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THE FRONT COVER

Ferrites Speed

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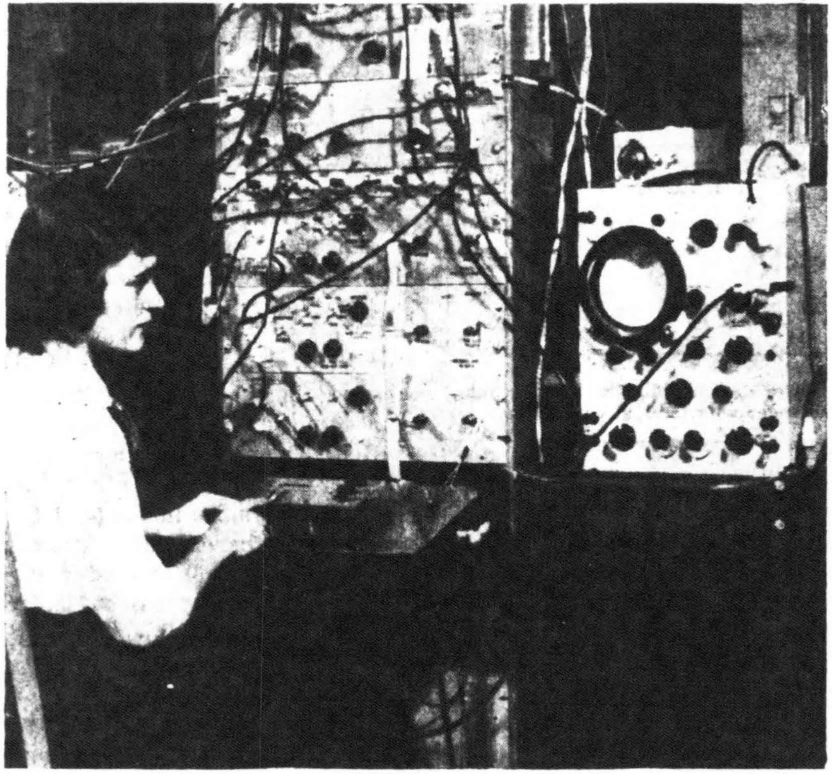
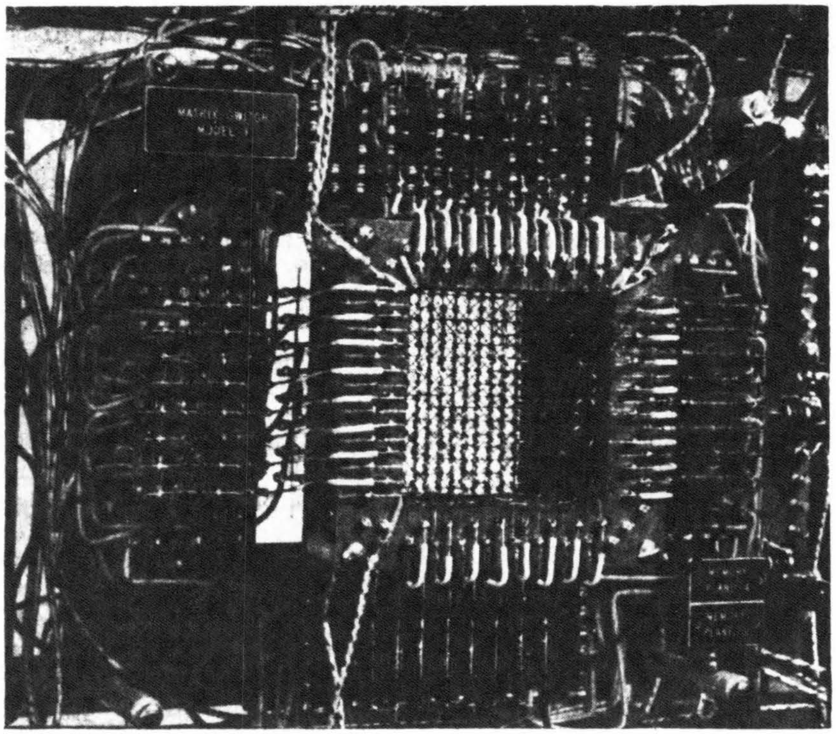


Test equipment for examining pulse characteristics of individual toroids under typical circuit conditions



An experimental coincident-current memory containing two 16-by-16 arrays. This unit is driven by a magnetic matrix switch

RELIABILITY is the paramount factor in the design of large systems such as electronic digital computers. Present operating machines are so large that the limit imposed by the frequency of failures prohibits further expansion. Pulse circuits in these machines have been pushed to the upper limit of operating speed. Yet the need for larger-capacity higher-speed systems is urgent.

A new material for increasing reliability is a ferrite (ferromagnetic ceramic) having a nearly rectangular hysteresis loop. The most important application for this material is a high-speed arbitrary-access memory in which tiny ferrite toroids are used to store binary information. Many other pulse-circuit applications are significant, some depending on the hysteresis of the material for memory and others using its non-linear characteristic for switching applications.

Coincident-Current Memory

Magnetic drum and acoustic delay line storage units are inherently serial devices and use time as one selection coordinate, resulting in a great loss in computing speed or flexibility. The electrostatic storage tube, now the most widely used high-speed arbitrary-access memory, is a complex device requiring considerable maintenance and lacking satisfactory reliability for many applications. The coincident-current memory, using ferrite toroids for storage of binary information, is an inexpensive, simple, high-speed, arbitrary-access memory

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Digital Computers

Memory units and matrix switches using new square-loop ferrite material increase speed and reliability of digital computers. Storage units with arbitrary-access and read-out time of five microseconds or less makes stored information rapidly available without scanning time required by other systems

which promises to provide the degree of stability and reliability required.

Operation

A flux-current (Φ-I) characteristic of a ferrite toroid is shown in Fig. 1A. The positive and negative remanent magnetizations are defined as the one and zero states respectively. In the 4-by-4 memory array illustrated in Fig. 2, information is read out of the array by applying coincident current pulses of amplitude $-I_m/2$ to one vertical and one horizontal element, causing a large change in the flux of the selected core if it holds a one and a very small change if it holds a zero.

A flux change in any core in the array will induce a voltage on the output winding which threads every core. Voltages obtained by reading a one or a zero from a single core are shown in Fig. 1B. Since reading out always leaves the selected core in the zero state, rewriting is necessary if information is to be retained. This is accomplished by applying coincident-current pulses, of amplitude $+I_m/2$, to one horizontal and one vertical element. Writing new information is accomplished during a normal read-rewrite cycle by disregarding the old information read out and writing the new information by the same mechanism used for rewrite.

A possible arrangement for a parallel computer memory is shown in Fig. 2B. An array is placed in each column and only one x-coordinate switch and one y-coordinate switch are used to provide the coincident-current pulses for the entire memory. If n is the number of x or

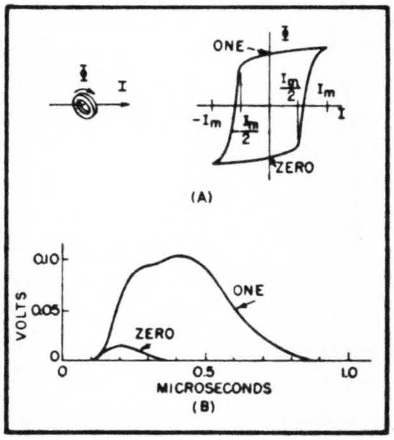

FIG. 1—Characteristic curve (A) of ferrite toroid. Voltages produced (B) by a one or zero stored in a toroid

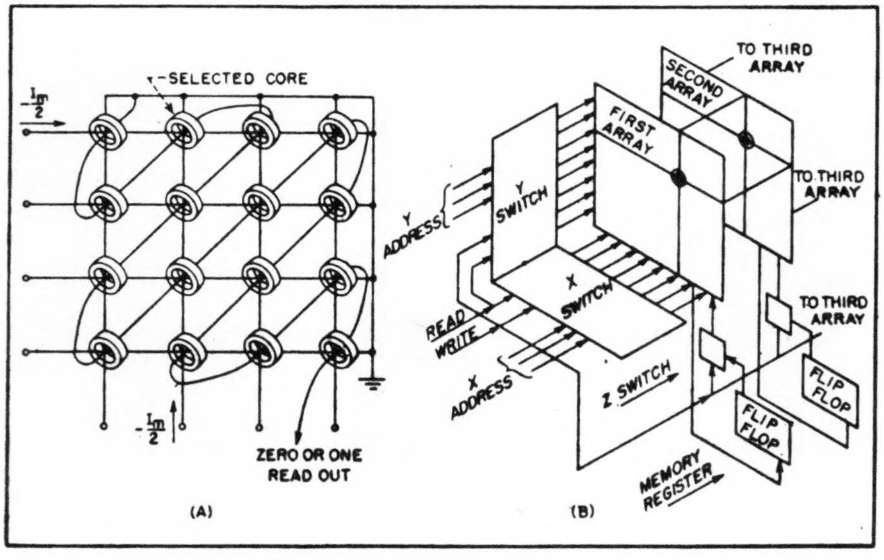

FIG. 2—A 4-by-4 memory array (A) with current pulses $-I_m/2$ reading out the selected core. Arrangement in (B) permits selecting from a number of arrays

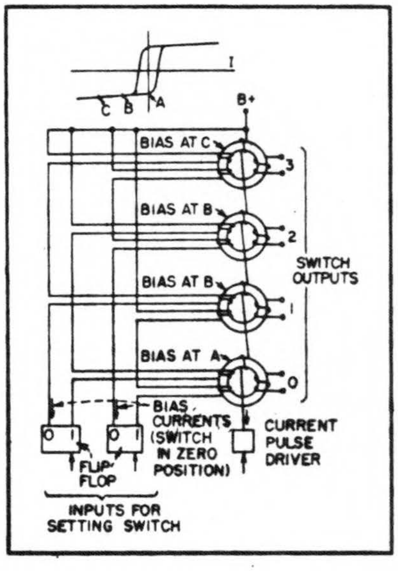

FIG. 3—A four-position magnetic matrix switch using ferrite toroids

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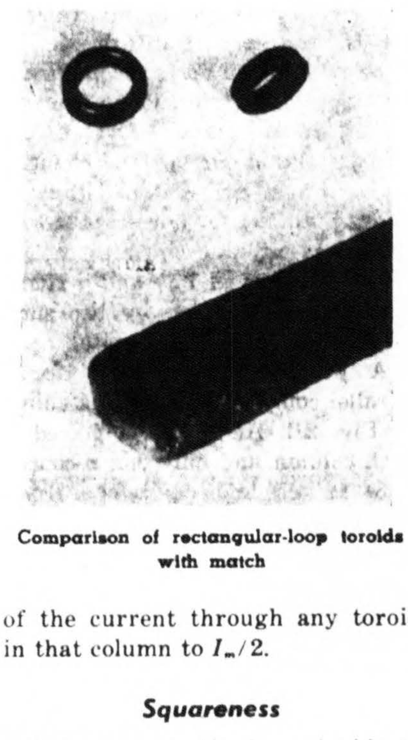
y elements, each switch can be set by a binary number containing $\log_2 n$ digits, and n^2 binary digits are stored in each column of the memory. When the two switches are pulsed for read, the information is read out of the selected x-y location in all columns simultaneously into the memory register.

For rewrite, the switches write into the same x-y location in all columns. However, in each column in which the memory-register flip-flop holds a zero, a coincident current pulse of amplitude $+I_m/2$ is applied to every toroid in the array. The z-coordinate switch provides this inhibiting current pulse for each column in which a zero is to be written, to limit the magnitude of the current through any toroid in that column to $I_m/2$.



Comparison of rectangular-loop toroids with match

Squareness

Squareness ratio for coincident-current memory cores may be determined from the hysteresis loop

$$R_s = \frac{\Phi\left(-\frac{I_m}{2}\right)}{\Phi\,(I_m)}$$

Note that R_s is a function of I_m. Any given ferrite toroid, however, will have a single maximum R_s which occurs at the optimum value of I_m.

Magnetic-Matrix Switch

A 2^n-position matrix switch employing 2^n non-linear magnetic cores is very similar to the familiar diode-matrix switch. An n-digit binary number sets the flip-flops which bias the cores so that all but one are biased into the saturation region. This selected core is then the only one which is switched when the current pulse from the driver is applied.

A driving pulse of opposite polarity must be applied to reset the switch before it is again ready for operation. Two 16-position switches have been used to drive a 16-by-16 coincident-current memory array during the last year at MIT. These switches employ the same rectangular-hysteresis-loop material as that used for the memory array.

Slightly different characteristics are desired for switch cores, however. Instead of a high squareness ratio as defined for the coincident-current memory, a high ratio of remanent magnetization to saturation magnetization is desired together with a low coercivity.

Other Applications

Ferrite toroids possessing rectangular hysteresis loops may be used for high-speed storage of binary information in other ways than the coincident-current memory. If the total number of digits to be stored is small, so that direct selection is practical, a single-coordinate selection scheme may be used. In this case, the current pulses used for reading and writing may vary between rather wide limits provided they exceed a certain miniumum amplitude.

Where time selection may be used, rectangular loop ferrites may be employed in a static-magnetic delay line of the type developed by the Computation Laboratory of Harvard University.

Magnetic cores possessing nonlinear characteristics can be used for other switching or logical operations besides the magnetic-matrix switch, particularly for operations similar to those performed by crystal-diode and or gates

Testing

A high squareness ratio is a necessary but not sufficient condition for a satisfactory toroid. To properly evaluate ferrite toroids for the memory application, a pulse test has been designed which subjects a single toroid to the conditions tha might be encountered in an operat in array. Actually, two tests are performed, one to determine the smallest possible voltage from a selected toroid holding a one and another to determine the largest possible voltage from a selected toroid holding a zero.

Figure 4 shows a pulse pattern which writes a one into a toroid followed by a number of half-selecting read pulses which disturb the one and tend to decrease its magnitude, as shown on the hysteresis loop. The disturbed one is finally read out by a full-amplitude read pulse. In the case of a satisfactory toroid, the voltage from the disturbed one is not a function of the number of half-selecting pulses provided that the number of half-selecting pulses is greater than some small number, usually two or three.

A test which determines the largest zero is shown in Fig. 5. In this case, the zero is disturbed by a number of half-selecting write pulses. A large ratio of disturbed-one voltage to disturbed-zero voltage is necessary for a satisfactory toroid. This ratio may be calculated on a peak-amplitude basis or on the basis of instantaneous voltages sampled at the time that the ratio is a maximum.

To prevent the voltage from half-selected toroids in a large array from adding so that the total voltage from all half-selected toroids might swamp the voltage from the selected toroid, the output winding is arranged so that the polarity of the voltage induced on it will alternate with each toroid along any element of the array. This, incidentally, means that the voltage from the selected toroid may be positive or negative.

The total voltage observed on the output winding is

$$V_T = \pm\,[\,V_s - 2V_{hs} + (n-2)\,V_\delta] + V_l$$

where V_s is the magnitude of the voltage from the selected toroid, V_{hs} is the magnitude of the voltage from a half-selected toroid, V_δ is the uncancelled voltage from a pair of half-selected toroids of opposite polarity, and V_l is the voltage induced in the output winding due to leakage flux or flux not con-

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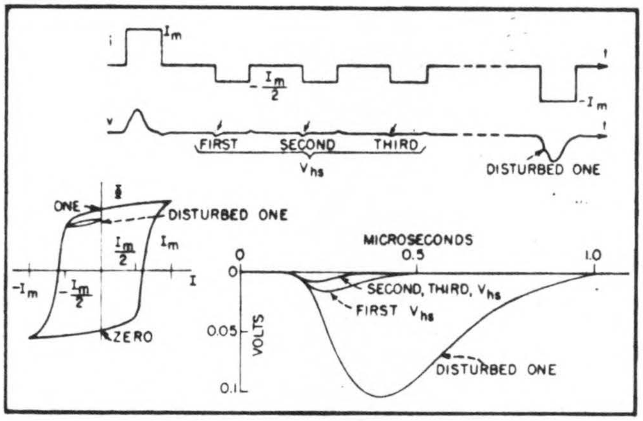


FIG. 4—Results of a pulse test used to determine smallest possible voltage from a toroid holding a one

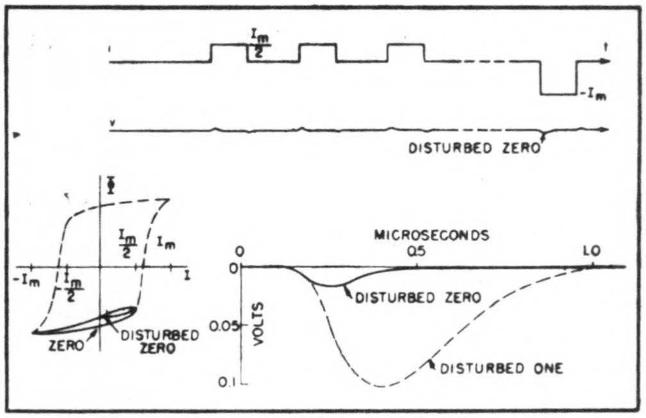


FIG. 5—Results of pulse test used to determine largest possible voltage from a toroid holding a zero

fined to the toroids.

The voltage V_s may be positive or negative; in the ideal case it would be zero. Since it appears in the expression for the total voltage with a coefficient $(n - 2)$ it establishes an upper limit on the size of the array. Perhaps the most important factor behind V_s is the uniformity of the magnetic characteristics of the toroids. The requirement for small V_s makes a high degree of uniformity essential. Another contribution to V_s may come because V_{hs} will be different for a given toroid depending on whether it contains a one, a zero, a once-disturbed one, a twice-disturbed one and so on. However, although the difference between the voltage from a half-selected undisturbed one and a half-selected undisturbed zero may be significant the number of such pairs is limited to two. The large number of V_s's will be from half-selected cores containing disturbed ones or disturbed zeros, where the difference will be much less.

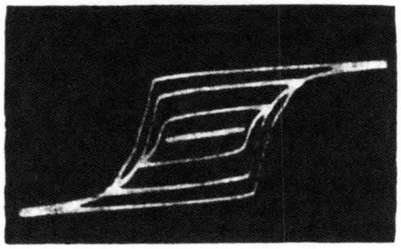
Ferrite Characteristics

The rectangular-loop ferrite now used at MIT was developed by the General Ceramics and Steatite Corporation from a magnesium ferrite. The saturation flux density of this body, MF-1118, is approximately 2,000 gausses and the coercivity is 1.5 oersteds. A family of hysteresis loops is shown in the photograph, and other characteristics are listed in Table I.

The toroids for coincident-current-memory application have an outside diameter of 0.090 inch. The small size is necessary to reduce the power requirements for driving the arrays. The I_m for this toroid is 1.0 ampere and the maximum squareness ratio is 0.7. The disturbed one voltage has a peak amplitude of 0.1 volt and a duration of 1 microsecond. The ratio of disturbed one to disturbed zero is 10 on a peak-amplitude basis and greater than 200 on the basis of sampled instantaneous voltages.

Table I—Properties of the Rectangular-Loop Body MF-1118

μ_o	40
μ_{max}	515 at 1,040 gausses
B_s	1,780 gausses at 25 oersteds
B_r	1,590 gausses
B_r/B_s	0.9 approx.
H_c	1.5 oersteds
Volume Resistivity	2×10^7 ohm-cm
Curie Temperature	300 deg C



Family of hysteresis loops for General Ceramics MF-1118 ferrite

The process by which a rectangular hysteresis loop is obtained in a polycrystalline ferrite is not understood, nor are the factors which determine the switching time or waveshape of the output voltage. Rec-

For some polycrystalline ferrites with large magnetostrictive coefficients, notably nickel-zinc ferrite, rectangular hysteresis loops have been obtained by compressing a toroid by means of a clamp around the outside diameter. In this case, the stresses set up an easy direction of magnetization which accounts for the rectangularity of the hysteresis loop. Residual mechanical strains in MF-1118 may be responsible for its rectangularity.

The same rectangularity and performance has been observed in toroids ranging in diameter from 0.060 inch to 2 inches.

Recent experiments to reduce the coercivity of the body MF-1118 have produced rectangular-loop bodies with coercivities as low as 0.5 oersted. However, this switching time increases from 1 microsecond to approximately 5 microseconds.

The high degree of uniformity required for the coincident-current-memory application necessitates careful control in the production process. The uniformity of the toroids produced must be considered an integral factor in the evaluation and development of satisfactory toroids.

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