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The Ferreed — A New Switching Device

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An experimental switching device is described that has the following properties: (a) sealed metallic contacts, (b) control times in the microsecond range, (c) coincident selection, (d) memory without holding power and (e) small size. The device, named the ferreed, may be used as a crosspoint in telephone switching networks of the space-separation type. The development of the ferreed is traced from a conceptual model, through realization of a practical model, to possible applications in switching networks. Two methods of coincident control are discussed, and three devices related to the conceptual ferreed are described briefly.

I. INTRODUCTION

The spectacular success of the electronic technology during the last decade, particularly in the field of computers and semiconductors, has provided a challenge to the communication industry. The problem of realizing the promise of electronics in telephone switching systems has been taken up by many communications laboratories.[1,2,3] Many different approaches were and are being taken. But no component of the telephone office has received a more varied treatment than has the usually most voluminous and costly part that permits the telephone customers to be interconnected — the switching network.

The multiplicity of solutions considered for the network problem can be grouped into three main categories:

i. space-separation networks combining electronic controls with conventional electromechanical switches;

ii. space-separation networks making use of electronic devices such as gas tubes or semiconductor elements as crosspoints; and

iii. time-division techniques that attempt to utilize fully the switching speeds of the electronic devices.

It is perhaps due to the complex nature of the network problem that none of these solutions has shown very clear and conclusive evidence of economic superiority. Solutions involving conventional electromechanical networks with electronic controls suffer from the time incompatibility between the two. While removing this difficulty, the purely electronic solutions bring with them handicaps of their own: the need for different and perhaps more costly telephone sets leading to difficult and unprecedented cutover procedures, new protection problems and limitations in transmission properties.

It was in this climate that a new class of switching devices was conceived. The ferreeds, as the new devices were named, are characterized by providing metallic contacts while being controllable at electronic speeds. Furthermore, the ferreeds can be left operated without holding power being required, have sealed contacts and can be selected by coincident current methods. These properties make the devices attractive for use as network crosspoints in electronic switching systems.

II. THE CONCEPTUAL DEVICE

2.1 *Ferrite + Magnetic Reeds = Ferreed*

The ferreed, as its name implies, comprises a magnetically hard ferrite member in combination with a magnetic reed switch. The switch consists of two soft magnetic reeds, which are responsive to the remanent magnetic field of the ferrite and which also serve as electrical contacts.

A conceptual model of the ferreed may be developed from the basic device shown in Fig. 1(a). In this simple structure a pair of overlapping reeds is fastened between the ends of a semicircular ferrite member. An exciting winding is uniformly distributed over the length of the ferrite. A short pulse of current applied to the exciting winding magnetizes the ferrite, which in turn induces unlike magnetic poles at the overlapping ends of the reeds. The reeds are mutually attracted, and, if the remanent flux is sufficient to overcome the spring force, the reeds will close, thereby establishing an electrical connection.

The connection is released by means of an exciting current pulse smaller in magnitude and of opposite polarity, which reduces the remanent flux of the ferrite member below that value necessary to hold the reeds closed. Since the force of attraction is proportional to the square of the flux between the reeds, the release current must not be allowed to exceed a certain maximum value; otherwise, sufficient reverse remanent flux will be produced to reclose the reeds. The rather precise control of release current required is therefore a fundamental limitation of this basic structure.

In Fig. 1(b) the ferrite hysteresis loop resulting from the asymmetrical excitation necessary for cyclic closure and release of the reeds is compared with the major loop produced by symmetrical cyclic excitation. Following a closure pulse, I_c, the operating point resides at c, and there is sufficient remanent flux to close the reeds. The reeds are held closed

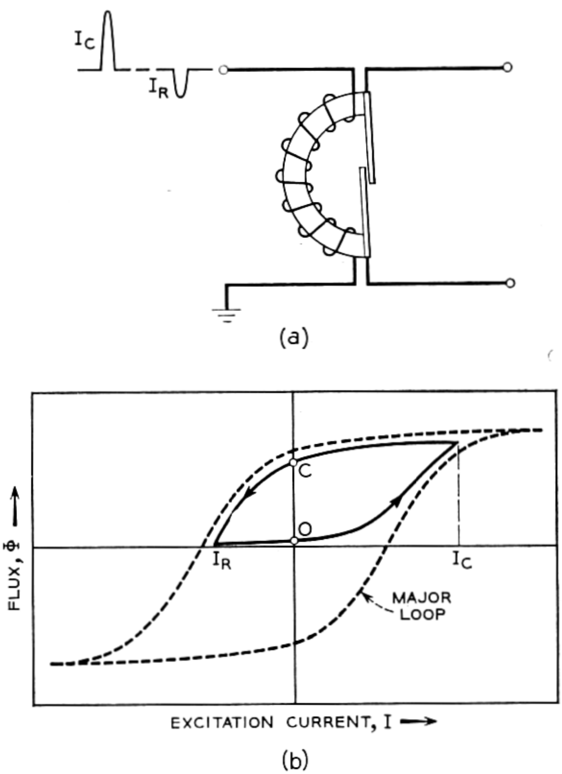

Fig. 1 – (a) The single-branch ferreed; (b) its magnetization characteristic.

until a release pulse, I_R, reduces the remanent flux to that at point o.

At first glance, the simple device of Fig. 1(a) appears similar to well-known types of reed relays. Perhaps most closely related is the magnetically latched reed relay, which is actuated by means of the additive fields produced by an exciting current and a permanent magnet. On closer examination, however, several important differences emerge. In the conventional magnetically latched relay, the remanent flux of the permanent magnet is only sufficient to hold the reeds closed and is essentially unaffected by the exciting current. Consequently, the closure excitation must be maintained throughout most of the reed closure interval, which may be in the order of one millisecond.

In contrast, the ferrite in the structure of Fig. 1(a) is controlled by the exciting current, and its remanent flux alone is sufficient to close the reeds. Furthermore, the ferrite may be switched from one magnetic state to another in a few microseconds, and as a consequence, this device may be readily controlled by currents applied for a like period of time.

Another important characteristic of the ferreed, contributed by the square-loop ferrite, is the well-defined threshold of magnetomotive force that must be exceeded before sufficient remanent flux is produced to close the reeds. This threshold can be made sufficiently large to mask variations in reed sensitivity, thereby permitting use of the device in coordinate arrays employing conventional methods of coincident current selection.

The ferreed affords an unusual opportunity to determine indirectly the state of its output contacts. Because the device incorporates internal magnetic memory, it can be interrogated without its electrical output circuit being disturbed. Methods for the nondestructive readout of the memory may be adapted from the magnetic core technology. However, the delay between ferrite switching and reed operation suggests a different approach. This method requires application of a short current pulse to the ferrite and observation of induced voltage in another winding to determine the memory state. The memory state can then be restored before the contact state is altered.

2.2 *Two-Branch Ferrite Structure*

The attractive features of the ferreed shown in Fig. 1(a) are considerably offset by the difficulty encountered in demagnetizing the ferrite to effect release. This basic limitation may be overcome by the addition of a second ferrite branch, as shown in Fig. 2. In this structure the reeds are closed by exciting the two windings so as to produce parallel magnetization in the two ferrite branches, and they are released by an excitation that causes series magnetization in the two branches.

The two-branch or parallel ferreed is adaptable to various methods of excitation, one of which is illustrated in Fig. 2. In this case, parallel magnetization is produced by equal coincident currents of the same polarity, whereas series magnetization is obtained by equal currents of opposite polarity. With equal parallel magnetization, the two-branch structure is equivalent to the closure condition in the single-branch structure of Fig. 1(a); with equal series magnetization, however, the two-branch structure appears demagnetized and the terminal magnetomotive force applied to the reeds is reduced to zero. It is significant that the condition of zero terminal magnetomotive force is obtained for arbitrarily large excitations above a certain minimum value and, as a consequence, a maximum limit is no longer imposed on the release current.

The basic concepts described above may be extended to structures having more than two ferrite branches. As an example, a structure of four parallel branches might be realized in which each branch is independently magnetizable in one direction or the other. In this structure, the reeds will be closed when three or four branches are magnetized in the same direction and released when pairs of branches are magnetized in opposite directions.

2.3 *Possible Magnetic States*

Prior to discussing methods of exciting a parallel ferreed, it may be appropriate to define the magnetic states that are to be produced by such excitation. Since its remanent flux is a function of the applied magnetomotive force, each ferrite member may assume an indeterminate number of magnetic states. However, if exciting currents sufficient for

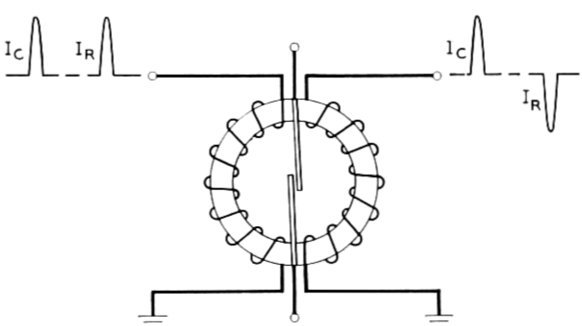

Fig. 2 – The two-branch or parallel ferreed.

saturation of the ferrite members are assumed, the number of possible states reduces to four. Fig. 3 illustrates the four saturated magnetic states: two modes of parallel magnetization that result in reed closure, and two modes of series magnetization that cause the reeds to release.

2.4 *Coincident Methods of Ferrite Excitation*

Establishing a path through a switching network is accomplished by the activation of relatively few among a large number of crosspoint switches. Individual selection of crosspoints is not economically attractive. Instead, it is desirable that the crosspoint device respond only to a coincidence of two or more input conditions. To this end, two coincident control schemes have been devised for the ferreeds: the additive and the differential excitation methods.

2.4.1 *Additive Excitation*

The fact that a square hysteresis loop offers a means for coincident current selection has been widely exploited in magnetic core memory arrays.[4] If a magnetic member of material with a square hysteresis loop is surrounded by two identical windings, and if the excitation in each is limited to a value slightly below the coercive force, then the magnetic state of the material will be altered only if both windings are excited simultaneously and for a sufficient length of time.

One of the ways in which this principle can be applied to the ferreed is shown in Fig. 4(a). The left-hand ferrite member is surrounded by

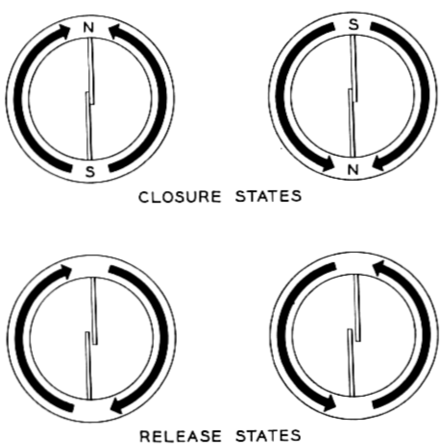

Fig. 3 – Saturated magnetic states of the parallel ferreed.

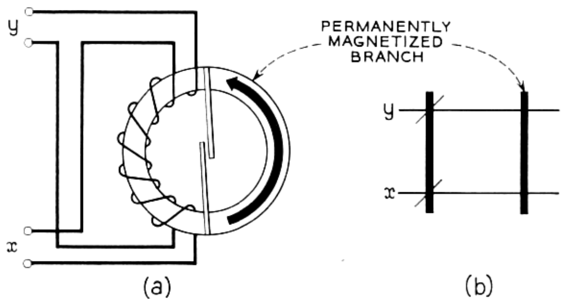

Fig. 4 – (a) Additive excitation applied to one branch of a parallel ferreed; (b) symbolic representation.

two identical overlapping coils, while the right-hand member is assumed to remain in a permanently magnetized state as indicated. Fig. 4(b) shows a symbolic representation of the parallel ferreed adapted from magnetic core work.[5]

Fig. 5 shows a typical relationship between the total remanent magnetomotive force developed across the ferreed structure and the excitation. It can be seen that, even with a two-to-one variation in reed switch sensitivity, coincident current levels can be established for successful closure operation.

Conceptually, the release of the ferreed can be accomplished on a coincident current basis by inverting the pulse polarity on the two wind-

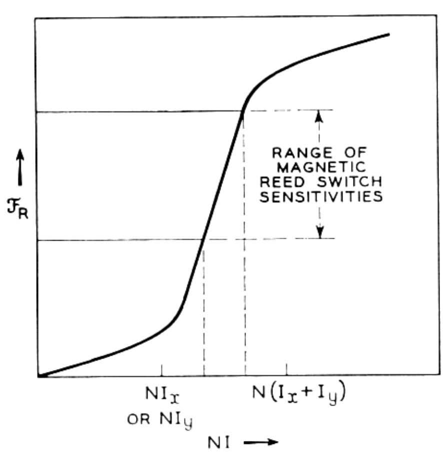

Fig. 5 – Remanent magnetomotive force applied to the reeds as a function of closure excitation.

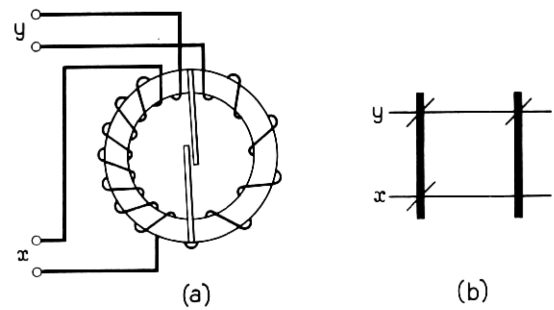

Fig. 6 – (a) Additive excitation with additional winding for maintaining magnetization of permanent branch; (b) symbolic representation.

ings. It has been found, however, that release thresholds are not well defined, due to the bias applied to the device by its own magnetic poles in the closure state. This bias increases the tendency toward magnetic "walk-down"; i.e., cumulative decrease in remanent flux upon repetitive application of partial release currents. Fortunately, the selection problem for release in switching networks is simpler than that for closure. In a two-dimensional array of crosspoints, the release function can be associated with one of the coordinate drives rather than with a specific crosspoint.

A preferred form of the additive case is shown in Fig. 6. The added winding placed around the permanently magnetized leg prevents the demagnetization that might result from finite magnetic coupling between it and the switched leg. The release function in this case is noncoincident and requires a current pulse in winding x of polarity opposite to that used for closure.

2.4.2 *Differential Excitation*

Consider a toroid of remanent magnetic material wound as shown in Figs. 7(a) and 7(b). With application of a sufficiently large current pulse into winding y, clockwise remanent flux is produced in the toroid; the direction of this flux can be reversed by subsequently pulsing the x coil. The magnetic states so produced correspond to the two possible release states of the ferreed. Either closure state can be brought about by simultaneously driving both windings with current pulses of like polarity and approximately equal amplitude.

The basic selection concept explained above, although plausible, cannot be easily implemented without certain modifications. Actually, if the toroid consists of a square-loop ferrite with high coercive force, a large portion of the flux generated in one of the windings will return through the air, bypassing the other half of the toroid and failing to influence its magnetic state. Also, physical separation of the two ferrite members, which facilitates assembly of the device, tends to further reduce the magnetic coupling.

The practical implementation of the selection principle implied above will be referred to as *differential excitation*. The insufficient magnetic coupling between the two ferrite members is compensated for by an additional winding on each of the ferrite members that is connected as shown symbolically in Fig. 7(c). The auxiliary windings contain only a fraction (typically one-third to one-half) of the turns in the main windings, and the drive current is chosen so that the magnetomotive force produced by the auxiliary windings is equal to or greater than that required to saturate the surrounded ferrite member. In addition, when both pairs of coils are excited to produce a closure state, the differential ampere-turns must also be sufficient to saturate both ferrite members.

Unlike the additive case, differential excitation places no upper limit on the exciting currents. Apart from sufficient amplitude, the two drive currents need only exhibit reasonable amplitude tracking and time coincidence. The tracking requirement can be relaxed, at the cost of increased driving power, by resorting to larger turns ratios between the main and the auxiliary windings.

It should be observed that only one current polarity is required. Actually, as will be discussed more fully in Section V, use of this method removes the necessity for a separate release action. When closure is produced in a ferreed element at an intersection of two coordinates, all other ferreeds located along these coordinates receive only single drives and are left in a released state.

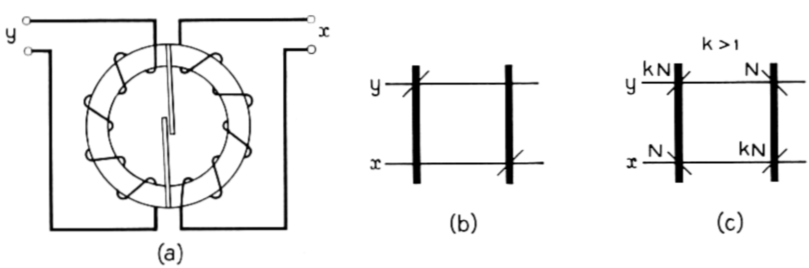

Fig. 7 – (a) Hypothetical model for differential excitation; (b) symbolic representation; (c) winding pattern required for practical realization.

III. A PRACTICAL FERREED

3.1 *The Glass-Sealed Magnetic Reed Switch*

Mention was made before of the structure of the ferreed's contacts and armature members — the magnetic reeds. Successful reduction to practice of the ferreed concept was facilitated by the availability of the glass-sealed magnetic reed switch.

A magnetic reed switch, currently manufactured by the Western Electric Company, and a miniature version of the switch, now under development, are shown in Fig. 8. The miniature switch was adopted for inclusion in the ferreed structure because of its smaller size and greater sensitivity — the excitation required for reed closure is in the order of 30 ampere-turns.

The glass seal allows use of relatively small contact force for a contact life in excess of one million operations, which is adequate for a typical network application. The contact life in the switching network can be preserved by not requiring the reed switch to close or open circuits having battery connected to them. This precaution is also observed in most crossbar networks.

Fig. 9 shows the relationship between applied magnetomotive force and the flux through the gap of the reed switch as obtained by a recording fluxmeter measurement. This plot gives a qualitative picture of the behavior of a typical magnetic reed switch.

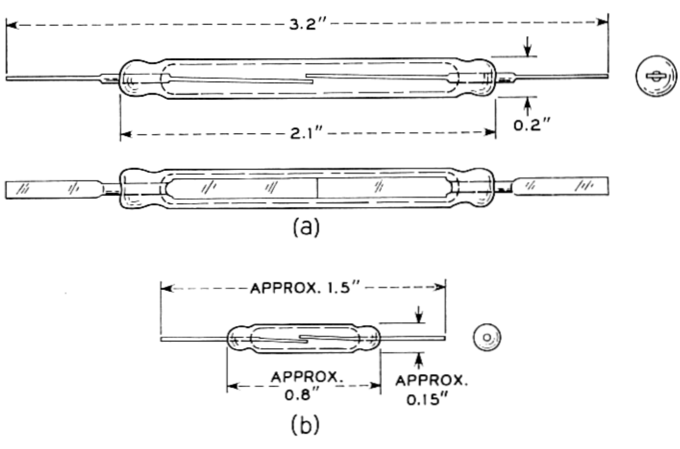

Fig. 8 – (a) Magnetic reed switch in current manufacture (Western Electric Type 224A); (b) miniature magnetic reed switch.

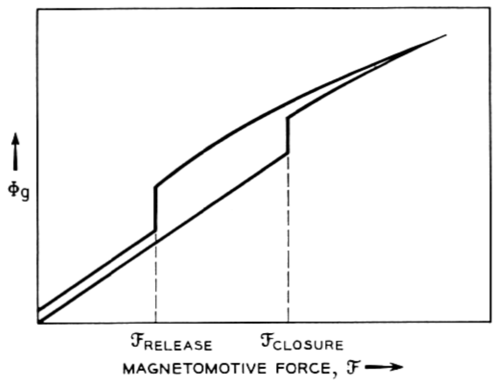

Fig. 9 – Plot of flux in the gap of the magnetic reed switch, showing discontinuities at closure and release.

3.2 *The Ferreed Structure*

A practical model of the ferreed, in which the exciting windings are omitted to present a clearer view of the structure, is shown in Fig. 10. Two magnetic reed switches are associated with the structure to provide two-wire switching as desired for the intended application. The opera-

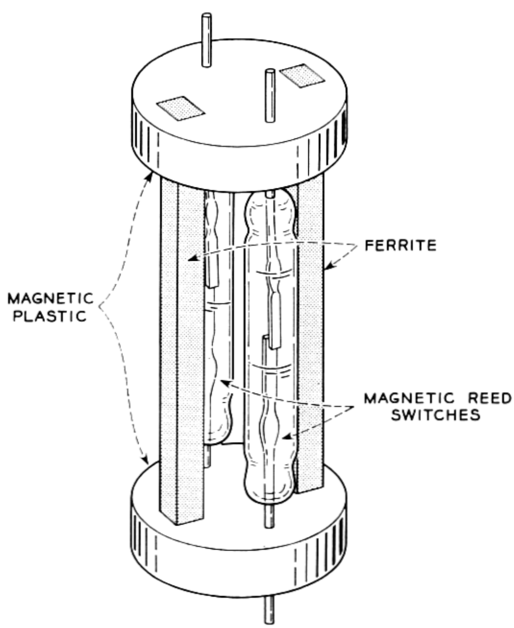

Fig. 10 – Parallel ferreed structure, with windings removed.

tion of this model is based on the concept described above for the two-branch ferrite structure; thus, two ferrite members can be seen in the drawing.

The function of coupling the ferrite bars to the magnetic reed switches is accomplished by the two end-pieces shown in the drawing. Several magnetically soft materials suitable for this purpose have been considered. The material adopted for the model shown consists of a plastic in which a sufficient amount of ferrite powder is suspended to produce adequate permeability (about 20) for this application. This material provides electrical isolation of the reed switches and good mechanical support for the assembly.

The ferrite members of Fig. 10 may be wound prior to assembly for either additive or differential excitation. Fig. 11 is a photograph of a typical experimental ferreed wound for differential excitation.

3.3 *The Ferrite*

The sensitivity and geometry of the reed switches define the length, cross section and magnetic properties of the ferrite bars. In order to operate the most insensitive reed switches, the magnetomotive force existing between the ends of the reeds in the active state of the device should

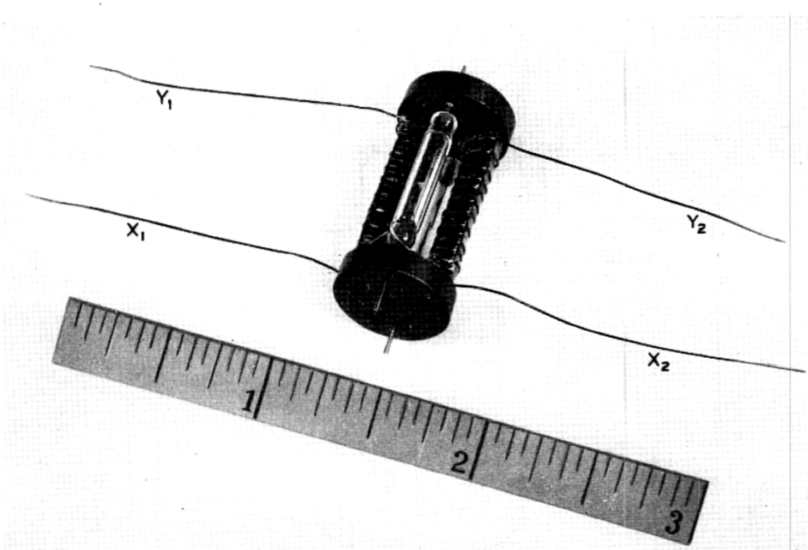

Fig. 11 – Experimental model of parallel ferreed, wound for differential excitation.

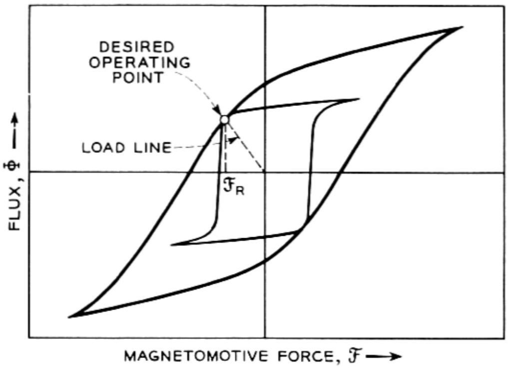

Fig. 12 – Comparison of two hysteresis loops sharing the same operating point.

be in the order of 60 oersted-centimeters. For lengths comparable with that of the reed switch, this implies a coercive force in the two magnetizable members of approximately 30 oersteds.

The desirability of squareness in the the hysteresis loop is illustrated by Fig. 12. If a given operating point is to be established, the material with the squarer of the two loops will permit lower excitation power — an important consideration in large arrays. Also, if the additive scheme of excitation is employed, the squareness of the hysteresis loop has a direct bearing on the obtainable margins.

While it is convenient to make the ferrite body compatible in length with the magnetic reed switches, the cross-sectional area is determined by the maximum flux density available at the point of operation and the over-all magnetic efficiency of the structure. The latter is defined as the ratio of the flux in the gaps of the magnetic reed switches to the total flux flowing through the center cross section of the ferrite. The efficiency of most ferreed models amounts, at best, to about 25 per cent.

Among the ferrites found to be applicable to the design were a cobalt ferrite and a cobalt-zinc ferrite. The latter of these has higher resistivity, a property sought for early ferreed models employing metallic end pieces. A hysteresis loop of a representative cobalt ferrite is shown in Fig. 13.

Apart from ferrites, there exist other materials, such as carbon steel, with suitable coercive forces. Ferrites were found preferable for attaining the ultimate control speeds, since eddy-current delays remain apparent in metallic structures, even when they are laminated. For lower-speed applications, however, metals offer some advantages, e.g., better temperature stability of magnetic properties.

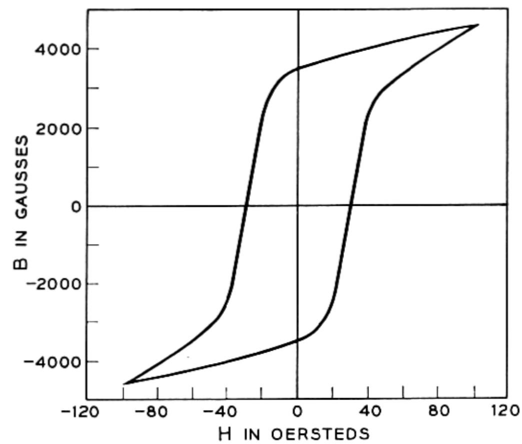

Fig. 13 – Hysteresis loop of a cobalt ferrite suitable for ferreed structures.

3.4 *Operating Characteristics*

The description of a practical ferreed would not be complete without some quantitative account of its behavior. While a detailed report of ferreed performance is not within the scope of this paper, the more important operating characteristics will be summarized.

The closure sensitivity of the ferreed is largely determined by the ferrite magnetization characteristic, the efficiency of the magnetic structure, the sensitivity of the reed switch and, to a lesser extent, by the shape and duration of the excitation pulse. The variation in ferreed closure sensitivity with pulse width for a two-to-one variation in reed sensitivity is given in Table I. Typical values of release sensitivity and

Table I — Typical Performance Characteristics for Parallel Ferreed with Half-Sine Pulse Excitation

Sensitivity		
Pulse width, microseconds	Closure, ampere-turns	Release, ampere-turns
10	100 → 145	70 → 95
100	80 → 125	60 → 80

Reed Response Time	
Initial Closure	220 microseconds
Final Closure	450
Release	20

reed closure and release times are included. The time between initial and final closures represents a period of contact chatter that is characteristic of the magnetic reed switch.

Although no precise measurements of ferrite switching times have been made, the response of the ferrite to half-sine pulses as short as 5 microseconds is quite satisfactory. Pulses of this short duration, however, are not considered suitable for driving a series chain of ferreeds (e.g., in a switching array) because of the large back voltages encountered by the pulse source. As a consequence, longer pulses are likely to be used in the control of a multistage ferreed switching network.

The half-sine pulse shown in Fig. 14(a) represents the exciting current that must be applied simultaneously to all windings of a differentially wound parallel ferreed to effect closure. Also shown, in Figs. 14(b) and 14(c), are the voltage developed across the main winding of the ferrite

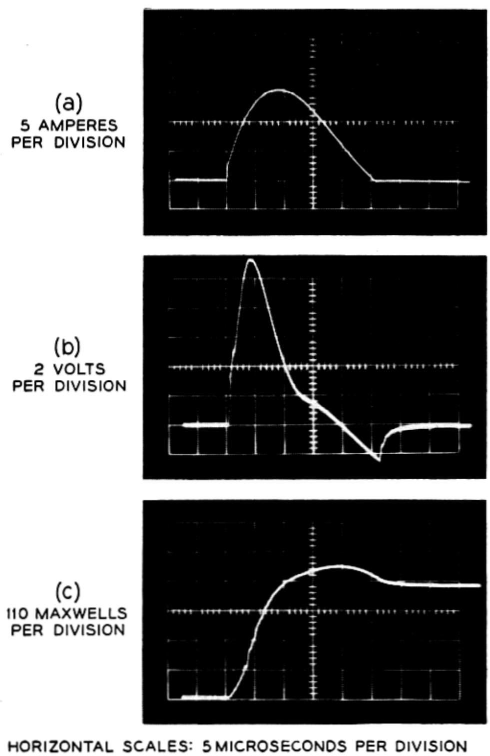

Fig. 14 – Waveforms observed in the switching of a ferrite branch: (a) applied current; (b) voltage induced in the winding; (c) change of flux in the ferrite.

branch being switched and the change of flux in that branch. The average pulse power dissipated in this ferreed is approximately 80 watts, corresponding to an energy requirement of about two milliwatt-seconds.

Variations in current are of particular concern when the ferreed is selectively operated by coincident current methods. The extent to which these variations must be limited for reliable operation represents the operating margins of the device. Fig. 15 presents a graphical comparison of these margins for the additive and differential methods of excitation. In Fig. 15 and in the following development of operating margins, magnetomotive forces applied to the ferrite members have been normalized by assuming the number of turns in each winding to be invariant. This permits reference to the terminal magnetomotive force required for reed closure in terms of a closure current, I_c.

The operating margins for additive excitation are determined from the following considerations: The algebraic sum of the two coincident currents must equal or exceed the closure current; each current must be less

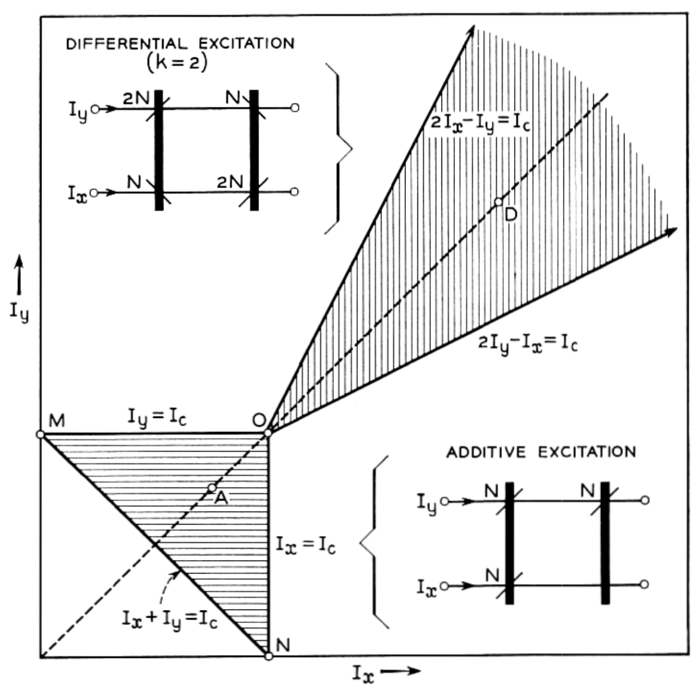

Fig. 15 – Graphical comparison of operating margins: additive excitation valid in horizontally shaded area; differential excitation valid in vertically shaded area.

than the closure current. The limiting conditions are therefore

$$I_x + I_y \geqq I_c , \tag{1}$$

$$I_x < I_c , \tag{2}$$

$$I_y < I_c . \tag{3}$$

These conditions, plotted as equalities in Fig. 15, define a valid region of operation within the triangle MNO. A logical choice for the nominal value of the exciting currents would be $I_x = I_y = \frac{3}{4}I_c$ (point A) which allows a maximum variation of $\pm\frac{1}{4}I_c$, corresponding to $\pm 33\frac{1}{3}$ per cent of the nominal value of I_x or I_y. This is the maximum margin obtainable with additive excitation for a fixed value of closure current I_c. It is evident that variations in ferreed sensitivity will reduce the valid region of operation and decrease operating margins.

A further limitation may be imposed on the margins obtainable with additive excitation by reed vibrations resulting from release. These vibrations occur at a frequency of about 2 kc and decay exponentially with a time constant of approximately 10 milliseconds. Since the closure sensitivity of the reed switch increases with decreasing gap between the reeds, a pulse applied to either winding alone during the post-release period of reed vibration may cause false reclosure of the switch. This situation may arise in coordinate switching arrays using additive excitation unless sufficient time is allowed between the release of one ferreed and the subsequent closure excitation of another sharing the same x or y coordinate.

In the differential mode of operation the condition for closure depends on the preceding release state. If the previous release was obtained by a positive pulse applied to the x winding, the direction of magnetization is down in the left branch and up in the right branch. A subsequent reed closure is effected by reversing the magnetization in the left branch, so the excitation requirement for coincident current closure is

$$kI_y - I_x \geqq I_c . \tag{4}$$

On the other hand, if the previous release was obtained by a positive pulse applied to the y winding, the direction of magnetization is down in the right branch and up in the left. Reed closure is now effected by reversing the magnetization in the right branch, and, in this case, the required excitation is

$$kI_x - I_y \geqq I_c . \tag{5}$$

These two conditions, also plotted in Fig. 15 (for $k = 2$), define a valid region of operation for differential excitation between the two semi-infinite lines coverging at point O. For the differential case the nominal value of exciting current $I_x = I_y$ may be chosen anywhere along the 45° line that bisects the valid operating region. Starting from a typical operating point, D, it can be seen that the locus for equal variations in I_x and I_y of the same sense is along the 45° line, while the locus for equal variations of the opposite sense is perpendicular to this line. Although the operating margins are most restricted by the latter type of variation, with proper design of the pulse source the former (tracking) type of variation is more likely to occur.

A value of 2 for the turns ratio, k, was arbitrarily chosen for this example. Increasing this ratio increases the angle between the semi-infinite lines, thereby improving the operating margins. However, the accompanying increase in driving power for a given pulse width establishes a practical upper limit on the value of k.

From the graph of I_y versus I_x in Fig. 15, a qualitative comparison of the two methods of excitation can readily be made. The advantage of the open-ended operating region obtained by differential excitation is clearly evident from a comparison with the closed operating region characteristic of additive excitation. With differential excitation, excellent operating margins are obtainable by increasing the exciting current and/or the turns ratio; with additive excitation, good operating margins are realizable only by close control of exciting current and device sensitivities.

IV. RELATED DEVICES

4.1 *The Series Ferreed*

The preceding sections have dealt with a two-branch or parallel ferreed, in which parallel excitation of both branches produced closure states and series excitation produced release states by reducing the flux through the reed switches to zero.

A dual device can be constructed, based on the observation that in a single rod of remanent magnetic material a magnetic state can be induced that corresponds to two shorter magnets connected in series opposition (Fig. 16). The device based on this principle has been named the series ferreed.

A practical form of the series ferreed appears in Fig. 17. The centrally located soft magnetic shunt greatly improves the release sensitivity by reducing the effective air reluctance shunting the individual magnet sections. Both additive and differential methods are applicable to the excitation of a series ferreed.

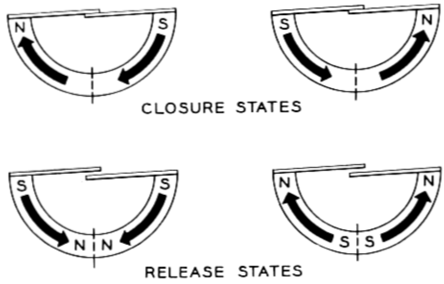

Fig. 16 – Conceptual model of the series ferreed.

4.2 *The Permanent Magnet Reed Switch*

If, in one of the magnetic reed structures shown in Fig. 8, the soft magnetic material used for the reeds is replaced by material of suitably high coercivity and retentivity, a device is obtained that potentially has all the characteristics of the ferreed. It is well known that, for improved magnetic efficiency in permanent magnet structures, the hard magnetic material should be in close proximity to the working air gap. Regarded

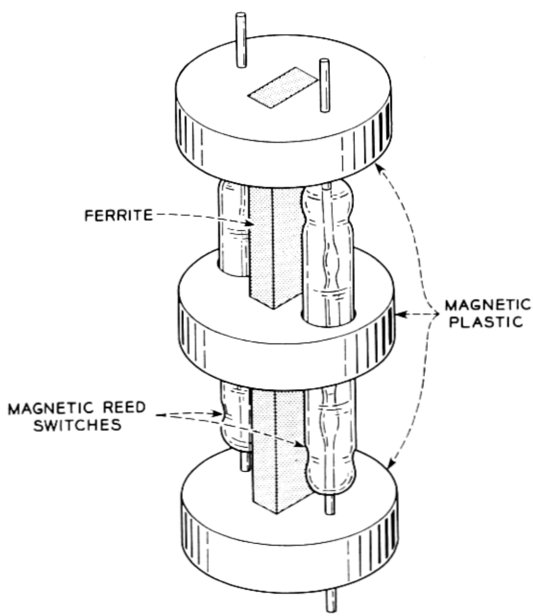

Fig. 17 – Series ferreed structure; windings (not shown) surround upper and lower halves of ferrite bar.

in this light, the permanent magnet reed switch can be viewed as a variation of the series ferreed.

The magnetic states of the device are shown in Fig. 18, together with a differential winding configuration that can produce them. As with the series ferreed, the release sensitivity of the device is improved by a central shunt. A magnetic return path (not shown) helps to increase operate sensitivity.

In experimental units built to test the principle, carbon steel quenched and annealed to produce a remanent flux density of approximately 12,000 gausses and a coercive force of 20 oersteds was successfully used as the reed material.

Although the device can be made to respond to current pulses in the microsecond range, longer pulses, persisting through most of the reed closure interval, result in better current sensitivity and relaxed design requirements.

4.3 *The Polar Ferreed*

The magnetic reed switch of Fig. 8(b) may be replaced in certain ferreed structures by another sealed magnetic switch of the type used in mercury relays. This switch employs a compliant magnetic reed as the transfer contact between two stationary magnetic contacts. By maintaining opposite magnetic poles at the two stationary contacts and vary-

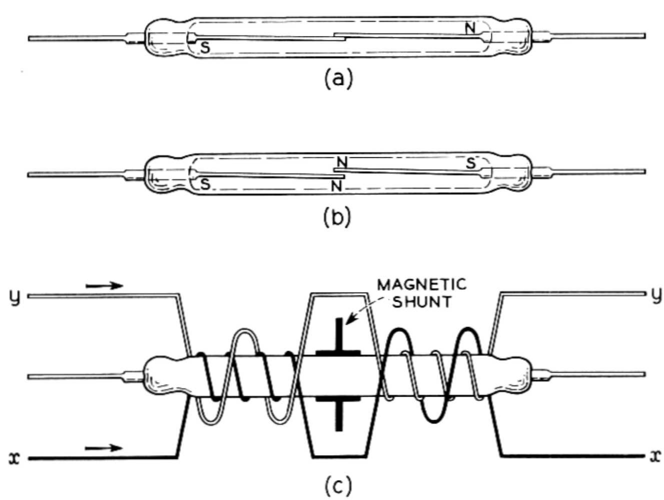

Fig. 18 – The permanent magnet reed switch: (a) closure state; (b) x release state; (c) differential winding pattern.

ing the relation between them and a pole produced in the movable contact, a transfer switching function may be realized. As before, the magnetomotive forces required for operating the switch may be produced by external or internal remanent members.

Ferreeds of this type can be operated by current pulses in the 5-microsecond range, with sensitivities comparable to those of the parallel ferreed. The advantages gained in the polar ferreed are transfer switching action and improved contact performance due to mercury-wetted surfaces.

V. FERREED SWITCHING ARRAYS

5.1 *Space-Separation Networks*

A switching network employing space separation will generally consist of several stages of switching arrays connected in a distributive pattern such as that shown in Fig. 19. A number of alternate paths may be used in the interconnection of two specific terminals. This path redun-

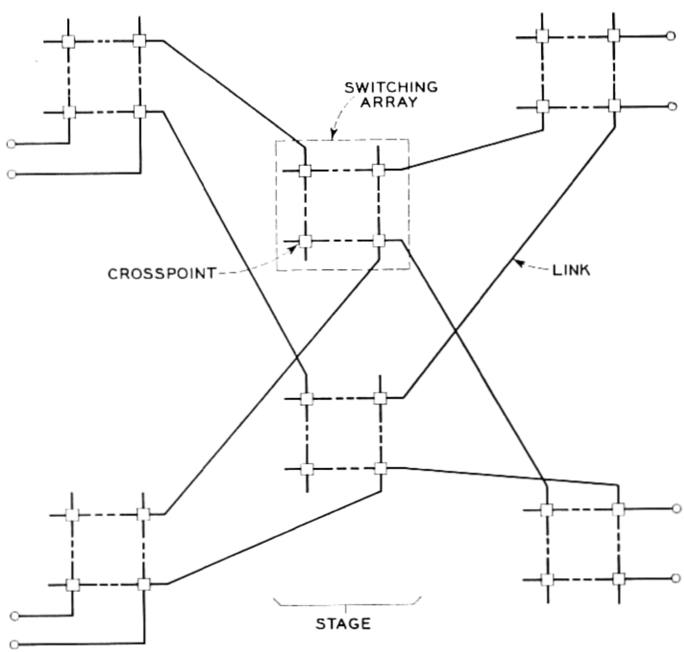

Fig. 19 – Interconnection of switching arrays in a multistage network.

dancy and the number of paths that can be simultaneously maintained are determined by the statistical character of the traffic loads on the lines or trunks to be served.

Four basic control operations may be defined for a switching network of this type. The first of these is the choice of an unoccupied path between two terminals to be connected. Next is the actual closure of the chosen path. When the connection is no longer required by one of the terminals, a third operation re-establishes the identity of the opposite terminal and intervening links. The final operation prepares these terminals and links for subsequent use in other connections.

Switching devices that combine transmission and control circuits, e.g., gas tubes and semiconductor crosspoints, also combine the first two and last two operations. End-marked networks of this type perform path selection in the closure process and path tracing during release.[6] On the other hand, switching devices with separate circuits for transmission and control, such as crossbar switches and ferreeds, employ facilities distinct from the transmission path for the first operation, and usually for the third operation as well.

In a representative crossbar switching network,[7] a third conductor parallels the two conductors of the transmission circuit in each network path. This superimposed circuit, called the "sleeve", permits determination of unoccupied network paths between two terminals and facilitates subsequent release operations. Path selection and tracing may be accomplished in ferreed networks by the addition of a third sealed reed switch to each device, by interrogation of the inherent ferrite memory, or by the use of memory elements external to the switching devices. Of these techniques, the last two are illustrated in the following examples.

5.2 *Array Using Additive Excitation*

The coordinate control paths for a general rectangular switching array of mn crosspoints are shown in Fig. 20. Transmission path multiples (not shown) will be assumed to follow a like pattern, so that simultaneous excitation of a horizontal control path and a vertical control path will effect a transmission connection between the corresponding terminals: one of m to one of n.

Additive excitation may be applied to the ferrite members of a rectangular ferreed array as a means of accomplishing coordinate control. Fig. 21 presents such an array in symbolic form, incorporating the ferreed shown in Fig. 6 for each crosspoint. The right-hand ferrite member of each ferreed is assumed to be switched upward initially and to maintain that polarization indefinitely. When the left-hand ferrite member is

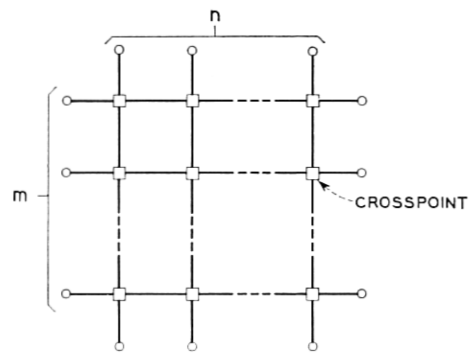

Fig. 20 – Coordinate control paths in a rectangular switching array.

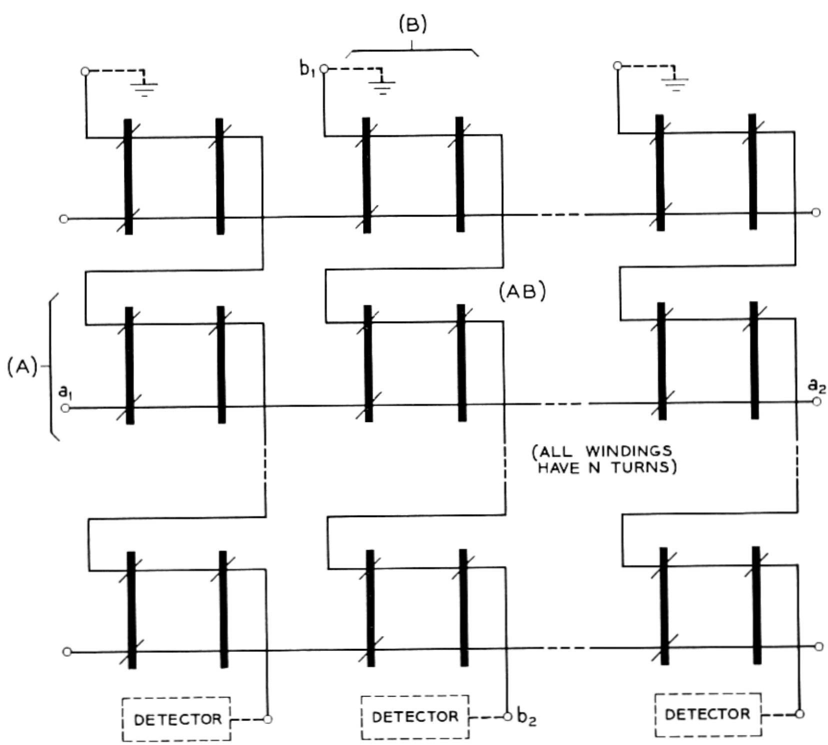

Fig. 21 – Additive excitation applied to a rectangular ferreed array.

switched upward by coincident driving currents, a winding on the right-hand member opposes any tendency for that member to be switched downward due to the finite magnetic coupling between members. The left-hand member of each ferreed is assumed to be switched downward initially, resulting in the release of all contacts.

For illustration, a transmission connection will be established between the terminals marked (A) and (B) in Fig. 21. Initial choice of the path that includes connection (A)–(B) is made by reference to an external memory containing occupancy records for terminals (A), (B) and other affected terminals within the network. Closure of the ferreed (AB) is effected by the simultaneous application of current pulses having amplitudes between one-half and the full ferrite switching excitation along control paths a_1a_2 and b_1b_2.

During application of these pulses, the left-hand ferrite member of ferreed (AB) is switched upward by the addition of the two magnetomotive forces applied. No other ferrite members are reversed, because the others along control paths a_1a_2 and b_1b_2 receive only one-half the required excitation. Control operations within the array are complete when control paths a_1a_2 and b_1b_2 have been pulsed; subsequent closure of the reed contacts (AB) will occur after a delay due to reed inertia.

When it is recognized that terminal (A) no longer requires its present connection, terminal (B) must be identified and both terminals prepared for subsequent use. A current pulse of sufficient amplitude to produce full switching excitation is applied along control path a_2a_1. This pulse switches the left-hand ferrite member of ferreed (AB) downward, but has no effect on the corresponding members of other ferreeds along control path a_2a_1, since they are already switched downward. Before the pulse was applied along control path a_2a_1, sensing elements were temporarily connected to terminals b_2, etc., and terminals b_1, etc., were grounded. The switching of the left-hand ferrite member in ferreed (AB) induces a voltage pulse in control path b_1b_2 that permits identification of the previously connected terminal (B). Control operations are then complete; subsequent opening of the reeds leaves terminals (A) and (B) receptive to new instructions.

In applying this excitation technique to switching networks composed of many such arrays, advantage may be taken of the fact that only one-half excitation is applied along control path b_1b_2. Since this partial excitation will not operate ferreeds that receive no other simultaneous excitation, the vertical control paths shown may be extended into several arrays as a means of conserving access circuits. However, the use of full excitation for release limits control path a_1a_2 to a single array. Fig. 22

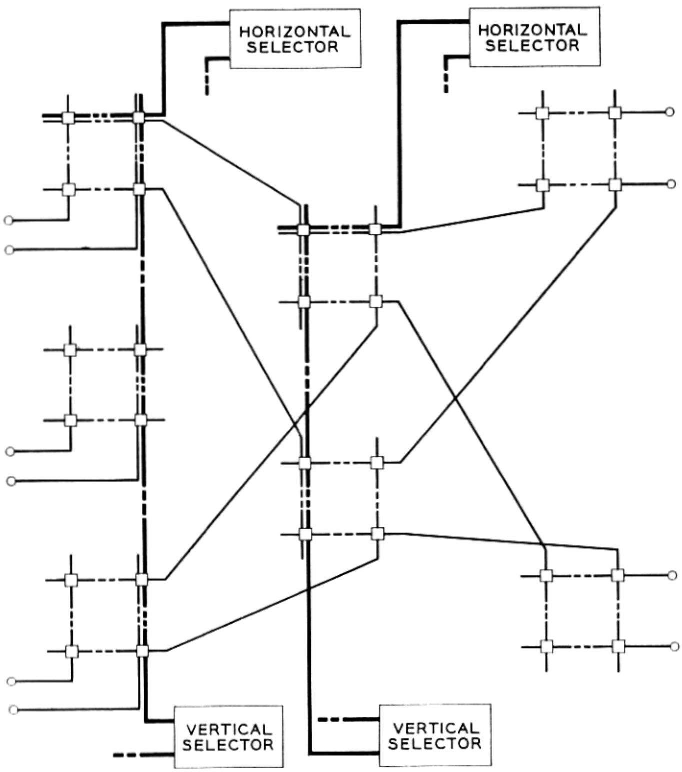

Fig. 22 – Additive excitation in a multistage network with vertical multiple selection (heavy lines represent control paths, light lines represent transmission paths).

illustrates the use of vertical selectors in applying simultaneous excitation along control paths analogous to b_1b_2 in several arrays. In the same way, vertical sensing elements (not shown) may be shared by a number of arrays.

5.3 *Array Using Differential Excitation*

Fig. 23 illustrates the application of differential excitation to the control of a rectangular ferreed array. Horizontal and vertical control paths are provided as before, but with different winding patterns on the individual ferreeds. A typical transmission connection will be established between the terminals marked (C) and (D).

All ferreeds in Fig. 23 are assumed to be released, but this assumption does not specify the magnetic polarization of the various ferrite members. Because differential excitation produces two release states, the direction of magnetization (i.e., clockwise or counterclockwise) of any released ferreed will depend on the history of its associated control paths. For this example, it is further assumed that all ferreeds in the array initially exhibit magnetic saturation of their ferrite members in a clockwise direction.

The choice of a network path including connection (C)–(D) is again made by reference to an external memory of available terminals (or links) within the network. Closure of the ferreed (CD) is accomplished by the simultaneous application of current pulses along control paths c_1c_2 and d_1d_2. However, in this case, pulse amplitudes are sufficient to produce saturation of ferrite members through windings of either N or $(k - 1)N$ turns.

Due to the opposition of unequal magnetomotive forces, both ferrite members of ferreed (CD) are switched upward. All other ferreeds along

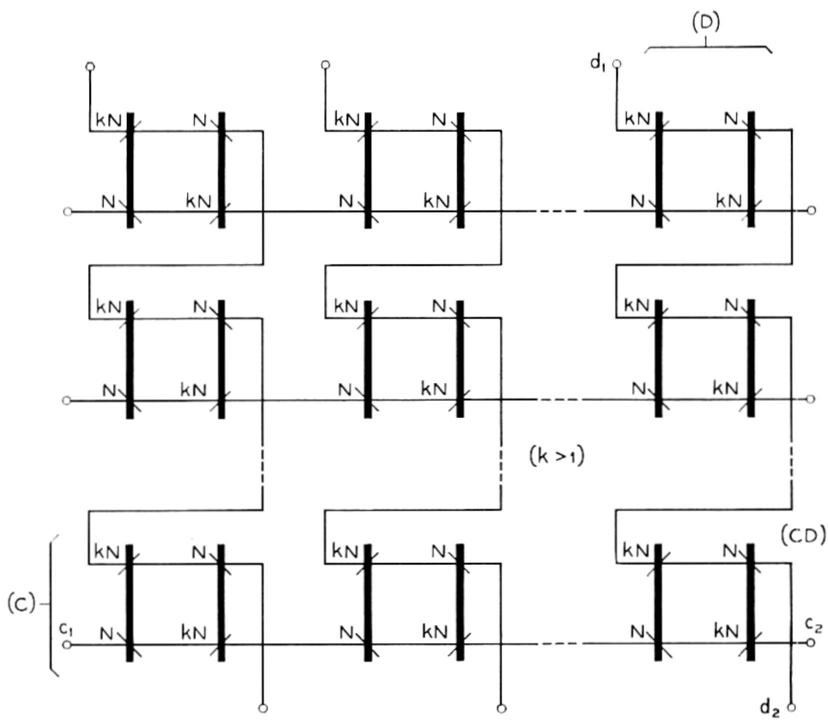

Fig. 23 – Differential excitation applied to a rectangular ferreed array.

control path c_1c_2 experience a reversal in release state, from clockwise to counterclockwise magnetic saturation. The other ferreeds along control path d_1d_2, however, undergo no reversal, because their initial states agree with those imposed by the current pulse along that path. After some delay due to reed inertia, the contacts of ferreed (CD) will close.

When it is recognized that terminal (C) no longer requires its present connection, terminal (D) is identified by reference to another external memory. With the posting of this memory and of the path selection memory, terminals (C) and (D) are prepared for subsequent use. No deliberate release operation is required for ferreed (CD); subsequent path choices that include terminal (C) or (D) will automatically return (CD) to a release state.

The extension of this excitation technique to multistage networks requires a different approach from that employed with additive excitation. In this case, no control path is used for partial excitation; rather, currents in each control path unconditionally release all associated ferreeds

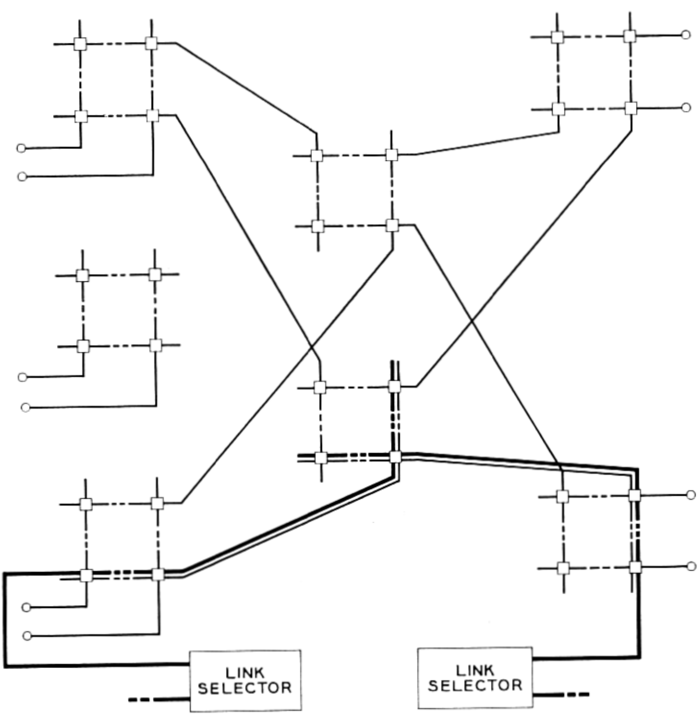

Fig. 24 – Differential excitation in a multistage network with link selection (heavy lines represent control paths, light lines represent transmission paths).

except those located at intersections with other active control paths. For this reason, control paths must conform to transmission paths as a means of assuring that conflicting connections are undesired connections. One significant economy in access circuits can be realized, however: the selection of control paths for two related array terminals may be combined, as in the link selector of Fig. 24.

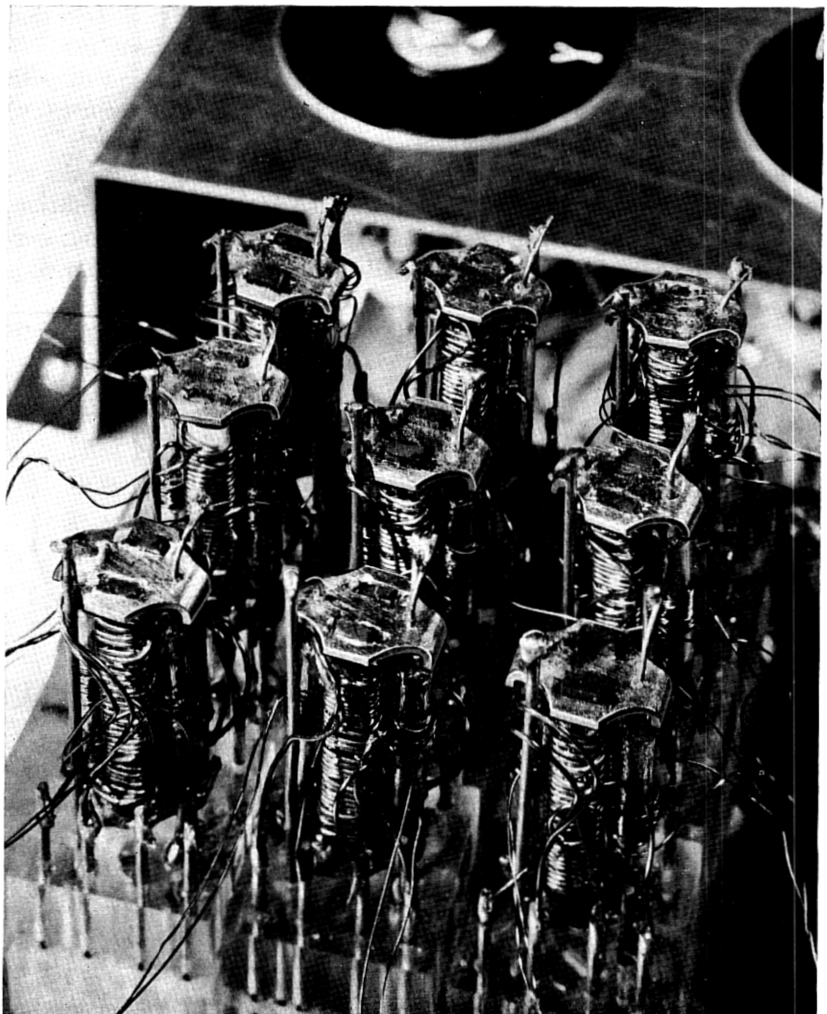

Fig. 25 – An early experimental array of nine parallel ferreeds. (The coils on the glass enclosures are used for flux measurements, and play no part in control.)

Because differential excitation eliminates old connections while establishing new ones, a multistage network of this type can be expected to contain numerous fragmentary connections at any given time. These do not interfere with network operations and do not justify separate release instructions; however, lines and trunks are disconnected from the network to provide isolation of battery and supervision.

VI. CONCLUSION

The union of magnetic reed switches with elements having controllable magnetic remanence has yielded a new class of switching devices. One conceptual model from this class appears to have the properties of microsecond control time, coincident selection, memory without holding power, enclosed contacts and compact structure. Design and construction of experimental forms of the ferreed have borne out predictions of the early concepts and have suggested further variations on the theme.

The ferreed was created to fill a need for a network crosspoint providing high-speed coincident selection and metallic contacts. Because of the specific nature of this objective, primary emphasis has been placed on optimization of the ferreed's characteristics as a crosspoint switch. It appears promising as a network element and may also prove suitable for a number of other applications.

In digital systems, the properties of rapid control, metallic output and absence of holding power suggest the use of ferreeds as memory for display, buffer and input-output functions. Ferreeds can also be used to realize switching functions as combinations of flux patterns in multiple-branch ferrite structures, or as combinations of magnetomotive force in multiple windings such as those used for differential excitation.

VII. ACKNOWLEDGMENTS

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