Any intersection that occurs above this line will result in a junction temperature in excess of 150°C and is not an appropriate operating condition.



TL/H/9312-5

FIGURE 5. Package Power Capability vs Temperature

The thermal capabilities of all integrated circuits are expressed as a power capability at 25°C still air environment with a given derating factor. This simply states, for every degree of ambient temperature rise above 25°C, reduce the package power capability stated by the derating factor which is expressed in mW/°C. For our example—a θ_{JA} of 63°C/W relates to a derating factor of 15.9 mW/°C.

FACTORS INFLUENCING PACKAGE THERMAL RESISTANCE

As discussed earlier, improving any portion of the two primary thermal flow paths will result in an improvement in overall thermal resistance junction-to-ambient. This section discusses those components of thermal resistance that can be influenced by the manufacturer of the integrated circuit. It also discusses those factors in the overall thermal resistance that can be impacted by the end user of the integrated circuit. Understanding these issues will go a long way in understanding chip power capabilities and what can be done to insure the best possible operating conditions and, thus, best overall reliability.

Die Size

Figure 6 shows a graph of our 16-pin DIP thermal resistance as a function of integrated circuit die size. Clearly, as the chip size increases the thermal resistance decreases—this relates directly to having a larger area with which to dissipate a given power.

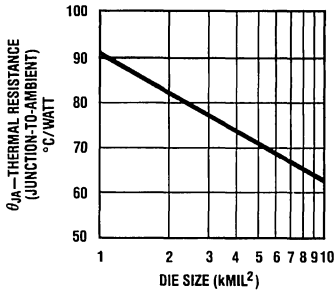


FIGURE 6. Thermal Resistance vs Die Size

TL/H/9312-6

Lead Frame Material

Figure 7 shows the influence of lead frame material (both die attach and device pins) on thermal resistance. This graph compares our same 16-pin DIP with a copper lead frame, a Kovar lead frame, and finally an Alloy 42 type lead frame—these are lead frame materials commonly used in the industry. Obviously the thermal conductivity of the lead frame material has a significant impact in package power capability. Molded interface circuits from National Semiconductor use the copper lead frame exclusively.

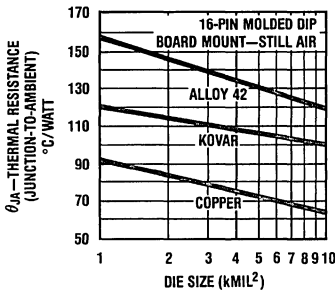


FIGURE 7. Thermal Resistance vs Lead Frame Material

TL/H/9312-7

Board vs Socket Mount

One of the major paths of dissipating energy generated by the integrated circuit is through the device leads. As a result of this, the graph of Figure 8 comes as no surprise. This compares the thermal resistance of our 16-pin package soldered into a printed circuit board (board mount) compared to the same package placed in a socket (socket mount). Adding a socket in the path between the PC board and the device adds another stage in the thermal flow path, thus increasing the overall thermal resistance. The thermal capabilities of National Semiconductor's interface circuits are specified assuming board mount conditions. If the devices are placed in a socket the thermal capabilities should be reduced by approximately 5% to 10%.

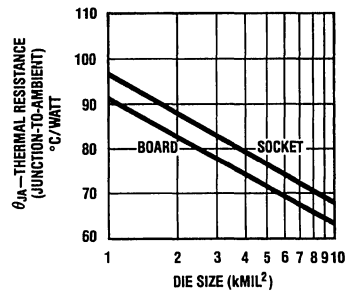


FIGURE 8. Thermal Resistance vs Board or Socket Mount

TL/H/9312-8

Air Flow

When a high power situation exists and the ambient temperature cannot be reduced, the next best thing is to provide air flow in the vicinity of the package. The graph of Figure 9 illustrates the impact this has on thermal resistance. This graph plots the relative reduction in thermal resistance normalized to the still air condition for our 16-pin molded DIP. The thermal ratings on National Semiconductor's interface circuits data sheets relate to the still air environment.

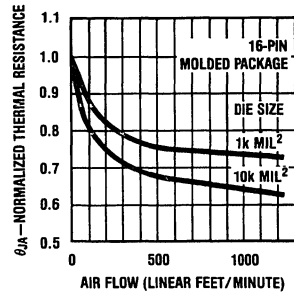


FIGURE 9. Thermal Resistance vs Air Flow

TL/H/9312-9

Other Factors

A number of other factors influence thermal resistance. The most important of these is using thermal epoxy in mounting ICs to the PC board and heat sinks. Generally these techniques are required only in the very highest of power applications.

Some confusion exists between the difference in thermal resistance junction-to-ambient (θ_{JA}) and thermal resistance junction-to-case (θ_{JC}). The best measure of actual junction temperature is the junction-to-ambient number since nearly all systems operate in an open air environment. The only situation where thermal resistance junction-to-case is important is when the entire system is immersed in a thermal bath and the environmental temperature is indeed the case temperature. This is only used in extreme cases and is the exception to the rule and, for this reason, is not addressed in this application note.

NATIONAL SEMICONDUCTOR PACKAGE CAPABILITIES

Figures 10 and 11 show composite plots of the thermal characteristics of the most common package types in the National Semiconductor Linear Circuits product family. Figure 10 is a composite of the copper lead frame molded package. Figure 11 is a composite of the ceramic (cavity) DIP using poly die attach. These graphs represent board mount still air thermal capabilities. Another, and final, thermal resistance trend will be noticed in these graphs. As the number of device pins increase in a DIP the thermal resistance decreases. Referring back to the thermal flow chart, this trend should, by now, be obvious.

RATINGS ON INTERFACE CIRCUITS DATA SHEETS

In conclusion, all National Semiconductor Linear Products define power dissipation (thermal) capability. This information can be found in the Absolute Maximum Ratings section of the data sheet. The thermal information shown in this application note represents average data for characterization of the indicated package. Actual thermal resistance can vary from $\pm 10\%$ to $\pm 15\%$ due to fluctuations in assembly quality, die shape, die thickness, distribution of heat sources on the die, etc. The numbers quoted in the linear data

sheets reflect a 15% safety margin from the average numbers found in this application note. Insuring that total package power remains under a specified level will guarantee that the maximum junction temperature will not exceed the package maximum.

The package power ratings are specified as a maximum power at 25°C ambient with an associated derating factor for ambient temperatures above 25°C. It is easy to determine the power capability at an elevated temperature. The power specified at 25°C should be reduced by the derating factor for every degree of ambient temperature above 25°C. For example, in a given product data sheet the following will be found:

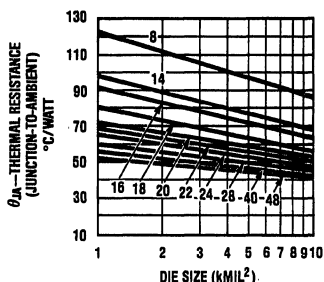
Maximum Power Dissipation* at 25°C
 Cavity Package 1509 mW
 Molded Package 1476 mW

* Derate cavity package at 10 mW/°C above 25°C; derate molded package at 11.8 mW/°C above 25°C.

If the molded package is used at a maximum ambient temperature of 70°C, the package power capability is 945 mW.

$$P_D @ 70^\circ\text{C} = 1476 \text{ mW} - (11.8 \text{ mW}/^\circ\text{C}) \times (70^\circ\text{C} - 25^\circ\text{C}) = 945 \text{ mW}$$

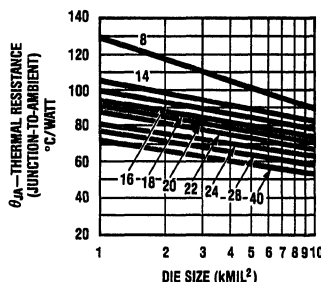
**Molded (N Package) DIP*
 Copper Leadframe—HTP
 Die Attach Board Mount—
 Still Air**



*Packages from 8- to 20-pin 0.3 mil width TL/H/9312-10
 22-pin 0.4 mil width
 24- to 40-pin 0.6 mil width

FIGURE 10. Thermal Resistance vs Die Size vs Package Type (Molded Package)

**Cavity (J Package) DIP*
 Poly Die Attach Board
 Mount—Still Air**



*Packages from 8- to 20-pin 0.3 mil width TL/H/9312-11
 22-pin 0.4 mil width
 24- to 48-pin 0.6 mil width

FIGURE 11. Thermal Resistance vs Die Size vs Package Type (Cavity Package)

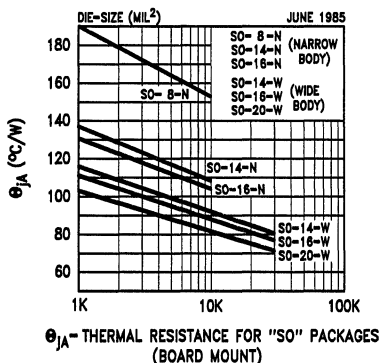


FIGURE 12

TL/H/9312-12



APPENDIX F

How to Get the Right Information From a Data Sheet

Not All Data Sheets Are Created Alike, and False Assumptions Could Cost an Engineer Time and Money

By Robert A. Pease

When a new product arrives in the marketplace, it hopefully will have a good, clear data sheet with it.

The data sheet can show the prospective user how to apply the device, what performance specifications are guaranteed and various typical applications and characteristics. If the data-sheet writer has done a good job, the user can decide if the product will be valuable to him, exactly how well it will be of use to him and what precautions to take to avoid problems.

SPECIFICATIONS

The most important area of a data sheet specifies the characteristics that are guaranteed—and the test conditions that apply when the tests are done. Ideally, all specifications that the users will need will be spelled out clearly. If the product is similar to existing products, one can expect the data sheet to have a format similar to other devices.

But, if there are significant changes and improvements that nobody has seen before, then the writer must clarify what is meant by each specification. Definitions of new phrases or characteristics may even have to be added as an appendix.

For example, when fast-settling operational amplifiers were first introduced, some manufacturers defined settling time as the time after slewing before the output finally enters and stays within the error-band; but other manufacturers included the slewing time in their definition. Because both groups made their definitions clear, the user was unlikely to be confused or misled.

However, the reader ought to be on the alert. In a few cases, the data-sheet writer is playing a specsmanship game, and is trying to show an inferior (to some users) aspect of a product in a light that makes it look superior (which it may be, to a couple of users).

GUARANTEES

When a data sheet specifies a guaranteed minimum value, what does it mean? An assumption might be made that the manufacturer has actually tested that specification and has great confidence that no part could fail that test and still be shipped. Yet that is not always the case.

For instance, in the early days of op amps (20 years ago), the differential-input impedance might have been guaranteed at 1 M Ω —but the manufacturer obviously did not measure the impedance. When a customer insisted, “I have to know how you measure this impedance,” it had to be explained that the impedance was not measured, but that the base current was. The correlation between I_b and Z_{in} permitted the substitution of this simple dc test for a rather messy, noisy, hard-to-interpret test.

Every year, for the last 20 years, manufacturers have been trying to explain, with varying success, why they do not measure the Z_{in} *per se*, even though they do guarantee it.

In other cases, the manufacturer may specify a test that can be made only on the die as it is probed on the wafer, but cannot be tested after the die is packaged because that signal is not accessible any longer. To avoid frustrating and confusing the customer, some manufacturers are establishing two classes of guaranteed specifications:

- The tested limit represents a test that cannot be doubted, one that is actually performed directly on 100 percent of the devices, 100 percent of the time.
- The design limit covers other tests that may be indirect, implicit or simply guaranteed by the inherent design of the device, and is unlikely to cause a failure rate (on that test), even as high as one part per thousand.

Why was this distinction made? Not just because customers wanted to know which specifications were guaranteed by testing, but because the quality-assurance group insisted that it was essential to separate the tested guarantees from the design limits so that the AQL (assurance-quality level) could be improved from 0.1 percent to down below 100 ppm.

Some data sheets guarantee characteristics that are quite expensive and difficult to test (even harder than noise) such as long-term drift (20 ppm or 50 ppm over 1,000 hours).

The data sheet may not tell the reader if it is measured, tested or estimated. One manufacturer may perform a 100-percent test, while another states, “Guaranteed by sample testing.” This is not a very comforting assurance that a part is good, especially in a critical case where only a long-term test can prove if the device did meet the manufacturer’s specification. If in doubt, question the manufacturer.

TYPICALS

Next to a guaranteed specification, there is likely to be another in a column labeled “typical”.

It might mean that the manufacturer once actually saw one part as good as that. It could indicate that half the parts are better than that specification, and half will be worse. But it is equally likely to mean that, five years ago, half the parts were better and half worse. It could easily signify that a few parts might be slightly better, and a few parts a lot worse; after all, if the noise of an amplifier is extremely close to the theoretical limit, one cannot expect to find anything much better than that, but there will always be a few noisy ones.

If the specification of interest happens to be the bias current (I_b) of an op amp, a user can expect broad variations. For example, if the specification is 200 nA maximum, there might be many parts where I_b is 40 nA on one batch (where the beta is high), and a month later, many parts where the I_b is 140 nA when the beta is low.

Absolute Maximum Ratings (Note 11)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	+35V to -0.2V
Output Voltage	+6V to -1.0V
Output Current	10 mA
Storage Temperature,	
TO-46 Package	-76°F to +356°F
TO-92 Package	-76°F to +300°F

Lead Temp. (Soldering, 4 seconds) *	
TO-46 Package	+300°C
TO-92 Package	+260°C
Specified Operating Temp. Range (Note 2)	
	T_{MIN} to T_{MAX}
LM34, LM34A	-50°F to +300°F
LM34C, LM34CA	-40°F to +230°F
LM34D	+32°F to +212°F

DC Electrical Characteristics (Note 1, Note 6)

Parameter	Conditions	LM34A			LM34CA			Units (Max)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	T _A = +77°F T _A = 0°F T _A = T _{MAX} T _A = T _{MIN}	±0.4 ±0.6 ±0.8 ±0.8	±1.0 ±2.0 ±2.0		±0.4 ±0.6 ±0.8 ±0.8	±1.0 ±2.0	±2.0 ±3.0	°F °F °F °F
Nonlinearity (Note 8)	T _{MIN} ≤ T _A ≤ T _{MAX}	±0.35		±0.7	±0.30		±0.6	°F
Sensor Gain (Average Slope)	T _{MIN} ≤ T _A ≤ T _{MAX}	+10.0	+9.9, +10.1		+10.0		+9.9, +10.1	mV/°F, min mV/°F, max
Load Regulation (Note 3)	T _A = +77°F T _{MIN} ≤ T _A ≤ T _{MAX} 0 ≤ I _L ≤ 1 mA	±0.4 ±0.5	±1.0	±3.0	±0.4 ±0.5	±1.0	±3.0	mV/mA mV/mA
Line Regulation (Note 3)	T _A = +77°F 5V ≤ V _S ≤ 30V	±0.01 ±0.02	±0.05	±0.1	±0.01 ±0.02	±0.05	±0.1	mV/V mV/V
Quiescent Current (Note 9)	V _S = +5V, +77°F V _S = +5V V _S = +30V, +77°F V _S = +30V	75 131 76 132	90 92	160 163	75 76 116 117	90 92	139 142	μA μA μA μA
Change of Quiescent Current (Note 3)	4V ≤ V _S ≤ 30V, +77°F 5V ≤ V _S ≤ 30V	+0.5 +1.0	2.0	3.0	0.5 1.0	2.0	3.0	μA μA
Temperature Coefficient of Quiescent Current		+0.30		+0.5	+0.30		+0.5	μA/°F
Minimum Temperature for Rated Accuracy	In circuit of Figure 1, I _L = 0	+3.0		+5.0	+3.0		+5.0	°F
Long-Term Stability	T _j = T _{MAX} for 1000 hours	±0.16			±0.16			°F

Note 1: Unless otherwise noted, these specifications apply: -50°F ≤ T_j ≤ +300°F for the LM34 and LM34A; -40°F ≤ T_j ≤ +230°F for the LM34C and LM34CA; and +32°F ≤ T_j ≤ +212°F for the LM34D. V_S = +5 Vdc and I_{L,OAD} = 50 μA in the circuit of Figure 2; +6 Vdc for LM34 and LM34A for 230°F ≤ T_j ≤ 300°F. These specifications also apply from +5°F to T_{MAX} in the circuit of Figure 1.

Note 2: Thermal resistance of the TO-46 package is 292°F/W junction to ambient and 43°F/W junction to case. Thermal resistance of the TO-92 package is 324°F/W junction to ambient.

Note 3: Regulation is measured at constant junction temperature using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested limits are guaranteed and 100% tested in production.

Note 5: Design limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specification in **BOLDFACE TYPE** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10 mV/°F times the device's case temperature at specified conditions of voltage, current, and temperature (expressed in °F).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of Figure 1.

Note 10: Contact factory for availability of LM34CAZ.

**** Note 11:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions (see Note 1).

A Point-By-Point Look

Let's look a little more closely at the data sheet of the National Semiconductor LM34, which happens to be a temperature sensor.

Note 1 lists the nominal test conditions and test circuits in which all the characteristics are defined. Some additional test conditions are listed in the column "Conditions", but Note 1 helps minimize the clutter.

Note 2 gives the thermal impedance, (which may also be shown in a chart or table).

Note 3 warns that an output impedance test, if done with a long pulse, could cause significant self-heating and thus, error.

Note 6 is intended to show which specs apply at all rated temperatures.

Note 7 is the definition of the "Accuracy" spec, and Note 8 the definition for non-linearity. Note 9 states in what test circuit the quiescent current is defined. Note 10 indicates that one model of the family may not be available at the time of printing (but happens to be available now), and Note 11 is the definition of Absolute Max Ratings.

* Note—the "4 seconds" soldering time is a new standard for plastic packages.

** Note—the wording of Note 11 has been revised—this is the best wording we can devise, and we will use it on all future datasheets.

APPLICATIONS

Another important part of the data sheet is the applications section. It indicates the novel and conventional ways to use a device. Sometimes these applications are just little ideas to tweak a reader's mind. After looking at a couple of applications, one can invent other ideas that are useful. Some applications may be of no real interest or use.

In other cases, an application circuit may be the complete definition of the system's performance; it can be the test circuit in which the specification limits are defined, tested and guaranteed. But, in all other instances, the performance of a typical application circuit is not guaranteed, it is only typical. In many circumstances, the performance may depend on external components and their precision and matching. Some manufacturers have added a phrase to their data sheets:

"Applications for any circuits contained in this document are for illustration purposes only and the manufacturer makes no representation or warranty that such applications will be suitable for the use indicated without further testing or modification."

In the future, manufacturers may find it necessary to add disclaimers of this kind to avoid disappointing users with circuits that work well, much of the time, but cannot be easily guaranteed.

The applications section is also a good place to look for advice on quirks—potential drawbacks or little details that may not be so little when a user wants to know if a device will actually deliver the expected performance.

For example, if a buffer can drive heavy loads and can handle fast signals cleanly (at no load), the maker isn't doing anybody any favors if there is no mention that the distortion goes sky-high if the rated load is applied.

Another example is the application hint for the LF156 family: "Exceeding the negative common-mode limit on either input will cause a reversal of the phase to output and force the amplifier output to the corresponding high or low state. Exceeding the negative common-mode limit on both inputs will force the amplifier output to a high state. In neither case does a latch occur, since raising the input back within the common-mode range again puts the input stage and, thus the amplifier, in a normal operating mode."

That's the kind of information a manufacturer should really give to a data-sheet reader because no one could ever guess it.

Sometimes, a writer slips a quirk into a characteristic curve, but it's wiser to draw attention to it with a line of text. This is because it's better to make the user sad before one gets started, rather than when one goes into production. Conversely, if a user is going to spend more than 10 minutes using a new product, one ought to spend a full five minutes reading the entire data sheet.

FINE PRINT

What other fine print can be found on a data sheet? Sometimes the front page may be marked "advance" or "preliminary." Then on the back page, the fine print may say something such as:

"This data sheet contains preliminary limits and design specifications. Supplemental information will be published at a later date. The manufacturer reserves the right to make changes in the products contained in this document in order to improve design or performance and to supply the best possible products. We also assume no responsibility for the use of any circuits described herein, convey no license under any patent or other right and make no representation that the circuits are free from patent infringement."

In fact, after a device is released to the marketplace in a preliminary status, the engineers love to make small improvements and upgrades in specifications and characteristics, and hate to degrade a specification from its first published value—but occasionally that is necessary.

Another item in the fine print is the manufacturer's telephone number. Usually it is best to refer questions to the local sales representative or field-applications engineer, because they may know the answer or they may be best able to put a questioner in touch with the right person at the factory.

Occasionally, the factory's applications engineers have all the information. Other times, they have to bring in product engineers, test engineers or marketing people. And sometimes the answer can't be generated quickly—data have to be gathered, opinions solidified or policies formulated before the manufacturer can answer the question. Still, the telephone number is the key to getting the factory to help.

ORIGINS OF DATA SHEETS

Of course, historically, most data sheets for a class of products have been closely modeled on the data sheet of the forerunner of that class. The first data sheet was copied to make new versions.

That's the way it happened with the UA709 (the first monolithic op amp) and all its copies, as well as many other similar families of circuits.

Even today, an attempt is made to build on the good things learned from the past and add a few improvements when necessary. But, it's important to have real improvements, not just change for the sake of change.

So, while it's not easy to get the format and everything in it exactly right to please everybody, new data sheets are continually surfacing with new features, applications ideas, specifications and aids for the user. And, if the users complain loudly enough about misleading or inadequate data sheets, they can help lead the way to change data sheets. That's how many of today's improvements came about—through customer demand.

Who writes data sheets? In some cases, a marketing person does the actual writing and engineers do the checking. In other companies, the engineer writes, while marketing people and other engineers check. Sometimes, a committee seems to be doing the writing. None of these ways is necessarily wrong.

For example, one approach might be: The original designer of the product writes the data sheet (inside his head) at the same time the product is designed. The concept here is, if one can't find the proper ingredients for a data sheet—good applications, convenient features for the user and nicely tested specifications as the part is being designed—then maybe it's not a very good product until all those ingredients are completed. Thus, the collection of raw materials for a good data sheet is an integral part of the design of a product. The actual assembly of these materials is an art which can take place later.

WHEN TO WRITE DATA SHEETS

A new product becomes available. The applications engineers start evaluating their application circuits and the test engineers examine their production test equipment.

But how can the users evaluate the new device? They have to have a data sheet—which is still in the process of being written. Every week, as the data sheet writer tries to polish and refine the incipient data sheet, other engineers are reporting, "These spec limits and conditions have to be revised," and, "Those application circuits don't work like we thought they would; we'll have one running in a couple of days." The marketing people insist that the data sheet must be finalized and frozen right away so that they can start printing copies to go out with evaluation samples.

These trying conditions may explain why data sheets always seem to have been thrown together under panic conditions and why they have so many rough spots. Users should be aware of the conflicting requirements: Getting a data sheet "as completely as possible" and "as accurately as possible" is compromised if one wants to get the data sheet "as quickly as possible."

The reader should always question the manufacturer. What are the alternatives? By not asking the right question, a misunderstanding could arise; getting angry with the manufacturer is not to anyone's advantage.

Robert Pease has been staff scientist at National Semiconductor Corp., Santa Clara, Calif., for eleven years. He has designed numerous op amps, data converters, voltage regulators and analog-circuit functions.

Appendix G

Obsolete Product Replacement Guide

Some device types, individual temperature grades and package options have been discontinued. This guide is provided to help design engineers select and specify an appropriate alternative.

NSC Part Number	Replacement	Note
ADB1200	ADC3711	2
AF100	None	
AF121	None	
AF134	None	
DAC1200/1201	DAC1265	2
DH3467	None	
DH3725	None	
DS8627	None	
DS8628	None	
LF352	LM3631	2
LF400	None	
LF401	None	
LF13300	ADC3711	2
LF13741	None	
LH0001	LM4250	2
LH0005/LH0005A	LH0003	2
LH0020	LH0101	2
LH0022	AD506	2
LH0023	AD585	2
LH0037	LH0036	3
LH0038	None	
LH0043	AD583	2
LH0044	OP07	2
LH0045	None	
LH0052	OP100	2
LH0053	None	
LH0061	None	
LH0062	HA5162	2
LH0075	None	
LH0076	None	
LH0082	None	
LH0084	None	
LH0086	None	
LH0091	None	
LH0132	LH0032	2
LH2011	LM11	2
LH2101	LM101	2
LH2108	LM108	2
LH2110	LM110	2
LH2201A	LM201A	2

NSC Part Number	Replacement	Note
LH2208	LM208	2
LH2208A	LM208A	2
LH2301	LM301	2
LH2308	LM308	2
LH2310	LM310	2
LH4003	EL2031	2
LH4006	CLC110	2
LH4008	BB3553	2
LH4009	BB3553	2
LH4010	EL2004	2
LH4011	None	
LH4012	None	
LH4033	LH0033	2
LH4063	LH0063	2
LH4101	LM6313	2
LH4105	LM6218	2
LH4106	LM6313	2
LH4117	LM6181	2
LH4124	LM6181	2
LH4141	OPA654	2
LH4161	LM6361	2
LH4162	LM6361	2
LH4200	CLC104	2
LH4201	CLC104	2
LH4266	None	
LH4267	None	
LH4810	None	
LH4860	None	
LH7001	None	
LH7070	LH0070	2
LH24250	LM11	2
LM170/270/370	LM13600N	2
LM171/271/371	None	
LM172/272/372	None	
LM173/273/373	None	
LM174/274/374	None	
LM175/275/375	None	
LM216/316	LM11	2
LM363	None	
LM388N-2/N-3	LM388N-1	2
LM377N	LM2877P	3

Note 1: Pin for Pin replacement.

Note 2: FUNCTIONAL REPLACEMENT: Consult datasheet to determine suitability of the replacement for specific application.

Note 3: SIMILAR DEVICE with superior performance: Consult datasheet to determine suitability of the replacement for specific application.



NSC Part Number	Replacement	Note
LM378N	LM2878P	3
LM379	LM2879T	3
LM322H	LM122H	2
LM565CH	LM565H	2
LM567CH	LM567H	2
LM592	None	
LM733	None	
LM776	None	
LM1014	None	
LM1017	None	
LM1019	None	
LM1800	None	
LM1801	None	
LM1822	LM1823	3
LM1812	None	
LM1837	None	
LM1863	LM1868	3
LM1866	None	
LM1870	None	
LM1871	None	
LM1872	None	

NSC Part Number	Replacement	Note
LM1877N-1/N-2/N-3	LM1877N-9	2
LM1880	None	
LM1884	None	
LM1889	None	
LM1895	LM1896	3
LM1897	None	
LM1965	LM1865	3
LM2002	None	
LM2005	None	
LM2065	LM1865	3
LM2895	LM2896	3
LM2905N	LM3905N	2
LM3011	None	
LM3064	None	
LM3075	None	
LM3820	None	
LM4500	None	
LM776	None	
LMC669	None	
MH0007	CTS0007	1
MM54240	None	

Note 1: Pin for Pin replacement

Note 2: FUNCTIONAL REPLACEMENT: Consult datasheet to determine suitability of the replacement for specific application.

Note 3: SIMILAR DEVICE with superior performance: Consult datasheet to determine suitability of the replacement for specific application.

Appendix H

Safe Operating Areas for Peripheral Drivers

National Semiconductor
Application Note 213
Bill Fowler

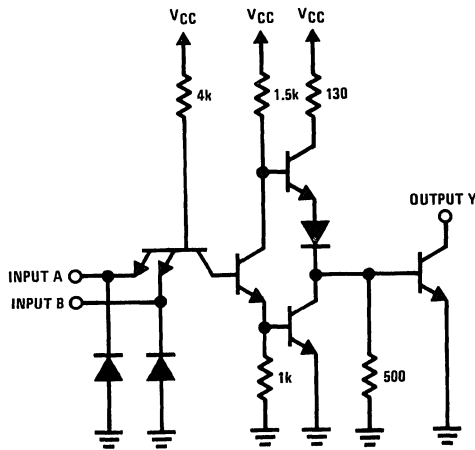


AN-213

Peripheral Drivers is a broad definition given to Interface Power devices. The devices generally have open-collector output transistors that can switch hundreds of milliamps at high voltage, and are driven by standard Digital Logic gates. They serve many applications such as: Relay Drivers, Printer Hammer Drivers, Lamp Drivers, Bus Drivers, Core Memory Drivers, Voltage Level Transistors, and etc. Most IC devices have a specified maximum load such as one TTL gate can drive ten other TTL gates. Peripheral drivers have many varied load situations depending on the application, and requires the design engineer to interpret the limitations of the device vs its application. The major considerations are *Peak Current*, *Breakdown Voltage*, and *Power Dissipation*.

OUTPUT CURRENT AND VOLTAGE CHARACTERISTICS

Figure 1 shows the circuit of a typical peripheral driver, the DS75451. The circuit is equivalent to a TTL gate driving a 300 mA output transistor. Figure 2 shows the characteristics of the output transistor when it is ON and when it is OFF. The output transistor is capable of sinking more than one amp of current when it is ON, and is specified at a $V_{OL} = 0.7V$ at 300 mA. The output transistor is also specified to operate with voltages up to 30V without breaking down, but there is more to that as shown by the breakdown voltages labeled BVCES, BVCEER, and LVCEO.

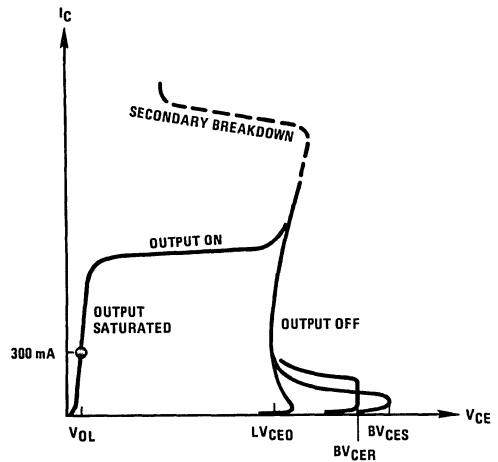


TL/F/5860-1

FIGURE 1. Typical Peripheral Driver DS75451

BVCEER corresponds to the breakdown voltage when the output transistor is held off by the lower output transistor of the TTL gate, as would happen if the power supply (V_{CC}) was 5V. BVCES corresponds to the breakdown voltage when the output transistor is held off by the 500 resistor, as would happen if the power supply (V_{CC}) was off (0V). LVCEO corresponds to the breakdown voltage of the output transistor if it could be measured with the base open. LVCEO can be measured by exceeding the breakdown voltage BVCES and measuring the voltage at output currents of 1 to 10 mA on a transistor curve tracer (LVCEO is some-

times measured in an Inductive Latch-Up Test). Observe that all breakdown voltages converge on LVCEO at high currents, and that destructive secondary breakdown occurred (shown as dotted line) at high currents and high voltage corresponding to exceeding the power dissipation of the device. The characteristics of secondary breakdown voltage vary with the length of time the condition exists, device temperature, voltage, and current.



TL/F/5860-2

FIGURE 2. Output Characteristics ON and OFF

OUTPUT TRANSFER CHARACTERISTICS VS INDUCTIVE AND CAPACITIVE LOADS

Figure 3 shows the switching transfer characteristics superimposed on the DC characteristics of the output transistor for an inductive load. Figure 4 shows the switching transfer characteristics for a capacitor load. In both cases in these examples, the load voltage (V_B) exceeds LVCEO. When the output transistor turns on with an inductive load the initial current through the load is 0 mA, and the transfer curve switches across to the left (V_{OL}) and slowly charges the inductor. When the output transistor turns off with an inductive load, the initial current is I_{OL} , which is sustained by the inductor and the transfer curve switches across to the right (V_B) through a high current and high voltage area which exceeds LVCEO and instead of turning off (shown as dotted line) the device goes into secondary breakdown. It is generally not a good practice to let the output transistor's voltage exceed LVCEO with an inductive load.

In a similar case with a capacitive load shown in Figure 4, the switching transfer characteristics rotate counter-clockwise through the DC characteristics, unlike the inductive load which rotated clockwise. Even though the switching transfer curve exceeds LVCEO, it didn't go into secondary breakdown. Therefore, it is an acceptable practice to let the output transistor voltage exceed LVCEO, but not exceed BVCEER with a capacitive load.

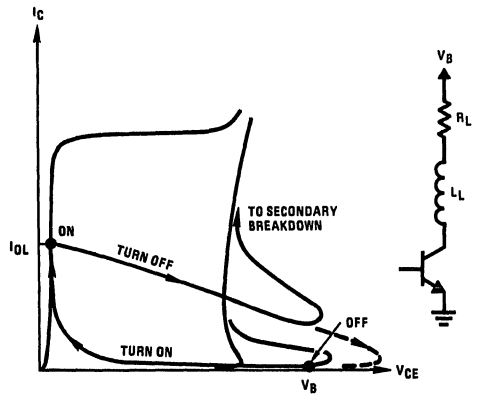


FIGURE 3. Inductive Load Transfer Characteristics
TL/F/5860-3

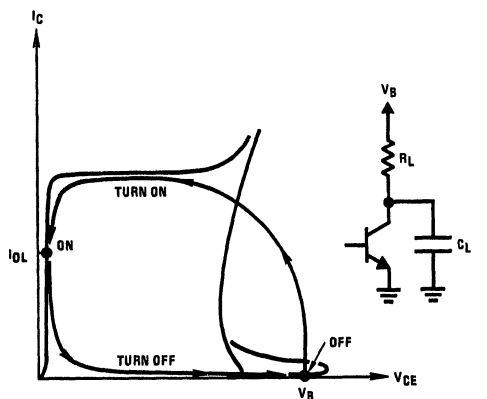


FIGURE 4. Capacitive Load Transfer Characteristics

Figure 5 shows an acceptable application with an inductive load. The load voltage (V_B) is less than V_{CE0} , and the inductive voltage spike caused by the initial inductive current is quenched by a diode connected to V_B .

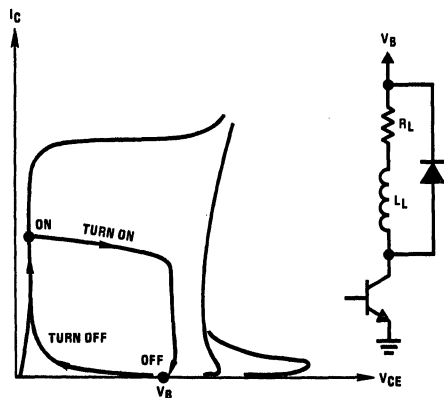


FIGURE 5. Inductive Load Transfer Characteristics Clamped by Diode
TL/F/5860-5

Figure 6 shows the switching transfer characteristics of a capacitive load which leads to secondary breakdown. This condition occurs due to high sustained currents, not breakdown voltage. In this example, the large capacitor prevented the output transistor from switching fast enough through the high current and high voltage region; in turn the power dissipation of the device was exceeded and the output transistor went into secondary breakdown.

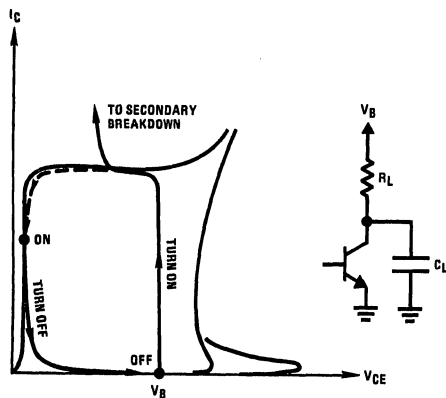


FIGURE 6. Capacitive Load Transfer Characteristics

Figure 7 shows another method of quenching the inductive voltage spike caused by the initial inductive current. This method dampens the switching response by the addition of R_D and C_D . The values of R_D and C_D are chosen to critically dampen the values of R_L and L_L ; this will limit the output voltage to $2 \times V_B$.

$$\frac{L_L}{(R_L + R_D)} \times \sqrt{\frac{1}{L_L C_D}} \leq 0.5$$

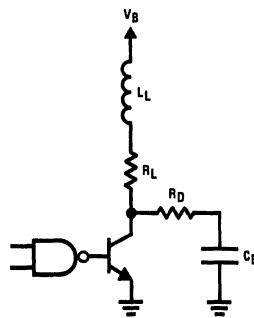


FIGURE 7. Inductive Load Dampened by Capacitor

Figure 8 shows a method of reducing high sustaining currents in a capacitive load. R_D in series with the capacitor (C_L) will limit the switching transistor without affecting final amplitude of the output voltage, since the IR drop across R_D will be zero after the capacitor is charged.

As an additional warning, beware of parasitic reactance. If the driver's load is located some distance from the driver (as an example: on the inclosure panel or through a con-

necting cable) there will be additional inductance and capacitance which may cause ringing on the driver output which will exceed LVCEO or transient current that exceeds the sustaining current of the driver. A 300 mA current through a small inductor can cause a good size transient voltage, as compared with 20 mA transient current observed with TTL gates. For no other reason than to reduce the noise associated with these transients, it is good practice to dampen the driver's output.

In conclusion, transient voltage associated with inductive loads can damage the peripheral driver, and transient currents associated with capacitive loads can also damage the driver. In some instances the device may not exhibit failure with the first switching cycle, but its conditions from ON to OFF will worsen after many cycles. In some cases the device will recover after the power has been turned off, but its long term reliability may have been degraded.

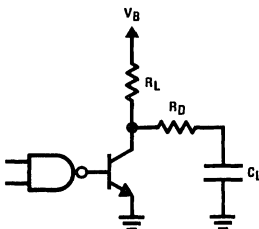
POWER DISSIPATION

Power Dissipation is limited by the IC Package Thermal Reactance and the external thermal reactance of the environment (PC board, heat sink, circulating air, etc.). Also, the power dissipation is limited by the maximum allowable junction temperature of the device. There are two contributions to the power: the internal bias currents and voltage of the

device, and the power on the output of the device due to the Driver Load.

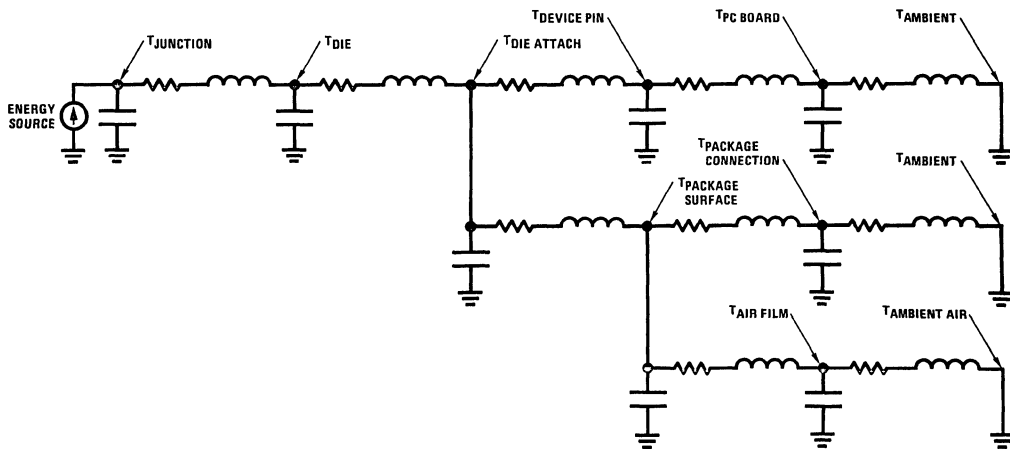
POWER LIMITATIONS OF PACKAGE

Figure 9 shows the equivalent circuit of a typical power device in its application. Power is shown equivalent to electrical current, thermal resistance is shown equivalent to electrical resistance, the electrical reactance C and L are equivalent to the capacity to store heat, and the propagation delay through the medium. There are two mediums of heat transfer: conduction through mass and radiant convection. Convection is insignificant compared with conduction and isn't shown in the thermal resistance circuits. From the point power is generated (device junction) there are three possible paths to the ultimate heat sink: 1) through the device leads; 2) through the device surface by mechanical connection; and 3) through the device surface to ambient air. In all cases, the thermal paths are like delay lines and have a corresponding propagation delay. The thermal resistance is proportional to the length divided by the cross sectional area of the material. The Thermal Inductance is proportional to the length of the material (copper, molding compound, etc.) and inversely proportional to the cross sectional area. The thermal capacity is proportional to the volume of the material.



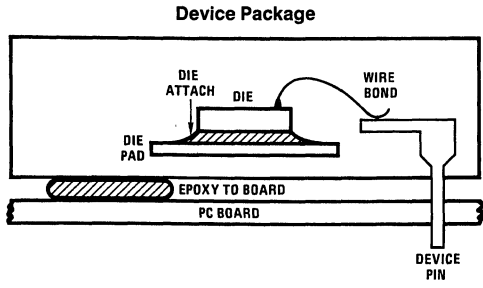
TL/F/5860-8

FIGURE 8. Capacitive Load with Current Limiting Resistor



TL/F/5860-9

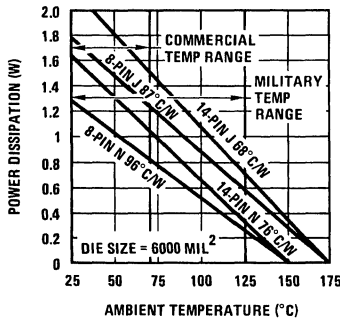
FIGURE 9. Thermal Reactance from Junction to Ambient



TL/F/5860-10

FIGURE 10. Components of Thermal Reactance for a Typical IC Package

National Semiconductor specifies the thermal resistance from device junction through the device leads soldered in a small PC board, measured in one cubic foot of still air. Figure 11 shows the maximum package power rating for an 8 pin Molded, an 8 pin Ceramic, 14 pin Molded and a 14 pin Ceramic package. The slope of the line corresponds to thermal resistance ($\phi_{JA} = \Delta P / \Delta T$).

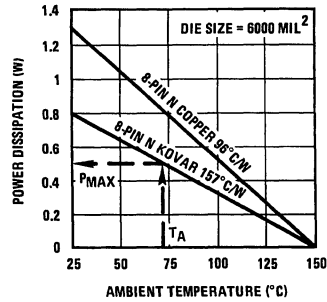


TL/F/5860-11

FIGURE 11. Maximum Package Power Rating

The maximum allowable junction temperature for ceramic packages is 175°C; operation above this temperature will reduce the reliability and life of the device below an acceptable level. At a temperature of 500°C the aluminum metallization paths on the die start to melt. The maximum allowable junction temperature for a molded device is 150°C, operations above this may cause the difference in thermal expansion between the molding compound and package lead frame to shear off the wire bonds from the die to the package lead. The industry standard for a molded device is 150°C, but National further recommends operation below 135°C if the device in its application will encounter a lot of thermal cycling (such as powered on and off over its life).

The way to determine the maximum allowable power dissipation from Figure 11, is to project a line from the maximum ambient temperature (T_A) of the application vertically (shown dotted in Figure 12), until the line intercepts the diagonal line of the package type, and then project a line (shown dotted) horizontally until the line intercepts the Power Dissipation Axis (P_{MAX}).

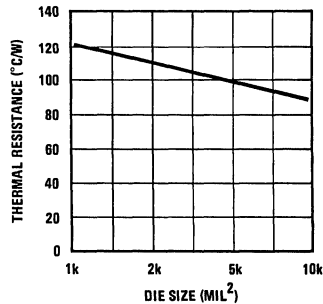


TL/F/5860-12

FIGURE 12. Maximum Package Rating Copper vs Kovar Lead Frame Packages

Figure 11 shows that 14 pin packages have less thermal resistance than 8 pin packages; which should be expected since it has more pins to conduct heat and has more surface area. Something that may not be expected is that the Thermal Resistance of the molded devices is comparable to the ceramic devices. The reason for the lower thermal resistance of the molded devices is the Copper lead frame, which is a better thermal conductor than the Kovar lead frame of the ceramic package. Almost all the peripheral drivers made by National Semiconductor are constructed with Copper lead frames (refer to ϕ_{JA} on the specific devices data sheet). The difference between the thermal resistance of Copper and Kovar in a molded package is shown in Figure 12.

Another variance in thermal resistance is the size of the IC die. If the contact area to the lead frame is greater, then the thermal resistance from the Die to the Lead Frame is reduced. This is shown in Figure 13. The thermal resistance shown in Figure 11 corresponds to die that are 6000 mil² in area.

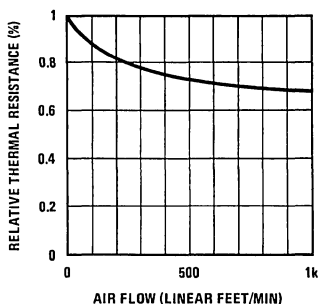


TL/F/5860-13

FIGURE 13. Thermal Resistance vs Die Size

In most applications the prime medium for heat conduction is through the device leads to the PC board, but the thermal resistance can be significantly improved by cooling air driven across the surface of the package. The conduction to air is limited by a stagnant film of air at the surface of the package. The film acts as an additional thermal resistance. The thickness of the film is proportional to its resistance. The thickness of the film is reduced by the velocity of the air

across the package as shown in *Figure 14*. In most cases, the thermal resistance is reduced 25% to 250 linear feet/min, and 30% at 500 linear feet/min, above 500 linear feet/min the improvement flattens out.



TL/F/5860-14

FIGURE 14. Thermal Resistance vs Air Velocity

The thermal resistance can also be improved by connecting the package to the PC board copper or by attaching metal wings to the package. The improvement by these means is outside the control of the IC manufacturer, but is available from the manufacturer of the heat sink device. If the IC is mounted in a socket rather than soldered to a PC board, the thermal resistance through the device leads will worsen. In most cases, the thermal resistance is increased by 20%; again this is a variable subject to the specific socket type.

The maximum package rating shown in this note corresponds to a 90% confidence level that the package will have thermal resistance equal to or less than the value shown. The thermal resistance varies $\pm 5\%$ about the mean due to variables in assembly and package material.

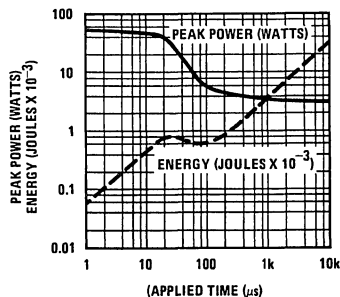
CALCULATIONS OF POWER DISSIPATION

Most IC devices (such as T²L) operate at power levels well below the device package rating, but peripheral drivers can easily be used at power levels that exceed the package rating unknowingly, if the power dissipation isn't calculated. As an example, the DS3654 Ten Bit Printer Driver could dissipate 3 watts (DC and, even more AC), and it is only in a 0.8 watt package. In this example, the device would be destroyed in moments, and may even burn a hole in the PC board it is mounted on. The DS3654 data sheet indicated that the 10 outputs could sink 300 mA with a V_{OL} of 1 volt, but it wasn't intended that all the outputs would be sinking this current at the same time, and if so, not for a long period. The use of the DS3654 requires that the power be calculated vs the duty cycle of the outputs.

The DC power dissipation is pretty obvious, but in another example, a customer used the DS3686 relay driver to drive 6.5h inductive load. The DS3687 has an internal clamp network to quench the inductive back swing at 60V. At 5 Hz the device dissipates 2 watts, with transient peaks up to 11 watts. After 15 minutes of operation, the driver succumbs to thermal overload and becomes non-functional. The DS3687 was intended for telephone relay, which in most applications switches 20 times a day.

Peripheral driver will dissipate peak power levels that greatly exceed the average DC power. This is due to the capacity of the die and package to consume the transient energy while still maintaining the junction temperature at a safe level.

This capacity is shown as a capacitor in *Figure 9*. In the lab (under a microscope) a device may be observed to glow orange around the parameter of the junction under excessive peak power without damage to the device. *Figure 15* shows a plot of maximum peak power vs applied time for the DS3654, and the same information plotted as energy vs applied time. To obtain these curves, the device leakage current when it switches off was used to monitor device limitation. Note in *Figure 15* there is a transition in the curve about 10 μ s. At this point, the thermal capacity of the die has been exceeded. The thermal delay to the next thermal capacity (the package) was too long, and limited the peak power. These levels are not suggested operating levels, but an example of a Peripheral Driver to handle peak transient power.

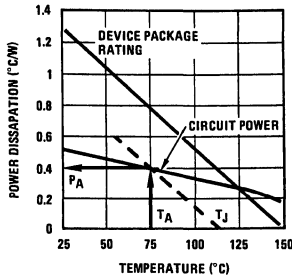


TL/F/5860-15

FIGURE 15. Peak Power and Energy vs the Period of Time the Power was Applied

To calculate power dissipation, the only information available to the design engineer is the parametric limits in the device data sheet, and the same information about the load reactance. If the calculations indicate the device is within its limits of power dissipation, then using those parametric limits is satisfactory. If the calculation of power dissipation is marginal, the parametric limits used in the calculations might be worst case at low temperature instead of high temperature due to a positive temperature coefficient (T_C) of resistance. IC resistors and resistors associated with the load generally have a positive T_C . On the other hand, diodes and transistor emitter base voltages have a negative T_C ; which may in some circuits negate the effect of the resistors T_C . Peripheral output transistors have a positive T_C associated with V_{OL} ; while output Darlington transistors have a negative T_C at low currents and may be flat at high currents. *Figure 16* shows an example of power dissipation vs temperature; note that the power dissipation at the application's maximum temperature (T_A) was less than the power dissipation at lower temperatures. Since maximum junction temperature is the concern of the calculation, then maximum ambient temperature power should be used. The junction temperature may be determined by projecting a line (shown dotted in *Figure 16*), with a slope proportional to ϕ_{JA} back to the horizontal axis (shown as T_J). If the point is below the curve then T_J will be less than 150°C. T_J must not exceed the maximum junction temperature for that package type. In this example, T_J is less than 150°C as required by a molded package. To calculate the power vs temperature, it is necessary to characterize the device parameters vs temperature. Unfortunately, this information is not always provided by IC manufacturers in the device data sheets. A method to calcu-

late I_{CC} vs temperature is to measure a device, then normalize the measurements vs the typical value for I_{CC} in the data sheet, then worst case the measurements by adding 30%. Thirty percent is normally the worst-case resistor tolerance that IC devices are manufactured to.



TL/F/5860-16

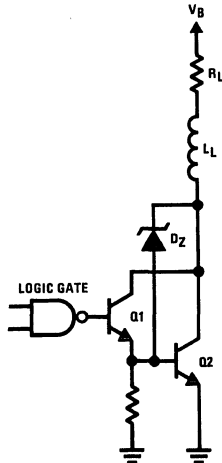
FIGURE 16. IC Power Dissipation vs Temperature

CALCULATION OF OUTPUT POWER WITH AN INDUCTIVE LOAD

For this example, the device output circuit is similar to the DS3654 (10-Bit Printer Solenoid Driver) and the DS3686 and DS3687 (Telephone Relay Driver) as shown in Figure 17. Special features of the circuit type are the Darlington output transistors Q1 and Q2 and the zener diode from the collector of Q1 to the base of Q2. The Darlington output requires very little drive from the logic gate driving it and in turn dissipates less power when the output is turned ON and OFF, than a single saturating transistor output would. The zener diode (D_Z) quenches the inductive backswing when the output is turned OFF.

Device and Load Characteristics Used for Power Calculation

V_{OL}	Output Voltage ON	1.5V
V_C	Output Clamp Voltage	65V
V_B	Load Voltage	30V
R_L	Load Resistance	120Ω
L_L	Load Inductance	5h
T_{ON}	Period ON	100 ms
T_{OFF}	Period OFF	100 ms
T	Total Period	200 ms



TL/F/5860-17

FIGURE 17. Peripheral Driver with Inductive Load

Refer to Figure 18 voltage and current waveforms corresponding to the power dissipation calculated for this example of an inductive load.

P_{ON} = Average power dissipation in device output when device is ON during total period (T)

$$\tau = \frac{L_L}{R_L} = \frac{5h}{120\Omega} = 41.7 \text{ ms}$$

$$I_L = \frac{V_B - V_{OL}}{R_L} = \frac{30 - 1.5}{120} = 237.5 \text{ mA}$$

$$I_P = I_L (1 - e^{-T_{ON}/\tau})$$

$$I_P = 237.5 \text{ mA} (1 - e^{-100 \text{ ms}/41.7 \text{ ms}})$$

$$I_P = 215.9 \text{ mA}$$

$$P_{ON} = V_{OL} \times I_L \times \frac{T_{ON}}{T} \left[1 - \int_0^{T_{ON}} \frac{e^{-t/\tau} dt}{T_{ON}} \right]$$

$$P_{ON} = V_{OL} \times I_L \times \frac{T_{ON}}{T} \left[1 - \frac{\tau}{T_{ON}} (1 - e^{-T_{ON}/\tau}) \right]$$

$$P_{ON} = 1.5 \times 237.5 \text{ mA} \times \frac{100}{200} \left[1 - \frac{41.7}{100} (1 - e^{-100/41.7}) \right]$$

$$P_{ON} = 110.6 \text{ mW}$$

P_{OFF} = Average power dissipation in device output when device is OFF during total period (T)

$$I_R = \frac{V_C - V_B}{R_L} = \frac{65 - 30}{120\Omega} = 291.7 \text{ mA}$$

$$t_x = \tau \ln \left(\frac{I_P + I_R}{I_R} \right)$$

$$t_x = 41.7 \text{ ms} \ln \left(\frac{215.9 + 291.7}{291.7} \right) = 23.1 \text{ ms}$$

$$P_{OFF} = V_C \times \frac{t_x}{T} \left[(I_P + I_R) \int_0^{t_x} \frac{e^{-t/\tau} dt}{t_x} - I_R \right]$$

$$P_{OFF} = V_C \times \frac{t_x}{T} \left[(I_P + I_R) \times \frac{\tau}{t_x} (1 - e^{-t_x/\tau}) - I_R \right]$$

$$P_{OFF} = 65 \times \frac{23.1}{200} \left[(215.9 \text{ mA} + 291.7 \text{ mA}) \frac{41.7}{23.1} (1 - e^{-23.1/41.7}) - 291.7 \text{ mA} \right]$$

$$P_{OFF} = 736 \text{ mW}$$

P_O = Average power dissipation in device output

$$P_O = P_{ON} + P_{OFF} = 110.6 + 736 = 846.6 \text{ mW}$$

In the above example, driving a 120Ω inductive load at 5 Hz, the power dissipation exceeded a more simple calculation of power dissipation, which would have been:

$$P_O = \frac{V_{OL} (V_B - V_{OL})}{R_L} \times \frac{T_{ON}}{T}$$

$$P_O = \frac{1.5 (30 - 1.5)}{120} \times \frac{100 \text{ ms}}{200 \text{ ms}} = 182.5 \text{ mW}$$

An error 460% would have occurred by not including the reactive load. The total power dissipation must also include other outputs (if the device has more than one output), and the power dissipation due to the device power supply currents. This is an example where the load will most likely exceed the device package rating. If the load is fixed, the power can be reduced by changing the period (T) and duty rate (T_{ON}/T_{OFF}).

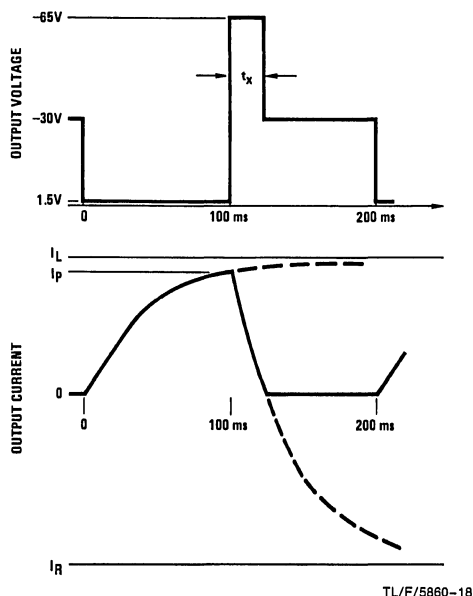


FIGURE 18. Voltage and Current Waveforms Corresponding to Inductive Load

CALCULATION OF OUTPUT POWER WITH AN INCANDESCENT LAMP

An incandescent lamp is equivalent to a reactive load. The reactance is related to the period of time required to heat the lamp and the filaments positive temperature coefficient of resistance. Figure 19 shows the transient response for a typical lamp used on instrument panels, and the equivalent electrical model for the lamp. Much like IC packages the lamp has a thermal circuit and its associated propagation delay. This lamp filament has an 8 ms time constant, and a longer 250 ms time constant from the lamp body to ambient. The DC characteristics are shown in Figure 20. Note the knee in the characteristics at 2 volts; this is where power starts to be dissipated in the form of light. This subject is important, since more peripheral drivers are damaged by lamps than any other load.

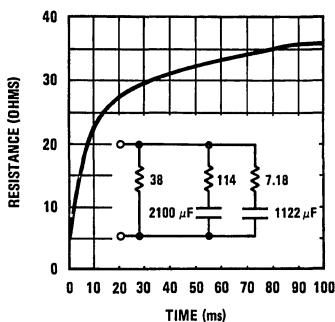


FIGURE 19. Transient Response of an Incandescent Lamp

TL/F/5860-19

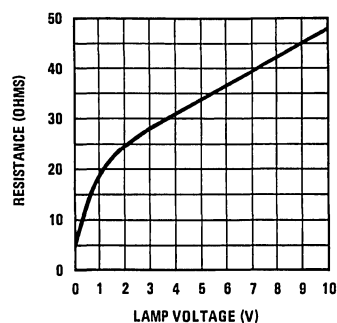


FIGURE 20. DC Characteristics of an Incandescent Lamp

TL/F/5860-20

Figure 21 shows the transient response of a driver similar to a DS75451 driving the lamp characterized in Figures 19 and 20. The equivalent load doesn't include the reactance of the lamp base to ambient, which has a 250 ms time constant, since 10 ms to an IC is equivalent to DC. The peak transient current was 1 amp, settling to 200 ms, with an 8 ms time constant. Observe the peak current is clamped at 1 amp, by the sinking ability of the driver; otherwise the peak current may have been 1.2 amps. The DS75451 is only rated at 300 mA, but it is reasonable to assume it could sink 1 amp because of the designed force β required for switching response and worst case operating temperature.

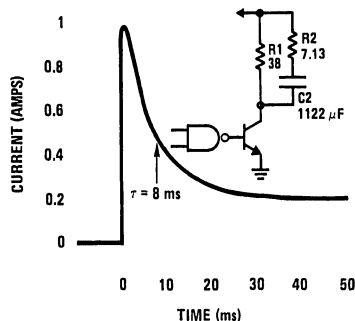


FIGURE 21. Transient Incandescent Lamp Current

TL/F/5860-21

Calculation of the energy dissipated by a peripheral driver for the transient lamp current shown in Figure 21 is shown above, and the plot of energy vs time is shown in Figure 22. Figure 22 also includes as a reference the maximum peak energy from Figure 15. It can be seen from Figure 22 that in this example there is a good safety margin between the lamp load and the reference max peak energy. If there were more drivers than one per package under the same load, the margin would have been reduced. Also, if the peripheral driver couldn't saturate because it couldn't sink the peak transient lamp current, then the energy would also reduce the margin of safe operation.

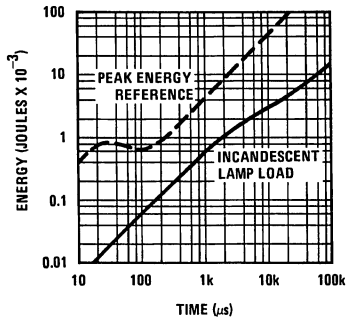


FIGURE 22. Energy vs Time for a Peripheral Driver with an Incandescent Lamp Load

TL/F/5860-22

CALCULATION OF ENERGY IN AN INCANDESCENT LAMP

$$\text{Energy} = \int_0^t V_{OL} (I_{R1} + I_{R2}) dt$$

$$I_{R1} = \frac{V_B - V_{OL}}{R1} = I_{R1}$$

$$I_{R2} = \left(\frac{V_B - V_{OL}}{R2} \right) e^{-t/\tau}$$

$$= I_{R2} e^{-t/\tau} \quad \tau = R2C2$$

$$\text{Energy} = \int_0^t V_{OL} (I_{R1} + I_{R2} e^{-t/\tau}) dt$$

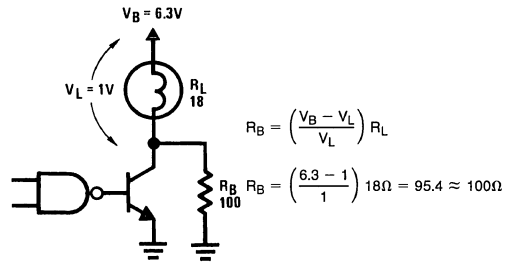
$$= V_{OL} [I_{R1}t + I_{R2}\tau (1 - e^{-t/\tau})]$$

Given: $V_{OL} = 0.6V$

$$I_{R1} = 0.2 \text{ Amps}$$

$$I_{R1} + I_{R2} = 1 \text{ Amp}$$

A common technique used to reduce the 10 to 1 peak to DC transient lamp current is to bias the lamp partially ON, so the lamp filament is warm. This can be accomplished as shown in Figure 23. From Figure 20 it can be seen that the lamp resistance at 0V is 5.7Ω , but at 1V the resistance is 18Ω . At 1V the lamp doesn't start to emit light. Using a lamp resistance of 100Ω and lamp voltage of 1V, R_B was calculated to be approximately 100Ω . This circuit will reduce the peak lamp current from 1 amp to 316 mA.



TL/F/5860-23

FIGURE 23. Circuit Used to Reduce Peak Transient Lamp Current

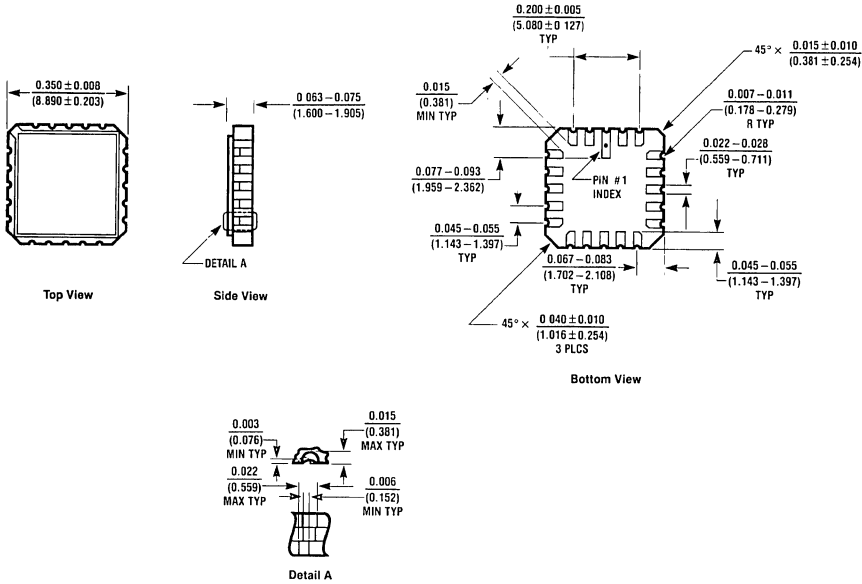
PERIPHERAL DRIVER SECTION

National Semiconductor has a wide selection of peripheral drivers as shown in this section's guide. The DS75451, DS75461, DS3631 and the DS3611 series have the same selection of logic function in an 8-pin package. The DS75461 is a high voltage selection of the DS75451 and may switch slower. The DS3611 and DS3631 are very high voltage circuits and were intended for slow relay applications. The DS3680, DS3686, and DS3687 were intended for 56V telephone relay applications. The DS3654 contains a 10-bit shift register followed by ten 250 mA clamped drivers. The DS3654 was intended for printer solenoid applications.

High current and high voltage peripheral drivers find many applications associated with digital systems, and it is the intention of the application note to insure that reliability and service life of peripheral drivers equal or exceed the performance of the other logic gates made by National.

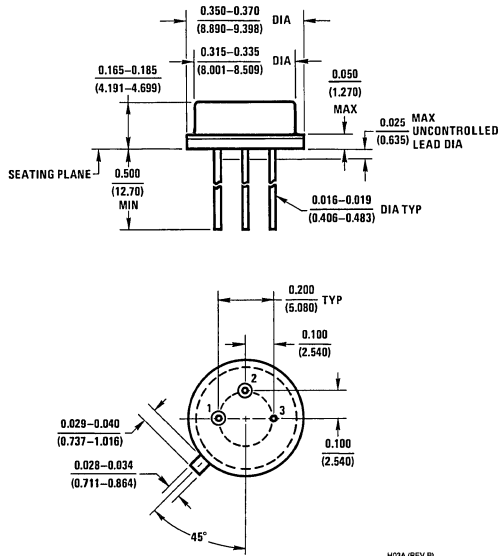
For additional information, please contact the Interface Marketing Department at National or one of the many field application engineers world-wide.

20 Terminal Ceramic Leadless Chip Carrier (LCC) NS Package Number E20A



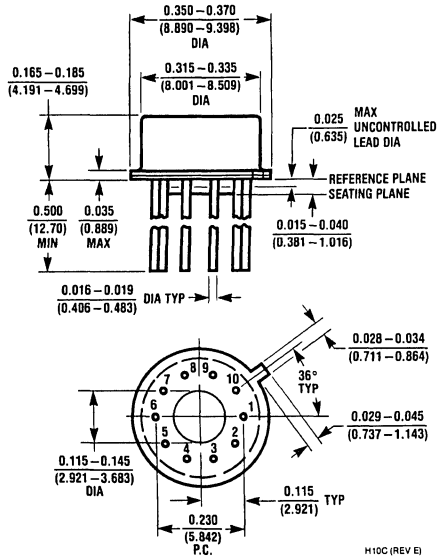
L20A (REV D)

3 Lead (0.200" Diameter P.C.) Metal Can Package (H) NS Package Number H03A

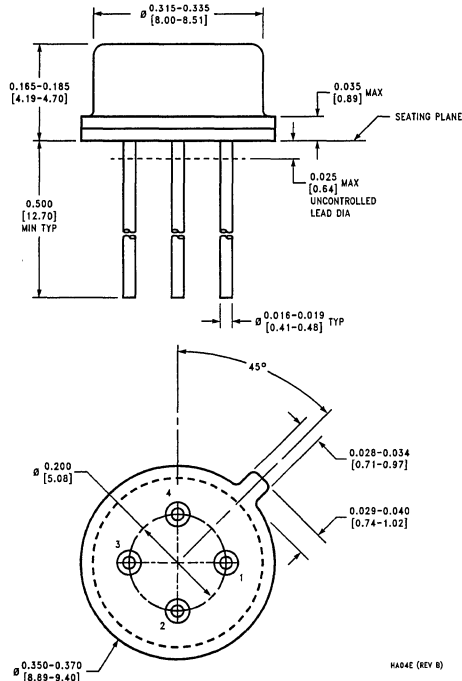


H03A (REV B)

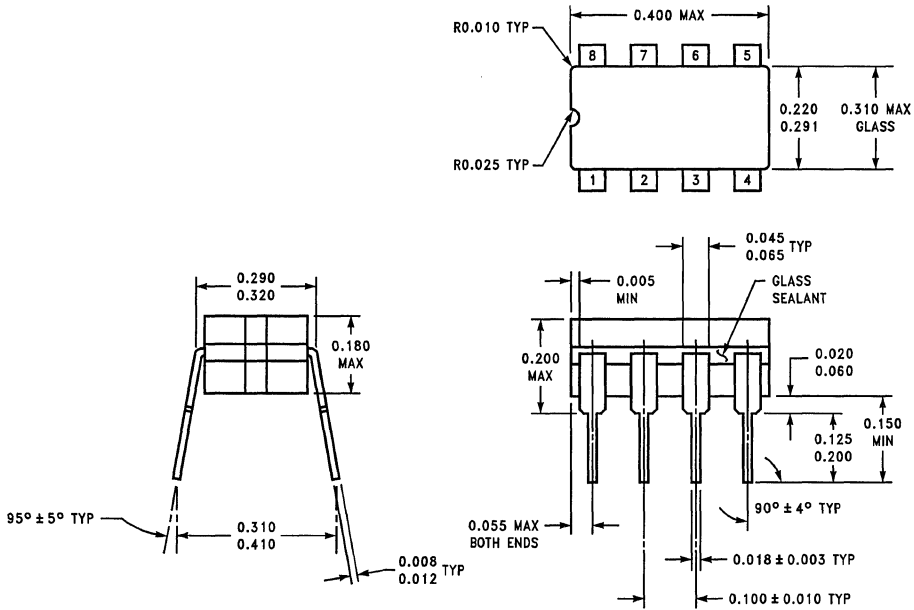
10 Lead (0.230" Diameter P.C.) TO-100 Metal Can Package (H) NS Package Number H10C



4 Lead (0.200" Diameter P.C.) Metal Can Package (H) NS Package Number HA04E

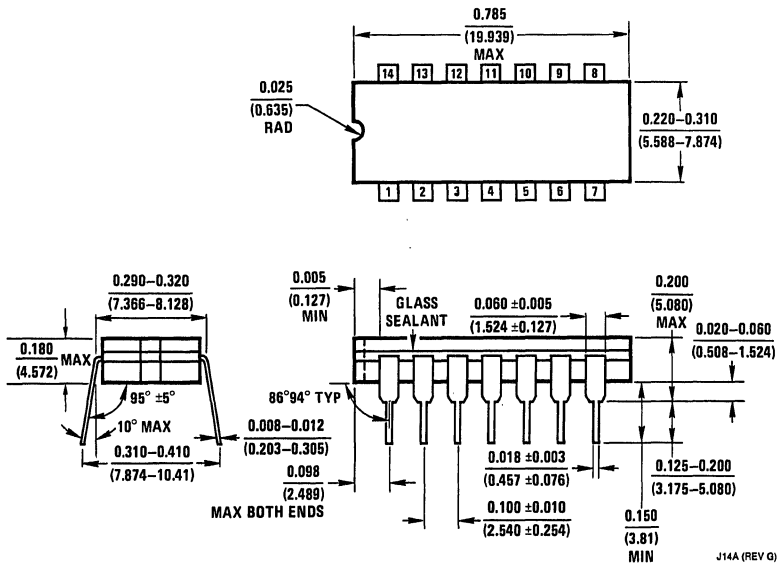


8 Lead Ceramic Dual-In-Line Package (J) NS Package Number J08A



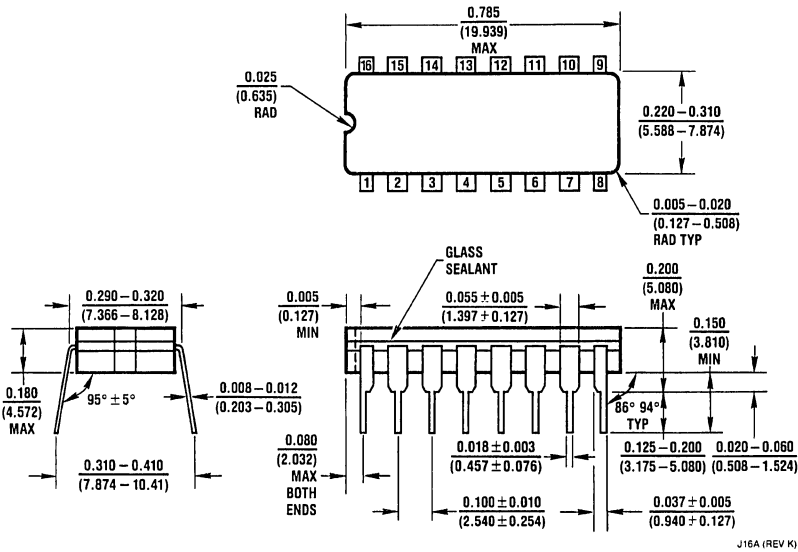
J08A (REV K)

14 Lead Ceramic Dual-In-Line Package (J) NS Package Number J14A

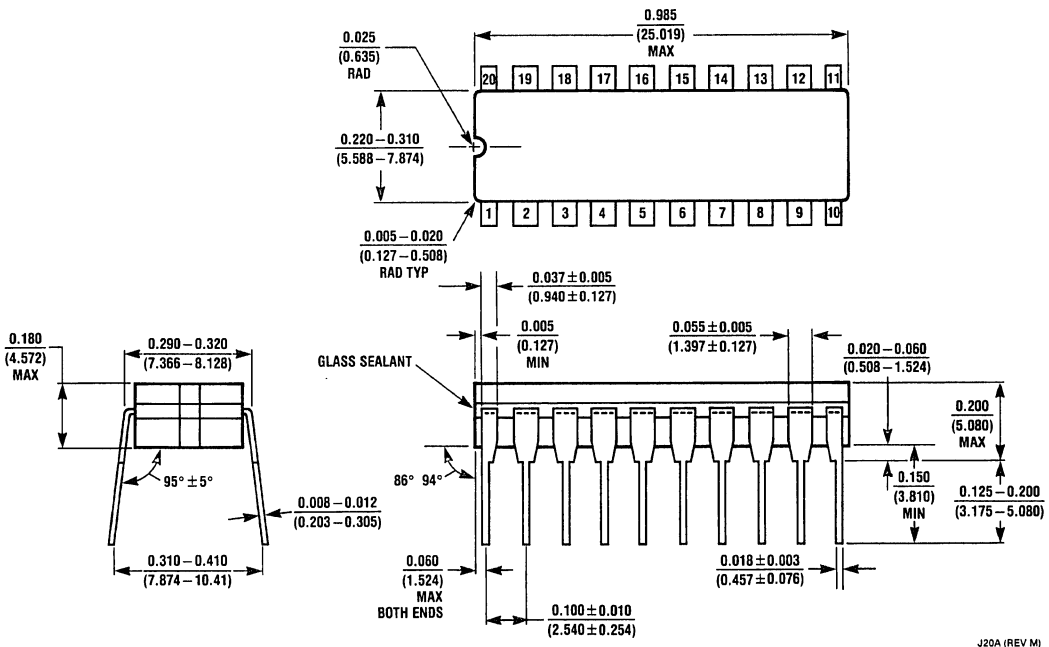


J14A (REV G)

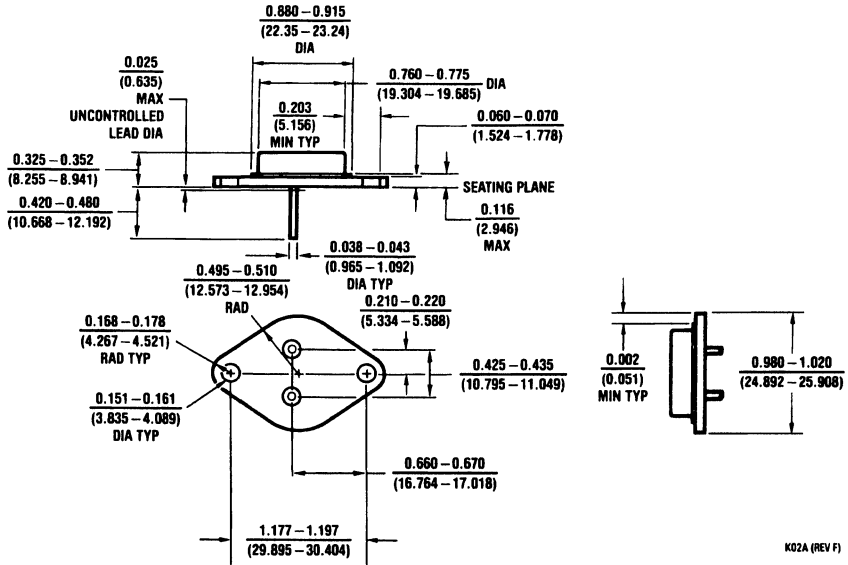
16 Lead Ceramic Dual-In-Line Package (J) NS Package Number J16A



20 Lead Ceramic Dual-In-Line Package (J) NS Package Number J20A

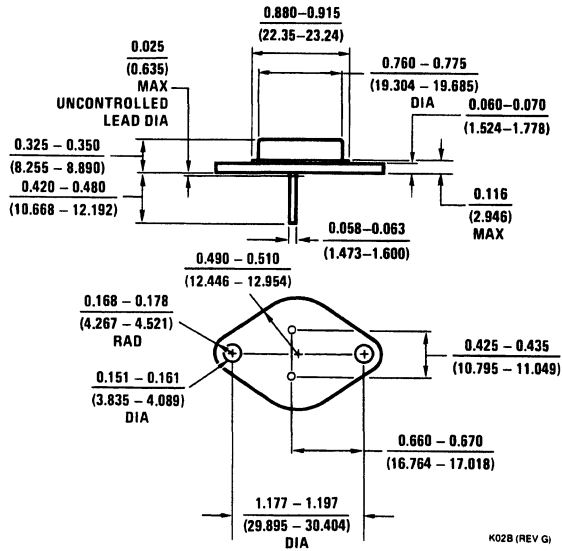


2 Lead TO-3 Metal Can Package (K) NS Package Number K02A



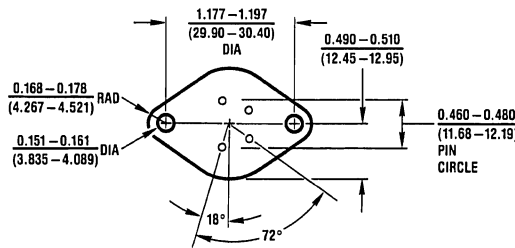
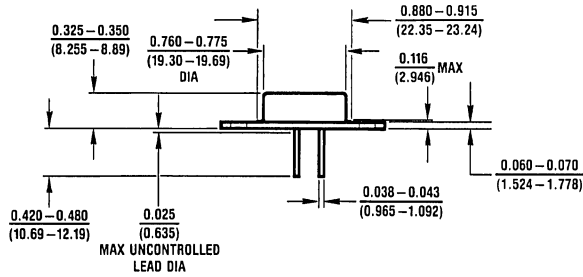
K02A (REV F)

2 Lead TO-3 Metal Can Package (K) NS Package Number K02B



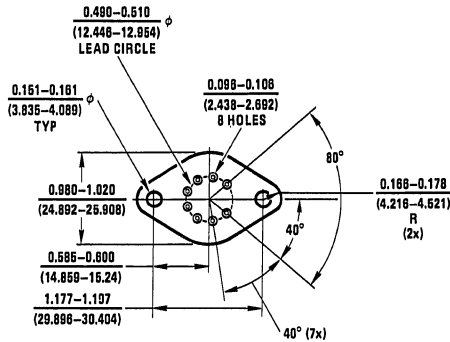
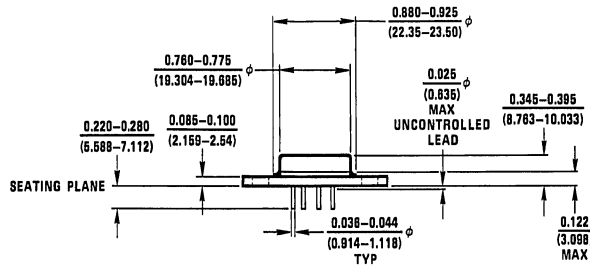
K02B (REV G)

4 Lead TO-3 Metal Can Package (K) NS Package Number K04A



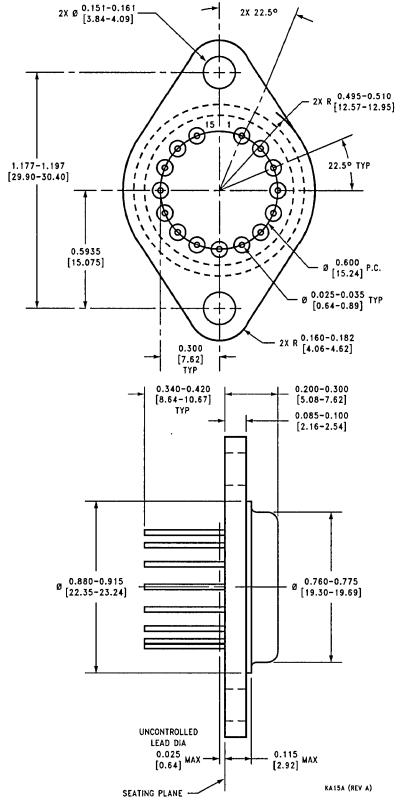
K04A (REV E)

8 Lead TO-3 Metal Can Package (K) NS Package Number K08A

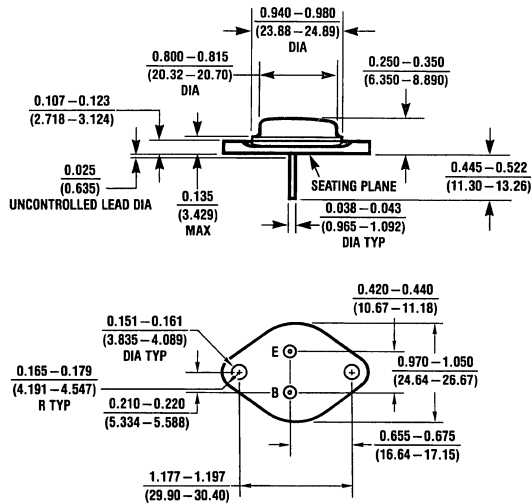


K08A (REV C)

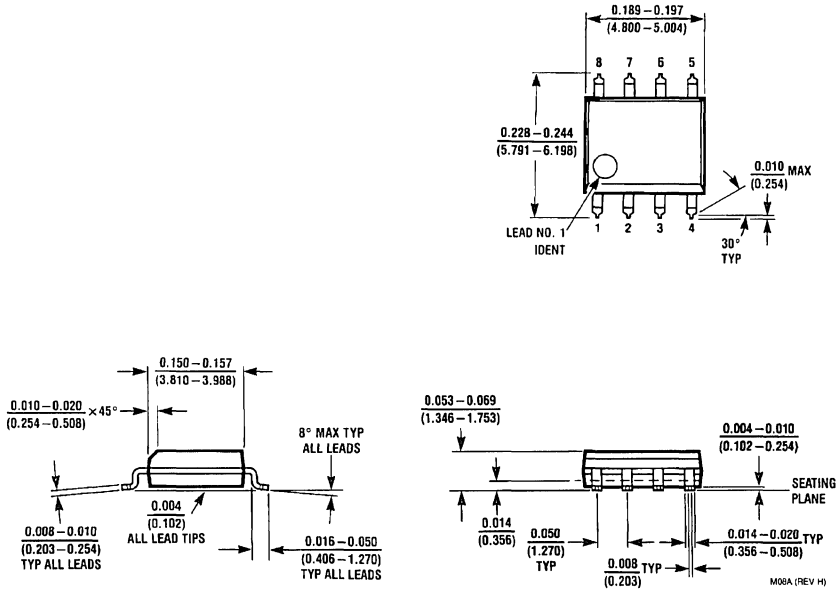
15 Lead TO-3 Metal Can Package (KA) NS Package Number KA15A



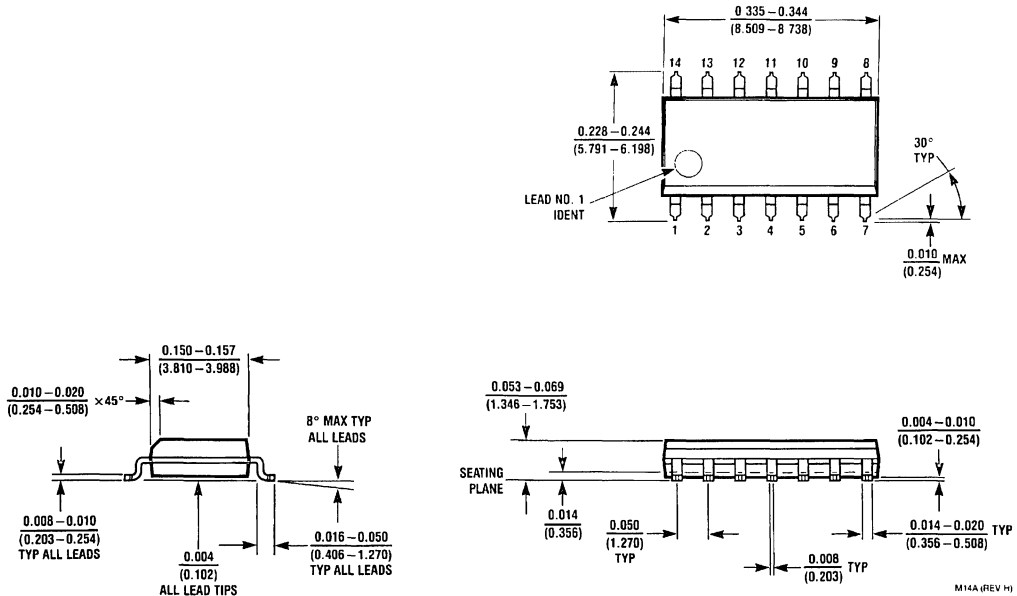
2 Lead TO-3 Aluminum Metal Can Package (K or KC) NS Package Number KC02A



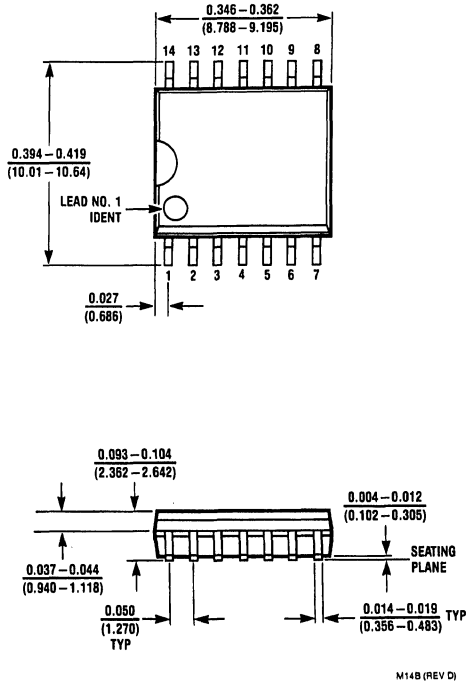
8 Lead (0.150" Wide) Small Outline Molded Package (M) NS Package Number M08A



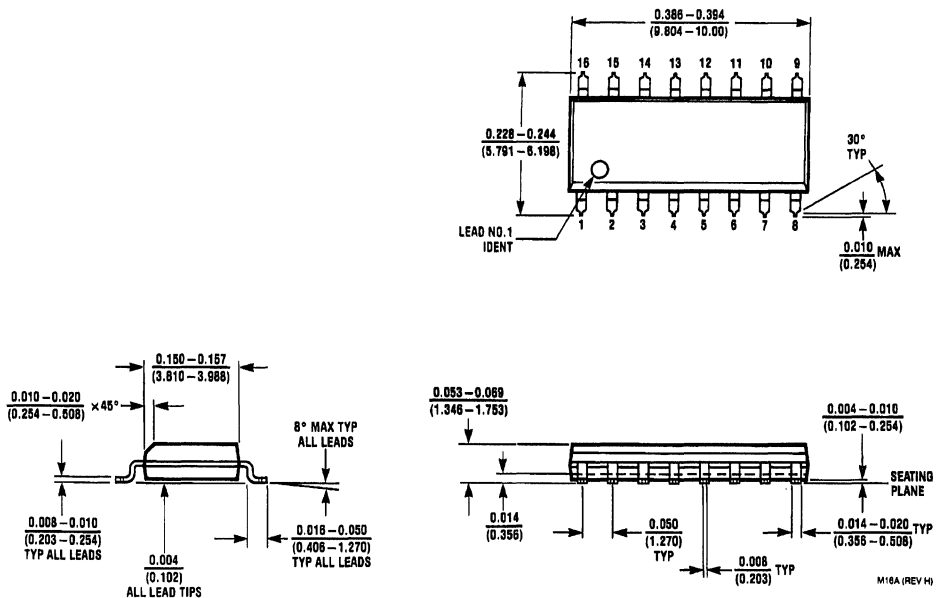
14 Lead (0.150" Wide) Small Outline Molded Package (M) NS Package Number M14A



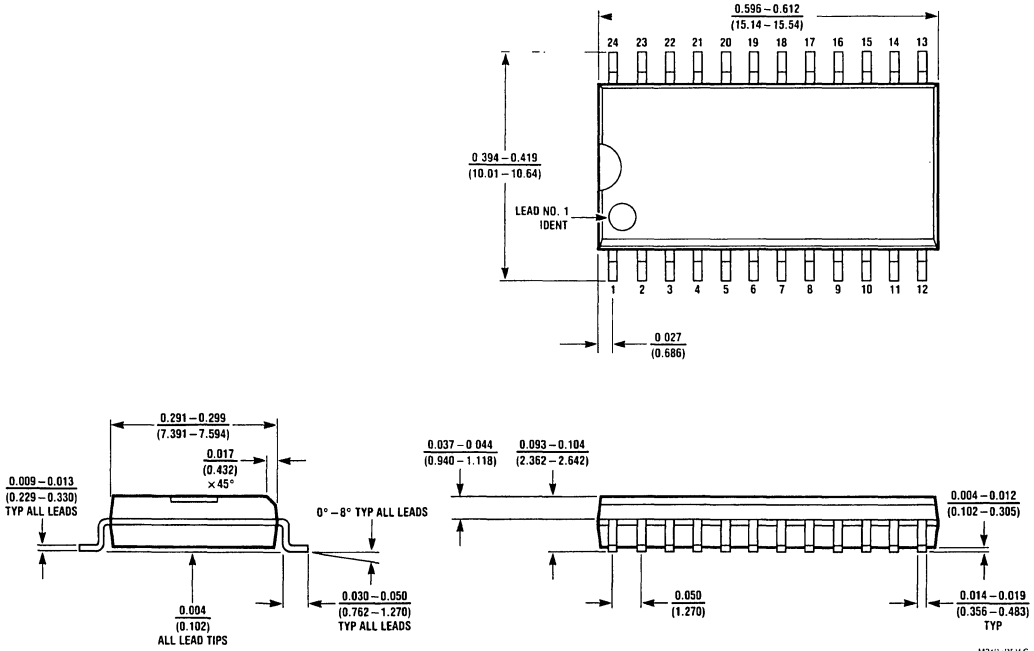
14 Lead (0.300" Wide) Small Outline Molded Package (WM) NS Package Number M14B



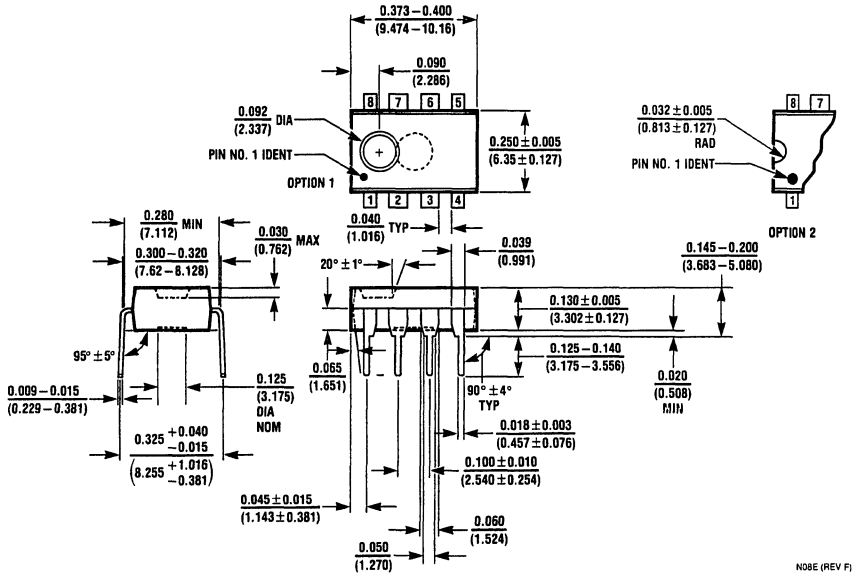
16 Lead (0.150" Wide) Small Outline Molded Package (M) NS Package Number M16A



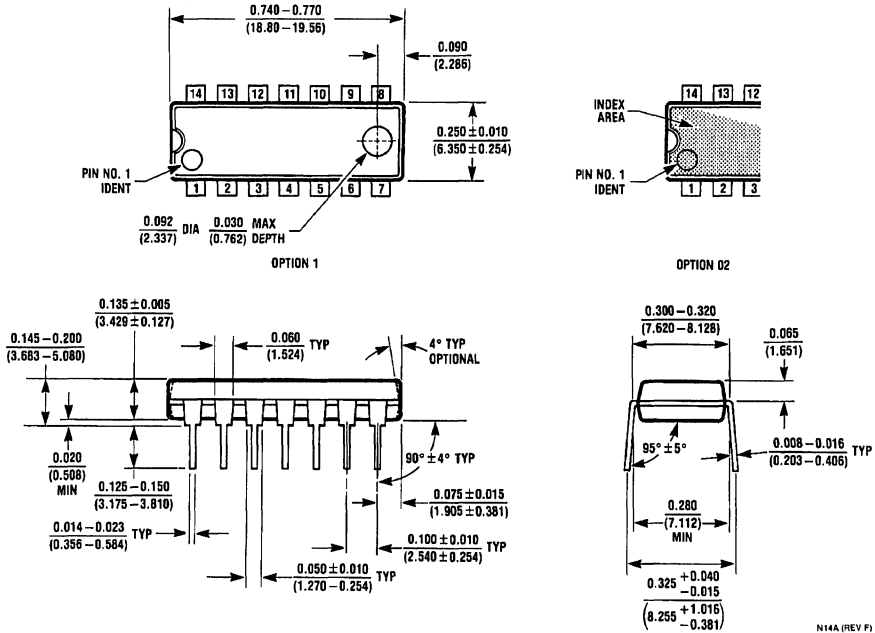
24 Lead (0.300" Wide) Small Outline Molded Package (M) NS Package Number M24B



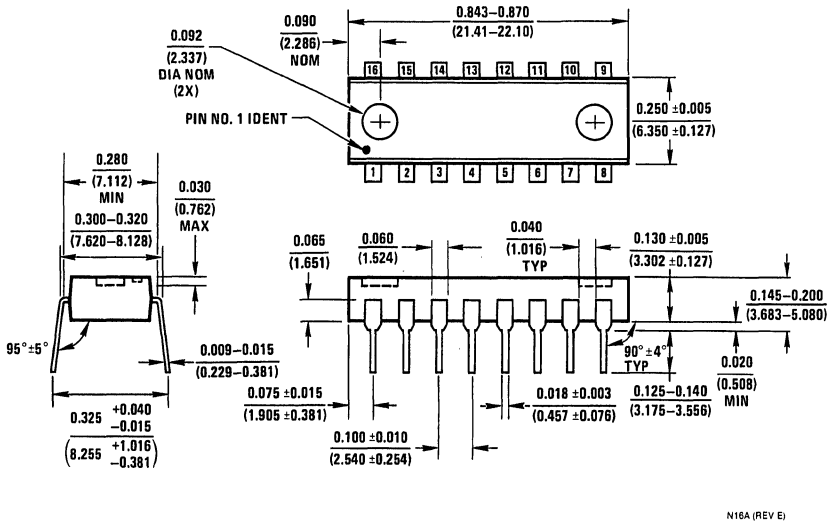
8 Lead Molded Dual-In-Line Package (N) NS Package Number N08E



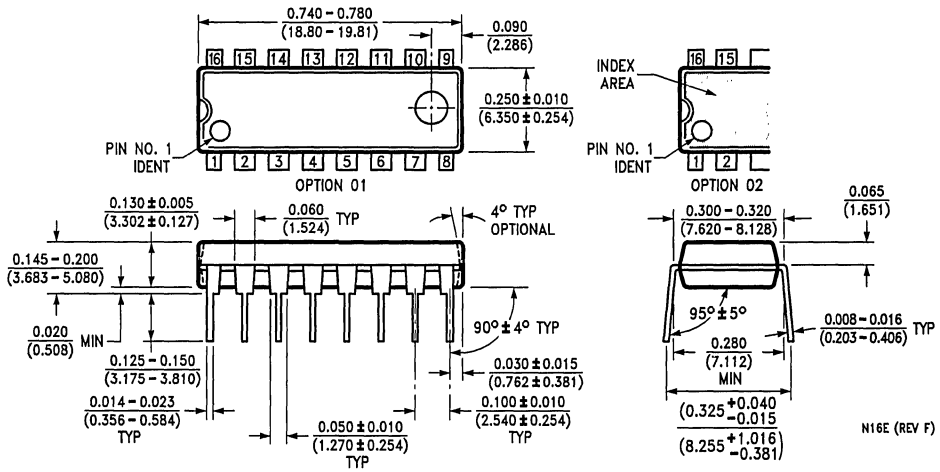
14 Lead Molded Dual-In-Line Package (N) NS Package Number N14A



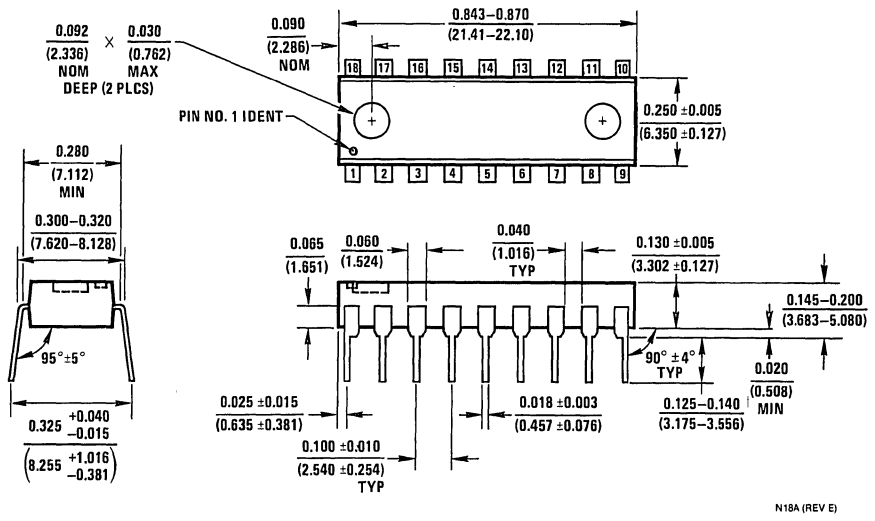
16 Lead Molded Dual-In-Line Package (N) NS Package Number N16A



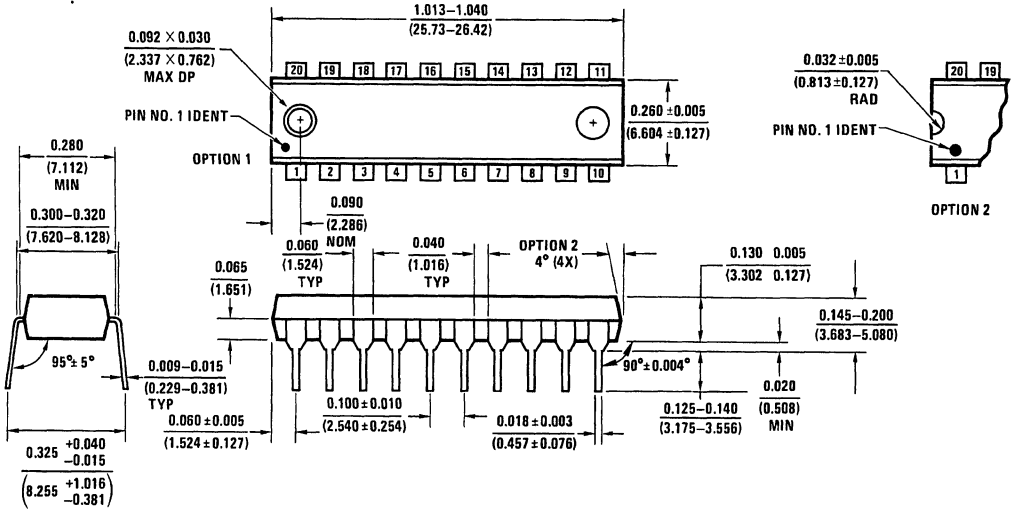
16 Lead Molded Dual-In-Line Package (N) NS Package Number N16E



18 Lead Molded Dual-In-Line Package (N) NS Package Number N18A

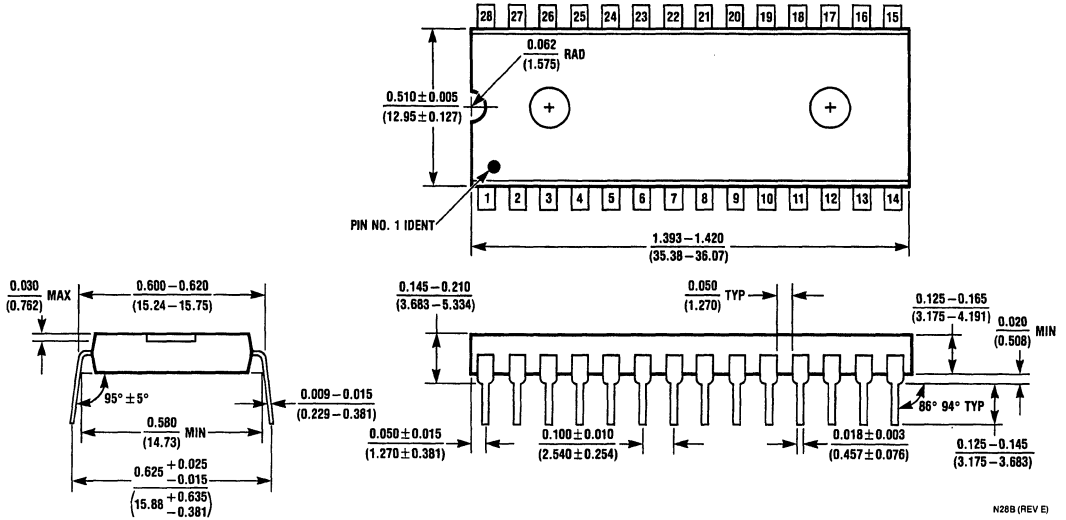


20 Lead Molded Dual-In-Line Package (N) NS Package Number N20A



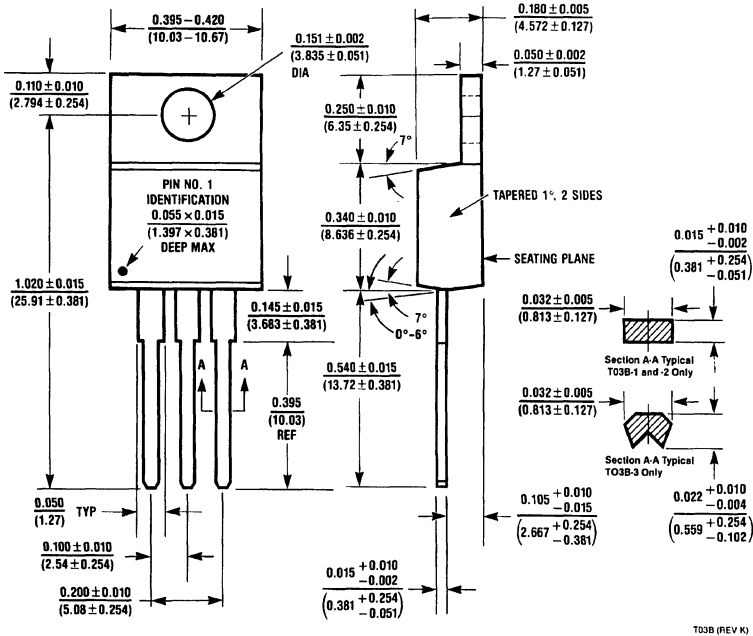
N20A (REV G)

28 Lead Molded Dual-In-Line Package (N) NS Package Number N28B

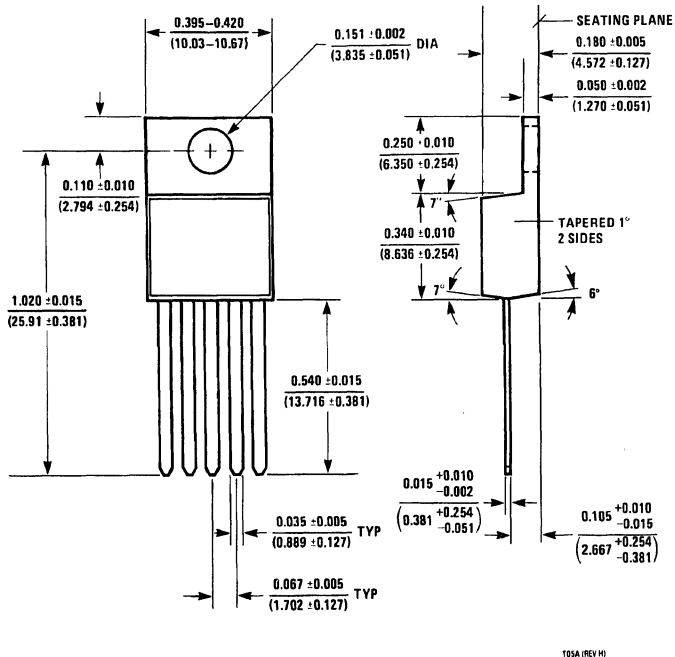


N28B (REV E)

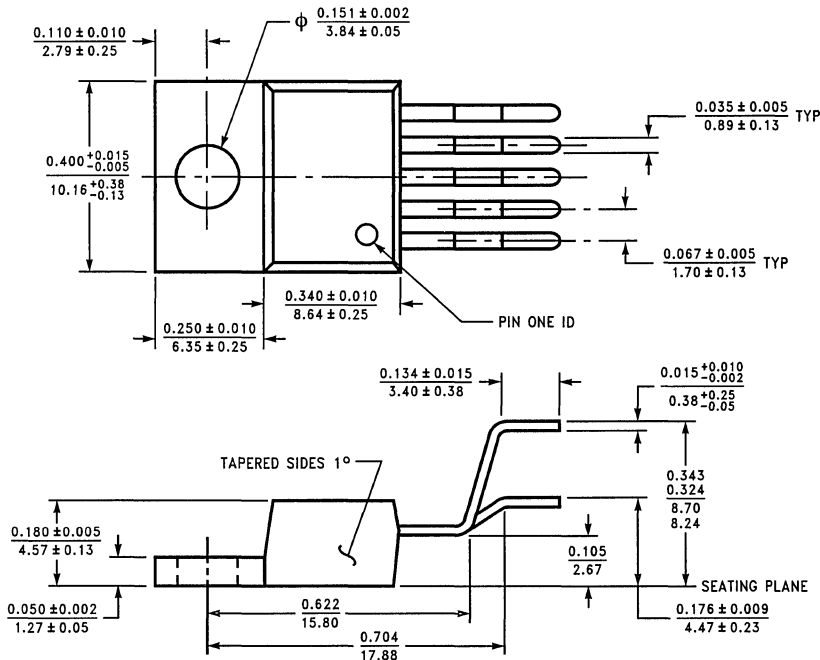
3 Lead TO-220 Molded Package (T) NS Package Number T03B



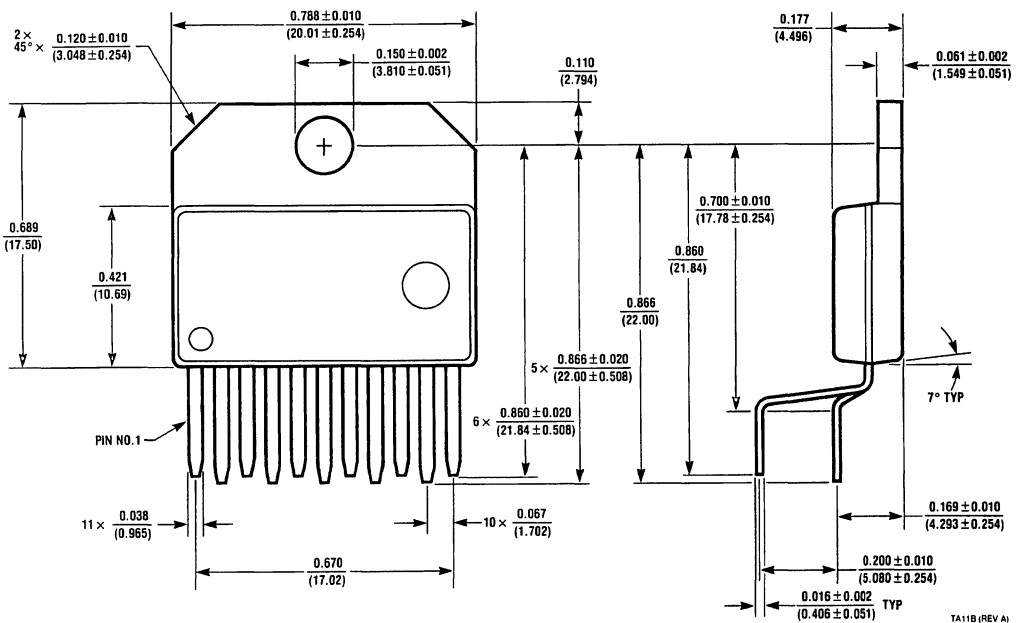
5 Lead TO-220 Molded Package (T) NS Package Number T05A



5 Lead TO-220 Molded Package (T) NS Package Number T05D



11 Lead TO-220 Molded Package (T) NS Package Number TA11B





Bookshelf of Technical Support Information

National Semiconductor Corporation recognizes the need to keep you informed about the availability of current technical literature.

This bookshelf is a compilation of books that are currently available. The listing that follows shows the publication year and section contents for each book.

For datasheets on new products and devices still in production but not found in a databook, please contact the National Semiconductor Customer Support Center at 1-800-272-9959.

We are interested in your comments on our technical literature and your suggestions for improvement.

Please send them to:

Technical Communications Dept. M/S 16-300
2900 Semiconductor Drive
P.O. Box 58090
Santa Clara, CA 95052-8090

ALS/AS LOGIC DATABOOK—1990

Introduction to Advanced Bipolar Logic • Advanced Low Power Schottky • Advanced Schottky

ASIC DESIGN MANUAL/GATE ARRAYS & STANDARD CELLS—1987

SSI/MSI Functions • Peripheral Functions • LSI/VLSI Functions • Design Guidelines • Packaging

CMOS LOGIC DATABOOK—1988

CMOS AC Switching Test Circuits and Timing Waveforms • CMOS Application Notes • MM54HC/MM74HC
MM54HCT/MM74HCT • CD4XXX • MM54CXXX/MM74CXXX • Surface Mount

DATA ACQUISITION DATABOOK—1993

Data Acquisition Systems • Analog-to-Digital Converters • Digital-to-Analog Converters • Voltage References
Temperature Sensors • Active Filters • Analog Switches/Multiplexers • Surface Mount

DATA ACQUISITION DATABOOK SUPPLEMENT—1992

New devices released since the printing of the 1989 Data Acquisition Linear Devices Databook.

DISCRETE SEMICONDUCTOR PRODUCTS DATABOOK—1989

Selection Guide and Cross Reference Guides • Diodes • Bipolar NPN Transistors
Bipolar PNP Transistors • JFET Transistors • Surface Mount Products • Pro-Electron Series
Consumer Series • Power Components • Transistor Datasheets • Process Characteristics

DRAM MANAGEMENT HANDBOOK—1991

Dynamic Memory Control • Error Detection and Correction • Microprocessor Applications for the
DP8408A/09A/17/18/19/28/29 • Microprocessor Applications for the DP8420A/21A/22A
Microprocessor Applications for the NS32CG821

EMBEDDED CONTROLLERS DATABOOK—1992

COP400 Family • COP800 Family • COPS Applications • HPC Family • HPC Applications
MICROWIRE and MICROWIRE/PLUS Peripherals • Microcontroller Development Tools

FDDI DATABOOK—1991

FDDI Overview • DP83200 FDDI Chip Set • Development Support • Application Notes and System Briefs

F100K ECL LOGIC DATABOOK & DESIGN GUIDE—1992

Family Overview • 300 Series (Low-Power) Datasheets • 100 Series Datasheets • 11C Datasheets
Design Guide • Circuit Basics • Logic Design • Transmission Line Concepts • System Considerations
Power Distribution and Thermal Considerations • Testing Techniques • 300 Series Package Qualification
Quality Assurance and Reliability • Application Notes

FACT™ ADVANCED CMOS LOGIC DATABOOK—1990

Description and Family Characteristics • Ratings, Specifications and Waveforms
Design Considerations • 54AC/74ACXXX • 54ACT/74ACTXXX • Quiet Series: 54ACQ/74ACQXXX
Quiet Series: 54ACTQ/74ACTQXXX • 54FCT/74FCTXXX • FCTA: 54FCTXXXA/74FCTXXXA

FAST® ADVANCED SCHOTTKY TTL LOGIC DATABOOK—1990

Circuit Characteristics • Ratings, Specifications and Waveforms • Design Considerations • 54F/74FXXX

FAST® APPLICATIONS HANDBOOK—1990

Reprint of 1987 Fairchild FAST Applications Handbook

Contains application information on the FAST family: Introduction • Multiplexers • Decoders • Encoders
Operators • FIFOs • Counters • TTL Small Scale Integration • Line Driving and System Design
FAST Characteristics and Testing • Packaging Characteristics

HIGH-PERFORMANCE BUS INTERFACE DESIGNER'S GUIDE—1992

Futurebus+ /BTL Devices • BTL Transceiver Application Notes • Futurebus+ Application Notes
High Performance TTL Bus Drivers • PI-Bus • Futurebus+ /BTL Reference

IBM DATA COMMUNICATIONS HANDBOOK—1992

IBM Data Communications • Application Notes

INTERFACE: LINE DRIVERS AND RECEIVERS DATABOOK—1992

EIA-232 • EIA-422/423 • EIA-485 • Line Drivers • Receivers • Repeaters • Transceivers • Application Notes

LINEAR APPLICATIONS HANDBOOK—1991

The purpose of this handbook is to provide a fully indexed and cross-referenced collection of linear integrated circuit applications using both monolithic and hybrid circuits from National Semiconductor.

Individual application notes are normally written to explain the operation and use of one particular device or to detail various methods of accomplishing a given function. The organization of this handbook takes advantage of this innate coherence by keeping each application note intact, arranging them in numerical order, and providing a detailed Subject Index.

LINEAR APPLICATION SPECIFIC IC's DATABOOK—1993

Audio Circuits • Radio Circuits • Video Circuits • Display Drivers • Clock Drivers • Frequency Synthesis
Special Automotive • Special Functions • Surface Mount

LOCAL AREA NETWORK DATABOOK—1992

Integrated Ethernet Network Interface Controller Products • Ethernet Physical Layer Transceivers
Ethernet Repeater Interface Controller Products • Hardware and Software Support Products • FDDI Products • Glossary

LOW VOLTAGE DATABOOK—1992

This databook contains information on National's expanding portfolio of low and extended voltage products. Product datasheets included for: Low Voltage Logic (LVQ), Linear, EPROM, EEPROM, SRAM, Interface, ASIC, Embedded Controllers, Real Time Clocks, and Clock Generation and Support (CGS).

MASS STORAGE HANDBOOK—1989

Rigid Disk Pulse Detectors • Rigid Disk Data Separators/Synchronizers and ENDECs
Rigid Disk Data Controller • SCSI Bus Interface Circuits • Floppy Disk Controllers • Disk Drive Interface Circuits
Rigid Disk Preamplifiers and Servo Control Circuits • Rigid Disk Microcontroller Circuits • Disk Interface Design Guide

MEMORY DATABOOK—1992

CMOS EPROMs • CMOS EEPROMs • PROMs • Application Notes

OPERATIONAL AMPLIFIERS DATABOOK—1993

Operational Amplifiers • Buffers • Voltage Comparators • Instrumentation Amplifiers • Surface Mount

POWER IC's DATABOOK—1993

Linear Voltage Regulators • Low Dropout Voltage Regulators • Switching Voltage Regulators • Motion Control Peripheral Drivers • High Current Switches • Surface Mount

PROGRAMMABLE LOGIC DEVICE DATABOOK AND DESIGN GUIDE—1993

Product Line Overview • Datasheets • Design Guide: Designing with PLDs • PLD Design Methodology
PLD Design Development Tools • Fabrication of Programmable Logic • Application Examples

REAL TIME CLOCK HANDBOOK—1991

Real Time Clocks and Timer Clock Peripherals • Application Notes

RELIABILITY HANDBOOK—1987

Reliability and the Die • Internal Construction • Finished Package • MIL-STD-883 • MIL-M-38510
The Specification Development Process • Reliability and the Hybrid Device • VLSI/VHSIC Devices
Radiation Environment • Electrostatic Discharge • Discrete Device • Standardization
Quality Assurance and Reliability Engineering • Reliability and Documentation • Commercial Grade Device
European Reliability Programs • Reliability and the Cost of Semiconductor Ownership
Reliability Testing at National Semiconductor • The Total Military/Aerospace Standardization Program
883B/RETSTM Products • MILS/RETSTM Products • 883/RETSTM Hybrids • MIL-M-38510 Class B Products
Radiation Hardened Technology • Wafer Fabrication • Semiconductor Assembly and Packaging
Semiconductor Packages • Glossary of Terms • Key Government Agencies • AN/ Numbers and Acronyms
Bibliography • MIL-M-38510 and DESC Drawing Cross Listing

TELECOMMUNICATIONS—1992

COMBO and SLIC Devices • ISDN • Digital Loop Devices • Analog Telephone Components • Software
Application Notes

National Semiconductor Corporation

2900 Semiconductor Drive
P.O. Box 58090
Santa Clara, CA 95052-8090

For sales, literature and technical support for North America, please contact the National Semiconductor Customer Support Center at 1-800-272-9959.

SALES OFFICES**CANADA****National Semiconductor**

5925 Airport Rd.
Suite 615
Mississauga, Ontario L4V 1W1
Tel: (416) 678-2920
Fax: (416) 678-2535

PUERTO RICO**National Semiconductor**

La Electronica Bldg.
Suite 312, R.D. #1 KM 14.5
Rio Piedras, Puerto Rico 00927
Tel: (809) 758-9211
Fax: (809) 763-6959

**INTERNATIONAL
OFFICES****National Semiconductor**

(Australia) Pty. Ltd.
16 Business Park Dr.
Notting Hill, VIC 3168
Australia
Tel: (3) 558-9999
Fax: (3) 558-9998

National Semiconductor

(Australia) Pty. Ltd.
Suite #4, Level 5
3 Thomas Holt Drive
North Ryde, N.S.W. 2113
Sydney, Australia
Tel: (02) 887-4355
Telex: AA 27173
Fax: (02) 805-0298

National Semicondutores

Do Brazil Ltda.
Av. Brig. Faria Lima, 1409
6 Andar
Cep-01451, Paulistano,
Sao Paulo, SP
Brazil
Tel: (55-11) 212-5066
Telex: 391-1131931 NSBR BR
Fax: (55-11) 212-1181

National Semiconductor

**Bulgaria
P.C.S.A.**
Dondikov Bld, 2/3/3
Sofia 1000
Bulgaria
Tel: (02) 88 01 16
Fax: (02) 80 36 18

National Semiconductor

(UK) Ltd.
Valdemarsgade 21
DK-4100 Ringsted
Denmark
Tel: (57) 67 20 80
Fax: (57) 67 20 82

National Semiconductor

(UK) Ltd.
Mekaanikonkatu 13
SF-00810 Helsinki
Finland
Tel: 358-0-759-1855
Telex: 126116
Fax: 358-0-759-1393

National Semiconductor

France
Centre d'Affaires "La Boursidière"
Bâtiment Champagne
BP 90
Route Nationale 186
F-92357 Le Plessis Robinson
Paris, France
Tel: (01) 40-94-88-88
Telex: 631065
Fax: (01) 40-94-88-11

National Semiconductor

GmbH
Dieselstrasse 23
D-3004 Isernhagen 2
Germany
Tel: (05-11) 72 34 49
Fax: (05-11) 77 88 72

National Semiconductor

GmbH
Eschborner Landstrasse 130-132
D-6000 Frankfurt 90
Germany
Tel: (0-69) 78 91 09 0
Fax: (0-69) 78-95-38-3

National Semiconductor

GmbH
Industriestrasse 10
D-8080 Fürstenfeldbruck
Germany
Tel: (0-81-41) 103-0
Telex: 527649
Fax: (0-81-41) 10-35-06

National Semiconductor

GmbH
Untere Waldplätze 37
D-7000 Stuttgart 80
Germany
Tel: (07-11) 68-65-11
Telex: 7255993
Fax: (07-11) 68-65-260

National Semiconductor

Hong Kong Ltd.
13th Floor, Straight Block
Ocean Centre
5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 737-1600
Telex: 51292 NSHKL
Fax: (852) 736-9960

National Semiconductor

(UK) Ltd.
Unit 2A
Clonskeagh Square
Clonskeagh Road
Dublin 14
Ireland
Tel: (01) 269-5344
Fax: (01) 283-0650

National Semiconductor SpA

Strada 7, Pallazo R/3
I-20089 Rozzano-Milanofiori
Italy
Tel: (02) 57500300
Telex: 352647
Fax: (02) 57500400

National Semiconductor

Japan Ltd.
Sansendo Bldg. 5F
4-15-3, Nishi-shinjuku,
Shinjuku-ku
Tokyo
Japan 160
Tel: (03) 3299-7001
Fax: (03) 3299-7000

National Semiconductor

(Far East) Ltd.
Korea Branch
13th Floor, Dai Han
Life Insurance 63 Building
60, Yoido-dong, Youngdeungpo-ku
Seoul
Korea 150-763
Tel: (02) 784-8051
Telex: 24942 NSRKL0
Fax: (02) 784-8054

Electronica NSC

de Mexico SA
Juventino Rosas No. 118-2
Col Guadalupe Inn
Mexico, 01020 D.F., Mexico
Tel: (525) 524-9402
Fax: (525) 524-9342

National Semiconductor

Benelux B.V.
Flevolaan 4
Postbus 90
1380 AB Weesp
The Netherlands
Tel: (02) 94 03 04 48
Fax: (02) 94 03 04 30

National Semiconductor

(UK) Ltd.
Isveien 45
N-1390 Vollen
Norway
Tel: (2) 79-6500
Fax: (2) 79-6040

National Semiconductor

Asia Pacific Pte. Ltd.
200 Cantonment Road # 13-01
Southpoint
Singapore 0208
Singapore
Tel: (65) 225-2226
Telex: NATSEMI RS 33877
Fax: (65) 225-7080

National Semiconductor

Calle Agustin de Foxa, 27 (9°D)
E-28036 Madrid
Spain
Tel: (01) 7-33-29-58
Telex: 46133
Fax: (01) 7-33-80-18

National Semiconductor AB

P.O. Box 1009
Grosshandlarvaragen 7
S-12123 Johanneshov
Sweden
Tel: (08) 7228050
Fax: (08) 7229095

National Semiconductor

Alte Winterthurerstrasse 53
CH-8304 Wallisellen-Zürich
Switzerland
Tel: (01) 8-30-27-27
Fax: (01) 8-30-19-00

National Semiconductor

(Far East) Ltd.
Taiwan Branch
9th Floor, No. 18
Sec. 1, Chang An East Road
Taipei, Taiwan, R.O.C.
Tel: (02) 521-3288
Fax: (02) 561-3054

National Semiconductor

(UK) Ltd.
The Maples, Kembrey Park
Swindon, Wiltshire SN2 6UT
United Kingdom
Tel: (07-93) 61 41 41
Telex: 444674
Fax: (07-93) 52 21 80