THE BELL SYSTEM
TECHNICAL JOURNAL

VOLUME XLIII | JANUARY 1964 | NUMBER 1, PART 1

The Ferreed

By A. FEINER

(Manuscript received August 20, 1963)

The advantages of the ferreed as a switching network crosspoint led to an early decision to adopt it for use in electronic switching systems. The prospect of large-scale use of the device gave impetus to a search for an economical, easily fabricated component. This paper describes the considerations which influenced the choices of a suitable magnetic material, magnetic circuit geometry, and coil design that were made for the production model.

I. INTRODUCTION

The concept of the ferreed was presented in an earlier article in this journal.[1] The purpose of this paper is to describe the evolution of this device during its further development.

To recollect, a ferreed is a device born of marriage between miniature sealed reed contacts (see Ref. 2) and an external magnetic circuit containing remanently magnetizable members. Operation or release of the sealed contacts can be controlled by setting the remanent members in one of two magnetic states by means of short current pulses.

Among the several useful properties that can be brought about in the ferreeds by selection of the proper magnetic configurations and coil design is the ability to respond to coordinate excitation — a vital requirement for any device considered for a network crosspoint.

Recognition of the potential advantages of a switching network crosspoint with metallic contacts, absence of holding power and the ability to operate in times much shorter than prior electromechanical devices led to an early decision to adopt it for the network of No. 1 ESS (Electronic Switching System) — the new telephone switching system scheduled for its commercial debut in 1965.

The intended application of the ferreed in the switching network of No. 1 ESS, where it would appear in very large numbers (14–20 crosspoints per line), gave impetus to a search for an economical, easily fabricated embodiment. Several important choices had to be made with regard to the geometry of the magnetic circuit, the winding configuration and the remanent magnetic material. At the same time, the requirements of the sealed reed contact were reexamined, and a modified version of it known as the 237B contact was adopted for ferreed use.

II. THE CROSSPOINT FERREED

2.1 *Choice of Remanent Material*

All original work on the ferreeds was based on the use of a specially developed cobalt ferrite as the remanent material. In time, certain inherent difficulties became apparent: notably, a strong temperature dependence of the magnetic properties and low flux density, leading to structures of large cross section and poor efficiency. Furthermore, as more thought was given to the ferreed as a system component, it was found that the originally postulated microsecond speeds for the actuation of the ferreed were neither required nor practical from the standpoint of driving requirements.

These considerations opened the way to a search for a metallic substitute. Several chromium and tungsten steel compositions were investigated and found wanting due to lack of squareness and fullness of the hysteresis loop — properties whose importance were stressed in Ref. 1.

The attention soon centered on a recent addition to the list of cobalt-iron-vanadium alloys — Remendur. The name of this alloy refers to its primary magnetic characteristic, i.e., a remanence greater than 17,000 gauss. This is coupled with a square hysteresis loop and a coercive force from 1 to 60 oersteds. With a nominal composition of 48 per cent cobalt, 48 per cent iron, 3.5 per cent vanadium and 0.5 per cent manganese, Remendur bridges the gap between the high coercive force of Vicalloy and the low coercive force and high permeability properties of 2V-Permendur and Supermendur. Fig. 1 shows a hysteresis loop obtained on a Remendur strip developed for ferreed use. Of importance to the ferreed application is the squareness B_r/B_s and fullness $\sqrt{H_oB_o/H_cB_r}$

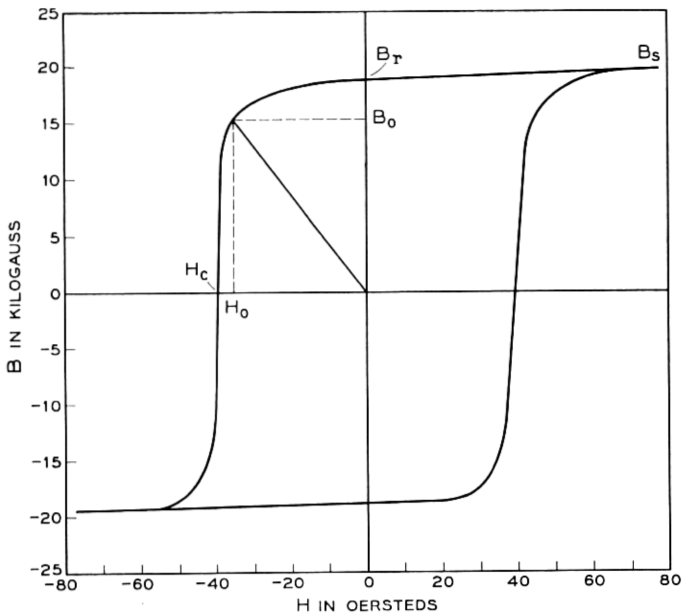


Fig. 1 — Hysteresis loop of Remendur used in ferreeds.

of the hysteresis loop. This property implies that the energy expenditure in establishing a desired end state approaches a minimum, and that the excess flux generated in the same process is small—important in view of the interference problems present in ferreed arrays.

2.2 *Choice of Geometry*

There exist two basic forms of ferreed structures — the parallel and the series ferreeds. These are illustrated in Fig. 2. The choice of Remendur, the need for tight magnetic coupling between the remanent members and the reed contacts, and the relative ease of fabrication led to adoption of the series structure for the crosspoint ferreed.

That structure is shown in Fig. 3 in the form used in the ESS network. Mounted on each side of the reed contacts, which are molded together in plastic to form a single piece part, and extending approximately over the length of the glass envelopes, are two flat plates of Remendur. Notches on the plastic and on the plates permit accurate relative positioning of the two.

The reeds and the remanent plates are inserted into plastic coil forms

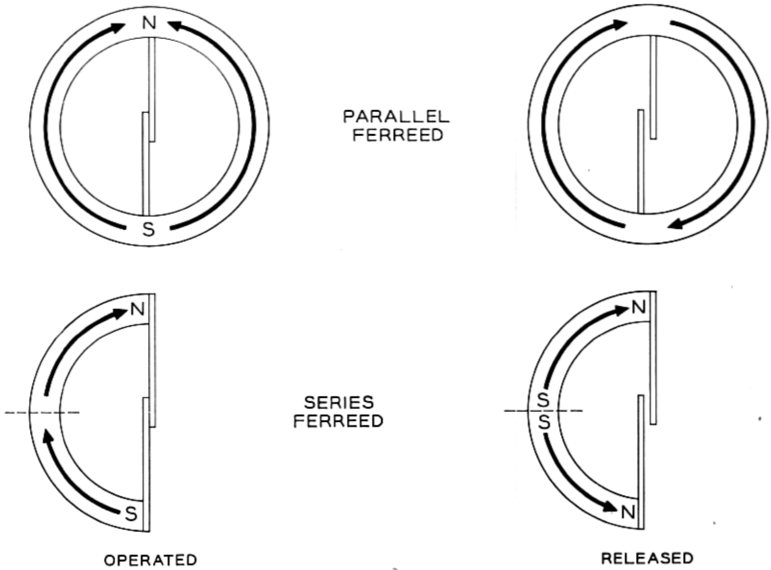


Fig. 2 — Principles of parallel and series ferreeds.

molded into a steel plate. This steel plate acts as a common shunt for the whole array — it divides each crosspoint magnetically into two separately controllable halves, greatly reducing the energy requirement for producing the release state in which, as shown in Fig. 4, the two halves of the remanent members are magnetized in opposing directions. The same steel plate acts as the mechanical backbone of the whole array.

2.3 *Coil Design*

The differential excitation mode was selected to provide coordinate addressing of crosspoints. Fig. 5 reviews this principle as applied to a series ferreed. Each crosspoint has two sets of windings — one for each coordinate. Each set contains a winding of N turns on one side of the shunt plate and one with a larger number, typically $2N$, on the other side. The $2N$-turn winding is connected series opposing the N-turn winding. One pair of windings is in series with the corresponding pairs of all crosspoints in the same row, while the other is in series with the pairs of all crosspoints in the same column of the array. As the paired windings oppose each other, energization produces the release state in every crosspoint energized, except the one where both pairs of windings are energized simultaneously — the crosspoint at the intersection of the energized row and the column.

The logic inherent to differential excitation was found to be well suited to network array operation, in which, in general, only one crosspoint in each row or column need be operated.

No separate release actions are required, as operating a crosspoint automatically releases other crosspoints associated with the same row and column.

The design of the coils has to take in account the energization requirements of a single crosspoint as well as the system requirement

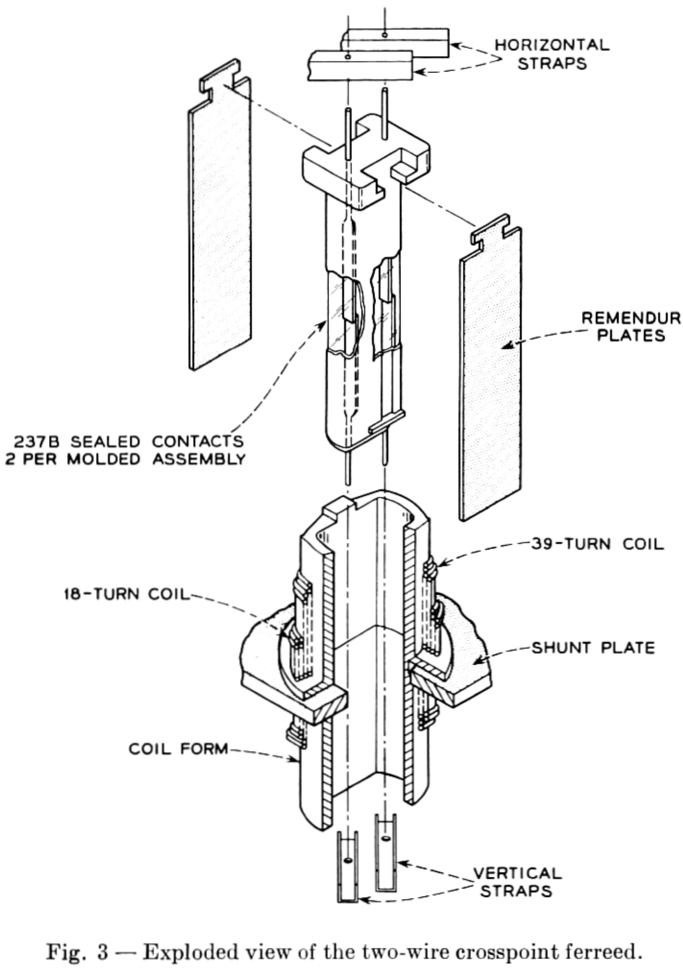


Fig. 3 — Exploded view of the two-wire crosspoint ferreed.

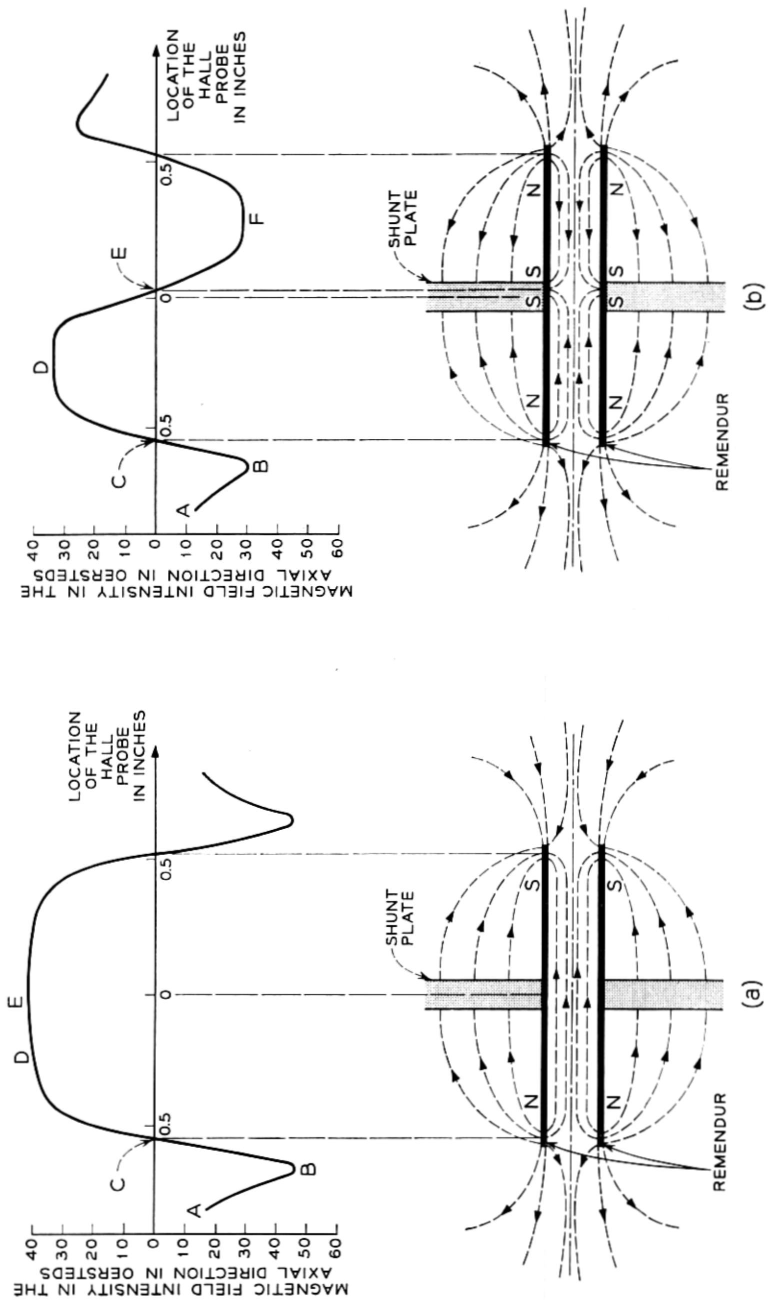


Fig. 4 — Field distribution of the crosspoint ferreed in the operated and released states.

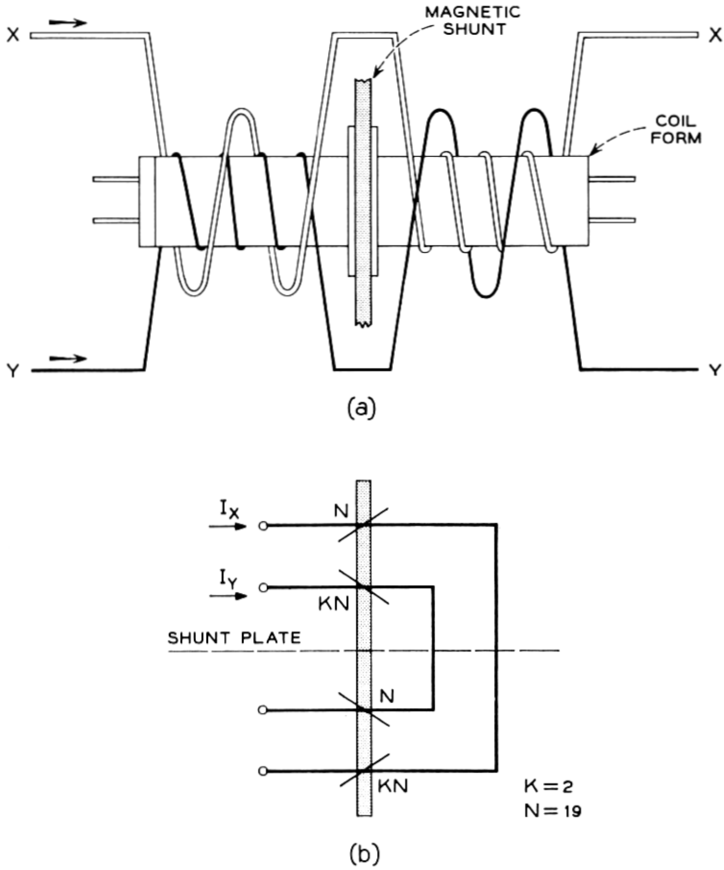


Fig. 5 — Winding configuration for differential excitation of the series ferreed: (a) winding pattern, (b) mirror symbol notation.

calling for simultaneous pulsing of 32 winding pairs in the process of establishing a connection through two stages of ferreed switches.

In ESS, these considerations led to the adoption of coils with windings of 18 and 39 turns wound with 25-gauge copper wire. With these coils, the nominal operating current pulse of 10 amperes peak amplitude and 250 microseconds duration insures adequate margins for both operation and release of the crosspoint.

The coils are wound directly on the coil forms by a machine that winds eight rows (or columns) of crosspoints simultaneously in a continuous succession, each with a single length of wire. This eliminates soldered connections between coils, thus reducing the winding cost and improving the reliability of the assembly.

The winding sense is reversed in adjacent crosspoints. This magnetic "checkerboarding" was found to be an effective means for reducing magnetic interaction phenomena as well as the noise pickup in the transmission pairs due to ferreed energizing pulses.

2.4 *Crosspoint Arrays*

Switching network considerations led to selection of an 8 × 8 crosspoint array as a basic network building block. In Fig. 6, such an array is shown. In addition, specifically for the concentrating stages of the network, several other array types were required: a switch providing each of 16 input terminal pairs with an access to 4 out of 8 available outputs, and 8 × 4 and 4 × 4 switches. It was found that each of these arrays could be derived from the basic 8 × 8 apparatus unit by suitably changing the connections of the control windings and the voice-pair strappings. Fig. 7 shows these connections for all the developed ferreed

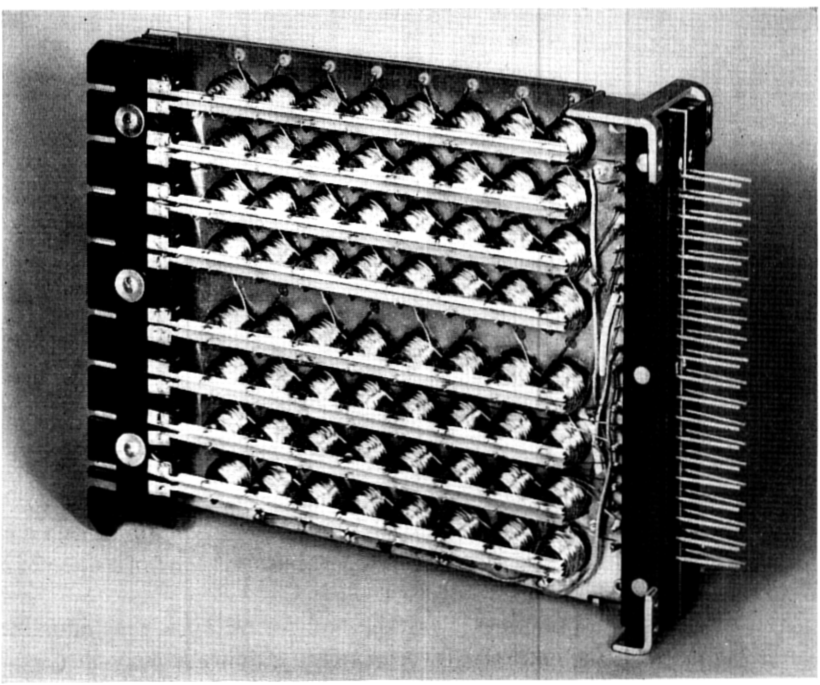


Fig. 6 — An 8 × 8 ferreed switch with covers removed.

switch types. As can be expected, this standardization of the physical size and component parts of the switches has eased the manufacturing and the network equipment design problems.

The connections shown between the ends of the row and column control winding chains stem from the access scheme adopted in the network design. In this scheme, identical current is applied to both coordinates by connecting them effectively in series when energizing a crosspoint at their intersection.

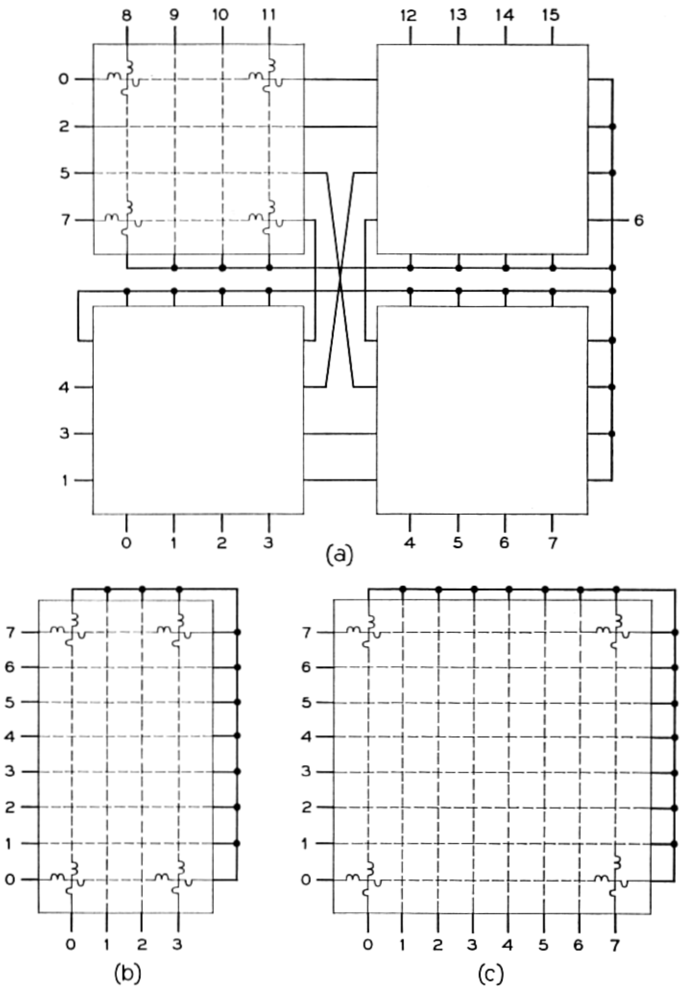


Fig. 7 — Control winding interconnection for three types of two-wire switches: (a) 16 × 4/8, (b) 8 × 4, and (c) 8 × 8.

III. DESIGN TECHNIQUE

When the problem of designing the ferreed was first approached, it was found that the usual lumped-constant, linear magnetic circuit approach, while sufficient to yield a workable device, did not provide the means for its optimization; neither did it give an assurance of margins in face of tolerance allowances that have to be made for the whole structure, and variations in reed contact properties and in the magnetic properties of Remendur. Several attempts were made to refine the analytical tools toward this end. While providing qualitative insight into the operation of the device, they were frustrated from attaining the ultimate goal of a quantitative, explicit solution by the complexity of the problem caused by the rather difficult geometry and the essential nonlinearity of the magnetic materials.

As a result, the refinements in the ferreed design had to be based largely on experimental techniques. Over the years, numerous experimental ferreed study techniques have been devised. These include the use of search coils with integrators, hysteresis measurements of reeds and the remanent magnetic members, Hall probes in the crosspoint structure and the reed gap, and reversible permeability measurements of the reeds. Supplemented by experiments in which the component parts of the structure, their positioning and the driving conditions underwent systematic variations, these techniques were instrumental in arriving at the present structure.

The use of Hall probes provided two study techniques. First, Hall probes were employed to measure longitudinal magnetic field intensity along the ferreed axis, after applying varying operate and release pulses. Second, via the use of specially constructed sealed reeds with Hall probes mounted in the gap of the reed, it was possible to measure the resultant magnetic flux density in the reed gap under varying operating conditions. The drawback of the techniques lies in the upsetting of the ferreed magnetic circuit by the absence of the reed or introduction of a permanently open reed structure.

Reversible permeability measurements of the sealed reeds, accomplished via inductance measurements of small sense coils at about 100 kc, provided a convenient means of determining the instantaneous applied mmf to the sealed reeds under varying operating and interference conditions. The technique was especially useful because it permitted the use of ordinary sealed reeds under actual operating conditions, and it was free of drift problems since no integrator circuits were involved. On the other hand, the nature of the reversible permeability characteristic of the sealed reed is so insensitive in the released state of the sealed reeds as to make its use not suitable in that region.

IV. OTHER FERREED TYPES

4.1 *The Bipolar Ferreed*

In the process of designing a ferreed switching network, the need arose for a device containing a pair of contacts that would be individually controllable. A typical use for this device is disconnection of the line current sensing element at the line circuit whenever a connection is established in the switching network (cutoff relay function). A postulated property of this device — to respond to control current pulse polarity to open or close its contacts — was found to permit integrating the control access with the one for the crosspoints.

An adaptation of the parallel ferreed principle, shown in Fig. 8, provided a suitable embodiment meeting this need. Of the two parallel remanent members, one consists of a permanent magnet material, Cunife I; the other, surrounded by a single coil, of Remendur. Contact closure or release depends on the polarity of the current pulse applied to the coil. Eight such devices packaged together form a single apparatus unit compatible in its length with the crosspoint units.

4.2 *The Four-Wire Crosspoint Array*

For use in switching networks requiring two separate directions of transmission, the two-wire crosspoint design has been extended to permit the operation of four contacts at every crosspoint location. The four contacts are arranged in a square pattern and are surrounded by an open-ended box formed by four remanent plates. The windings are similar to those of the two-wire array and again an eight-by-eight size has been chosen; Fig. 9 shows an individual crosspoint and an overall view of the unit.

V. SUMMARY

Out of the original concept of the ferreed originated a whole class of useful switching devices. Characterized by small size, high speed of operation and absence of holding power, they permit retaining the desirable aspects of metallic contacts in the environment of electronic switching machines without creating undue time compatibility problems.

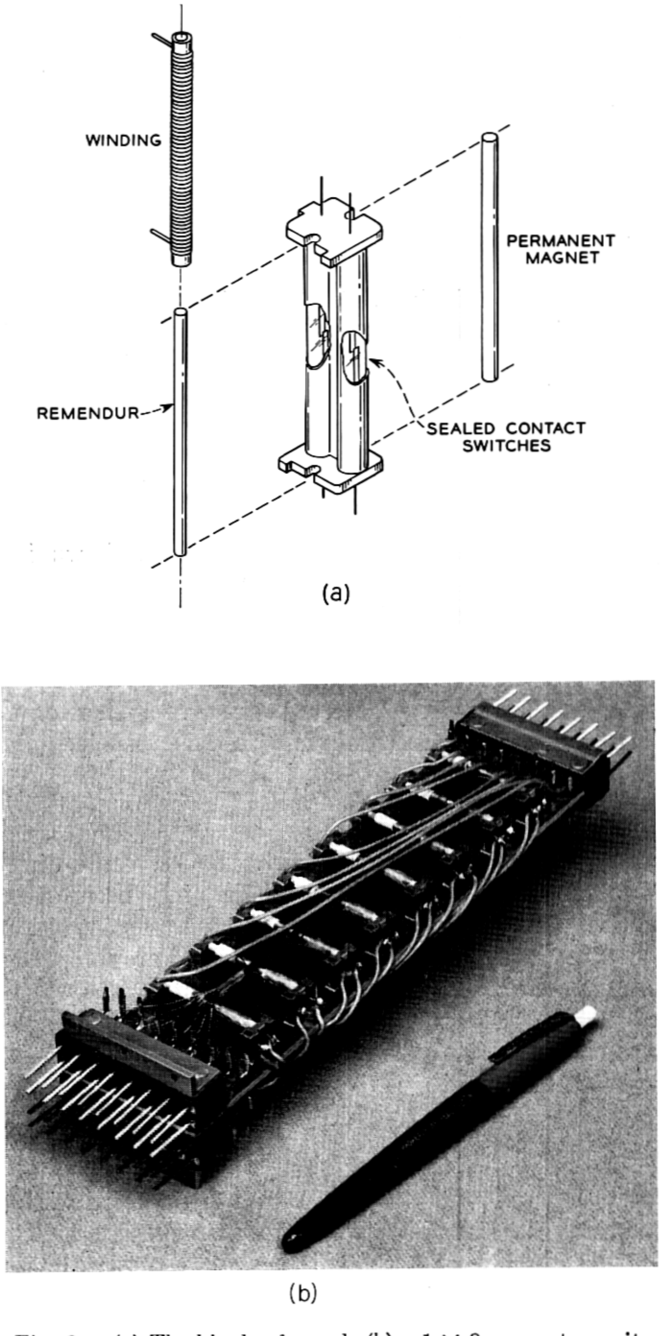
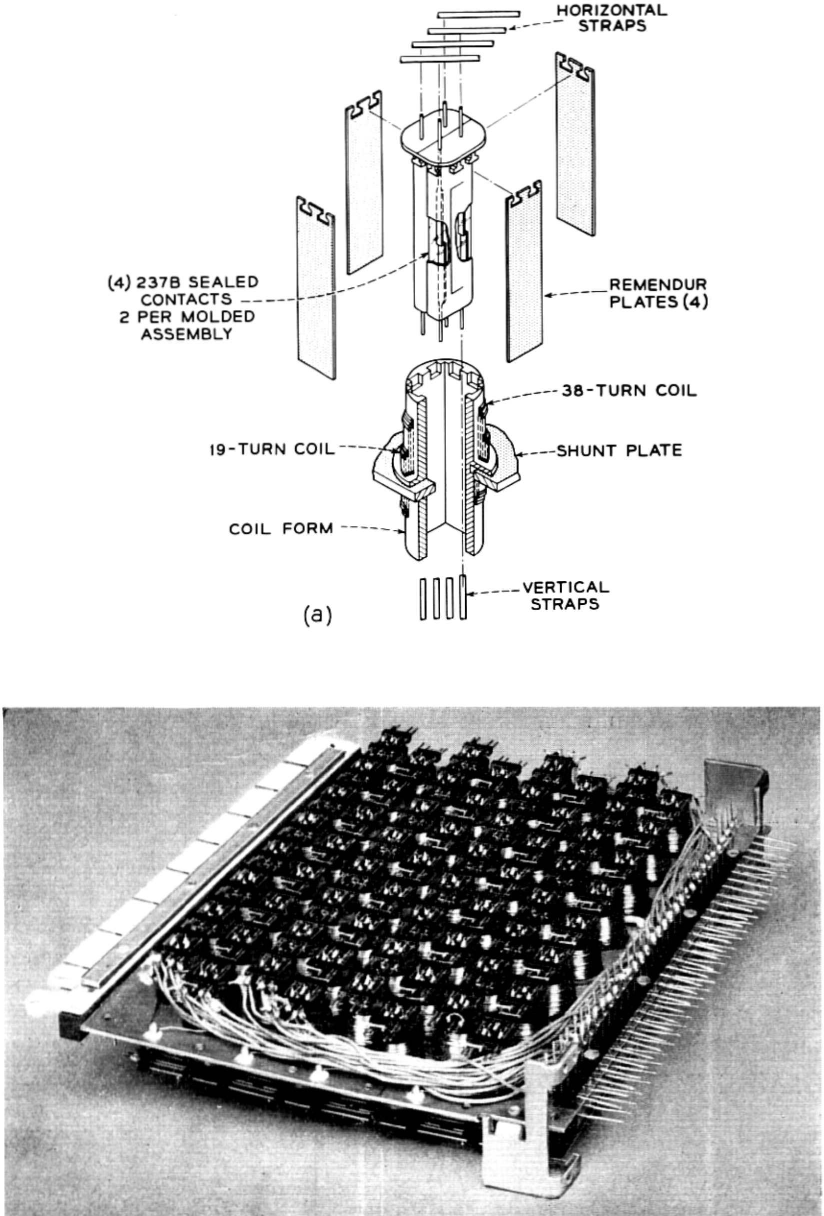


Fig. 8 — (a) The bipolar ferreed; (b) a 1 × 8 apparatus unit.



(b)

Fig. 9 — (a) Exploded view of a single four-wire crosspoint; (b) over-all view of an 8 × 8 switch with protective covers removed.

Table I — Summary of Ferreed Characteristics

Switch		Dimensions (Inches)			Operate and Release Pulse		Contact Characteristics			
Code	Type	Height	Width	Length	Peak Ampl. (A)	Width (μs)	Max. Res. (ohms)	Max. Operate Time (ms.)	Max. Surge Current	Life
242 A	2-wire 8 × 8	6¾	2⅛	9¼	9	200 to 500	0.2	3	3A*	2 × 10⁶†
242 B	2-wire (2) 8 × 4									
242 C	2-wire 16 × 4/8									
252 A	4-wire 8 × 8	9¾	2⅛	9¼	9	200 to 300				
241 B	2-wire 1 × 8	1⅝	2⅛	9¼	6	200 to 500	5‡	3	3A	2 × 10⁶

* To protect the contacts, crosspoints are operated and released in a dry circuit — maximum surge current refers to current value applied to closed contacts.
† Minimum life of 2×10^6 operations with contact resistance below 0.2 ohm.
‡ This contact breaks a maximum of 40 ma in its operation.

Table I gives a summary of the characteristics of the ferreed codes now in existence.

VI. ACKNOWLEDGMENTS

Many people have contributed important ideas and skills to make the ferreed a success; the author would like to offer his particular appreciation to Messrs. H. L. B. Gould and D. H. Wenny for their work on the Remendur, Messrs. R. L. Peek, F. H. Myers, and H. Raag for their work in magnetic design of the ferreed, and Messrs. H. J. Wirth and R. A. Billhardt for the mechanical design.

The credit for solving the manufacturing problems should go to Mr. G. A. Mitchell of the Western Electric Company at Columbus.

REFERENCES

1. Feiner, A., Lovell, C. A., Lowry, T. N., and Ridinger, P. G., The Ferreed — A New Switching Device, B.S.T.J., **39**, January, 1960, p. 1.
2. Keller, A. C., Recent Developments in Bell System Relays — Particularly Sealed-Contact and Miniature Relays, B.S.T.J., this issue, p. 15.