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SUBJECT: PULSE RESPONSES OF FERRITE MEMORY CORES*

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Abstract: The responses of magnetic-ferrite cores to current pulses such as used in a two-to-one selection coincident-current magnetic memory are classified as fourteen basic voltage outputs. These outputs are defined and described with relation to the hysteresis loops and pulse sequences involved. Photographs of the pulse responses are presented and certain distinctive differences compared. The concept of reversible and irreversible outputs is explained. Curves of the various core voltage outputs, and the switching and peaking times versus the driving current are presented for the General Ceramics' body Ferramic S-1, size F-394. Analytical expressions for the peak full-selected ONE and the switching time are given. The convergence ratio is defined and an example of its use in the evaluation of memory cores is given. The effect of disturb sensitivity caused by overdriving is illustrated.

Introduction

The development of magnetic-ferrite cores with rectangular hysteresis loops and short switching times has made the high-speed arbitrary-access magnetic-memory possible. The M.I.T. coincident-current memories utilize the permanent magnetic properties of ferrite cores to store binary information, and the nonlinear properties to descriminate between full-amplitude selecting pulses and half-amplitude pulses. Cores are assembled in square matrices called memory planes with selection wires passing through each row and column. Figure 1. A core is addressed by passing half-amplitude pulses of current down both the particular row and column of the core selected. In this way the selected core receives a net full-amplitude pulse; all other cores on the same row or column as the selected core receive half-amplitude current pulses. These cores are said to be half-selected. The cores which are neither half-selected, nor are the selected core, are called unselected cores.

Memory Plane Pulse Sequences

The binary information, ONE or ZERO, stored in a toroidal memory core is determined by the polarity of its remnant magnetization. See Figure 2. The information is extracted when the core is selected by a full-amplitude READ current-pulse. The READ pulse polarity is

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such that the magnetization is reversed when the core holds a ONE. The cores are relatively insensitive to half-amplitude pulses. A sense winding passes through all cores in a plane. Figure 1. A ONE is "read" by detecting the voltage that is induced in the sense winding by the reversal of the selected core's magnetization when a READ pulse is applied. The absence of such a voltage indicates no reversal and consequently a ZERO in the selected core.

When selecting a core, a READ pulse followed by a WRITE pulse of opposite polarity is used. Figure 2. The WRITE pulse will leave a ONE in the selected core. If it is desired to leave a ZERO in the selected core, an inhibiting half-READ pulse is supplied simultaneously with the WRITE pulse resulting in a net half-WRITE pulse. Therefore a ZERO is written into a core by pulsing it with a full-READ followed by a half-WRITE pulse. The inhibiting half-READ pulse is supplied by the inhibit winding which links all cores in the memory plane. See Figure 1.

On the basis of the mode of operation described above, Table I presents the various possible pulse sequences to which a core in a memory may be subjected. Theoretically, a core may be selected, half-selected, and unselected in any order. A study of Table I from this point of view will indicate the possible sequences of pulses a core may experience.

Core Voltage Outputs

As previously explained, the outputs of cores are sensed at the time of application of the READ pulses. Because this is so, the voltage responses to READ polarity pulses are the ones of interest.

Many distinct voltage outputs are possible, but basically only fourteen kinds exist.* Table II lists these outputs by name and symbol, and indicates the simplest series of pulses which will produce them. The last pulse of each sequence is the selecting pulse.

The output of a core depends on its magnetic state and whether it receives a full- or half-amplitude selecting pulse. The magnetic state is determined by the information (i.e. ONE or ZERO) and by the sequence of half-amplitude pulses that have preceded the selecting pulse in question. Half-amplitude pulses either leave the magnetic state of a core undisturbed or slightly modified. A core in one of the modified magnetic states is said to be a disturbed core; and a half-amplitude pulse that modifies the magnetic state is said to be a disturbing pulse. The disturbed states are referred to as write-disturbed or read-disturbed depending on whether the last disturbing pulse preceding the selecting pulse was a half-amplitude WRITE or a half-amplitude READ respectively.

Figure 3 shows the remnant magnetic states from which the fourteen basic pulsed voltage outputs are obtained, together with the magnetic hysteresis loops that memory cores operate on in a two-to-one

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* The use of very short duration driving pulses, overdriving cores, disturb sensitivity, and other such conditions give rise to output variations which are less basic in nature. All such observed outputs may be classified as special cases of the basic fourteen outputs.

selection system. In Figure 3, the remnant magnetic states are identified by the subscripts of the symbols used to designate the corresponding full-selected voltage outputs obtained from those states.

Voltage Outputs from Reversible Magnetization Changes

Figure 3 shows ten states of remnant magnetization which occur in two-to-one selection of magnetic cores. By tracing the various hysteresis loops involved, it is seen that the remnant magnetizations of cores in the rl, rz, or uz states are not changed by the application of half-amplitude READ pulses and even full-amplitude READ pulses do not affect the uz state. The output voltages that occur under these conditions are the result of reversible magnetization changes. Such reversible outputs are spikes of voltage which for any practical consideration are linear functions of the time derivative of the driving current pulse. That is to say, that in the case of reversible outputs, a core responds essentially as a linear inductance. Therefore, a reversible output from a core may be expressed mathematically as

$$V_r = M \frac{dI_m}{dt} \qquad (1)$$

where V_r is the reversible voltage output of the core,

I_m the current of the driving pulse,

t the time,

and M the mutual inductance between the drive wires and the sense winding.

The mutual inductance, M, depends on the core dimensions, the winding geometry, and the differential permeability of the particular assymmetrical minor hysteresis loop traversed. The voltage outputs reported in this paper are the responses from General Ceramics' Ferramic S-1 memory cores, size F-394, with single turn sense windings wound tightly about the core cross sections and leads twisted to eliminate air pickup. The drive wire is oriented axially through the cores.

Outputs from the Undisturbed ZERO State (uVz, uVhz)

A study of the possible pulse sequences as indicated by Table I shows that full-amplitude READ pulses are always followed by WRITE polarity pulses. For this reason, neither the undisturbed ZERO nor the half-selected undisturbed ZERO outputs can ever occur in the memory. However, because of the basic nature of uVz and uVhz they are included for the sake of completeness.

The undisturbed ZERO, uVz, and the half-selected undisturbed ZERO, uVhz, are the most rudimentary pulse responses that can be obtained from a magnetic core. Since they are reversible they have the shape of the time derivative of the driving current pulse. Figure 4 shows a composite photograph of a full-amplitude READ current pulse and the resulting uVz output. The shape of the output is seen to be that of the time derivative of the driving pulse.

Figures 5 and 12 include photographs of the uVhz and uVz outputs respectively. The only difference between the two outputs is in their amplitudes. The relative amplitudes depend on the rate of rise of the respective driving currents, therefore, with the same rise time, the uVz amplitude should be essentially twice that of the uVhz. However, due to slight differences in the differential permeabilities of their respective hysteresis loops, the uVhz is found to be somewhat greater than half the uVz.

Half-Selected Read-Disturbed Outputs (rVhl, rVhz)

As previously explained, the undisturbed ZERO outputs are never obtained in the coincident-current magnetic-memory. The half-selected read-disturbed outputs, rVhl and rVhz, however, are of prime importance in the memory. rVhl and rVhz are reversible and therefore have the same shapes as the uVz and uVhz outputs. Figures 5 and 6 are photographic comparisons of the various half-selected ZERO and half-selected ONE outputs respectively. With a particular drive current the relative amplitudes of reversible outputs depend only on the differential permeabilities of their respective assymmetrical minor loops. The differential permeabilities of these loops are greater for smaller magnetization, being maximum for the loop at zero remnant magnetization, and least for the loop at saturation. Understanding this fact and referring to the relative values of magnetization represented by the rl, rz, and uz states, it is clear that

$$ {}_{r}V_{hl} > {}_{r}V_{hz} > {}_{u}V_{hz} \qquad (2) $$

Equation 2 is substantiated by the curves in Figure 7.

Figure 7 shows the reversible half-selected outputs to be relatively insensitive to the amplitude of the driving current. This fact is due to the compensating effects of two factors governing the amplitudes of reversible outputs. For a given rise time, the reversible output of a core is directly proportional to the amplitude of the driving pulse. However, the magnitude of the magnetization of the remnant state also depends on the amplitude of the driving pulses. At low driving currents the remnant magnetization is low and therefore the differential permeability is larger. These compensating effects make the various reversible outputs nearly insensitive to driving current variations.

Voltage Outputs from Irreversible Magnetization Changes

Figure 3 indicates that the voltage outputs obtained with half-amplitude READ polarity pulses from cores in the ul, wl, dz, and wz states are irreversible because the remnant magnetization is changed by the driving pulse; also, all full-selected outputs except the uVz are irreversible. Irreversible outputs retain the reversible "spike" of voltage caused by the rise of the drive current pulse, but in addition produce a voltage caused by the change of magnetic flux which results from irreversible domain wall growth. The superposition of these two voltages is the total output. The irreversible wall motion essentially begins instantaneously when the necessary driving force is applied. The duration of the motion depends on the relaxation time and the total flux change involved. The relaxation time is longer when a core is being demagnetized than when the magnetization is being increased by the driving pulse. With a step function drive the irreversible voltage response begins from an initial value and ultimately decays assymptotically to zero. For full-amplitude pulses, and for half-amplitude pulses at high driving currents, the irreversible voltage may increase from its initial value to a "peak" before decaying to zero. See Figures 5, 6, 8 and 12.

Half-Selected Write-Disturbed Outputs (wVhl, wVhz, dVhz)

The half-selected write-disturbed outputs are irreversible. Figure 7 shows their characteristics to be very much alike. It is seen that these outputs are larger than the reversible half-selected outputs already discussed. This is due to the contribution of the irreversible voltage. Figure 7 shows that with currents where the half-amplitude pulses are large enough to cause an appreciable switching of the core, an abrupt increase in the amplitudes of the half-selected write-disturbed outputs occurs. Under these conditions a core is said to be overdriven.

The amplitude of the irreversible component of voltage depends on the amount of magnetic flux change resulting and the relaxation time. Two symmetrical minor hysteresis loops are shown in Figure 3 which represent the half-amplitude responses from the dz and wz states. The dVhz output involves a flux change represented by the larger loop. The subsequent wVhz outputs traverse the smaller loop inside. Because of the greater flux change attending the dVhz at normal driving currents than the wVhz outputs, the dVhz output is proportionately larger. This difference is clearly shown in Figure 5 and also indicated by the curves in Figure 7. A similar analysis of the wVhl outputs shows, that to a lesser extent, a difference between the first wVhl and the subsequent wVhl outputs also might be expected. A split in the wVhl outputs may be observed but the difference is very much smaller than that between the dVhz and wVhz.

For normal driving currents the wVhl and dVhz are slightly larger than the wVhz. However, when overdriven Figure 7 shows the wVhz to be the largest half-selected output. READ polarity pulses tend to demagnetize the ONE states but act oppositely on the ZERO states, therefore, the relaxation time of the irreversible component of the wVhl is longer than those of the dVhz and wVhz outputs. For this reason when overdriving, the wVhz and dVhz outputs are larger in amplitude but proportionately shorter in duration than the wVhl outputs. See Figures 5 and 6. For the same reason Figure 5 shows the dVhz to be of smaller amplitude and longer duration than the wVhz outputs when overdriven.

First Half-Selected ONE Output (uVhl)

The first half-selected ONE is important because of its large irreversible component. In the normal driving range the uVhl is decidedly the largest half-selected output. See Figures 6 and 7. Unlike the other irreversible half-selected outputs however, its amplitude is relatively insensitive to overdriving; rather, the uVhl responds to overdriving by developing an extremely prolonged irreversible voltage output which has a duration several times longer than the total full-selected switching time of the core. See Figure 6. This fact has a significant effect on the operation of a magnetic memory since, if sufficient time is not allowed for the irreversible change associated with the uVhl to take place, the phenomenon of disturb sensitivity is introduced. Disturb sensitivity is a condition where a single disturbing pulse is not sufficient to stabilize the remnant magnetic state of a core. It is this same effect, when acting from the uz state with the half-WRITE pulse that causes the wVhz to become greater than the dVhz when overdriving.

Disturb sensitivity occurs with all irreversible outputs when overdriving. For example, Figure 14 shows the effect of disturb sensitivity on the strobe time value of the wVhl output. Figures 5 and 6 photographically show the differences between the first and second wVhz and wVhl respectively.

Undisturbed ONE Output (uVl)

The undisturbed ONE output is the fundamental pulse response of a magnetic core. Figure 8 is a set of composite photographs of the full-selected ONE outputs at three different drive currents. The reversible "spike" at the time of maximum current rise may be seen and subsequently the "peak" of the irreversible voltage output occurs. It is the peak voltage that is of prime interest and usefulness.

Figure 9 shows the value of the peak undisturbed ONE to be a linear function of the drive current amplitude, I_m. The slope S_v, of the uVl versus I_m curve is called the transfer coefficient. The value of the peak undisturbed ONE for a given drive current may be expressed analytically as

$$ {}_{u}V_{1}(I_m) = {}_{u}V_{1}(I_t) + S_v(I_m - I_t) \quad I_m > I_t \tag{3} $$

I_t is the threshold current, below which no voltage "peak" appears. This point is called the threshold of switching. See Figure 8. A core is said to be underdriven when $I_m < I_t$.

Switching Time (T_s)

The switching time of a core is defined as the elapsed time between the time at which the drive current attains the value of the half-amplitude driving current and the time at which the switching voltage has dropped to ten percent of its peak. The time of peak output is measured from the same initial time. Figure 10 is a plot of the switching and peaking times of the full-selected ONE outputs; and the reciprocal of the switching time versus the driving current for the uV1 output is plotted in Figure 11. Figure 11 reveals that at higher driving currents the switching time of a core varies inversely with the drive and therefore may be expressed analytically as

$$(I_m - I_o)T_s = S_w \qquad I_m > 2I_o \qquad (4)$$

where I_o is called the intercept current, and S_W the switching coefficient. The switching coefficient is a good figure of merit for a core. Since both low driving currents and fast switching times are desirable, low S_W is favorable. The departure from linearity of the inverse switching time curve at lower currents is a function of core geometry.

Read-Disturbed ONE Output (rV1)

The read-disturbed ONE output responds substantially like the undisturbed ONE except at high driving currents where the core is overdriven. When a core is overdriven the half-amplitude disturbing pulses are of sufficient magnitude to cause excessive degradation of the rV1 output. See Figures 8 and 9. Observation of the photographs in Figure 8 shows, that in addition to having a slightly smaller peak value, the rV1 response is also slightly delayed. The response of the rV1 output to a step function is faster than the uV1; however, contrary to the situation for the uV1, the rV1 irreversible magnetization change cannot begin until the driving pulse has risen to the half-amplitude value. Therefore, a delay in the rV1 switching equal to the time required to achieve half-amplitude drive occurs. Up to this time the rV1 output is completely reversible. Consequently, with rise times of the order of 0.1 µs or greater, the peak of the rV1 output occurs after the peak of the uV1 output; also, for the same reason, the spike of the rV1 is more pronounced and smaller in amplitude.

Write-Disturbed ONE Output (wV1)

The write-disturbed ONE has much in common with the other fully-selected ONE outputs. As might be expected the wV1 has a spike of intermediate amplitude between those of the uV1 and rV1; and the switching and peaking times at normal driving currents and ordinary rise times are slightly shorter than the rV1 but longer than the uV1. See Figures 8, 9, and 10. The wV1 output departs strikingly from both the uV1 and rV1 when a core is overdriven. The wV1 becomes assymetrical in appearance and the response time becomes increasingly shorter in comparison to the uV1. At very high driving currents the peak wV1 becomes greater in amplitude than the peak uV1 although the total integrated value (i.e. the flux change) does not. This is because the wV1 switching time shortens proportionately.

Irreversible Full-Selected ZERO Outputs (dVz, wVz, rVz)

Figure 12 is a composite photograph of the full-selected ZERO outputs. The reversible uVz output is the smallest and is included for comparison purposes. Slightly larger than the uVz is the rVz output which is characterized by a distinctive double peak. The double peak of the rVz is the result of the accentuation of the spike caused by the delay in the commencement of the irreversible portion of the voltage output analogous to the situation explained for the rVl output. This delay is further manifested in the slower response of the rVz than the other irreversible ZERO outputs.

The largest output in Figure 12 is that of the first-disturbed ZERO, dVz. It is the full-selected counterpart of the dVhz and is the ZERO output obtained from a core in a memory which has not been otherwise disturbed since writing. The remaining output shown in Figure 12, slightly smaller than the first-disturbed ZERO, is the trace of the wVz output.

Analysis of Memory Plane Outputs

Consider a memory plane consisting of a square array of n^2 cores. When a particular core is selected, the output voltage on the sense winding is the sum of the selected core output plus the half-selected outputs of the 2(n-1) half-selected cores. In order to distinguish between a ONE and a ZERO, it is necessary that the largest possible ZERO read out of the plane not be sufficiently large to be confused with a ONE. To minimize the contribution of the half-selected outputs on the read-out voltage, the sense winding is passed through the cores of the plane in a manner which results in core voltage outputs of alternate polarities on the sense winding. A study of Figure 1 shows that the net output voltage of a plane is composed of the selected core output minus two half-selected outputs plus the net output of the remaining half-selected cores which tend to cancel one another. This latter output is referred to as the delta voltage of the plane. An equation expressing the output of such a memory plane may be written as follows:

$$V_{out} = V_s - 2V_{hs} \pm (n-2)V_\delta \qquad (5)$$

where V_{out} is the read-out voltage of the plane;

V_s the voltage output of the selected core;

V_{hs} the voltage output of any half-selected core whose output polarity on the sense winding is opposite to that of the selected core;

and V_δ the difference between the average voltage output of the half-selected cores whose polarities on the sense winding are the same as that of the selected core and the average voltage output of the half-selected cores whose polarities on the sense winding are opposite to that of the selected core, exclusive of the two Vhs outputs.

A comparison of the lowest possible ONE read-out with the largest possible ZERO read-out yields a figure of merit for a memory plane. The absolute value of the ratio of the largest possible ZERO read-out to the smallest possible ONE read-out is called the convergence ratio, C_V. The delta voltage may be either positive or negative with respect to the output of the selected core, therefore the maximum absolute value of the delta voltage is always the one which yields the most adverse output and therefore is the one of interest in evaluating cores for a memory.

Strobe Time Values

Since it is desirable to minimize the convergence ratio, the output voltage of a plane is sensed for 0.1 μs at approximately the peaking time of the rVl output. This time of sensing is called the strobe time. Therefore the strobe time value of a core output is its value at the time of peak rVl for the normal operating current. Figure 13 shows curves of the strobe time values versus driving current for the various half-selected outputs and the wVz and rVz outputs. No curves are shown for the reversible outputs since for a flat topped driving pulse no reversible output exists after the current rise is over. Also, it is seen that because of their short relaxation times the half-selected write-disturbed ZERO outputs do not have strobe time values in the normal driving range. However, due to the more prolonged duration of the irreversible half-selected ONE outputs, significant strobe time values do exist for them.

Memory Core Evaluation

The curves of Figure 13 enable a computation of the convergence ratio, C_V. The largest half-selected strobe time value in the normal driving range is seen to be the uVhl output. However, due to the inherent principle of operation of a memory plane, only one undisturbed core can exist on any row or column. Therefore no more than two uVhl outputs can occur with any read-out. At the lower and normal driving currents it is found that

$$C_V = \frac{{}_wV_z - 2\,{}_uV_{hl} - (n-2)({}_wV_{hl} - {}_wV_{hz})}{{}_wV_l - 2\,{}_uV_{hl} - (n-2)({}_wV_{hl} - {}_wV_{hz})} \qquad (6)$$

When overdriving,

$$C_V = \frac{{}_rV_z - 2\,{}_wV_{hz} - (n-2)({}_wV_{hz} - {}_rV_{hz})}{{}_rV_l - 2\,{}_wV_{hz} - (n-2)({}_wV_{hz} - {}_rV_{hz})} \qquad (7)$$

Experience with M.I.T. magnetic memories indicates that the maximum limit of convergence that is acceptable is approximately 25-30 percent. In computing C_V, the driving current operating range should be taken into account by computing the numerator for the upper current limit and the denominator for the lower limit. For example, the normal driving range for the 64 x 64 M.I.T. magnetic memories is between 720 and 900 ma. For this range and the cores represented by the curves of Figure 13, the convergence ratio from equation 6 is

$$C_v = \frac{0.16 - 2 \times 1.24 - 62 \times 0.21}{74 - 2 \times 1.20 - 62 \times 0.16} = \frac{15.3}{62} \qquad (8)$$

Therefore, for the operating range between 720 and 900 ma the convergence is 25 percent, a satisfactory figure. A smaller convergence ratio may be assured by using a narrower driving range.

When overdriving, disturb sensitivity becomes a consideration in the determination of C_V. Figure 14 shows the strobe time values of wVhl at 1125 ma as a function of the number of times the core has been half-selected for a ONE. The same phenomenon holds for all irreversible outputs. Therefore, when using equation 7 to determine the convergence ratio, the values of the voltage outputs used should be those for a core many times disturbed.

Conclusions

The pulsed voltage outputs obtained from magnetic cores with two-to-one selection may be classified as either reversible or irreversible. Basically, only fourteen different outputs exist, four reversible and ten irreversible. Reversible outputs are linear functions of the time derivative of the driving current pulse whereas irreversible outputs have an additional component caused by an irreversible change in the magnetization. Reversible outputs are insensitive to overdriving whereas irreversible outputs are extremely sensitive.

The linear characteristic of the full-selected ONE output may be expressed analytically by equation 3 and the switching time by equation 4.

The output voltage of a magnetic core memory plane of the M.I.T. type is given by equation 5. Based on equation 5 and the knowledge presented concerning core voltage outputs, the quality of memory cores may be evaluated by the computation of the convergence ratio as demonstrated.

Signed James Robt. Freeman
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Approved DRB
D. R. Brown

JRF/jk

cc: Group 63 Staff
Group 62 Memory Section

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Figure Captions

Figure 1. Diagram of M.I.T. magnetic core memory plane showing the scheme of core selection and the wiring patterns used.

Figure 2. Schematic indication of the storage of binary information in a magnetic core. READ pulses magnetize the cores in the ZERO direction, WRITE pulses in the ONE.

Table I. Sequences of pulses received by cores in a magnetic memory plane.

Table II. The fourteen basic pulsed voltage outputs of magnetic memory cores for a two-to-one selection system.

Figure 3. The basic hysteresis loops associated with magnetic memory core operation in a two-to-one selection system.

Figure 4. A photographic comparison of the uVz output with the driving current pulse producing it illustrates how reversible outputs are constant multiples of the time derivative of the driving current pulses.

Figure 5. Photographs of the half-selected ZERO outputs. For normal drive, from smallest to largest, uVhz, rVhz, wVhz, dVhz. For overdriven, uVhz not shown, rVhz purely reversible, wVhz and dVhz outputs show great sensitivity to overdriving. When overdriven, the dVhz is smaller in amplitude but longer in duration than the wVhz outputs. The first and second wVhz outputs are shown in order to illustrate the effect of disturb sensitivity.

Figure 6. Photographs of the half-selected ONE outputs. For normal drive, from smallest to largest, rVhl, wVhl, uVhl. For overdriven, rVhl purely reversible, wVhl shows great sensitivity to overdriving, uVhl responds to overdriving by developing extremely prolonged irreversible output. The first and second wVhl outputs are shown to illustrate the effect of disturb sensitivity.

Figure 7. Curves of the peak half-selected memory core outputs versus driving current.

Figure 8. Photographs of the full-selected ONE outputs showing the outputs at the threshold of switching, at normal drive, and when overdriven. From smallest to largest the outputs are rVl, wVl, and uVl.

Figure 9. Curves of the peak full-selected memory core outputs versus driving current. Note the linear response of the full-selected ONE outputs with respect to drive.

Figure 10. Curves of the peaking and switching times of the full-selected ONE outputs versus driving current.

Figure 11. Curve of the reciprocal of the switching time versus driving current showing the linear relationship of the inverse switching time with drive.

Figure 12. Photographs of the full-selected ZERO outputs, showing from smallest to largest, uVz, rVz, wVz, dVz.

Figure 13. Curves of the strobe time values of the various core voltage outputs versus driving current.

Figure 14. Curve of strobe time values of the half-selected write-disturbed ONE outputs when overdriven versus the number of times the core has been disturbed by a half-READ followed by a half-WRITE pulse. This curve illustrates the effect of disturb sensitivity on core voltage outputs.

Drawing Numbers:

B-59727
B-59726
A-59790
A-59894
B-57238-1
A-59810
A-59817
A-59818
C-59785
B-59820
B-59770
B-59807
B-59806
A-59819
A-60222
A-60221

A-59790

IF THE CORE IN QUESTION IS:	IF THE INFORMATION WRITTEN INTO THE SELECTED CORE IS: ONE	ZERO
SELECTED	READ, WRITE	READ, $\frac{1}{2}$ WRITE
HALF-SELECTED	$\frac{1}{2}$ READ, $\frac{1}{2}$ WRITE	$\frac{1}{2}$ READ, NONE
UNSELECTED	NONE, NONE	NONE, $\frac{1}{2}$ READ

TABLE I

SEQUENCES OF PULSES RECEIVED BY CORES IN A MEMORY PLANE

A-5989 4

NAME	SYMBOL	PULSE SEQUENCE (READ PULSES UP, WRITE PULSES DOWN)
UNDISTURBED ONE	uV_1	
READ-DISTURBED ONE	RV_1	
WRITE-DISTURBED ONE	wV_1	
UNDISTURBED ZERO	uV_z	
FIRST-DISTURBED ZERO	dV_z	
READ-DISTURBED ZERO	RV_z	
WRITE-DISTURBED ZERO	wV_z	
FIRST HALF-SELECTED ONE	uV_{h1}	
HALF-SELECTED READ-DISTURBED ONE	RV_{h1}	
HALF-SELECTED WRITE-DISTURBED ONE	wV_{h1}	
HALF-SELECTED UNDISTURBED ZERO	uV_{hz}	
FIRST HALF-SELECTED ZERO	dV_{hz}	
HALF-SELECTED READ-DISTURBED ZERO	RV_{hz}	
HALF-SELECTED WRITE-DISTURBED ZERO	wV_{hz}	

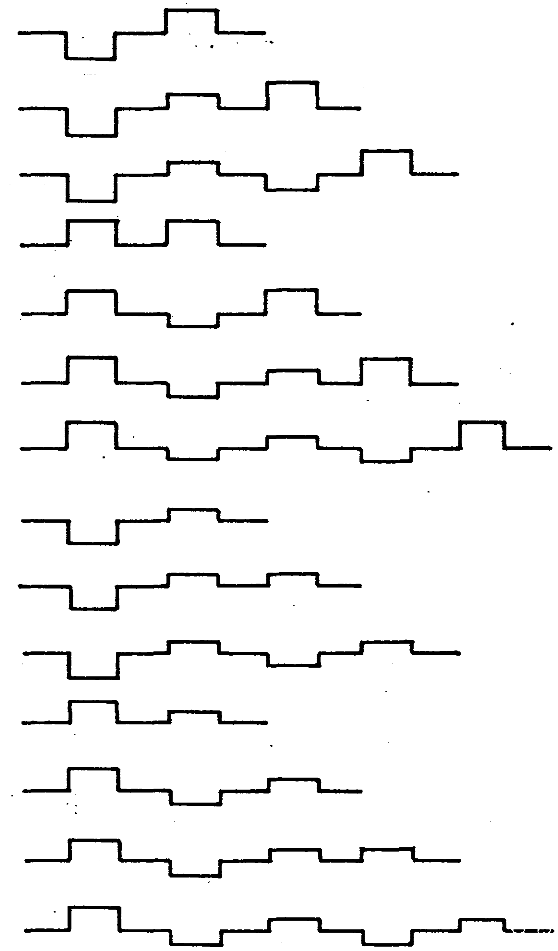


TABLE II

PULSED VOLTAGE OUTPUTS OF MAGNETIC MEMORY CORES

IN A TWO-TO-ONE SELECTION SYSTEM

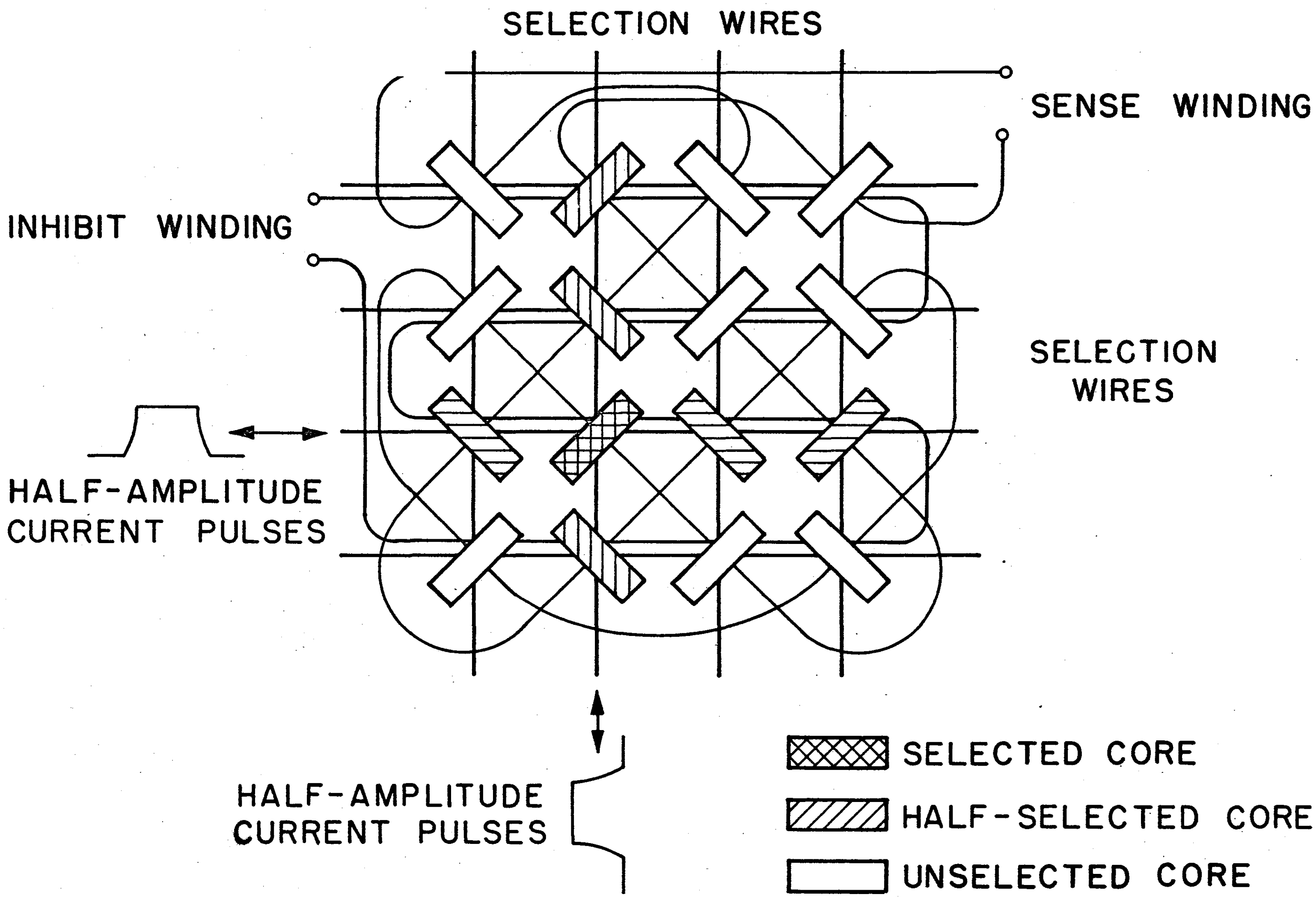


FIG. 1-1

M.I.T. MAGNETIC CORE MEMORY PLANE

B-59726

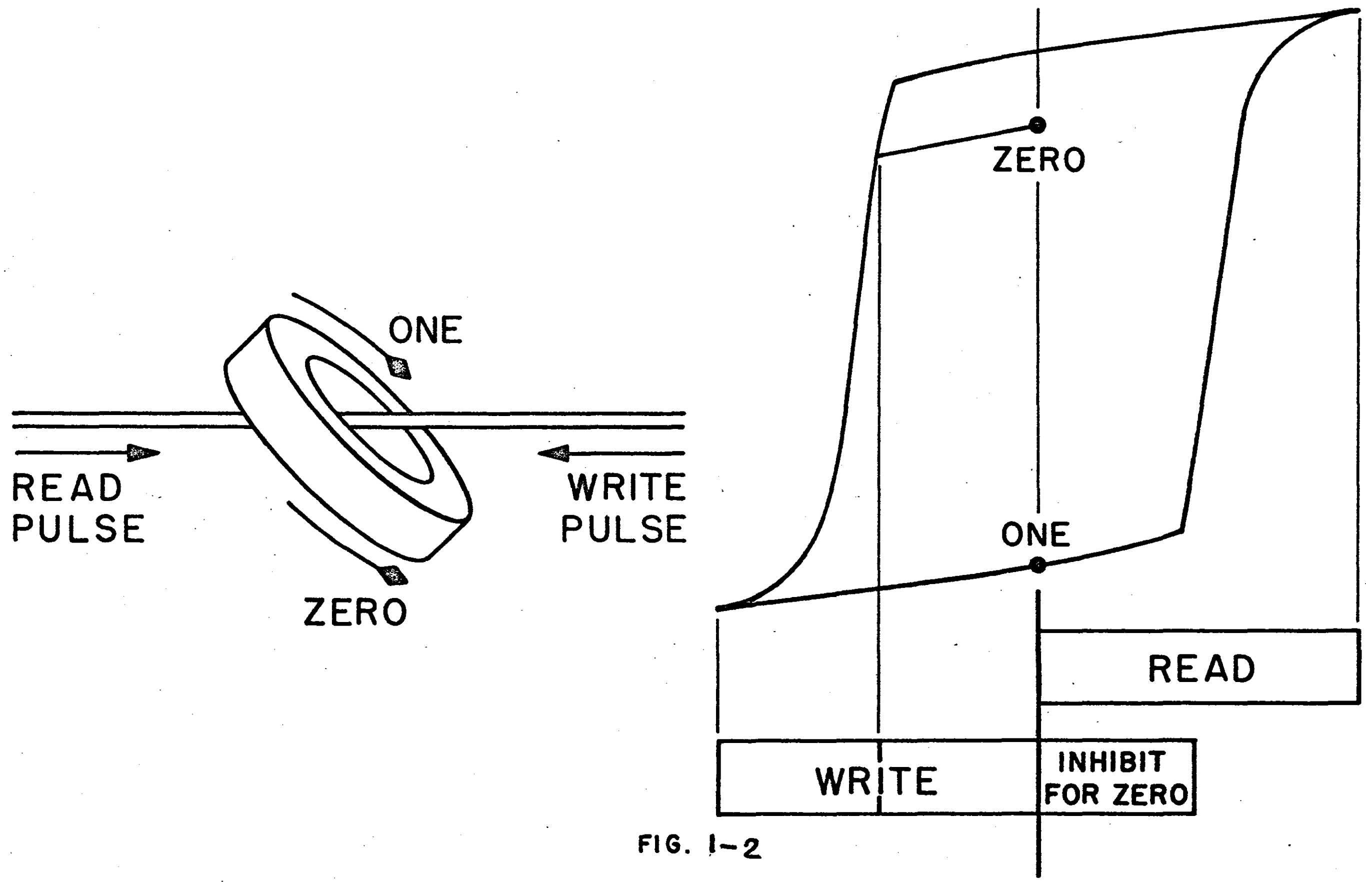


FIG. 1-2

STORAGE OF BINARY INFORMATION
IN A MAGNETIC CORE

B-57238-1

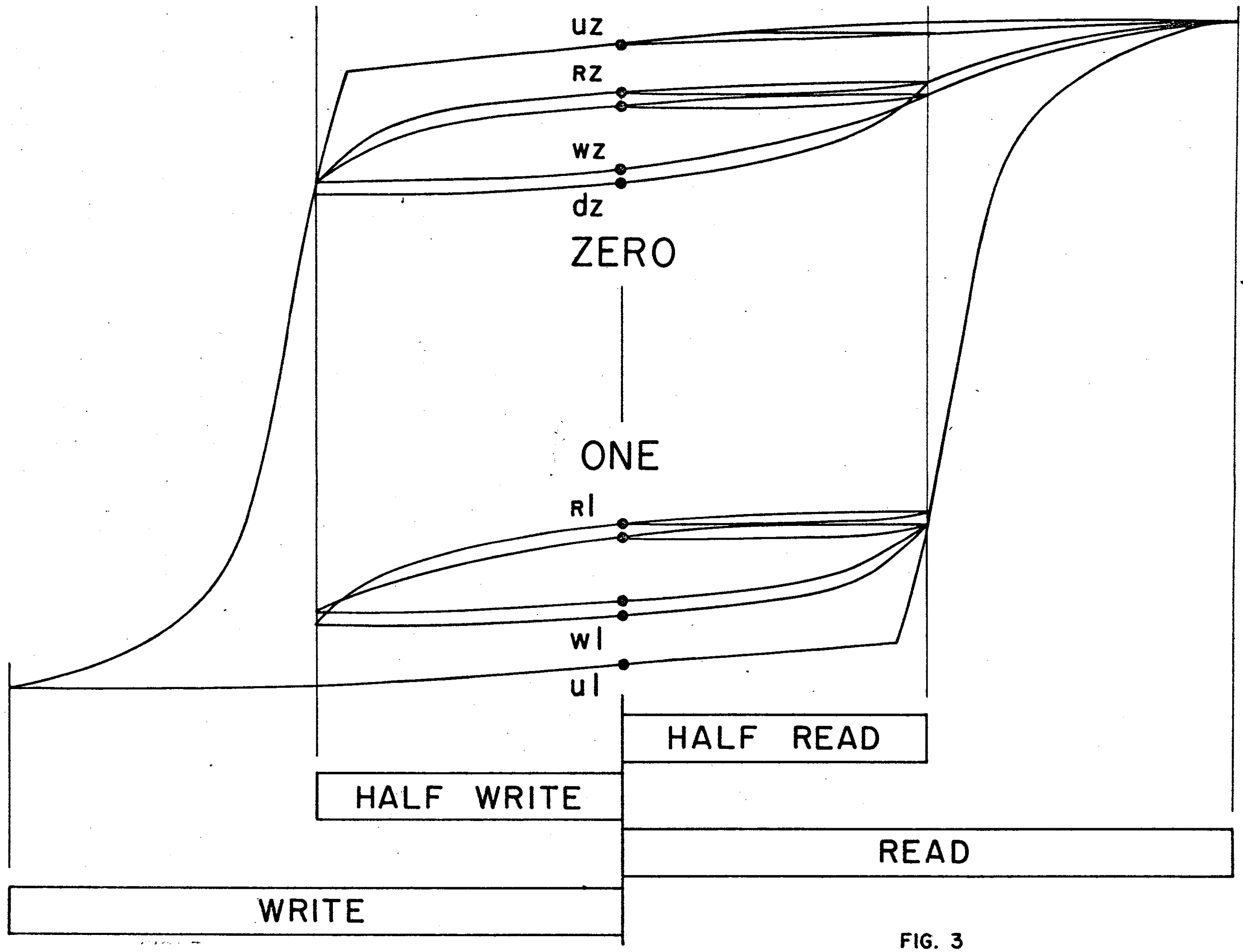


FIG. 3

HYSTERESIS LOOPS ASSOCIATED WITH MAGNETIC MEMORY CORE OPERATION

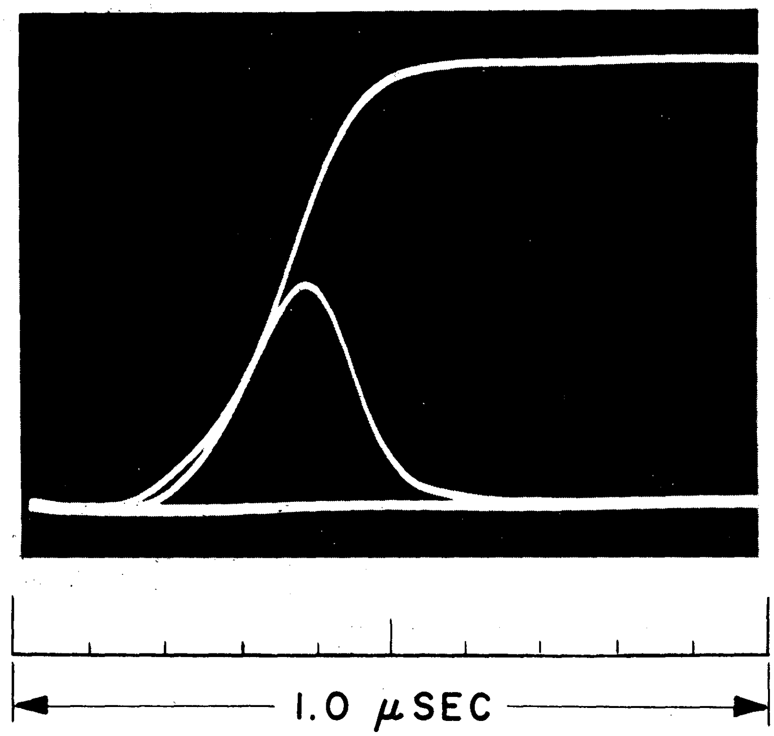
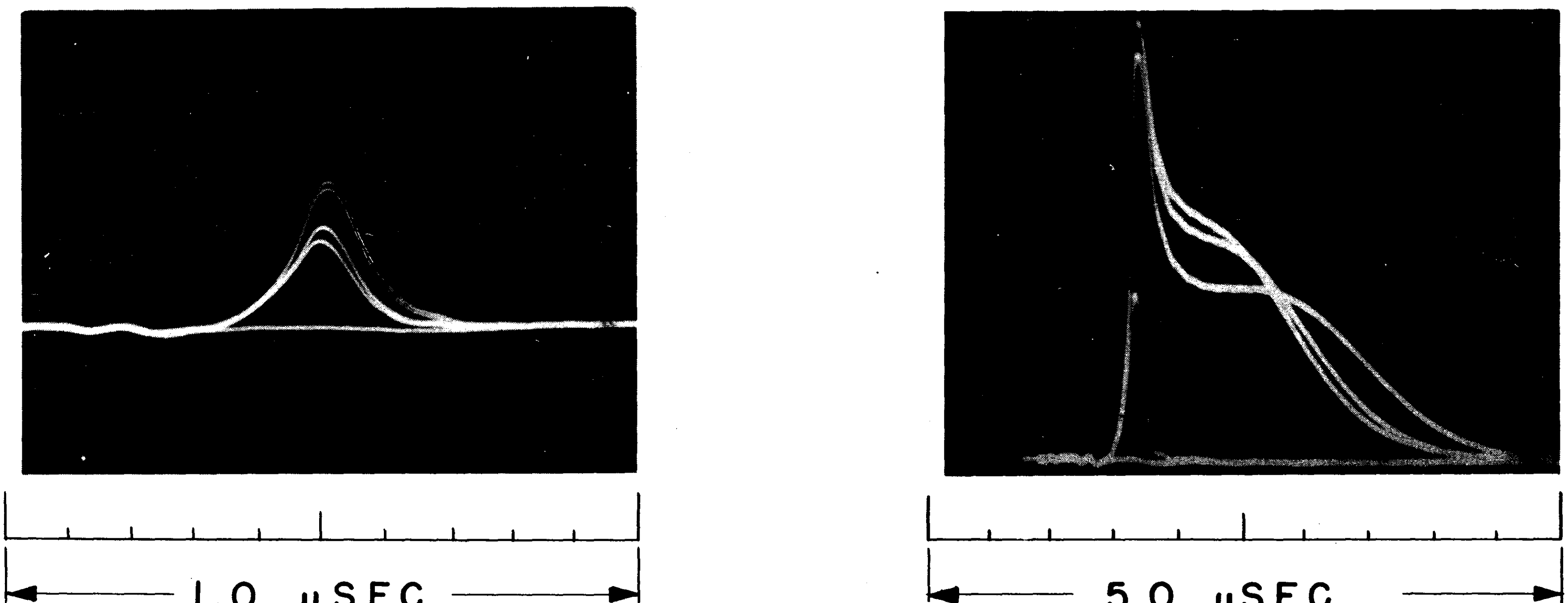


FIG. 4

COMPARISON OF FULL-AMPLITUDE READ CURRENT PULSE AND RESULTANT uV_Z OUTPUT

A-59810

FERRAMIC S-1 MEMORY CORE



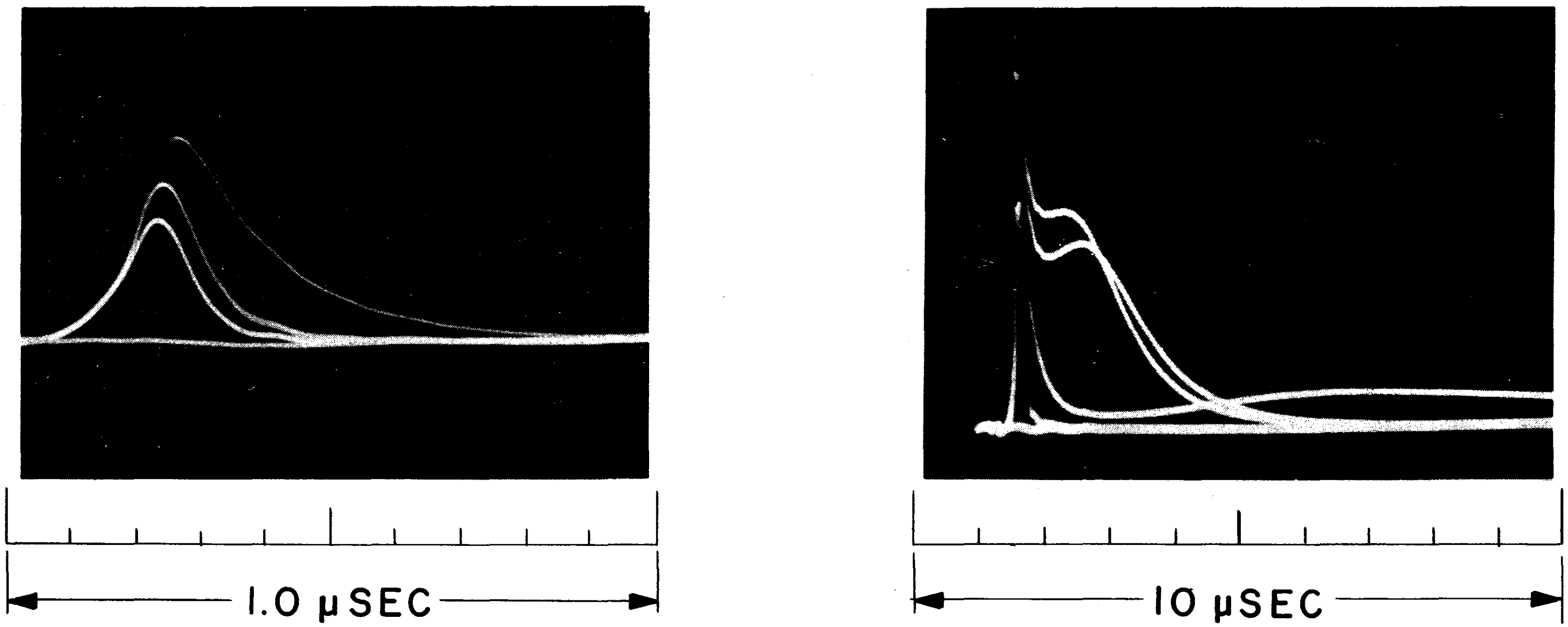
NORMAL DRIVE (810 ma) OVERDRIVEN (1125 ma)

FIG. 5

HALF-SELECTED ZERO OUTPUTS

A-598

FERRAMIC S-1 MEMORY CORE



NORMAL DRIVE (810 ma)

OVERDRIVEN (1125 ma)

FIG. 6

HALF-SELECTED ONE OUTPUTS

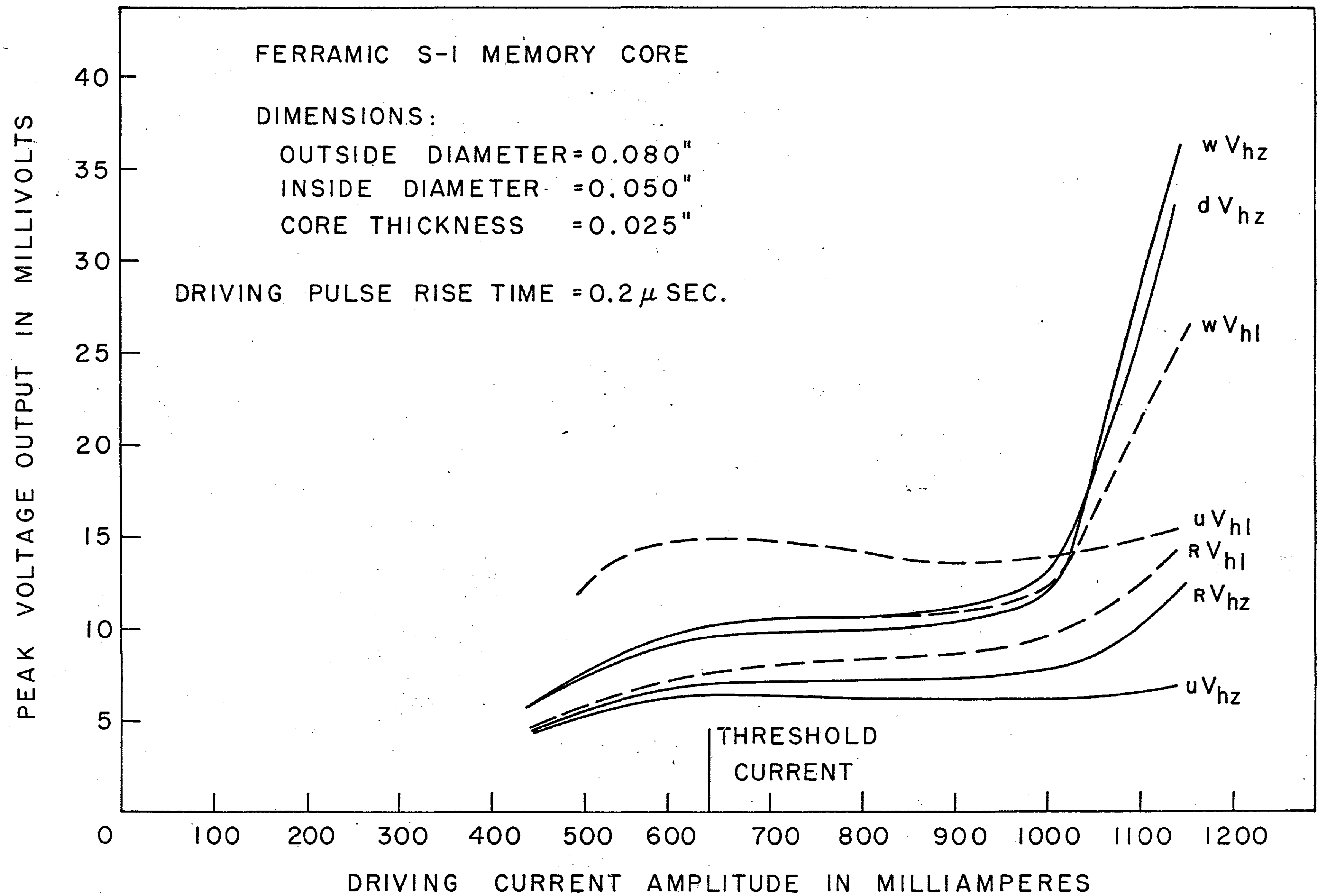
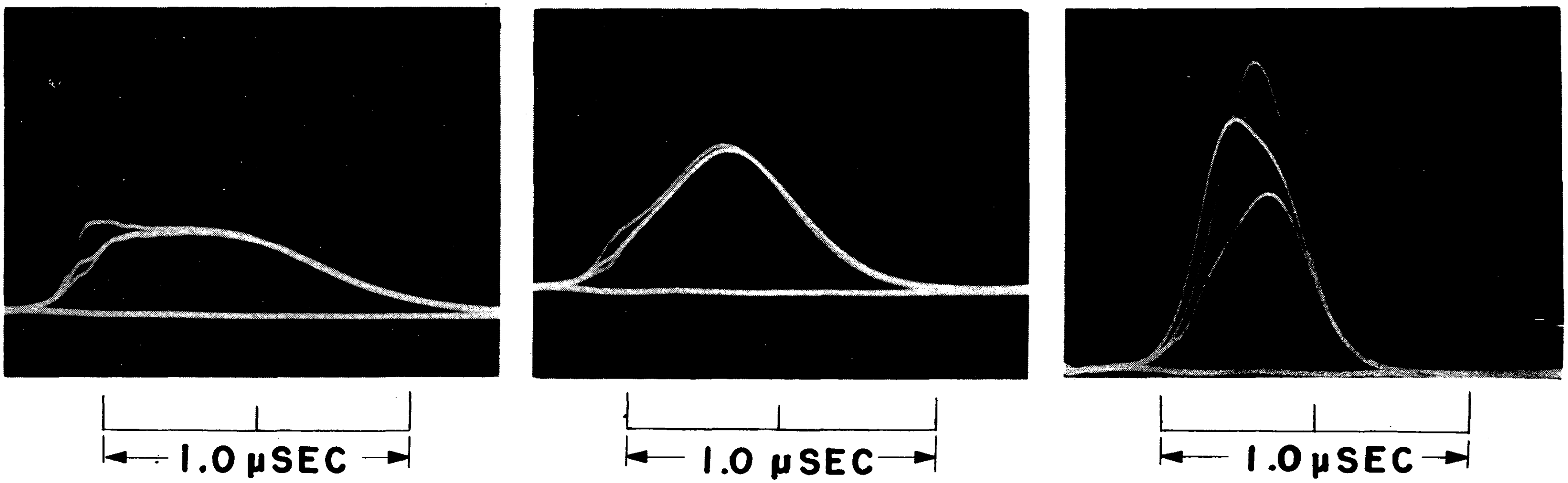


FIG. 7

HALF-SELECTED MEMORY CORE OUTPUTS

FERRAMIC S-1 MEMORY CORE



THRESHOLD OF SWITCHING (635 ma)

NORMAL DRIVE (810 ma)

OVERDRIVEN (1125 ma)

FIG. 8

FULL-SELECTED ONE OUTPUTS

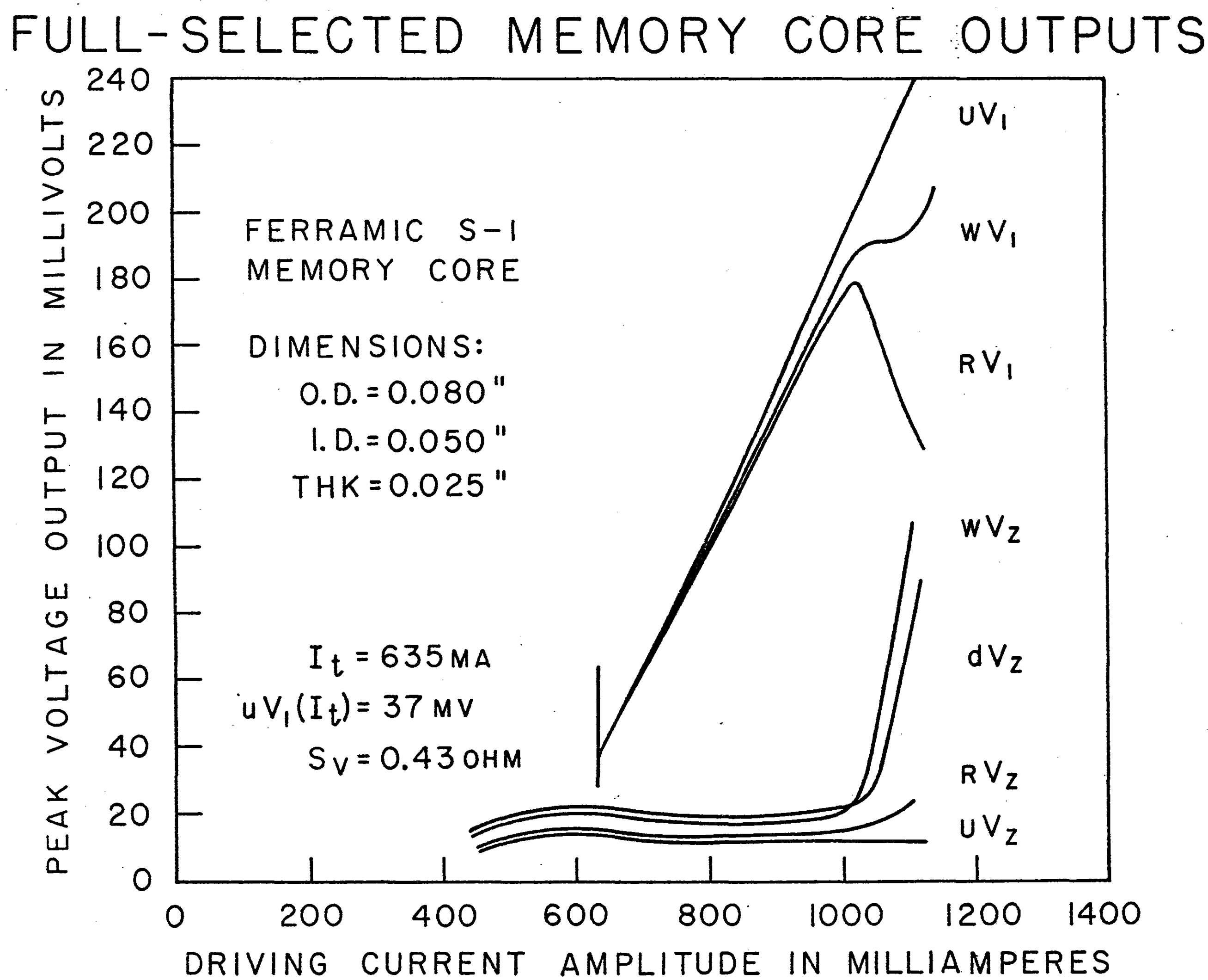

FULL-SELECTED MEMORY CORE OUTPUTS
PEAK VOLTAGE OUTPUT IN MILLIVOLTS
0
20
40
60
80
100
120
140
160
180
200
220
240
DRIVING CURRENT AMPLITUDE IN MILLIAMPERES
0
200
400
600
800
1000
1200
1400
FERRAMIC S-1
MEMORY CORE
DIMENSIONS:
O.D. = 0.080"
I.D. = 0.050"
THK = 0.025"
I_t = 635 MA
$uV_1(I_t)$ = 37 MV
S_V = 0.43 OHM
uV_1
wV_1
rV_1
wV_z
dV_z
rV_z
uV_z

FIG. 9

B-(3807

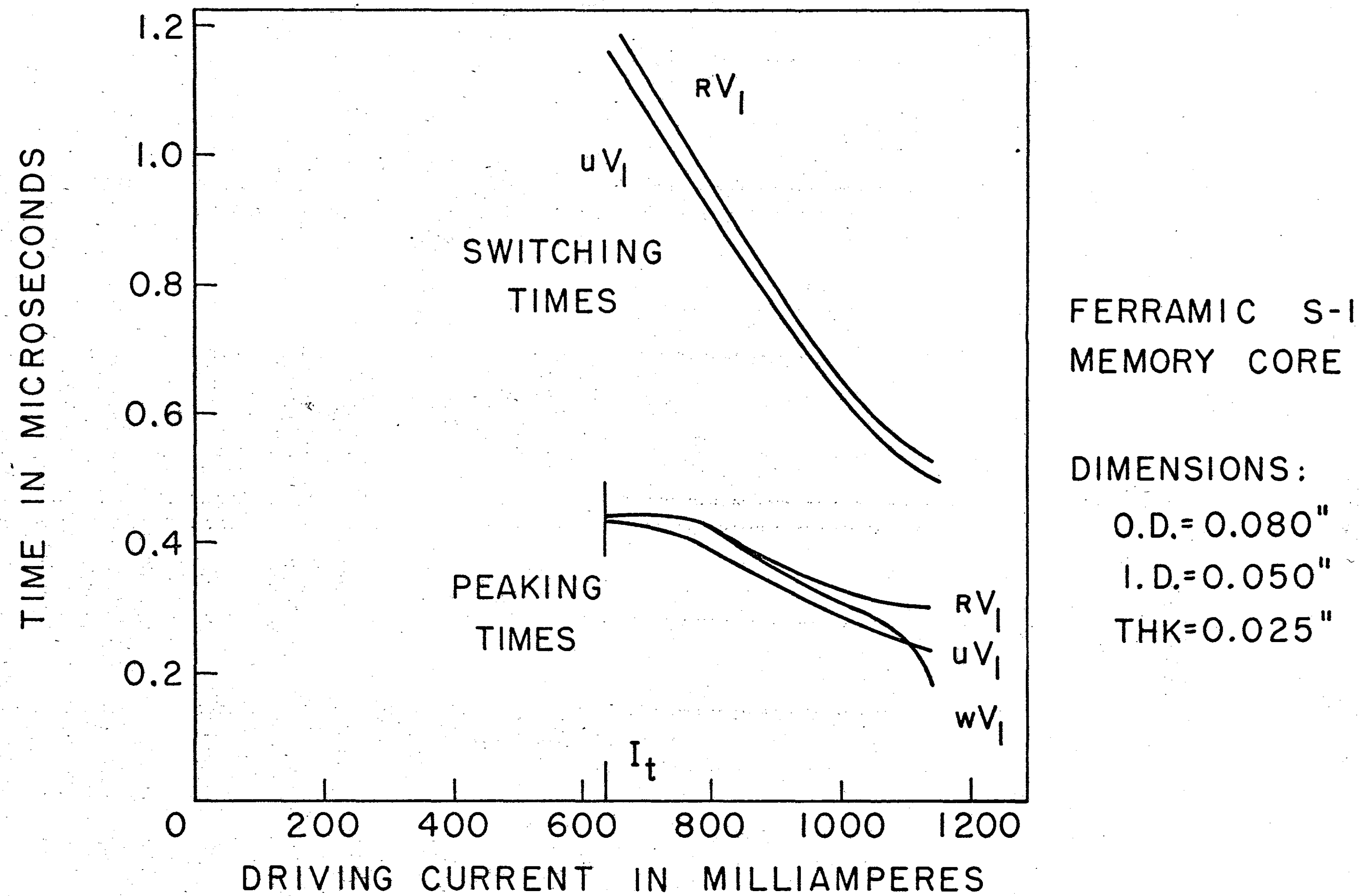


FIG. 10

PEAKING AND SWITCHING TIMES
OF FULL-SELECTED ONE OUTPUTS

B-59806

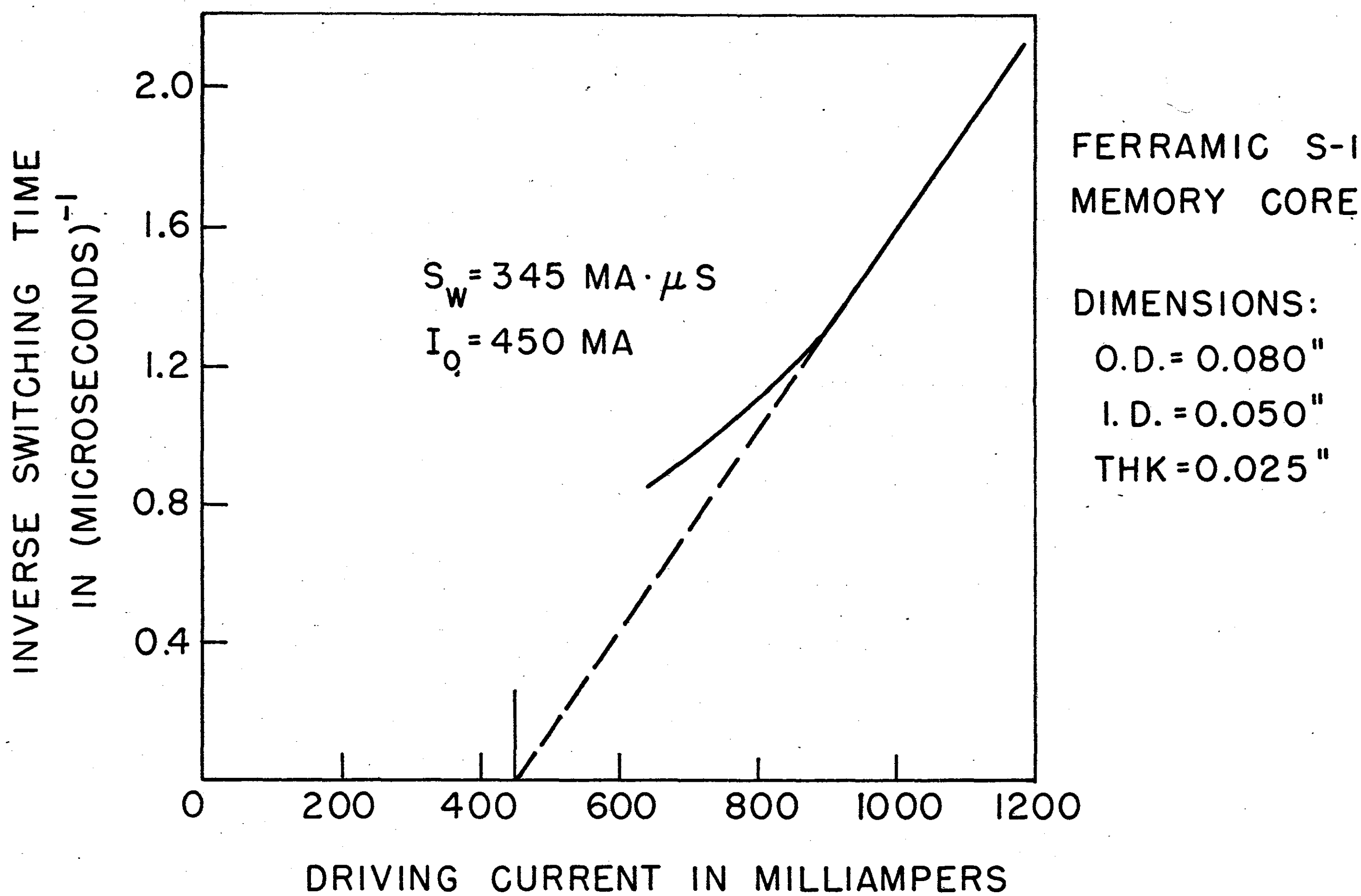
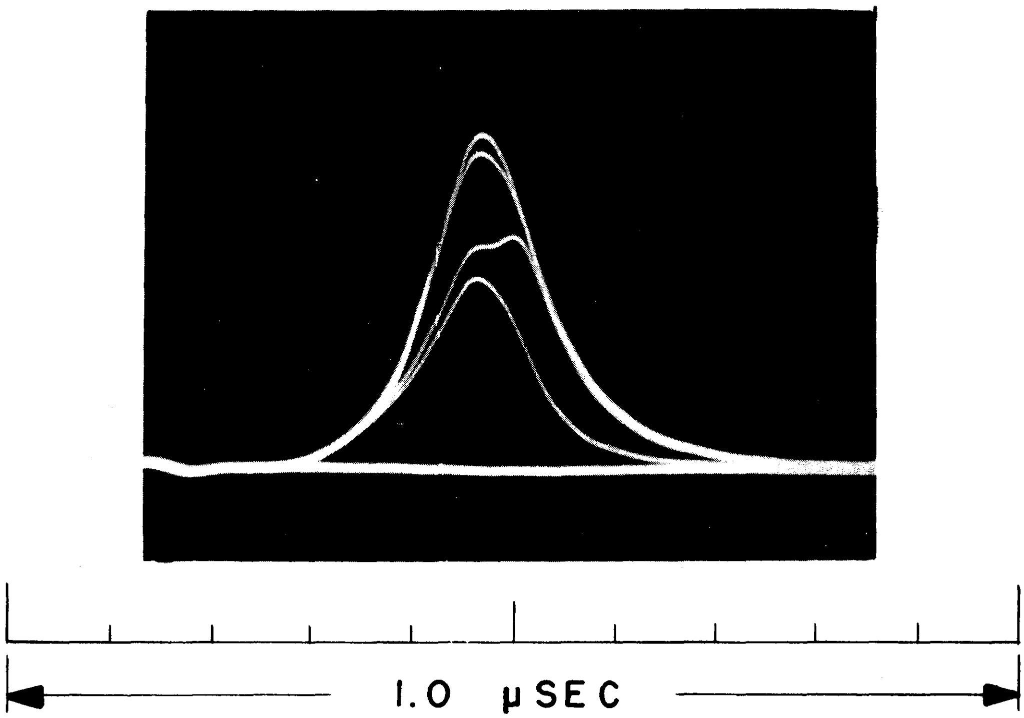


FIG. 11

INVERSE SWITCHING TIME
OF UNDISTURBED ONE OUTPUT

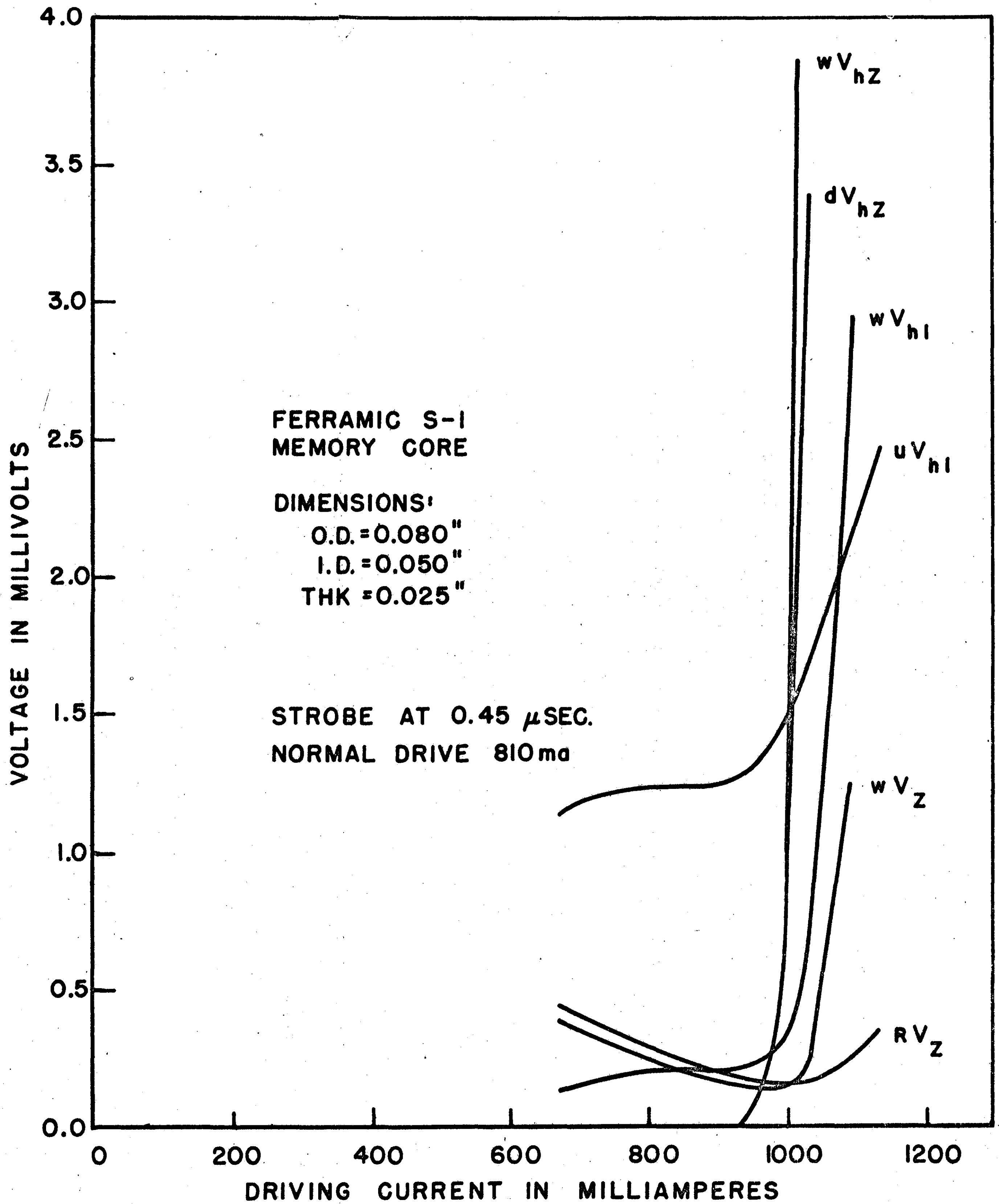
FERRAMIC S-1 MEMORY CORE



NORMAL DRIVE (810 ma)

FIG. 12

FULL-SELECTED ZERO OUTPUTS



A-60222

FIG. 13

STROBE TIME VALUES OF MEMORY CORE OUTPUTS

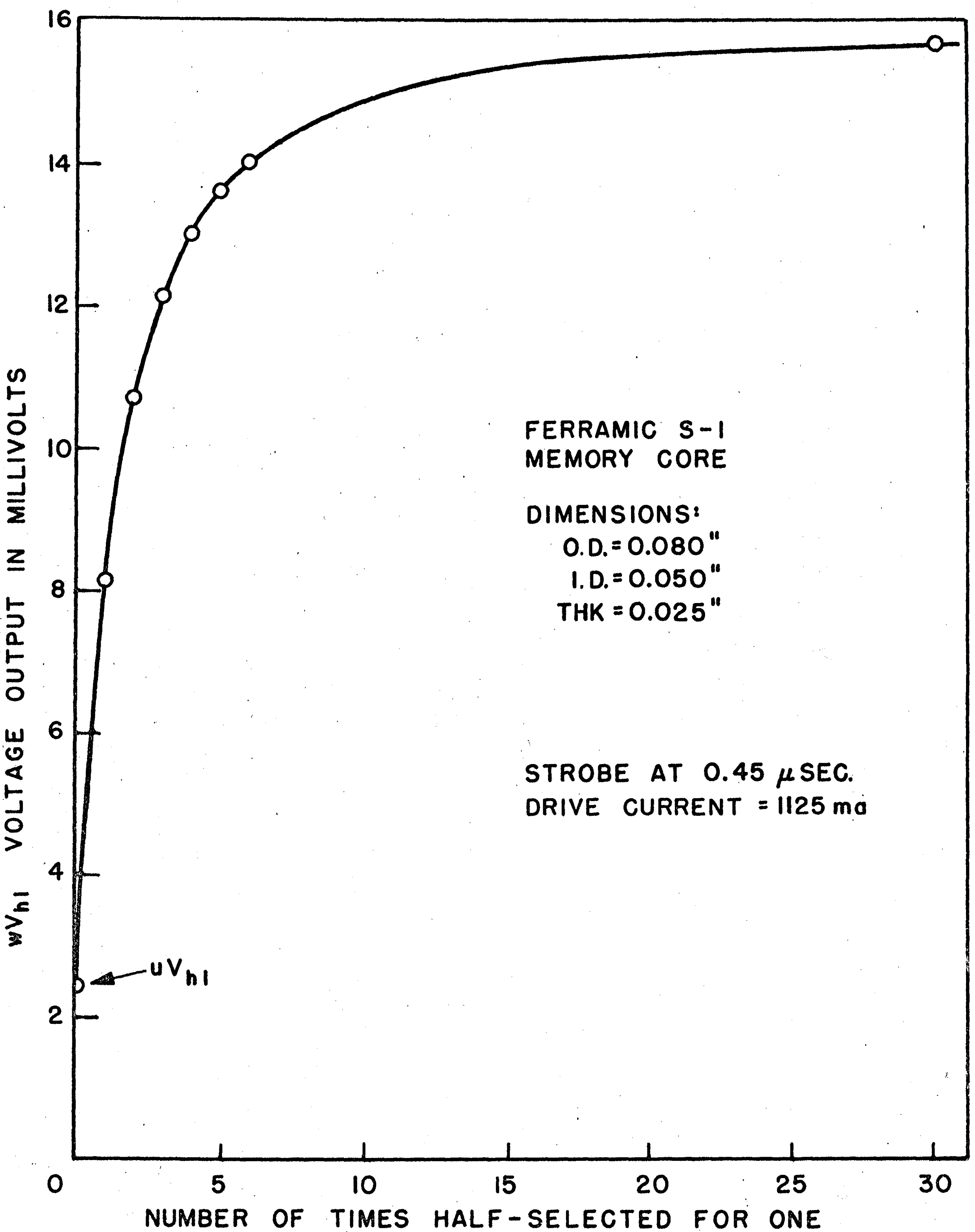


FIG. 14

EFFECT OF DISTURB SENSITIVITY ON THE HALF-SELECTED WRITE-DISTURBED ONE OUTPUTS