The Transfluxor

J. A. RAJCHMAN  A. W. LO

In a recent paper the authors have announced a novel device showing that completely new switching and storing functions can be performed by employing magnetic cores with two or more apertures. Magnetic circuits using multi-aperture cores have also been reported elsewhere instead of the conventional single-aperture cores, thereby creating a number of distinct flux paths via the legs of the core. The new device operates by the controlled transfer of flux from leg to leg in the magnetic circuit and was consequently named “transfluxor.”

One of the most important properties of the transfluxor is its ability to store a level of control established by a single electric pulse. An energizing a-c drive will or will not produce an a-c output depending upon the nature of the last setting pulse to which the transfluxor was subjected. Furthermore, intermediate setting is possible for which an output of any desired level in a continuous range between almost zero and a maximum level will be produced according to the amplitude of a single setting pulse.

In the present paper, after a short review of the principle of the new device, its operation is illustrated in detail by the characteristics of a typical 2-aperture transfluxor and some of its applications. Several examples of logical functions attainable with multiapertured transfluxors are also included.

Principle of the 2-Aperture Transfluxor

Consider a core made of magnetic material such as a molded ceramic “ferrite” which has a nearly rectangular hysteresis loop and consequently a remanent induction B_r substantially equal to the saturated induction B_s. Let there be two circular apertures of unequal diameter which form three distinct legs, 1, 2, and 3, in the magnetic circuit, as illustrated in Fig. 1. The areas of the cross sections of the legs 2 and 3 are equal and the cross section of leg 1 is equal to, or greater than, the sum of those of legs 2 and 3.

The operation of the device previously explained is reviewed here for convenience. Assume that at first an intense current pulse is sent through winding W_1 on leg 1 in a direction to produce a clockwise flux flow which saturates legs 2 and 3. This is possible since the larger leg 1 provides the necessary return path. These legs will remain saturated after the termination of the pulse since remanent and saturated inductions are almost equal.

Consider now the effect of an energizing alternating current in winding W_1 linking leg 3, producing an alternating magnetomotive force along a path surrounding the smaller aperture, as shown by the shaded area in Fig. 1. When this magnetomotive force has a clockwise sense, it tends to produce an increase in flux in leg 3, and a decrease in leg 2. But no increase of flux is possible in leg 3 because it is saturated; consequently, there can be no flux flow at all, since magnetic flux flow is necessarily in close paths. Similarly, during the opposite phase of the alternating current, the magnetomotive force is in a counterclockwise sense and tends to produce an increase of flux in leg 2, but in the case leg 2 is saturated. Consequently, flux flow is blocked as the result of the direction of saturation of either leg 2 or 3. The transfluxor is in its blocked state and no voltage is induced in an output winding W_0 linking leg 3.

Consider now the effect of a current pulse through winding W_1 in a direction producing a counterclockwise magnetomotive force. Let this pulse be intense enough to produce a magnetizing force in the last leg 2 larger than the coercive force H_c, but not large enough to allow the magnetizing force in the more distant leg 3 to exceed the critical value. This pulse, called hereafter the “setting pulse,” will cause the saturation of leg 2 to reverse and become directed upwards (Fig. 1), but will not affect leg 3 which will remain saturated downward. In this condition, the alternating magnetomotive force around the small aperture resulting from the alternating current in winding W_1 will produce a corresponding flux flow around the small aperture. The first counterclockwise phase of the alternating current will reverse the flux, the next clockwise phase will reverse it again, etc., indefinitely. This flow may be thought of as a back-and-forth transfer of flux between legs 2 and 3. The alternating flux flow will induce a voltage in the output winding W_0. This is the unblocked or “maximum-set” state of the transfluxor.

It is seen that the transfluxor is blocked when the directions of remanent induction of the legs surrounding the smaller aperture are the same, and unblocked when they are opposite. In the blocked state the magnetic material around the small aperture provides essentially no coupling between the primary (W_1) and secondary (W_0) windings, while it provides a relatively large coupling between these two windings in the unblocked state. It is interesting to note that the information as to whether the transfluxor is blocked or unblocked can be thought of as being stored in terms of the flux through leg 1, and that this stored flux does not change when output is produced by interchange of flux between legs 2 and 3.

The transfluxor can also be set to any level in a continuous range in response to the amplitude of a single setting current pulse. Once set, it will deliver indefinitely an output proportional to the setting. This may be explained in a simplified manner as follows: Consider first the transfluxor in its blocked condition. Let there be a setting current pulse through winding W_1 of a chosen amplitude and, of course, of a polarity opposite that of the original blocking pulse. A magnetizing force H, proportional to this current, is produced around the large hole. This force in the magnetic material is greatest at the periphery of the hole and diminishes gradually with distance. In the case of a circular aperture it is inversely proportional to the radius. Therefore, for the given selected amplitude of the setting current pulse, there will be a critical circle separating an inner zone, in which the magnetizing force is larger than the threshold magnetizing force H_c required to reverse the sense of flux flow, and an outer zone, where this field is smaller than the threshold value. These two zones are shown in Fig. 2. Consider now the alternating magnetomotive force on leg 3 produced by an indefinitely long sequence of pulses of alternating polarity. The first pulse, applied to leg 3 in a direction to produce downward magnetization in leg 2, can change only that part of the flux in leg 2 which is directed upwards, namely that part which has been set or trapped into that leg by the setting pulse. This changing part of the flux will flow through.
leg 3 until leg 2 reaches its original downward saturation. The amount of flux set into leg 2 is therefore transferred to leg 3. The next pulse, applied to leg 3, will saturate it to its original downward direction and thereby retransfer the trapped amount of flux back to leg 2. There is no danger of any transfer of flux to leg 1, since the magnetizing path is much longer through that leg, and, once leg 3 is saturated, no further flux flow is possible however intense this second pulse. It is apparent, therefore, that the succession of pulses of alternating polarity on leg 3 will cause an interchange between legs 2 and 3 of an amount of flux just equal to that initially set into leg 2. This will produce across the output winding \( W_o \) an indefinitely long train of voltage pulses. The magnitude of the output or the analogue information can be thought of as stored in terms of the flux in leg 1 (or algebraic sum of fluxes in legs 2 and 3), just as was the case for the on-off information. This stored flux is not affected by the output-producing interchange of flux between legs 2 and 3.

There is a possibility that, in the blocked condition, or any intermediary set condition, a sufficiently large alternating current in the phase tending to produce counterclockwise flux flow could in fact change the flux in leg 3 by transferring flux to leg 1. There is, therefore, a limit to the permissible amplitude of the energizing alternating current because of the possibility of spurious unblocking. The limiting amplitude is increased by the use of unequal hole diameters rendering the flux path via legs 1 and 3 much longer than via legs 2 and 3.
There is no danger of spurious unblocking by the alternating current in the phase tending to produce a clockwise flux flow, since in this phase leg 3 is being magnetized in the direction in which it is already saturated. Therefore, there is a considerable advantage in using asymmetric-energizing alternating current or a train of interlaced relatively large driving pulses (clockwise) and relatively small priming pulses (counterclockwise). The driving pulses, which cannot possibly spuriously unblock a blocked transfluxor, can be arbitrarily large, with the result that, when the transfluxor is unblocked by proper setting, these pulses may not only provide the required minimal reversing magnetizing force around the small aperture, but also provide substantial power to deliver large output currents. The priming pulses must be of sufficient magnitude to provide the required magnetizing force around the small aperture, but insufficient to provide it around both apertures.

The Prototype 2-Aperture Transfluxor

Inherent Characteristics

The core of the transfluxor for which the characteristics are given in the following was made of magnetic ceramic material (manganese-magnesium ferrospinal; 30 per cent MnO, 30 per cent MgO, 40 per cent Fe₂O₃), of composition and processing identical to those used for memory cores. The dimensions are shown in Fig. 3.

The knowledge of the actual amounts of flux set in leg 2 and leg 3 by a pulsed magnetomotive force applied to leg 1 can be used to evaluate the idealized explanation of the operation given in the foregoing as well as to predict the detailed operation. These inherent setting properties, illustrated in Fig. 4, were obtained as follows: Leg 1 was subjected first to a relatively large blocking pulse of 5 ampere-turns magnetomotive force, and then to a setting pulse the amplitude of which is the abscissa of the plot. The instantaneous voltages on 1-turn windings linking legs 2 and 3 were integrated throughout the duration of the setting pulse, including the rise and decay of the pulse. These integrated values are the irreversible, or net, flux changes \( \Phi_2 \) and \( \Phi_3 \) produced by the setting, and are shown as the ordinates of the plot.

Ideally, the variations of the fluxes \( \Phi_2 \) and \( \Phi_3 \) can be predicted by considering the location of the closed line of magnetic induction passing through leg 1.
Operating Characteristics

The amount of flux which is interchanged between legs 2 and 3 for a given setting by priming and driving pulses, determines the output from the transfluxor and will be referred to as the output flux. The setting pulse will determine the maximum interchangeable amount of flux while the priming and driving pulses will determine what part of that flux is actually interchanged. It is convenient to consider as setting characteristics the plots of the output flux as a function of the setting magnetomotive force for given priming and driving pulses, and as driving characteristics the plots of the output flux as a function of the driving pulse for given setting and priming pulses. The main mode of operation consists of blocking and setting on leg 1, priming and driving on leg 3, and deriving the output from leg 3. There are two cases of interest: (1) asymmetrical energization consisting of unequal drive and prime pulses useful when efficient loading is desired, and (2) symmetrical energization consisting of equal drive and prime pulse or sinusoidal current encountered in small signal a-c transmission.

The setting characteristics for asymmetrical energization shown in Fig. 5, can be explained as follows: the flux change \( \phi_{1b} \) in leg 1, set into it by the setting pulse, will divide itself, in general, between legs 2 and 3 where the changes of flux \( \phi_{1b} \) and \( \phi_{1c} \) will be produced \( \phi_{1b} = \phi_{1c} + \phi_{1d} \). When the set flux \( \phi_{1b} \) is smaller than the maximum flux containable in the narrowest leg, (in this case leg 3, which is slightly narrower than leg 2) the setting is referred to as normal. For normal setting the first prime pulse on leg 3 will saturate leg 2 in its original blocked direction of saturation, transferring the flux \( \phi_{1b} \) set in leg 2 to leg 3, thereby concentrating the amount of flux equal to \( \phi_{1b} \) in leg 3. When the drive pulse is of an amplitude just sufficient to saturate the entire width of leg 3 (1 ampere-turn), the flux concentrated in that leg by the prime pulse will be retransferred to leg 2. The steady-state interchanged output flux between legs 2 and 3 will, therefore, be precisely that set initially in leg 1, which in turn is equal to the sum of fluxes \( \phi_{1c} \) and \( \phi_{1b} \) shown on the inherent set curves of Fig. 4. This flux increases linearly up to the limit of normal setting which is about 1.5 ampere-turns.

When the drive is not sufficient to transfer all the flux of leg 3 back to leg 2, only a part of the interchangeable flux set in leg 3 will be, in general, actually interchanged. This explains the shape of the setting characteristic for lower drives (less than 1 ampere-turn). These curves follow the main characteristic only up to the value of drive for which the whole set-in flux can be transferred.

When the flux \( \phi_{1b} \) set in leg 1 exceeds that containable in the wider of the two legs, 2 or 3, it oversets the transfluxor by starting to reverse the fluxes in all legs, producing blocking. Therefore, the amount of output flux interchanged between legs 2 and 3 diminishes. The rate of decrease of the output flux with increasing setting current is smaller in the overset region than the rate of increase in normal region because of the asymptotic nature of the curve near saturation (see Fig. 4). The loss of output flux due to oversetting may be corrected by overdriving. A large enough driving pulse on leg 3 will saturate it completely in the original blocked downward direction by transferring flux first to leg 2 until it is saturated and then the excess to leg 1. Therefore an overset and overdriven transfluxor will produce the maximum output, as shown by the characteristic curves of Fig. 5.

The driving characteristics of Fig. 6, for the same asymmetrical energization, show that arbitrarily large driving pulses may be used without disturbing normal setting as was explained before. There
is a threshold value of 0.2 ampere-turn, corresponding to the value of magnetomotive force producing a magnetizing force just equal to the coercive force at the periphery of the small aperture, below which there is no interchange of flux between legs 2 and 3. Each curve exhibits a sharp threshold followed by an approximately linearly rising curve.

The setting characteristics for symmetrical energization with equal drive and prime pulses, shown on Fig. 7, may be explained by considering first the idealized situation for a normal setting in which two zones are created in leg 2; one near the large aperture where the flux is reversed, and one near the smaller aperture where it remains unaffected (see Fig. 9). When the prime pulse on leg 3 is insufficient to produce a magnetizing force greater than the coercive force at the location of the boundary between the two zones, no flux will be transferred to leg 3. There will be a definite value of prime for a given setting, for which transfer will start to occur. The amount of transferred flux will be proportional to that portion of the cross section of leg 2 which is included between the boundary separating the set and nonset zones around the larger aperture, and the boundary between the primable and nonprimable zones around the small aperture, as shown in Fig. 9. This flux increases with setting, for a given prime, at a rate which is independent of the priming value. When the priming pulse becomes large enough to produce interchange of flux between legs 3 and 1, it will effectively produce a setting of leg 1 even when no previous setting on leg 1 was applied. This is the spurious unblocking due to symmetrical drive and prime mentioned earlier. The characteristics of Fig. 7 have approximately the shape to be expected from these considerations.

The driving characteristics for the symmetrical energization case are shown in Fig. 8. The range of the priming pulses, and consequently also of the driving pulses, is restricted to the values (up to 1 ampere-turn) which do not produce spurious settings. For a given setting, the amount of interchangeable output flux is proportional to the flux in leg 2 which is both set and primable. The threshold value of prime, below which no flux is interchanged, is smaller the greater the setting, since the boundary between set and nonset zones is closer to the small aperture in this case.

In the main mode, with either asymmetrical or symmetrical energization, the input control (setting) circuits are completely separated from the output circuits, since the block and set winding is on leg 1 and the priming, driving, and output windings are on leg 3. There is negligible coupling between the control and output circuits because there is practically no interchange of flux between legs 1 and 3 in normal operation. For example, in the prototype transfluxor set to maximum, the back-and-forth interchange of flux between legs 2 and 3 is 1.5 volt-microseconds, and this is accompanied by only 0.01 volt-microsecond of flux change in leg 1, or less than 1 per cent. Furthermore, normal setting pulses produce only slight changes of flux in leg 3, of only about 3 per cent of the flux set into leg 2 by maximum setting. If blocking occurs after driving, rather than priming, it produces a negligible flux change in leg 3 since the drive pulse has already saturated that leg in the direction of blocking.

An arbitrarily large priming pulse, rather than one needing to be of a prescribed amplitude, can be used by priming on leg 2 rather than on leg 3. After normal setting, the prime pulse will saturate leg 2 downward to its original blocked direction and transfer flux to leg 3 rather than leg 1 because the flux path is shorter. A further increase of the prime pulse on leg 2 produces no further flux change because leg 2 is saturated. When the transfluxor is overset, the prime pulse on leg 2 transfers to leg 3 that part of its flux that leg 3 can accept and forces the excess flux to leg 1, where it readjusts the setting. Oversetting is thus corrected for by the first prime pulse which causes the transfluxor to be set for maximum output. In this mode of priming on leg 2, the setting pulse induces a voltage in the prime winding. Thus, there is an interaction between setting and priming circuits. This interaction can be tolerated in the many practical cases in which the priming winding is in the plate circuit of a vacuum tube.

In some on-off applications of the transfluxor, it is convenient to set on leg 2 rather than on leg 1 to avoid the possi-
bility of oversetting. The setting amplitude is not critical as long as it is greater than some required minimum (about 1.3 ampere-turns). In this case the large setting pulse producing an upward magnetomotive force on leg 2 forces the flux of leg 2 to reverse its blocked direction. Since flux flow through leg 3 is impossible, necessary continuity of flux is satisfied by an interchange of flux between legs 2 and 1, which leaves leg 1 with practically zero flux and leg 2 with an upward saturation. This is the unblocked state of the transfluxor. The pulses on legs 1 and 2 serve respectively as the blocking and unblocking pulses and close or open the transfluxor gate. In this mode there is direct coupling between the setting winding on leg 2 and the output, since the output flux is precisely the interchangeable flux between legs 2 and 3. Here again this coupling is tolerable in many practical cases, e.g., when the setting winding is in the high impedance circuit of a vacuum tube. It is possible also to use leg 2 both for setting and priming.

Output From the Transfluxor

The transfluxor exercises control by means of the amount of flux which can be transferred for an indefinitely long time between legs 2 and 3, and which amount can be set by a single pulse to any desired value in a continuous range. This back-and-forth transfer of flux between legs 2 and 3 can be considered also as a back-and-forth reversal of flux around the small aperture along a path which is effectively the output magnetic circuit and may be characterized by a conventional hysteresis loop relating the flux flow and the magnetomotive force on leg 3 producing it. Fig. 10 shows oscilloscope traces of a family of such loops, each obtained for a different setting, including the blocked and maximum settings.

It is apparent that the transfluxor operates as if the output magnetic circuit consisted of a conventional 1-aperture core with the essential property that the effective cross-sectional area of that core can be adjusted by a single set pulse to any desired value from practically zero to a maximum value equal to the physical cross-sectional area of its smallest leg.

The relations which exist between the primary and secondary circuits of a pulse transformer apply equally well to the output circuit of the transfluxor, provided account is taken of the definite set cross-sectional area of the equivalent core and the properties of the material of the core. These include the shape of the hysteresis loops and the intrinsic possible rates of flux reversal. The salient properties of the output circuit can be illustrated by the cases of very high and very low impedance loading.

Output voltage wave forms are shown in the oscilloscope traces of Figs. 11a and 11b for the case of an open-circuited output winding, i.e., a very high impedance load. The traces are for the various values of setting, as indicated. For the relatively large (5 ampere-turn) and fast rising (3.5 ampere-turns per microsecond) drive of Fig. 11a, and for the relatively slow (1 ampere-turn) and slow rising (0.7 ampere-turn per microsecond) drive of Fig. 11b, the voltage peaks vary linearly with the current settings. The unloaded transfluxor may therefore be considered as a device furnishing a controllable voltage. The short flux-reversal time of 0.1 microsecond for large drive is noteworthy.

The ratio of output voltage at maximum setting (1.5 ampere-turn) to that at zero setting or blocked condition, is 15 to 1 for the large drive of Fig. 11a, and 50 to 1 for the smaller drive of Fig. 11b. The slight voltage output in the blocked condition results from the elastic or reversible flux excursion because of the lack of perfect saturation at remanence of the material composing the transfluxor's core. There is actually no measurable irreversible output flux for zero setting. (See Figs. 5, 6, 7, and 8.)

The output voltage wave forms, developed across a very low resistance load, for different settings, are shown in Fig. 12a. The setting is seen to control the duration of the pulses rather than the voltage maximums which are very flat and almost the same for all settings. This results from the fact that the counter-magnetomotive force due to the secondary current tends to keep the rate of change of flux constant. The output current in a low resistance load for a transfluxor set to maximum is shown in Fig. 12b for different drive currents. The output current increases linearly with drive current; the heavily loaded transfluxor may therefore be considered to be a current transformer. The efficiency of power transmission is high for large drives since only a small part of the drive is wasted in magnetizing the output magnetic circuit and the major part neutralizes the secondary counter-magnetomotive force and produces the output current. Efficiencies of 75 per cent have been obtained. This important property of the transfluxor reflects the advantage of using unsymmetrical output circuit energization, i.e., small and slowly rising priming current pulses producing negligible output and no spurious setting, and fast-rising large-amplitude drive pulses producing the useful output.

In the foregoing illuminations the transfluxor was used as an adjustable transformer with a primary winding energized by a current generator and a secondary winding carrying the load. In many applications it is convenient to use it as an adjustable inductance with a single winding (on leg 3) in series with a voltage generator and the load. In that case a high output is obtained when the transfluxor is blocked and a low output when it is unblocked, but besides this inversion, all operations as an inductance or as a transformer are similar.

The material composing the core of the prototype transfluxor permits short switchover times. Conventional memory cores, made of this material, switch in about 1.5 microseconds when driven by a current giving optimum discrimination in a 2-to-1 driving system. In the

Fig. 10. Hysteresis loops of the output magnetic circuit for various settings

Fig. 11. Voltage output wave forms for open circuit

(a) Large drive

(b) Small drive

Rajchman, Lo—The Transfluxor
in the operating characteristics, the setting requires about 2 microseconds. As was noted, very much shorter output pulses are possible when strong drives are used. The repetition rates of the driving and priming pulses or the frequency of sinusoidal a-c energization can be 1 megacycle or more without any appreciable heating of the core of the transfluxor. There is no lower limit to the frequencies used in the output circuit, other than that imposed by the practical use of the low voltages resulting therefrom.

Applications of the Transfluxor

INFORMATION REGISTERS FOR DIGITAL COMPUTERS

The transfluxor can be operated as an on-off gate utilizing only the blocked and the set-to-maximum or unblocked settings. The amplitude of the blocking pulse on leg 1 is not critical provided it is greater than some minimum. Similarly, the unblocking pulse can be rendered uncritical if applied to leg 2, as was mentioned in the foregoing, or if a third setting aperture is provided, as will be described. In this operation the transfluxor performs the same function in digital computing applications as does a gate controlled by a conventional tube or transistor flip flop. Once set, the gate remains open or closed without requiring any holding power. A bank of transfluxors constitutes a register for storing a number of binary signals from which read-out signals can be obtained any number of times without destroying the stored information. These signals can be conveniently generated from a common source gated by the individual transfluxors. No signals in the setting circuits result from the interrogation when proper arrangements are made.

RANDOM-ACCESS MEMORY WITH NONDESTRUCTIVE READ-OUT

An array of transfluxors can be used as a random-access memory with so-called nondestructive read-out, i.e., where the read-out is obtained without changing at any time the physical state representing the information. The two stored states are the blocked and unblocked remanent conditions of the transfluxor. Current coincidence can be utilized for selection, as is done in conventional core memories.

Consider two selecting windings on leg 1 and two selecting windings on leg 3 of each transfluxor. Let these windings be connected in series by rows and columns as shown for simplicity by single linking wires on Fig. 13. Address-selecting writing pulses are applied simultaneously to one row and one column winding linking leg 1. The additive effect of these pulses on the selected transfluxor at the intersection of the row and column windings is sufficient to produce a setting, but the amplitude of the pulses is insufficient to affect the transfluxors on which they act singly. The direction of the writing pulses determines whether the selected transfluxor is set to the blocked or unblocked condition. Reading, based also on current coincidence selection, is obtained by applying pulses of the proper amplitude to the selected row and column winding linking leg 3. A read-out is obtained by a pair of pulses on each selecting line, one in the prime and one in the drive direction. As a result, fluxes in legs 2 and 3 reverse back and forth and return to their initial state, if the transfluxor is unblocked, or remain in that initial state, if the transfluxor is blocked. These flux reversals can be detected as induced voltages on a common read-out winding linking leg 3 of all transfluxors. (See Fig. 13.)

Coincident current selections for write-in and read-out are possible because there are thresholds below which pulses linking leg 1 and leg 3 produce negligible flux changes. Satisfactory operation is obtained with the prototype transfluxor when the selecting currents are approximately equal to the threshold values of setting and prime drive shown on the characteristic of Fig. 7. Somewhat better results are found when the blocking write-in pulses are larger than the setting write-in pulses. The coincident current selection principle can be extended to the simultaneous addressing of many plane arrays used in parallel by using selective inhibiting of the planes, as is customary with core memories.

Read-out from a magnetic storage device must necessarily be dynamic, since induced voltages are possible only by changing flux. Nevertheless, in the transfluxor memory, the read-out may be considered to be nondestructive, because the flux in leg 1 is not altered by the interrogating pulses, retains at all times the stored information, and yet its value determines whether or not flux in legs 2 and 3 will be interchanged as a result of interrogation. The second interrogating pulse is necessary to restore the altered states of legs 2 and 3 due to the first, in a manner similar to the rewrite pulse in destructive read-out memories required when a read-out signal is obtained, but with the essential difference that its unconditional occurrence at every read-out is not dependent on the presence of the read-out signal.

In the transfluxor coincident current memory the read-out circuits are very simple since no feedback into the write-in circuits are required. A further, perhaps more important, advantage, is the possibility of simultaneously writing-in and reading-out on two unrelated addresses, by energizing the proper lines of the independent write-in and read-out selecting grids. This possibility may speed up the operation and simplify the logic of some types of computing machines.

CHANNEL SELECTOR

Transfluxors may be used with advantage to select one channel out of many for transmission of modulated signals. The transmission from, or to, a common channel to, or from, each one of a

Fig. 12. Voltage output wave forms for low resistance load
(a) Various settings
(b) Various drives

Fig. 13. Array of transfluxors used as random access memory with nondestructive read-out

Rajchman, Lo—The Transfluxor
number of selectable channels is controlled by a transfluxor. All transfluxors are blocked except one which is set and which determines the selected channel.

A channel selector for selecting one out of \( N = 2^n \) channels in response to \( n \) binary pulsed signals is illustrated in Fig. 14 for the case of eight channels and three binary inputs. The selection system is similar to that used in combinatorial decoding switches using conventional cores. For each binary input there is a pair of conductors, one of which links leg 1 of half the transfluxors and the other, the other half. The division of transfluxors in halves by the various input pairs is by juxtaposed halves, interlaced quarters, interlaced eighths, etc., so that the pattern of linkages is according to a binary code. To select a channel, current is sent through one or the other conductor in each pair in a direction tending to block the transfluxors which are linked by these conductors. For every combination of inputs there will be one transfluxor, and one only, which is not linked by conductors carrying the blocking currents. The transfluxor, thus selected, is set by a current pulse sent through a winding which links leg 2 of all transfluxors. The setting pulse, occurring while the selecting current pulses are on, has insufficient amplitude to overcome the blocking effect of even a single one of these blocking currents and therefore sets the selected noninhibited transfluxor only. The setting is to maximum, but there is no danger of oversetting, since leg 2 is used for setting, and the region of flux change during selection is around the large aperture only. The selected transfluxor remains set until a different combination of input pulses is applied to the selector, at which time a new transfluxor is set, and the previously selected one is automatically blocked.

Flux changes around the small aperture are possible only in the selected unblocked transfluxor of which the output magnetic circuit may be considered to be a regular transformer. Since a transformer transmits in either direction, the selector can be used either to transmit from the common channel to a selected channel or vice versa, depending on which channel corresponds to the primary winding. The primary winding can be energized by symmetric alternating current, provided that the resulting magnetization around the small aperture exceeds a certain threshold, but does not exceed a value producing spurious unblocking. In the prototype transfluxor the permissible range is from 0.25 to 1 ampere-turn. With asymmetric primary excitation a greater efficiency of power transmission is possible, as was explained in the foregoing. In this case it may be convenient to prime the transfluxor by a common winding linking leg 2 of all units (not shown on Fig. 14), to use a fixed amplitude prime pulse (1 ampere-turn for the prototype) and to modulate by the amplitude of the drive pulse.

The selector of Fig. 14 is shown with tube drivers to illustrate fully a concrete example. For simplicity, single turn windings are shown. Fig. 14b is a simplified representation of the selector, shown conventionally in Fig. 14a. The apertures of the transfluxors are represented by heavy horizontal lines which are assumed to be linked through by the vertical conductors when a 45 degree line is drawn at the intersection, the direction of inclination of the line denoting the direction of linkage.

It is possible to use the channel selector not only to gate sustained modulated signals, but also to control the amplitude of the transmitted signal in the selected channel according to the amplitude of a single-control current pulse. To accomplish this, the control pulse is sent through the set winding linking leg 2 of all transfluxors simultaneously with the selecting pulses, and sets the noninhibited selected transfluxor to a particular level in a continuous range dictated by its amplitude. Constant amplitude energization of the output circuits of all transfluxors produces through the selected one a sustained output of an amplitude determined by this level. The energization can be symmetric or asymmetric, a-c or by pulses.

The arbitrary selection, in any desired order, of the transmission channel in the channel selector described earlier is accomplished by considering the large aperture of the transfluxor as if it were a simple core and linking it through systems of selecting windings known in conventional core decoding switches. Similarly, a commutator switch for establishing transmission through the channels in ordered succession can be made by coupling the large aperture of successive transfluxors by the circuits used in con-
from a central computer, may easily be obtained with transfluxors.

These examples are cited to illustrate the variety of applications of the transfluxor.

**Multiaperture Transfluxors**

The 2-aperture transfluxor has been discussed in detail to illustrate the principles of operation and the general properties of the device in one of its simplest forms. The use of more than two apertures creates many new modes of flux transfer and broadens the kind and number of switching and storing functions, making possible many novel applications. A few illustrative examples of multiaperture transfluxors are described in the following.

A transfluxor with three apertures in a row, as shown in Fig. 15, can be operated as a 2-input sequential gate. An output is produced if the two inputs $A$ and $B$ are applied in the order $AB$, and no output is produced if either input is missing or if the two inputs are applied in the order $BA$. The operation is illustrated by the symbolic diagrams, Figs. 15b, 15c, and 15d. After a clear pulse the legs 2, 3, and 4 are saturated downward. The output flux path around the last aperture via legs 3 and 4 is blocked and neither the prime nor the drive pulse can produce any flux change. The flux path around the second aperture via legs 2 and 3 is also blocked so that the signal $B$ cannot produce any flux change. However, the flux path around the first aperture, via legs 1 and 2, is not blocked and the signal $A$ can reverse the direction of flux in leg 2 by transfer of flux to leg 1. If $A$ is present and leg 2 was reversed, the flux path via legs 2 and 3 is unblocked, with the result that the occurrence of $B$ can now reverse the flux of legs 2 and 3. This returns leg 2 to its original downward direction, reverses leg 3 and unblocks the flux path via legs 3 and 4. Consequently the output flux path is now unblocked, and a succession of priming and driving pulses will produce an output for as long as desired. This 3-aperture transfluxor can also be operated with intermediate setting. The analogue intelligence can be carried by either signal $A$ or $B$ or both.

The transfluxor with five apertures arranged in a flower-like pattern, Fig. 16, can be operated as a 4-input AND gate. The occurrence, in any order, of all four input signals $A$, $B$, $C$, and $D$ is required to open the gate. The principle of operation depends upon the fact that the output flux, via legs 1, 2, 3, and 4, around the central aperture can be blocked by any one of the four legs and is unblocked only when the senses of flux saturation around the central hole in all legs are the same. There are two unblocked states corresponding to the two senses of flux rotation around the small aperture. In many applications it is convenient to use one leg as a reference, yielding a 3-input gate, and to eliminate one of these states.

A third aperture added to the two of the transfluxor described earlier, in detail, can eliminate any possibility of over-setting. The four legs 1, 2, 3, and 4 of the transfluxor illustrated in Fig. 17 are of equal cross section. The amount of flux that can be set is limited by the width of leg 1 to precisely the amount

---

*Rajchman, Lo—The Transfluxor*
This development represents an increase in information rates as high as 2 1/2 megacycles with moderate power gains in magnetic amplifiers between one and two orders of magnitude over what has previously been reported. This large step forward was due to a number of factors:
1. Improved circuits.
2. Improved methods of analysis of high-frequency magnetic amplifiers.
3. Improved magnetic materials and new developments in core construction.

In conclusion, the transfluxor is not only capable of storing a given amount of set-in flux, but also is capable of furnishing on demand, and for an indefinite length of time, an output according to a stored setting without affecting that setting in the least. In a sense, the transfluxor combines the functions of a magnetic amplifier and a memory core.

The multiaperture transfluxor core, made of square hysteresis-loop material, used at present for ring-shaped cores, is simple to manufacture. Like other magnetic elements it is a solid-state passive element which is rugged, stable in operation, and immune to permanent deterioration due to accidental overdriving of its associated circuits.

For these reasons it is believed that there is a great future for the transfluxors described in this paper, and similar ones that can be made with artifices based on manipulating the flux distribution in cores of square-loop-magnetic material having a number of apertures in various geometrical configurations.

References

Bilateral Magnetic Selection Systems for Large-Scale Computers
A. H. Sepahban

Selective writing of information on a chosen channel of a large memory system (e.g., a magnetic drum memory) and selective reading of information from one out of many such memory channels can be accomplished by use of a single 2-way magnetic pyramid made solely of high quality magnetic saturable cores. A description is given of a working magnetic selection unit used in a large inventory control system with a few thousand magnetic drum channels.

The Megacycle Ferractor
T. H. Bonn

The Ferractor is a magnetic amplifier designed to replace vacuum tubes in digital computer pulse circuits. Operation at information rates as high as 2 1/2 megacycles with moderate power gains and power levels has been achieved. This development represents an increase in the operating gain-bandwidth of magnetic amplifiers between one and two