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2,874,372

MAGNETIC CORE DEVICES

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This invention relates to magnetic devices which utilize the hysteresis characteristic of magnetic materials as a means for switching or gating information.

The value of saturable reactors comprised of suitably wound small cores of ferromagnetic material as storage and logical elements in electronic data handling systems is being increasingly recognized, particularly because of their miniature size, low power requirements, dependability and their ability to retain stored information for long periods of time in spite of power failure. The cores of such reactor elements are able to store binary information in the form of residual magnetization after the cores are magnetized to saturation in either of two directions. The saturation can be achieved by passing either a constant direct current or a pulse current through a winding on the core. When a current is applied to a winding on the core to create a magnetomotive force in the sense opposite to the pre-existing flux direction, the core is driven to saturation in the opposite polarity, provided that the magnetomotive force exceeds a certain critical value. The total change in flux accompanying this shift in flux direction occurs in a relatively short time, thereby inducing a sizable voltage pulse across any winding on the core, which pulse may be utilized to drive other saturable reactor elements to saturation in a pre-determined polarity or in a variety of other ways as will be discussed in greater detail below. On the other hand, magnetizing pulses applied to a saturable reactor element which drive it further into saturation in the same direction as that of the residual flux produce a change in flux which is small compared to that created in reversing the flux polarity and so induce correspondingly small voltage pulses in windings on the core.

In order to achieve a large ratio between the voltage pulses induced when a saturable magnetic reactor element is driven to the opposite polarity as compared to that obtained when driving it to saturation in its original polarity, its core material is preferably one having at least a quasi-rectangular hysteresis characteristic so that the residual flux density is a relatively large percentage of the flux density present during the application of a saturating magnetomotive force. A number of suitable magnetic materials are available such as Deltamax, ultrathin 4-79, Permalloy and ferromagnetic ferrites. In order to improve high frequency response by reducing eddy current losses, metallic ferro-alloys are preferably used in thin strips which may be wrapped around ceramic spools while ferrite cores may be molded and windings placed directly thereon, inasmuch as ferrites are relatively free from eddy current effects.

According to this invention, the core of a saturable reactor element may be held in one direction of residual magnetization by subjecting it to a continuous magnetomotive force in the pre-existing flux direction such as that produced by passing a direct current through a winding on the core. This biasing current may be readily adjusted so that the maximum magnetomotive force created by

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an information signal is insufficient to both balance out the biasing magnetomotive force and to switch the element to the opposite polarity. Normally, the biasing current will retain the magnetization of a saturable reactor element in the polarity arbitrarily designated as the binary digit "0." The opposite polarity of the residual magnetization of such a core will be referred to as the "1" state. Removal of the biasing current for a definite interval then allows the element either to be switched to the state of opposite polarity, designated as the "1" state, or to be held in the "0" state according to the information applied thereto during that interval. Following this interval the information is read out by reapplying the bias, assuming that such reapplication creates a sufficient magnetomotive force to switch the core of the element, if necessary, back to the "0" state. This is conveniently accomplished by reapplying the bias in a manner such that a surge of current results. Consequently, the saturable reactor element may function as a binary gate which blocks the flow of information until the biasing current is momentarily removed to allow one digit of binary information to be stored in its core. Reapplication of the bias induces a voltage in an output winding on the core indicative of the digit stored.

It is accordingly an object of this invention to provide novel means for gating digital information using a saturable reactor element.

It is a further object of this invention to provide a magnetic gate which accepts information either in the form of current pulses or of small D. C. current levels.

Normally in the use of saturable reactor elements as gates, two separate sources of control are required, one to allow information to be advanced into the gate and a second to drive the information out. It is accordingly an object of this invention to provide a magnetic gate which utilizes a single source both to control the passage of information and to provide means for advancing the information out in a usable form.

Information may be accepted by a magnetic gate embodying the principles of this invention in the form of a relatively small data control current compared to the amplitude of the biasing current surge. An object of this invention is then to provide a magnetic gate which incidentally acts as an amplifier and as a storage device.

These and other objects of the invention will be apparent and best understood from the following description and claims when considered in connection with the drawings, in which:

Figure 1 is a schematic diagram illustrating the basic principles of gating information through a single saturable reactor element in the practice of this invention;

Figure 2 is a schematic diagram of one stage of a serial shifting register embodying the concepts of this invention;

Figure 2A is a timing diagram demonstrating the operation of the shifting register of Figure 2; and

Figure 3 is a schematic diagram illustrating the use of this invention to provide magnetic gates for the output of a vacuum tube flip-flop.

The cores of the saturable reactor elements are shown in the drawings to be toroidal in shape. However, the shape of the cores is not critical so long as adequate coupling is achieved between the core and its windings. Toroidal cores are especially satisfactory in this respect, and incidentally produce a minimum external field. Each reactor which functions as a magnetic gate in the practice of this invention is provided with an input or data control winding, an output winding, and a driver or bias winding. When these windings are connected to windings on other magnetic cores in a circuit, unidirectional impedance devices such as semi-conducting diodes are included in the connecting leads to serve the dual purpose

of preventing signals from being transmitted from the input winding of one saturable reactor element to the output winding of another element or from being transmitted from the output winding of an element when that element is being switched from a given state of remanent magnetization to the opposite polarity.

Referring now to Figure 1, there is shown a toroidal-shaped saturable reactor element 10 which is provided with an input or data control winding 12, an output winding 14, and a driver or bias winding 16. The input winding 12 is connected by line 18 to a source of information which may be represented either by pulses or by D. C. current levels as will be demonstrated below. In either case the current flow which represents the binary digit "1," assuming that the element 10 normally is biased to the arbitrarily designated "0" polarity, must create a magnetomotive force which is sufficiently large to switch the polarity of element 10 if no current is flowing through control winding 16. Winding 16 is connected in series with the plate of biasing tube 20 which is normally conducting to cause a biasing current flow 13 through winding 16 of sufficient amplitude to prevent signals arriving on line 18 from switching the state of element 10, assuming that the element 10 is initially magnetized in the direction of the magnetomotive force set up by the current flow 13 through winding 16. In an actual embodiment, a steady driving current flow 13 of 25 milliamperes was found to be satisfactory.

Biasing tube 20 is controlled by the level of potential on lead 26 of cathode follower circuit 22 which in turn is controlled by the potential on the grid lead 24 of tube 23. If tube 23 is initially conducting, a negative voltage (e. g., pulse 25) on lead 24 will cut it off and cause the voltage drop across resistor 30 to reduce so that the movable arm 29, regardless of its position on the resistance of potentiometer 30, will assume a negative potential with respect to ground because of the negative bias applied at terminal 31. Therefore, line 26 and the potential of the control grid 33 will become negative and cut off tube 20 as at 15. By removing the negative voltage on lead 24, tube 23 of the cathode follower circuit 22 again becomes conducting, thereby causing the potential of line 26 to go positive so that a current again flows through winding 16. However, an A. C. coupling condenser 28 between cathode follower circuit 22 and the control grid of tube 20 causes a sharp leading edge to the plate current pulse 17 from tube 20 when tube 20 is brought to conduction. This surge of current 17 may be several times the amplitude of the steady biasing current and thus it can apply sufficient magnetomotive force to saturable reactor element 10 to switch its polarity after which the lower, steady state biasing current 13 is again applied to hold the element in that same polarity until its subsequent removal allows information arriving on line 18 to again change the state of element 10. It will be appreciated by those familiar with the art that the amplitude and duration of the current surge on line 26, and therefore of pulse 17, is dependent upon the RC time constant of capacitor 28 and potentiometer 30 and so can be varied by adjusting the latter. It has been found that a current surge 17 of 75 milliamperes is satisfactory.

It follows that in the circuit of Figure 1, saturable reactor element 10 is a gate for the transfer of information from line 18 to line 32 according to the voltage at lead 24. Suppose that the static residual magnetization of element 10 is initially in that polarity arbitrarily designated to correspond to the binary digit "0" and that biasing tube 20 is conducting to cause current to flow through winding 16 such that the magnetomotive force created thereby is in that same direction as the vector representing the aforementioned residual magnetization. Assuming that the driving current through winding 16 is sufficiently large, information signals on line 18 cannot cancel the bias, and element 10 remains in the "0" state until a negative potential is applied at lead 24. This

cuts off the biasing current 13 and allows a signal of the proper polarity on line 18 to switch the element 10 to the "1" state. Removal of the negative potential from lead 24 produces a current surge 17 through winding 16 which drives the element 10 back to the "0" state to induce a relatively large voltage across winding 14. The unidirectional impedance device 34 in output line 32 blocks pulses induced across winding 14, setting element 10 to "1" and allows pulses induced in driving it back to the "0" state to pass virtually without attenuation. Of course, if no signal was applied to line 18, or if the polarity of the signal was such that element 10 was driven further into the "0" polarity, reapplication of the bias from tube 20 would produce a negligible voltage across winding 14, assuming that element 10 is fabricated of material characterized by a generally rectangular hysteresis loop.

The circuit of Figure 1 not only possesses gating action but incidentally may act as an amplifier. Information signals on line 18 may be of minimum amplitude, just sufficient to switch the state of saturable reactor element 10, while tube 20 may be driven hard to cause a relatively large pulse to appear on line 32. Accordingly, the output on line 32 may be used directly without further amplification whereas an amplifier is usually required in the output of most electronic gates. It should also be noted that a large number of saturable reactor elements can be included in the plate circuit of biasing tube 20 if it is desired to control the gating action of such elements uniformly.

Reference is now made to Figure 2 in which is shown a single stage of a serial shifting register embodying this invention. Each stage of the register must contain two saturable reactor elements; a storage element 40 and a gating element 42. Elements 40, 42 are respectively provided with an input winding 44, 46 and an output winding 48, 50. Storage element 40 also has an "advance" winding 52 while the third winding of gate element 42 is a driver or biasing winding 54, the function of which is identical to the driver winding 16 of Figure 1.

For its operation the shifting register is energized by a two-phase, interlaced sequence of current pulses, the alternate periods in time of the sequence being conveniently designated as A_1 and A_2 periods. The A_2 periods are reserved for the input and output of information while A_1 periods are used to shift the information from the storage element 40 to the gating element 42 so that storage element 40 is able to accept information during each A_2 period without affecting the information received during the preceding A_2 period. An information signal arriving on line 56, if it is to indicate the binary digit "1," should be a current pulse of sufficient amplitude and of the proper polarity to cause storage element 40 to be switched to that polarity arbitrarily designated as the "1" state. The unidirectional element 58 is polarized in the wrong direction, however, to allow an output pulse from winding 48 as would otherwise be produced by a "1" input on line 56 during an A_2 period. On the other hand, an information signal arriving on line 56, if it is to indicate the binary digit "0," may be represented by the absence of a pulse during an A_2 period or by a pulse opposite in polarity to a "1" pulse.

During every A_1 period, storage element 40 is driven to or maintained at the "0" state by a current pulse applied to "advance" winding 52. The currents induced thereby are in a direction such that the unidirectional element 58 allows these output pulses to flow to winding 46. A shift is therefore accomplished.

The A_1 and A_2 pulses may be conveniently termed advance pulses. In a practical application involving associated circuitry based on saturable reactor elements, both A_1 advance pulses and A_2 advance pulses are invariably required for a number of operations. However, in the shifting register of Figure 2, only A_1 advance pulses are utilized.

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When it is desired to gate information through saturable reactor element 42, the biasing current which normally flows through winding 54 is removed for the duration of one A_1 period. This allows the information being advanced out of storage element 40 by the A_1 advance pulse to set gating element 42 in accordance with the information. Reapplication of the bias at the start of the next A_2 period then causes the information to appear across winding 50 either as a large or as an insignificant voltage pulse according to whether the gated information indicated a binary digit "1" or a binary digit "0," respectively.

The gating action of element 42 may be better understood with reference to Figure 2A which is a timing diagram showing the action of the circuit of Figure 2 for various situations. Waveforms (a) and (b) of Figure 2A show A_1 and A_2 advance pulses, respectively, which are invariably present in a data handling system based on saturable reactor elements. As noted above, only the A_1 advance pulses are applied to the circuit of Figure 2 although the A_2 advance pulses may be used indirectly in connection with the bias control and the input of information. In the example illustrated by Figure 2A, a positive pulse 60 representing the binary digit "1" is applied to winding 44 during the first A_2 time. This switches storage element 40 to the "1" polarity and induces a voltage across winding 48. However, rectifier element 58 of Figure 2 presents a high reverse impedance to the flow of current which would otherwise result from the potential difference across winding 48 so that element 42 is not subjected to a switching magnetomotive force.

The next advance pulse 62, which may conveniently be, but is not necessarily a square pulse, resets element 40 to "0" to induce a voltage across winding 48 indicative of the binary digit "1." In this case rectifier 58 has a low forward impedance so that it permits a current pulse to flow in winding 46. To gate this "1" through element 42, the bias is removed simultaneously with the application of advance pulse 62 as indicated by reference character 64 and is reapplied, as explained above, with a surge of current 66. Shunting diode 59 prevents winding 48 from receiving any current during the removal and reapplication of biasing current on winding 54 so that element 40 does not change its magnetic state at this time. However, an output pulse 68 appears across winding 50, which pulse may be applied to the input winding of the first saturable reactor element of the next stage (not shown) of a shifting register. During the same A_2 period, a second positive pulse 70 may switch storage element 40 again to the "1" polarity. However, suppose that this time the bias current is not removed from winding 54 during the A_1 period for pulse 74, and the signal 72 generated across winding 48 by advance pulse 74 is blocked and cancelled. Input of a binary digit "0" may be either a negative-going signal 76 or no signal at all. Advance current pulse 78 would merely drive element 40 further into the "0" state so that in either case virtually no pulse would be applied to the input winding 46 of the gating element 42. Hence, element 42 would remain at "0" during removal of the bias current as at 79 so that no voltage would appear across winding 50. To complete the possibilities, a "0" pulse 80 is shown arriving at storage element 40 during the fourth A_2 period, and the bias current is left on to allow no output across winding 50.

To demonstrate the application of this invention to the gating of data or information in the form of D. C. voltage levels, Figure 3 shows the use of two magnetic gating circuits 100, 102, each in one plate circuit of a conventional bi-stable vacuum tube flip-flop circuit 104 illustrated within chain line 104'. A description of the operation of this flip-flop may be found in U. S. Patent No. 2,614,169 issued October 14, 1952 to A. A. Cohen et al. If tube 106 of flip-flop 104 is initially conducting, a condition which may be arbitrarily designated as the

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"1" condition, a current will flow through winding 108 to produce a magnetomotive force tending to drive element 100 to the "1" state. Current flowing through winding 110 from the plate of biasing tube 20a, which is controlled by the level of potential on line 26a derived from a cathode follower (not shown) in a manner similar to that of biasing tube 20 of Figure 1, counteracts this magnetomotive force; but when the bias is removed, saturable reactor element 100 is switched to the "1" state. Reapplication of the biasing current produces a surge of current sufficient both to cancel the effect of the plate current from tube 106 and to switch element 100 back to the "0" state, thereby inducing a voltage pulse on output line 112. At the same time tube 114 is at cut off ("0" output) so that saturable reactor element 102 remains in the "0" state and no output is obtained on line 116. It follows that with each removal and reapplication of the biasing current on line 118, a pulse is generated on output line 112 if tube 106 is conducting or on line 116 if tube 114 is conducting and tube 106 is at cutoff. A pulse on line 112 then indicates flip-flop 104 stores a "1" and a pulse on 116 says it stores a "0."

It will be appreciated by those familiar with the art that a great many uses may be made of gates in electronic circuits and that numerous other applications in addition to those described hereinabove could be made without departing from the scope of this invention. Therefore, it is intended that the matter contained in the foregoing description and the appurtenant drawings be considered as illustrative and not in a limiting sense.

What is claimed is:

1. A circuit comprising a saturable magnetic core having input winding means for receiving input electrical data to be gated, output winding means for applying externally the gated data, driver winding means for receiving a substantially continuous biasing signal to control the gating of the received electrical data, and means to control the amplitude of the biasing signal through said driver winding means, the arrangement being such that amplitudes of the biasing signal in a first range will hold the core in a first state regardless of received input data while amplitudes of the biasing signal in a second range will permit the core to shift to a second state if the then received data so dictates.
2. A circuit as in claim 1 wherein the output winding means includes a unidirectional current conducting device.

3. Apparatus as in claim 1 wherein the biasing signal control means includes a vacuum tube having its plate circuit connected to said driver winding means.

4. A circuit as in claim 2 wherein said unidirectional device is polarized such that the output therethrough from said output winding means occurs only during the return of the amplitude of said biasing signal to said first range.

5. A circuit as in claim 4 wherein the amplitude controlling means includes means for causing said biasing signal to surge substantially upon changing from said second range into said first range.

6. Apparatus as in claim 5 wherein the means to cause the biasing signal to surge includes a capacitive means for control of the biasing signal.

7. Apparatus as in claim 1 further including a second saturable magnetic core having an input winding, an output winding, and a control winding, and unidirectional current conducting means for coupling the output winding of said second core to the input winding means of the first mentioned core and for precluding current generated in the input winding means of the first core from influencing the second core, the arrangement being such that the input winding of the second core receives data to be stored when the control winding of the second core receives current pulses to cause the received data to be presented to the input winding means of the first mentioned core.

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8. A circuit as in claim 7 wherein said unidirectional means includes a unidirectional current conducting device in series with the output winding of said second core and a second unidirectional current conducting device shunting said input winding means of the first mentioned core.

9. A circuit as in claim 1 further including a second saturable magnetic core having input winding means for receiving input electrical data to be gated, output winding means for applying externally the gated data, driver winding means connected with the driver winding means of the first core for concurrent operation with said substantially continuous biasing signal, the output winding means of said first mentioned core and the second core

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being connected to receive said input electrical data in the form of direct current at one or the other of the two input winding means, the arrangement being such that when the amplitude of the biasing signal is in said first range both of the magnetic cores remain in a first state regardless of the presence of said direct current, and when the amplitude of the biasing signal is in said second range, the core receiving said direct current at its input winding means is shifted to a second state.

References Cited in the file of this patent

UNITED STATES PATENTS

2,614,169 Cohen et al. ----- Oct. 14, 1952