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meteorological conditions. Diversity reception will prove beneficial in reducing the effects of multipath transmission.

ACKNOWLEDGEMENT

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Magnetic Triggers*

AN WANG†, ASSOCIATE, IRE

***Summary*—Magnetic cores of fairly rectangular hysteresis loop material are used as a trigger device. Magnetic fluxes are used instead of electrical currents to indicate the two stable positions of the trigger. This paper shows how the magnetic flux level may be detected without a mechanical motion. The construction and functioning of several types of such magnetic triggers are discussed.**

I. INTRODUCTION

TRIGGER CIRCUITS have been used extensively during recent years in various electronic devices. They usually consist of a pair of vacuum tubes connected in such a way that two stable states of the system exist. The magnetic triggers to be described below are a result of research in utilizing the fundamental hysteretic properties of a ferromagnetic material as a trigger device.

Any magnetic material, easily saturated and having fairly large retentivity properties, can be considered as a trigger device by itself. Consider the hysteresis loop shown in Fig. 1. When the material has been under the influence of a large positive magnetizing force, positive residual magnetism is retained. The material will remain at the point *1*. If it was last subjected to a negative magnetizing force, the material will remain in the state of negative magnetization represented by the point *0*. These two states, *1* and *0*, represent the two possible stable conditions of the magnetic material. They can be easily reversed by the application of a magnetizing force of sufficient amplitude in the opposing direction. In contrast to the vacuum-tube trigger pair, the magnetic flux polarity, rather than the voltage level, determines the two stable states. While dc voltages are necessary to maintain the dc currents flowing in the vacuum-tube trigger pair, it is not necessary to have a magnetizing force to maintain a flux in the magnetic core material. Thus, a magnetic trigger should be able to maintain the triggered position without the need of any power. The magnetizing pulse then takes the place of the triggering pulse. It should be powerful enough to

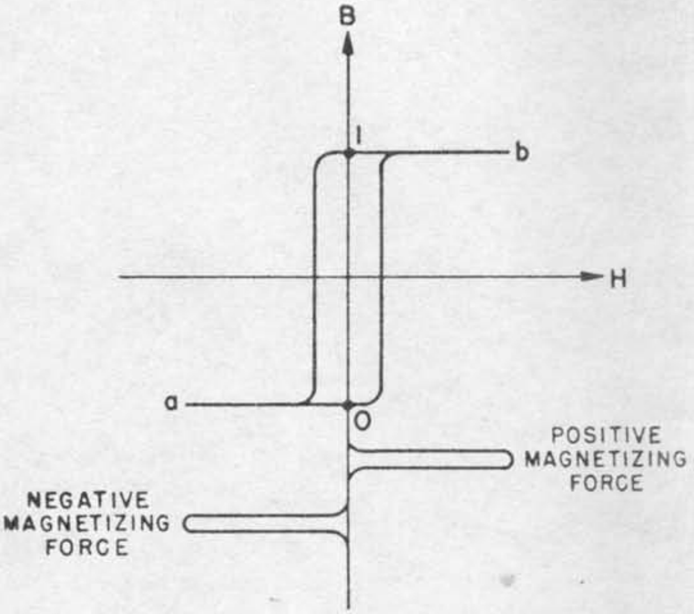
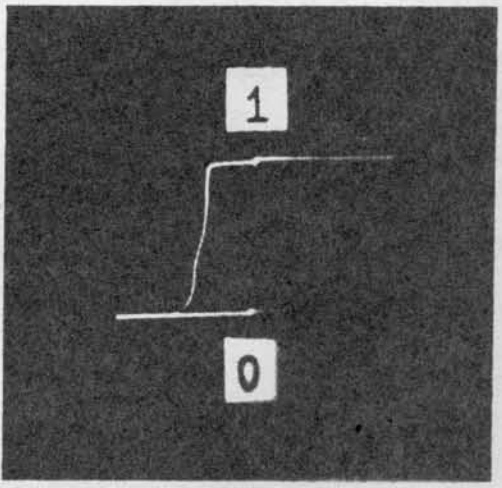


Fig. 1—Hysteresis loop curve of a highly saturated magnetic material.



F[illegible] Operating path of the [illegible] diagram.

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† Computation Laboratory, Harvard University, Cambridge, Mass.

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drive the magnetic core to saturation. Alternate magnetizing pulses of 10 microseconds duration are applied to a magnetic material. The flux of the material is flip-flopped between two saturation values. The material travels around the hysteresis loop while being triggered and remains at one of the two stable points *1* and *0* when not being triggered. (See Fig. 2.) Notice that the points *1* and *0* are stationary when no magnetizing pulses are applied.

While it is very easy to detect the difference of electric current, it is very difficult to sense the magnetic flux polarity unless it is changing. Thus, the simple magnetic trigger will not work statically until means of detecting the flux polarity are found.

II. Magnetic Trigger Pair

By the nature of the saturation phenomena of magnetic materials, it is possible to determine the polarity of the residual magnetism by applying a powerful magnetizing force. Assume that this magnetizing force is in the negative direction (Fig. 1). Then, if the residual magnetism is at the point *0*, very little flux change results. When the magnetizing force is discontinued, the magnetization returns to the point *0*. If the residual magnetism is at point *1*, a large change of flux results along the trace of the hysteresis loop dropping from *1* to *a* and then returning from *a* to *0*. During the sharp decrease of flux, a large voltage is induced across the coils linking the magnetic core. Then, no matter what polarity the residual magnetism, eventually the magnetic core returns to point *0*. A large induced voltage across the secondary coil indicates that the original state was at point *1*, while a very small induced voltage indicates that the original state was at point *0*.

A similar magnetic core is now used in addition. Let us assume that it is at position *0*. If the large induced voltage from the first core is able to drive the second core from its *0* position to *1*, the flux condition of the first core is transferred to the second core. This has been demonstrated experimentally.[1] The connections are as shown in Fig. 3. The hysteresis curve below each core represents its magnetic state. When both cores are at *0* position, the first magnetizing pulse, being negative, changes the flux of core number 1 very little, so that core number 1 produces very little linking current i_{12} to change the flux of core number 2. Similarly, the application of the second pulse will do the same. Cores number 1 and number 2 experience small loops *oac* and *o′a′c′*, constituting a stable limit cycle for each core. When a *1* is stored in core number 1, the application of the first magnetizing force changes the flux from *1* to *a*, from where it drops back to *0*. This large change of flux induces sufficient voltage in its coil N_1 to produce current i_{12} which should be able to drive core number 2 from *0′* to *b′* to *1′*. The differential equation of the link circuit is

$$-N_1\frac{d\phi_1}{dt} - N_2\frac{d\phi_2}{dt} = Ri_{12} + L\frac{di_{12}}{dt}. \tag{1}$$

Integrating this,

$$-N_1\Delta\phi_1 - N_2\Delta\phi_2 = Ri_{12}dt + L\Delta i_{12}. \tag{2}$$

As the flux of core number 1 changes from position 1 to position *a*, the flux of core number 2 changes from *0′* to *b′*. N_1 and N_2 should be equal if they are symmetrical. The current i_{12} is always positive, and so is Δi_{12} during this change. It is necessary that

$$\Delta\phi_1 + \Delta\phi_2 = \text{a negative value.} \tag{3}$$

This means that the change of flux from 1 to *a* should always be greater than the change of flux from *0* to *b*.

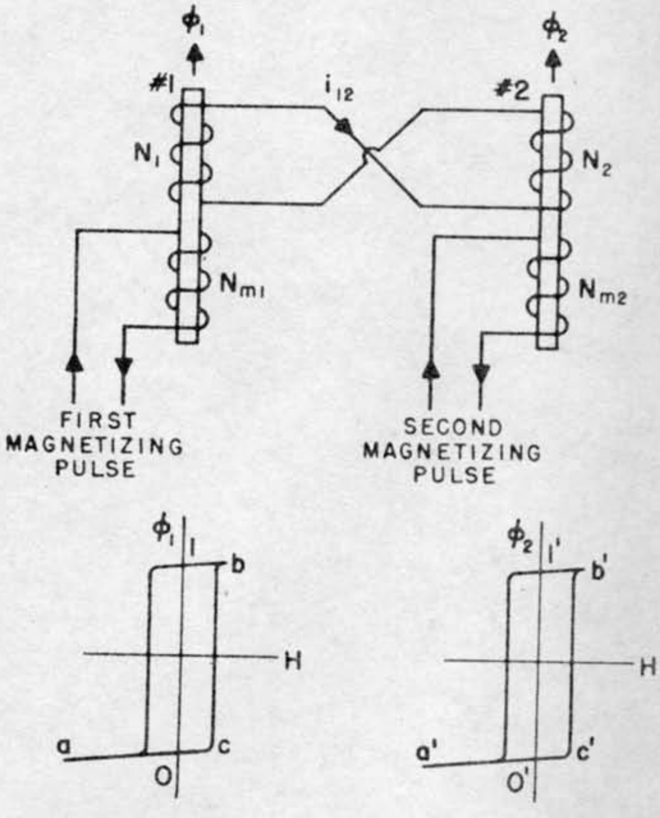

Fig. 3—Magnetic trigger pair and its operation.

If it is possible to make core number 1 return from *0* to *b* to *1* by the application of the second magnetizing pulse, the stored digit is kept there. This requires the existence of a stable major hysteresis loop with slight unsymmetry, which has been available. The operation of such a magnetic trigger pair is then stable.

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[1] Air Force Contract W19-122-AC-24 Progress Report No. 2, Harvard Computation Laboratory, sect. IV, 8; Nov. 10, 1948. Progress Report No. 4, Harvard Computation Laboratory, sect. V, 3; May 10, 1948.

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III. MODIFIED MAGNETIC TRIGGER PAIR

The above-mentioned unsymmetry in hysteresis loops can be stable only in a limited region. If $\Delta\phi_2$ is smaller than $\Delta\phi_1$ by a certain amount, the next time $\Delta\phi_1$ is less than $\Delta\phi_2$, and so on. Gradually, in several cycles, both cores will end up a position *0*, and the stored information will be lost. This is the case experimentally when too much resistance or leakage inductance is present in the linking circuit. Also, to produce change of flux as the frequency of operation is made higher, i_{12} must necessarily be larger, due to the presence of eddy current. This makes the loop more unsymmetrical and consequently more unstable. The trouble can be eliminated by a modification of the basic circuit. Note that *(2)* can be satisfied by using a value of N_1 greater than N_2, while $\Delta\phi_1$ and $\Delta\phi_2$ are exactly equal and opposite. Under this condition, stable operation of the trigger pair is possible without the necessity of having stable unsymmetrical hysteresis loops. The circuit of Fig. 4 is used. Rectifiers are necessary in the linking circuit so that when the first core is driven, the upper link is operative, and when the second core is driven, the lower link is operative.

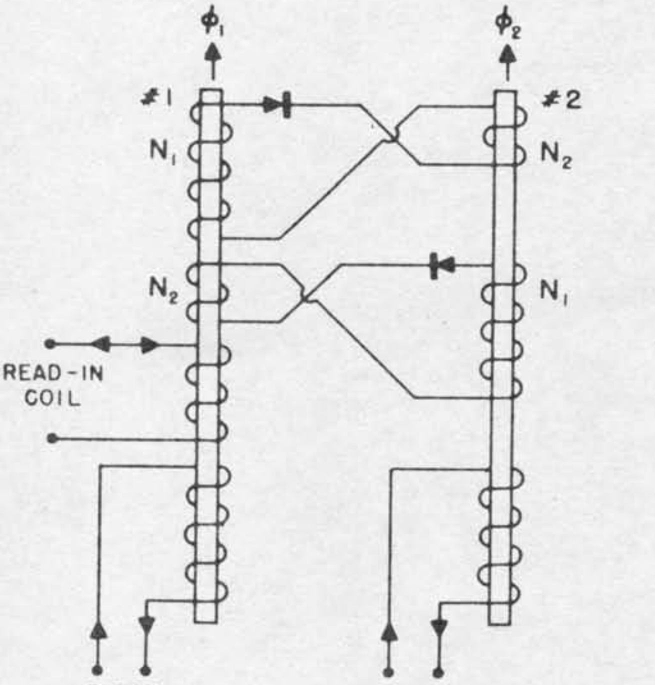

Fig. 4—Modified magnetic trigger pair.

In this case, stability of operation can be obtained more easily at the expense of two extra rectifiers. This form of trigger pair has been tested to hold information for an indefinitely long time, and can be triggered back and forth at a repetition frequency up to 50 kilocycles per second. The rectifiers used are of selenium type. Germanium diodes of course can also be used. There are many ways of introducing signals into the trigger pair. One way is to apply the positive or negative read-in pulse to the first core at the same instant as the second magnetizing pulse is applied to the second core.

Fig. 5 shows the flux variation of the first core as the two magnetizing pulses are alternately applied. The upper portion represents the condition when a *0* is stored in the trigger pair, while the lower portion represents the condition when a *1* is stored. The oscillogram shows the operation at a repetition frequency of 5 kilocycles per second.

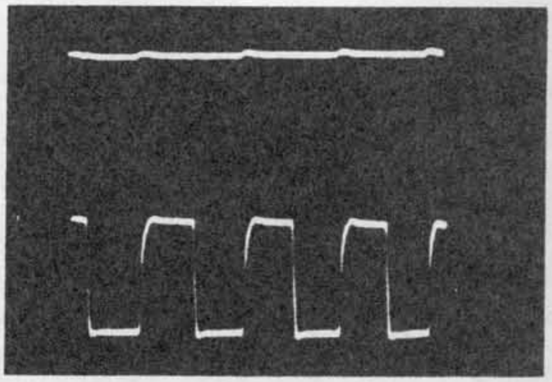

Fig. 5—Flux variation of the magnetic trigger pair.

IV. SINGLE STROKE TRIGGER

The trigger pairs described in the above two sections use two magnetic cores. The magnetic flux condition of the first core is transferred to the second core for temporary storage by the first magnetizing pulse; then the state is transferred back by the second magnetizing pulse. Since there is no other way of telling the flux polarity statically, two transfers must be made. There is a great advantage in the use of a single core and a single magnetizing pulse to determine the polarity of the magnetic flux, while preserving that flux.

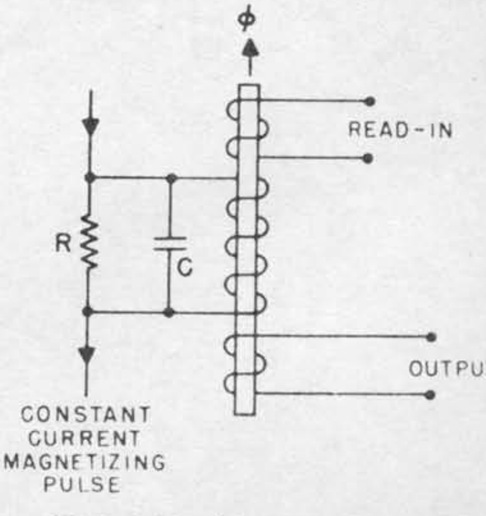

Fig. 6—Single stroke magnetic trigger.

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The procedure is as follows (Fig. 6): Assume first that the core is magnetized in the positive direction, or at the position *1*. The magnetizing pulse changes the position from *1* to *a*; this causes a large voltage across the coil and charges the capacity *C*. Then the magnetizing pulse ceases to flow. *C* is discharged through the coil which offers very low inductance because it is already saturated in the direction of the current. During the discharge of the capacity *C*, the circuit operation is very like a parallel resonance of *L*, *C*, and *R*, where *R* is high and *L* very low. The *Q* of this parallel circuit is equal to $R\sqrt{C/L}$, which is high. The charge on the condenser *C* is easily reversed without much damping. However, when the condenser discharges again, the discharging current flowing in the winding is in such a direction as to cause the flux of the core to change from *0* to *1* again. The coil offers a high inductance, the discharging rate is much slower, and the damping high. If the values of *R*, *C*, and this inductance are such that damping is closed to critical, the condenser is completely discharged while the flux returns from *0* to *1* again. This situation is very similar to a single-stroke electrical trigger pair. The polarity of the flux of the core returns to the original condition automatically a certain time after the first triggering. This interval is determined by the discharging time of the condenser. In Fig. 7 are shown the change of flux ϕ with time as the magnetizing pulse is applied, the voltage across the condenser V_c, the current i_L through the coil, and the magnetizing current i_M. If originally the core is in the state *0*, the magnetizing pulse does not change the flux by any appreciable amount. The coil essentially short-circuits the *CR* circuit. The condenser is not charged and everything remains the same as the magnetizing pulse subsides. The output is very small. The flux change for this case is shown as the last curve in Fig. 7.

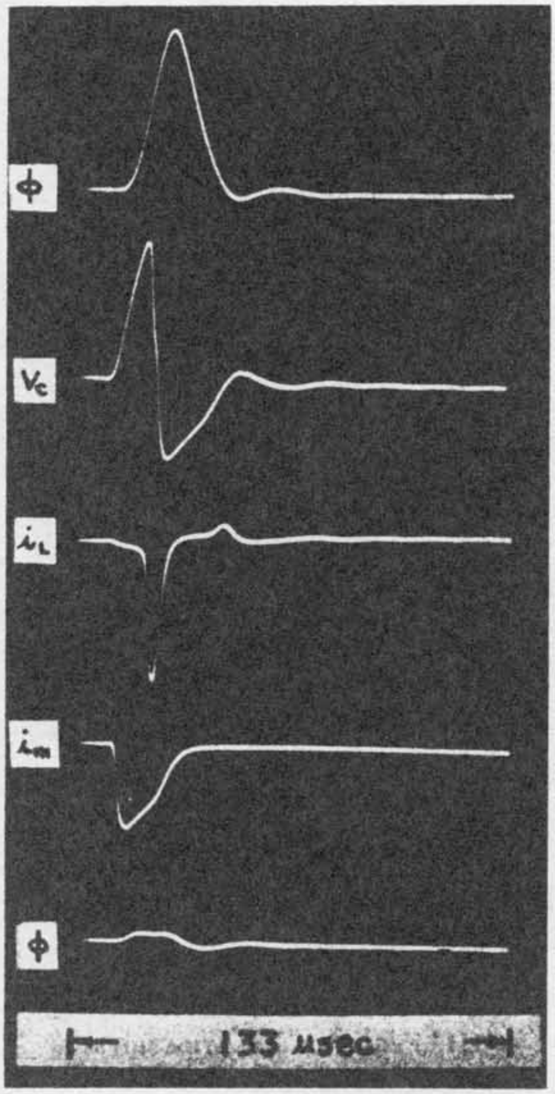

Fig. 7—Flux, voltage, and current shape of the single-stroke magnetic trigger during triggering.

V. CONCLUSION

The above discussions show the general feasibility of using magnetic cores as triggers. There is every possibility that such a magnetic trigger can take the place of vacuum-tube trigger pairs for some of their applications. Binary digits can be stored in such units. A stored digit can be delivered out or be transferred to another core. The possibility of transferring binary digits from core to core directly makes it possible to construct an information delay line in which a series of binary digits can be pushed along a series of such cores by magnetizing pulses at any rate from a very low speed up to about 30 kilocycles per second. This has been described in another paper.[2] Exact mathematical treatment of the subject is still difficult in view of the highly nonlinear characteristic of the hysteresis loop of the core material.

VI. ACKNOWLEDGMENT

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[2] A. Wang and W. D. Woo, "Static magnetic storage and delay line," *Jour. Appl. Phys.*, vol. 21, pp. 49–54; January, 1950.

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