

Memorandum 6M-4089

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SUBJECT: GEOMETRY OF MAGNETIC MEMORY ELEMENTS

To: Group 63, Staff

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Date: January 18, 1956

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Abstract: Two possible memory element geometries -- the thin film and the toroid -- are considered. The calculations show that under certain conditions the thin film geometry may be preferable for use in a very high-speed memory.


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The research reported in this document was supported jointly by the Department of the Army, the Department of the Navy, and the Department of the Air Force under Air Force Contract No. AF 19(122)-458.

Introduction:

The peak current and average power which the memory-plane drivers must deliver can be reduced by decreasing the dimensions of the magnetic memory elements. The following analysis indicates the limits of size reduction and the results which such reductions may yield.

I. Theoretical Ruminations

A. Possible Geometries

The two geometries to be considered and their dimensions are shown in Fig. 1A - Thin Film and Fig. 1B - Toroid.

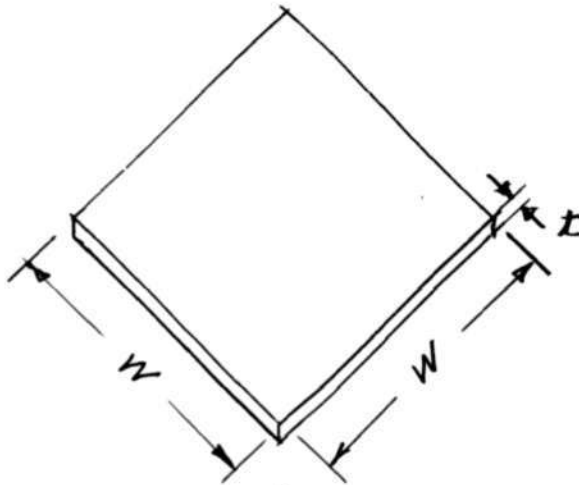


Fig. 1A - Thin Film

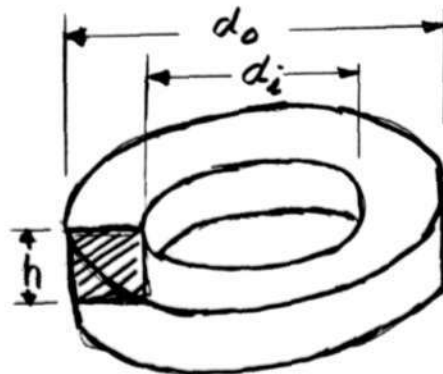


Fig. 1B - Toroid

B. Primary Limits on Geometry

The primary limits on geometry are (1) the peak voltage signal V_p must be great enough to be sensed reliably and (2) the switch time τ_s must be suitable to the desired memory cycle time (certainly less than half the cycle time).

The instantaneous output voltage for a one turn sense winding is

$$v(t) = 10^{-8} A \frac{dB}{dt} .$$

Therefore

$$\int_{-B_r}^{+B_m} dB = \frac{10^{+8}}{A} \int_0^{\infty} v(t) dt \approx \frac{1}{2} \times \frac{10^{+8}}{A} \times V_p \tau_s \approx 2B_m,$$

where V_p is in volts, τ_s in seconds, A in square centimeters, and B_m (the maximum induction in the square hysteresis loop) in gauss. We can express the requirement on A in terms of the material parameter B_m and the memory limits V_p and τ_s as

$$A \gtrsim \frac{1}{4} \times 10^{+8} \frac{V_p \tau_s}{B_m} \tag{1}$$

C. Cross-Sectional Areas

1. Thin Film

Let $w = C_1 t$, where C_1 is a constant determined by the magnitude of the demagnetizing field tolerable for a square loop; C_1 is in the order of 10^3 . The cross-sectional area is thus

$$A = \frac{w^2}{C_1} \tag{2}$$

2. Toroid

Because about four mutually perpendicular wires of assumed diameter d_w must pass through the toroidal memory element, the inner diameter d_i has a lower limit, $d_i > 2d_w$; also geometry dictates that

the following assumptions be made:

$$(a) \quad d_o = C_2 d_i; \quad C_2 > 1$$

$$(b) \quad h = C_3 d_i; \quad C_3 > 1$$

The area is given as

$$A = C_3 \frac{C_2 - 1}{2} d_i^2 \quad (3)$$

D. H-I Relationships:

1. Thin Film

In the calculation of the field between two sheets of current, the following approximations are made:

- (a) The field inside a rectangular coil of length w centimeters and of N turns is the same as for a similar solenoid.
- (b) The current sheets above and below the thin film can be created by overlapping the rectangular coil as shown in Fig. 2.

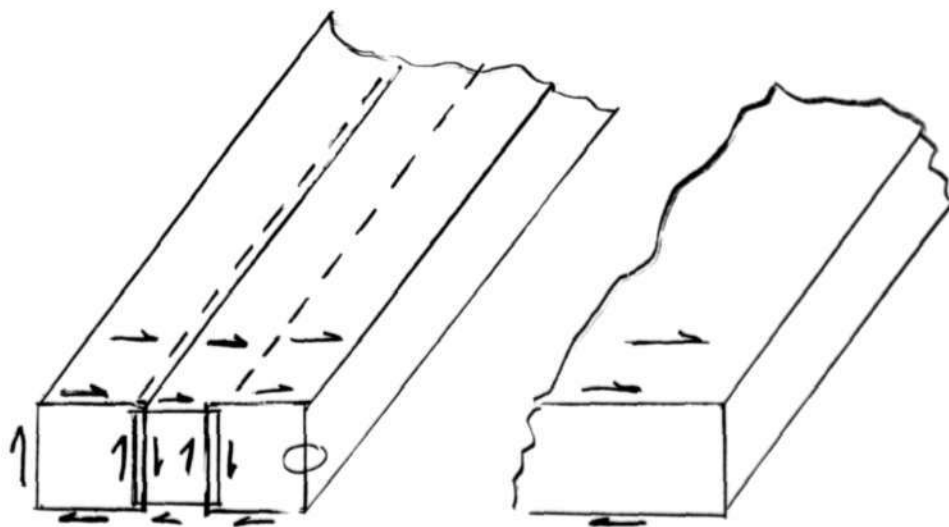


Fig. 2 - Approximation of Current Sheets

From this crude analysis we get

$$H \approx \frac{4\pi N_i}{10w} = \frac{4\pi I}{10w} \quad (4)$$

where I is the total current in amperes flowing in both sheets (split equally between the two) and H is in oersteds.

2. Toroid

The field in a toroid is

$$H \approx \frac{8I}{10(d_o + d_i)} \quad (5)$$

E. Geometry Factor

We define a geometry factor F_g as

$$F_g = \frac{H}{I} \quad (6)$$

Substituting the cross-sectional area limit of Eq. (1) into Eqs. (2) and (3) and these into Eqs. (4) and (5), respectively, gives

$$F_g(\text{thin film}) \approx \frac{8\pi}{\sqrt{C_1}} \times 10^{-5} \sqrt{\frac{B_m}{V_p \tau_s}} \quad (7)$$

and

$$F_g(\text{toroid}) \approx 8 \sqrt{2} \times 10^{-5} \frac{\sqrt{C_3(C_2-1)}}{C_2+1} \sqrt{\frac{B_m}{V_p \tau_s}} \quad (8)$$

F. Order-of-Magnitude Calculations

For purposes of comparison, the geometry factor of the F397 toroid ($d_i = 54$ mills, $d_o = 80$ mills, $h = 22$ mills) is 2.4. We make the following general assumptions for both geometries:

- (1) $V_p \approx 10^{-2}$ volt (in present memory $V_p \approx 10^{-1}$ volt)
- (2) $\tau_s \approx 10^{-7}$ second (present τ_s is 10^{-6} second).

With these assumptions, we get for thin films

$$F_g(\text{thin film}) \approx 16 \frac{\text{oersted}}{\text{ampere}}$$

where $C_1 = 2 \times 10^3$; $B_m = 8 \times 10^3$ gauss, typical for square loop metals. For a toroid where $C_2 = 1$; $C_3 = 2$; $B_m = 1.5 \times 10^3$ gauss, typical for ferrites,

$$F_g(\text{toroid}) \approx 50 \frac{\text{oersted}}{\text{ampere}}$$

The next section indicates the relative difficulty of obtaining the above geometry factors.

II. Discussions and Conclusions:

The ease of fabrication is one factor governing the practicality of a given memory-element geometry. In the F_g factors above, the thin film would have the dimensions $w = 7 \times 10^{-2}$ cm by $t = 3.5 \times 10^{-5}$ cm; the toroid, $d_i \approx 3 \times 10^{-3}$ cm, $d_o = 6 \times 10^{-3}$ cm, $h = 3 \times 10^{-3}$ cm. The thin film could be made by evaporation techniques with relative ease; but the ultra-small toroid would be almost impossible to make. A toroid a scale magnitude larger would be possible; this gives $F_g \approx 5$. Also it must be remembered that a minimum of three conductors each capable of carrying milliamperes currents must pass through the toroid.

Thus fabrication difficulties seem to make the thin film geometry more feasible. Other geometries may offer more than the thin film so that a further study of geometry is worthwhile.

Changing geometry alone is not the answer to the very-fast-memory problem. In the preceding calculations it has been assumed that magnetic materials and memory scheme exist such that a memory cycle time of about 2×10^{-7} second is possible and the $V_p \approx 10^{-2}$ volts can be sensed reliably.

In conclusion, a memory element can be reduced in size
 (1) yielding an improvement in the peak current-average power requirement of the memory (2) at the expense of the peak signal voltage if and only if

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(3) a material and memory scheme exist such that $\tau_s \approx 10^{-7}$ second is possible.


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