May 30, 1967 D. R. BENNION 3,323,113

SHIFT REGISTER

Original Filed Nov. 25, 1959 3 Sheets-Sheet 1

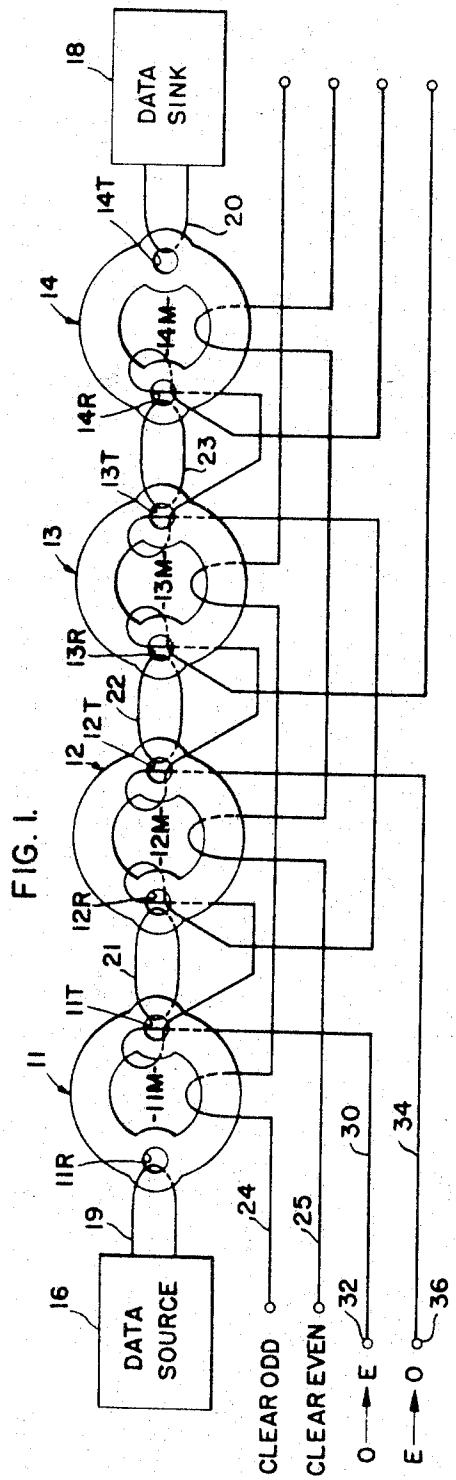


FIG. 1.

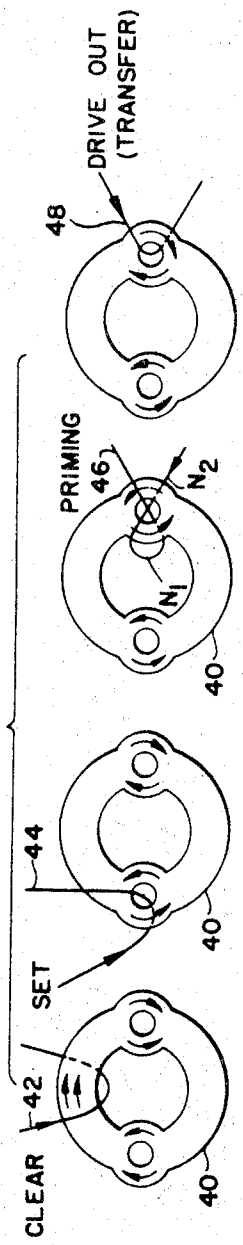


FIG. 2.

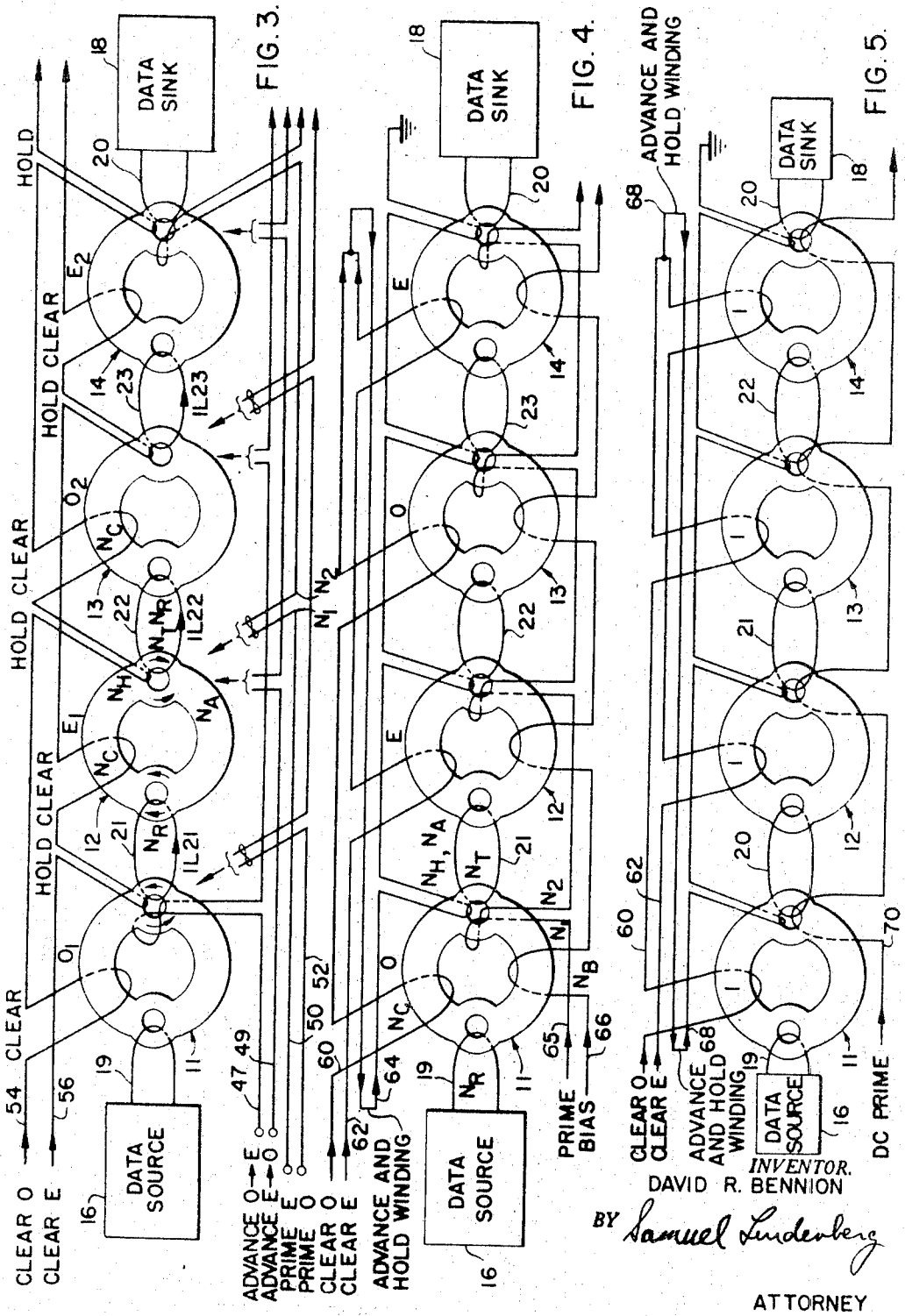
FIG. 2A. FIG. 2B. FIG. 2C. FIG. 2D.

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SHIFT REGISTER

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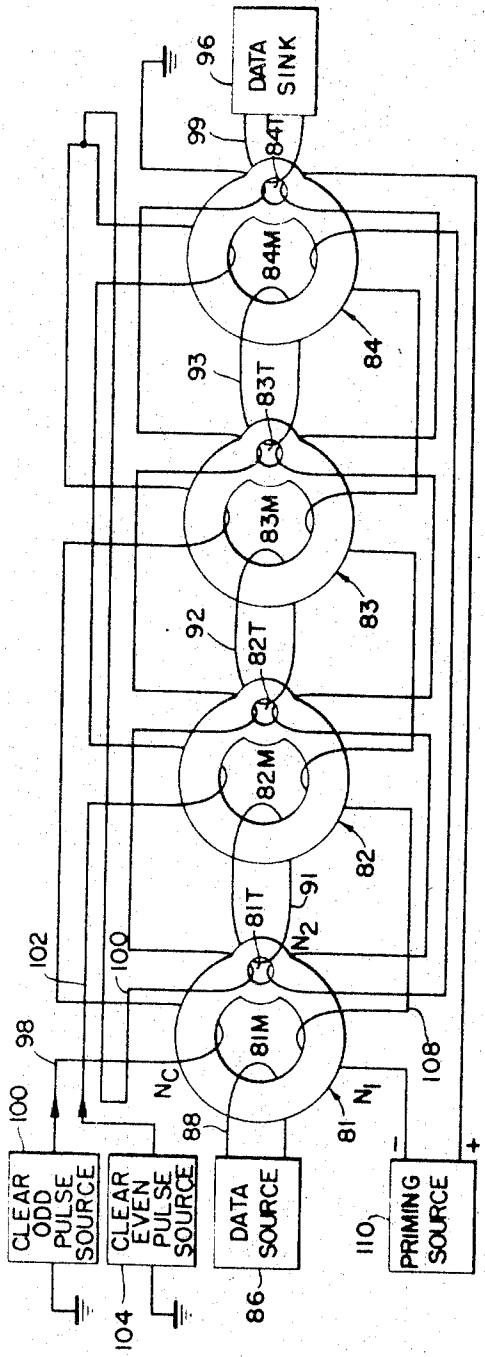


FIG. 6.

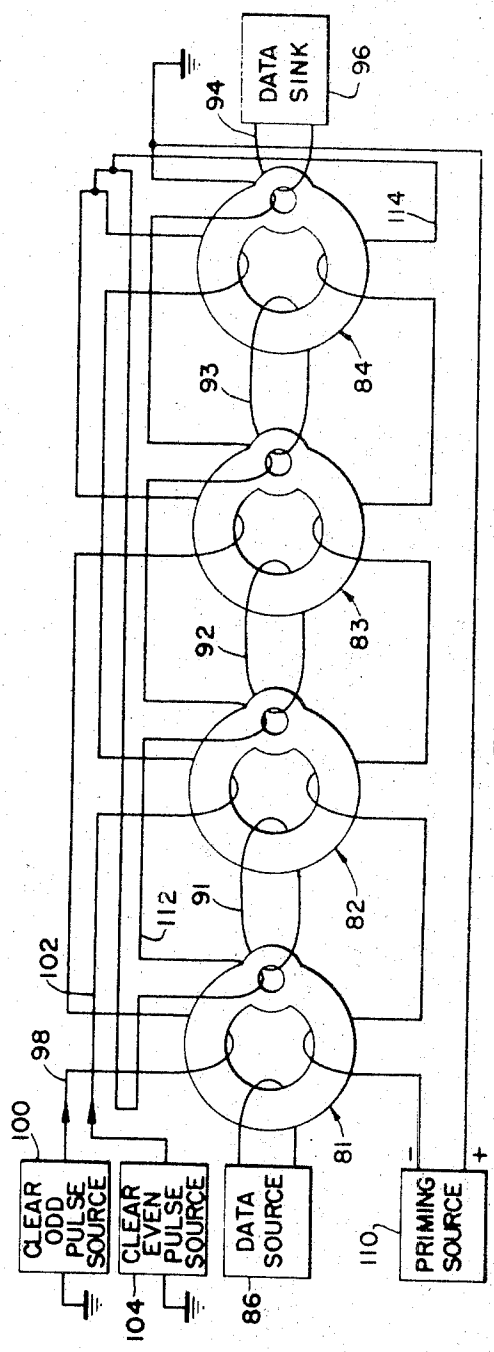


FIG. 7.

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3,323,113

SHIFT REGISTER

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Original application Nov. 25, 1959, Ser. No. 855,335, now Patent No. 3,125,747, dated Mar. 17, 1964. Divided and this application July 1, 1963, Ser. No. 291,995

7 Claims. (Cl. 340—174)

This application is a division of application Ser. No. 855,335, filed Nov. 25, 1939 now Patent No. 3,125,747 by this inventor.

This invention relates to magnetic-core shift registers and, more particularly, to improvements therein.

In articles by H. D. Crane, entitled "A High-Speed Logic System Using Magnetic Elements and Connecting Wire Only," found in The Proceedings of the I.R.E., volume 47, pp. 63 through 73, January 1959, and also by H. D. Crane and D. R. Bennion, entitled "Design and Analysis of MAD Transfer Circuitry," Proceedings of the Western Joint Computer Conference, March 1959, there are described shift registers using multiaperture cores. These cores are toroidal in shape and, besides a main toroidal aperture, may have two other apertures in the material of the toroidal ring. One of these may be designated as the transmit aperture, and the other as the receive aperture. While the operation of shift registers, made as described in these articles, is satisfactory, it has been found that the drive currents required to achieve such satisfactory operation must be closely regulated. It appears that there is very little permissible tolerance. In order to achieve the required regulation, an expensive power supply must be provided.

Accordingly, an object of the present invention is to provide a magnetic-core shift register, using multiaperture cores, where a wider variation in drive currents can be tolerated than has occurred heretofore.

Another object of the present invention is to provide an improved magnetic-core shift register, using multiaperture cores, which are simpler and more inexpensive to make.

Still another object of the invention is to simplify the windings of a magnetic-core shift register.

Yet another object of the present invention is the provision of a novel method and means for operating a multiaperture-core shift register whereby an improved operation therefor is achieved.

These and other objects of the invention may be effectuated by causing an effect, hereafter called "priming," in those of the magnetic cores in a shift register which are in their set state of magnetic remanence, before transferring this set state to the succeeding core. For an explanation of "priming" let it first be assumed that all the flux in a core circulates in one direction, for example, clockwise. This is commonly called the "clear" state. When a multiaperture core is said to be in its "set" state, it is usually understood that part of the flux therein circulates in the clockwise direction, and the remainder in the counterclockwise direction. This is achieved by applying a magnetomotive force to the receive aperture of the multiaperture core which exceeds a certain critical value required to effectively reverse some of the flux about the main aperture of the core from a clockwise to a counterclockwise direction. As a result, the flux conditions at the transmit aperture are such that the flux in the core material between the transmit aperture and the main aperture (commonly called the inner leg of the core) is represented as circulating in a counterclockwise direction. The flux in the core material between the transmit aperture and the outside of the

core (commonly called the outer leg of the core) may be represented as circulating in a clockwise direction. By priming is meant that a magnetomotive force is applied to the material of the core surrounding the transmit aperture, whereby the flux in the material around the transmit aperture is reversed in a direction from that which exists when the core is in its initial set state. The use of priming in the operation of the shift register enables a widening of the tolerances required for the driving current, as well as a simplification of the wiring of the shift register.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a circuit diagram of a shift register employing multiaperture cores which is shown for the purpose of assisting in an understanding of this invention;

FIGURES 2A, 2B, 2C, 2D, are representations of cores with different flux directions, shown also to assist in an understanding of this invention;

FIGURE 3 is a schematic diagram of an embodiment of this invention;

FIGURES 4 and 5 are schematic diagrams of further embodiments of the invention; and

FIGURES 6 and 7 are schematic diagrams of still further embodiments of the invention.

FIGURE 1 is a schematic circuit diagram of a shift register of the general type described in the previously mentioned articles. A brief description of this type of shift register will be provided, since it is believed that it will afford both a better understanding as well as an appreciation of this invention. The shift register is composed of a plurality of magnetic cores **11**, **12**, **13**, **14**, only four being shown as representative of the plurality. As is known, two cores are provided for each bit of data which it is desired for the shift register to store. The cores in the shift register are in a sequence, since the operation thereof is serial. The first, third, etc., cores are usually designated as the odd cores, and the second, fourth, etc., cores are usually designated as the even cores. Thus, for storing each data bit there are provided an odd core **11** and an even core **12**. Input to the shift register is obtained from a data source **16** over an input coupling winding **19**, and the output from the shift register is received by a data sink **18**, using an output coupling winding **20**.

Each magnetic core in the shift register is substantially toroidal in form and will have a main aperture **11M**, **12M**, **13M**, **14M**, a receive aperture **11R**, **12R**, **13R**, **14R**, and a transmit aperture **11T**, **12T**, **13T**, **14T**. A transfer winding **21**, **22**, **23**, is provided for inductively coupling an odd core to an even core and for inductively coupling an even core to an odd core. The manner of coupling is to have the transfer winding pass through the transmit aperture of the preceding core in the sequence and then through the receive aperture of the core to be coupled to the preceding core.

In order to clear all the odd cores to a condition to receive information, current is applied from a first current source **21** to a clear-odd winding **24**, which is inductively coupled to all the odd cores in the shift register sequence by being passed through their main apertures. Similarly, in order to clear all the even cores in the shift registers to be in condition for receiving data, current is applied from a second current source **23** to a clear-even winding **25**, which is inductively coupled to all the even cores by being passed through their main apertures.

A "floating" coupling-loop arrangement is shown for transferring data between cores. Data is simultaneously transferred from all the odd cores in the shift registers to all the even cores. To effectuate this an odd-to-even advancing winding **30** is employed. By way of illustration, this winding **30** extends from an advance-current source **32** through the transmit aperture **11T** of the core **11**, then around the leg of the core defined by the material between the transmit aperture and the main aperture (hereafter called the inner leg) through the transmit aperture again, and then is extended to the receive aperture of the succeeding core **12**. The winding passes through the receive aperture **12R** of the core **12** and then back through the main aperture and around the inner leg to pass through the receive aperture **12R** again, and then on to the transmit aperture **13T** of the next odd core **13**. The winding is thereafter coupled to the transmit aperture of this odd core and again to the receive aperture of the succeeding even core in the manner described for the respective transmit and receive apertures of the cores **11** and **12**. This type of coupling of the odd-to-even advance winding **30** is made to all the cores in the shift register. The manner of coupling the winding **30** to the cores, as set forth in the previously mentioned article by Crane and Bennion, provides both a transformer coupling to the transfer winding which couple an odd to an even core, and also biases the cores so that the value of current required to achieve the critical switching value is reduced.

The windings required for advancing data bits from the even cores to the odd cores is the same as has been described for advancing data bits from the odd cores to the even cores. An even-to-odd advancing winding **34** extends from an advance-current source **36** in succession to the transmit aperture **12T** of an even core **12** and then to the receive aperture **13R** of an odd core **13**. The manner of coupling to the even and odd cores via their transmit and receive apertures is the same as has been just described for the odd-to-even advance winding **30**.

In the discussion of the operation of the shift register shown in FIGURE 1, consideration should also be given to FIGURES 2A and 2B, which represent the various magentic-flux patterns which occur in the cores in the course of the operation of the shift register. For example, considering the core **40**, represented in FIGURE 2A, the arrows adjacent the transmit and receive apertures represent the flux pattern which occurs in a core which has been driven to its clear state by the clear winding, for example, **42**, passing through the main aperture of the core **40**. This is represented by the arrows on both sides of the receive and transmit apertures, which indicates that the flux in the inner and outer legs circulate in the clockwise direction around the main aperture.

Thus, let it be assumed that in FIGURE 1 the clear-odd winding **24** has had current applied thereto, whereby all the odd cores are driven to their clear states. It should be noted at this time that a core which is in its clear state is in a condition which represents storage of a zero data bit. Assume, further, that it is desired to enter a one data bit from the data source **16** into the first core **11** in the shift register. A magnetic core which is driven to its one-representative state of remanence is said to be in the set state. The condition assumed by the flux in a core driven to its set state is represented by FIGURE 2B. Upon the application of a sufficient current to the input winding **19**, which is coupled to the receive aperture of the core **11** in FIGURE 1, a flux reversal occurs in a path which passes around the main aperture. Essentially, the flux has reversed in a path which includes the outer leg adjacent the receive aperture and also in a path which includes the inner leg adjacent the transmit aperture. The flux in the inner leg of the core adjacent the receive aperture and in the outer leg of the core adjacent the transmit aperture remains in the same direction as before.

The mechanism for effectuating this flux switch is a simple one. The current which flows in the winding threaded through the receive aperture must have a sufficient amplitude, or the magnetomotive force applied to the core through its receive aperture must be sufficient to effectuate a flux reversal of the type just described about the main aperture. It has been found that a critical value for this magnetomotive force exists which must be exceeded in order for the flux reversal to occur. If this magnetomotive force is not exceeded, then the application thereof to the core causes substantially no change in the core and it remains essentially in the condition shown in FIGURE 2A.

The mechanism for entering data bits essentially has just been described. The data source **16** supplies a current to the coupling winding **19**, which, if less than the required critical value, effectuates no change in the flux pattern existing in the core **11**. If it exceeds the critical value, then the core **11** is driven to its set condition.

The clear-even winding **25** is then excited. This causes all the even cores to be driven to their clear states. Next the odd-to-even advance winding **30** is excited by current. The amplitude of this current is such as to cause a magnetomotive force a little less than or equal to, but not exceeding, the critical value required to drive core **12** to its set state. If core **11** has remained in its clear, or zero, storage state in response to the data entered from the source **16**, then effectively the core **11** will remain undisturbed, as will core **12**. Thus, a zero can be said to have been transferred from the odd to the even core. The current applied to the advance winding is in a direction to cause a flux reversal about the transmit aperture of the core to which the winding is coupled. However, when this core is in its clear state, a flux reversal can only occur about its main aperture, and since the applied magnetomotive force does not exceed the required critical value, no flux reversal occurs.

When a core is in its set state, however, a flux reversal about the transmit aperture can occur by the application of a magnetomotive force which is less than the critical value, or less than the value required to cause a flux reversal about the main aperture. As a result, with core **11** in its set state, the current applied to the advance winding can cause a flux reversal about the transmit aperture of the odd core **11**. This causes a voltage to be induced in the transfer winding which adds current to that already flowing, whereby the critical value of current required to cause a switching of flux about the main aperture of the core **12** is exceeded. Core **12**, as a result, will be driven to its set condition, represented by FIGURE 2B.

After a clearing operation of the odd cores, effectuated by exciting the clear-odd winding **24** again, the advance even-to-odd winding **34** is excited to transfer the data bit in core **12** to the odd core **13**. Core **11** can also at this time have a new data bit entered thereinto. It will be appreciated that by successive activation of the windings, data can be transferred from the odd to the even cores, then from the even to the odd cores, and finally shifted out of the shift register.

In accordance with this invention, assume that, as shown in FIGURE 2C, each magnetic core has coupled to its transmit aperture a priming winding **46**. This winding effectively is coupled to the transmit aperture with a figure **8** arrangement, which is similar to the manner in which the advancing windings are shown coupled to the transmit or receive apertures in FIGURE 1. The number of turns of this priming winding around the inner leg is designated by **N1** and around the outer leg by **N2**. Assume that a current is caused to flow in the priming winding **46** in a direction to reverse the flux around the transmit aperture as represented in FIGURES 2C, without affecting the flux around the main aperture. As previously indicated, this can be done with a current which is less than the critical value when a core is in the set

state. When a core is in a clear state, then the priming current is insufficient to cause undesired flux reversal. As shown in FIGURE 2C, the flux around the transmit aperture circulates in a counterclockwise direction when the core is primed. As shown in FIGURE 2B, the flux around the transmit aperture circulates in a clockwise direction when the core is not primed. The application of current to transfer winding **48** (FIGURE 2D) will cause a flux reversal about the transmit aperture, exactly as in the situation where the core is set. However, the flux about the transmit aperture now circulates in a clockwise direction, as shown in FIGURE 2D, exactly as is the case when the core is initially set.

From the above description, it should be appreciated that one operation of the shift register in accordance with this invention will require that after a core is driven to its set state, which may be considered as one wherein the flux around the transmit aperture circulates in a clockwise direction, an excitation is applied to a priming winding to effectuate priming, whereby the flux around the transmit aperture is reversed to circulate in a counterclockwise direction. One arrangement for performing this operation is shown in FIGURE 3, which is a schematic diagram of an embodiment of this invention. The structures which are similar to the ones shown in FIGURE 1 and which perform the identical functions bear the same reference numerals. The advancing windings **47**, **49** may be coupled to the respective odd and even cores, either in the manner shown in FIGURE 1, or in any other suitable manner. However, the polarity of the coupling must be such as to result in a clockwise flux switch about the transmit aperture when these windings are excited. To preserve clarity in the drawing, a suitable manner of coupling the advancing windings to the transmit apertures is exemplified on core **11**. It will not be shown for the other cores, but will be represented by line endings coupled by an arrow. A prime even-core winding **50** is inductively coupled to the transmit apertures of all the even cores in the manner shown in FIGURE 2C for the winding **46**. The actual coupling of this winding to the transmit apertures is shown on core **20**, but for preserving simplicity in the drawing is represented by a figure-eight looped about the winding ends. Similarly, a prime odd-core winding **52** is coupled to the transmit aperture of all the odd cores. The manner of coupling is that shown in FIGURE 2C for the winding **46**. The clear-odd core winding **54** will couple in sequence to an odd core through its main aperture and then to an even core around the outer leg adjacent its transmit aperture, and thereafter to the succeeding odd core through its main aperture, and thence to the succeeding even core around the outer leg adjacent its transmit aperture. Similarly, the clear-even core winding **56** in sequence will couple to the transmit aperture of an odd core, and then through the main aperture of an even core to the successive odd-core transmit aperture, etc. As will become more clear as this explanation progresses, the portion of the clear winding coupled to the transmit apertures serves to provide a holding action on a core against the "setting" effect caused by clearing the succeeding core to which its transfer winding is coupled.

The sequence of excitation of the various windings shown in FIGURE 3 is shown in Table I below:

TABEL I

Clock Sequence	Even core 12		Odd core 13		Loop currents	
					I_{L21}	I_{L22}
Advance O→E 47	↓↑	↑↓			Positive	
Clear O 54	↓↑	↑↓	↑↑	↓↓		
Prime E 50	↓↑	↓↑	↑↑	↓↓		Negative.
Advance E→O 49	↓↑	↑↓	↓↑	↑↓		Positive.
Clear E 56	↑↑	↓↓	↓↑	↑↓	Positive	
Prime O 52	↑↑	↓↓	↓↑	↓↓		

For the purpose of this table, it is assumed that the core **11** has been driven to its set condition and thereafter primed. Adjacent the sequence of excitation of the various windings are two columns with arrows under the heading "even-core **12**" and two further columns with arrows under the heading "odd-core **13**." The arrows in the first of the respective two columns represent the direction of flux circulation in the outer and inner legs adjacent the receive apertures. The arrows in the second of the respective two columns represent the direction of flux circulation in the inner and outer legs adjacent the transmit aperture.

The table also shows the direction of the currents which occur in the respective transfer windings **21** and **22**. These currents are respectively designated as I_{L21} and I_{L22}. The meaning of the words "positive" and "negative" will become more clear as this explanation progresses.

Upon excitation of the advance odd-to-even winding, the set state of core **11** is transferred into core **12**. The flux in core **12** will then have the flux path represented under the column heading "even core" in the first line. A current flows in the transfer winding **21**, as indicated under I_{L21} in a positive direction. Thus, this current is in a direction which tends to set core **12**, a desirable operation at this time. The clear-odd core winding **54** is next excited. As shown, this leaves the even core unaffected in its set state, but drives the odd core **13** to its clear state. The direction of the arrows in the second column show this condition.

The next winding to be excited is the prime even-core winding **50**. This operates to reverse the state of flux in the inner and outer leg adjacent the transmit aperture of all the even cores. However, only those of the even cores which have been set will have such a flux reversal. A negative current is induced in the transfer winding **22** as a result of the current flowing through the prime even-core winding. This current is in a direction and has an amplitude which will not affect the flux states of the odd cores or of the even cores which are in their clear state. Thereafter, the even-to-odd core advance winding **49** is excited. This causes core **13** to be driven to its set state and core **12** to assume a flux condition identical with that it assumed when first driven to its set condition. A positive current flows in the transfer loop **22**, which is desirable to effectuate the setting of the core **13**.

The next winding to be excited is the clear-even core winding **56**. In being cleared, there is a flux reversal which occurs in the outer leg of the core **12**, adjacent the receive aperture, as a result of which a positive current is made to flow in the transfer winding **21**. This current can attain an amplitude sufficient to result in a spurious

setting of the odd core to which the transfer winding **21** is coupled. To overcome this, the clear-even core winding **56** is coupled to the transmit aperture of the odd cores. The sense of the coupling is such as to oppose the effects which the induced positive current in the transfer winding have on the odd cores. These "hold" couplings of the clear windings effectively prevent the spurious setting of the odd cores. Operation is possible without them, but this places a low upper limit on the clear pulse amplitude and a high lower limit on the pulse width, resulting in poor current tolerances and lowered speed of operation.

The magnetomotive force employed on the inner leg prime winding, the turns of which are represented by N1 in FIGURE 2C, is limited to the main aperture threshold in order to avoid partial unsetting of a core during the priming. The outer leg priming winding magnetomotive force applied by the turns represented by N2, is also limited to the main aperture threshold value to avoid spurious setting of elements in the zero state. Hence, the total maximum possible priming magnetomotive force is a value equal to twice the critical value. Operation is possible with any ratio of N1 turns to N2 turns, and in principal with any ratio of turns of the portion of the transfer winding coupled to the transmit aperture (N_T) to the number of turns of the portion of the transfer winding coupled to the receive aperture (N_R), which is greater than unity, but the minimum lower limit on priming pulse width is obtained when $N1=N2$ and $N_T=2N_R$, with the resistance of the transfer-loop winding R_L at its corresponding upper limit (the latter determined by flux gain considerations). This condition relates closely to an upper limit on a bit rate for the system, since the time required for priming is the major limitation on bit rate.

At this time it may be stated that the basic distinction between the type of register shown in FIGURE 1 and the one in FIGURE 3 may be sated as follows: In the FIGURE 1 type register, flux always switches during a given drive pulse in either zero or two of the legs or paths linking a given coupling loop. In the FIGURE 3 type of register, flux switches in only one leg linking a coupling loop during some phases of the operation. For example, in FIGURE 3 such is the case for the transfer loop **22** during the excitation of the prime even-core winding **50** and clear-odd core winding **54**. The resulting $N_T\phi_E$, or $N_R\phi_O$ EMF's (where ϕ_E and ϕ_O, respectively, represent the flux changes in the even and odd cores) must be balanced by R_LI_L voltage drop, where I_L is the transfer winding current and R_L is the transfer winding resistance. As a result, R_L (which can be controlled by diameter, length, and composition of the coupling loop wire) plays a role of a first order of importance, in the system shown in FIGURE 3, but is considerably reduced in importance in the system shown in FIGURE 1, provided it is sufficiently low in value.

FIGURE 4 represents an embodiment of the invention wherein the wiring is considerably simplified over that shown in FIGURE 3. Inspection of the sequence of flux changes shown in Table I above during a complete clock cycle will show that the clear-odd-core winding **54** and the clear-even-core winding **56** may be respectively pulsed at the same times as the odd-to-even advance winding **47** and the even-to-odd advance winding **49** are respectively pulsed. Since the hold portion of the clear-odd-core winding **54** and clear-even-core winding **56** are respectively substantially identical to the advance-winding couplings on the cores, a single winding coupled to the transmit aperture on each core may be used for the function of advancing and holding, providing the number of turns for this holding winding is made equal to the number of turns which the transfer winding has at this transmit aperture. With these considerations, the wiring arrangement shown in FIGURE 4 may be obtained.

The clear-odd-core winding **60** extends to and through the main aperture of every odd core **11, 13** in the shift register. Similarly, the clear-even-core winding **62** extends through every main aperture **12, 14** of the even cores in the shift register. After the respective clear-odd and clear-even windings **60, 62**, have passed through the main apertures of the respective odd and even cores, they are joined and connected in series with what may be termed an advance-and-hold winding **64**. This advance-and-hold winding is coupled to the transmit aperture of every core in the shift register. Thus, it is excited when either the clear-odd-core winding **60** or the clear-even-core winding **62** is excited.

A single priming winding **65** is inductively coupled to the transmit apertures of every core in the shift register sequence. Since the magnetomotive force applied for priming never exceeds the critical value required to reverse flux around the main aperture, these priming magnetomotive forces may be applied to the odd cores when the even cores are being primed, and to the even cores when the odd cores are being primed, and, hence, to all cores simultaneously. If desired, the priming can be applied to all cores continuously, provided compensating adjustment of clear currents is allowed to balance out the additional magnetomotive force due to continuous priming current. That is why a single priming winding linking all the elements may be used. A shift register excitation or clock sequence may be employed, as shown in Table II below:

TABLE II

For Pulsed Priming	For D.C. Priming
Cl O Prime Cl E Prime	Cl O Cl E

With the windings arranged as in FIGURE 4 the shift register may be driven by a sequence of four windings excitations at most, and these may be obtained using only three pulse sources, since two of the excitations consist of priming. With an appropriate adjustment of the number of turns, a direct current may be employed for priming which results in a two-phase sequence. Such an arrangement is shown in FIGURE 5.

The clear-odd and clear-even windings **60, 62**, are coupled to the cores **11, 12, 13 14** in the same manner as is shown in FIGURE 4. An advance and hold winding **68** is coupled to the transmit apertures of all the cores. The advance-and-hold line is connected in series with the clear-odd and clear-even windings, and thus is driven when either one of these windings is driven. There is also provided a priming winding **70**, which is inductively coupled to all the transmit apertures of the cores in the shift register. FIGURES 4 and 5 are essentially the same when the bias winding **66** in FIGURE 4 is omitted. The excitation sequence used when direct-current priming is employed is shown in Table II above.

Referring back to FIGURE 4, another winding may be provided optionally, which is called the bias winding **66**. This winding passes in sequence through the main apertures of all the cores. Its purpose is to enable the application of a positive (set direction) bias on all receiving cores during the transfer of data between cores in order to reduce the transfer-winding current required and accordingly the amplitude of advance magnetomotive force needed. The fact of the application of the bias magnetomotive force to all the transmitting elements at the same time only affects the choice of the value of N_C (number of clear coil turns). This bias line may be connected in series with the advance-and-hold line, in which case there is a fairly strict upper limit to the amplitudes of the clear-odd and clear-even core winding excitations. If direct-current bias is used, the values of N_1 and N_2 must be adjusted.

It is to be noted that when direct current is used for priming as shown in FIGURE 5, a prime winding on

the inner leg has the effect of a negative direct-current receiver bias. This must either be cancelled out by a pulsed bias current applied to the inner leg adjacent the transmit aperture or an additional constraint must be accepted on the values of the bias magnetomotive force F_B and the priming magnetomotive force F_p, which constraint may be expressed as $F_B+F_P \leq F_2$, where F_2 is the main aperture threshold magnetomotive force and where $-F_2<F_B<F_2$. The prime winding **70** in FIGURE 5 is shown coupled to the outer legs only of the respective cores, resulting in $F_B=D$, $F_P \leq F_2$.

If the hysteresis loop of the core material were perfectly square, then in principle there would be no upper limit on the amplitude of the pulse applied to the advancing windings (nor on the speed of actual transfer), since by reason of the priming of the cores and advance pulse serves to change the flux orientation in a core toward a clear direction. However, because of elastic-flux coupling in the transmitting core (i.e., flux which resets as soon as the driving magnetomotive force is removed), some loop current will flow during zero transfer. Hence, for sufficiently high current (and rate of change of current), this current will cause enough inelastic flux change in the receiver to start zero build-up and hence impose an upper limit on advance current. Upper limits of at least three times the lower limit have been obtained in operating circuits.

There is also no upper limit on clear-pulse amplitude, provided the ratio N_H/N_C (holding-coil turns/clear-coil turns) is greater than a certain value (about 2 for $N_T/N_R=2$).

Using the priming technique in accordance with the teachings of this invention enables further structural simplification to be achieved. Consideration of Table I reveals that no change in flux direction occurs in the inner leg of a core adjacent the receive aperture during a complete cycle of operation. This means that the receive aperture can be omitted from a core used in accordance with this invention. As a result, not only may a simpler core be used, but a simpler fabrication is provided for the register, since the transfer winding previously required to be inserted through the small receive aperture may now be inserted through the large main aperture. Also, with the elimination of the receive aperture, a lower drive current may be employed, since losses due to elastic flux changes around the receive aperture are eliminated. Thus, the embodiments of the invention shown in FIGURES 3, 4 and 5 may be constructed using magnetic cores without the receive apertures. The transfer winding in each case may be wound through the transmit aperture and then through the main aperture of the succeeding core.

FIGURE 6 shows an embodiment of the invention wherein the cores **81, 82, 83, 84**, do not have receive apertures but do have main apertures **81M, 82M, 83M, 84M** and transmit apertures **81T, 82T, 83T, 84T**. A data source **86** is coupled to the first core **81** by an input winding **88**, which passes through the main aperture of the core **81**. A transfer winding **91, 92, 93**, respectively couples the cores **81, 82, 83, 84** for transmission of data from the odd to the even, to the odd cores. Each transfer winding passes through the transmit aperture of the transmitting core and the main aperture of the receiving core. An output winding **94** couples the transmit aperture **84T** to a data sink **96**.

A clear-odd winding **98** has the required current pulses applied from a clear-odd pulse source **100**. The clear-odd winding **98** is coupled to the odd cores through their main apertures. A clear-even winding **102** has the required current pulses applied from a clear-even-pulse source **104**. The clear-even winding **102** is coupled to all the even cores through their main apertures. The ends of the clear-even and clear-odd windings **98, 102**, are connected together and to an advance-and-hold winding **106**, which is serially coupled to all the core-transmit apertures **81T, 82T, 83T, 84T**. The priming winding **108** is driven by current from a priming source **110**. As an alternative to the coupling arrangement of the priming winding to the cores, which is shown in FIGURE 4, the arrangement in FIGURE 6 may be used. The winding couples to all the main apertures in sequence and then couples to all the transmit apertures in the same sequence. The turns taken through the main apertures are the N_1 turns and those through the transmit apertures are the N_1 and N_2 turns.

The arrangement of the windings in FIGURE 6 is substantially the same as those in FIGURE 4, except for the specified differences. However, the operation of the register or the sequence of winding excitation is identical with that described for FIGURE 4. A pulsed or direct-current priming bias may be used with polarity applied as indicated in the drawing.

Another winding simplification is shown in FIGURE 7. In this arrangement, advantage is taken of the fact that the advance-and-hold winding can be used as part of the priming winding. In FIGURE 7, similar functioning apparatus to that shown in FIGURE 6 has been given the same reference numerals.

The clear-odd core and clear-even core windings **98, 102**, after passing through the main apertures of the respective odd and even cores, are connected together and to one end of the advance-and-hold winding **122**, which passes in succession through each one of the transmit apertures. The other end of the advance-and-hold winding is connected back to the clear-odd and clear-even pulse sources. The connected-together end of the celar-odd core and clear-even core windings **98, 102** are also connected to a portion of the priming winding **114**, which passes through all the core main apertures in reverse order back to the priming power source **110**. The other end of the advancing winding is also connected back to the priming source.

Excitation by either the clear-odd core or clear-even core pulse source of the respective windings operates as before to clear and advance data in the odd or even cores and to prevent spurious setting caused by voltages induced in a transfer winding by the clearing of a core. Excitation of the priming winding by the source **110** sends current through the winding **114** and the winding **112**, serving now as a complete priming winding. The usual well known precautions are required to maintain isolation between the clear-odd pulse source, the clear-even pulse source, and the priming source.

There has accordingly been shown and described herein a novel, useful arrangement for a shift register wherein the complexity of the winding is reduced and the operational tolerances on drive currents may be increased, thereby reducing the cost of the power supply required to be used.

I claim:

1. An improved shift register comprising a plurality of magnetic cores arranged in a sequence and being successively designated as odd and even cores in said sequence, each of said cores having a clear and a set state of magnetic remanence and being drivable therebetween, each of said cores having a main aperture and a transmit aperture, a plurality of closed loop transfer windings a different one of which inductively couples a different pair of cores and is coupled to a transferring core through its transmit aperture, means for priming those of said plurality of cores which are in their set state of magnetic remanence including priming winding means having a first priming winding inductively coupled to each odd core in said sequence, and a second priming winding inductively coupled to each even core in said sequence, said first and second priming windings each being coupled to a respective core by being passed through the transmit aperture of said core, then back through the main aperture of said core, and then through the transmit aperture of

said core again, means for transferring the remanence state of alternate cores in said sequence to the remaining cores in said sequence, including a first advance winding inductively coupled to all the odd cores in said sequence by their transmit apertures, and a second advance winding inductively coupled to all the even cores in said sequence by their transmit apertures; and means for driving all said cores to their clear state of magnetic remanence including a first clear winding inductively coupled to all the odd cores in said sequence by their main apertures and to all the even cores in said sequence by their transmit apertures, and a second clear winding inductively coupled to all the even cores of said sequence by their main apertures and to all the odd cores in said sequence by their transmit apertures.

2. An improved shift register comprising a plurality of magnetic cores arranged in a sequence and being successively designated as odd and even cores in said sequence, each of said cores having a clear and a set state of magnetic remanence and being drivable therebetween, each of said cores having a main aperture and a transmit aperture, a plurality of closed loop transfer windings a different one of which inductively couples a different pair of cores and is coupled to a transferring core through its transmit aperture, means for priming those of said plurality of cores which are in their set state of magnetic remanence including priming winding means having a first priming winding inductively coupled to each odd core in said sequence, and a second priming winding inductively coupled to each even core in said sequence, said first and second priming windings each being coupled to a respective core by being passed through the transmit aperture of said core, then back through the main aperture of said core, and then through the transmit aperture of said core again, means for transferring the remanence state of alternate cores in said sequence to the remaining cores in said sequence, and means for driving said plurality of cores to their clear state of magnetic remanence including a first clear winding inductively coupled to all the odd cores in said sequence by their main apertures, a second clear winding inductively coupled to all the even cores in said sequence by their main apertures; and wherein said means for transferring the remanence state of alternate cores in said sequence to the remaining cores in said sequence includes an advance winding inductively coupled to all said cores by their transmit apertures, one end of each of said first and second clear windings being connected together and to one end of said advance winding.

3. An improved shift register as recited in claim 2 wherein each of said closed loop transfer windings is wound through the transmit aperture of one core and then through the main aperture of the immediately following core in said sequence.

4. An improved shift register as recited in claim 3 wherein there is included a bias winding inductively coupled to all said cores by their main apertures.

5. An improved shift register as recited in claim 3 wherein each of said closed loop transfer winding is wound through the transmit aperture of one core and

then through the main aperture of the immediately following core in said sequence.

6. An improved shift register comprising a plurality of magnetic cores arranged in a sequence and being successively designated as odd and even cores in said sequence, each of said cores having a clear and a set state of magnetic remanence and being drivable therebetween, each of said cores having a main aperture, a receive aperture, and a transmit aperture, a plurality of closed loop transfer windings a different one of which inductively couples a different pair of cores, means for driving said plurality of cores to their clear state of magnetic remanence including a first clear winding inductively coupled to all the odd cores in said sequence by their main apertures, a second clear winding inductively coupled to all the even cores in said sequence by their main apertures, a data advance winding inductively coupled to all the cores by their transmit apertures, means connecting one end of said first and second clear windings together and to one end of said data advance winding, and a priming winding inductively coupled to all the cores by their transmit apertures.

7. An improved shift register comprising a plurality of magnetic cores arranged in a sequence and being successively designated as odd and even cores in said sequence, each of said cores having a clear and a set state of magnetic remanence and being drivable therebetween, each of said cores having a main aperture, a receive aperture, and a transmit aperture, a plurality of closed loop transfer windings a different one of which inductively couples a different pair of cores, each transfer winding being wound through the transmit aperture of one core and then through the receive aperture of the immediately following core in said sequence, means for driving said plurality of cores to their clear state of magnetic remanence including a first clear winding inductively coupled to all the odd cores in said sequence by their main apertures, a second clear winding inductively coupled to all the even cores in said sequence by their main apertures, a data advance winding inductively coupled to all the cores by their transmit apertures, means connecting one end of said first and second clear windings together and to one end of said data advance winding, and a priming winding, said priming winding having a first and second section, said first section being inductively coupled to all said plurality of cores by their transmit apertures and then connected to said second section, said second section being inductively coupled to all said cores by their main apertures.

References Cited

UNITED STATES PATENTS

2,911,628	11/1959	Briggs	340—174
2,968,795	1/1961	Briggs	340—174
3,045,215	7/1962	Gianola	340—174
3,163,854	12/1964	Engelbart	340—174

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