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SUBJECT: GEOMETRY OF MAGNETIC MEMORY ELEMENTS

To: Group 63, Staff

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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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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 RuminationsA. Possible Geometries

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

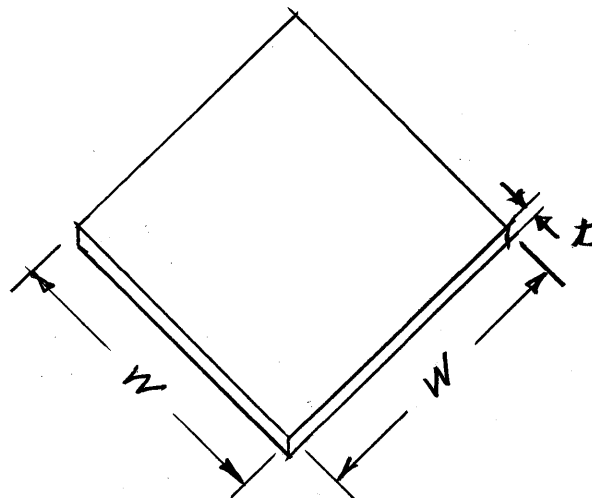


Fig. 1A - Thin Film

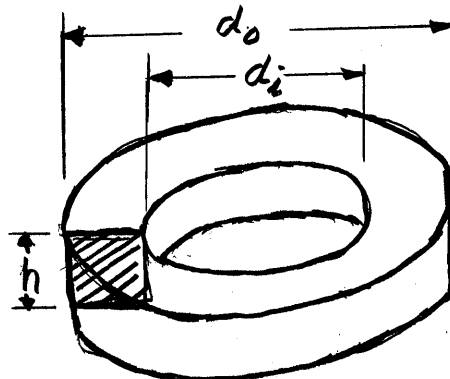


Fig. 1B - Toroid

### 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  $\tau_s$  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,  $\tau_s$  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  $\tau_s$  as

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

### 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

$$A = \frac{w^2}{C_1} \quad (2)$$

#### 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.

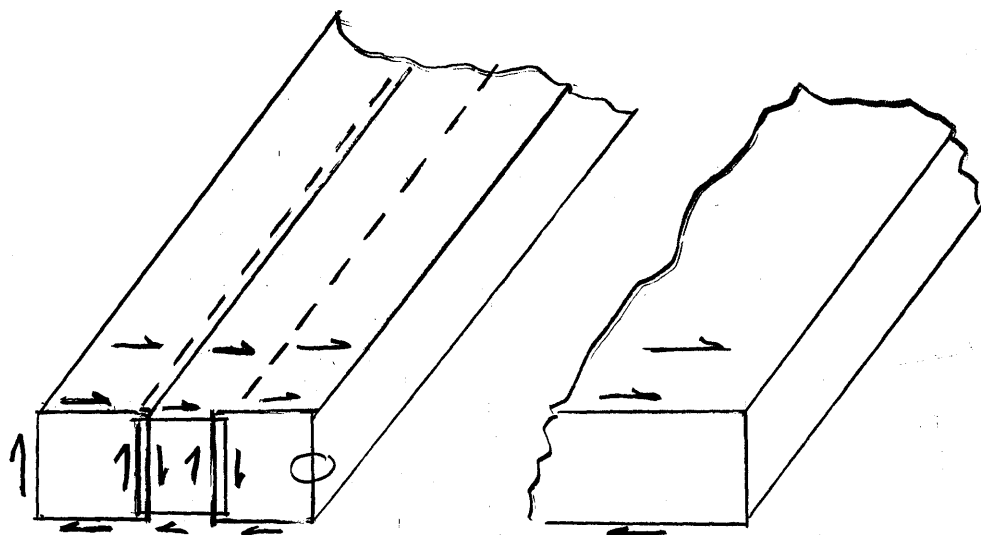


Fig. 2 - Approximation of Current Sheets

From this crude analysis we get

$$H \approx \frac{4\pi N_1}{10w} = \frac{4\pi I}{10w} \quad (4)$$

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

$$H \approx \frac{8I}{10(d_0 + d_1)} \quad (5)$$

## 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 ( $d_1 = 54$  mills,  $d_0 = 80$  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  $\tau_s$  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 milliampere 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  $2 \times 10^{-7}$  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

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

  
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