

Aug. 18, 1964

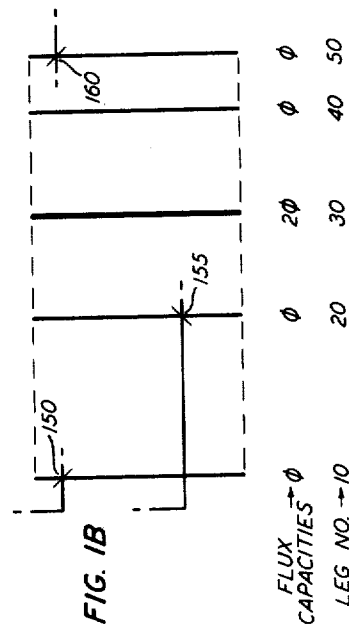
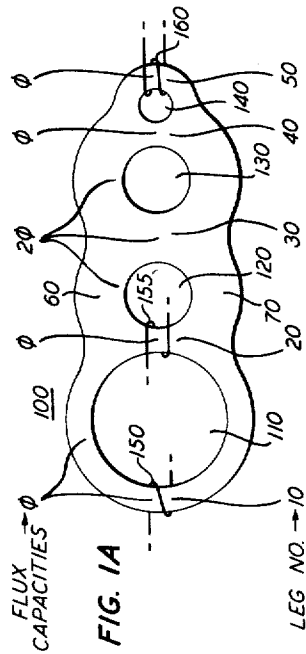
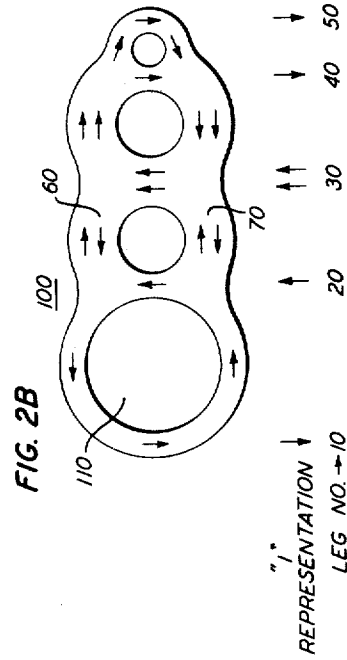
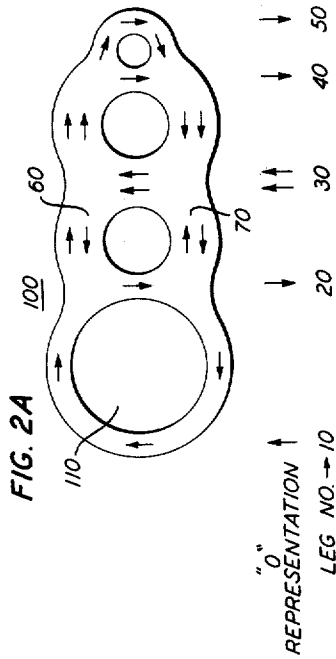
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3,145,371

MULTIAPERTURED MAGNETIC CORES

Filed June 25, 1962

2 Sheets-Sheet 1



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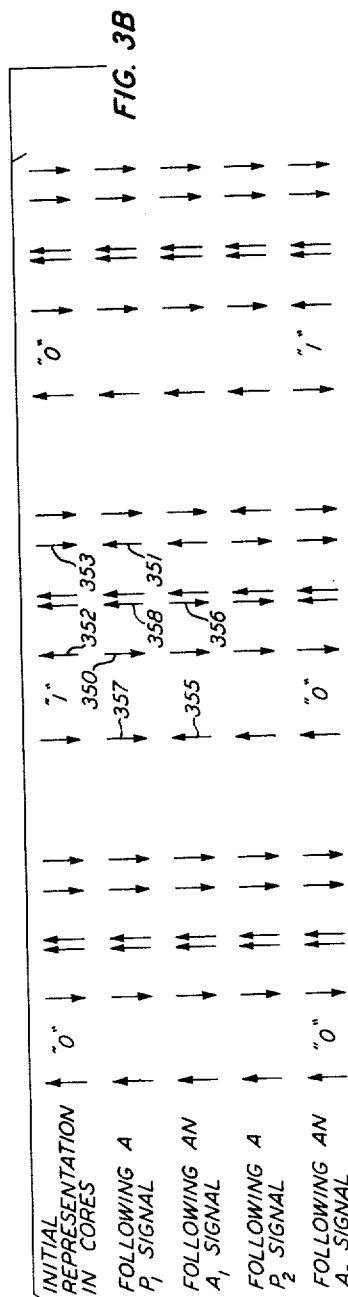
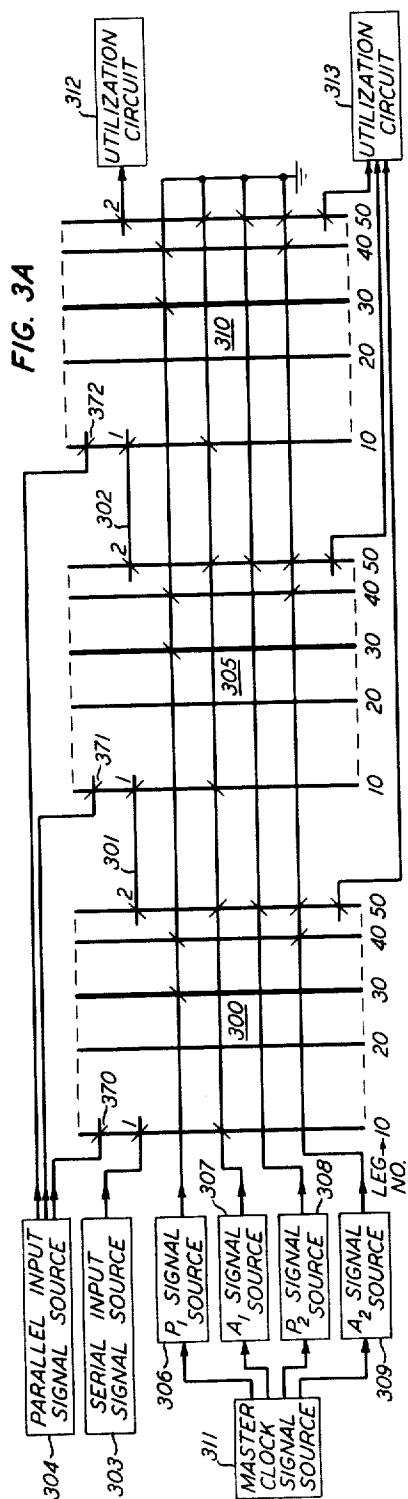
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2 Sheets-Sheet 2



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MULTIAPERTURED MAGNETIC CORES

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Filed June 25, 1962, Ser. No. 204,683

13 Claims. (Cl. 340-174)

This invention relates to the processing of digital information signals, and more particularly to magnetic devices and circuits for processing such signals.

Circuits composed as far as possible of compatible rectangular loop magnetic devices, and having a capacity for memory, gain and unidirectionality, have many advantages which make them attractive as elements of information processing systems. These advantages include the relatively low cost, small size, and high reliability of such magnetic devices as, for example, ferrite cores.

In one type of information processing circuit, signals are propagated in a step-by-step fashion along directed paths of a network of bit storage locations without signal degradation. One approach to the design of magnetic circuits of this type involves interconnecting a number of simple toroidal cores by means of wires and associated components such as diodes. However, this approach frequently results in considerable wiring complexity. The wiring required and the number of associated components needed in this general type of core circuit can often be reduced, and its efficiency increased, by using more complicated magnetic devices, such as multiapertured cores, for example, those of the type disclosed in my copending application Serial No. 822,907, filed June 25, 1959, now Patent 3,045,215, issued July 17, 1962.

The above-cited application describes a novel magnetic shift register circuit each stage of which includes two two-hole cores and two inter-core coupling windings. Experience has shown that the cost of placing coupling windings between the cores of such circuits represents a substantial part of their cost. In addition, coupling windings dissipate power and thereby decrease the efficiency of the circuits. Therefore, there is considerable merit to any approach that can reduce the total number of inter-core windings needed. Also, it is frequently advantageous, from the standpoint of ease of assembling these circuits, to reduce the total number of individual cores required therein.

Accordingly, it is an object of the present invention to provide improved magnetic devices and circuits.

More specifically, it is an object of this invention to provide an improved multiapertured magnetic core device from which may be constructed simple and efficient magnetic circuits.

Another object of the present invention is an efficient magnetic circuit characterized by memory, gain, and unidirectionality.

A further object of this invention is a one-core-per-stage magnetic circuit in which signals are advanced in a step-by-step manner and in which part of the advance sequence is carried out by flux transfers within the core itself, whereby the number of cores and inter-core coupling windings required in the circuit are thereby reduced.

These and other objects of the present invention are realized in a specific illustrative embodiment thereof which comprises a multistage magnetic shift register circuit, each stage of which includes a four-hole magnetic core. The holes in each core and the flux paths defined by various cross-sectional areas thereof are so proportioned that in response to an applied four-phase clock signal sequence, the flux condition of each core is transferred via a single inter-stage coupling winding to the core in the next adjacent stage of the embodiment.

An illustrative core made in accordance with the prin-

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ciples of this invention comprises a body of material exhibiting a rectangular hysteresis loop characteristic. The four holes therethrough define five substantially parallel flux-carrying legs, the middle one of which has a minimum cross-sectional area substantially equal to twice the minimum cross-sectional area of each of the other legs, the minimum cross-sectional areas of the other legs being substantially equal to each other. The body also includes two side members respectively interconnecting the ends of the five substantially parallel legs to form a plurality of closed magnetic paths in the body, the portions of the side members which interconnect the three middle legs having a minimum cross-sectional area substantially equal to that of the middle leg.

A feature of the present invention is that a magnetic core include four holes therethrough to define five substantially parallel flux-carrying legs, the middle one of which is characterized by a flux-carrying capacity twice that of any of the other legs.

Another feature of this invention is that a four-hole magnetic core include side members interconnecting the five substantially parallel legs to form a plurality of closed magnetic paths, the portions of the side members which interconnect the three middle legs having a minimum cross-sectional area substantially equal to that of the relatively large middle leg.

Still another feature of the present invention is that each stage of a magnetic shift register include a single multiapertured core and a single inter-core coupling winding.

Yet another feature of this invention is that a magnetic shift register circuit include a single multiaperture core and one inter-core coupling winding per stage, and that the circuit be responsive to a four-phase clock signal sequence by propagating information through the circuit from stage to stage in a step-by-step manner.

A complete understanding of the present invention and of the above and other features and advantages thereof may be gained from a consideration of the following detailed description of an illustrative embodiment thereof taken in conjunction with the accompanying drawing, in which:

FIG. 1A depicts a specific illustrative magnetic core device made in accordance with the principles of the present invention;

FIG. 1B is a symbolic representation of the core shown in FIG. 1A;

FIGS. 2A and 2B each illustrate a core of the type shown in FIG. 1A and, further, indicate the flux conditions thereof illustrative of the binary representations "0" and "1," respectively;

FIG. 3A shows in symbolic form a magnetic shift register circuit made in accordance with the principles of the present invention; and

FIG. 3B illustrates, for a complete cycle of operation of the circuit shown in FIG. 3A, the flux conditions of the cores thereof in response to signals from a four-phase clock signal source.

Referring now to FIG. 1A, there is shown a core 100 made of a ferromagnetic or ferrimagnetic material that has a substantially rectangular hysteresis loop characteristic. The core 100 includes therethrough four apertures 110, 120, 130, and 140 whose relative dimensions are specified in detail later hereinbelow. The apertures define five parallel vertically-oriented legs 10, 20, 30, 40, and 50 and, in addition, two generally horizontal side members 60 and 70 which respectively interconnect the ends of the five parallel legs and thereby form therewith a plurality of closed magnetic paths.

The minimum cross-sectional areas of the vertical legs 10, 20, 40, and 50 of the core 100 shown in FIG. 1A are selected to be approximately the same and may each be regarded as having a flux-carrying capacity of ϕ flux

units. By contrast, the minimum cross-sectional area of the middle vertical leg 30 is dimensioned such that the leg 30 has a flux-carrying capacity of 2ϕ flux units. Similarly, that portion of the side member 60 which interconnects the top ends of the legs 20, 30, and 40, and, in addition, that portion of the side member 70 which interconnects the bottom ends of the legs 20, 30, and 40, are each dimensioned to have a flux-carrying capacity of at least 2ϕ flux units. On the other hand, those portions of the side member 60 which interconnect the top ends of the legs 10 and 20, and the top ends of the legs 40 and 50, are each dimensioned to have a minimum flux-carrying capacity of ϕ flux units. Also those portions of the side member 70 which interconnect the bottom ends of the legs 10 and 20, and the bottom ends of the legs 40 and 50, are each dimensioned to have a minimum flux carrying capacity of ϕ flux units. The above-specified flux capacities of the vertical legs 10, 20, 30, 40, and 50, and of some portions of the side members 60 and 70, are indicated in FIG. 1A.

For illustrative purposes windings 150, 155, and 160 are shown in FIG. 1A as being inductively coupled to the vertical legs 10, 20, and 50, respectively. The winding 150 is arranged on the leg 10 in a sense such that a current flow into the upper end of this winding and out of the lower end thereof will tend to drive flux downward in the leg 10. The winding 155 is arranged in a sense opposite to that of the winding 150. Therefore, a current flow into the upper end of the winding 155 and out of the lower end thereof will tend to drive flux upward in the leg 20. Illustratively, the winding 160 is a coupling winding and is wound such that a reversal in the magnetization of leg 50 from an upward to a downward direction will induce a current in the winding 160 which will flow out of the upper end and into the lower end thereof.

Before proceeding to a specific discussion of FIG. 1B, it is noted by way of background that the schematic representation of magnetic circuits is considerably facilitated by the use of mirror symbols. This type of symbology is clearly described in "Pulse Switching Circuits Using Magnetic Cores," by M. Karnaugh, pages 570-584, Proceedings of the Institute of Radio Engineers, May 1955, volume 43.

In accordance with the symbology described in the Karnaugh article, magnetic cores are represented by heavy vertical line segments, winding leads are represented by horizontal line segments, and winding turns are represented by 45-degree mirror symbols at the intersections of the vertical cores and horizontal leads. The sense of the magnetic field associated with a current in a given winding is obtained by reflecting the current in the winding mirror symbol. To find the direction of the electromotive force induced in a winding when the applied field switches a core, reverse this field and reflect it in each winding mirror symbol. These conventions are completely consistent with Lenz's Law.

The application of a current pulse in a given direction to a first type of winding which is wound around a core in one direction and is represented by a 45-degree mirror symbol that extends into the first and third quadrants, causes the core to switch to one magnetic state, while the application of a similarly-directed pulse to a second type of winding which is wound around the core in the opposite direction and is represented by a 45-degree mirror symbol that extends into the second and fourth quadrants, causes the core to switch to its other stable magnetic state. In switching from one to the other of its two stable states, a core experiences a magnetic flux reversal which induces a voltage of one polarity in the first type of core winding and a voltage of the opposite polarity in the second type of core winding.

Herein a slightly modified mirror symbol representation will be used to describe cores of the FIG. 1A type and circuits made therefrom. The modified representation is shown in FIG. 1B wherein each leg of the core

100 is represented by a heavy vertical line whose width is proportional to the flux-carrying capacity thereof. Accordingly, the vertical line representative of the maximum flux capacity leg 30 is shown in FIG. 1B as being twice as wide as any of the lines representative of the legs 10, 20, 40, and 50. The horizontal dashed lines are included in FIG. 1B to draw attention to the fact that the vertical legs are interconnected magnetically by the side members 60 and 70, thereby forming a plurality of closed magnetic paths. Also shown in FIG. 1B in symbol form are the windings 150, 155, and 160 depicted in FIG. 1A.

The flux distributions in a multiapertured core device of the type shown in FIG. 1A can be easily determined if the following two facts are kept in mind. First, flux continuity must be preserved. Second, when a magnetomotive force exceeding a predetermined threshold value is applied to a leg, a preferential flux reversal will first take place in that flux path which includes the leg and which presents the lowest reluctance to the applied force. In general the lowest reluctance path is the shortest path having flux available for reversal.

In accordance with the principles of the present invention, the flux distributions in a core device of the type shown in FIG. 1A may assume a number of discrete patterns. Two of these distributions, specifically those which will be considered representative of the binary values "0" and "1," are illustrated in FIGS. 2A and 2B, respectively, wherein arrows indicate the states of remanent magnetization of the vertical legs 10, 20, 30, 40, and 50 and, also, of various portions of the side members 60 and 70. Each arrow represents a magnetization of one flux unit. Thus in FIGS. 2A and 2B the leg 30 is shown to be magnetized in the upward direction in the amount of two flux units, and each of the legs 10, 20, 40, and 50 is indicated to be magnetized either in an upward or a downward direction in the amount of one flux unit. It is noted that those portions of the side members 60 and 70 which interconnect the upper and lower ends of the vertical legs 20 and 30 each contain opposed arrows, thereby indicating a zero resultant magnetization for each of those portions.

It should be kept in mind that the flux patterns shown in FIGS. 2A and 2B are merely convenient representations and that the actual magnetic domain structures of the various regions of the core 100 will, in fact, be considerably more complicated than indicated. Nevertheless, the model is in general helpful and for present purposes completely adequate.

It is noted that the "0" and "1" representations shown in FIGS. 2A and 2B, respectively, differ only in the flux states of the two leftmost legs 10 and 20. Specifically, in the "0" flux pattern of FIG. 2A, the leg 10 is magnetized in an upward direction and the leg 20 in the downward direction, while in the "1" flux pattern shown in FIG. 2B the converse is true. Thus, to switch the core 100 from a "0" representation to a "1" simply requires that the clockwise magnetization around the periphery of the largest or input hole 110 be switched to a counterclockwise orientation. This may be done, for example, by applying a positive switching current to the upper end of the winding 150 shown in FIG. 1A. In practice this switching current could be applied to the leg 10 via a coupling winding that interconnects the leg 10 with the leg 50 of a preceding core device in an array of such devices, and could be induced by the flux change produced by switching the leg 50 of the preceding core.

In accordance with the principles of the present invention magnetic memory devices of the type described above and shown in FIGS. 1A, 2A, and 2B may be interconnected in an array through which signals are propagated along directed paths in a step-by-step fashion without signal degradation. The proper operation of such arrays depends on the core flux patterns thereof being changed or shifted in an ordered manner. This, in turn, depends on selectively driving each core with multiphase signals

whose amplitudes are controlled relative to the switching thresholds characteristic of the various flux paths in the core. By these techniques the number of cores and inter-core coupling windings required in such arrays are minimized.

Turning now to FIG. 3A, there is shown a specific illustrative shift register circuit made in accordance with the principles of the present invention. The circuit includes three core devices 300, 305, and 310, each of which is depicted in FIG. 3A in accordance with the mirror symbology described above in connection with FIG. 1B. Each core included in the FIG. 3A circuit is of the type shown in FIGS. 1A, 2A, and 2B. Each vertical leg except leg 20 of each of the cores 300, 305, and 310 includes one or more windings inductively coupled thereto. In particular, it is noted that each pair of adjacent cores is interconnected by a coupling winding. Thus, winding lead 301 extending between the cores 300 and 305 is a part of the coupling winding extending therebetween. In FIG. 3A, the numerals 2 and 1 near the respective ends of the lead 301 are intended to indicate that the coupling winding of which the lead 301 is a part includes, for example twice as many turns on the leg 50 of core 300 as on the leg 10 of core 305. In this way, it is possible to obtain a flux again or a flux transfer without loss between the cores 300 and 305 of the circuit shown in FIG. 3A. Also, by means of the coupling winding which includes the winding lead 302, it is possible to obtain a flux gain between the adjacent cores 305 and 310. This flux gain technique is well known in the art. See, for example, in this connection pages 7-11 of my article entitled "Integrated Magnetic Circuits for Synchronous Sequential Logic Machines," in the Bell System Technical Journal, volume 39, March 1960.

Input information can be applied to the cores 300, 305, and 310 of the FIG. 3A circuit from either a serial signal source 303 or a parallel signal source 304. Assume, for example, that appropriate signals are supplied by the source 304 to the input leg 10 of each of the cores 300, 305, and 310 to set them initially to the representation "0," "1," and "0," respectively. These flux conditions of each of the legs 10, 20, 30, 40, and 50 of the three cores are depicted in the top or first row of FIG. 3B. It is not necessary to show the flux states of the interconnecting members 60 and 70 in FIG. 3B since there are automatically determined by the flux conditions of the legs of the cores and by the condition of flux continuity within a core.

Subsequently, as described in detail hereinbelow, the representations of the cores 300, 305, and 310 are shifted to the right in a step-by-step manner in response to a four-phase clock signal sequence supplied by sources 306, 307, 308, and 309 under the control of a master clock signal source 311. As the result of a complete cycle of operation of the circuit shown in FIG. 3A, the initial representation of the cores 300, 305, and 310 is applied in serial form to utilization circuit 312. Alternatively, the representation in the register may be applied in parallel form to utilization circuit 313.

To begin a cycle of operation, the cores 300, 305, and 310 shown in FIG. 3A are primed by a P_1 signal from the source 306. This signal is coupled to the legs 30 and 40 of each of these cores in a sense to tend to maintain the existing positive magnetization of each of the legs 30 and to reverse the negative magnetization of each of the legs 40. The amplitude of the P_1 signal is selected to exceed the threshold for switching flux around the short path including legs 40 and 20. Therefore, a flux reversal between these two legs takes place in a core storing a "1" representation. The amplitude of the P_1 signal is not, however, sufficient to exceed the threshold for switching flux around the longer path including legs 40 and 10. Therefore, there is no flux change produced in a core storing a "0" representation.

The second row of FIG. 3B depicts the magnetization states of the cores 300, 305, and 310 subsequent to the application thereto of a P_1 signal. Note that the states of the cores 300 and 310 are unchanged as a result thereof because, as specified above, the P_1 signal is not sufficient in amplitude to switch the condition of the longer flux path which includes the legs 40 and 10. In addition, it is noted that there cannot be any switching of the short flux path which includes the legs 40 and 20 since leg 20 did not have any flux available for reversal. On the other hand, the initial condition of the core 305 is such that there is flux available for reversal in the path thereof which includes the legs 40 and 20. Hence, the P_1 signal reverses the magnetization condition of the legs 40 and 20 of the core 305. This is evident by noting that the arrows 350 and 351 in the second row and middle column of FIG. 3B are respectively opposed to the arrows 352 and 353 immediately thereabove.

Next, an A_1 signal is applied from the source 307 to the legs 10 and 50 of each of the cores 300, 305, and 310. This signal tends to produce a positive (i.e., upwards) magnetization in each of the legs 10 and to maintain the existing negative (i.e., downwards) magnetization of each of the legs 50. The amplitude of the A_1 signal is selected to be at least sufficient to exceed the threshold for switching between the legs 10 and 30, taking into account any opposing magnetomotive force produced by currents induced in the coupling windings 301 and 302 by flux changes in the legs 10. There are, however, no restrictions on the maximum amplitude of A_1 except to reasonably limit any reversible flux excursions in legs 10 and 50 that may be produced because of a non-ideal "squareness" of the rectangular hysteresis loop of a practical core material.

Since the legs 10 of the cores 300 and 310 are already magnetized in a positive direction, the A_1 signal produces no appreciable flux change in these cores. On the other hand, the A_1 signal reverses the magnetization of the flux path in the core 305 which includes the legs 10 and 30. This is evident by noting that the arrows 355 and 356 in the third row and middle column of FIG. 3B are respectively opposed to the arrows 357 and 358 immediately thereabove. In response to the P_1 and A_1 signals the left-hand section or the legs 10 and 20 of the core 305 are reset to a clear or "0" representation, and the previous "1" information state of those legs is shifted into the right-hand section, specifically, into the legs 30 and 40, of the core 305.

It is noted that the flux reversal of leg 10 of the core 305 in response to the A_1 signal induces a current in the inter-core coupling winding which extends between leg 10 of the core 305 and leg 50 of the core 300. This tendency to propagate information in the backward direction, i.e., to drive leg 50 of the core 300 in a positive magnetization direction, is, however, effectively inhibited by the action of the A_1 signal on leg 50 of the core 300, for, as noted above, the A_1 signal acts to maintain the existing negative magnetization of the legs 50 of all three cores 300, 305, and 310.

Subsequently, the output or right-hand aperture of each of the cores represented in FIG. 3A is primed by applying to each of the legs 50 a P_2 signal from the source 308, which acts to reverse the negative magnetization states of these legs. The amplitude of the P_2 signal is selected to be greater than the threshold for switching between legs 50 and 40 but less than the threshold for switching to reset leg 50 of the core 305 to its negative magnetization conditions of the legs 40 and 50 of the "1" core 305 are respectively reversed in response to a P_2 signal, while the magnetization conditions of the legs 40 and 50 of each of the "0" cores 300 and 310 are left undisturbed as a result thereof. The conditions of the three cores following a P_2 signal are depicted in the fourth row of FIG. 3B.

The flux reversal in leg 50 of the core 305 in response to the P_2 signal induces a current in the inter-core cou-

pling winding which extends between leg 50 of the core 305 and leg 10 of the core 310. This induced current produces a magnetomotive force in the direction of existing magnetization of leg 10 of the core 310, thereby producing no appreciable flux change therein. The induced current does, however, oppose the switching action of P_2 and reduces the net magnetomotive force on leg 50 of the core 305. Therefore, the magnitude of the induced current should be reduced as far as possible by making the resistance of this coupling winding as large as possible compatible with the gain provided by the turns-ratio thereof to compensate for losses in the subsequent transfer operation described below. Practically, the optimum resistance is generally provided by appropriate choice of the diameter and length of wire used for the coupling winding.

Finally, the application of an A_2 signal from the source 309 to the cores 300, 305, and 310 clears the right-hand section of the core 305 and transfers the "1" representation formerly stored in that core to the left-hand section of the adjacent core 310. Specifically, the A_2 signal acts to reset leg 50 of the core 305 to its negative magnetization state, while maintaining the existing negative magnetization of leg 40 of the core 305. By selecting the amplitude of the A_2 signal to exceed the threshold for switching between the legs 50 and 30, taking into account the opposing magnetomotive force produced by the current induced in the inter-core coupling winding, a flux reversal is produced in the path which includes legs 50 and 30 of the core 305.

The flux change in the leg 50 of the core 305 in response to an A_2 signal induces a current in the inter-core coupling winding which includes the lead 302. This current flows in a direction to reverse the magnetization of leg 10 of the core 310, thereby inserting a "1" representation therein. As mentioned above, the turns ratio of the coupling winding provides the flux gain needed to compensate for transfer losses.

The action of A_2 on cores 300 and 310 is to maintain the existing negative magnetization of legs 50 of these cores so that no large transfer current is induced in the corresponding output windings, with the result that a "0" is effectively transferred from core 300 to core 305 and zero output is induced in the winding connecting core 310 to the utilization circuit 312. Any small current that may be induced in these output windings as a result of reversible flux changes in leg 50 attributable to the non-ideal rectangular hysteresis loop of a practical core material will be effectively absorbed by the inductance and dissipated in the resistance of the output windings.

The final representation of the cores 300, 305, and 310 in response to the above-specified four-phase clock signal sequence is shown in the bottom row of FIG. 3B. In an exactly similar manner the word stored in the shift register depicted in FIG. 3A is transferred one further digit to the right following the completion of each P_1 , A_1 , P_2 , and A_2 signal sequence.

A new binary digit may, for example, be inserted serially into the first core 300 during or immediately following each A_2 signal. In addition, the serial output from the right-hand core 310 may, of course, be used to provide the input to additional stages of the type of the three depicted in FIG. 3A and described in detail herein. Also, a new word may be written into the register shown in FIG. 3A during the application thereto of an A_2 signal by using the parallel input windings 370, 371, and 372 coupled to the parallel signal source 304.

In order to increase the operational minimum and maximum margins for the P_1 and P_2 signals, the geometry of each of the herein-described cores should be such that the mean flux path length for switching between legs 10 and 40 is greater than that between legs 20 and 40. Also, the mean flux path length for switching between legs 40 and 50 should be greater than that between legs 30 and 50. The ratio of the maximum and minimum drive signals is determined by and ideally approximately equal to

the ratio of the flux path lengths. Practically what this means is that the diameter of the aperture between the legs 40 and 50 should be smaller (for example, by a factor of 2) than the diameter of the aperture between the legs 30 and 40, and that the diameter of the aperture between the legs 10 and 20 should be larger (for example, by a factor of 2) than the combined diameters of the apertures bordered by the legs 20 and 30 and the legs 30 and 40.

Also, in order to reduce the spill-over of flux into the legs 40 during the application to the cores of the A_1 signal, and into the legs 20 during the application to the cores of the A_2 signal, it would be advantageous to have the path length for switching between the legs 10 and 40 much greater than that between the legs 10 and 30. Furthermore, to reduce spill-over, it would be advantageous to have the path length for switching between the legs 20 and 50 much greater than that between the legs 30 and 50. The first-mentioned relationship suggests that the apertures bordered by the legs 20 and 30 should be smaller than the aperture bordered by the legs 30 and 40. However, the second-mentioned relationship suggests the converse. A satisfactory practical compromise is obtained by making the diameters of these two apertures approximately equal to each other, and making the aperture bordered by the legs 10 and 20 twice as large. These general dimensions are the ones depicted in FIGS. 1A, 2A, and 2B.

Because of the gain provided by the turns ratio of the inter-core coupling windings of the illustrative shift register circuit shown in FIG. 3A, each core thereof can be used to drive a number of other core structures in addition to the core structure of the next immediately adjacent stage. Thus, utilization circuit 313 may, for example, contain a plurality of cores driven from an appropriate winding on leg 50 of each of the cores 300, 305, and 310. Alternatively, as noted above, the utilization circuit 313 can simply be used to provide a parallel readout of the information stored in the three cores of the shift register circuit, with an output voltage corresponding to that induced by a full reversal of the flux in leg 50 occurring during the A_2 phase if the core contained a "1" immediately prior to the A_2 phase, and essentially zero output voltage occurring if the core contained a "0."

It is noted that my copending application Serial No. 204,682, filed concurrently herewith, is directed to a three-hole magnetic core device which is related to the subject matter hereof.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention. For example, the teachings contained hereinabove concerning the relative flux capacities and aperture sizes of the specific core device depicted in FIGS. 1A, 2A, and 2B may be embodied in a variety of modifications thereof each of which is within the scope of the principles of the present invention.

What is claimed is:

1. In combination in a magnetic shift register circuit, a plurality of cores arranged in a linear array, each of said cores being made of a rectangular hysteresis loop material and having four apertures therethrough which define five substantially parallel flux-carrying legs including an input leg and an output leg, means for setting said cores to an initial binary representation, inter-core winding means coupling the output leg of one core to the input leg of the next adjacent core of said array, and four-phase clock signal means coupled to said cores for advancing said initial representation from core to core in a digit-by-digit manner.

2. A combination as in claim 1 wherein said setting means includes serial input signal source means inductively coupled to the input leg of the first core of said array.

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3. A combination as in claim 1 wherein said setting means includes parallel input signal source means inductively coupled to the input leg of each of the cores of said array.

4. A combination as in claim 1 wherein each of said inter-core winding means is characterized by a step-down turns ratio.

5. A combination as in claim 4 further including utilization circuit means inductively coupled to the output leg of the last core of said array.

6. A combination as in claim 4 further including utilization circuit means inductively coupled to the output leg of each of the cores of said array.

7. A combination as in claim 4 wherein said four-phase clock signal means includes first winding means comprising a winding inductively coupled in a first winding direction to the middle leg of each core of said array and a winding inductively coupled in the first winding direction to the leg immediately adjacent the output leg of each core of said array.

8. A combination as in claim 7 wherein said four-phase clock signal means further includes second winding means comprising a winding inductively coupled in the first winding direction to the input leg of each core of said array and a winding inductively coupled in the opposite winding direction to the output leg of each core of said array.

9. A combination as in claim 8 wherein said four-phase clock signal means further includes third winding means comprising a winding inductively coupled in the first winding direction to the output leg of each core of said array.

10. A combination as in claim 9 wherein said four-phase clock signal means still further includes fourth winding means comprising a winding inductively coupled in the opposite winding direction to the leg immediately adjacent the output leg of each core of said array and a winding inductively coupled in the opposite winding direction to the output leg of each core of said array.

11. A combination as in claim 10 wherein said four-phase clock signal means includes means for applying signals to said first, second, third, and fourth winding means in sequence in the listed order.

12. In combination in a magnetic core circuit, a core

made of a rectangular hysteresis loop material and having four apertures therethrough which define five substantially parallel flux-carrying legs including an input leg and an output leg, the middle one of said flux-carrying legs being structurally dimensioned to have a minimum cross-sectional area substantially equal to twice the minimum cross-sectional area of each of said other legs, means inductively coupled to said input leg for applying thereto an input signal, means inductively coupled to said output leg for abstracting therefrom an output signal, and clock signal means inductively coupled to selected ones of said legs for shifting the magnetization condition of said core to a clear state in a four-phase advance sequence, thereby to deliver to said abstracting means an output signal representative of the input signal applied to said core.

13. A core element comprising a body of material exhibiting a substantially rectangular hysteresis loop characteristic, said body having four apertures therein defining five substantially parallel flux-carrying legs, the middle one of said legs having a minimum cross-sectional area substantially equal to twice the minimum cross-sectional area of each of said other legs, the minimum cross-sectional areas of said other legs being substantially equal to each other, said body also including two side members respectively interconnecting the ends of said five substantially parallel legs to form a plurality of closed magnetic paths in said body, the portions of said side members which interconnect the three middle legs having a minimum cross-sectional area substantially equal to that of said middle leg, and wherein said four apertures comprise an input aperture, an output aperture, and two intermediate apertures, the areas of said intermediate apertures being approximately equal to each other, the area of said output aperture being approximately one-quarter that of either of said intermediate apertures and the area of said input aperture being approximately four times that of either of said intermediate apertures.

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