

April 4, 1961

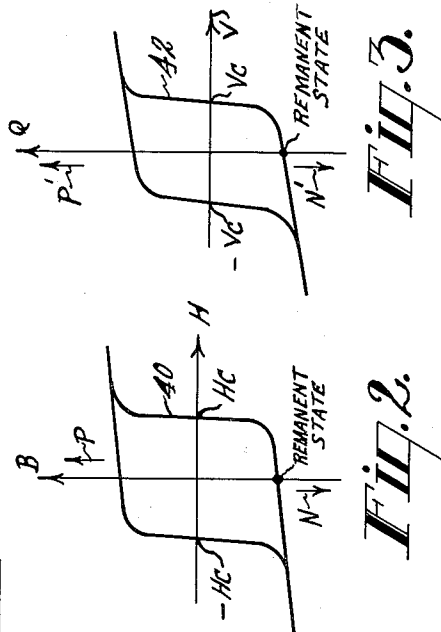
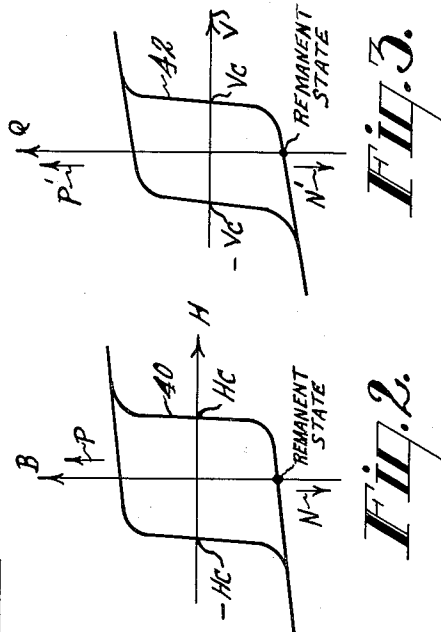
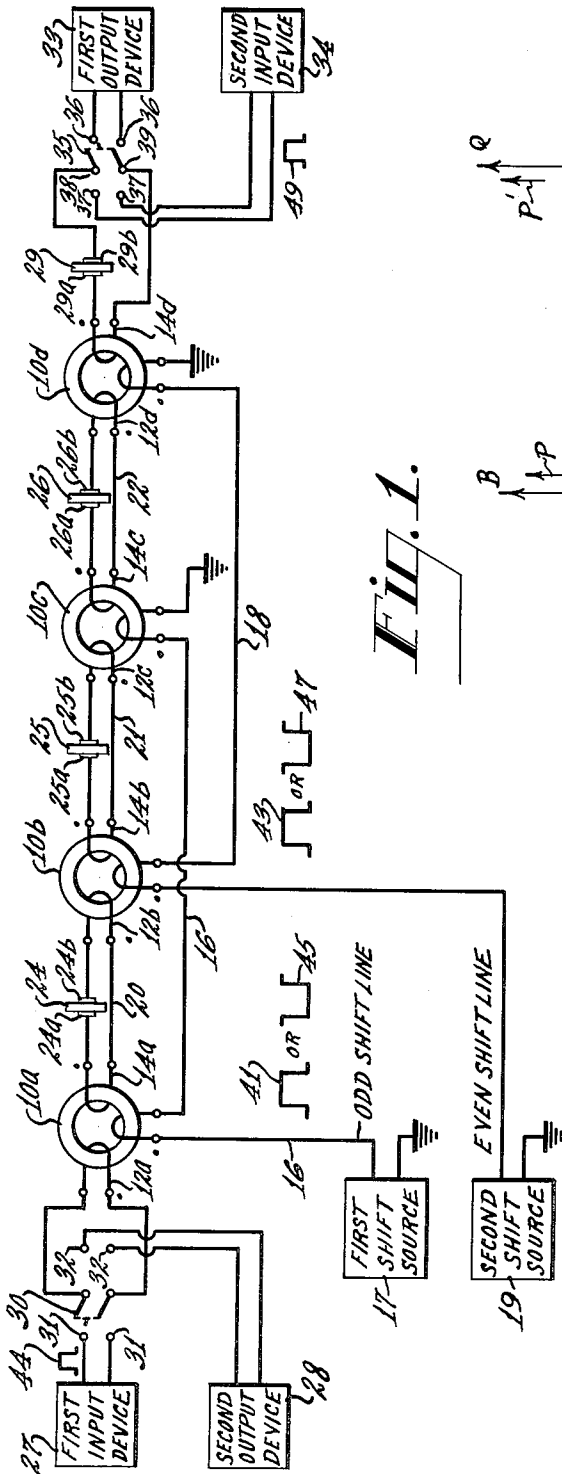
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2,978,682

HYSTERETIC DEVICES

Filed March 20, 1957

5 Sheets-Sheet 1



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5 Sheets-Sheet 2

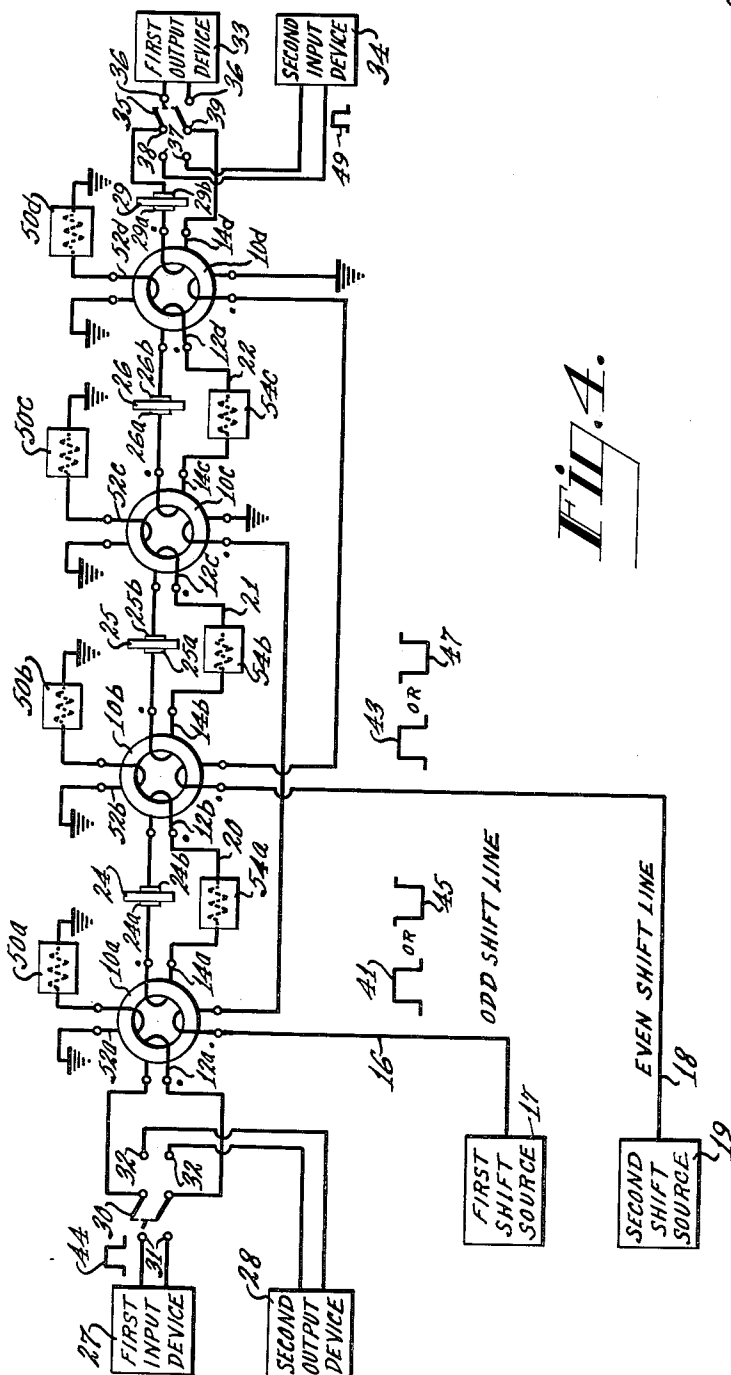


Fig. 4.

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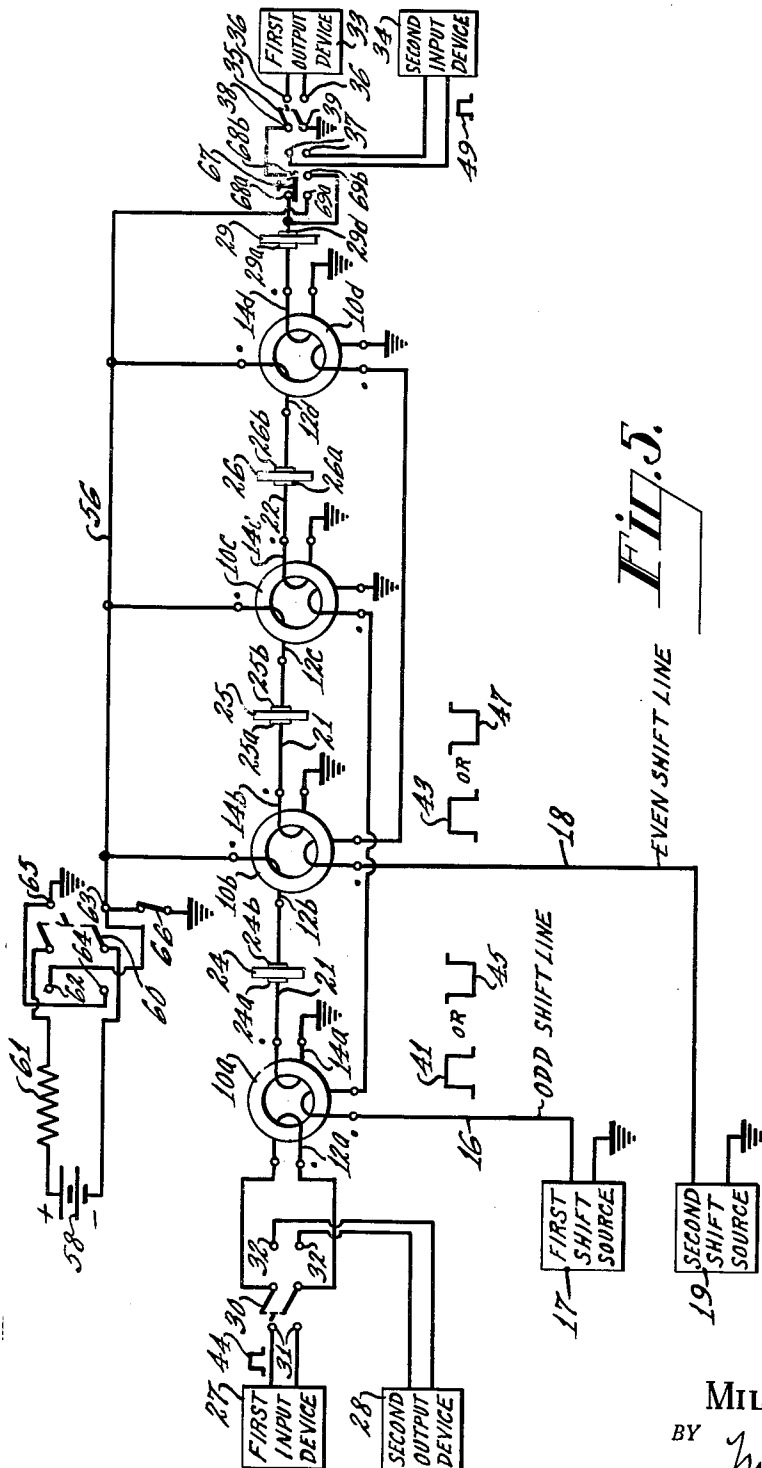
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5 Sheets-Sheet 3



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5 Sheets-Sheet 4

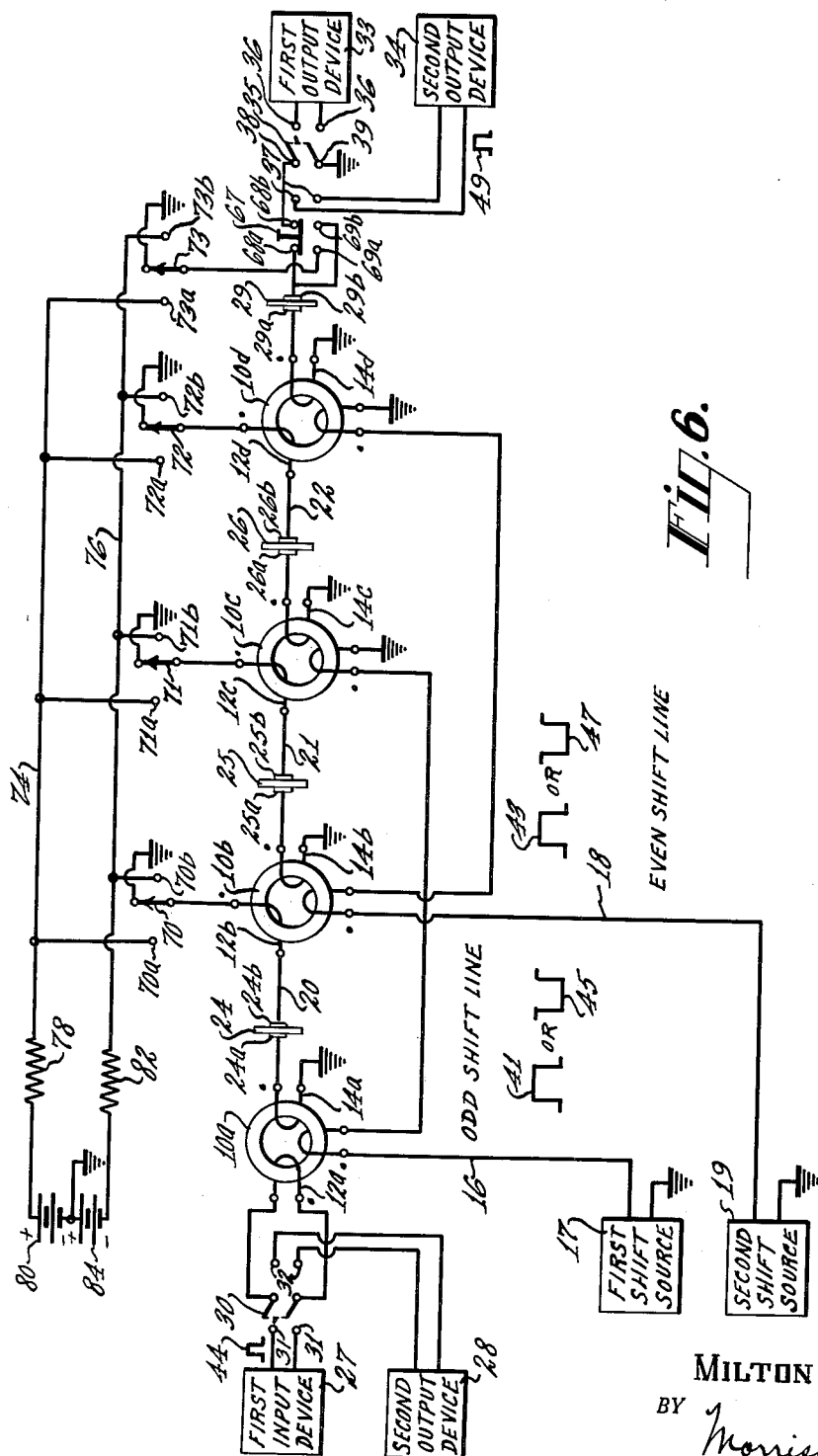


Fig. 6.

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5 Sheets-Sheet 5

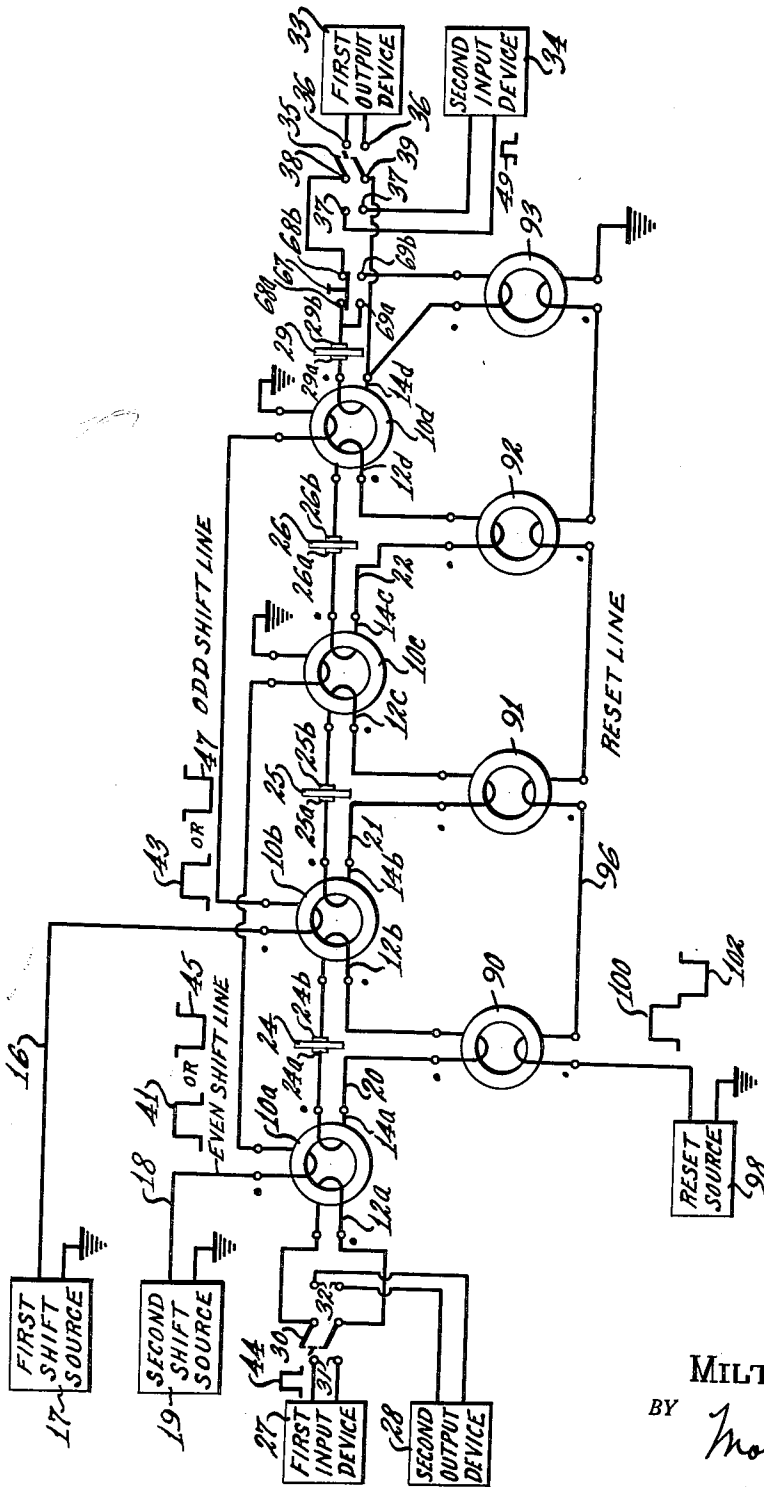


Fig. 7

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HYSTERETIC DEVICES

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14 Claims. (Cl. 340—174)

This invention relates to information handling systems which make use of both magnetic and ferroelectric elements, and more particularly to systems useful as shift registers in which stored signals are successively shifted under the control of shifting signals, and to scaling circuits and counting circuits which are used to provide an output signal after a given number of shifting signals, and the like.

It is an object of the present invention to provide systems of the type set forth in which use is made of the ferroelectric elements in a novel manner.

Another object of the present invention is to provide improved systems of the type set forth, wherein the ferroelectric elements are used in a manner to prevent undesired interactions.

Still another object of the present invention is to provide improved systems as above set forth which make use of ferroelectric elements in a novel manner and which can be operated in either forward or reverse directions in accordance with the polarity of the shifting signals.

According to the present invention, a plurality of cores of magnetic material having rectangular hysteresis loop characteristics are successively interconnected by transfer loops. Each transfer loop includes a condenser of ferroelectric material also having a rectangular hysteresis loop characteristic. First and second shift lines are linked to alternate ones of the cores. A signal stored in one of the cores is successively transferred through the ferroelectric condensers to successively higher order cores by alternately applying shifting signals to the shift windings. The ferroelectric condensers operate to prevent current flow in the transfer loops except when a signal is being transferred between desired ones of the cores.

In the accompanying drawing:

Fig. 1 is a schematic diagram of a device according to the invention, using magnetic cores and ferroelectric condensers;

Fig. 2 is a graph of the hysteresis characteristic for a suitable rectangular hysteresis loop magnetic material useful in explaining the operation of the device of Fig. 1;

Fig. 3 is a graph of the hysteresis characteristic for a suitable rectangular hysteresis loop ferroelectric condenser useful in explaining the operation of the device of Fig. 1;

Fig. 4 is a schematic diagram of a device according to the invention, illustrating various ways of coupling load devices to the elements;

Fig. 5 is a schematic diagram of a device according to the present invention, having means for setting the ferroelectric cells to desired states;

Fig. 6 is a schematic diagram of a device according to the invention, having means for resetting the ferroelectric condensers, and

Fig. 7 is a schematic diagram of another embodiment of a device according to the invention, using an auxiliary magnetic core in each transfer loop.

In Fig. 1, a system according to the invention illustratively has four separate stages. More or less than four stages may be used, if desired. Each stage includes a

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separate one of the magnetic cores 10a, 10b, 10c and 10d. The cores 10 each are made from magnetic material having appreciable remanence, and each may be of rectangular hysteresis loop magnetic material. Certain ceramic material such as manganese-magnesium ferrite, and certain metallic materials such as molybdenum-Permalloy, exhibit the desired characteristics. Each core 10 is provided with an input winding 12 and an output winding 14. For convenience of drawing, the windings are shown as single-turn windings. It is understood, however, that multiturn windings may be used. One shift line 16 links the cores 10 of the odd-numbered stages, and another shift line 18 links the cores 10 of the even-numbered stages. First and second sources 17 and 19 of shift signals are connected respectively to the first and second shift lines 16 and 18. The shift lines 16 and 18, after linking the cores 10, are connected to a source of reference potential, indicated in the drawing by the conventional ground symbol. The shift sources 17 and 19 also are connected to ground. The conventional transformer notation is used to indicate the sense of linkage of the windings to the cores.

Three transfer loops 20, 21 and 22 connect the cores 10 in cascade by connecting the output winding 14 of one core 10 to the input winding 12 of a succeeding core 10. Each of the transfer loops 20, 21 and 22 includes a separate one of the ferroelectric condensers 24, 25 and 26 having respectively the pairs of terminals 24a, b, 25a, b and 26a, b. Any one of the condensers is connected in any one of the transfer loops in series with the output and input windings 14 and 12 of that transfer loop. The a electrode of a condenser is connected to the marked terminal of a transfer loop output winding 14, and the b electrode of any condenser is connected to the unmarked terminal of the transfer loop input winding 12. Each of the condensers has two states of appreciable remanence, and may have a dielectric of substantially rectangular hysteresis loop material. Certain materials, such as barium-titanate, exhibit the desired characteristics.

A first input device 27 or a second output device 28 may be selectively connected across the terminals of the input winding 12a of the lowest order core 10a by means of a first double-pole, double-throw reversing switch 30. The terminals of the input winding 12a are connected to the movable arm of the first reversing switch 30. The output terminals of the first input device 27 are connected to one pair of fixed terminals 31 of the reversing switch 30; and the input terminals of the second output device 28 are connected to the other pair of fixed terminals 32 of the reversing switch 30. By means of a second, double-pole, double-throw reversing switch 35, selectively, the output from the highest order core 10d may be applied to a first output load device 33, or input signals may be applied to the output winding 14d from a second input device 34. The output winding 14d of the core 10d is connected to the movable arm of the second reversing switch 35. The first output device 33 is connected to one pair 36 of fixed terminals of the second reversing switch 35; and the second input device is connected to the other pair 37 of fixed terminals of the second reversing switch 35. A ferroelectric condenser 29 has one electrode 29a connected to the marked terminal of the output winding 14d, and has its other electrode 29b connected to one center terminal 38 of the second reversing switch 35. The other center terminal 39 of the second reversing switch 35 is connected to the unmarked terminal of the output winding 14d. Any suitable electronic switching means can be used for the reversing switches 30 and 35.

A hysteresis curve 40 for a magnetic material suitable for use in the system of Fig. 1 is shown in Fig. 2. A core 10 of Fig. 1 has two remanent states, arbitrarily designated in Fig. 2 as positive P and negative N, in

which the remanent induction B is an appreciable portion of the saturation induction. One remanent state, for example the state P , corresponds to a flux oriented in one direction, for example clockwise, in a core 10 as viewed in Fig. 1; and the other remanent state N corresponds to a flux oriented in the counterclockwise direction in a core 10. Relatively little flux change is produced in a core 10 when it is driven from remanence to saturation along a horizontal portion of the hysteresis curve 32. A positive magnetizing force H , greater than a coercive force H_c changes the magnetization of the core from the state N to the state P . Similarly, a negative magnetizing force greater in amplitude than a coercive force $-H_c$ changes a core from the state P to the state N .

A hysteresis curve 42 plotting charge (Q) against applied voltage (V) for a capacitor having a ferroelectric material dielectric and suitable for use in the system of Fig. 1 is shown in Fig. 3. A condenser having a dielectric of ferroelectric material also has two remanent states, arbitrarily designated as positive P' and negative N' in which the remanent charge is an appreciable portion of the saturated charge. One remanent state P' corresponds to a charge in one direction, say which the electrode a being positive relative to the electrode b of a condenser; and the other remanent state N' corresponds to a charge in the opposite direction with the electrode b being positive relative to the electrode a of a condenser. Relatively little change of charge is produced in a condenser when it is driven by a voltage from remanence to saturation along a horizontal portion of the hysteresis curve 42. An applied voltage of one polarity, for example a voltage making the condenser electrode a positive relative to the condenser electrode b , greater than a coercive voltage V_c changes a condenser from the state N' to the state P' . An applied voltage of opposite polarity, making the condenser electrode b positive relative to the condenser electrode a , greater in amplitude than a coercive voltage $-V_c$ changes a condenser from the state P' to the state N' .

Referring now to Fig. 1, assume that it is desired to shift signals in the forward, or left-to-right, direction from the first input device 27 to the first output device 33. The first input device 27 is coupled to the first stage core 10a by throwing the movable arm of the first reversing switch 30 to the left (as viewed in the drawing), and the first output device 33 is coupled to the last stage core 10d by throwing the movable arm of the second reversing switch 35 to the right, as viewed in the drawing. Assume also that all the cores 10 are magnetized in the same one state, say the state P , and that all the condensers are polarized in the same state, say the state N' .

If, now, a positive shift pulse 41 is applied to the odd shift line 16, the cores 10a and 10c are each driven from remanence in the state P to saturation in the same state P . Accordingly, a relatively small flux change is produced in each of the cores 10a and 10c. These relatively small flux changes each induces a relatively small voltage across the input windings 12a and 12c and the output windings 14a and 14c in a direction to make their marked terminals positive relative to their unmarked terminals. The small, positive voltages at the marked terminals of the output windings 14a and 14c of the cores 10a and 10c are applied between the electrodes of the condensers 24 and 26 of the transfer loops 20 and 22, respectively. The positive voltages at the electrodes 24a and 26a are each in a direction to change the condensers 24 and 26 from their initial state N' to their other states P' . However, these small, positive voltages are each less than the coercive voltage V_c of the condensers 24 and 26. Accordingly, relatively little change of charge is produced in the condensers 24 and 26 and, upon termination of the positive shift pulse 41, the condensers 24 and 26 return to, or very near, their initial remanent conditions in the initial state N' . The input device 27 may

be open-circuited when the shift signals are applied or, if desired, a separate condenser (not shown) may be connected between the first input device 27 and the core 10a input winding 12a. The relatively small voltage induced in the input winding 12c of the core 10c by the positive shift pulse 41 also is in a direction to change the condenser 25 of the transfer loop 21 from the initial state N' to the other state P' . However, this small induced voltage also is less than the coercive voltage V_c of the condenser 25. Therefore, substantially no change of charge is produced in the condenser 25. After the shift pulse 41 terminates, the condenser 25 returns to, or very near, its initial remanent condition in the state N' .

When a positive shift pulse 43 is applied to the even shift line 18, the cores 10b and 10d are driven from remanence in the initial state P to saturation in the state P . The relatively small flux changes produced in the cores 10b and 10d likewise do not produce any significant change in the initial remanent conditions of the condensers 24, 25 and 26 of the coupled transfer loops 20, 21 and 22. No significant changes of charge are produced in the condensers 24, 25 and 26 for the same reasons that the small flux changes in the cores 10a and 10c do not produce changes of charge in these condensers. The system of Fig. 1 responds in similar fashion to repeated applications of odd and even shift pulses 41 and 43. The above-described condition of the system corresponds to a reset condition where each core 10 and each condenser remains in its initial remanent state.

Assume, now, that a positive input pulse 44 is applied by the first input device 26 to the input winding 12a of the first stage core 10a. The positive input pulse 44 is in a direction to make the unmarked terminal of the input winding 12 positive relative to the marked terminal. The positive input pulse 44 changes the core 10a from the initial state P to the state N . The relatively large flux change produced in the core 10a is in a direction to make the marked terminal of the output winding 14a negative relative to its unmarked terminal. Accordingly, the condenser 24 of the transfer loop 20 is driven from remanence in the state N' to saturation in the state N' , and relatively little current flows in the transfer loop 20. Relatively little current flows in the transfer loop 20 because the point representing the state of the condenser 24 moves from remanence to saturation along the bottom horizontal portion of the curve 42 of Fig. 2. Accordingly, relatively little change of charge is produced in the condenser 24. Therefore, only a relatively small current, proportional to the change of charge in the condenser 24, can flow in the transfer loop 20. This relatively small current produces insufficient magnetizing force to significantly change the initial remanent condition of the second-stage core 10b. A voltage also is induced in the odd shift line 16 when the core 10a is changed from the state P to the state N . However, the first shift current source 17 is open-circuited at this time.

Now, when a positive shift pulse 41 is applied to the odd shift line 16, the first-stage core 10a is changed from the state N to the state P . A relatively large flux change is produced in the core 10a, and a relatively large voltage is induced across its output winding 14a in a direction to make its marked terminal positive relative to its unmarked terminal. This large induced voltage changes the condenser 24 of the transfer loop 20 from the initial state N' to the other state P' , thereby inducing a relatively large transfer current in the transfer loop 20. The relatively large transfer current flows into the input winding 12b at its unmarked terminal, and changes the core 10b from the initial state P to the other state N . The relatively large flux change in the core 10b induces a voltage in its output winding 14b in a direction to make its marked terminal negative relative to the unmarked terminal. However, substantially no current flows in the transfer loop 21 because this induced voltage drives the condenser 25 from remanence to saturation in its

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initial state N'. The flux change produced in the second-stage core 10b also induces a voltage in the even shift line 18. However, no current flows in the even shift line 18 because the even shift current source 19 is open-circuited at this time.

Accordingly, after termination of the odd shift pulse 41, the first stage core 10a is in its initial state P, the condenser 24 of the transfer loop is in its other state P', and the second-stage core 10b is in the other state N. Each of the other cores 10 and the condensers are in their initial remanent states.

When an even shift pulse 43 is next applied to the even shift line 18, the second-stage core 10b is changed from the state N to the state P. A voltage is induced in the output winding 14b of the core 10b, making its marked terminal positive relative to its unmarked terminal. This relatively large voltage changes the condenser 25 of the transfer loop 21 from the initial state N' to the other state P'. The resulting transfer current flowing in the transfer loop 21 changes the third-stage core 10c from its initial state P to the other state N. No significant current flow is produced in the third transfer loop 22, when the third-stage core 10b is changed from the state N to the state P, because the condenser 26 of the third transfer loop 22 is driven from remanence in the state N' to saturation in the same state N'. Likewise, substantially no transfer current flows in the first transfer loop 20, when the second-stage core 10b is changed from the state P to the state N, because the voltage induced across its input winding 12b is in a direction to drive the condenser 24 of the first transfer loop 20 from remanence in the state P' to saturation in the state P'. Also, no current is produced in the odd shift line 16, when the third-stage core 10c is changed from the initial state P to the other state N, because the first shift current source 17 is open-circuited at this time.

Accordingly, after the even shift pulse 43 is terminated, the second-stage core 10b is in the initial state P, the condensers 24 and 25 are each in the other state P', and the third-stage core 10c is in the state N. Each of the other cores and the remaining condensers are in their initial remanent states P and N', respectively.

Alternate application of odd and even shift pulses 41 and 43 transfers the input signal successively from the third-stage core 10c to the fourth-stage core 10d, and from the fourth-stage core 10d to the first output device 33, in similar manner.

After the input signal initially received from the first input device 27 is transferred to the output device 33, all of the condensers are polarized in their other remanent states P' and all the cores 10 are magnetized in their initial remanent states P. Accordingly, before another signal is transferred from the first input device 27 to the first output device 33, each of the condensers is changed from the other state P' to the reset state N'. Suitable means for restoring the condensers to their reset states are described hereinafter.

In shifting the input signal from one core to a succeeding core, the output voltage produced in the output winding of the transferring core must be greater than the coercive voltage of the coupled condenser. This core output voltage depends upon the number of turns of the output winding and on the amplitude and rise time of the shift pulse applied to the shift line. Also, for a given number of turns of an input winding, the transfer current produced in a transfer loop must be of sufficient amplitude and duration to produce a magnetizing force greater than the coercive force of the receiving core. The amount of transfer current also depends, at least in part, upon the amplitude and the rise time of the shift pulse. Proportionally larger transfer currents can be produced in the transfer loop coupling the transferring and the receiving cores by making the voltage produced in the output winding of the transferring core proportionally larger. That is, the condenser of the transfer loop can pass any suit-

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able amount of transfer current by making the voltage applied to its electrodes sufficiently large. After all the flux change is carried out in the receiving core in changing from remanence in its initial state to saturation in its other state, substantially all the voltage from the transferring core output winding appears across the condenser. Accordingly, the condenser, if it is not already in its saturated state, is thereby completely switched to its saturated state. Therefore, the cores 10 and the condensers need not be matched with each other and may be of different sizes. Thus, each core 10 and each condenser is completely changed from remanence to saturation, provided the shift pulses cause voltage pulses of sufficiently large amplitude and duration to be induced in the transfer loops.

The first and second shift sources 17 and 19 preferably are constant-current sources. Suitable, known constant-current sources include other magnetic core circuits, pentode-type amplifier circuits, etc. Constant-current sources for driving a magnetic-core shifting device are commercially available.

Signals from the second-input device 34 can be shifted in the reverse, or right-to-left, direction to the second output device 28. In such case, the first and second reversing switches 30 and 35 are thrown to the right and to the left, respectively. Each of the cores 10, however, is magnetized in the state N. The cores 10 can be changed to their states N by applying negative-polarity currents to the odd and even shift lines 16 and 18. These applied currents may have relatively long rise times so that the voltages induced across the input and the output windings 12 and 14 of the cores 10 are of relatively small amplitude. Any suitable means, including the shift sources 17 and 19, may be used for changing the cores 10 to their states N. Each of the condensers is polarized in the state P' by any suitable means, described hereinafter. Negative-polarity shift signals 45 and 47 are applied to the odd and even shift lines 16 and 18, respectively.

In operation, when all the cores 10 are in the state N, a negative shift pulse 45 from the first shift source 17 drives the cores 10a and 10c from remanence in the initial state N to saturation in the same state N. A relatively small flux change is produced in the cores 10a and 10b. These relatively small flux changes induce relatively small amplitude voltages in the input and the output windings linked to the cores 10a and 10c in a direction to make their unmarked terminals positive relative to their marked terminals. Each of the condensers connected to the windings receiving an induced voltage is driven from remanence in the initial state P' towards the other state N'. However, the relatively small induced voltages do not exceed the coercive voltages $-V_c$ of the condensers. Accordingly, after the negative shift pulse 45 is terminated, each of the cores and each of the condensers returns to its initial remanent state. Similarly, when a negative shift pulse 47 is applied to the even shift line 18, the cores 10b and 10d have a relatively small flux change produced therein. These relatively small flux changes also produce relatively small amplitude voltages in the windings coupled to the cores 10b and 10d in a direction to drive the connected condensers from remanence in their initial state P' towards the other state N'. After the negative shift pulse 47 is terminated, however, each of the cores and each of the condensers is substantially in its initial remanent state. Repeated application of negative odd and even shift pulses 45 and 47 does not cause any of the cores or any of the condensers to change its initial remanent state. This condition of the system, therefore, corresponds to another reset condition wherein the cores 10 are all in the same state N and all the condensers are in the same state P'.

Assume, now, that a positive voltage pulse 49 is applied by the second input device 34 to the output (now input) winding 14d of the fourth stage core 10d through the condenser 29. The voltage pulse 49 changes the condenser

29 from its initial state P' to its other state N'. The resulting current flows into winding 14d at its marked terminal and changes the core 10d from its initial state N to its other state P. The relatively large flux change in the core 10d induces a voltage in its input (now output) winding 12d in a direction to drive the condenser 26 from its initial state P' to saturation in the same state P'. Accordingly, relatively little current flows in the transfer loop 22 between the cores 10d and 10c. After the input signal 49 is terminated, the fourth-stage core 10d is in the other state P, and the condenser 29 is in its other state N'. Each of the other cores and condensers is in its initial remanent state N or P', respectively.

The next, negative, even shift pulse 47 changes the core 10d from its state P to its initial state N. The relatively large flux change in the core 10d induces a voltage across its input (now output) winding 12d in a direction, and of sufficient amplitude, to change the condenser 26 from its initial state P' to the other state N'. The resulting current flow in the transfer loop 22 flows into the winding 14c at its marked terminal and changes the core 10c from its initial state N to its other state P. The relatively large flux change in the core 10c, in changing between the states N and P, does not produce any significant current flow in the transfer loop 21 between the cores 10c and 10b. The flux change in the core 10d also induces a relatively large voltage in the output (now input) winding 14d of the core 10d. However, this induced voltage is in a direction to drive the condenser 29 further into saturation in the state N' in which it is already polarized. Therefore, relatively little current can flow in the winding 14d, the condenser 29, and the second input device 34. If desired, the second input device 34 can be open-circuited after the input signal 49 is applied to the core 10d.

Accordingly, after the negative, even shift signal 47 is terminated, the core 10c is magnetized in the other state P, and the condensers 26 and 29 are each polarized in the other state N'. Each of the other cores and each of the other condensers is in its initial remanent state N and P', respectively.

The next, negative, odd shift pulse 45 shifts the input signal from the core 10c to the core 10b in similar manner. The core 10c is returned to its initial remanent state N, and the core 10b and the condenser 25 are each changed to their other states P and N', respectively.

The next sequence of negative even and odd shift pulses 47 and 45 shifts the input signal from the core 10b to the core 10a, and from the core 10a to the second output device 28.

After the input signal received from the second input device 34 is shifted to the second output device 28, the cores 10 are all magnetized in their initial remanent states N, and the condensers are all polarized in their other remanent states N'.

The relatively large voltage induced in the input (now output) winding 12a, when the first-stage core 10a is changed from its initial state N to the other state P, is applied to the second output device 28. In certain applications, this induced voltage is not desired. For these applications, an additional ferroelectric condenser (not shown) may be connected between the core 10a winding 12a and the movable arm of the reversing switch 30 to block current flow from the input winding 12a when the core 10a is changed to the other state P. Also, any suitable known means can be used in the second output device 28 to discriminate against the undesired voltage from the core 10a.

The system of Fig. 1 can be returned to its other reset condition by returning the cores 10 to their states P by applying positive current pulses to the odd and even shift lines 16 and 18. The condensers may be returned to their remanent states P' as described hereinafter.

The systems of the present invention provide great flexibility in the manner of connecting load devices to the magnetic core and ferroelectric elements, as shown

in Fig. 4. The system of Fig. 4 is similar to the system of Fig. 1, and in Fig. 4 and the remaining figures, like elements are designated by like reference numerals.

A plurality of separate load devices 50a, 50b, 50c and 50d may be linked to respective ones of the cores 10 by linking additional output windings 52a, 52b, 52c and 52d respectively to the separate cores 10. Each of the loads is connected across a different one of these output windings. Each time a relatively large flux change is produced in a core, an output signal is induced across the output winding linked to that core, and a signal is applied to its individually-connected load. The loads 50a to 50d may be devices which are responsive to both polarity signals produced in the output windings 52a to 52d. For example, these devices may offer a resistive load, as indicated by the dotted resistive elements in each of the boxes representing the loads. If desired, however, an additional element, such as a ferroelectric condenser, individual to each output winding 52a to 52d, may be connected in series with each of the output windings 52a to 52d. The additional ferroelectric element prevents an output signal of one polarity in an output winding from producing a signal in the connected load.

Also, if desired, separate loads 54a, 54b and 54c may be connected individually in each of the separate transfer loops 20, 21 and 22. A separate load (not shown) may be connected in series with the condenser 29 and the output winding 14d of the core 10d in place of the first output device 33. Each time a transfer current flows in one of the transfer loops 20, 21 or 22, a signal is applied to the load device 54a, b, or c of that transfer loop. Preferably, these load devices offer a resistive load to signals induced in the core output or input windings. When these separate load devices 52a, b, or c or 54a, b, or c are coupled to the system elements, the amplitude and the rise time of the shift signals are adjusted to assure complete switching of the magnetic cores 10 and the condensers, despite the additional energy absorbed by the load devices.

A reset circuit suitable for establishing all the condensers in an initial remanent state N' or P' is shown in Fig. 5. Each of the transfer loops 20, 21 and 22 is connected to a common bus 56 to which reset signals are applied by a source of potential, such as a battery 58. A third, double-pole, double-throw reversing switch 60 is connected between the battery 58 and the common bus 56. The battery 58 is connected in series with a current-limiting resistor 61 across the center terminals of the switch 60. The diagonally opposite fixed terminals 62 and 63 of the reversing switch 60 are connected to the common bus 56. The other diagonally opposite fixed terminals 64 and 65 of the reversing switch are connected to ground. The marked terminals of the input windings 12b, 12c and 12d of the transfer loops 20, 21 and 22, respectively, are connected to the common bus 56. The unmarked terminals of the output windings 14a, b, and c are all connected to ground. A single-pole, single-throw shorting switch 66 connects the common bus 56 to ground at the fixed terminal 63 of the third reversing switch 60. The shorting switch 66 is normally closed. The condenser 29, if used, can be reset to a desired state by using a single-throw switch 67. The upper pair of contacts 68a and 68b are normally closed and connect the electrode 29b of the condenser 29 to the center terminal 38 of the second reversing switch 35. The other center terminal 39 of the reversing switch 35 is connected to ground. The lower pair of contacts 69a and 69b of the single-throw switch 67 are connected respectively to the common bus 56 and the electrode 29b of the condenser 29.

During the reset operation, the single-throw switch 67 is depressed to connect the condenser 29 to the reset battery 58. The shorting switch 66 is opened. If it is

desired to reset the condensers to the state N', the reversing switch 60 is thrown to the left (as viewed in the drawing) to connect the positive terminal of the reset battery 58 to the common bus 56. A positive voltage, therefore, is applied to each of the condensers 24, 25, 26 and 29 in a direction to make their *b* terminals positive relative to their *a* terminals. This positive voltage changes each of the condensers from the state P' to the state N'. The resistance element 61 is used to limit the amount of current that can flow in any of the transfer loops when their connected condensers are being changed to the state N'. The value of the resistance element 61 is chosen so that the resultant current flow is limited by the resistance element 61, rather than by the relatively small impedances of the cores which are driven further into saturation in their reset states P by this current. After the condensers are reset to their N' states, the reversing switch 60 is opened and the shorting switch 66 is closed. The shorting switch 66 provides a relatively low resistance path to ground for the transfer currents that flow during subsequent shifting operations of the device. Any suitable electronic switch device, such as a transistor, may be used instead of the single-pole shorting switch 66. For example, by biasing a junction transistor in known fashion, its collector-to-emitter path can be made to appear as a relatively low resistance, in the order of a few ohms, or as a relatively high resistance in the order of a megohm or more. The single-throw switch 67 is released to connect the condenser 29 to the first output device 33.

The condensers can be reset to their P' states by throwing the third reversing switch 60 to the right (as viewed in the drawing) to connect the negative terminal of the reset battery 58 to the common bus 56. The terminals *a* of the condensers are thereby made positive relative to their terminals *b*, and each condenser is reset to its P' state. Recall that the condensers are reset to their P' states when the shifting operation is carried out in the reverse direction, from right-to-left. The current-limiting resistor 61 also serves to limit the amount of reset current flowing in the transfer loops when the condensers are reset to their P' states. The transfer currents are each in a direction to drive the cores 10 from remanence in the state N to saturation in the state N. Thus, after the condensers are reset to their states P', the cores 10 all return to, or very near, their initial remanent conditions in the state N.

The system of Fig. 6 provides another means for resetting the condensers to desired remanent states. Each of the transfer loops 20, 21 and 22 is connected to the movable arm of a different one of four single-pole, double-throw switches 70, 71, 72 and 73. The center terminal of each of these switches 70, 71, 72 and 73 is connected to ground. One fixed terminal 70a, 71a, 72a and 73a (that on the left) of each of these switches is connected to a first bus 74. The other fixed terminal 70b, 71b, 72b and 73b (that on the right) of each of these switches is connected to a second bus 76. The first bus 74 is connected through a first current-limiting resistor 78 to the positive terminal of a first reset source, such as a battery 80. The second bus 76 is connected through a second current-limiting resistor 82 to a negative terminal of a second reset source, such as a battery 84. The negative terminal of the battery 80 and the positive terminal of the battery 84 are connected to ground. Accordingly, by connecting the movable arms of the switches 70, 71, 72 and 73 to either the left or to the right fixed terminals, as desired, the condensers 24, 25, 26 and 29 can be reset to either the N' or the P' states. After the condensers are reset to desired states, the movable arms of the switches 70, 71, 72 and 73 are returned to their center grounded terminals.

A system arranged as is the system of Fig. 6 is useful in certain applications where it is desired to change the length of the register at different times. For example, 75

the system of Fig. 6 can be changed to a two-stage register by resetting the condensers 26 and 29 to the P' state, as by throwing the movable arms of the switches 72 and 73 to the right, and by resetting the condensers 24 and 25 to the N' state by throwing the movable arms of the switches 70 and 71 to the left. The shifting operation then stops after the input signal is shifted from the core 10b to the core 10c. When the core 10c is returned to its initial remanent state P, no transfer current flows in the transfer loop 22 because the condenser 26 already is polarized in the P' state.

An additional group of auxiliary cores 90, 91, 92 and 93 may be used for resetting the condensers to a desired remanent state. In the system of Fig. 7, each of the transfer loops 20, 21 and 22 includes an additional auxiliary core 90, 91 or 92. The auxiliary core 93 is coupled between the core 10d and the condenser 29 by way of the lower set of contacts of the single-pole switch 67. A reset line 96 is linked to all the auxiliary cores. A reset source 98 is connected across the reset line 96.

In operation, each of the auxiliary cores is magnetized in an initial state, for example, the state N. When a signal is shifted from one main core, for example, core 10b, to a succeeding main core, as 10c, the resultant transfer current is in a direction to drive the coupled auxiliary core 91 further into saturation in the state N. Accordingly, an auxiliary core merely presents a small, additional resistance in the coupled transfer loop when a signal is shifted from one main core to another. After the signal is shifted through all the main cores of the device, the main cores are all magnetized in their initial remanent states, for example, the state P, and all the condensers are magnetized in one state, for example, the state P'. In resetting the condensers, the reset source 98 first applies a positive reset pulse 100 to the reset line 96. The positive reset pulse 100 changes each of the auxiliary cores from its initial remanent state N to the other state P. The flux changes in the auxiliary cores each induce a voltage in its coupled transfer loop in a direction to drive the connected condenser from remanence in the state P' to saturation in the same state P'. Accordingly, relatively little current flows in any of the transfer loops when the auxiliary cores are changed to the state P. After the positive reset pulse 100 is terminated, the reset source 98 applies a negative polarity reset pulse 102 to the reset line 96. The negative reset pulse 102 changes each of the auxiliary cores from the state P to the state N. The flux changes in the auxiliary cores each induces a voltage in the connected transfer loop in a direction to change the condenser of that loop from the state P' to the state N. Thus, these induced voltages are each positive at the electrode *b* relative to the electrode *a* of any of the condensers. The resultant current flow in the transfer loops, in returning the condensers to the state N', flows into the marked terminals of any of the windings, output or input, of the main cores. Accordingly, the transfer loop currents drive each of the main cores from remanence in the initial state P to saturation in the same state P. Upon termination of the negative reset pulse 102, all the auxiliary cores are magnetized in the state N, all the main cores are magnetized in the state P, and all the condensers are polarized in the state N'.

Note that the system can be changed to its reset condition at any time, even before an input signal is shifted to an output device. If a main core 10 is magnetized in the state N during the reset operation, the auxiliary cores, in changing from the state N to the state P, change all the main cores succeeding the one main core 10 from their initial states P to their other states N, and change all the condensers succeeding the one core from their initial states N' to their other states P'. The one main core 10 remains in the state N and the main cores 10 preceding the one main core 10 remain in the state P. The condensers preceding the one main core 10 remain in

their other states P'. When the negative reset pulse 102 is applied, the auxiliary cores are each changed to their remanent states N, the main cores 10 that are in the state N are changed to their initial states P, and the condensers that are in the state P' are changed to the state N'.

There have been described herein improved systems of the shift-register type having a plurality of cores of substantially rectangular hysteresis loop material interconnected by a plurality of transfer loops each including a different ferroelectric condenser. Note that the transfer loops receive only induced voltages from the core windings during the shifting operation. Information is shifted from core to core by means of a pair of shift lines each linking alternate ones of the cores. Information may be shifted in either direction by applying either polarity signal to the shift lines.

What is claimed is:

1. A system comprising a plurality of cores of substantially rectangular hysteresis loop material, input and output windings on each of said cores, a plurality of transfer loops connecting said cores by respectively connecting successive output and input windings of succeeding said cores, said transfer loops receiving only induced voltages from said core windings, a plurality of ferroelectric condensers having two terminals, each of said condensers having a rectangular hysteresis loop characteristic and each of said condensers being connected in a different one of said transfer loops by directly connecting one of said terminals to the input windings of the loop in the other of said terminal to the output windings of the loop, a first shift line linking alternate ones of said cores, and a second shift line linking the other, alternate ones of said cores.

2. A system as claimed in claim 1, said cores each having two remanent states, and including means for establishing one of said cores in a desired one of said remanent states and the remaining ones of said cores in the other of said remanent states.

3. A system as claimed in claim 1, including means for applying signals of either one polarity or the other polarity to said shift lines.

4. A system comprising a plurality of main cores of substantially rectangular hysteresis loop magnetic material, output and input windings on said cores, a plurality of auxiliary cores of substantially rectangular hysteresis loop magnetic material, a plurality of transfer loops connecting said main cores by respectively connecting successive output and input windings of succeeding said main cores, said transfer loops receiving only induced voltages from said core windings, a plurality of ferroelectric condensers of substantially rectangular hysteresis loop material, each said transfer loop linking a different one of said auxiliary cores and including a different one of said ferroelectric condensers.

5. A system as claimed in claim 4, including first and second shift lines alternately linking said main cores.

6. A system as claimed in claim 4, including first and second shift lines alternately linking said main cores, and a reset line linking said auxiliary cores.

7. A system as claimed in claim 4, including first and second shift lines alternately linking said main cores, and means for applying to said shift lines shift signals of either the one polarity or of the opposite polarity.

8. A system as claimed in claim 6, including means for applying to said reset line a reset signal comprising a first pulse of one polarity followed by a second pulse of the opposite polarity.

9. A signal shifting system comprising first and second cores each having two remanent states, windings on said cores, a condenser having a dielectric of ferroelectric material, said condenser having two remanent states, means for setting said cores in different ones of their said

remanent states and for setting said condenser in one of its said remanent states, a transfer loop connecting one winding of said first core, said condenser, and one winding of said second core, means for changing the remanent state of one of said cores, said changed core inducing a signal in said transfer loop, said induced signal changing said condenser and the other of said cores to the other of said remanent states.

10. A signal shifting device as claimed in claim 9, including a load device connected in said transfer loop.

11. A signal shifting device as claimed in claim 9, including a load device coupled to one of said cores.

12. A shifting system comprising a plurality of cores of substantially rectangular hysteresis loop material, windings having terminals on said cores, separate transfer loops between successive pairs of said cores, said transfer loops each connecting one terminal of one said winding on one said core of a pair to one terminal of said winding on the other core of the same said pair, a plurality of ferroelectric condensers of substantially rectangular hysteresis loop material, each of said transfer loops including a different one of said ferroelectric condensers, shift means linked to said cores, separate switch means connected across each of said ferroelectric condensers for applying unidirectional voltages of either the one or the other polarity to said condensers, and means for short-circuiting said transfer loops between the other terminals of said one windings.

13. A system comprising a plurality of magnetic cores each having two remanent states, and each being magnetized in an initial one of said states, a plurality of ferroelectric condensers each having two remanent states, and each being polarized in an initial one of said states, a plurality of transfer loops each including a different one of said condensers and each being coupled between different successive ones of said cores, a first shift line linking alternate ones of said cores for changing said alternate cores from the other to said initial states, and a second shift line linking the other alternate ones of said cores for changing said other alternate cores from said other to said initial state, any one of said cores in changing to said initial state producing a signal in one of said coupled transfer loops to change said one transfer loop condenser from said initial to said other state and to change the other core of said one transfer loop from said initial to said other state.

14. A system comprising a plurality of cores of substantially rectangular hysteresis loop material, each said core having two remanent states, a plurality of transfer loops connecting said cores in cascade, a first of said transfer loops coupling a first and second of said cores, a second of said transfer loops coupling said second and a third of said cores, and so on, a plurality of ferroelectric condensers, each having two remanent states, and each connected in a different one of said transfer loops, a first shift line for receiving first shift signals linking alternate ones of said cores, and a second shift line for receiving second shift signals linking the other, alternate ones of said cores, a shift signal, when applied, being effective to change the remanent state of one of said cores, said one core producing a signal in one of said transfer loops linked thereto, and said induced signal changing the remanent states of both said ferroelectric condenser and the other said core of said one transfer loop.

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