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MAGNETIC CORE DIGITAL CIRCUIT

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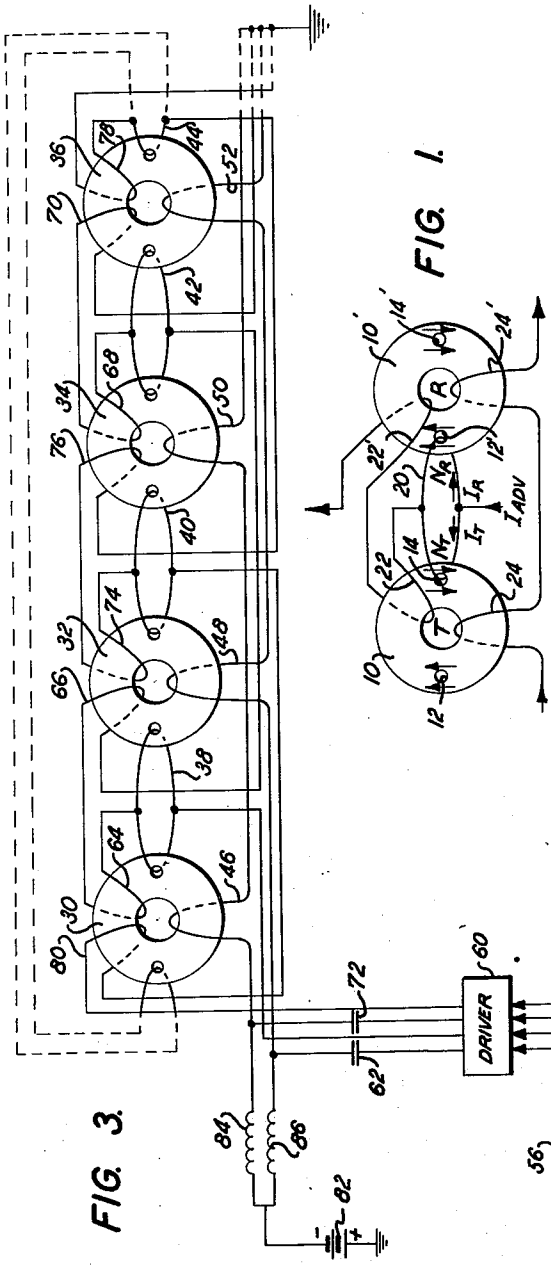


FIG. 3.

FIG. 1.

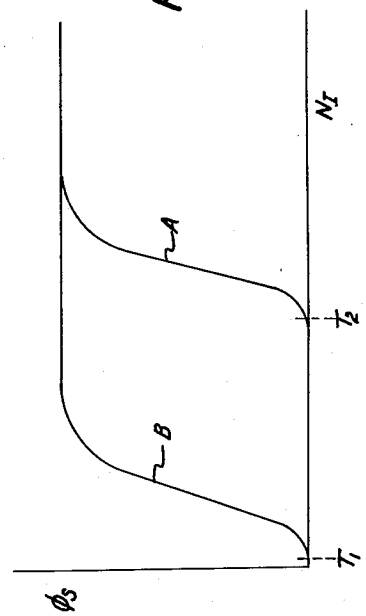


FIG. 2.

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MAGNETIC CORE DIGITAL CIRCUIT

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This invention relates to binary information storage and transfer apparatus, and more particularly, is concerned with magnetic core pulse-operated circuits for storing and controlling the transfer of binary information.

In copending application Serial No. 704,511, filed December 23, 1957 in the name of Hewitt D. Crane, and assigned to the assignee of the present invention, there is described an improved core register having a novel transfer circuit requiring no diodes or other impedance elements in the transfer loops between the magnetic core devices in the register. Information is transferred from one core device to another by means of pulses of predetermined current level. By means of a biasing arrangement on the core devices, as therein described, the range over which this current level of the transfer pulse might be varied without materially affecting the information transfer is greatly extended, and certain other advantages are also achieved.

The present invention constitutes a further improvement on the register therein described. Thus by the present invention the range over which the current level of the transfer pulse may vary is further extended. This increased range is achieved by additional D.C. bias windings on the magnetic core elements.

In brief, the present invention is incorporated in a register comprising at least two annular cores of magnetic material having high flux remanence. Means including windings on the cores are provided for saturating the flux in one direction in both of the cores. Each core has a pair of apertures, the cores being coupled by a transfer loop linking the cores through one of these apertures in each core. The loop consists of a pair of windings, one winding on each core, connected in parallel. Information transfer is effected by applying a current pulse of predetermined magnitude through the two windings of the transfer loop, the current level of the pulse being just below the threshold current level required to switch flux around either of the annular cores.

Bias windings are wound on the cores which are connected in series with each other and in series with the transfer loop so as to be energized by the transfer pulse.

According to the improvement of the present invention a further bias winding is provided on each of the cores which is energized from a D.C. source. The direction of current through the additional bias windings is such as to tend to switch flux in the same direction within the cores as the transfer pulse. The D.C. bias permits the bias produced by the transfer pulse to be increased, thereby increasing the self-compensating effect of the bias produced by the transfer pulse.

For a more complete understanding of the invention, reference should be had to the accompanying drawings, wherein:

FIG. 1 shows a transfer circuit with the addition of counter bias;

FIG. 2 is a graphical plot of flux switched in a core as a function of ampere-turns linking the core and is used in explaining the operation of the circuit of FIG. 1; and

FIG. 3 is a schematic drawing of a shifting register incorporating the features of the present invention.

As described in more detail in the above mentioned copending application, a binary register and transfer circuit can be constructed using basic core elements arranged

as shown in FIG. 1. This circuit includes a pair of magnetic annular cores **10** and **10'** made of Ferrite or similar magnetic material having a "square" hysteresis characteristic, i.e., a material having a high flux remanence. A coupling loop **20** links the transmitting core **10** through an output aperture **14** to the receiving core **10'** through an input aperture **12'**. Transfer of information stored in the transmitter core **10** to the transmitter core **10'** is effected by an advance current pulse by means of which a current I_{Adv} is applied to the transfer loop **20** in the direction indicated by the arrow. The advance current divides in the transfer loop into a current I_T passing through the aperture **14** of the transmitting core **10** and a current I_R passing through the aperture **12'** of the receiving core **10'**.

It can be shown that with the flux in a given core extending in the same direction on either side of the aperture linked by the transfer loop, the current in the loop must exceed a certain threshold level before any of the flux around the core can be reversed or switched. This is shown by curve A of FIG. 2, which shows the relationship between the flux switched in the core with increase of ampere-turns in the portion of the transfer loop linking the core. Ampere-turns must exceed a threshold level T_2 before a substantial amount of flux is switched in the core.

However, if the flux on either side of the aperture initially extends in opposite directions, the current required in the transfer loop to switch flux is greatly reduced. This relation is shown by curve B of FIG. 2, which shows that the ampere-turns must only exceed a much lower threshold level T_1 before flux is switched in the core. The reason is that in the latter case, flux does not switch around the core, but only switches locally around the aperture.

This property is used to effect the transfer between the transmitting core and the receiving core. The advance current I_{Adv} is set at a level such that the ampere-turns linking the two cores is below the threshold level T_2 when the cores are both cleared with all the flux in one direction, as indicated by the arrows in FIG. 1. As a result no flux is switched in either core by an advance current pulse. However, if the transmitter flux is initially set with the flux extending in opposite directions on either side of the aperture **14**, the ampere-turns linking the core **10** through the aperture **14** will exceed the lower threshold level T_1 when the advance pulse is applied to the transfer loop **20**. As a result the flux is switched by the transfer pulse in the transmitter core **10**. The switching of flux around the aperture **14** increases the impedance to the flow of current I_T, thereby increasing the portion of the advance current I_R. As a result the ampere-turns linking the receiver core **10'** is increased above the threshold level T_2 resulting in switching of flux in the core **10'**. In this manner the flux configuration in the receiver core **10** is not modified or modified in response to an advance current pulse, depending upon the initial flux condition of the transmitter core **10**.

As pointed out in the above-identified patent application, bias windings may be provided on both the transmitter core **10** and the receiver core **10'**, as indicated at **22** and **22'** respectively. The current through the bias windings is in a direction to oppose the switching of flux in the cores in response to the advance current pulse. The effect is to increase the upper threshold level T_2, thereby permitting the advance current to be greatly increased.

As further pointed out heretofore in the above-mentioned patent application, the bias winding **22** and **22'** may be connected in series with transfer loop **20** so as to be energized by the advance current pulse. This has the effect of providing a "moving threshold" with changes in

level of the advance current, so as to provide a self-compensating effect. Since the upper threshold T_2 depends upon the amount of bias, any change in the advance current changes the amount of bias and thereby moves the threshold. If the threshold were not moving, an increase in advance current might cause the transfer to exceed the threshold so as to produce a switching of flux in the receiver core 10' when it was not desired. However, with the threshold moving to a higher level as the result of the increase in bias with the increase in advance current, a greater increase in advance current is required before the threshold level could be exceeded by the advance pulse.

With the circuit arranged as thus far described the ampere-turns in the bias windings on the transmitter core must be less than half the ampere-turns linking the aperture 14. Otherwise, the ampere-turns of the bias winding would exceed the threshold at which flux can be switched around the core 10. However, since the ampere-turns of the bias winding is less than half that of the transfer winding on the core 10, the circuit cannot be fully compensating. It will be appreciated that if the ampere-turns of the bias winding could be made more nearly equal to the ampere-turns of the transfer winding on the core 10, the circuit would be more completely compensating with changes in the advance current level. The reason is that the change in ampere-turns in the bias winding produced by an increase of the advance current would be substantially equal to the change in ampere-turns produced in the transfer winding by the increase in the advance current level.

The present invention provides a means for increasing the ampere-turns of the bias winding 22 so as to provide an increased compensating effect. This is accomplished by providing an additional winding 24 linking the core 10, hereinafter referred to as a counterbias winding, to which is applied a D.C. current. The current passes through the counterbias winding 24 in a direction so as to aid the switching of flux by the advance current as applied to the transfer loop 20. By the same token the counterbias winding 24 opposes the bias winding 22. The maximum ampere-turns of the counterbias winding 24 is limited by the threshold level at which flux begins to switch around the core 10. Since the counterbias winding opposes the action of the bias winding 22, the ampere-turns of the bias winding 22 can be accordingly increased by the same amount. Thus the ampere-turns in the bias winding 22 can be substantially increased to the point where it may be made almost equal to the ampere-turns linking the aperture 14. By permitting the ampere-turns at the bias winding 22 to be increased, the counterbias winding 24 has the effect of causing the threshold to move more with changes in advance current level, thereby increasing the compensating effect of the bias winding 22.

In the case of the receiver bias on the core 10', the same limitations are not imposed on the ampere-turns as are imposed on the ampere-turns of the bias winding 22 of the transmitting core 10, i.e., that the ampere-turns should be below the threshold at which flux switches in the core. The reason is that the receiver core, unlike the transmitter core, always starts in the cleared condition, and hence it is immaterial whether the bias ampere-turns exceeds the threshold so as to tend to clear the core. However, because of symmetry reasons, as where bi-directional shifting between the cores is contemplated, it is desirable that the receiver bias winding and the transmitter bias winding have the same number of turns. For this reason and also for the reason that the receiver core 10' on a subsequent transfer in turn becomes the transmitting core, a counterbias 24' is provided on the core 10'. This counterbias winding may be connected in series with the counterbias winding 24 on core 10 to a single D.C. source.

A typical shift register circuit utilizing counterbias in the maner described above for extending the current range of the transfer pulses is shown in FIG. 3. The circuit shown is suitable for storing and shifting two binary bits and comprises four core elements 30, 32, 34, and 36. While a two-bit register is shown in the figure, it will be understood that any number of pairs of core elements may be used in the register for the storage of additional binary bits. The core elements 30 and 32 are linked by a transfer loop 38 and the remaining cores are similarly linked by transfer loops 40, 42, and 44. The transfer loop 44 may be coupled back to the core element 30 as indicated by the dotted lines to provide a closed loop shifting register. Clearing windings are provided on each of the cores as indicated by the windings 46, 48, 50, and 52.

Clearing pulses and transfer pulses are derived from a pulse source 56, the output of which is applied to a suitable delay line 58 having four output leads coupled to a suitable driver circuit 60. The first pulse produced in point of time from the output of the driver 60 in response to a pulse from a source 56 is coupled through a condenser 62 to the clearing windings 48 and 52, whereby the cores 32 and 36 are initially cleared.

The next pulse generated in point of time from the output of the driver circuit 60 in response to the pulse from the source 56 is coupled to the transfer loops 38 and 42. A transmitter bias winding 64 and a receiver bias winding 66 on the cores 30 and 32 respectively are connected in series with each other and with the transfer loop 38. Similarly a transmitter bias winding 68 and a receiver bias winding 70 are wound on the cores 34 and 36 respectively. These bias windings are connected in series with transfer loop 42. Each of these bias windings is energized by the pulse coupled to the loops 38 and 42.

The third pulse generated from the driver 60 in point of time in response to the pulse from the source 56 is coupled through a condenser 72 to the clearing windings 46 and 50 on the cores 30 and 34 respectively.

The fourth pulse derived from the driver 60 in point of time in response to the pulse from the source 56 is coupled to the transfer loops 40 and 44 in series. A transmitter bias winding 74 on the core 32 and a receiver bias winding 76 on the core 34 are connected in series with each other and with the transfer loop 40. Similarly a transmitter bias winding 78 and a receiver bias winding 80 are wound on the cores 36 and 30 respectively, and are connected in series with each other and with the transfer loop 44.

The clearing windings 46, 48, 50, and 52, are used to provide counterbias by connecting them to a D.C. potential source 82 through choke windings 84 and 86. The condensers 62 and 72 isolate the driver circuit 60 from the D.C. source 82 and the chokes 84 and 86 provide a high impedance to the transfer pulses so that the D.C. source 82 does not bypass the transfer pulses.

In operation, following one pulse from the source 56, the cores 32 and 36 are cleared by the first pulse from the driver 60 preparatory to receiving information transferred from the cores 30 and 34. Next, the transfer loops 38 and 42 are energized to transfer information to the cores 32 and 36. Next, the cores 30 and 34 are cleared preparatory to receiving information from the cores 32 and 36. Finally, the transfer loops 40 and 44 are energized to transfer information to the cores 30 and 34, thereby completing the shifting cycle.

It has been found that considerable improvement in operating range of the transfer current pulses is possible using the counterbias technique as described above. By using the clearing windings for applying the counterbias, the counterbias can be added without complicating the winding problem and with the minimum of extra external circuitry. While the addition of counterbias requires an extra source which also can drift, drift stabilization of a D.C. source is relatively easy compared to the problem of stabilizing the current of a pulse source, such as the driver circuit 60.

What is claimed is:

1. Apparatus comprising at least two storage elements,

each element including an annular core of magnetic material having a substantially rectangular hysteresis loop, the core having at least two apertures therethrough which are of substantially smaller size than the central opening formed by the annular shape of the core, a clearing winding linking the core through the central opening thereof for saturating the core in response to a unidirectional current passed through the clearing winding, an input winding linking the core through one of said apertures, and an output winding linking the core through the other of said apertures, the output winding of one core being directly connected across the input winding of the other core whereby the two windings are connected in parallel to form a closed conductive loop, means for applying a transfer pulse across the two windings in parallel, the transfer pulse being of predetermined magnitude to bring the cores when saturated by the clearing winding to substantially the threshold level at which flux starts to reverse in the cores, whereby the pulse does not materially alter the flux condition of the cores when they are both saturated by the respective clearing windings, first bias windings wound on the cores and connected in series with each other and in series with the transfer loop, the first bias windings being connected so as to oppose the switching of flux in the cores by the transfer pulse, second bias windings wound on the cores, and means for passing a continuous direct current through each of the second bias windings in a direction to assist the switching of flux in the cores by the transfer pulse.

2. Apparatus comprising at least two storage elements, each element including a magnetic core material having a substantially rectangular hysteresis loop having at least three openings therethrough, the openings separating the core into four separate core legs, the closed flux path linking the first and second of the core legs and the flux path linking the third and fourth of the core legs being substantially shorter than any other flux paths linking the respective legs of the core, an input winding linking the core through a first one of said openings and being wound on a first one of said legs, an output winding linking the core through a second one of said openings and being wound on a fourth one of said legs, a clearing winding linking the core through a third one of said openings and wound on a portion of the core of larger cross-sectional area than any of said legs, means for pulsing a unidirectional current through the third winding of sufficient magnitude to saturate the flux in each of said legs, the output winding of one core being directly connected across the input winding of the other core in parallel, whereby the two windings form a closed loop conductive path, means for applying a transfer pulse across the two windings in parallel, the transfer pulse being of predetermined magnitude to bring the cores when saturated by the clearing windings to the threshold level at which flux starts to reverse in the cores, whereby the pulse does not materially alter the flux condition of the cores when they are both saturated by the respective clearing windings, first bias windings wound on the cores and connected in series with each other and in series with the transfer loop, the first bias windings being connected so as to oppose the switching of flux in the cores by the transfer pulse, second bias windings wound on the cores, and means for passing a continuous direct current through each of the second bias windings in a direction to assist the switching of flux in the cores by the transfer pulse.

3. Apparatus comprising at least two storage elements, each element including a magnetic core material having a substantially rectangular hysteresis loop having at least three openings therethrough, the openings separating the core into four separate core legs, an input winding linking the core through a first one of said openings and being wound on a first one of said legs, an output winding linking the core through a second one of said openings and being wound on a second one of said legs, a clearing winding linking the core through a third one of said openings and wound on a portion of the core of larger cross-sectional area than any of said legs, means for pulsing a unidirectional current through the third winding of sufficient magnitude to saturate the flux in each of said legs, the output winding of one core being directly connected across the input winding of the other core in parallel, whereby the two windings form a closed loop conductive path, means for applying a transfer pulse across the two windings in parallel, the transfer pulse being of predetermined magnitude to bring the cores when saturated to the threshold level at which flux starts to reverse in the cores, whereby the pulse does not materially alter the flux condition of the cores when they are both saturated by the respective clearing windings, first bias windings wound on the cores and connected in series with each other and in series with the transfer loop, the first bias windings being connected so as to oppose the switching of flux in the cores by the transfer pulse, second bias windings wound on the cores, and means for passing a continuous direct current through each of the second bias windings in a direction to assist the switching of flux in the cores by the transfer pulse.

4. Apparatus for storing and transferring binary information comprising at least two magnetic cores having a substantially rectangular hysteresis loop, each of the cores being annular in shape and having at least one input aperture and one output aperture extending through the core material, the apertures being of smaller size than the opening formed by the annular core, an input winding linking the input aperture of the first core, an output winding linking the output aperture of the second core, a bidirectionally conductive transfer loop including a winding linking the output aperture of the first core and a winding linking the output aperture of the second core, the windings being directly connected in parallel to form the loop, means for applying a transfer pulse across the loop between the two windings whereby a current is provided simultaneously through the two windings, the current dividing between the two loops according to the respective impedances of the two windings, first bias windings wound on the cores and connected in series with each other and in series with the transfer loop, the first bias windings being connected so as to oppose the switching of flux in the cores by the transfer pulse, second bias windings wound on the cores, and means for passing a continuous direct current through each of the second bias windings in a direction to assist the switching of flux in the cores by the transfer pulse.

5. Apparatus for storing and transferring binary information comprising at least two annular magnetic cores having a substantially rectangular hysteresis loop defining a closed magnetic flux path, each of the cores having at least two small apertures extending through the core material, each small aperture dividing the flux path in the core into two sections, a bidirectionally conductive transfer loop including two windings in parallel, the windings respectively linking one aperture in each of the two cores, means for applying a transfer pulse across the two windings in parallel, the magnitude of the pulse being such as to produce a current in each of the windings that is slightly less than the threshold current level required to switch flux in the associated cores when all the flux is set in one direction around the annular cores, first bias windings wound on the cores and connected in series with each other and in series with the transfer loop, the first bias windings being connected so as to oppose the switching of flux in the cores by the transfer pulse, second bias windings wound on the cores, and means for passing a continuous direct current through each of the second bias windings in a direction to assist the switching of flux in the cores by the transfer pulse.

6. A magnetic shift register including at least two core elements of magnetic material having a substantially rec-

tangular hysteresis loop, each core element having a large aperture defining a relatively long flux path and a pair of small apertures defining relatively short flux paths, each of the small apertures dividing the relatively long flux path into two parallel branches, a closed bidirectionally conductive loop including a first winding linking one of said parallel branches of a first one of the core elements through one of the small apertures and a second winding linking one of said parallel branches of a second one of the core elements through one of the small apertures, a first clearing winding linking the relatively long flux path of the first core element through the large aperture, a second clearing winding linking the relatively long flux path of the second core element through the large aperture, first and second bias windings linking the relatively long flux path of the first core element, a shifting control circuit including means for

pulsing a transfer current through the two apertures linked by the windings of said loop and simultaneously pulsing a current through the first bias winding, and means for passing a continuous unidirectional current through the second bias winding in a direction to assist the switching of flux around the long flux path in response to the transfer current.

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