# Recent Developments in Bell System Relays — Particularly Sealed Contact and Miniature Relays

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(Manuscript received February 25, 1963)

*Relays are among the most important electromechanical devices. They have been in use for many years and continue, in modern form, to be essential elements in modern Bell System and military applications, including electronic switching systems.*

*The most important recent developments are miniaturization, sealed contact relays using glass-enclosed contacts, and "remanent" type devices.*

*Ferreed and bipolar ferreed coordinate arrays and individual units are new and important switching elements. These devices make use of miniature glass-enclosed contacts in combination with "square loop" magnetic material* such as ferrite or certain iron alloys. They are magnetic "latching" units and are operated or released by short pulses.*

## I. INTRODUCTION

An important article entitled "Relays in the Bell System" was published[1] in the B.S.T.J. in 1924. This was a comprehensive article on relays which were then in use in the Bell System, and it gave some information on typical applications. Since that time, a few articles have appeared in the B.S.T.J. covering relays, particularly the article[2] in 1952 describing the general purpose wire spring relay. This is the most widely used relay in Bell System equipment at the present time. In addition there have been several comprehensive publications on the design of relays[3,4] and several new forms of the wire spring relay, namely the "two-in-one" relay[5] and a magnetic latching form of this device. Miniature wire spring relays have been and are being studied.

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* In this paper, this is a remanent material of suitable coercive force range, generally intermediate between the common permanent magnets and the materials used for memory, such as cores, thin films, etc.

It is the purpose of this paper, in part, to bring together in one article some of the newer relays of importance to the Bell System, including a few which are experimental at this time. In this survey, the most important recent developments are miniaturization, sealed contact relays using glass-enclosed contacts, and magnetic latching devices. Frequency sensitive relays[6] are included, as are ferreed[7] and bipolar coordinate arrays. Such arrays consist of individual units of miniature glass-enclosed contacts (typically 2 or 4 at each crosspoint) in combination with a suitable "square loop" magnetic material such as certain ferrites or certain iron alloys which have controllable magnetic remanence. These devices are magnetic latching devices and can be operated or released by pulses as short as 5 microseconds. Arrays of this type are important units in Bell System electronic switching systems such as No. 1 ESS.[8]

Relays are made in larger quantities by the Bell System than ever before, and also more relays are made by more manufacturers outside the Bell System than ever before. The increasing use of relays is of interest in view of the rapid development of solid-state switching devices and systems and their higher switching speeds. In general, solid-state devices operate in microseconds or better compared with milliseconds or longer for electromechanical devices. The reasons[9] for the continued use and expansion of the uses of relay type switching devices are: (*i*) relays, with their large ratio of open to closed contact impedance, often result in equipment designs which are simple and inexpensive yet fast enough to make unimportant any increase in switching speed; (*ii*) relays can be used singly and in small numbers without the associated common control equipment often required to take full advantage of the sensational speeds of solid-state switching devices; (*iii*) the rapid expansion of switching of all kinds requires more of many types of switching equipment, including both solid-state and electromechanical types; and (*iv*) relays and solid-state devices are developing a compatibility, and in fact combinations of both have been developed, notably the ferreed. Compatibility has accelerated the miniaturization of new relay designs because they are often used together. Relay size reductions of $\frac{1}{10}$ or more in volume have been achieved.

Reliability is also becoming increasingly important, and lower failure rates are often required under more severe operating conditions. In military applications, this relates particularly to vibration, shock, temperature and humidity. Miniature relays often perform better under vibration and shock conditions than larger types because of the lower inertia of the moving parts and the higher natural frequencies of their smaller parts.

## II. MINIATURE SEALED CONTACTS AND RELAYS USING THESE

There are two general classes of sealed contacts of the glass enclosed type. These are the dry reed[10] type and the mercury-wetted[11] type.

Relays using the larger form of dry reed sealed contacts have been described in previous papers.[10] Two new miniature dry reed sealed contacts are shown in Fig. 1, and for comparison the larger 224A type,[10] which has been in Bell System applications for a number of years, particularly in the digit register package in the No. 5 crossbar system. All of these sealed contacts, shown in Fig. 1, consist of two magnetic reeds sealed in a glass tube. Dry reed sealed contacts are free from external influences such as dust, corrosive atmospheres, and ambient pressures, and are relatively free of temperature effects. They do require a high degree of care and control during manufacture if maximum performance and uniformity are needed. In general, the mating contact surfaces are plated with gold, silver, rhodium, etc., or combinations of these, sometimes diffused under a controlled atmosphere. These operations are necessary in order to achieve a low and stable contact resistance and to avoid sticking, which may be the case with certain soft precious metals. The 237A (or G29) was the first of the miniature dry reed sealed contacts to be applied in systems applications. As described in Ref. 10, it is essentially a scaled-down (1 to 3) version of the larger 224A sealed contact.

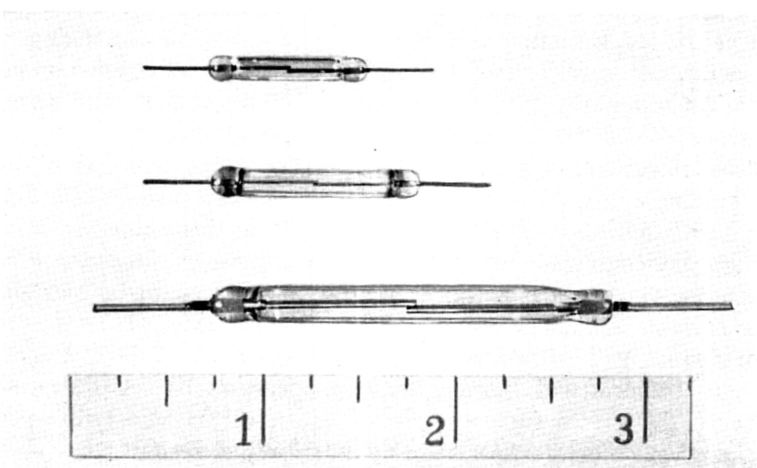



Fig. 1 — Dry reed sealed contacts: top, miniature type 237A (G-29); center, miniature type 237B; lower, standard type 224A.

The 237B miniature dry reed sealed contact was developed specifically for the crosspoint contacts of the switching network in electronic switching systems, although it is now also applied in certain relays in such systems and is suitable for general applications. The new requirements for the crosspoint application are: (*i*) higher breakdown voltage — of the order of 880 volts, (*ii*) closer operate and release values, and (*iii*) contact resistance of less than 0.2 ohm during 1,000,000 operations. These new and more severe requirements made it necessary (*i*) to pressurize the sealed contacts, (*ii*) to control tolerances more closely, and (*iii*) to improve the contact life by combinational plating of gold and silver. In addition, the reeds of the 237B design have been simplified by eliminating the "hinge" sections at a slight sacrifice in size. The increase is from the 237A length of 0.875 inch to 1.00 inch.

Operation of such contacts is by the application of a magnetic field, and several different methods are shown in Fig. 2. Fig. 2(a) shows the operation by passing the current through a winding surrounding the sealed contact. Fig. 2(b) shows one elementary form of ferreed where the operation results from pulse operation and magnetizing a "square loop" ferrite element. In this case the sealed contact remains closed without holding power because it is "magnetically latched." Release is by a pulse smaller in magnitude and of opposite polarity. Figs. 2(c) and 2(d) show other ferreed structures.

Typical values for the operating characteristics of these sealed contacts in air core coils are as shown in Table I. These operate ampere-turn values are minimum values in a simple air core test winding and, in general, faster speeds are obtained by increasing the applied ampere-turns. The minimum operate times as listed result, in general, by applying several times* the minimum operate ampere-turns.

Although sealed contacts can be operated by pulses of sufficient duration in the circuit shown in Fig. 2(a), the contact will remain closed only during an interval approximately the time that the current flows through the winding. Pulse operation of most interest is associated with "magnetic latching." This can be done by using a magnetic bias either by a suitable remanent member — as shown in Fig. 2(b) — or by a biasing winding. The operating time of such devices can be of the order of that obtained with normal neutral operation of sealed contacts. However, the ferreed type of operation can result in "effective" operating times very much faster and in the microsecond region.

There is another form of magnetic latching of sealed contacts which uses remanent reeds for the elements of the sealed contact. In this case,

* Operate time is a function of applied power ($EI$).

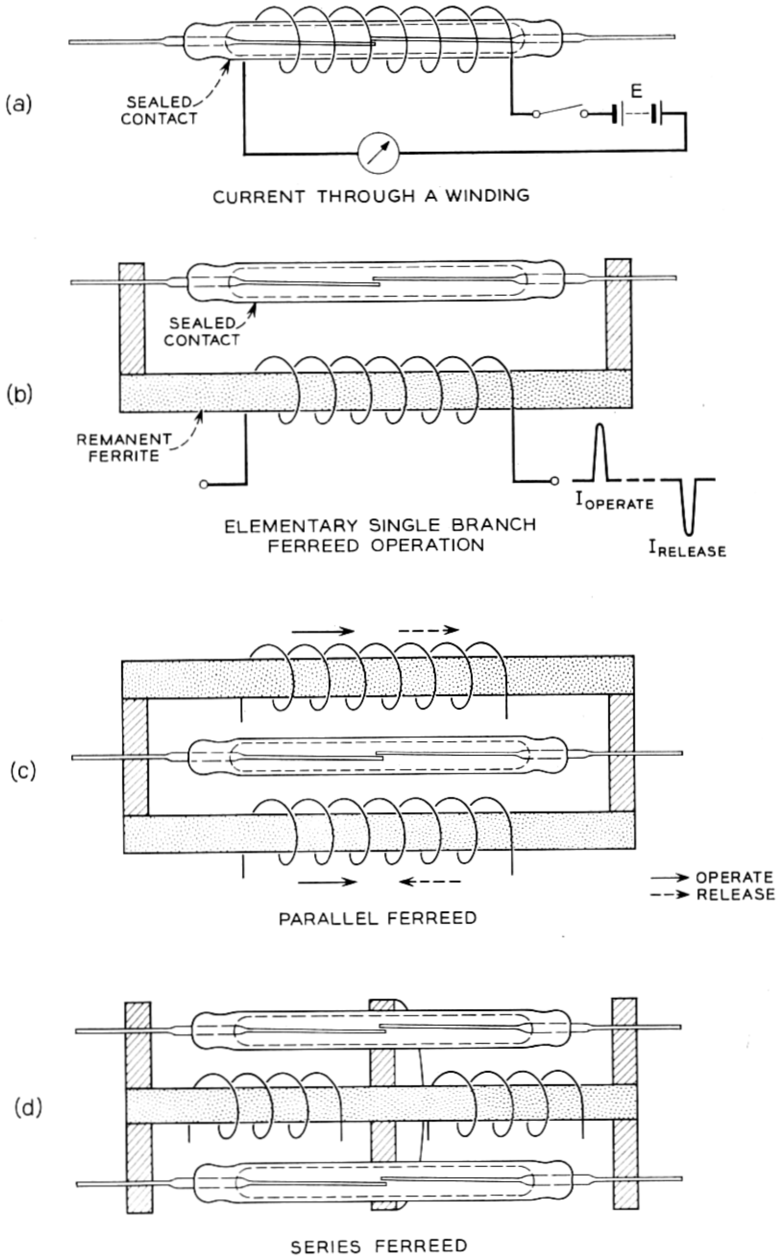



Fig. 2 — Operation of dry reed sealed contacts: (a) current through a winding, (b) elementary single-branch ferreed operation, (c) parallel ferreed, (d) series ferreed.

TABLE I — TYPICAL OPERATING CHARACTERISTICS

| Sealed Contact | Operate (Ampere-Turns) | Release (Ampere-Turns) | Approximate Minimum Operate Time |
|---|---|---|---|
| | | | (milliseconds) |
| 224 A | 90 ± 12 | 34 ± 8 | about 1.0 |
| 237A (G29) | 34 ± 12 | 18 ± 8 | " 0.5 |
| 237B | 30.5 ± 5.5 | 15 ± 4 | " 0.5 |

discussed in Refs. 7 and 12, the contacts are also locked by residual magnetism. As is the case with series or parallel ferreeds using non-remanent reed contacts, remanent reed sealed contacts may be operated by pulses shorter than the time of contact closure, but they may also be operated with longer pulses of lower power because the operation is dependent essentially on the input pulse energy. The advantage of remanent reeds is chiefly in the lower energy levels when they are used as crosspoints in a switching network, although these energy levels are somewhat higher than required to operate soft reeds in permanent magnet latching relays of this type. In comparing remanent reed sealed contacts and remanent sleeve crosspoints, the minimum energy in microwatt seconds, $EIt$* for operate and release, is important. Estimates are shown in Table II.

The energy relations also show how it is possible, in a given ferreed or remanent reed device, to trade time for the magnitude of the pulse current. For example, a 5-microsecond operate time would require a pulse of about 10 times the current value of that required to operate the same device (with a different winding) in 50 microseconds, etc.

Conventional type relays using the miniature 237A and 237B sealed contacts are shown in Fig. 3. Fig. 3(a) shows the 237A (G-29) sealed contact in a 2-make relay (GA 53702) as used in certain missile systems. Fig. 3(b) shows the 311A relay, which is a 3-make switching system relay using the 237B sealed contact. These relays are operated, under nominal conditions, at about 0.2 watt and 0.32 watt, respectively. Other designs with break contacts or transfer contacts have been made of similar size. Such relays make use of permanent magnets to bias the break contacts closed in the unenergized condition. By energizing the coil, these contacts are caused to open. Break and transfer contacts of this type have been made using the larger 224A sealed contact and have been described in a previous article.[13] There are limitations relating to

* $E$ = applied steady-state voltage in volts
$I$ = peak current in amperes
$t$ = time in seconds

TABLE II — INPUT REQUIREMENTS FOR OPERATE AND RELEASE FOR TWO SEALED CONTACTS PER CROSSPOINT

| | Operation | | Release | |
|---|---|---|---|---|
| | $NI_O$ | $EIt_{min}$ | $NI_R$ | $EIt_{min}$ |
| Remanent reed contact | 32 | 94 | 36 | 80 |
| Remanent sleeve crosspoint | 100 | 1900 | 70 | 900 |

reoperation at high currents through the coil and also to variations with operating current of the break and make sequence in such transfer contacts. In particular, break-before-make contacts cannot always be assured under all operating conditions. For this reason several forms of 3-element transfer sealed contacts have been studied to provide break-before-make action under all conditions. One such experimental dry reed transfer[14] sealed contact is shown in Fig. 4(a). In this particular form, all 3 reeds are made of magnetic material. Fig. 4(b) shows the design relations required for good operation and a sketch of the device. Other dry reed transfer sealed contact forms are also under consideration.

## III. FERREEDS AND BISTABLE DEVICES USING MINIATURE SEALED CONTACTS

Ferreeds were first described in an article[7] in the B.S.T.J. in 1960. Figs. 5 to 7 show several ferreed units. Fig. 5(a) shows one of the origi-

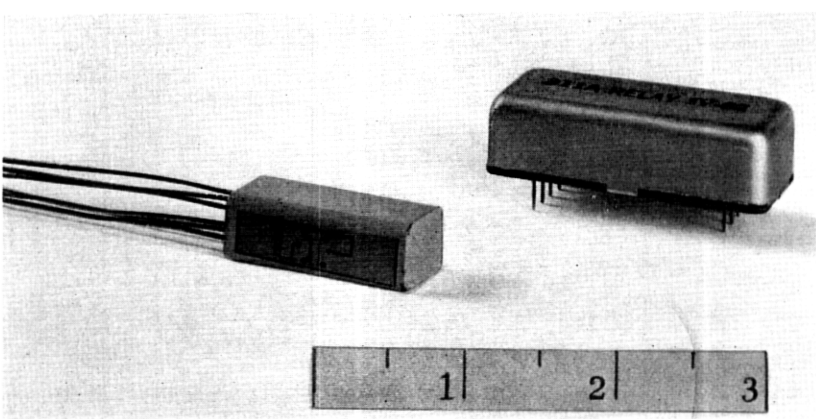
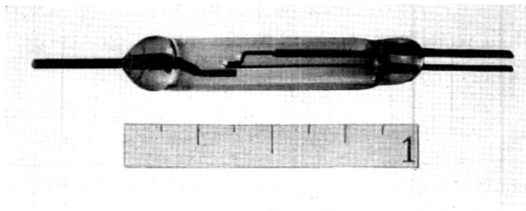
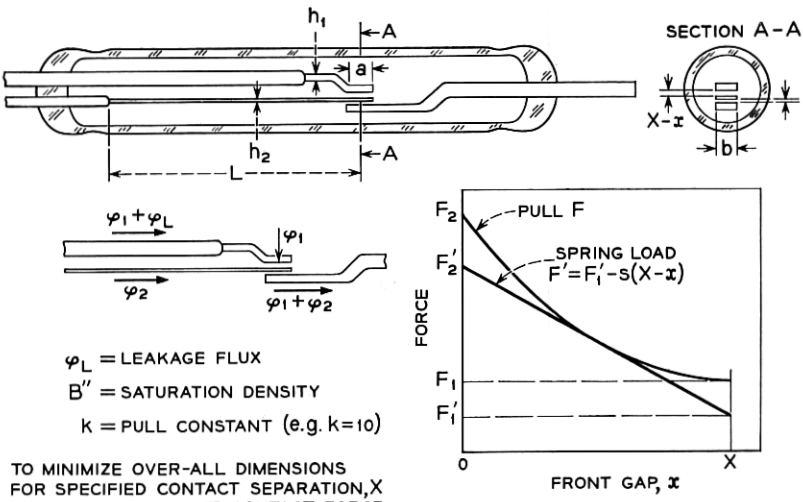



Fig. 3 — Relays using miniature sealed contacts: (a) 2 make contact missile relay GA 53702, (b) 3 make contact relay type 311A.




(a)




TO MINIMIZE OVER-ALL DIMENSIONS FOR SPECIFIED CONTACT SEPARATION, $X$ AND SPECIFIED FRONT CONTACT FORCE, $F_2 - F_2'$ AND BACK CONTACT FORCE, $F_1' = F_2 - F_2'$,

TAKE: $a = \frac{3}{4} kX$,

$$bh_2 = \frac{\varphi_2}{B''} \quad \text{FOR} \quad \frac{\varphi_2^{\,2}}{8\pi k b X} = F_1 = 2F_1',$$

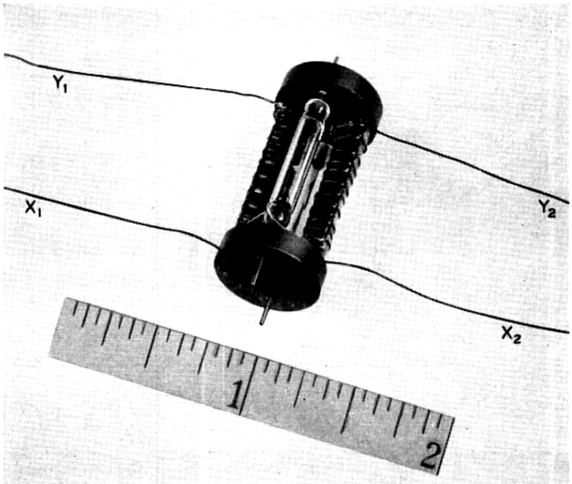
$$bh_1 = \frac{2(\varphi_1 + \varphi_L)}{B''} \quad \text{FOR} \quad \varphi_1 = \frac{3}{4}\varphi_2$$

$L$ TO MAKE: $s = 2.4 \frac{F_1}{X}$

(b)

Fig. 4 — Miniature dry reed transfer sealed contact: (a) model G-54, (b) optimum design relations.

(a)




(b)

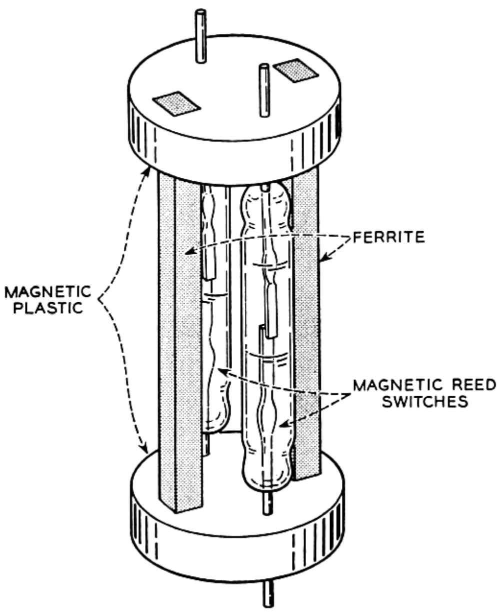



Fig. 5 — Ferreed designs: (a) photograph of 1960 design, (b) drawing of 1960 design.

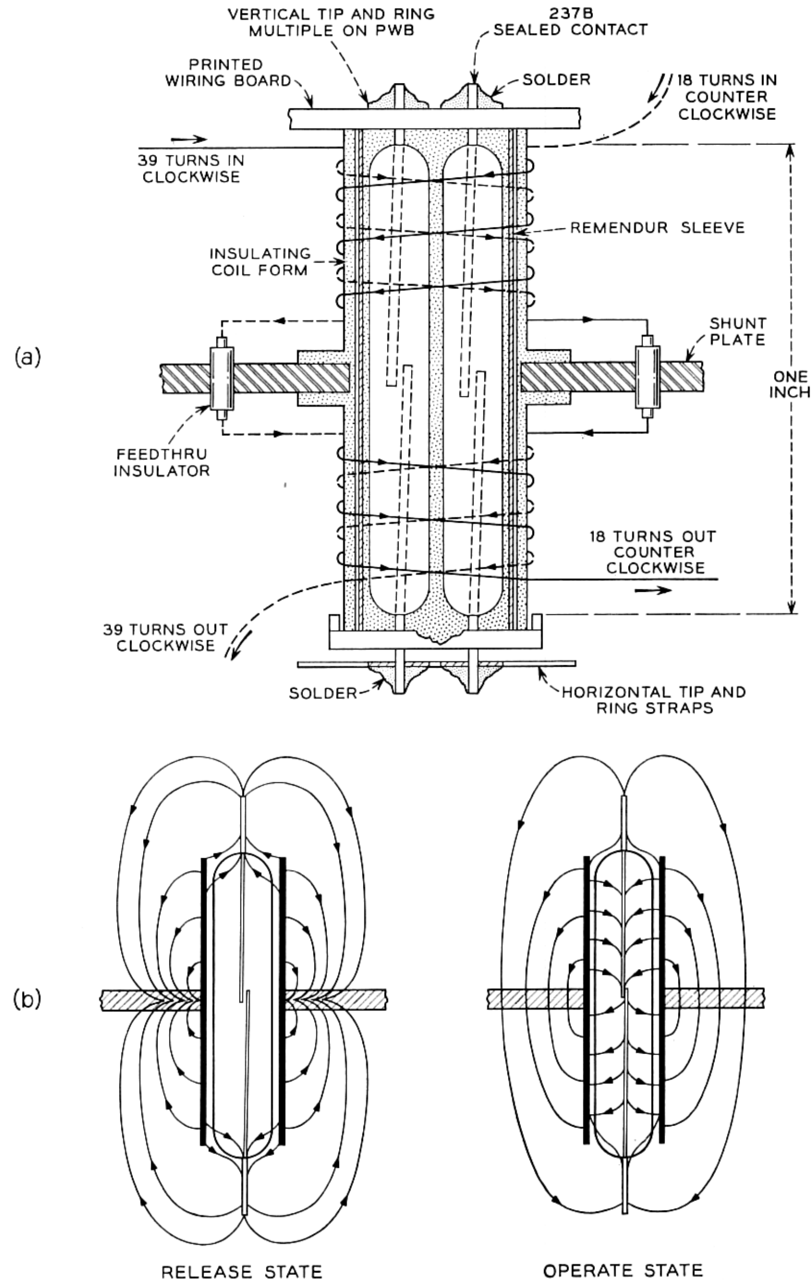



Fig. 6 — Ferreed designs (cont.): (a) crosspoint design with Remendur sleeve, (b) flux patterns with Remendur sleeve.

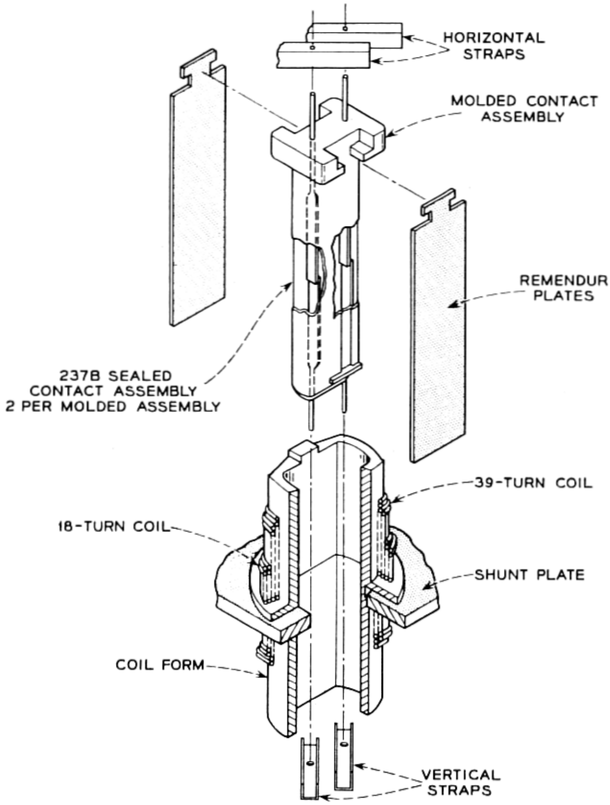



Fig. 7 — Ferreed designs (cont.): crosspoint design with Remendur plates.

nal parallel type ferreeds described in the 1960 article. Fig. 5(b) is a drawing of the same device. Fig. 6(a) shows another later series ferreed in which a sleeve of a "square loop" material (Remendur*) of the iron alloy type is used. Fig. 6(b) shows the flux patterns for the ferreed shown in Fig. 6(a). Fig. 7 shows a crosspoint using Remendur plates. An important characteristic of all of the ferreeds shown in Figs. 5 to 7 is the balanced magnetic release arrangement that eliminates marginal requirements on the release current.

In all cases one remanent member remains magnetized (half the remanent member in the series ferreed) while the field in the other member (or half member) is reversed in changing states. The field

* Remendur is an alloy of vanadium-iron-cobalt.

energy* which must be supplied to the operating coils to reverse magnetization is of the order of 3 to 5 times the remanent field energy of the remanent member and of the order of 10 or more on a pulse energy basis.

There should be no inherent difference in the performance of the parallel and series type ferreeds except (a) due to the energy requirement and (b) due to the dynamic characteristics in the sleeve or plate series ferreed where the flux through the reeds is necessarily reversed during each pulse. In this case the field due to the operating winding is in the opposite direction to the field supplied by the remanent members when the winding is not energized. The energy requirement mentioned in (a) can be less for the parallel type due to somewhat smaller air return reluctance, but on the other hand, the sleeve or plate series type provides better magnetic coupling.

The ferreeds having operate times down to about 5 microseconds use "square loop" ferrite magnetic materials. Somewhat simpler, less expensive and less temperature-sensitive forms of ferreeds use iron alloy metallic remanent materials in sleeve, plate, etc., form at some sacrifice in speed. However, speeds of about 50 microseconds or less are quite feasible. In any of these ferreeds, the magnetic material is set to the magnetized condition in microseconds. As a result of this, the sealed contacts close about 0.2 to 0.5 millisecond later. For almost all practical circuit conditions, this can be taken as operation in microseconds because circuit elements of this type are not usually required to release until other circuit operations are completed. Typical important *ferrite* characteristics for ferreed operation are coercive force, $H_c$, of 30–35 oersteds at maximum field, $H$, of 1000 and saturation flux density, $B$, of 4500 gauss, with corresponding remanence $B_R$ about 2800. Typical magnetic characteristics of an iron alloy (Remendur) used with ferreeds are: $H_c$, 37–42 oersteds at maximum field, $H$, 100 and saturation flux density of 21,000 gauss, with corresponding remanence $B_R$ of 17,000.

### 3.1 *Ferreed and Bistable Arrays*

In switching networks for electronic switching systems,[8] arrays and equipment assemblies of individual ferreed units are needed, for example 8 by 8, 1 by 8, etc. These have been needed in 2-wire and 4-wire forms. Accordingly, in the 8 by 8 array of the 4-wire type, 256 sealed contacts are needed. In one form, such arrays use four flat plates of

* The field energy is proportional to the product of the saturation flux for the reeds and the magnetomotive force required to develop this flux. Better magnetic coupling between the remanent members and the reeds will reduce the field energy required.

Remendur which are rolled in such a direction as to give the maximum magnetic properties in the direction of the reed axes.

The operation of a ferreed array is somewhat similar to that of a crossbar switch in that a particular crosspoint is operated by the simultaneous operation of particular vertical and horizontal rows. A particular crosspoint is thereby operated and held in this condition without holding power. The winding arrangements of the ferreed elements are such that the other crosspoints remain unoperated. To release the crosspoint, in effect, reverse currents reset the magnetic material to the unmagnetized condition; hence the sealed contacts open. Fig. 8 shows an 8 by 8,2-wire array or switch.

The ferreed shown in Figs. 6(a) or 7 is the basic crosspoint element of the array shown in Fig. 8. This form contains 2 miniature dry reed sealed contacts surrounded by a sleeve (flat plates are more recent) of remanent magnetic material (Remendur). The magnetic shunt plate, positioned at the midpoint of the sleeve, separates the sleeve or plates magnetically into two independent halves. When the two halves are magnetized series-aiding, the flux return is through the reeds, causing the sealed contacts to close. When they are magnetized in series-opposition, the sealed contacts open.

Each end of each crosspoint has two windings. A winding on one end is connected in series-opposition, with the winding of half the number of turns on the other end, as shown in Fig. 6(a). When either of the two sets of windings is energized, the two ends of the sleeve or plate are poled oppositely and the sealed contacts are opened. When the two sets of windings are energized simultaneously with equal currents, the two ends are poled series-aiding and the sealed contacts close.

In a typical switch, 64 ferreed crosspoints are assembled together to form an 8 by 8 switch. Internal to the switch, the windings of rows and columns form a common multiple. To close a crosspoint, current is passed in one column and out one row via a common multiple. The crosspoint at the intersection of the column and row then closes. At the same time, current passes through one of the two windings of all other ferrends in the same row and column, causing any that are operated to release. This is a differential mode of operation, called "destructive mark"; it is characterized by the absence of specific network release operations, i.e. "taking down" connections. Connections are "taken down" as a direct result of, and at the same time as, connections that are set up.

Bipolar ferreeds are also needed in switching systems. Fig. 9 shows the magnetic circuit of one form of an individual bipolar element. A

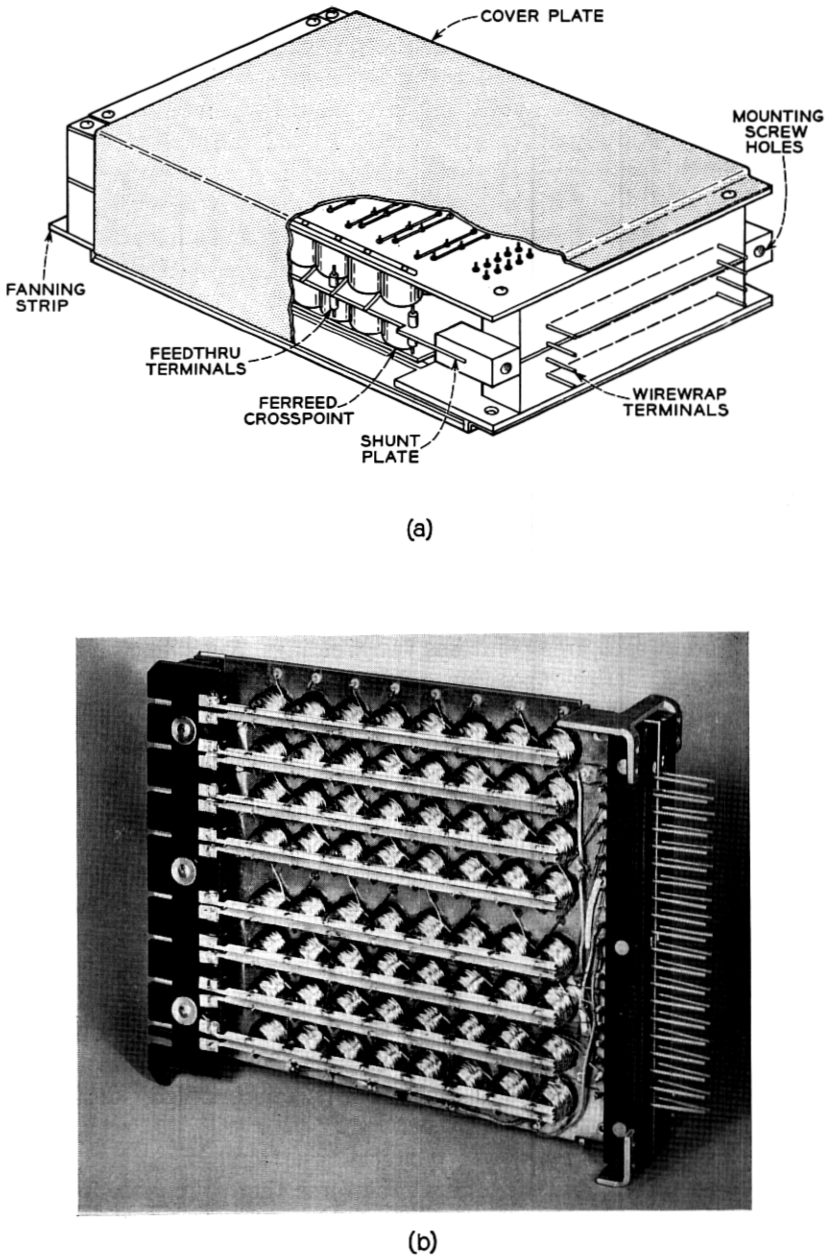



Fig. 8 — 8 by 8, 2-wire ferreed switch: (a) complete switch, (b) switch with cover removed.

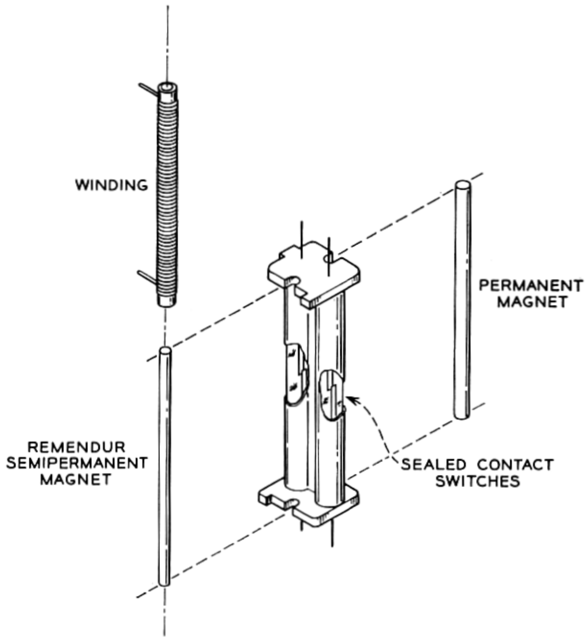



Fig. 9 — 2-contact bipolar ferreed.

combination of a "square loop" material is used together with a permanent magnet arranged as shown in relation to the sealed contacts. In this case more than one sealed contact may be used at each crosspoint. The bipolar unit gives a cutoff relay action. Fig. 10 shows a 1 by 8 unit of the 2-wire type. These open or close the reed contacts in response to the polarity of the current through a single winding.

## IV. MERCURY-WETTED SEALED CONTACTS AND RELAYS

Fig. 11 shows a number of mercury-wetted sealed contacts of the transfer contact type. The 226D type is one of the smallest and most recent types. It is different from the others shown in that it is a break-before-make contact. The break-before-make action is the result of design changes, Fig. 11, of the pole-piece contact elements. Sealed contacts with mercury-wetted contacts are important because they have been shown to have the least contact chatter, often none, also have the longest operating life of any relays yet designed, and can exceed one billion operations.

The small size of the 226D mercury sealed contact can be packaged

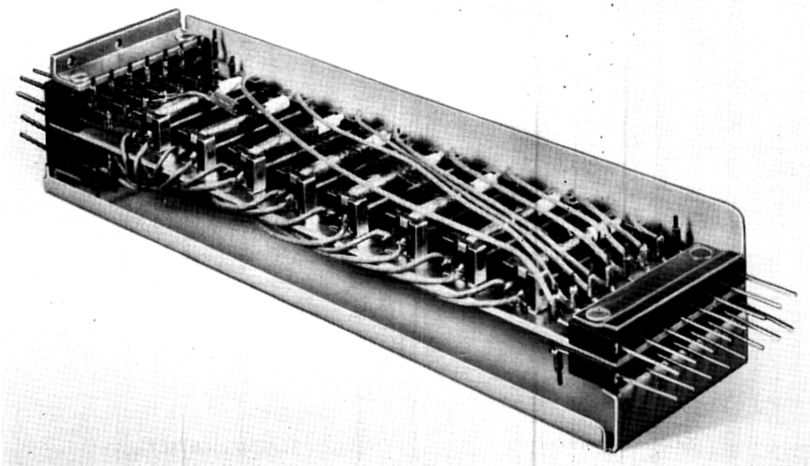


Fig. 10 — 1 by 8 assembly of 2-wire bipolar ferreeds.

in a small-size relay. However, two new relay designs using the new mercury sealed contact, the 314A and the 315A, do not require size reduction because they are chiefly expected to replace larger Bell System relays, namely the 255 and 280 types in certain applications where improved performance is needed.

The 314A is expected to replace the 255 type polar relay in telegraph circuits and to reduce maintenance in these. Fig. 12 shows the 255 relay and the new 314A relay. As can be seen, these are plug-in types and are interchangeable.

The 315A shown in Fig. 13 is a plug-in type and is expected to replace some of the codes of the 280 type polar relay, particularly those used in the No. 5 crossbar system, in order to improve performance and reduce maintenance. This is important in that the 280 type relays used in the No. 5 crossbar system show the highest relay trouble rate in terms of troubles per 1000 relays per year. However, 280 type relays are used in smaller numbers, in such systems, to perform special and exacting functions.

All of the mercury sealed contacts discussed, or used by the Bell System up to the present time, are required to operate in a vertical position within certain limits, usually $\pm$ 30 degrees. Military applications, particularly, would be served by an "all-position" mercury sealed contact. Several forms of such contacts have been built and studied. Most of these have been judged to be rather complicated and relatively expensive to control and manufacture. A more recent and simpler experimental design is shown in Fig. 14. Basically, this is a modification of the 226D sealed contact shown in Fig. 11 but modified in two ways: (*i*) excess mercury is removed during manufacture, including the usual pool of mercury, and (*ii*) armature changes have been made to improve the contact performance under shock and vibration conditions. By reducing the amount of available mercury for replenishment at the contact surface, the life of the sealed contact is reduced, but several million op-

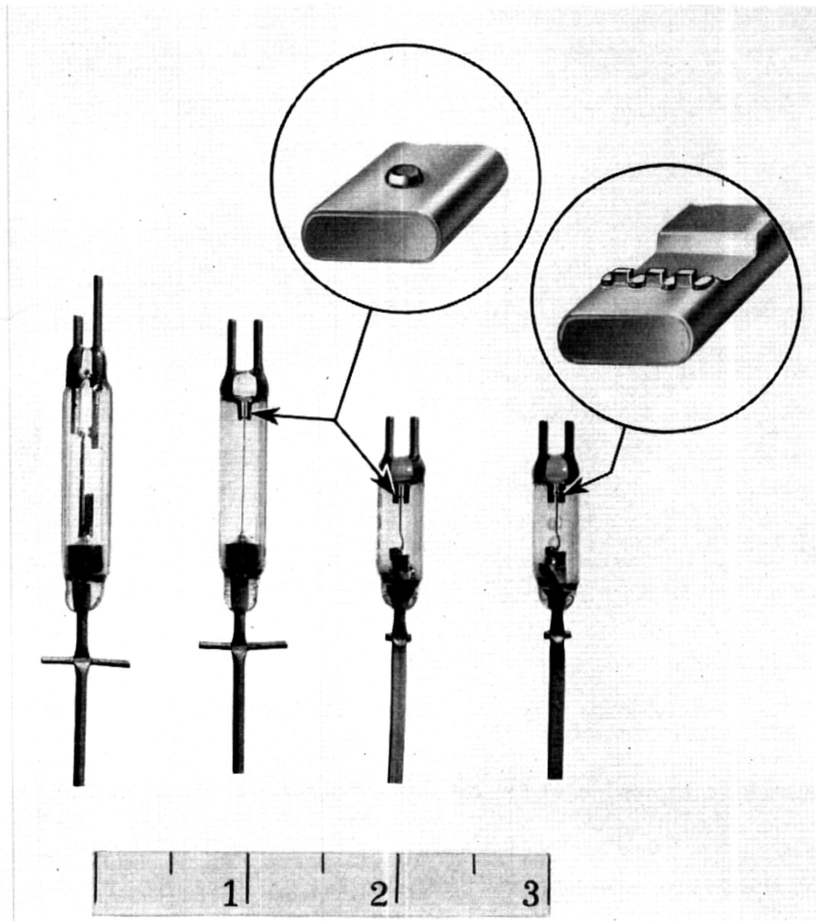



Fig. 11 — Mercury-wetted sealed contacts: left, 218 type; left center, 222 type make-before-break contact; right center, 226B type make-before-break contact; right, 226D type break-before-make contact.

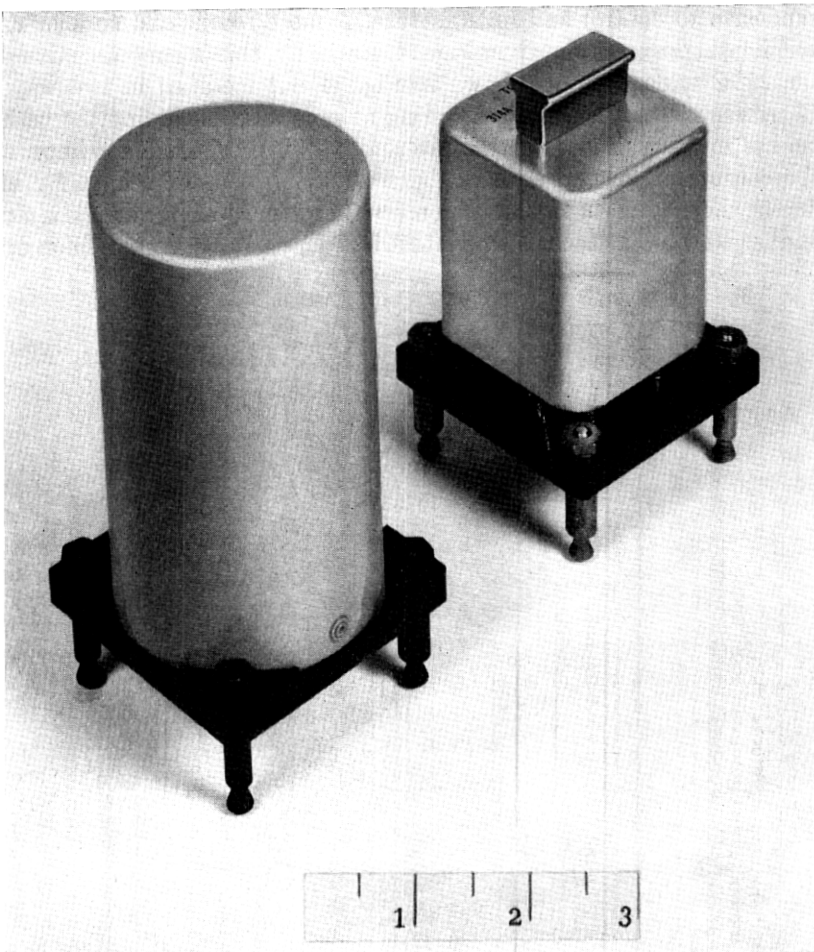


Fig. 12 — Telegraph relays: left, standard 255 type; right, new 314A type using 226D sealed contact.

erations are possible. For many applications this is adequate. This relay is described in detail in an article[15] in the Bell Laboratories Record.

## V. MINIATURE ARMATURE TYPE RELAYS

### 5.1 *Rotary Armature Relays*

A miniature relay of this type was described in a paper[16] in 1959. Fig. 15(a) is a photograph of this relay and Fig. 15(b) is a drawing of its

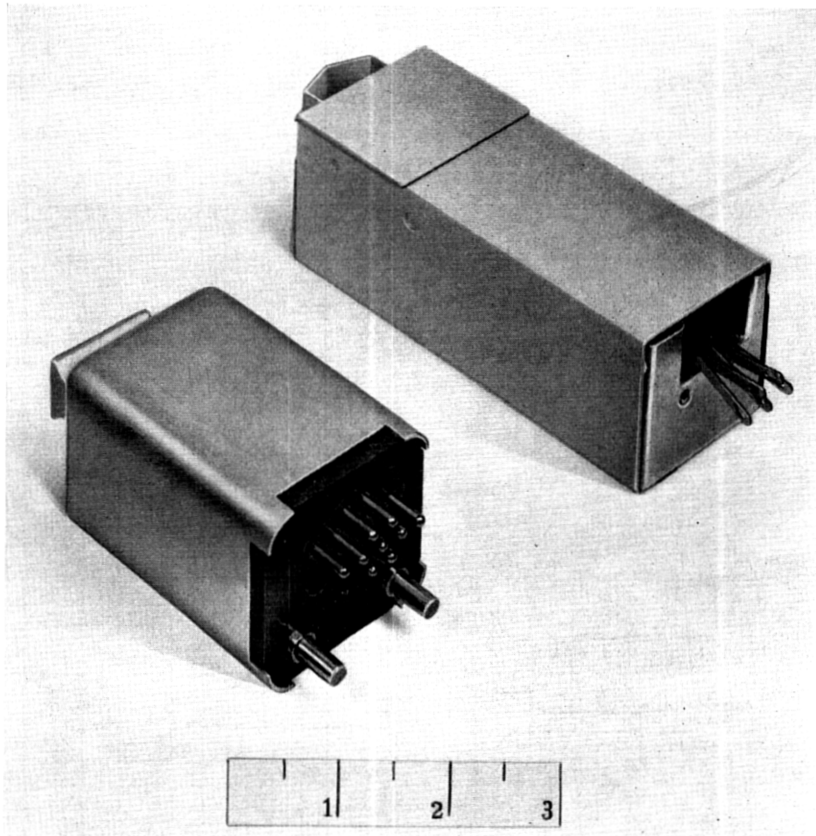


Fig. 13 — Polar relays: right, standard 280 type; left, new 315A type using 226D sealed contact.

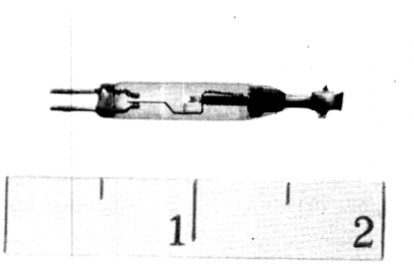
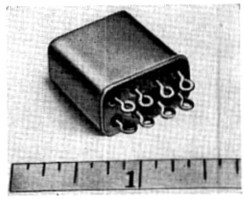
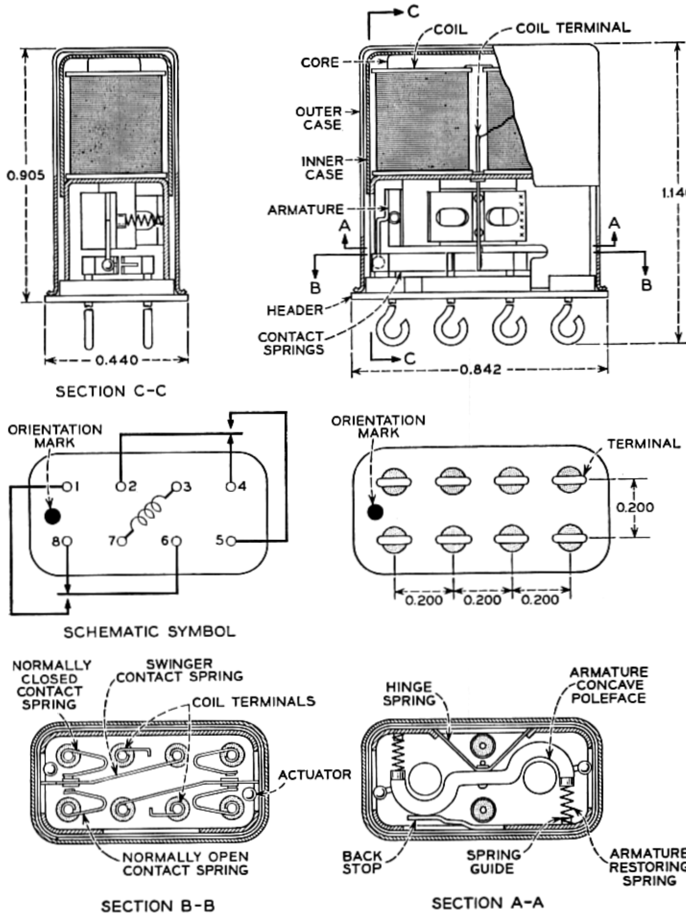


Fig. 14 — Experimental "all position" mercury-wetted sealed contact model T-116.

(a)






(b)

Fig. 15 — Miniature rotary armature relay: (a) photograph of GS 57668 relay, (b) drawing showing relay construction.

major elements. It has been in manufacture for military applications as the GS 57668 relay. It is of the "crystal can" size and has a rotary armature operating two transfer contacts symmetrically arranged. As compared with similar relays it has the following advantages: (*i*) improved contact reliability, particularly in dry circuits, by the use of twin precious metal contacts in a separate sealed contact chamber free of all organic materials; this eliminates the so-called "brown powder" problem in which organic polymers are formed with resulting high-resistance contacts; (*ii*) elimination of bearing friction and the associated erratic performance; this is accomplished by using a reed type spring armature suspension; and (*iii*) a magnetic design of improved sensitivity with corresponding reduced effect due to stray magnetic fields.

### 5.2 Telstar *Satellite Type Relays*[17]

Fig. 16 shows a relay similar to the "crystal can" relay shown in Fig. 15 except that it operates or releases on pulses. It uses magnetic latching so that no holding power is required. This relay is used in the Bell System Telstar satellites; in fact nine each are used in Telstar I and Telstar II. Fig. 16(a) is a photograph of the relay, and Fig. 16(b) is a drawing of the chief features. It is characterized by the dual armatures in which the two armatures are connected together by a small permanent magnet. Fig. 16(c) shows the control circuit in Telstar I using the relay.

### 5.3 *MA and MB Miniature Relays*[18]

A new series of relays known as MA and MB types has recently been developed, primarily to save space for equipment installed on the premises of Bell System customers. Manufacture of these was started at the Western Electric Co. plant at Kearny, N. J., in 1962. Fig. 17 shows the MA and MB relays. The MA relay has a maximum contact capacity of 4 transfer contacts and the MB, which uses some of the same piece parts, has a maximum contact capacity of 6 transfer contacts.

These relays have most of the basic features of the standard wire spring relay (Ref. 2), namely: (*i*) code card operation to provide a simple means for a wide variety of contact combinations; (*ii*) low stiffness, pretensioned springs; (*iii*) coplanar spring groups to simplify welding and handling and to standardize assembly in manufacture; (*iv*) contact materials and contact forces identical with the standard wire spring relay; (*v*) essential elimination of locked contacts because of the card operation; (*vi*) twin precious metal contacts; etc. The basic contact springs are shown in Fig. 18 before and after shearing the ends of the

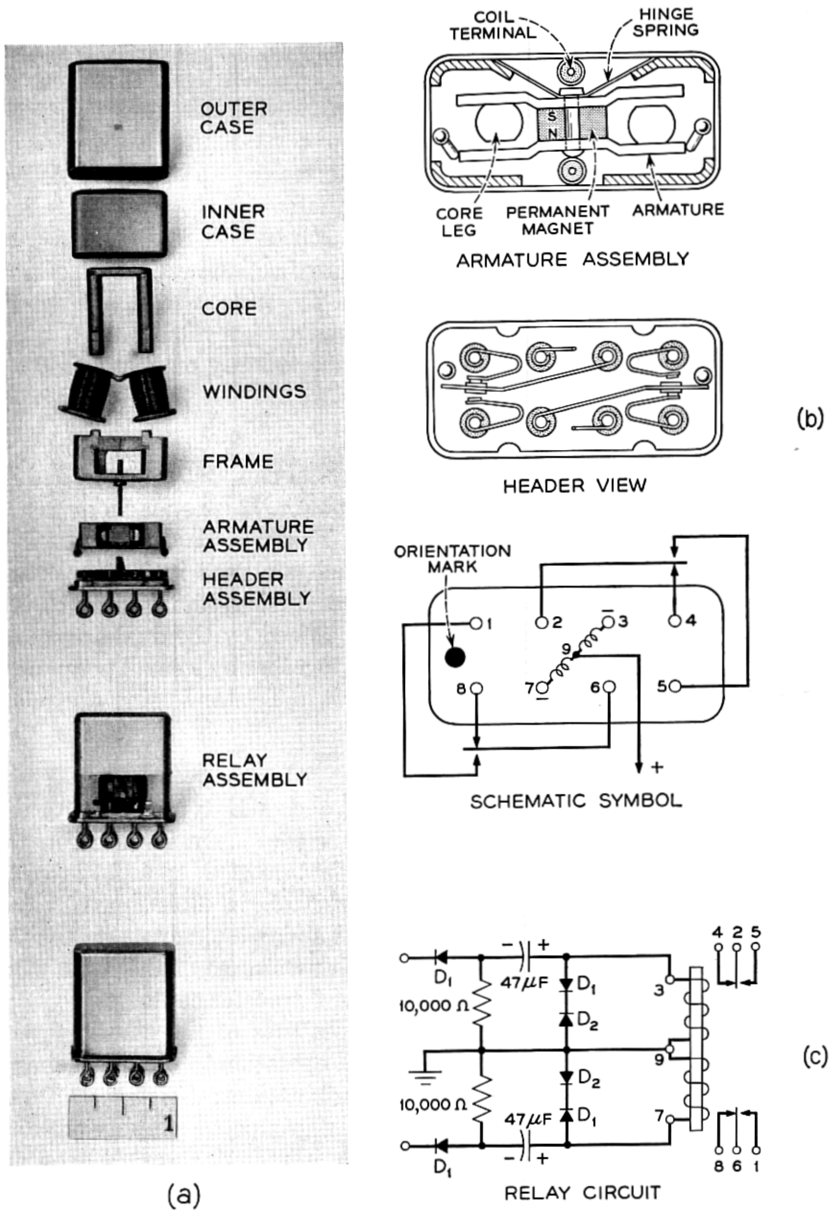



Fig. 16 — Miniature rotary armature latching relay (Telstar): (a) photograph of relay and relay parts, (b) relay armature assembly and circuit used in Telstar satellite, (c) control circuit in Telstar I.

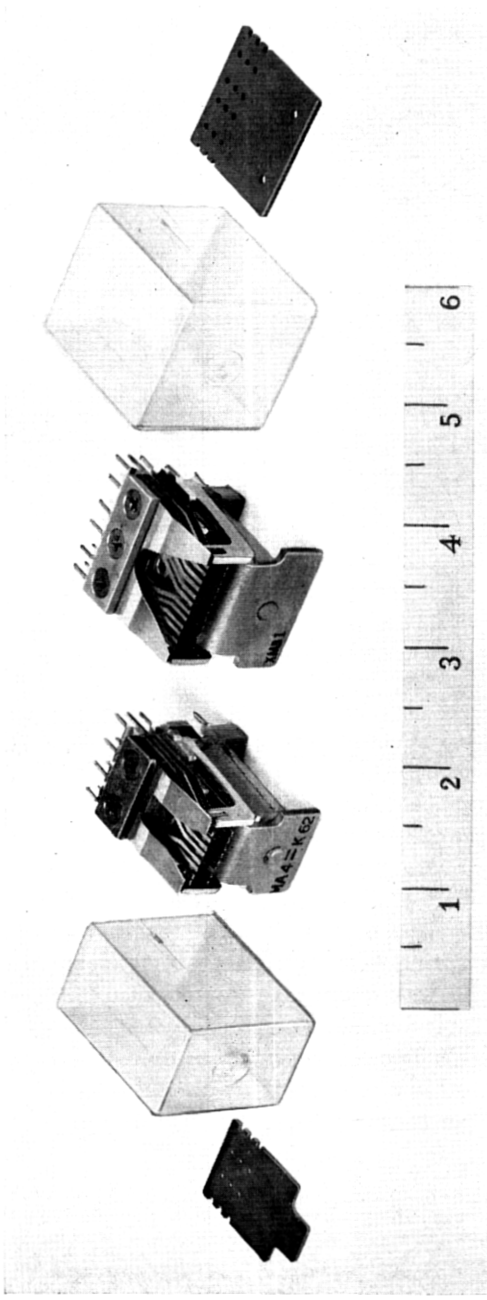



Fig. 17 — Miniature MA and MB type relays: left, MA type; right, MB type.

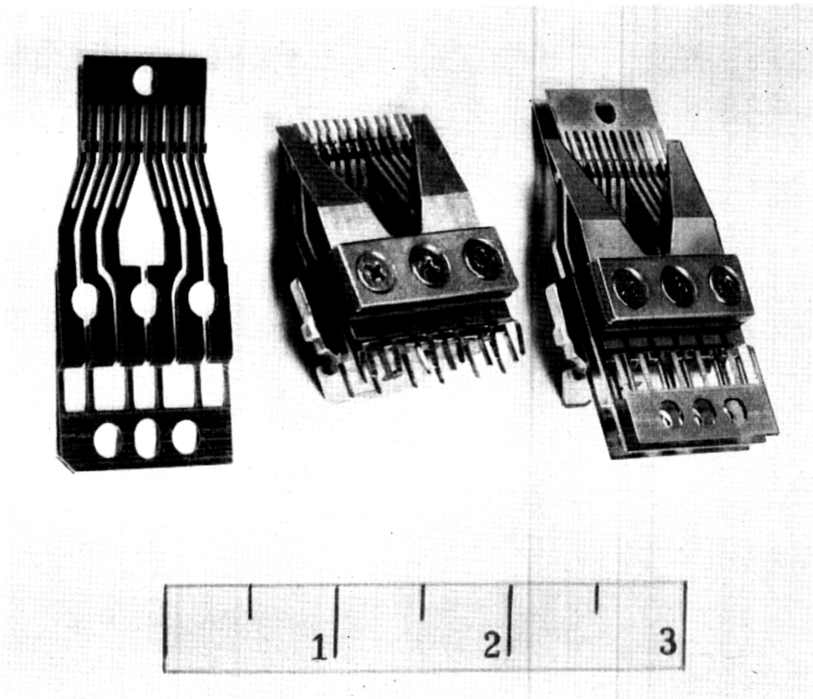


Fig. 18 — Contact springs for MB type relay.

contact spring groups. Typical contact and winding information and operating currents are given in Table III. As is the case for the standard general purpose wire spring relay, a few code cards are sufficient for a large number of contact combinations.

The MA and MB relays do not have the sensitivity* or the contact capacity of the wire spring relays, but they are much smaller, i.e., about $\frac{1}{10}$ the volume, and they are suitable for mounting on printed circuit boards. One such typical plug-in printed circuit package is shown in Figs. 19(a) and 19(b). The same principles used in the MA and MB relays can also be used in crossbar switch designs to reduce the size and weight to about 15 per cent of the present types.

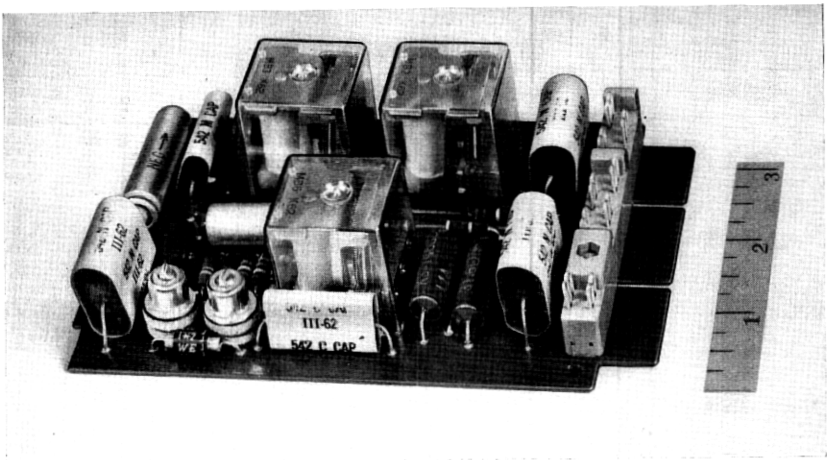
* Ampere-turn sensitivity of the 6 transfer MB relay is about 185, compared with 160 for the AF wire spring relay and 220 for the AK (5 transfer) relay. However, because of the larger coil on wire spring relays, the relative power sensitivities for 6 transfer relays are about: 0.45 watt for the MB, 0.18 for the AF, 0.14 for the AJ, and 0.55 for the AK relay.

TABLE III — SOME TYPICAL MA AND MB RELAY CODE INFORMATION

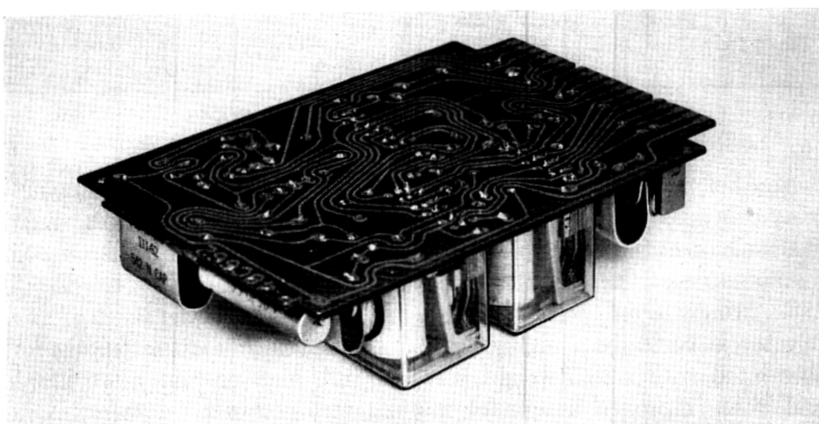
| Code | Springs | Winding Resistance | Operate Current |
|---|---|---|---|
| | | (ohms) | (amperes) |
| MA 1 | 4 transfers | 915 | 0.016 |
| MA 3 | 2 makes<br>2 breaks | 590 | 0.013 |
| MA 4 | 3 transfers<br>1 continuity | 915 | 0.016 |
| MA 7 | 3 makes<br>1 transfer | 2100 | 0.0078 |
| MA 11 | 2 transfers<br>2 continuities | 590 | 0.021 |
| MB 1 | 6 transfers | 590 | 0.024 |
| MB 3 | 2 transfers<br>1 continuity<br>2 makes<br>1 break | 915 | 0.018 |
| MB 4 | 6 makes | 915 | 0.016 |
| MB 6 | 2 continuities<br>2 makes<br>1 early break | 915 | 0.0175 |
| MB 7 | 3 transfers<br>3 continuities | 590 | 0.024 |

## VI. FREQUENCY SENSITIVE RELAY—THE VIBRATING REED SELECTOR

Another miniature device, shown in Fig. 20, is a frequency sensitive relay called the 215 type tuned reed selector.[6] Fig. 21 shows a drawing of the basic operating principles. The selector shown in Fig. 20 has been in manufacture at the Western Electric Co. in North Carolina, starting in 1962, primarily for the Bell System BELLBOY radio paging service.[19] The selector is basically a highly precise and stable miniature tuning fork associated with a lightweight contact. It is smaller and more stable, and is an improved design for manufacture compared with an earlier similar device known as the type 212 selector.[20] These devices are very sensitive, responsive only to sustained frequencies of the order of 0.5 second, and insensitive to noise interference. Fig. 22 shows the data over a wide temperature range for two of these devices, operating at nominal frequencies of 517.5 and 997.5 cycles per second and at corresponding bandwidths of about 1.1 and 1.3 cycles per second. Sufficient stability has been achieved so that, for the BELLBOY service, 33 different frequencies spaced 15 cycles apart are provided in less than one octave between 517.5 and 997.5 cycles. By using three different frequencies at a time, more than 5000 combinations are possible for selective ringing of a particular customer.




(a)



(b)

Fig. 19 — Plug-in printed wiring board with MB type relays: (a) apparatus side, (b) wiring side.

Stability of materials and design have been measured, and these show the total frequency change from $-40°C$ to $+80°C$ to be less than 0.5 cycle and the bandwidth change to be less than 0.2 cycle. At operating power levels of 100 microwatts, the intermittent contact will close to a low-resistance level over 20 per cent or more of the cycle time. An important factor in this has been the use of a nickel-iron-molybdenum alloy[21] (Vibralloy). This material has controlled elastic and magnetic properties.

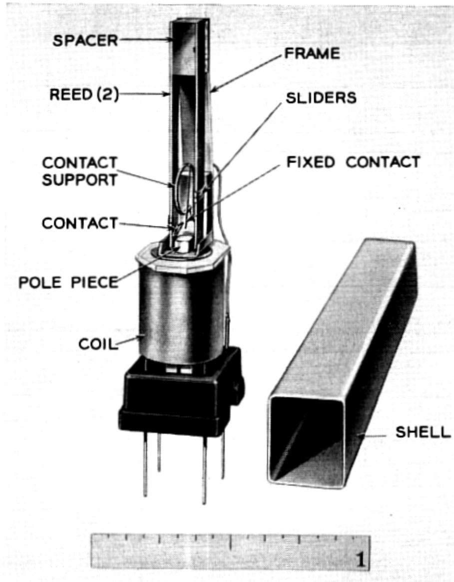



Fig. 20 — Tuned reed selector (BELLBOY) — 215 type.

The lightweight contact is essential so that the selector frequency is unchanged when the intermittent contact is made. The contacts are rhodium against platinum rhodium. Clearly, contact life is important and circuits are used typically to change the potential on an electron tube or transistor to trigger a switching or signaling function without exceeding a contact current of a few milliamperes. In the BELLBOY application a transistor oscillator is triggered to give an audible signal. However, the short contact closures occurring at a rate of hundreds per second may therefore control pulses that have an integrated or average power that is a substantial fraction of a watt. For example, only small

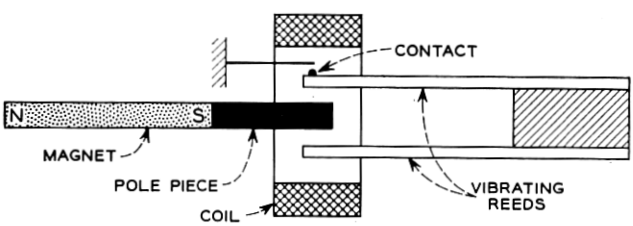



Fig. 21 — Tuned reed selector schematic.

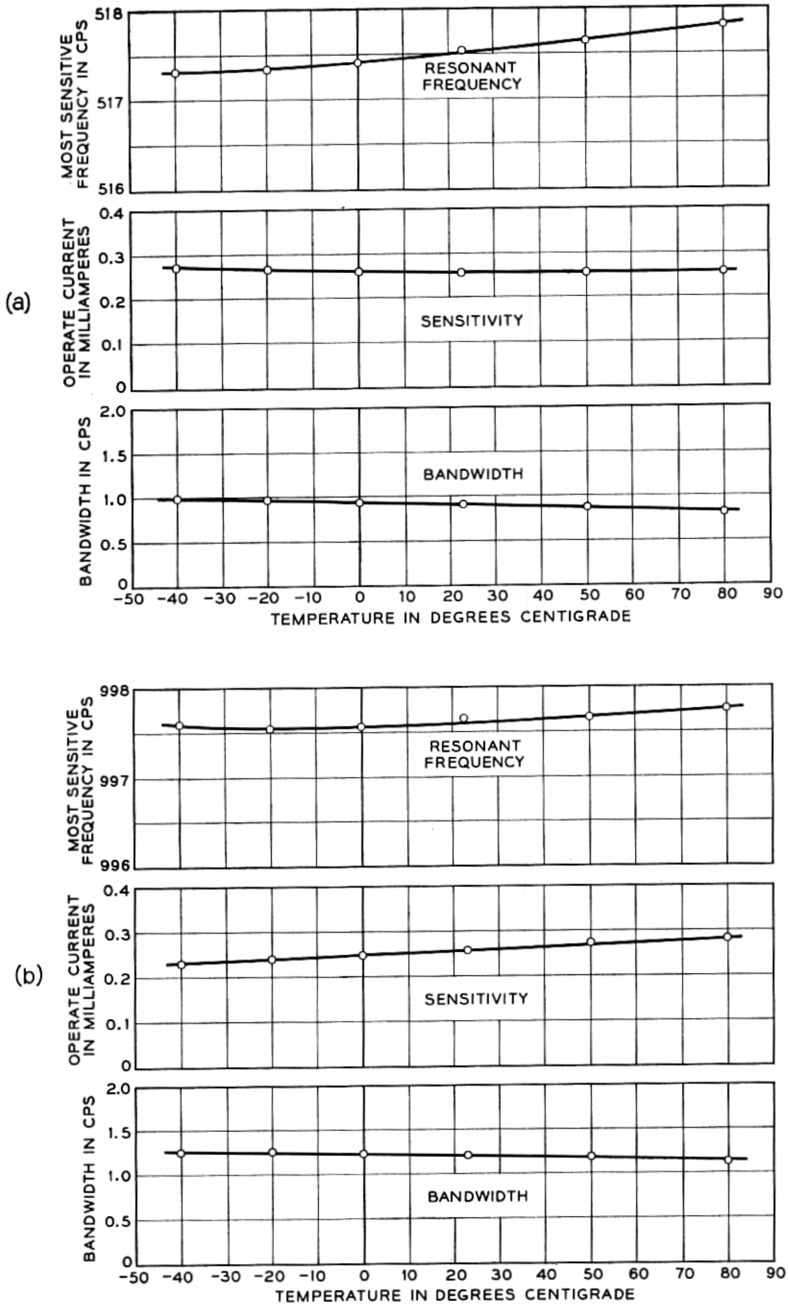



Fig. 22 — 215 type tuned reed selector data: (a) temperature characteristics of 517.5-cycle unit, (b) temperature characteristics of 997.5 cycle unit.

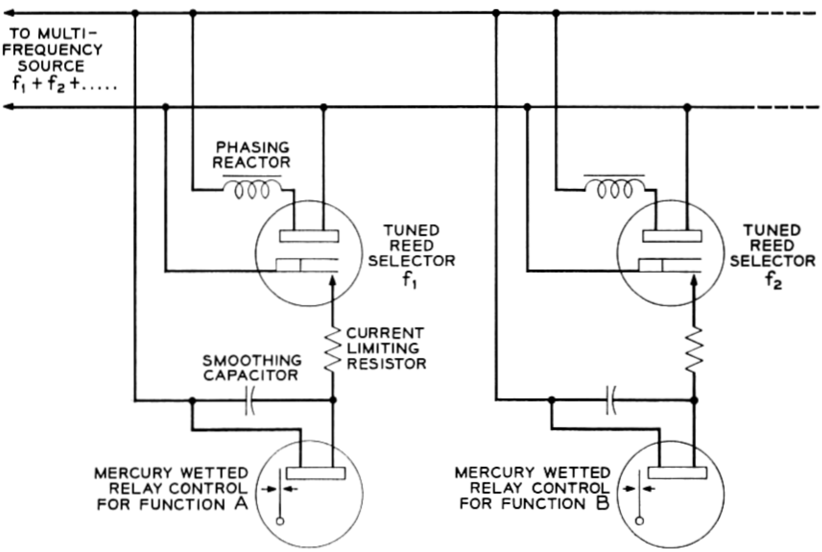



Fig. 23 — Direct operation of mercury-wetted relay from low-level frequency frequency signals via tuned reed selectors.

changes in frequency or sensitivity were measured over a test period of 1500 hours in a 12-volt circuit with a 240-ohm resistor giving a closing current of 50 milliamperes. The power capacity of the contacts can, in fact, be used to operate relays or other devices directly: for example, mercury sealed contact relays with large contact current capacity. One such circuit is shown in Fig. 23. In this circuit the selector contact is used as a synchronous rectifying means to generate dc from the same ac source that operates the selector. When the input frequency corresponds to that of the selector, the contact closes in synchronism once each cycle to send unidirectional pulses to the capacitor and relay in parallel. The capacitor serves to smooth the pulses so that the relay winding has nearly a constant current in it. Combination circuits using reed selectors and mercury-wetted contact relays provide a simple means of selectively controlling substantial powers to perform a multiplicity of functions over a single pair of wires.

## VII. REMARKS

In the telecommunications field, rapid advances are being made in many new areas of technology. Devices and systems based on these will naturally be compared and evaluated for Bell System applications with older devices and systems. In such comparisons, care is needed to do this, not only with devices at hand but with the possibilities that presently exist on the basis of general advances made in the older fields. One of the older and important areas is that of electromechanical devices such as the relays discussed in this article. Decisions can then be made and devices chosen, not on the basis of technology, but on the basis of the best performance, cost, and over-all systems requirements. Relays, in modern form, sometimes in miniature form, can be expected to be important devices in the future as they have been in the past.

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