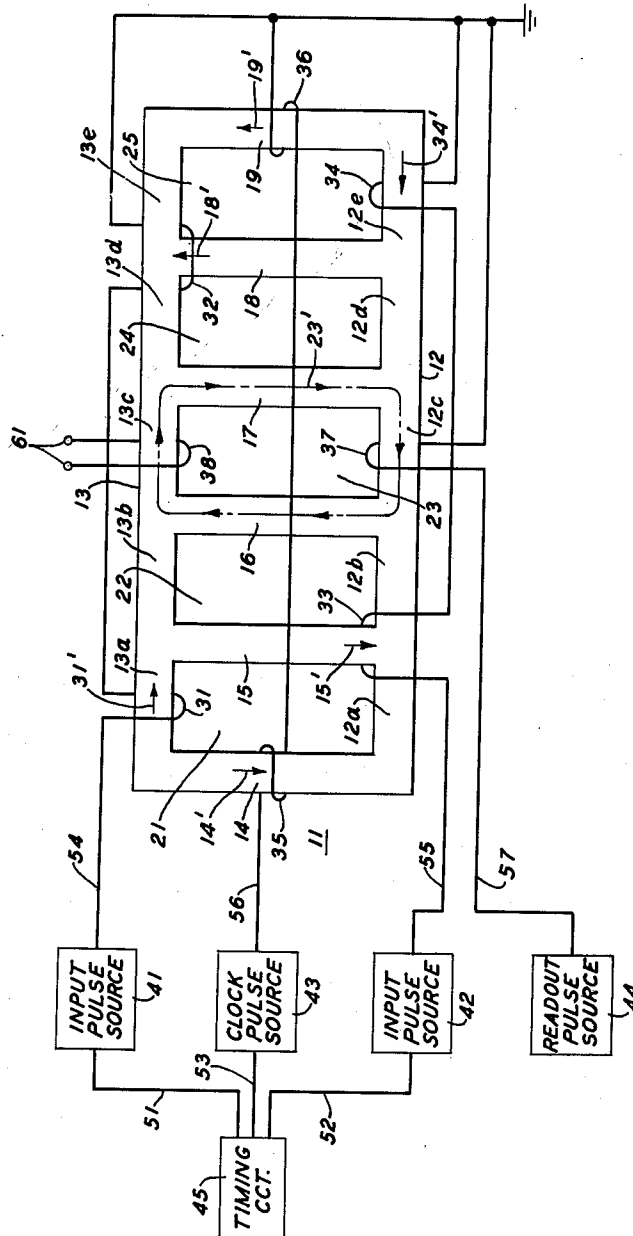


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MAGNETIC COMPARISON CIRCUIT

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INVENTOR
H. J. SCHULTE, JR.
BY
William H. Hamstra
ATTORNEY

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MAGNETIC COMPARISON CIRCUIT

Harry J. Schulte, Jr., Whippany, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

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This invention relates to information handling circuits employing magnetic memory devices and more particularly to matching circuits used for making bit-by-bit comparisons between two trains of current pulses.

Multipertured magnetic elements having substantially rectangular hysteresis characteristics have become well known in the art. Such an element is described, for example, in the copending application of T. H. Crowley and U. F. Gianola, Serial No. 732,549, filed May 2, 1958, now Patent No. 2,963,591, issued Dec. 6, 1960. By means of such multipertured elements, logic, memory, switching, translation operations, and the like, are made possible by controlling flux redistributions within a single unitary magnetic structure. One form of the structure comprises a pair of side rails between which a plurality of transverse members are disposed. The side rails, together with the transverse members, present a plurality of closed magnetic flux paths. As a result, flux induced in one transverse member by an applied magnetomotive force may be completed in whole or in part through the side rails and through one or more of the other transverse members. It has been found that when all of the available paths are flux limited, that is, when each has the same minimum cross-sectional area, a flux induced in a portion of the element common to all of the paths will be completed through a flux path defined by the nearest available structural member without regard to the magnitude of the applied magnetomotive drive force. Thus, by applying signals to selected ones of a plurality of windings inductively coupled to various transverse members and side rail portions, these structural members can be made to remain in a given flux condition while flux changes occur in other selected structural members. The flux changes occurring in selected transverse members and side rails may then be utilized to induce output signals in windings coupled to these structural elements to realize particular control functions.

A bit-by-bit comparison of trains of current pulses representing binary information is a frequent and important operation in information handling and computation processes generally. Comparison circuits in which two input sequences A and B may be compared and particular output signals generated as determined by the identity or lack of identity between the two sequences are well known. One such circuit employing vacuum tubes provides a half-adder circuit for each bit of each number sequence. When the outputs of all of the half adders as determined by suitable AND circuit means are zero, the two numbers being compared are indicated as being equal. Such a circuit is described, for example, by R. K. Richards, in Arithmetic Operations in Digital Computers (D. Van Nostrand Company, Inc., New York, 1955), at page 291. A circuit such as there described for performing comparison functions depends, however, on considerable power expenditures to operate the various circuits of the vacuum tubes employed, and more importantly, requires that power be continuously applied if a memory function

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is also to be realized in the comparison circuit. The situation is considerably improved by substituting well-known magnetic cores to perform both the switching and the memory functions. However, in this case also improvement may be achieved from the viewpoint of power requirements, ease of fabrication, initial cost, and the like. Thus the elimination of diodes, connecting circuitry, and other circuit components incident to the use of magnetic cores would represent a considerable advance in the comparison circuit art.

Accordingly, it is an object of this invention to provide a new and improved comparison circuit requiring only a single magnetic element for performing switching functions.

It is another object of this invention to accomplish the comparison of two binary numbers to determine whether the two numbers are identical.

It is yet another object of this invention to provide a new and improved information handling circuit utilizing both the logic and memory capabilities of multipertured magnetic elements.

It is a further object of this invention to provide a new and novel comparison circuit which realizes a substantial reduction in circuit components.

The foregoing and other objects of this invention are realized in one illustrative embodiment thereof for performing a comparison and other functions utilizing a single multipertured structure as the memory and switching element. The structure is fabricated from a magnetic material having substantially rectangular hysteresis characteristics and presents a sequence of flux limited flux legs. A normal flux condition is established through two adjacent legs around a comparison aperture in one direction by a read-out drive. Subsequently, a clock drive is applied simultaneously to both the first and the last legs of the structure. The flux paths available in the multipertured structure at this time are such that the switching flux so induced from either end of the structure is not able to cause a reversal of the normal flux around the comparison aperture. Whether such a reversal occurs and from which end is determined by the identity between bits of corresponding bit pairs of A and B sequences of input current pulses introduced into the circuit in phase with the clock pulses. A pulse representative of a bit from each sequence is applied via a pair of input circuits having windings coupled to the structure to control flux reversals around the comparison aperture by drives from either end of the structure. Thus, if an identity is present between a particular bit A_i and a bit B_i of a bit pair, then a flux switching is again prevented around the comparison aperture from either end of the structure. On the other hand, if a mismatch between particular bits occurs, the clock drive from one of the ends will reverse the normal flux around the comparison aperture. From which end the reversal occurs will depend upon which of the particular bits is present. A bit-by-bit comparison continues in this manner until each of the corresponding bits of the two sequences has been compared or until a mismatch has been detected.

After the termination of the bit pairs being compared, the read-out drive is again applied to the flux loop presented by the comparison aperture to reset the flux therearound to its normal condition. If the resetting causes a flux switching around the comparison aperture an output voltage signal is generated in an output winding coupled

thereto indicative of the mismatch present between at least one pair of bits of the A and B sequence of bits. If no flux switching results from the application of the read-out pulse, the absence of a signal on the output winding is indicative of a match between each bit of the bit pairs being compared. After a mismatch has occurred between the bits of any one of the bit pairs and thereby caused a reversal from the normal flux condition around the comparison aperture, the reversed flux condition cannot be restored to its previous condition by either a match or a mismatch between subsequent bit pairs, the restoration being accomplished only by the succeeding read-out operation.

It is thus a feature of this invention that drive windings are coupled to a first and a last leg of a multi-apertured magnetic structure and are serially connected in a clock drive circuit. The structure is so formed that when a clock pulse is applied to the clock circuit a magnetomotive drive is induced from both ends of the structure, either of which drives may be operative to cause a flux switching around a selected comparison aperture of the structure. The availability of flux closure paths normally prevents such a flux switching around the comparison aperture. However, when flux closure paths are denied to the switching flux from either side of the structure as controlled by a pair of simultaneously applied information input drives, a flux switching is caused around the comparison aperture.

It is another feature of this invention that a pair of input circuits are coupled to a multiapertured magnetic structure in such a manner that if input signals are present on both or neither of the input circuits, flux switching around a selected comparison aperture of the structure by a simultaneously applied drive from both ends of the structure is prevented. If a signal appears on either one of the circuits when neither circuit should have a signal thereon, or, conversely, if no signal appears on either one of the circuits when both of the circuits should have signals thereon, at the time of the simultaneously applied drives, one of the latter drives will cause a flux reversal around the comparison aperture to generate an output signal in an output winding threading the comparison aperture.

This invention, together with the foregoing and other objects and features thereof, will be better understood from a consideration of the detailed description of one illustrative embodiment thereof which follows, when taken in conjunction with the accompanying drawing, the single FIGURE of which depicts a specific comparison circuit according to the principles of this invention.

The drawing depicts a multiapertured magnetic element 11 which comprises side rails 12 and 13 and transverse legs 14 through 19. The side rails 12 and 13 are divided by the legs 14 through 19 into control portions 12a, 12b, 12d, 12e, 13a, 13b, 13d and 13e and into switching portions 12c and 13c. Additionally, legs 14 and 15 and side rail control portions 12a and 13a define aperture 21; legs 15 and 16 and side rail control portions 12b and 13b define aperture 22; legs 16 and 17 and side rail switching portions 12c and 13c define aperture 23; legs 17 and 18 and side rail control portions 12d and 13d define aperture 24; and legs 18 and 19 and side rail control portions 12e and 13e define aperture 25. The element 11 is advantageously formed of a magnetic material having square loop hysteresis characteristics and the legs are flux limited, that is, all of the legs have substantially the same minimum cross-sectional areas. A magnetic element of the character contemplated herein is described in detail, for example, in the copending application of T. H. Crowley and U. F. Gianola referred to previously herein.

Input windings 31 and 32 are inductively coupled to side rail control portion 13a and to leg 18, respectively, while input windings 33 and 34 are inductively coupled to leg 15 and to side rail control portion 12e, respectively.

Clock windings 35 and 36 are inductively coupled to legs 14 and 19, respectively. A read-out winding 37 is inductively coupled to side rail switching portion 12c, and an output winding 38 is inductively coupled to side rail switching portion 13c. Additionally, the output winding 38 has output terminals 61 connected thereto.

An input pulse source 41 is provided to transmit an A series of information pulses simultaneously to the input windings 31 and 32 via a first information input circuit 54, which circuit connects the latter windings in series. An input pulse source 42 is provided to transmit a B series of information pulses simultaneously to the input windings 33 and 34 via a second information input circuit 55, which circuit connects the latter windings in series. A clock pulse source 43 is provided to transmit a series of clock pulses to the clock windings 35 and 36 via a clock circuit 56, which clock circuit connects the clock windings 35 and 36 in series. The timing of each of the input pulse sources 41 and 42 and the clock pulse source 43 is controlled by a timing circuit 45 which is connected to the sources 41, 43 and 42 by conductors 51, 53 and 52, respectively. A read-out pulse source 44 is connected via a read-out circuit 57 to the read-out winding 37. Each of the circuits 54, 55, 56 and 57 is connected at its other end to ground. The pulse sources 41 through 44 may comprise any suitable circuits well known in the art capable of providing pulses of the magnitude and polarity to be hereinafter described and are consequently represented by block diagrams only. Similarly, the timing circuit 45 may comprise any well-known circuit capable of synchronizing the energization of the pulse sources to which it is connected, and it is therefore also represented in block diagram form.

Bearing in mind the foregoing organization of the depicted embodiment of a comparison circuit according to the principles of this invention, a detailed description of an illustrative operation of the circuit will now be set forth.

Initially a positive pulse from the read-out pulse source 44 generates, by means of the read-out winding 37, a remanent saturation flux through the legs 16 and 17 in a clockwise direction as viewed in the drawing, about the aperture 23, which aperture 23 may be designated for purposes of description as the comparison aperture. This saturation flux and its direction is represented in the drawing by the broken line 23' and its arrowheads. With the establishment of the normal flux state about the comparison aperture 23, the circuit is prepared for the introduction therein of the sequences of information bits, the pairs of which are to be compared.

The first illustrative operation which will be described is one in which a match occurs between the bits of the pair of bits being introduced into the circuit, the particular bits each comprising binary "0's." In the conventional manner, the latter values will be represented on the input circuits by the absence of signals during the input interval. Accordingly, during this interval no signals will appear on the information input circuits 54 and 55 and no drives will be applied to the magnetic element 11 by the windings 31, 32, 33 or 34. During each input interval, however, a positive clock pulse is applied from the clock pulse source 43 to the clock windings 35 and 36 via the clock circuit 56. The latter windings are in a sense with respect to the legs 14 and 19, respectively, that a magnetic flux is induced in the latter legs in the direction indicated by the arrows 14' and 19', respectively. Flux closure for the latter flux is readily found through the adjacent legs 15 and 18, respectively, since these legs provide the shortest closure paths and also in view of the fact that no other magnetic drives are being applied to the element 11 to interfere with such closure. Accordingly, as a result of the clock drive presently being applied, the remanent flux around the comparison aperture is left undisturbed. During the next succeeding input interval, should the clock pulse

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from the source 43 again be the only drive applied to the element 11, that is, if a match again occurs between a pair of "0" information bits, the remanent flux around the comparison aperture will again be left undisturbed.

A match may also occur between the bits of a pair of information bits when input signals representative of those bits appear on both of the input circuits 54 and 55 during the input interval. In this case a positive current pulse is supplied from each of the input pulse sources 41 and 42 representative of binary "1's." These pulses are timed to occur simultaneously with the clock pulse from the clock pulse source 43 by a control pulse supplied from the timing circuit 45. The input pulse applied to the winding 31 exerts a magnetomotive force on the side rail control portion 13a of the side rail 13 in a direction represented by the arrow 31'. However, the winding 31 is provided with the same number of turns as the clock winding 35 which, as may be determined from the drawing, is at the same time therefore exerting an equal magnetomotive force in the opposite direction on the leg 14. The two applied forces are thus cancelled out. Since, as was previously described, the circuit and magnetic element 11 are symmetrical, the same cancellation of magnetomotive forces exerted by the windings 36 and 34 occurs as a result of the current pulse being simultaneously applied to the circuit 55. The magnetomotive force on the side rail control portion 12e exerted by the pulse on winding 34 is in a direction represented by the arrow 34'. The winding 34 is also provided with the same number of turns as the winding 36. The effectiveness of the clock pulse to cause any flux changes in the magnetic element 11 from either end of the structure has thus been counteracted. The magnetomotive forces generated by the input pulses in the windings 32 and 33 of the input circuits 54 and 55, respectively, on the other hand, are able to induce a switching flux in the legs 15 and 18, respectively, in the direction as represented by the arrows 15' and 18'. Since no drives are presently effective to prevent it, the switching flux so generated finds ready closure through the end legs 14 and 19. Although closure paths through the legs 16 and 17 for the switching flux could also be available, the latter legs are already flux saturated in the direction of the switching flux by the previously applied read-out pulse during the read-out phase. Accordingly, the remanent flux around the comparison aperture 23 is also left undisturbed when simultaneous drives are applied as a result of energizing current pulses applied to the two input circuits 54 and 55 and to the clock circuit 56.

A mismatch between information bits of the sequence of information pairs being compared occurs when either one of the input circuits 54 or 55 alone has an input current pulse applied thereto. This is indicative of the fact that a binary "1" occurs where a "0" should occur in one of the sequences of bits or, conversely, a "0" occurs where a "1" should occur. Since the circuit according to this invention as well as the magnetic element 11 is symmetrical, a description of the operation of the circuit when a signal appears only on one of the input circuits also provides an understanding of the operation of the circuit when an information signal appears only on the other input circuit. When a signal representative of an information bit "1" is applied to the input circuit 54 alone simultaneously with the applied clock pulse to the clock circuit 56 the same cancellation of magnetomotive drives generated in the windings 31 and 35 occurs as was described previously herein. Thus no effect of these drives is had on the magnetic states of the element 11 from the left side as viewed in the drawing. However, since at this time no cancelling drive is being applied as a result of a current in the input winding 34, the clock pulse in the clock winding 36 is effective to apply a magnetomotive drive to the leg 19 and maintain a saturation flux in that leg in the direction represented by the arrow 19'. The latter leg is thus denied as a

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closure path for the switching flux induced in the leg 18 by the input current in the winding 32. Due to the flux limited nature of each of the available flux paths presented in the element 11 at least some of the switching flux induced in the leg 18 finds a closure path by switching flux in the side rail switching portion 13c of the side rail 31 and the leg 16. The direction of part of the flux around the comparison aperture 23 is thus left disturbed by a mismatch occurring in the information bit pairs being compared.

The pulses transmitted from the pulse sources 41 through 44 are of sufficient magnitude to magnetically drive the element 11 beyond the knee of its hysteresis loop in order to achieve the required switching action.

It may also be demonstrated that another match or a series of matches following a single mismatch will be ineffective to restore the saturation flux around the comparison aperture to its normal state. Thus, subsequent matches will again merely affect the flux about apertures 21 and 25, while subsequent mismatches tending to switch the flux from the end of the element 11 in which the switch occurred during the initial mismatch will have no further effect upon the flux around the comparison aperture. A subsequent mismatch tending to switch the flux from the other end of the element 11 will cause a flux switching to occur in whichever of the legs 16 and 17 is closer to the other end but will have no effect upon the flux conditions of the side rail switching portions 12c and 13c.

During a subsequent read-out phase of operation a read-out pulse is again applied to the read-out circuit 57. As a result, the magnetomotive drive developed in the read-out winding 37 restores the remanent saturation flux around the comparison aperture 23 to its normal state. This restoration involves a flux switching in the side rail switching portion 13c of the side rail 13 to which the output winding 38 is coupled. An output signal is induced in the latter winding 38 as a result of the restoration of the normal flux around the aperture 23, which output signal is indicative that a mismatch occurred in the sequence of information signals being compared. Manifestly, an output signal of the opposite polarity was also developed in the output winding 38 when the normal flux in the side rail switching portion 13c was first disturbed at the time when the mismatch occurred. The latter signal may either be suppressed by the use of suitable unidirectional current means, not shown in the drawing, or may be used instead of or in conjunction with the signal so developed during the read-out phase as dictated by considerations of the system of which the present invention may comprise a part.

In the foregoing description of representative operations of a comparison circuit according to this invention a particular order of operations was assumed for purposes of description. Thus, it was first assumed that a match represented by the absence of signals on the input circuits occurred, then a match represented by the presence of input signals on both of the input circuits was assumed, and finally it was assumed that an input signal was present on either one of the input circuits alone, each simultaneously with the applied clock drive. In these operations particular flux switchings and closures were assumed, and the flux behavior described in each case provides a sufficient theoretic explanation, bearing in mind the flux limited nature of each flux path of the magnetic element 11. It is to be understood, however, that the actual flux behavior within the physical structure of the element 11 may be considerably more complex; however, the details of the magnetic phenomena within the element 11 are not necessary for an understanding of the organization of the present invention and the manner of its practice. Further, it is obvious that the particular flux distribution within the element 11 is in part determined by the particular switching history, that is, the particular sequence of the match or mis-

match situations. Accordingly, the particular flux distribution need not necessarily be identical to those described above after each input interval. However, each distribution pattern may be described in terms of the illustrative operations and sequence described above; the flux limited nature of each flux path of the element 11 insuring that flux switching occurs in the side rail switching portions 12c and 13c only as the result of and at the times of the particular combinations of input signals described above.

What has been described is considered to be only one illustrative embodiment of the present invention. Accordingly, it is to be understood that various and numerous other arrangements may be devised by one skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. An electrical circuit comprising a magnetic element having substantially rectangular hysteresis characteristics, said element presenting a sequence of flux legs, means for inducing a normal flux condition in a switching portion of said element between a central pair of adjacent ones of said flux legs, means for inducing a drive flux simultaneously in a first and a last leg of said sequence of flux legs, a first input means for simultaneously counteracting said drive flux in said first leg and preventing closure of said drive flux in said last leg except through said switching portion of said element, a second input means for simultaneously counteracting said drive flux in said last leg and preventing closure of said drive flux in said first leg except through said switching portion of said element, and an output winding inductively coupled to said switching portion of said element.

2. An electrical circuit comprising a magnetic element having substantially rectangular hysteresis characteristics, said element having a sequence of flux legs to present a plurality of flux paths, each of said flux paths being flux limited to the same flux magnitude, means including a read-out pulse source operable in a first phase of operation for inducing a normal flux condition in a switching portion of said element, means including a clock pulse source for inducing a drive flux simultaneously in a first and a last leg of said sequence of flux legs, a first input means including a first input pulse source for simultaneously counteracting said drive flux in said first flux leg and preventing closure of said drive flux in said last leg except through said switching portion of said element, a second input means including a second input pulse source for simultaneously counteracting said drive flux in said last leg and preventing closure of said drive flux in said first leg except through said switching portion of said element, and an output winding inductively coupled to said switching portion of said element energized responsive to flux switching in said switching portion of said element when said read-out pulse source is operated in a second phase of operation for generating an output signal.

3. A comparison circuit comprising a magnetic element having substantially rectangular hysteresis characteristics, said element presenting a sequence of flux legs, a read-out winding on a switching portion of said element between a central pair of adjacent ones of said flux legs, means for applying a read-out pulse to said read-out winding for inducing a normal flux condition in said switching portion, a serially connected first and second drive winding on a first and a last flux leg, respectively, means for applying a clock pulse to said first and second drive windings for inducing a drive flux in each of said first and last flux legs, a first input winding on a control portion of said element between said first flux leg and its adjacent leg, a second input winding on a control portion of said element between said last flux leg and its adjacent leg, a third input winding on the leg adjacent said first leg, a fourth input winding on the leg adjacent said last leg, a first input circuit means including a first input

pulse source and said first and said fourth input windings for controlling flux switching in said switching portion of said element, a second input circuit means including a second input pulse source and said second and said third input windings for also controlling flux switching in said switching portion of said element, and an output winding on said switching portion of said element.

4. A comparison circuit according to claim 3 in which said sequence of flux legs comprises only said pair of central adjacent flux legs, said first flux leg and its adjacent flux leg, and said last flux leg and its adjacent flux leg.

5. An electrical circuit comprising a magnetic element of a material having substantially rectangular hysteresis characteristics, said element comprising a sequence of flux legs including a pair of central adjacent flux legs connected by switching portions of said element, a first flux leg connected to an adjacent flux leg by first control portions of said element, and a last flux leg connected to an adjacent flux leg by second control portions of said element, a read-out circuit including a read-out winding on one of said switching portions, a clock circuit including a clock winding on each of said first and said last flux leg, a first input circuit including input windings on one of said first control portions and said leg adjacent said last flux leg, respectively, a second input circuit including input windings on one of said second control portions and said leg adjacent said first flux leg, respectively, and an output winding on the other of said switching portions.

6. A comparison circuit comprising a multiapertured magnetic element having a pair of side rails with a plurality of flux legs transversely disposed in a spaced relationship therebetween, said side rails and flux legs presenting a plurality of flux paths, all of said flux paths being flux limited to the same flux magnitude, means for inducing a normal flux condition in a switching portion of one of said side rails between an interior pair of adjacent ones of said flux legs, means for inducing a first and a second drive flux simultaneously in a first and a last flux leg, respectively, of said sequence of flux legs, a first input means for simultaneously counteracting said first drive flux and preventing closure of said second drive flux except through said switching portion, a second input means for counteracting said second drive flux and preventing closure of said first drive flux except through said switching portion, and an output winding inductively coupled to said switching portion.

7. A comparison circuit as claimed in claim 6 in which said first input means comprises a first neutralizing winding coupled to a flux path including said first flux leg, a first blocking winding coupled to the flux leg adjacent said last flux leg, and means for simultaneously applying input pulses to said first neutralizing and blocking windings; and said second input means comprises a second neutralizing winding coupled to a flux path including said last flux leg, a second blocking winding coupled to the flux leg adjacent said first flux leg, and means for applying input pulses to said second neutralizing and blocking windings.

8. A comparison circuit according to claim 6 in which said means for inducing a normal flux condition in said switching portion comprises a read-out winding inductively coupled to a flux loop including said switching portion and means including a read-out pulse source for applying a read-out pulse to said read-out winding.

9. A comparison circuit according to claim 8 in which said means for inducing a first and a second drive flux simultaneously in a first and a last flux leg, respectively, comprises serially connected first and second drive windings on said first and last flux legs, respectively, and means for applying a clock pulse to said first and second drive windings.

10. A comparison circuit according to claim 9 in which said first input means comprises a first neutralizing winding inductively coupled to a flux loop including said first flux leg, a first blocking winding on a flux leg adjacent said

last flux leg, and a first circuit means including a first input pulse source and said first neutralizing and blocking windings.

11. A comparison circuit according to claim 10 in which said second input means comprises a second neutralizing winding inductively coupled to a flux loop including said last flux leg, a second blocking winding on a flux leg adjacent said first flux leg, and a second circuit means including a second input pulse source and said second neutralizing and blocking windings.

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