NEW DEVELOPMENT IN PULSED CIRCUIT TEST EQUIPMENT

by

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ABSTRACT

The usual method of transmitting intelligence in a large-scale system of pulsed circuits is to supply a signal pulse on a particular line at a specified time. To test such a system, external equipment is needed which will generate, route, delay, gate, store, shape, and measure pulses. The Electronic Computer Division of Servomechanisms Laboratory, M.I.T., has developed a new line of test units for all these operations.

This equipment is designed to operate with positive, 0.1-microsecond, half-sine-wave pulses and a minimum pulse period of 0.5 microsecond. Most of the units have a pulse-shaping circuit to insure that output pulses are uniform. Each contains an average of 6 vacuum tubes, may be mounted on a 19-inch relay rack, a performs some basic function of a pulsed circuit. A standard input and output impedance of 93 ohms permits interconnecting the units as basic building blocks for a large variety of pulsed systems.

Before the adoption of the building-block technique, a special test setup for the M.I.T. digital computer would require long periods of time to design and construct. After tests, the setup would be worthless, except for its salavage value. By using the new units, the engineer may now build an elaborate array in less than a day. When it is no longer needed, the setup is disassembled and the pieces of test equipment are ready for other uses.

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INTRODUCTION

The term "test equipment", when used to describe electronic devices, usually brings to mind signal generators, oscilloscopes, vacuum-tube voltmeters, and other commercial measuring instruments. These units are used generally in communication problems where a single input produces a single output, and the intelligence is provided by some method of modulation.

In a large-scale system of pulsed circuits, such as a digital computer, hundreds of pulse lines are switched to form pulse channels; and the usual method of transmitting intelligence is to supply a pulse on a particular line at a specified time. This problem of pulse routing, plus the fact that the pulse must often meet a required amplitude, shape, and duration, make system testing with conventional test equipment extremely difficult.

The test units described in this paper are flexible devices, built by the Electronic Computer Division of the Servomechanisms Laboratory, M.I.T., to test the design and construction of a digital computer which operates with 0.1-μsec pulses and a pulse repetition frequency varying from a push-button rate to 2 megacycles. Since the units can operate over such a wide frequency range, they could be used in other applications of pulsed circuits.

For the convenience of this discussion, the equipment is divided into two classes: (1) pulse-control units, and (2) pulse-measuring units.

PULSE-CONTROL UNITS

General Description

Each pulse-control unit performs some basic control function of a pulsed circuit; i.e., generating, delaying, routing, and gating pulses. All are designed to operate with positive 0.1-μsec half-sine-wave pulses and a minimum pulse period of 0.5 μsec; many contain a pulse-shaping circuit to insure that output pulses are uniform.

Each unit has an average of six vacuum tubes, draws its power from a central power supply, and may be mounted on a 19-inch relay rack. A standard input and output impedance level of 93 ohms permits interconnecting the pieces rapidly as building blocks for a variety of pulsed systems.

Functions of Pulse-Control Units

Now that we have a general picture of pulse-control equipment, let us examine briefly what each unit does. In order to test pulsed circuits, we need a device which will continuously supply uniform pulses. The Variable-Frequency Clock-Pulse Generator, shown in Figure 1, is designed for this job. It provides positive 0.1-μsec half-sine-wave pulses, which we call "standard" pulses, at a 93-ohm impedance level, with the pulse repetition frequency continuously variable from 200 kilocycles to 4.9 megacycles.

Once we have a pulse source, if we wish to send the same pulse simultaneously over a selected number of lines The Coder is available (see Figure 2). The Coder has a single input, but for each input pulse it will deliver up to five simultaneous output pulses at separate terminals. Although the input pulse must be positive, the output pulses may be individually selected as positive or negative, or may be omitted. A pulse-shaping circuit within the unit insures that the output pulses are "standard". The name "coder" was chosen because the five output lines can be switched to represent any 5-digit binary code, the presence of a pulse on a line indicating a 1 and the absence of a pulse, a 0.

If we wish to mix the outputs from a number of pulse lines onto a single line, The Pulse Mixer (Fig. 3) can be conveniently used for this purpose. It will take as many as eight independent input pulses on separate input jacks; and, so long as the pulses are at least 0.5-μsec apart, will mix them onto a single output jack. A pulse-shaping circuit is also included so that the output is independent of the input as far as pulse amplitude and shape are concerned, and all output pulses are standard 0.1-μsec pulses.

A basic circuit in many pulsed systems is the two-tube trigger circuit, or flip-flop. This electronic device has two stable states, and is capable of maintaining either state indefinitely until it is switched to the other by an external trigger pulse. Thus, if we interpret one stable state as an "ON", "YES", or "1" condition, and the other stable state as an "OFF", "NO", or "0" condition, we may transmit intelligence from one point to another in a system by sending a trigger pulse to switch a flip-flop.

The Register Panel, shown in Fig. 4, utilizes the flip-flop as a means of storing, or remembering, information. For example, in digital-computer applications, the information stored is the binary digit 0 or 1; and, since Register Panels can be used in cascade, a storage register of varying number length may be formed. Indicator lights on the front of this unit tell the operator the "content" of the flip-flop, while three separate inputs enable him to insert a 1, insert a 0, or switch the flip-flop from one state to the opposite regardless of content.

The Register Panel also contains a coincidence circuit known as a "gate Circuit". If we wish to stop the progress of a pulse on a particular line, we logically would place an obstacle in its path. However, we may wish to remove this obstacle quickly at another time, to let the pulse continue its journey. A fast and effective method of controlling pulse travel is the gate tube. An information pulse which reaches the No. 1 grid of this tube will appear at the output only when there is a "gating" voltage on the No. 3 grid of the tube. In the Register Panel, this gating voltage is supplied by the flip-flop. The gate tube is coupled to one of the flip-flop plates, called the "1 side"; and whenever the flip-flop contains a 1, a gating voltage is supplied to the No. 3 grid of the gate tube, and the "gate" is said to be open.

The remaining pulse-control unit of importance is the Gate and Delay (see Fig. 7). This equipment has the unique ability of producing a gating voltage, or "gate", of adjustable duration when triggered by a single input pulse. It will also supply a delayed 0.1-μsec pulse, the delay time being equal to the duration of the gate. Two controls for adjusting the delay from 0.5 μsec to 2500 μsec are available; a step or "course" control and a "fine" control which is used between steps. The "clipper" control in the gate output circuit enables us to eliminate negative overshoot. The delayed pulse output has the standard amplitude and pulse-polarity controls; and since a pulse-shaping circuit is included, the delayed pulse is a 0.1-μsec half-sine-wave pulse.

Typical Applications

A widely used device in computer work is the binary counter. Fig. 5 shows the setup for a 3-stage counter (scale of eight) using three Register Panels. Each flip-flop (FF) represents a binary digit (0 or 1) of a three-digit binary number. The content of the counter is displayed by the 0 and 1 indicator lights on each panel. If random input pulses are fed to the assembly at point A after each flip-flop is preset to 0 by some external triggering device, the eighth input pulse will return the counter to 000. For example, the first pulse arrives at point A, finds gate tube 1 (GT1) closed and switches FF1 to 1. The second pulse then finds GT1 open, switches FF1 to 0, and arrives at Point B, etc. After the seventh pulse passes point C, the counter is filled (the flip-flops contain 1's). The eighth pulse then passes through GT1 and GT2, and switches each flip-flop as it goes. The counter is now back to its original value (000) and is ready to count eight more pulses. The inherent delay of the triggering circuit in the flip-flop of each Register Panel is sufficient to obviate the need for the delay element (DE) shown. The scale of 8 may be changed to a scale of 7 by using GT3 and feeding its output, termed "end carry" (point D), back to the 1, or read-in, input of FF1 (point E).

Other widely used pulsed circuits which can be assembled rapidly with this new test equipment are storage registers, pulse distributors, and frequency dividers. An interesting simulation problem was solved at M.I.T. by constructing a "test control" for the digital computer, using pieces of test equipment (see Fig. 6). This control permitted the arithmetic element of the computer to operate while the regular control element was being constructed. It provided:

1. All timing and control pulses necessary for accurately simulating selected computer operations.

2. Three temporary toggle-switch registers for storing binary numbers.

3. Means for observing the performance of all circuits.

4. A system which permitted operations to be performed either at high speed or at a push-button rate.

PULSE-MEASURING UNITS

In the second class of new test units are the video probe and the video amplifier. These are used in conjunction with a synchroscope, rather than an oscilloscope, to permit pulse measurement and observation.

The Video Probe (Fig. 8)

Most video probes employ an R-C compensated voltage divider having a step-down ratio of usually 10:1 or 100:1. Such probes utilize the capacitance of a coaxial cable as part of the R-C circuit, and the cable itself as a flexible lead of fixed length from the test point to a video-amplifier input. This type of probe is useful for observing pulses which have longer rise times then the delay time of the cable; however, when the rise times of the pulses are about as long as the delay time, the probe cannot be used because reflections of the pulses are set up in the cable.

The probe now in use at M.I.T. is designed to feed a terminated cable having a characteristic impedance of 93 ohms. The advantage in using a terminated cable is that it can be made any reasonable length (up to 100 feet) without introducing reflections.

The probe is 7 inches long and 1 1/2 inches in diameter, and has two sections: the attenuator and cathode follower. Each section is encased in brass tubing to provide shielding against hand capacitance and pickup of stray voltages.

The cathode-follower circuit has a high-frequency response usable to 50 megacycles, an input impedance level of 10 megohms within the usable range, and an output impedance of 93 ohms. A type CS-968 subminiature triode was selected because of the tube's small size, high mutual conductance, and high dissipation ratings. Since the tube overloads at voltages greater than 1 or

2 volts at the input, plug-in attenuators are provided so that a wide range of input voltages can be accommodated. These attenuators include 10:1, 30:1, and 100:1 types; all have input impedances representable by a resistance of 10 megohms shunted by a capacitance of 2 to 8 micromicrofarads.

If the probe is used near its video amplifier and synchroscope, power is obtained from a supply mounted on the synchroscope chassis; if it is used at a remote distance from the sycnrhoscope and amplifier, a portable power supply is available. Voltages used are +75V and 6.3V a-c.

<u>The Video Amplifier</u> (Fig. 9)

Since the probe attenuator reduces signal amplitude and the cathode follower has a gain of only 1/3, a video amplifier has to be used if signals are to be observed on a synchroscope. The wide-band amplifier designed for this purpose at M.I.T., was constructed to fit inside the cabinet of a commercial synchroscope; several units are now in service. The specifications of this amplifier are as follows:

Circuits:

Five stages, the last four push pull.
Tube types used: 6AH6, 6AN5, 829-B.
Separate power supply.

Input:

The minimum signal amplitude at the input is 0.02 volt peak above average value; the maximum is 0.3 volt.

Frequency Response (with probe):

The frequency response at ± 1db is 25 cps to 20 mc.
The -3db points are 17 cps and 28 mc.

Output:

Over-all gain of the amplifier is 45 db.
The maximum output voltage is 75 volts peak.

CONCLUSION

Before the adoption of the building-block technique of testing at M.I.T., a special test setup for the digital computer would require long periods of time to design and construct. After tests, the setup would be worthless, except for its salvage value. By using the basic units described in this paper, the engineer may now build an elaborate test setup in less than a day. When the setup is no longer needed, it is disassembled, and the pieces of test equipment are ready for other uses.

It is true that for a given test a special design may require fewer tubes and components than one made of test equipment. However, the saving of engineering and shop time to be gained by using the new units more than offsets the slightly larger outlay of total equipment. For example, a special binary counter was designed, constructed, and debugged -- all of which required six weeks' work. Later, an equivalent binary counter was set up in ten minutes using three building blocks.

In addition to its varied applications in the field of digital computers, the new test equipment can be used for any type of work that requires pulse circuits, provided that the resolution time of the equipment is able to cope with the project at hand. Since this equipment is designed for a minimum pulse period of 0.5 μsec, it can be used for a large variety of industrial and scientific purposes. If some practical scheme for providing power is available, about all that would be required to adapt the equipment would be input and output panels which would lengthen, amplify, or change the impedance level of the output pulses in accordance with the circuits to be fed.

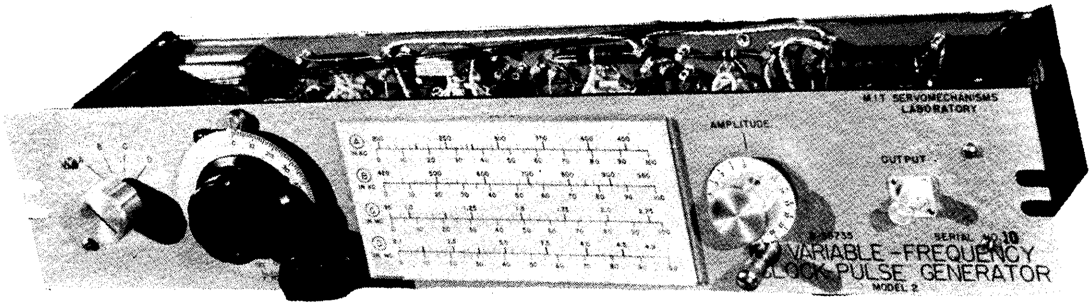

Fig. 1. Variable-Frequency Clock-Pulse Generator

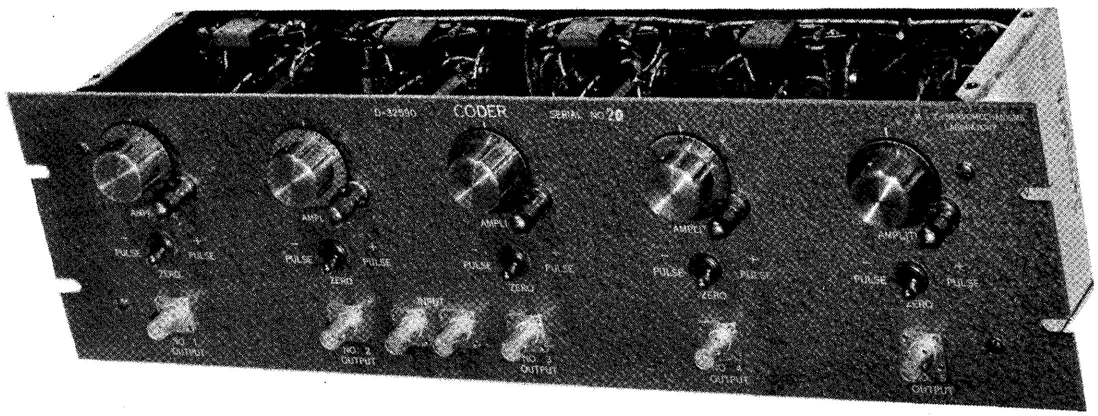

Fig. 2. Coder

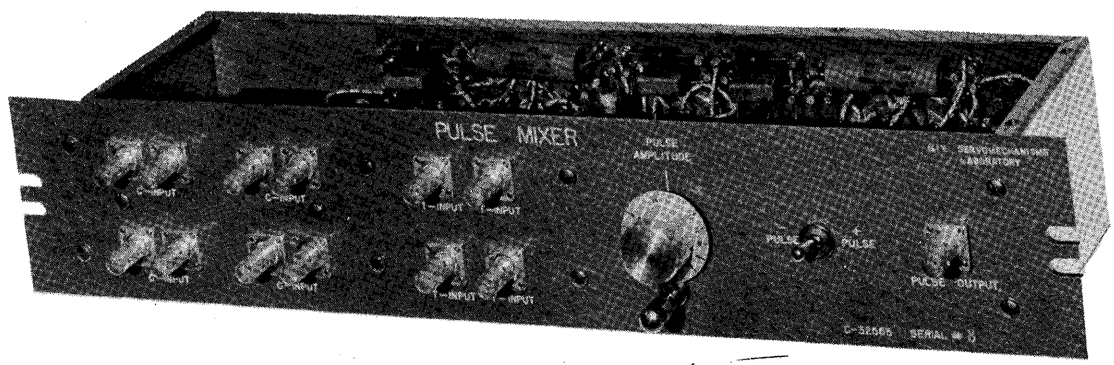

Fig. 3. Pulse Mixer

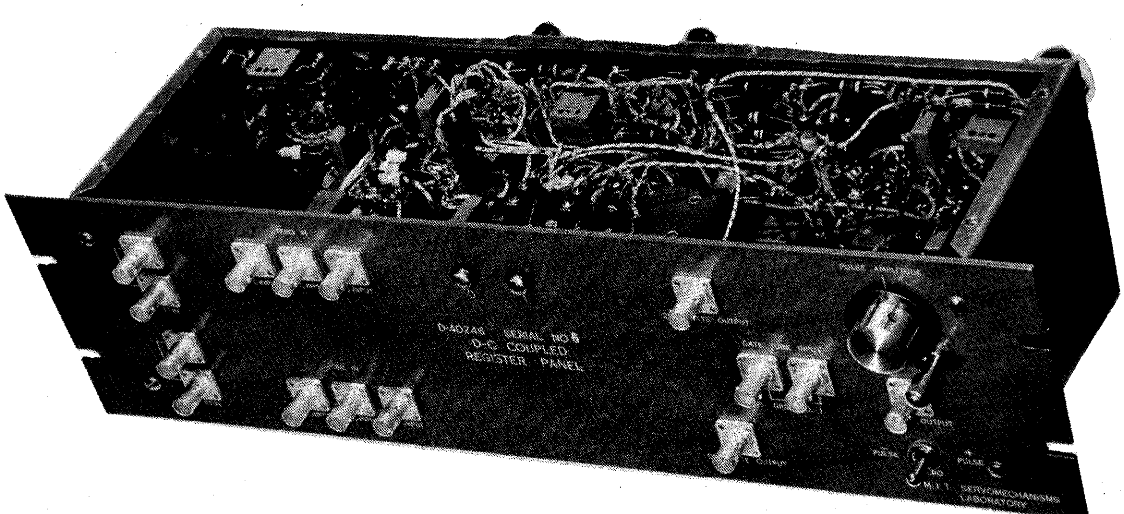

Fig. 4. Register Panel

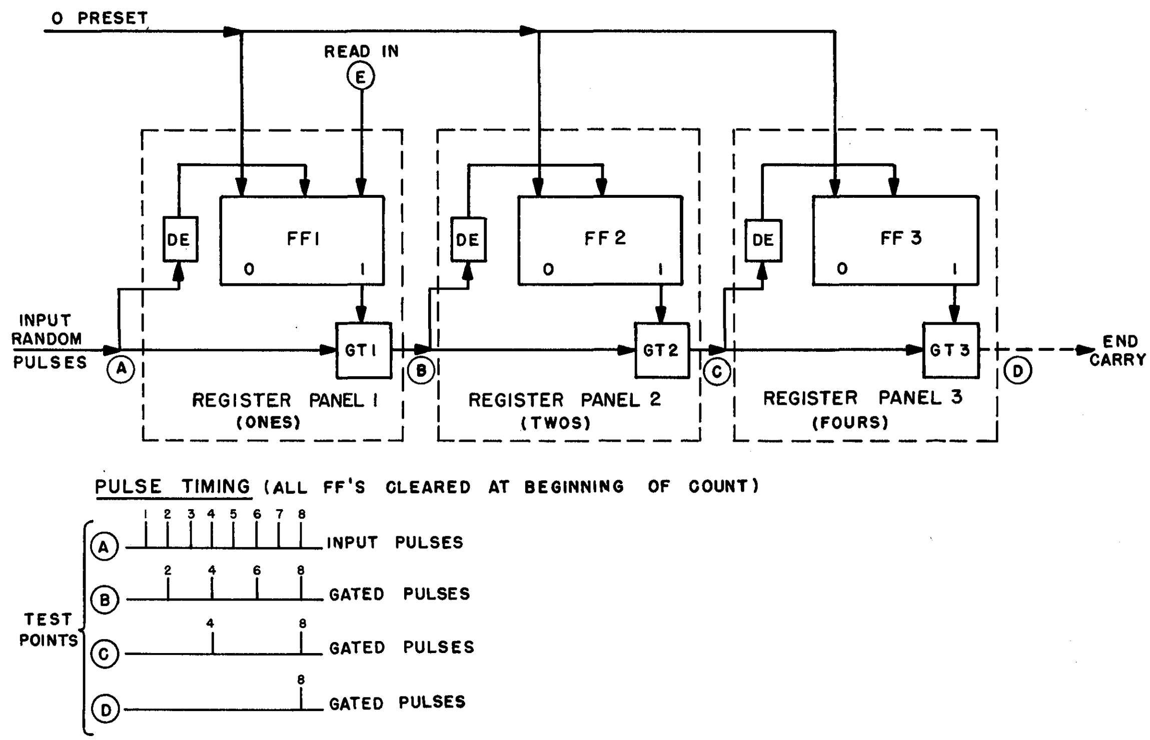

Fig. 5. Binary Counter

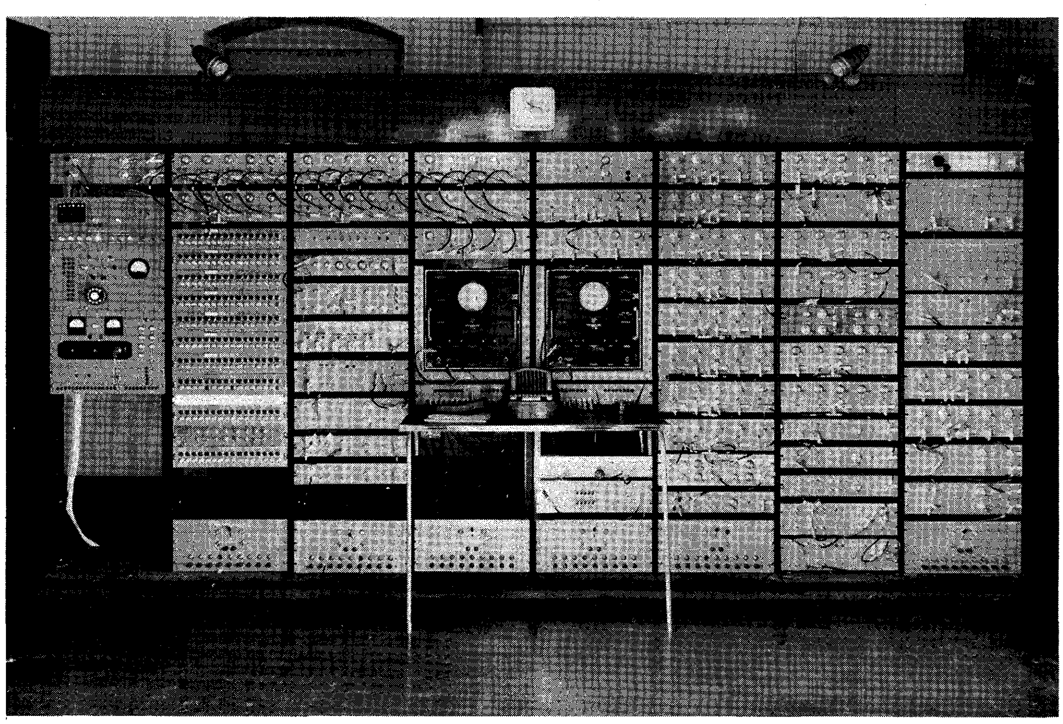

Fig. 6. Test Control

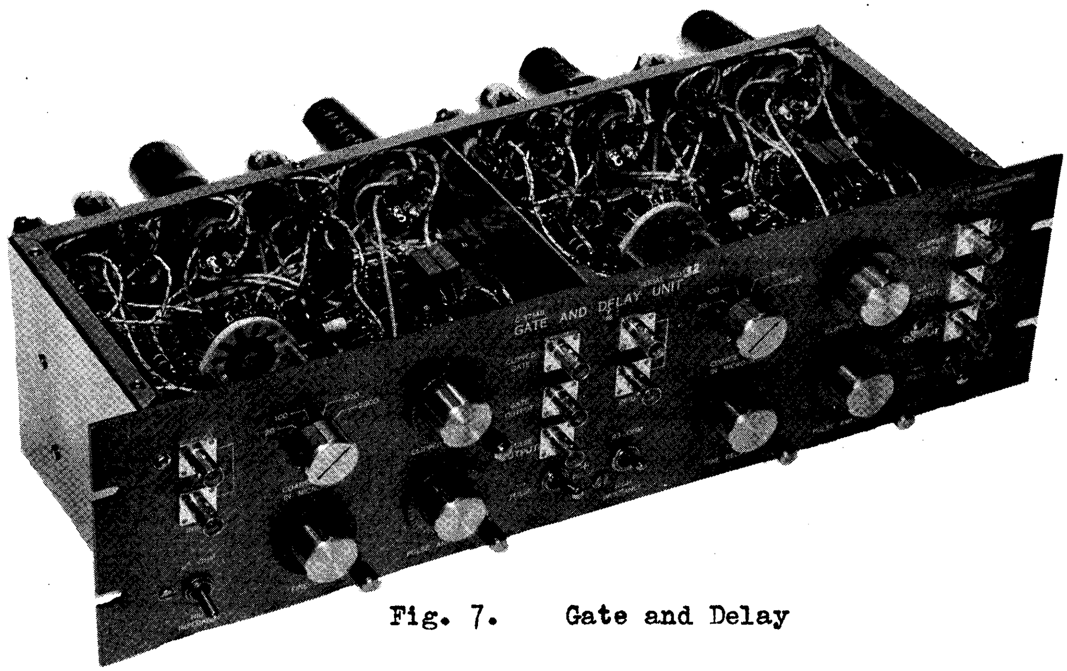

Fig. 7. Gate and Delay

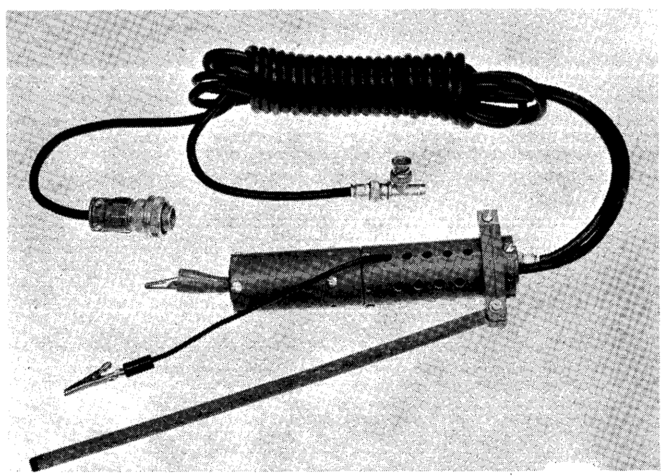

Fig. 8. Video Probe

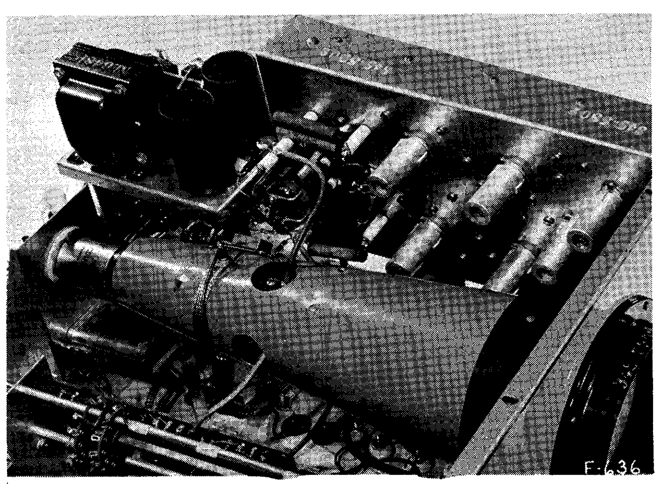

Fig. 9. Video Amplifier