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Remreed Switching Networks for No. 1 and No. 1A ESS:

System Overview

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(Manuscript received December 19, 1975)

This paper is an introduction to a series of detailed technical articles that describe the remreed switching network for No. 1 and No. 1A ESS. The developmental background, technological advances, design constraints and guidelines, objectives, advantages and status of the remreed network are outlined.

I. INTRODUCTION

More than 650 No. 1 ESS offices are now in service. Since the first cutover of No. 1 ESS at Succasunna, New Jersey, on May 30, 1965, constant attention has been given to improving system performance, increasing call capacity, and providing new features and services while holding down system costs.

In the process of developing any new system, compromises must be made in using existing technology as well as new developments to satisfy all the system objectives. It often happens that, following introduction of the system, continued progress in the development of components and devices reaches a point where new technologies can be applied successfully to improve the system. To capitalize on these new developments, either a new system can be designed or the existing system can be modified through an evolutionary process. The latter

course was chosen for the No. 1 Electronic Switching System (No. 1 ESS).

As the needed new technologies became available in recent years, opportunities were created for markedly reducing the cost and size of the original No. 1 ESS. In that system, the switching network accounted for about 40 percent of the office floor space and about 40 percent of the material cost of the office.

One new component design studied was a remanent reed contact (commonly referred to as a remreed contact) based on a better understanding of the processing and working of the magnetic alloy remendur. At the same time, electronic control of reed networks had also been under study for several years. After further study showed that large-scale reductions in size and cost could be realized using these new developments, the decision was made early in 1971 to redesign the network for No. 1 ESS. The new network design would take full advantage of the advances made with the remreed contact, electronic control, hybrid integrated circuits, and connectorization.

II. DESIGN GUIDELINES

Three important constraints were imposed on this project. Because a substantial amount of capital was invested in the manufacturing facilities for the ferreed contacts and switches used in the original No. 1 ESS, the first constraint was that a major portion of these facilities had to be capable of manufacturing the new designs. The second constraint was that the physical design used to apply electronic control to the network must make use of either the same technology used for No. 1 ESS or a new technology that could be shared with other projects. Because of the investment in software development for No. 1 ESS, the third constraint was that the building blocks of the new switching network must be compatible with those of the existing network and must function with the same call processing and maintenance software. These constraints limited the design options to some extent, yet they permitted meeting the major goals of the development—reduction in cost and size.

As a result of preliminary studies, some important design principles evolved that set the course for the final design. With respect to the contact design, it was anticipated that the cost of the contact would be approximately the same as the 237B. However, the size and performance of the contact would be such that it would permit other major cost reductions, such as the use of electronic network control by means of low-cost components. With respect to the size of the contact, only moderate reductions were anticipated so that it would be possible to use the same type of processing and assembly machinery as that

used for the 237B contact, yet the contact would be small enough to permit major savings in switch packaging.

The overall size of the switch package was to be such that a 1:1 trunk link network could be built and tested in the factory and shipped as an entity. To save the cost of mounting and wiring, many pulse-steering components were to be mounted in the switch packages.

Each line served by No. 1 and No. 1A ESS requires a scan point. Therefore, the design of an electronically controlled scanner was made an important and integral part of the line link network development. Again, to save the cost of mounting and wiring, the scan point and cut-off devices, as well as many of the pulse-steering components, were mounted in the switch packages.

The frame depth and height were to match the existing ferreed frames, while the maximum width to be shipped as an entity was 6 ft, 6 in. The switch packages were to be assembled in modules that could be removed from the front of the frame. All cables that interconnected these modules and the electronic circuit packs were to be connectorized. The module size was chosen so that the terminal hours of downtime due to module replacement to remove a fabric fault would be less than or equal to that experienced with ferreed. Based on this criterion and considering also the cost and reliability trade-offs at different levels of module connectorization, it was decided to make the grids and concentrators the modules.

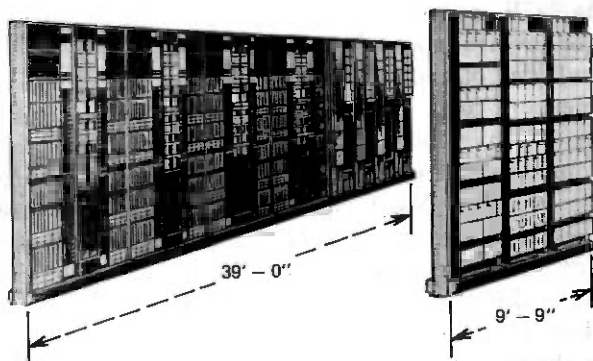
Following these principles, a study of the 1:1 trunk link network resulted in a forecast that approximately a 4:1 reduction in floor area for the network could be realized with an ultimate savings of about one-third the cost over ferreed. Starting with the 1:1 trunk link network,¹ a complete family of remreed switching networks was then designed and the space reductions realized. An equipment line-up comparison between a 4096 line link network using ferreed frames and the equivalent network using remreed frames is shown in Fig. 1.

III. ADVANTAGES

The advantages of remreed switching networks over ferreed include:

- (i) Reduced floor space.
- (ii) Increased cost reduction potential.
- (iii) Improved maintenance and reliability.
- (iv) Improved transmission capabilities.
- (v) Reduced installation effort.

Remreed networks were introduced into the Bell System very rapidly during the last three years so that these design advantages could be realized as soon as possible. The quantity of remreed product



4:1 FERREED

4:1 REMREED

1/4 VOLUME

Fig. 1—Line link network comparison.

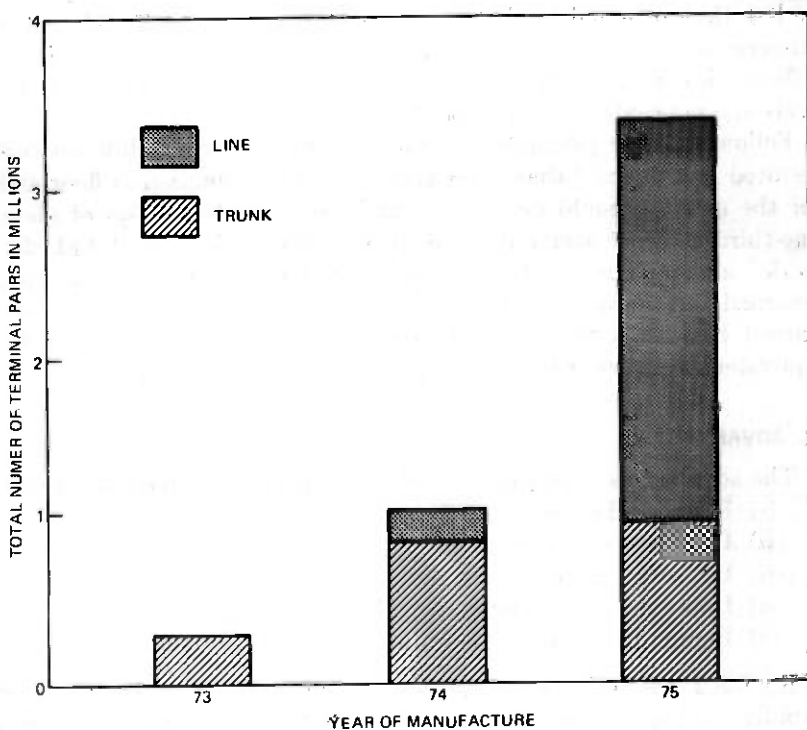


Fig. 2—Production buildup.

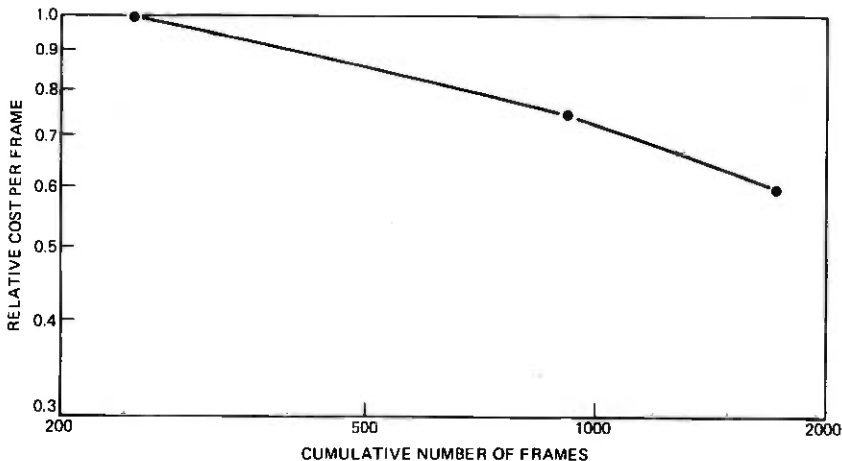
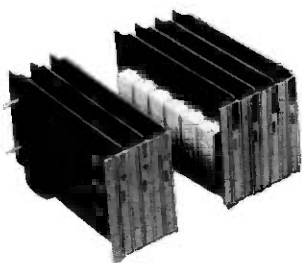


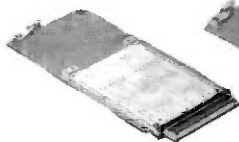
Fig. 3—Trunk link network learning curve.

shipped by Western Electric has approximately tripled each year in 1974 and 1975 (see Fig. 2).

The change to remreed from ferreed has permitted reed space division switching networks to progress on a steeper learning curve because of the opportunities afforded by the newer technologies involved. For example, the relative learning curve for the 1:1 remreed trunk link network is shown in Fig. 3. This curve is not corrected to constant dollars to remove the effects of inflation. Remreed networks



**FERREED
NETWORK
TRANSLATOR**
150 DISCRETE
COMPONENTS
24 REED RELAYS
44 BACKPLANE
WIRES



**REMREED
NETWORK
SSI TRANSLATOR**
36 SICS
1450 CROSSOVERS
GOLD GROUNDPLANE



**REMREED
NETWORK
LSI TRANSLATOR**
4 SICS

Fig. 4—Network translator comparisons.

are now lower in cost than ferreed networks. Like other major changes in technology, remreed proved more costly than the technology it supplemented during initial production buildup. Classically, this is the transient penalty incurred to make it possible to realize substantial savings in the future.

The network translator comparison shown in Fig. 4 and the network controller-logic comparison shown in Fig. 5 illustrate the opportunities in control hardware afforded by the newer technologies.

IV. SUMMARY

The objectives, design guidelines, and advantages of the new remreed network for No. 1 and No. 1A ESS have been outlined. The papers that follow describe the various detailed aspects of the development program.

The design of the remreed contact is reported first; an important subset of this effort was the work done on the metallurgy of remendur which has been published in this and other journals.²⁻⁷ Next, the design of the switch-code family for the line link and trunk link networks is described. A significant attribute of the remreed contact is that it permits hybrid electronic control. Electronic control accounts for about one-half the space savings and cost-reduction potential of the network and is discussed next. After this, the design of the electronically controlled scanner is described. The next paper deals with the physical design of the complete switching network which presented many challenges with its tightly integrated fabric, control, and scanner. Then transmission and environmental protection design are

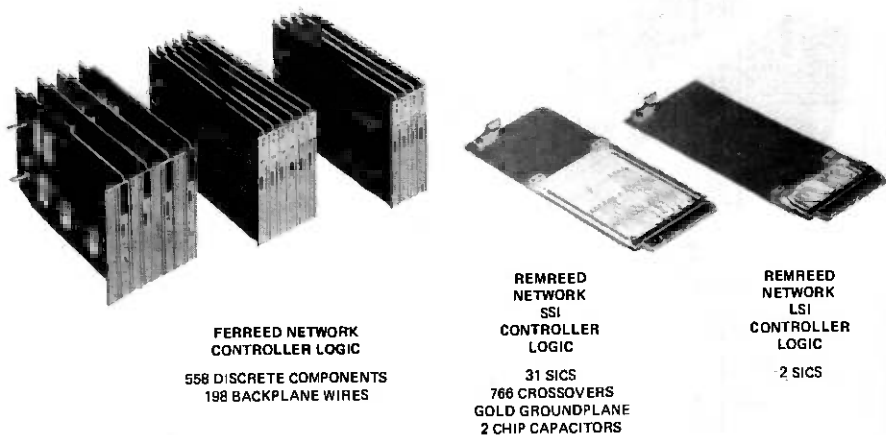


Fig. 5—Network controller-logic comparisons.

discussed. This paper addresses the transmission characteristics of the remreed network that are superior to the ferreed design and thus support a variety of switched services and transmission modes. Protection design was concerned with ensuring that the modern technologies used afforded adequate protection from the environment. Finally, throughout the course of the development, very extensive laboratory and in-service evaluations were done—perhaps more so than for any other switching network project. This is reported on in the last paper.

V. ACKNOWLEDGMENTS

Such a large number of people in Bell Laboratories and Western Electric Company made important contributions to this project that it is not feasible to list them here. We hope it is sufficient to recognize that the success of this development depended very much on their individual contributions and the close working relationships between those in Bell Laboratories with design responsibility and their counterparts in the Western Electric Company with manufacturing responsibility.

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2. The second part deals with the economic situation and the measures taken to improve it.

3. The third part deals with the social situation and the measures taken to improve it.

4. The fourth part deals with the political situation and the measures taken to improve it.

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Remreed Switching Networks for No. 1 and No. 1A ESS:

Development of a Remanent Reed Sealed Contact

By W. E. ARCHER, K. M. OLSEN, and P. W. RENAUT

(Manuscript received November 26, 1975)

The development of the remreed sealed contact is described with emphasis on the various problems that had to be solved to get a viable manufactured product. The necessary characteristics of the switchable reed material and the unique features of the material processing and contact processing steps are discussed. Details are then presented of the selection of hard gold as a contact material and the problems encountered in its application by electroplating. The contact assembly operation is described, and the difficulties encountered at this stage are elaborated on. Finally, the physical design and testing of the contact are discussed, along with the interactions among contact geometry material properties, processing steps, test parameters, and performance.

I. INTRODUCTION

The largest use for dry reed sealed contacts in the Bell System is for matrix switches of various types used in the network of the No. 1 Electronic Switching System (No. 1 ESS). To achieve the pulse actuation feature required in these arrays, switchable semihard magnetic plates are associated with the contacts at each point in the matrix.¹ It has been obvious for many years that it might be advantageous to make the reeds themselves out of the semihard magnetic material and eliminate the plates. Such a self-latching or remanent reed contact was first proposed by R. L. Peek in the late 1950s. Further development was carried out in the early 1960s using an iron-cobalt-vanadium alloy called Remendur as the magnetic material. Serious difficulties were encountered in a number of areas, while at the same time the soft reed matrix known as the ferreed switch was proving highly successful. The three most serious problem areas were reed stamping, electrodeposition of a contact material, and sealing.

To develop the desirable magnetic properties of Remendur, a high degree of cold work is necessary. This was accomplished by cold-drawing the wire to the required diameter. When reeds were stamped out of this highly cold worked material, they tended to split and crack, and tool life was extremely short. When sealed contacts were made and tested, many were found to have large leaks because the surface of the drawn wire was rough. Difficulties were also encountered in obtaining adherent electrodeposited films of contact material on the Remendur.

In 1969, interest in remanent reed contacts (commonly referred to as remreed contacts) was revived when they were considered for the No. 4 ESS toll network. However, at that time a two-piece reed design was considered to avoid the problems previously encountered. The idea was not pursued when estimates of development time indicated that such a project would not fit the No. 4 ESS development schedule, although a small effort did continue on development of a remreed contact with a monolithic reed structure.

By late 1970, the basic problems associated with a monolithic structure appeared to be solved. The reed-forming difficulties were overcome by demonstrating that the stamping operation itself introduced sufficient cold work into the material so that annealed wire could be used. The sealing problem that was related to surface defects in the wire was solved by improvements in wire processing. Poor adhesion of the contact material was solved by development of effective electrochemical cleaning procedures.

Meanwhile, serious interest was developing for a cost and size reduction of the network for No. 1 ESS. Paper studies of the design of remreed matrix switches and networks indicated that a size reduction of 4 to 1 in the trunk frames could be achieved along with substantial cost reduction. Early in 1971, the decision was made to go ahead with full-scale development of a remreed contact and an associated remreed network for No. 1 ESS. The remreed contact was subsequently coded as the 238A contact.

II. MAGNETIC MATERIAL

Rather than immediately pursuing the use of Remendur based on these early successes, it was decided to first review other magnetic materials. Only those commercially available were considered because of the very tight development schedule adopted for the project.

It was the unusual combination of required characteristics that made it difficult to provide a magnetic material suitable for use in the 238A sealed contact. To avoid a glass development program, the material should have thermal expansivity properties closely matching

that of the glass used in the manufacture of the 237-type soft reed contact. It must act as a permanent magnet whose magnetic strength (or flux) is high and whose coercive force is within prescribed limits dictated by switch design parameters such as dimensions, operate-and-release current requirements, contact pressure limitations, etc. Furthermore, these magnetic properties should not be deleteriously affected by the heating associated with the glass-sealing operation. The material must also be ductile enough to permit commercial fabrication into wire and subsequent stamping into reed members. Finally, the material must be amenable to processing in a manner which would yield wire having a very-high-quality, defect-free surface to ensure hermetic sealing to the glass.

The new survey of available magnetic materials led again to the selection of "Remendur-type alloys" as offering the best potential for meeting the diverse requirements. These alloys contain approximately 49 percent cobalt, 2 to 5 percent vanadium, and the balance iron. In these alloys, it is possible to control the coercive force by varying the vanadium content, provided that the material is adequately cold-worked and given a final 2-hour heat treatment at 600°C. A good rule-of-thumb approximation is that the maximum coercive force obtainable is equivalent to 10 times the vanadium content, expressed in weight percent. A variety of alloys, types 33, 38, and 48, have been used in switching applications, the numerical designation reflecting the desired coercive force obtainable from alloys containing 3.3, 3.8, and 4.8 percent vanadium, respectively. The residual induction for these alloys is above 16,000 gauss.

Initial design concepts for the 238A contact involving factors such as reed dimensions, gap between reeds, pulse current for operate and release, etc., indicated that the flattened portion of the reed member would have to have a coercive force of 27 ± 3 oersteds and a minimum remanence of 15,000 gauss. In keeping with past Remendur nomenclature, the new required alloy was tentatively designated as type 27 Remendur.

The thermal coefficient of expansion for Remendur was found to be 10.3×10^{-6} per °C over a temperature range of 30 to 500°C. This is very close to the 10.2×10^{-6} value for the 52 alloy (51 percent nickel—49 percent iron) used in the 237B sealed contact, and therefore no expansivity problems were anticipated in the glass-sealing operations. This was later substantiated in laboratory sealing tests, which are discussed in more detail in Section IV.

Thus, it became apparent that a Remendur alloy containing 2.7 percent vanadium would meet the magnetic and expansivity requirements for use in the 238A sealed contact. The remaining problems,

therefore, were whether the material could be processed to yield wire ductile enough for reed stamping, smooth enough to ensure hermetic glass sealing, and stable enough to resist degradation of magnetic properties due to heating during the sealing operation.

Softening of Remendur alloys is usually accomplished by heat treatment at 900 to 950°C followed by a drastic quench in ice brine. However, this procedure was found to be unsuitable for annealing the desired 0.53-mm diameter wire due to difficulties associated with quenching large coils of wire and because an adherent abrasive oxide scale was formed on the wire that would cause excessive die wear in the stamping operations. Experiments with short-time heat treatments resulted in the development of a strand-annealing process that produced wire having satisfactory ductility. The process consisted of pulling wire under a hydrogen atmosphere at a rate of 6 feet per minute through a 6-ft long furnace controlled at 950°C. After heating, the wire passed through a water-cooled chamber at the exit end of the furnace which rapidly cooled it to room temperature before it emerged into the air and was taken up on a spool. This strand-annealing process produced wire with a bright surface finish having a tensile strength of 1.31×10^9 N/m² and an elongation of 12 percent (in a 25.4-cm gauge length). Stamping tests showed that such wire could readily be formed into reed members with no excessive die wear.

Since reeds stamped from soft wire represent a composite structure consisting of annealed material in the shank and cold worked material in the paddle, it was apparent that the magnetic characteristics of the shank and paddle sections would be different. The magnitude of this difference was determined from measurements on specimens of 0.53-mm diameter wire and 0.18-mm thick tape flattened from the wire, after each were given a final 2-hour heat treatment at 600°C. The effect of strand-annealing temperature on the magnetic properties of heat-treated wire and tape is illustrated in Fig. 1. For the wire, there is a pronounced drop in coercive force starting above 700°C, reaching a minimum at 800 to 850°C, then rising to a maximum at 950°C and declining above 950°C. The residual induction or remanence drops with increasing temperatures with a leveling out at 850 to 950°C followed by a further decline. Interestingly enough, the amount of cold deformation induced by flattening is enough to increase the coercive force and remanence substantially, and the level of values reached remains relatively constant irrespective of the strand-annealing temperature. Other studies revealed that the magnetic properties of the tape are independent of the degree of flattening over the range in thickness from 0.14 to 0.23 mm. An analysis of the metallurgical phase changes responsible for the magnetic property behavior associated

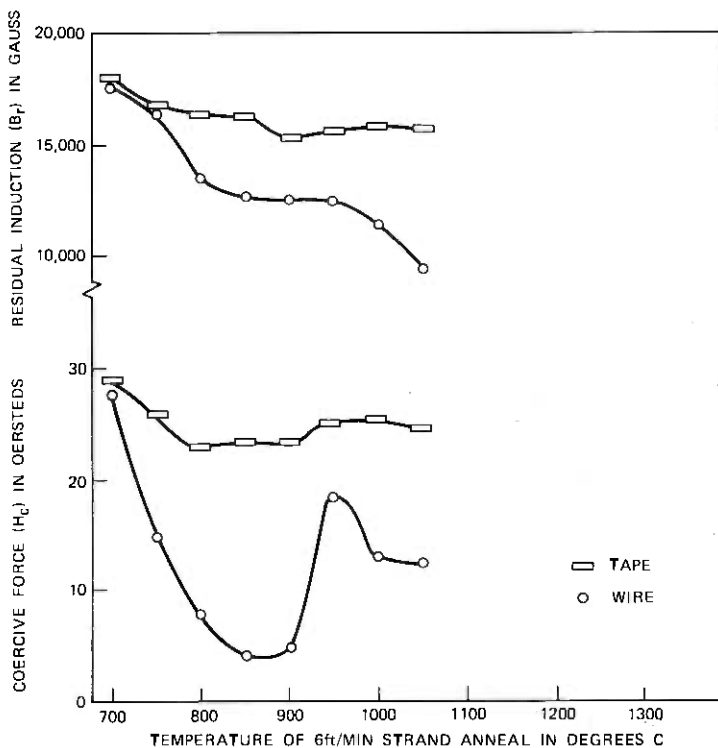


Fig. 1—Effect of strand-annealed temperature on heat-treated wire and tape.

with the strand-annealing process have been described in an earlier article in this journal.³

The data clearly showed that the desired minimum difference between properties of wire and tape would be obtainable by strand-annealing at 950°C and that good temperature control would be essential to ensure uniformity of properties. Subsequent data obtained on larger quantities of commercial wire and on sealed-contact switching performance enabled the establishment of tentative magnetic specifications for wire and tape which are given in Table I.

Magnetic tests and microscopic studies on type-27 Remendur reeds removed from sealed contacts revealed that fairly large changes in properties and structure were being produced in about one-half the length of the shank by the glass-seal heating.³ It was also found that the effects of this heating did not extend into the paddle section, and that there were no changes observed in this portion of the reed. Since the contact characteristics are much more sensitive to the paddle properties, the overall effect of the shank changes were relatively small

Table I — Physical and electrical characteristics of 238A contacts

I. CONTACT REQUIREMENTS

(Coil used for actuation is defined by Fig. 11.)

- A. Contact Sensitivity
 - 1. Release NI —20 to 37.
 - 2. Operate NI —92 to 127.
- B. Flux Ratio: Remanent Flux/Release Flux—1.2 to 1.9.
- C. Contact Resistance
(The resistance is measured between two points 34.54 mm apart on the 238A leads.)
 - 1. Static test: the contact resistance should be less than 90 m Ω after a 250 NI soak field.
 - 2. Dynamic test: the contact resistance should not exceed 150 m Ω for more than 1 μ s during a 5-ms interval beginning 5.5 ms after a pulse sequence of $-150 NI$, $+40 NI$, $+150 NI$.
- D. Contact Geometry
 - 1. Overall length— 38.05 ± 0.13 mm.
 - 2. Lead length—greater than 4.45 mm external to glass.
 - 3. Outside diameter—2.80 mm max.
 - 4. Concentricity—when rotated about the center line of the glass, all points on the surface of the external lead shall meet the following requirement: One external lead may fall within 1.78-mm diameter circle provided the other lead falls within a 1.52-mm diameter circle.
- E. Reed Geometry
 - 1. Overall length— 19.3 ± 0.05 mm.
 - 2. Paddle length— 10.54 ± 0.13 mm.
 - 3. Paddle thickness— 0.185 ± 0.008 mm.
- F. Voltage Breakdown: The contacts shall not break down when 800 V dc or 610 V ac, 60 Hz is applied to the terminals.

II. DESIGN PARAMETERS

- A. Contact Geometry
 - Contact gap—0.11 to 0.17 mm.
 - Contact overlap—0.46 to 0.71 mm.
- B. Contact Force: 1.3 to 5 grams.

III. PERFORMANCE CHARACTERISTICS

- A. Release Time
 - <200 μ s for a 4-A, 1-ms release pulse in a remreed crosspoint.
 - <500 μ s for a standard 4-A remreed control pulse.
- B. Chatter Time: <3 ms for a standard 4-A remreed control pulse from a static open condition.

IV. MAGNETIC MATERIAL REQUIREMENTS: The magnetic properties of the Remendur shall be measured on the strand-annealed 0.53-mm round wire and on sections of wire that have been roll flattened to 0.19 ± 0.01 mm thick. In both cases, the samples shall be heat treated for $2\frac{1}{2}$ hours at $615^\circ\text{C} \pm 5^\circ\text{C}$. The measurements shall be made on samples that are 203.2 mm long. Samples should be driven into saturation with a uniform field of $100 \text{ Oe} \pm 2 \text{ Oe}$.

- A. Round Wire
 - Coercive force, H_c to 18 to 28 Oe.
 - Remanent flux, 29 maxwells min.
 - Squareness, no requirement.
- B. Flattened Sections
 - Coercive force, H_c —25 to 31 Oe.
 - Remanent flux, ϕ_r —36 maxwells min.
 - Squareness, B_r/B_{100} —0.85 min. (B_{100} in the flux density measured at 100 Oe.)

and did not have a serious effect on switching performance of the sealed contact.

Wire with a near-perfect surface finish is required to ensure obtaining hermetic seals to the glass. Longitudinal striations as shallow as $3\ \mu\text{m}$ (Fig. 2) provide enough of a path to cause leaks.⁴ While commercial procedures had been developed for producing such wire from the 52 alloy used in the 237B contact, new or modified techniques would be required for the Remendur alloy since it was inherently much harder and more difficult to draw. Another complicating factor was that hot rolled Remendur rod is brittle and cannot be drawn unless it is annealed by reheating to 925°C and quenching in ice brine. This heating increases the thickness of the oxide scale on the rod. In addition, long-time heating can cause severe intergranular oxidation,⁴ as shown in Fig. 3. Another major source of surface defects results from the processing of billet material into 6.35-mm diameter rod by hot rolling in air at 1200°C . Some surface irregularities are produced by oxide scale chips or other contaminants being rolled into the rod, or by imperfections in the rolls. However, by far the most serious defects are the longitudinal seams caused by fold-overs and laps resulting from the rolling in of corners and fins when the material is being continuously hot-rolled into the variety of cross-sectional configurations necessary to produce rod. The nature of these seams is illustrated in Fig. 4. Figure 5 is a cross section showing the depth of the seams.

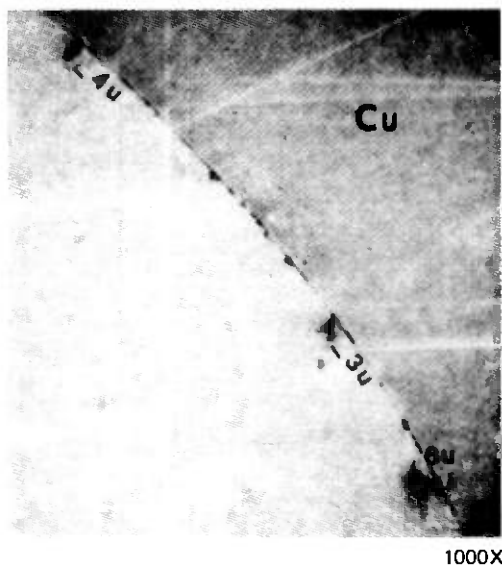
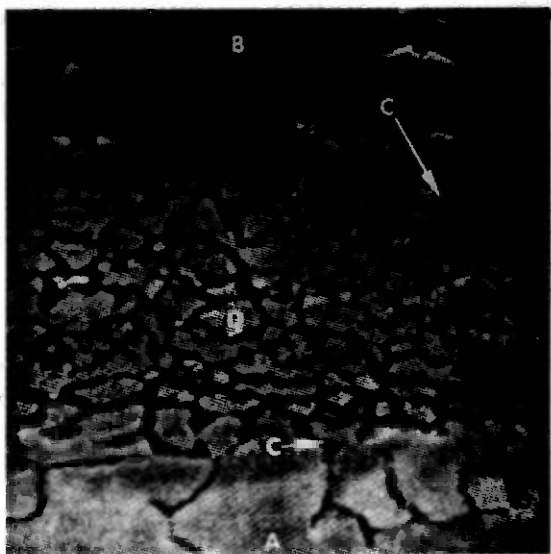


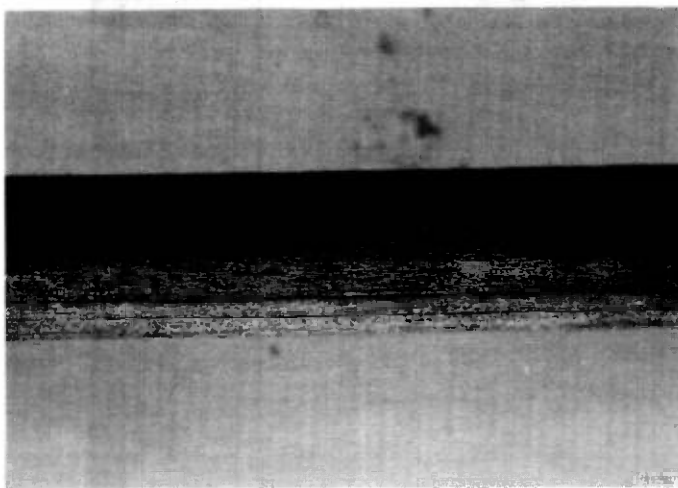
Fig. 2—SEM cross section of 0.53-mm wire showing surface defects.



2000X

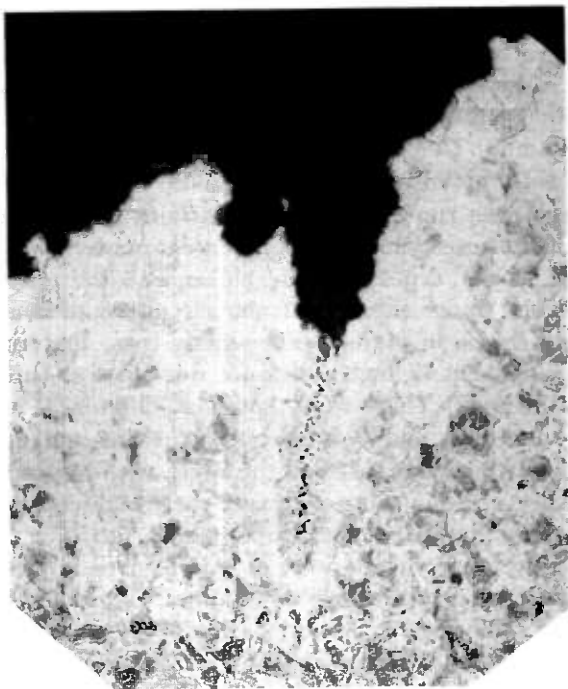
REGIONS OF VARYING COMPOSITION

- A—BULK REMENDUR
- B—SURFACE OXIDE
- C—INTERGRANULAR OXIDE
- D—ENVELOPED GRAINS



4X

Fig. 4—Rod surface seam defects in 0.64-cm diameter Remendur rod.



250X

Fig. 5—Cross section of 0.64-cm diameter Remendur rod showing seam defect.

Note that penetration of oxide exists below the bottom of the seam. Unless all this oxide defect is removed, seams will persist through wire drawing, and their presence in finished wire will give rise to leaky seals. Defects of this type and the oxide scale produced by annealing was removed by shaving and surface grinding a 0.51-mm thick layer from the rod. The resulting surface must be smooth and free of oxides or other hard contaminants. It was found that it was possible to produce Remendur wire with the desired surface finish by the rod conditioning indicated above and careful wire-drawing procedures, such as use of smooth dies, monitoring of die conditions, clean lubricants, etc. Cooperative efforts with Western Electric personnel, to translate laboratory processing procedures to commercial manufacture resulted in establishment of viable sources of satisfactory Remendur wire from outside suppliers.

III. CONTACT MATERIAL

Use of a diffused contact material similar to that employed in other Bell System sealed contacts was precluded by the fact that the mag-

netic anneal of Remendur is carried out at 600°C, and heating to the higher temperatures required for the diffusion of the contact material destroys the desirable magnetic properties of the Remendur reed.

The circuit conditions that the network contacts must withstand are relatively mild. They open and close dry except for cable discharge on make, mostly at voltages below 26 volts. Over the past 10 years life tests have been run under these conditions on soft reed contacts employing nondiffused electroplated contact materials. These tests have included many types of hard gold and all the members of the platinum group. Under these particular circuit conditions, there was very little difference in performance among these materials with respect to development of high resistance due to wear-through of the precious metal layer. There were, however, differences among these nondiffused materials and between any of them and our standard diffused gold-silver surface, used on the 237B, with respect to sticking, and with respect to the incidence of very early high-resistance failures due to contamination, particularly by organics.

The platinum group metals were essentially free from sticking but in general suffered from organic contamination problems. The hard golds also had some organic contamination problems, although not as severe as the platinum group metals. With respect to sticking, the hard golds were about equivalent to the diffused gold-silver surfaces of the 237B.

Hard gold was finally selected for use on the 238A contact for the following reasons:

- (i) Under the network circuit conditions, it is nearly as good as any of the platinum group metals with respect to wear-out.
- (ii) It is less susceptible to organic contamination problems.
- (iii) Western Electric and Bell Laboratories have had extensive experience with hard gold plating.
- (iv) The greater tendency toward sticking on hard gold compared to the platinum group metals is only a relative evaluation. In an absolute sense, the performance of hard gold below 5×10^6 operations is equivalent to diffused gold-silver which has proven acceptable in the ferreed switch used in the No. 1 ESS network.

Some difficulty was experienced initially in obtaining good adhesion of the plated hard gold layer to the Remendur. This was overcome by an anodic pretreatment step in an alkaline solution.

Stalica has shown by auger analysis that the critical factor in obtaining good adhesion and blister-free deposits is the removal of vanadium (in the form of both oxides and nitrides) from the surface.⁵

Eisenmann has shown that the anodic pretreatment step accomplishes this and that essentially any alkaline agent will suffice.⁵ Sodium hydroxide, trisodium phosphate, or potassium cyanide have been used with equal effectiveness, although potassium cyanide is now used in production.

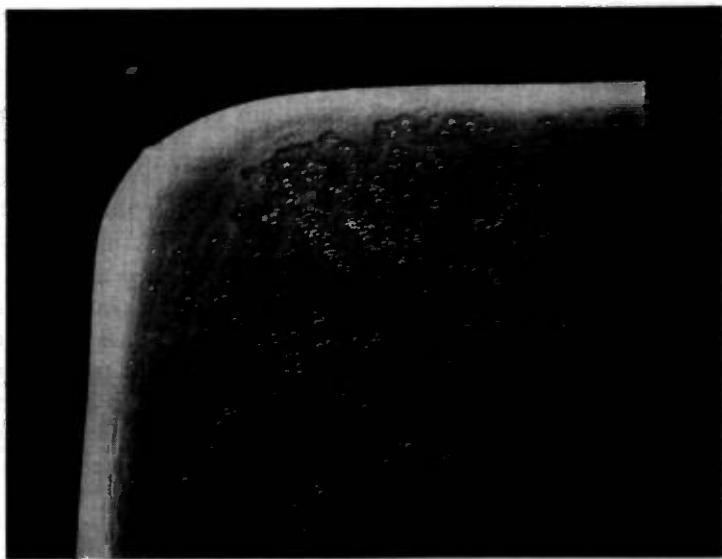
One serious problem associated with plating was encountered in early production of the 238A contact. This was the inability to obtain smooth deposits on the Remendur surface using production equipment. The deposits were highly nodular. Figure 6a is a typical example of the type of deposit obtained. The cause of the nodular plate was found to be magnetic particles on the reed surface. Figure 7 is a cross section of a nodule. Every nodule has been found to have a particle at its center. Electron probe analysis shows the particles to be magnetic material. The problem was enhanced by the fact that the production plating facility employed a magnet to hold the reeds against an electrical contact plate. This had two effects. First, it caused the reeds to act like magnetic brooms, picking up any magnetic particles in the baths associated with the plating process. Second, and much more important, it caused any magnetic particles on the reed surface to stand up like the quills of a porcupine with their long axis aligned with the magnetic field.

The final solution to the nodule problem involved installation of 1- μ m filters on all baths in the plating process, better demagnetization, improved cleaning procedures for the reeds prior to plating, and design of a nonmagnetic plating rack. Figure 6b shows a typical plated surface after introduction of the above modifications in the process.

IV. GLASS-TO-METAL SEALS

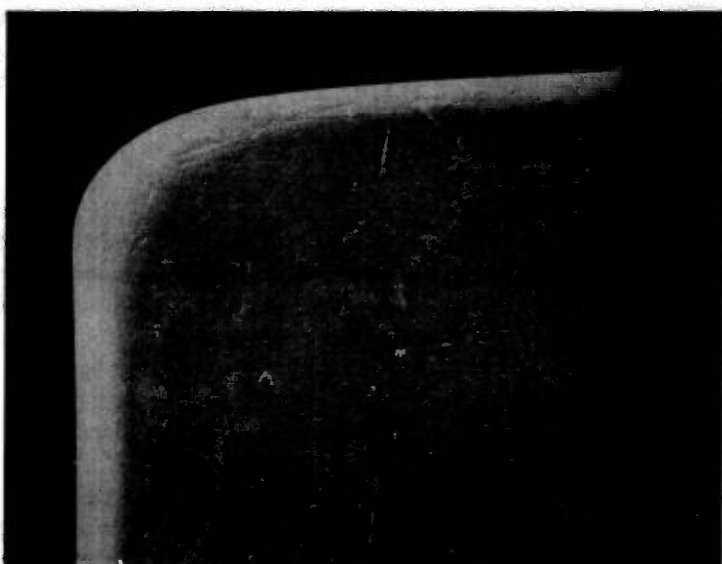
As previously indicated, one reason for selection of Remendur was the close match of its coefficient of expansion with that of the available glass used for the 237-type contact. The thermal expansion curves for both Remendur and the 52 alloy sealing glass are shown in Fig. 8. The slight mismatch in the coefficients is in the direction to put the glass-to-metal seal under slight radial compression. This is intentional and is intended to increase the strength of the seal under axial load. After initial problems with surface defects in the wire were cleared up, the incidence of seal leaks was less than 0.1 percent.

Figure 9 shows the results of axial pull tests on 238A-contact seals as compared to 237-contact seals. In this test, the seals are given an initial leak test and then subjected to an axial load for three minutes. The seal is then given a second leak test. Failure is defined as either complete fracture of the seal or development of a leak greater than 10^{-8} std cc/s. Normally, in laboratory tests, a helium leak detector is



(a)

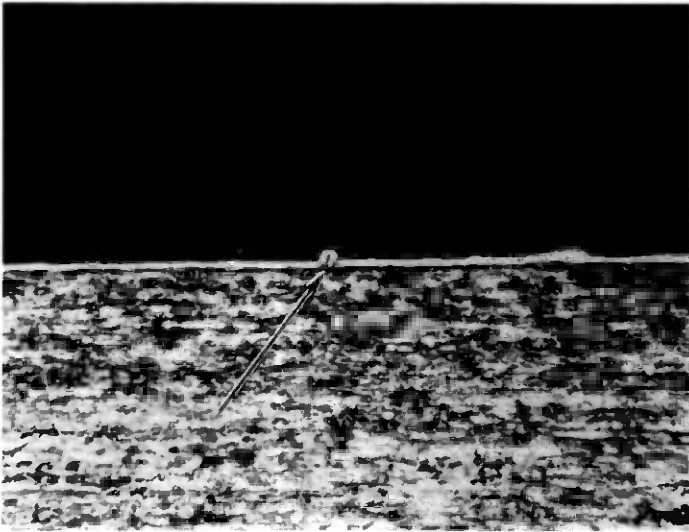
200X



(b)

200X

Fig. 6—(a) Remendur reed plated in magnetic rack. (b) Remendur reed plated in nonmagnetic rack.



1000X

Fig. 7—Remendur reed plated with hard-gold cross section through a nodule showing magnetic inclusion within the nodule (arrow).

used to check the leak rate. From many measurements like those in Fig. 9, the minimum axial seal strength of the remreed contact has been found to be 111 newtons compared to 40 newtons for the 237B.

The failure mode for the 238A contact when sufficient load is applied is generally complete destruction of the seal, while for the 237B it is development of a high leak rate ($>10^{-6}$ std cc/s) in a visually intact seal at fairly low loads or rupture of the bond between the glass and the 52 alloy shank at higher loads. The 237B failure mode exhibits a time-dependent effect while the 238A failure mode does not. If a 238A contact is going to fail, it happens within the first few seconds of load application. In the case of the 237B, if the load is applied beyond the normal three minutes, additional seals will fail for up to 50 hours.

These differences are not fully understood at the present time, although one possible explanation is that Remendur has a lower creep rate than 52 alloy. Unfortunately, creep data are not available for either material.

There is a second type of seal failure possible for 238A contacts which cannot occur in soft reed contacts. This mode is fracture of the seal due to lateral forces applied to the lead. Since Remendur has a comparatively high yield strength, lateral forces on the lead can be transmitted to the seal. In the case of the soft reed contact, the 52 alloy has such a low yield point that lateral forces on the lead simply

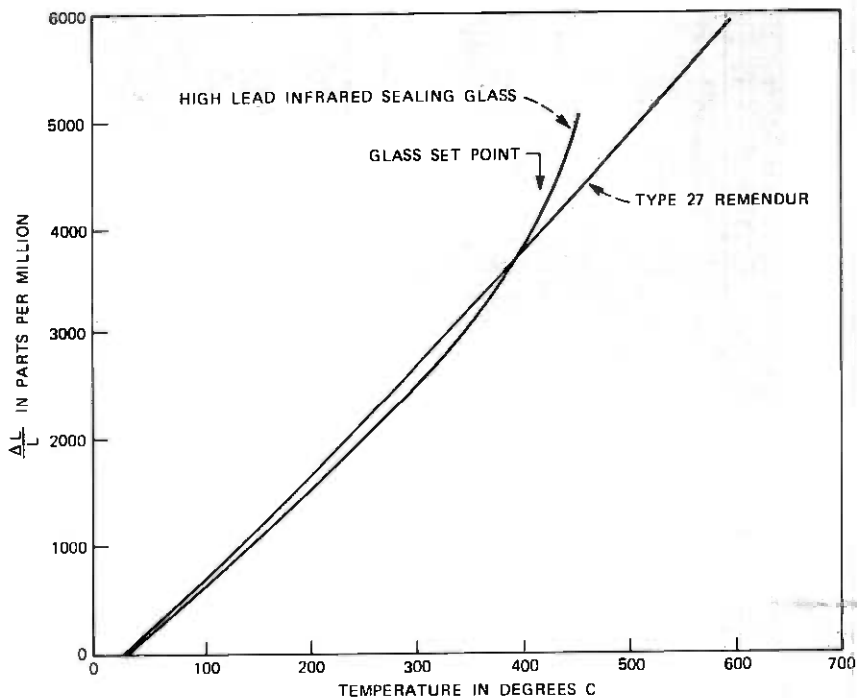


Fig. 8—Expansion curves for Remendur and 52-alloy sealing glass.

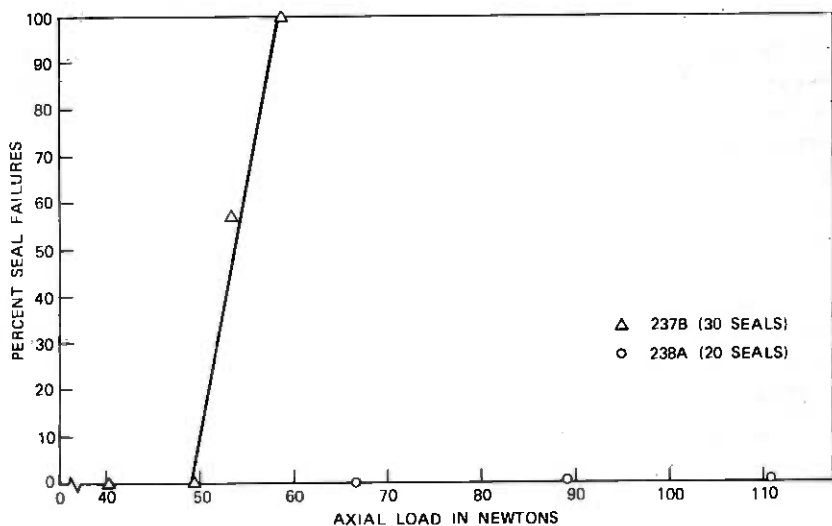


Fig. 9—Comparison of seal strength of 238A and 237B under axial load.

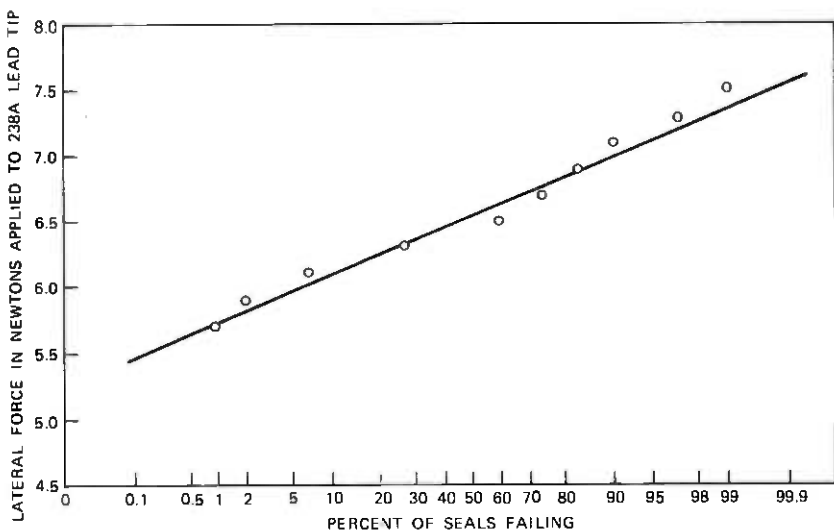


Fig. 10—Distribution of lateral force required to cause 238A seal failures.

result in bending of the lead with very little of the force transmitted to the seal. Figure 10 shows a plot of percent seal fractures versus lateral force applied to the tip of the lead for 238A contacts. Extensive tests of this type have shown that the maximum lateral force which can be applied to the tip of the lead without danger of fracture is 5 newtons.

To avoid seal failure by the above mechanism during switch assembly, a lead concentricity requirement was placed on the 238A contact. This requirement (item I, D, 4 in Table I) assures that the tip of the lead will pass through the associated holes in the flex circuit used in the switch⁶ without lateral forces being exerted on the leads.

V. ASSEMBLY

The 238A is assembled on the same machines used to manufacture the 237 contact, with modifications to accommodate the smaller size reeds and glass and to allow for demagnetization of the reeds prior to setting the gap. These are 12-head infrared-type assembly machines. During assembly, the contacts are flushed and filled with a mixture of 97 percent nitrogen and 3 percent hydrogen at a pressure of 2 atmospheres absolute. After cooling, this results in an internal pressure of approximately 1 atmosphere absolute.

One of the most serious problems initially encountered in the manufacture of the 238A contact was severe blistering of the hard gold contact material during the sealing operation. Electrodeposited hard

gold is known to blister when heated above 450°C. It has been assumed that this is due to the breakdown of the codeposited polymer.⁷ Rough measurements of the reed tip temperature during sealing, by means of temperature-sensitive paint, showed that it was exceeding 450°C.

At the time the blistering was first observed, an intensive study was made of the effects of plating variables on the blistering temperature.⁷ This study showed that the blistering temperature was not a strong function of the plating process. It was concluded at that time that the blistering problem could not be solved by changes in the plating process. What was needed was a reduction of the temperature to which the reed tip was heated during the sealing process.

Studies were carried out to determine if the primary source of heat at the paddle tip was conduction along the reed from the very hot seal area or whether a significant portion of the heat was associated with stray radiation from the infrared sealing lamps. One nonquantitative experiment which indicated that stray radiation was playing an important role was the assembly of contacts using special glass tubes which were coated on the inside with a reflecting material to keep out stray radiation. The hard gold on these special contacts was found to be free of blisters.

As a result of these studies, it was concluded that the blister problem could be completely eliminated by reducing the amount of stray radiation reaching the reed tips. This was accomplished by using a smaller-size infrared lamp with a much shorter filament. The radiation from the shorter filament could be focused into a smaller area.

VI. PHYSICAL DESIGN OF THE 238A

Two significant advantages were obtained in the design of the 238A contact as compared to its predecessor, the 237B: (i) a significant miniaturization of the contact—length reduced from 44.96 to 38.05 mm and diameter reduced from 4.32 to 2.79 mm, (ii) the inclusion of the magnetic latching elements in the reeds themselves, i.e., replacing 52 alloy with Remendur. The crosspoint volume required for two 238A contacts versus two 237B contacts and their associated Remendur plates is significantly reduced from 2110 to 994 mm³. The aim of the physical design of the 238A was to obtain this volume reduction with no change in the performance of the contact with respect to the 237B contact. With such a remanent contact design, it was possible to design switch packages so that a complete trunk link network could be built on a 6 ft, 6-in. frame.

The contact parameters which remained to be determined were contact overlap and gap, diameter of wire, reed thickness, plating

thickness, and material properties. The ultimate criteria for judgment of the many contact designs considered was crosspoint performance. In general, minimization of ampere turns necessary for operate and release with ample margin for walkdown effects were the criteria used for judging contact performance.

To measure the relative performance of contacts without laborious measurements in the crosspoint itself, a $B-H$ loop is generated for a sealed contact. The coil specifications and the applied magnetic field profile used for the applied drive is shown in Fig. 11.

A typical $B-H$ loop is shown in Fig. 12. As the contact is cycled by applying ± 250 ampere-turns at a rate of about 100 ampere turns/s, it passes through numerous points of interest. They are defined as follows:

- (i) Operate field, NI_{op} : that applied field in ampere turns necessary to operate a contact.
- (ii) Saturate flux, ϕ_s : the absolute value for the flux when $d\phi/dNI$ approaches zero.
- (iii) Saturate field, NI_s : that applied field in ampere turns to drive ϕ to ϕ_s .
- (iv) Remanent flux, ϕ_{rem} : the flux measured after the applied field has been cycled through $+NI_s$ to 0.
- (v) Release field, NI_{rel} : the applied field in ampere turns necessary to cause a saturated contact to open.
- (vi) Release flux, ϕ_{rel} : the contact flux at the release point, i.e., for NI_{rel} applied field.
- (vii) Coercive force, NI_c : the applied field in ampere turns necessary to reduce ϕ to zero after saturation.

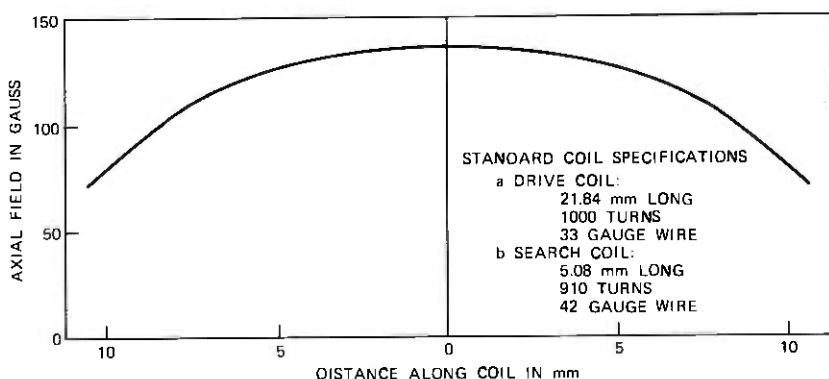


Fig. 11—Field profile and specifications for a standard coil.

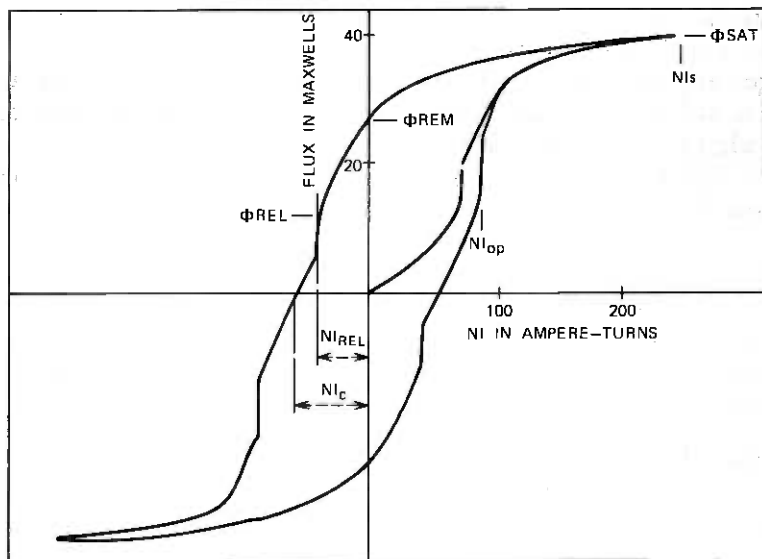


Fig. 12—Typical $B-H$ loop.

The points of discontinuity in the $B-H$ loop are generated by the reed blades closing and opening. The physical movement of the reeds occurs in a time, $\Delta t \sim 200 \mu s$, during which the states of magnetization of the reeds change very significantly due to changes in reluctance of the magnetic circuit.

Each sealed contact has a magnetic performance as measured by the $B-H$ loop that is dependent on the physical geometry of the contact and the magnetic characteristics of the material. The $B-H$ loop data serves a connection between crosspoint characteristics and contact parameters. The contact parameters determine the $B-H$ characteristics of a contact design and crosspoint operating characteristics can be related to some of the above defined parameters.

For example, the NI_{rel} value for a sealed contact obtained in a solenoidal coil is directly related to its release value in a crosspoint, while the NI_{op} value determines its susceptibility to false closures, etc. These relationships are covered in more detail in Ref. 6.

Initially, several contact designs were considered, based on variations in the diameter of the Remendur wire. The wire diameters considered were 0.60, 0.53, and 0.51 mm. After these designs were adjusted to have the same operate-and-release characteristics, the 0.53-mm diameter was selected because 0.60-mm wire designs did not provide adequate clearance between reed and glass and 0.51 wire

designs did not generate enough magnetic force. The process of changing contact designs was concurrent with adjustments in coil design, turns ratio, and magnetic structure in the remreed switch. These adjustments were aimed at obtaining an overall switch design with the desired features of low currents for actuation and minimum magnetic interference perturbations. The final result involved various compromises between contact and switch design.

Having selected the reed dimensions, the release sensitivity depends on the contact geometry through the contact gap, overlap, and the plating thickness of hard gold. The operate ampere turns also depends on the gap and overlap, but not the plating thickness.

The relationships among geometry, contact force, release flux, operate flux, and hold flux are well known, having been established by Peek⁹ in 1960. However, translation from operate-and-release flux to operate-and-release ampere turns involves the magnetic circuit (including the specific coil geometry) and the exact shape of the hysteresis loop of the reeds. For this reason, the equations relating contact geometry to operate-and-release ampere-turn values were derived empirically by applying curve-fitting techniques to the data obtained from a series of contacts in which the gap, overlap, and contact-material thickness were systematically varied over the ranges indicated below:

<i>Variable</i>	<i>Symbol</i>	<i>Range</i>
Gap	<i>X</i>	0.08–0.20 mm
Overlap	<i>a</i>	0.38–1.02 mm
Contact-material thickness	<i>t</i>	0 –3.8 μ m

The empirical relationships obtained are:

$$\log (NI_{rel}) = 1.03 - 0.083t - 0.558 \log X - 0.60 \log(a) \quad (1)$$

$$NI_{op} = 78.3 - 7.56a + 285.8X. \quad (2)$$

These relationships, of course, are only valid over the range of gap, overlap, and contact-material thickness from which they were derived.

Figures 13 and 14 were plotted using eq. (1) and show the effects of contact gap, contact overlap, and plating thickness on the NI_{rel} value of the contact. Figure 15 was plotted using eq. (2) and shows the effects of contact gap on the NI_{op} value of the contact for two different values of overlap.

The magnetic characteristics of the Remendur material determine the flux that can be obtained for any applied field; hence, they also have a direct impact on magnetic performance. Unfortunately, eqs.

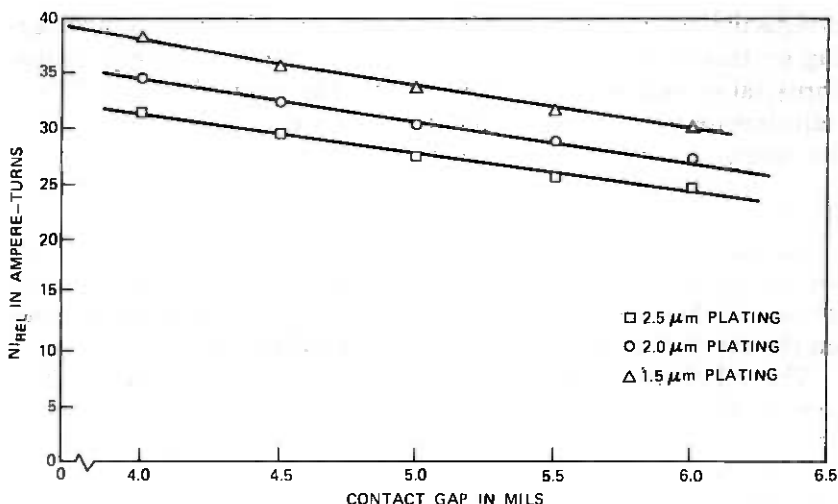


Fig. 13— NI_{REL} versus contact gap, 25-mil overlap.

(1) and (2) are of only limited usefulness, since they do not include the effects of variations in the magnetic properties of the Remendur. Work is currently in progress to derive a set of empirical relationships which will include the properties of the Remendur wire as independent variables.

Other constraints which directly influenced the final contact design were an acceptable range of contact force and a minimum requirement

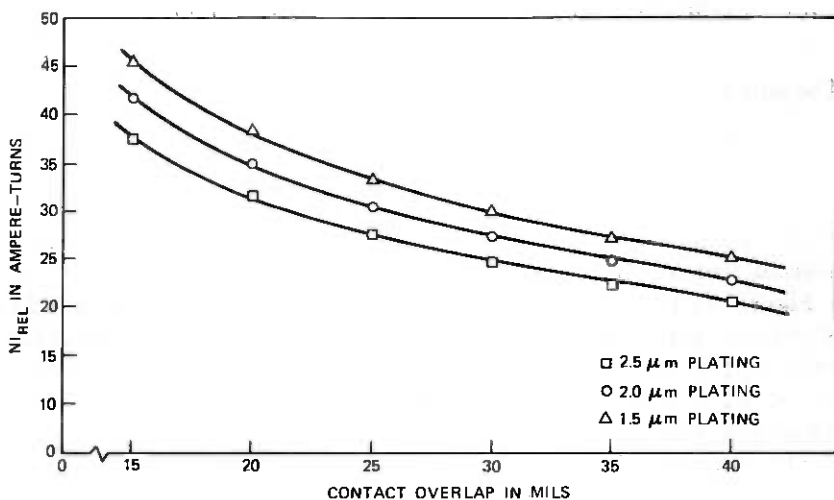


Fig. 14— NI_{REL} versus overlap length, 5-mil gap.

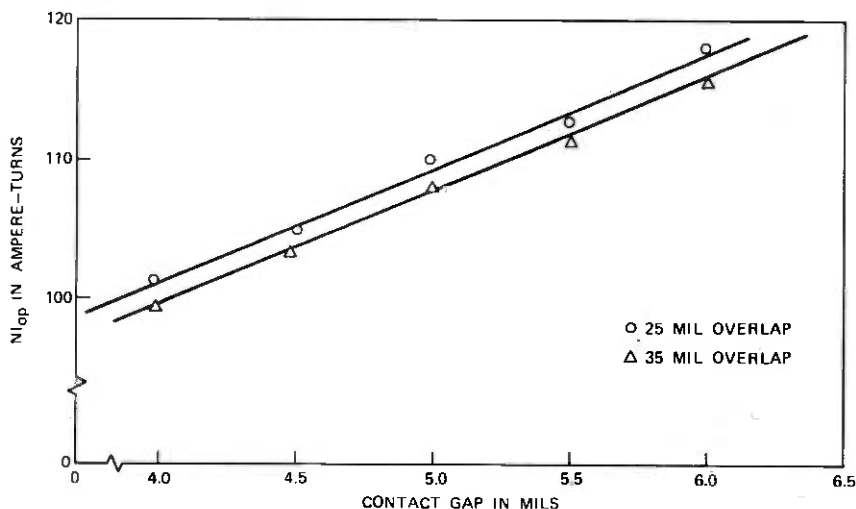


Fig. 15— NI_{op} versus contact gap.

on voltage breakdown. An estimate of the contact force can be made from geometric measurements and the magnetic test data. The contact force is given by

$$F_c = \left(\frac{\phi_{rem}^2}{\phi_{rel}^2} - 1 \right) F_R, \quad (3)$$

where F_R is the mechanical retractile force. F_R is equal to $SX/2$, where S is the stiffness of a single reed and X is the contact gap. S is approximately 32.3 grams/mm for the 238A. The maximum contact force is limited to reduce the incidence of contact sticking, and a minimum force is necessary for stable contact resistance. This is especially true for stable dynamic resistance, as explained in the next section. Requirements on the flux ratio control the range of contact force without specific mechanical requirements on overlap, gap, and reed alignment.

The voltage breakdown constraint, together with the assembly machine capability for controlling the gap, fixed the minimum gap that could be considered for the remreed design. As previously stated, remreed packaging constraints limited the overall length of the contact and the diameter of the glass bottle. These size constraints influenced the magnetic circuit by determining the open gap reluctance via the contact gap and the closed gap reluctance via the effective length-to-diameter ratio.

The actual procedure for precise determination of the contact geometry and the magnetic requirements for the Remendur wire was

related to measured performance of the remreed contact in the remreed crosspoint in the following way. From cross-point studies, requirements on the quasi-static performance of the contact were generated. Nominal values for the contact design parameters, geometry, and material properties were chosen to center the distributions of operate-and-release sensitivities and ratio within the acceptable range for proper performance. The variations in contact geometry—gap, overlap, and plating thickness—as well as variations in the magnetic properties of the Remendur reeds were estimated based on experience with outside suppliers of the Remendur wire and with previous experience with the assembly of the 237B contact. Many contacts were made with worst-case combinations of the related parameters. The final contact design was chosen so that it would meet the performance constraints, even if all the design parameters deviated from their nominal values in these worst-case combinations.

Thus, a contact design for a specific application, No. 1 ESS, was obtained which was capable of being manufactured with relatively high yields. It also utilized existing facilities and available materials.

VII. SEALED CONTACT ELECTRICAL PERFORMANCE

Each 238A contact is given a number of electrical tests to ensure a uniform and reliable product for application in the remreed switch. Table I shows both the required electrical characteristics and general design information presently used for remreed contact manufacture. Regarding the electrical characteristics, upper and lower limits are placed on operate and release sensitivities and the ratio of remanence and release flux. The ratio requirement indirectly controls the contact force since the range of retractile forces is relatively small. The operate-and-release requirements protect the remreed switch against defects in contact latching, failures to release, false closures, and false openings. Each contact is tested for voltage breakdown while in a release state at 800 V dc or 600 V ac with a background radiation of 80 μ Ci.

One concern with any dry reed sealed contact is sticking of the contact due to adhesion or welding between the mating surfaces. In addition to percussive and resistance welding, which can occur with any contact material under adverse circuit conditions, and mechanical locking of pip and crater late in life even under normal circuit conditions, hard gold is particularly susceptible to cold welding caused by magnetostrictive scrubbing. "Scrubbing" in the 238A is caused by the relative movement of the mating surfaces due to magnetostriction when successive operate pulses are applied without separation of the mating surfaces. The contact force during this relative movement of the mating surfaces can vary between 1.3 and 13 grams. The relative

movement of the mating surfaces is about $0.5 \mu\text{m}$. The probability of a contact sticking, i.e., failing to release when the magnetic force goes to zero, becomes significant after five scrubs with virtually all contacts sticking after 1000 scrubs.

Figure 16 shows the number of failures to release as a function of the number of scrubs for some standard contacts in remreed switches.

To eliminate scrub sticking in the remreed switch, an additional control pulse (the prerelease pulse) was added 7.2 ms before the operate pulse⁶ to ensure that the contact would open between successive operate pulses. This prerelease pulse prevents scrubbing of the contact surfaces. Life test data¹⁰ indicate that sticking due to other causes will be at an acceptable level.

To avoid scrub sticking, the time-to-release for contacts therefore must be less than 7 ms, since the prerelease pulse is 7.2 ms before the

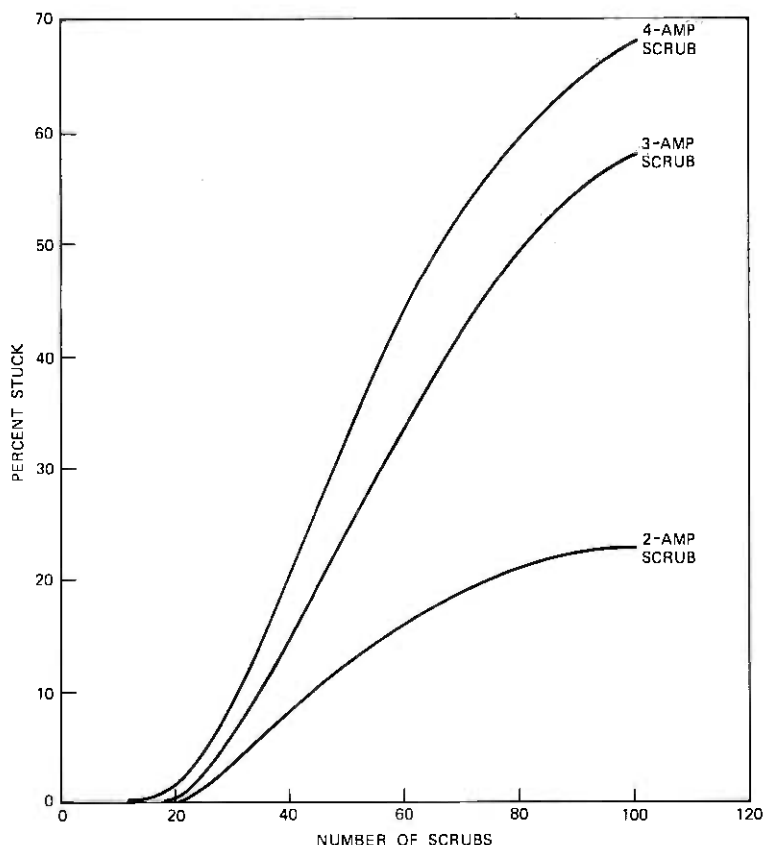


Fig. 16—Remreed scrub sticking.

operate pulse in the ESS application. Data given in Table I show that the mean release time plus three sigma is about 200 μ s for the 1-ms release pulse of 4 amperes amplitude used for prerelease in a remreed cross-point. With such ample margin, it is not necessary to test contacts for this characteristic.

A second failure mode is high resistance due either to contamination or wear-through of the thin, hard gold contact layer. Life tests have indicated that, under ESS circuit conditions, this failure mode is also at an acceptable level.¹⁰ The evaluation of the reliability of the 238A is more fully discussed in Ref. 10.

A static resistance test was, from past experience with the 237B soft reed contact, perceived to be of value for eliminating contacts that would cause contact resistance failures in remreed switches. After the introduction of the prerelease pulse to the operate pulse sequence in the remreed crosspoint, the level and the durations of dynamic resistance increased. Some factors which contribute to the tendencies of contacts to have high dynamic resistance are: contamination of the contact surfaces, low contact force, natural frequency differences between reeds, the pulse shape used for operation of the contacts, and the interpulse time between the prerelease pulse and the operate pulse.⁶ To eliminate contacts with these transient high-resistance characteristics, a dynamic-resistance test which closely simulates the operation of the contact in the crosspoint was developed.

Therefore, a sequence of dynamic- and static-resistance tests are applied to each contact to control the incidence of contamination of the contact surfaces and abnormal dynamic resistance. If the static contact resistance exceeds 90 milliohms after closure by a 250 NI soak field, or if the peak dynamic resistance exceeds 150 milliohms after application of a 150 NI pulse, the contact is rejected.

VIII. SUMMARY

A new contact in the family of sealed contacts, the 238A, has been successfully developed for application in ESS. A semihard magnetic material, Remendur, is used as the reed material to provide the residual holding force for latched operation. The mating surfaces of the contacts are hard gold, which is electroplated on the reed tips.

The impetus for this contact development hinged on the solution of three major problems in sealed contact manufacture: (i) processing of the Remendur into reeds; (ii) electroplating of a suitable precious metal on the reeds; and (iii) making a secure glass-to-metal seal. The physical design and magnetic material selection for magnetic properties was based on the required performance of the remreed crosspoint and the use of commercially available material. A testing scheme

which reduces switch failures while allowing good contact yield has evolved and is still being perfected.

IX. ACKNOWLEDGMENTS

Many people in both Western Electric and Bell Laboratories were involved in the development of the 238A contact, and to mention them all individually would be a monumental task. The authors would, however, like to acknowledge those who contributed in some specific way to this paper. We thank M. R. Pinnel, J. E. Bennett, G. V. McIlhargie, and D. E. Heath who did much of the work on Remendur and who contributed the pictures used in Figs. 2, 3, and 5. We thank A. A. Tartaglia who did the cross-section work on nodules and took the picture used in Fig. 7. We thank E. T. Ratliff for the SEM picture used in Fig. 6. Finally, we thank E. T. Eisenmann who did the work involved in generating the empirical equations (1) and (2). In addition, we would like to thank R. G. Baker and T. A. Palumbo for the many days they spent straightening out the many initial problems we had with the hard gold plating process.

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Remreed Switching Networks for No. 1 and No. 1A ESS:

Remreed Switches

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D. H. YANO, and R. C. ZOLNOSKI

(Manuscript received October 7, 1975)

This paper describes a series of new two-wire matrix switches that have been developed for No. 1 ESS remreed networks. These switches utilize the new 238A sealed contact, are designed to maximize the use of automatic manufacturing techniques, and typically contain twice the number of crosspoints as conventional ferreed switches. However, as a result of increasing the crosspoint packing density, the new remreed switches consume less frame area and total volume than their ferreed counterparts.

In addition to the increase in the number of crosspoints, the new switches also contain many semiconductor devices required in the control scheme adopted for No. 1 ESS remreed networks. The extensive use of printed-wiring boards to interconnect the individual crosspoints facilitated the mounting of semiconductor components within the switch, thus yielding a natural integration of the crosspoints and the devices used to control them.

A total of seven switch codes have been developed to produce No. 1 ESS line link and trunk link networks. The manufacture of these switches has been simplified by achieving a high degree of commonality among the piece parts used to produce each code.

I. INTRODUCTION

The major apparatus development undertaken for the No. 1 ESS remreed project was the design of a series of new crosspoint switches. The goals of the new switch development were to produce designs that would be both smaller and more economical than their ferreed forerunners. These goals were met by taking advantage of the new 238A sealed contact to increase the crosspoint packing density and by designing the overall switch structure to allow for the maximum use of automatic manufacturing techniques.

The increased crosspoint packing density allowed by the 238A sealed contact is due to two factors. First, the reduced physical dimensions

of the new 238A sealed contact led to a corresponding reduction in the dimensions of the new crosspoint. Second, the reduction in the amount of permanent magnetic material utilized in each crosspoint reduced the magnitude of stray magnetic fields and, hence, the total interference field felt by any crosspoint due to surrounding nearest neighbors is small. In combination, these factors resulted in an intercrosspoint spacing of 0.450 in. and led to the design of switches that contain as many as twice the number of crosspoints as conventional ferreed switches, yet consume less frame area and less total volume. This design philosophy is one key to the cost savings attributed to the remreed switch technology. The creation of switches having 128 crosspoints rather than the conventional 64 reduces the cost per crosspoint of many common manufacturing steps.

In addition to the crosspoints themselves, remreed switches also contain many semiconductor devices required in the control scheme adopted for remreed networks. The decision to include semiconductor control devices within the switch structure was made after careful consideration of their failure modes, rates, and service-affecting consequences. The printed-wiring boards inherent in the remreed switch designs made it relatively easy to mount the required semiconductor devices.

Allowing for the use of automatic manufacturing techniques was a constant constraint in the design of the basic remreed switch package. As a result, the switch design borrows heavily from the ideas incorporated in the beamless ferreed switches developed for the No. 1 ESS service link frame.¹ These concepts include the use of printed wiring boards to interconnect the crosspoint matrices, automatic insertion of the sealed contacts into their coil forms, machine termination of all control coils, and mass soldering of the final assembly. In addition, the switch designs developed were such that many existing ferreed facilities could be modified to produce the new remreed product.

II. PHYSICAL DESIGN

A total of seven remreed switch codes, generally termed the 296 types, have been developed to produce No. 1 ESS line link and trunk link networks. The 296C-1A switch shown in Fig. 1 is the workhorse code of No. 1 ESS remreed trunk link networks and, hence, will be used to illustrate general design features.

The basic construction consists of two parallel printed-circuit boards separated by approximately one inch by a series of rigid standoffs. The 238A contacts used at each crosspoint are mounted cordwood fashion between the two circuit boards. The external leads of each sealed contact fit through holes provided in the boards and are eventu-

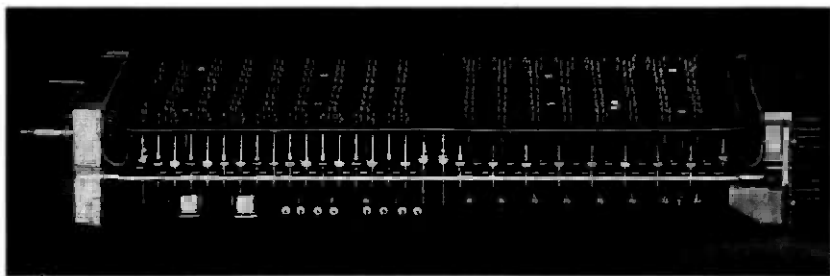


Fig. 1—296-1 type remreed switch.

ally mass soldered. The solder joints provide electrical connection to printed paths on the circuit boards and also fix the final position of each sealed contact.

Interconnecting the crosspoint arrays contained in the switch (tip-and-ring wiring) is achieved by printed paths on the two circuit boards. In addition to this tip-and-ring wiring, interconnecting the energizing coils is also accomplished via paths on the circuit boards. The tip-and-ring multiples of the crosspoint matrices are brought to terminal blocks located at the front and rear of the switch package. The input tip-and-ring leads appear at the front of the switch on terminals that are gold-plated for connector compatibility. The output leads as well as all the control leads appear on terminals at the rear of the switch. These base metal rear terminals are located on a 0.125-in. grid and have position tolerances compatible with automatic 30 AWG solderless wrap techniques.

Like the ferreed switch, each remreed crosspoint consists of two sealed contacts housed in a molded plastic coil form which is wound with the control coils used to operate and release the contacts. The basic change in the new crosspoint is the elimination of the rectangular Remendur plates used in the ferreed structure for providing the source of latching magnetic field since this function is efficiently incorporated in the reeds of the 238A sealed contacts. In principle, the remreed crosspoint functions much like the ferreed crosspoint in that both are series-magnetic structures. When the two reeds of each contact are magnetized series-aiding, the magnetomotive forces combine to produce a residual gap flux that maintains the contact closed. When the two reeds are magnetized series-opposing, the magnetomotive forces cancel and the residual gap flux is reduced to practically zero. This results in an opening of the contacts. As in the ferreed crosspoint, this latter magnetization state is produced by using pairs of unbalanced differentially wound coils; therefore, proper operation of a remreed crosspoint still requires a steel shunt plate to isolate magnetically the

unbalanced coils. This steel shunt plate also serves as the mechanical backbone of the remreed switch structure.

The overall dimensions of the 296C-1A remreed switch that contains 128 crosspoints (interconnected as two 8×8 arrays) are 10.5 in. long, 5.67 in. high, and 1.59 in. wide. The volume is 80 percent of that occupied by a conventional ferreed switch containing only a single 8×8 crosspoint array. More importantly, the frontal area or frame area consumed by a remreed package is only 9 in.² (5.67×1.59 in.), less than 70 percent of that occupied by a single ferreed switch.

2.1 Control coils

The coil scheme used to control an array of remreed crosspoints is identical to that used with ferreed crosspoints.² The crosspoints forming any row of the array are linked together with a continuous string of windings. These continuous coil strings associated with each row of crosspoints have historically been called horizontal windings. Likewise, separate continuous windings link the crosspoints that form each column of the array. The latter coil strings have historically been called vertical windings. The horizontal winding of any particular crosspoint consists of a pair of differentially wound coils; a primary coil with $2N$ turns on one side of the shunt plate connected in series to an N turn secondary coil on the opposite side of the shunt plate. The vertical winding at this crosspoint also consists of a primary and secondary coil, differentially wound and on opposite sides of the shunt plate. The full complement of coils at a remreed crosspoint, including the phase relationships, is illustrated in Fig. 2.

As a result of their differential construction, pulsing through either the vertical or horizontal winding alone magnetizes the reeds of each contact series-opposing and thus releases the crosspoint. To operate a crosspoint, a current pulse must pass through its vertical and horizontal windings simultaneously. In this situation, the primary coils on either side of the shunt plate dominate and result in magnetizing the reeds of each contact series-aiding. Remreed switches, like ferreed switches, therefore embody a destructive mark feature. A current pulse passing through a column and row of a crosspoint array operates the crosspoint at the intersection while releasing all other crosspoints along its path.

The primary coils or $2N$ coils of a remreed crosspoint have 64 turns, while the secondary or N turn coils have 31. The primary and secondary coils utilized in the ferreed design contain 39 turns and 18 turns, respectively. Increased turns were employed in the remreed design to lower the amplitude of the current pulse required to control the crosspoint to 4 A.

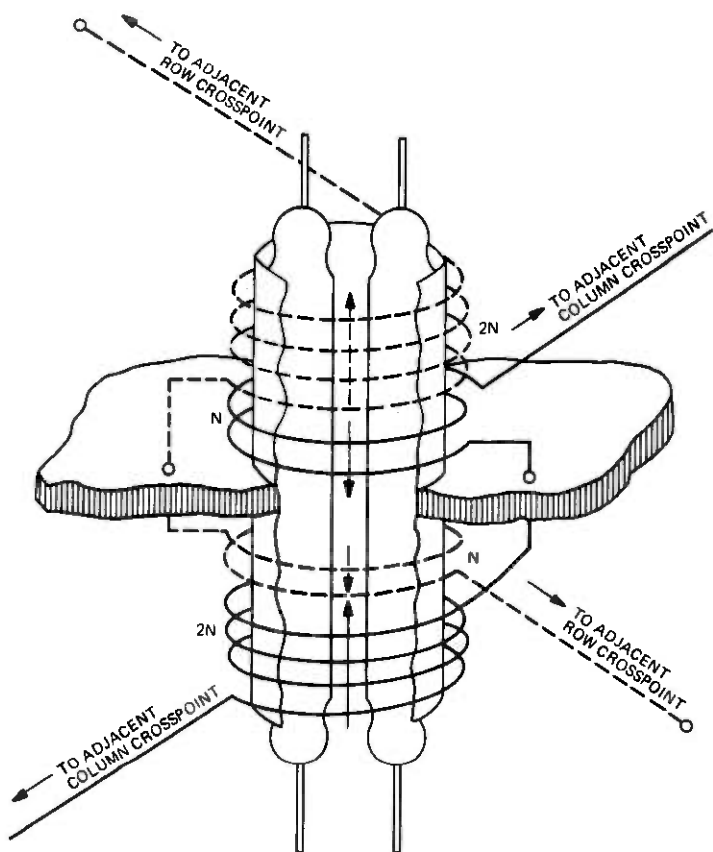


Fig. 2—Crosspoint control windings.

All the remreed control coils are wound with polyurethane-insulated 29 AWG copper wire. Given the volume available for the energizing coils, 29-gauge wire was selected as a compromise in an attempt to maximize the coil turns while minimizing coil resistance. The resistance of a complete pulse path through one row and column of an 8×8 array of remreed crosspoints is approximately 11 ohms. With a 4-A pulse, the peak power developed during pulsing through an 8×8 switch is 175 W. The peak power developed in pulsing a ferreed 8×8 is 250 W. However, as will be discussed later, the pulse required for remreed operation is significantly wider than the required ferreed pulse and, as a result, the total energy dissipated in pulsing a remreed 8×8 is greater.

2.2 Coil forms

The coil forms that house the sealed contacts and on which the control coils are wound are molded directly onto the steel shunt plate. The general shape of the coil form is illustrated in Fig. 3.

The internal configuration is hourglass in shape, providing a distinct channel or slot for each of the two sealed contacts. During coil winding, the hoop stresses produced tend to collapse the coil form and thus reduce the dimensions of the two contact channels. The wall thickness of the coil form was maximized within the space allowed for each crosspoint so that, after winding the coils, a 0.110-in. diameter gauge passes freely through each contact channel. This requirement is necessary to ensure that the sealed contacts can be automatically inserted into the coil forms.

The material selected for the coil forms is a glass-filled polyester thermoplastic, a relatively inexpensive, fire-retardant compound. As a

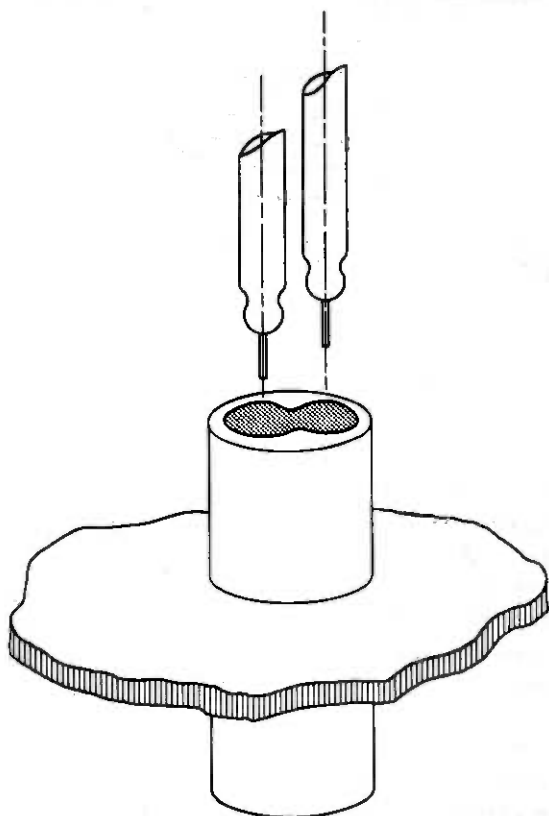


Fig. 3—Molded coil form geometry.

result of the smaller size, significantly less material is required for a remreed coil form than for a ferreed coil form. For the 128-crosspoint switch package shown in Fig. 1, all coil forms are molded in a single injection operation.

2.3 Shunt plate

Structurally, the shunt plate is the foundation around which the entire switch is built. Functionally, the shunt plate provides magnetic separation between the differentially wound coils at each crosspoint.

The shunt plate is fabricated from 0.063-in. thick low-carbon steel. Coincidentally, the amount of steel required is identical to that used in a single ferreed switch. All the openings and holes punched in the plate are referenced from a set of datum holes. These same datum holes are used for alignment throughout all subsequent switch fabrication and assembly operations. The thickness and flatness of the finished plates are closely monitored because of the dependence on these features in future coil form molding and coil winding operations.

Corrosion of the steel shunt plate is inhibited by a nickel-chrome plating applied after all punching and blanking operations are completed. A protective nickel-chrome plate was selected rather than the more standard zinc-chromate finish to avoid the whisker growth problems associated with the latter.

2.4 Printed-wiring boards

The printed-wiring boards used in remreed switches are a composite design. They consist of a conventional double-sided flexible circuit bonded to a stiff support board or support plane. There are openings or holes in the support plane corresponding to the plated-through holes in the flexible circuit member. These openings provide access to the flexible circuit for each component lead. All the semiconductor control components are mounted on the support plane side of the composite along the outside edges.

After final assembly of the switch, this edge location provides easy access to any control component in the event that replacement is required. The bonded flex composite board was selected for the remreed switch because it offers low cost as well as unique design features.

The rigid support plane to which the flexible circuit is bonded is epoxy-coated steel. The total thickness of the member is approximately 0.060 in. Epoxy-coated steel was selected as the support plane material for several reasons. First, the steel center or core of the board decreases the return path reluctance for each switch crosspoint and therefore functions as an integral magnetic member in the switch

design. Second, the metallic nature of the support plane core is used to provide a ground plane in close proximity to the transmission paths on the flexible circuit and thereby improves the crosstalk performance of the switch. Last, the steel core of the support plane shields the switch crosspoint from external magnetic influences and eliminates the need for a separate steel cover as utilized in ferreed switch designs.

The flexible circuit is several inches longer than the support plane to which it is bonded. The resultant flex tongues at each end of the composite board are used to access the front and rear terminal blocks of the switch. As described in Section 2.5, accessing the terminal blocks with these flexible tongues allows the terminal block connections to be made during the final wave-soldering operation.

Bonding the flexible circuit to the support plane is accomplished with an electrical grade adhesive. Of course, in those regions corresponding to holes in the support plane, there is no bond. In these regions, the flexible circuit spans the opening much like a drumhead. The support plane opening at each crosspoint site was purposely enlarged. This places the solder joint between the sealed contact lead and the flex circuit in the center of a compliant drumhead. Thus, stresses in the final switch assembly are partially absorbed through deflections of these drumheads and, hence, the relatively fragile glass-to-metal seals of the contacts are not abused.

2.5 Terminal blocks

The basic terminal block designs used in remreed switches are quite simple. Essentially, they consist of a rectangular molded plastic block containing a field of straight-through terminals. The material selected for the bodies of all remreed switch terminal blocks is the same polyester compound used for the coil forms. Figure 4 illustrates a typical block and its interconnection to the flexible circuit tongue described in Section 2.4.

The design simplicity of the terminal blocks stems from the feature of forming the flex circuit tongue through an S-bend to carry the wiring on the flex circuit to the rear surface of the terminal block. Terminating the flex to the rear of the terminal pins is accomplished during the final wave-soldering of the switch when the block is positioned as shown in Fig. 5. Two separate blocks are used at each end of the switch. The two front blocks are rigidly mounted to the shunt plate by a set of rivets. The terminals in the front blocks are 0.025-in.² pins on 0.200-in. centers and are gold-plated for connector compatibility. Two studs are provided at the front of the switch to lock on the mating female connector used in the interconnection plan adopted for remreed networks. The two rear blocks contain base metal terminals

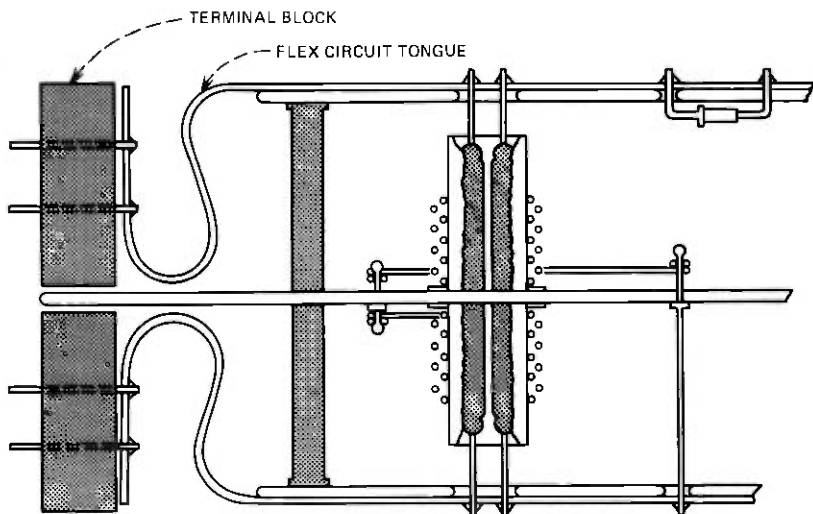


Fig. 4—Terminal block and flex circuit interconnection scheme.

spaced on 0.125-in. centers. Within each block, the position tolerance on the field of terminals is closely controlled to be compatible with automatic 30 AWG solderless wrap equipment. The rear terminals are 0.400 in. long and are secured in the plastic terminal block to withstand an axial pushout requirement compatible with solderless wrap equipment butting forces.

To guarantee proper position tolerances between the two individual terminal fields at the rear of the switch, the location of both rear blocks is adjustable. The adjustment is provided through the mounting screws used to secure the blocks to the rear of the switch.

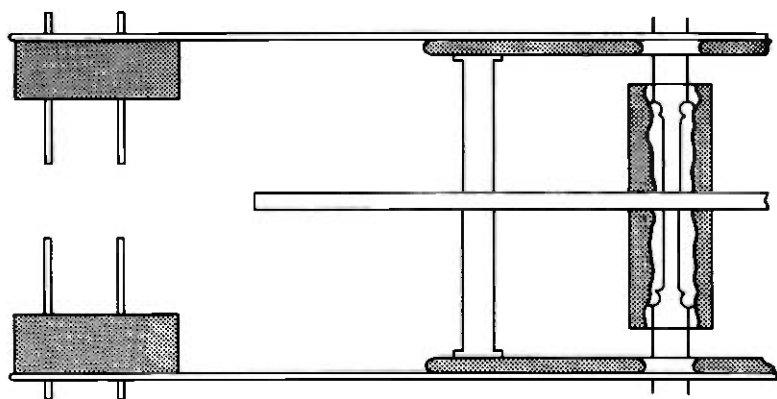


Fig. 5—Configuration for wave soldering terminal blocks.

2.6 Crosspoint spacing

The intercrosspoint spacing in a matrix switch is the principal dimension that determines the overall switch size. The intercrosspoint spacing used for remreed crosspoints is 0.450 in. The comparable dimension utilized in ferreed switch designs is 0.700 in. This reduction in crosspoint spacing allowed the development of remreed switches containing 128 crosspoints that consumed less volume than conventional 64-crosspoint ferreed switches.

The ability to mechanically space remreed crosspoints on 0.450-in. centers stems from the small diameter of the 238A sealed contact. The smaller diameter contact led to the design of a coil form with a significantly reduced cross section and this, in turn, stimulated the reduction in the intercrosspoint spacing. The factors that limited the allowable reduction to 0.450 in. were the coils required at each crosspoint and the parameters associated with the actual coil winding process. These limiting factors can be understood with the help of Fig. 6. This figure illustrates a top view of four neighboring remreed coil forms. The intercrosspoint distance, d , between these neighbors must allow enough space for the coils required on each as well as a residual aisle for the winding fingers used to lay down the coils. The rotating fingers used to wind the coils on the molded coil forms have a diameter of 0.070 in. Allowing for position tolerances and deflections of the fingers due to the wire feed tension, the residual aisle necessary for winding a field of remreed crosspoints was determined to be 0.080 in. The remaining factor to be considered is coil depth. The coil design used for remreed crosspoints has four layers (two layers for the primary coil and two layers for the secondary coil) of 29 AWG wire. The coil depth is approximately 0.040 in. Once the winding aisle and coil depth were determined, the minimum 0.450-in. intercrosspoint spacing was calculated from a diagram similar to Fig. 6.

Mechanical limitations such as coil form diameter, coil depth, and winding finger clearance requirements established a minimum crosspoint spacing of 0.450 in. for remreed switches. Subsequent to establishing the mechanical limitation, a program was initiated to study the degree of magnetic interactions between remreed crosspoints on 0.450-in. centers. This program, which showed that remreed crosspoints so spaced did not interact appreciably, is discussed in Section 3.3.

2.7 Assembly

The major assembly operations for a remreed switch are quite straightforward. First, one of the two circuit boards utilized is positioned parallel to the wound shunt plate via a series of standoffs. The sealed contacts are then automatically loaded into the coil forms. As

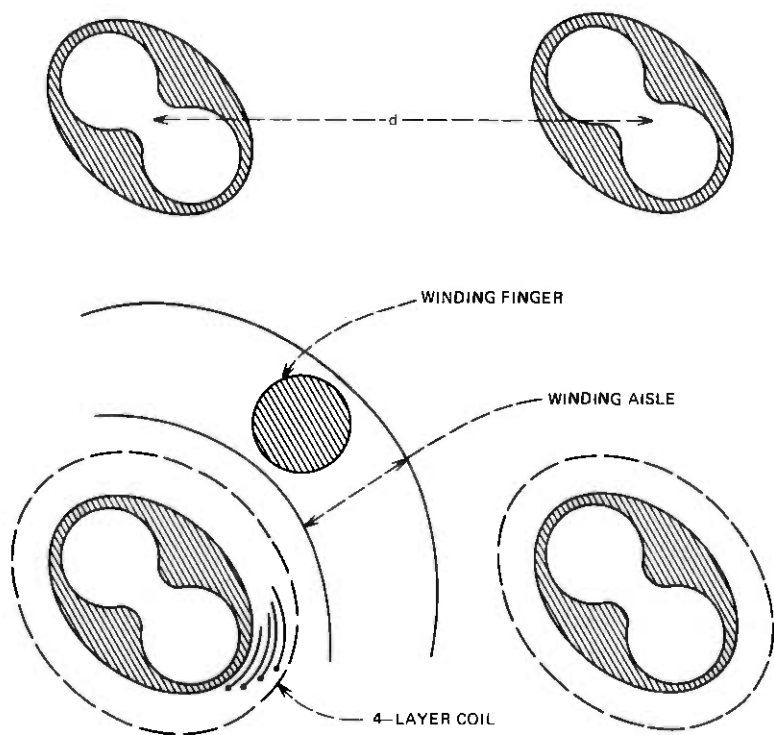


Fig. 6—Effects of coil winding on intercrosspoint spacing.

the contacts drop through the coil forms, the bottom lead of each contact enters a plated-through hole in the attached circuit board until finally the glass envelope of the contact comes to rest against the board, as shown in Fig. 7. In this position, the top leads of the sealed contacts are below the plane that will be occupied by the second circuit board. Therefore, as the second board is brought into position to complete the sandwich, only the coil feed-throughs and rivets must find holes in the circuit board. Once seated, the circuit boards and shunt plate are riveted together. Although now trapped, the contacts remain free-floating. The entire assembly is then inverted and the contacts are allowed to fall via gravity until their leads penetrate the holes in the second circuit board. Next, a magnetic fixture is used to axially center the contacts and the wave-soldering operation is performed.

Guaranteeing that the leads of each seal contact would readily enter the appropriate holes in the two circuit boards was a major design concern. To assure entry, the holes that accept the contact

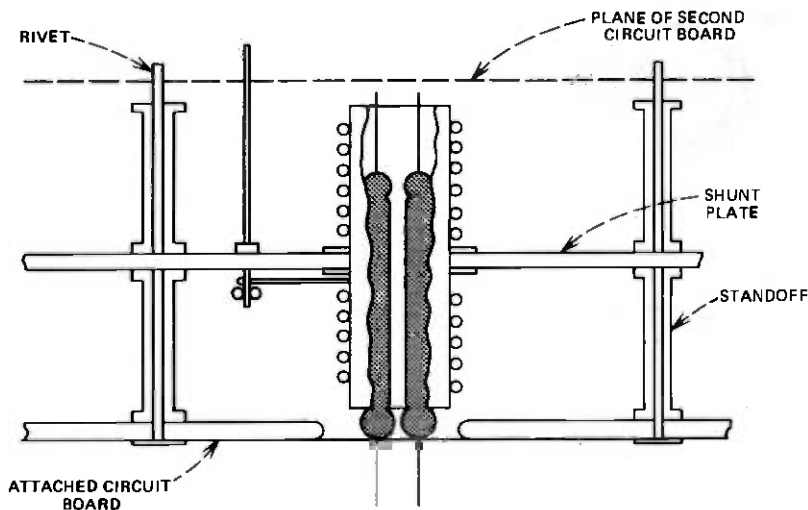


Fig. 7—Partially assembled remreed switch.

leads were made as large as possible consistent with all other design constraints. In addition, the location tolerances on each hole in the circuit board were tightly controlled. Finally, the acceptable eccentricity of 238A contact leads was constrained. These features enabled the sealed contacts to be inserted readily and not have the leads interfere with the holes in the two circuit boards.

As described in Section 2.5, the switch terminal blocks are soldered to the flex circuit tongues during the final wave-soldering operations. Subsequent to the soldering operation, the S-bends in the flex tongues are formed and the terminal blocks secured in their final positions. This type of flexible joint between the terminal blocks and the rigidly mounted support planes decouples the sealed contact leads from stresses that are applied to the ends of the switch as a result of such factors as connector insertions and wire wrap equipment.

III. OPERATING CHARACTERISTICS

The general character of a remreed crosspoint parallels in many ways that of the ferreed crosspoint. Both are pulse-operated devices that consume relatively small amounts of energy. Both are controlled with a set of differentially wound horizontal and vertical coils and employ the destructive mark feature. Both utilize Remendur as the switchable magnetic material that provides the final source of magnetic field to hold the contacts closed. Some basic differences do exist, however. These differences along with their consequences are discussed below.

The ferreed crosspoint is designed so that the residual field produced by the Remendur plates is sufficient to operate the associated 237B sealed contacts. The operation of a remreed crosspoint on the other hand is analogous to the operation of a latching relay and depends on the magnetic field of the energizing coils to actually close the 238A sealed contacts—the residual magnetism in the reeds produces only the final holding field. A second basic difference in the crosspoint designs involves the response to repetitive operate pulses. When an already operated ferreed crosspoint is given a second operate command (remarked), the net magnetic field seen by the 237B contacts is momentarily reversed. As the net field reverses direction, it passes through zero resulting in a momentary opening of the sealed contacts. This open interval occurs because the transient field produced by the energizing coils is in the direction opposite to the holding field established by the Remendur plates. Reoperating an already closed remreed crosspoint, however, results in reinforcing the residual field in the reeds of the 238A contacts. This transient reinforcing rather than reversing eliminates the open interval condition in the remreed crosspoint. The two basic differences described here had a significant impact on the characteristics of the control pulse required in remreed networks.

The current pulse developed for proper operation of a remreed crosspoint is shown in Fig. 8. Several characteristics of this current waveform deserve special attention. First, notice that the rise time or time to peak amplitude is relatively long (the entire width of the ferreed control pulse is approximately $350 \mu\text{s}$). This long rise time primarily is to suppress rapid voltage changes during pulsing which could have a deleterious effect on the electronic control scheme adopted for remreed networks. In addition, the dependency of the 238A contacts on the coil field to produce the initial closure or pull-in also dictates a long rise time. That is, the time-to-peak amplitude must be long

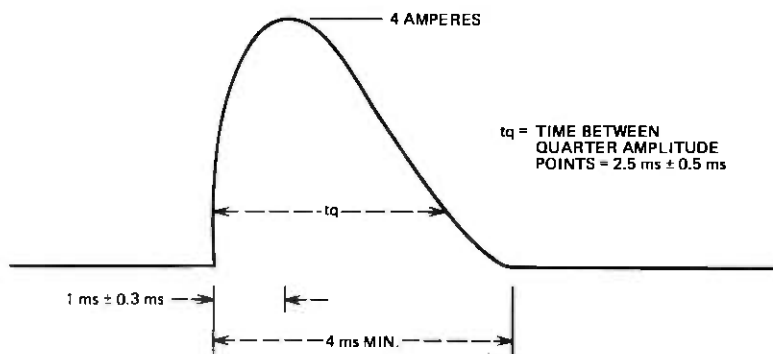


Fig. 8—Required control current profile.

compared to the operate response time of the sealed contact. Achieving initial closure prior to the peak of the pulse also guarantees the fullest level of residual magnetism in the 238A reeds since demagnetization effects resulting from any nonzero contact gap are minimized.

A second characteristic deserving special attention is the pulse amplitude. The 4-A peak current specified for controlling a remreed crosspoint can be compared to the 9-A pulse recommended for operation of a ferreed crosspoint. Reducing the control-current amplitude to the 4-A level was a requirement imposed on the remreed crosspoint design that stemmed from the decision to utilize a semiconductor scheme for steering the control pulses. Achieving the reduction in current resulted from a combination of several factors: the lower coercive force of the Remendur alloy utilized in remreed crosspoints, the smaller mean diameter of the energizing coils, the utilization of circuit support planes with magnetic cores to act as field return paths, and an increase in the number of coil turns. The first three factors are responsible for an increase in the efficiency of the remreed crosspoint. This increased efficiency results directly in a reduction of the current required to switch the magnetic material into its various configurations, thereby operating and releasing the contacts. The last factor, namely, an increase in the number of coil turns, is a tradeoff that can be made on most crosspoint or relay designs, the usual penalty being an increase in the coil impedance. In the case of the remreed crosspoint, the straightforward increase in coil turns is responsible for 65 percent of the reduction in the current amplitude. The remaining portion of the reduction is attributable to the increased efficiency of the remreed crosspoint design.

Finally, with regard to Fig. 8, note that the total pulse width specified is 4 ms minimum. The need for a longer control pulse to successfully operate the contacts in a remreed crosspoint is directly related to the fact that the residual magnetism developed in the reeds of 238A contact produces only a limited pull force, namely, that sufficient to hold the reeds closed and maintain the steady-state contact force. However, during the time immediately following initial impact of the reeds, the steady-state contact force may not be adequate to overcome the effects of reed vibration. As a result, a wide pulse is required to enhance the reed magnetization and, hence, maintain the contact force at a higher level until the violent vibrations that follow the initial impact of the reeds have appreciably subsided. If this additional pull force is not provided during the period following initial impact, the transient retractile forces associated with the various propped mode vibrations can result in a permanent reopening of the reeds. The result is a failure to operate. Even with the additional contact force provided

by the sustained coil field, transient opens (contact bounce or chatter) still occur during the initial period of closure.

The long control pulse is required only for proper operation of the crosspoint. Releasing a remreed crosspoint is more straightforward and almost independent of pulse width. All that is required is to switch the magnetization direction of the two reeds in opposite directions. Pulse widths as short as several hundred microseconds are adequate to perform this switching function.

As mentioned previously, the fact that reoperating an already closed remreed crosspoint does not create a momentary open condition also had a significant impact on the control pulse used in No. 1 ESS remreed networks. When a remreed crosspoint is given a reoperate pulse, the magnetization level in each reed is momentarily increased. This transient increase in field strength is accompanied by an increase in the reed length because of the positive magnetostrictive nature of the Remendur material. This momentary increase in the length of each reed results in relative motion at the contact interfaces. This motion produces a scrubbing of the mating contact surfaces. If repeated several times, this scrubbing can result in enough cold welding of the contact surfaces that the bonds formed may not be subsequently overcome by the retractile forces available. The result is a contact that will not release. The possibility of a crosspoint receiving a series of repeated operate pulses does exist in No. 1. ESS switching networks. To avoid the possibility of generating stuck contacts due to magnetostrictive scrubbing, the control pulse for remreed networks was modified to the sequence shown in Fig. 9.

The second pulse shown in Fig. 9 is identical to that described by Fig. 8. The first or leading pulse depicted in Fig. 9 is defined as the prerelease pulse. This pulse is steered through the vertical winding of the column containing the crosspoint to be accessed and, thus, releases the crosspoint. The second pulse is then steered through both

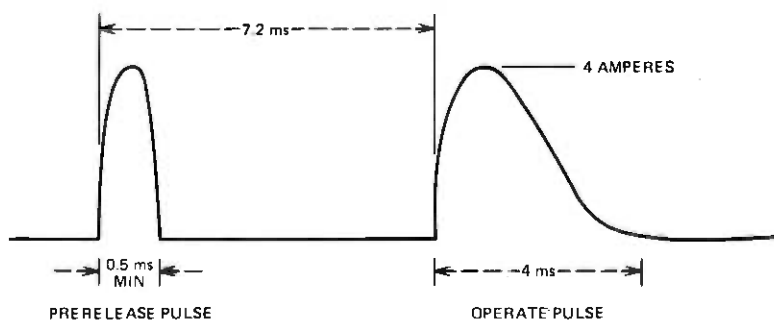


Fig. 9—Required pulse sequence for operation without scrubbing.

the vertical and horizontal windings and operates the crosspoint. Reconfiguration of the pulse path is accomplished during the 7.2-ms interval between pulses. By using this control scheme, a crosspoint that is repeatedly marked is actually released just prior to each operate pulse. In this manner, the possibility of sticking due to magnetostrictive scrubbing is avoided in remreed networks. Since the prerelease pulse is intended only to release a crosspoint, its width was reduced as shown in Fig. 9 to simplify the pulser design.

By introducing a prerelease pulse, the failure-to-operate mode discussed previously was enhanced. To understand the details of this enhancement, refer to Fig. 10. Employing a prerelease/operate pulse train created a special mode of operation known by the acronym OREO for Operate, RElease Operate. This situation is depicted by the contact state diagram included in Fig. 10 and refers to a crosspoint that is already operated and, then, is subsequently addressed by the prerelease/operate pulse train. The prerelease pulse releases the operated contacts and approximately 7 ms later the contacts are again operated. The kinetic energy of the reeds (gained as a result of being released from the initially closed state) is not damped significantly during the 7-ms interval between the prerelease and operate pulses. As a result, the operate pulse acts upon contacts whose reeds are vibrating at their natural frequencies. This reed motion can affect the ensuing closure characteristics of the contact in different ways, depending on the relative velocity and position of the reeds just prior to the initiation of the operate pulse. The effect of this initial reed motion can best be illustrated by considering several extreme situations. One extreme exists when the mismatch in natural frequencies of two reeds is such that, after approximately 7-ms of free vibration, the reeds achieve an in-phase relationship (relative velocity equal to zero at any point during their motion). This initial condition leads to closures with very little propped-mode vibrations. Instead, most of the energy gained by the reeds during closure is coupled directly into the lateral vibra-

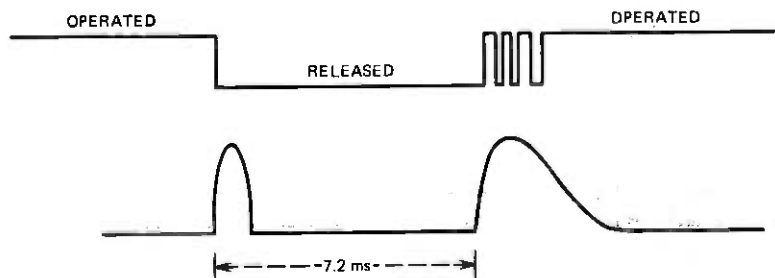


Fig. 10—Operate, release, operate sequence.

tion mode. This type of closure is not uncommon, since approximately 20 percent of the contact universe have reeds with the appropriate mismatch or beat frequency. Another limiting case exists when the natural frequencies of the two reeds are essentially identical. In this situation, after 7-ms of free vibration, the reed motion is such that the relative velocity between the reeds is periodic, alternately achieving maxima and minima. Operating a contact with reeds in this state can produce two extreme cases. The first exists when the buildup in operate field coincides with the reeds attaining a minimum separation. This condition minimizes the impact energy associated with the contact operation and results in a closure that is almost chatter- or bounce-free. The opposite of this situation exists when the buildup in operate field coincides with the reeds attaining their maximum approach velocity. In this case, the final impact velocity is maximized, resulting in extreme propped-mode vibrations. As stated previously, the effects of propped-mode vibrations following the initial impact of the reeds can lead to an operate failure if not overcome by the pull force generated during the initial closure interval.

In practice, the relative motion of the reeds just prior to the initiation of the operate pulse usually lies somewhere between the extremes just discussed. Data indicate that operating a crosspoint in the OREO sequence generally requires less current than operating a crosspoint from a quiescent release state.

Although the prerelease/operate pulse is used in every crosspoint operation in No. 1 ESS remreed networks, the OREO sequence occurs as the exception rather than the rule. In other words, most operations occur with the crosspoint initially released. In this case, the fact that a prerelease pulse precedes the actual operate pulse has no real effect on the final closure characteristics, since releasing an already released crosspoint does not produce any significant reed motion.

3.1 Operate

Remreed switches were designed to be controlled by a field pulse of 4 A. To ensure proper operation, the crosspoint developed is such that a 4-A pulse not only closes the contacts but also provides a magnetic field strength sufficient to effectively saturate the reed material. This criterion for reed saturation maximizes the steady-state contact force and, hence, yields the most stable operate condition.

The principal parameter used to evaluate the operate characteristics of the various crosspoint designs pursued during the remreed switch development was the just-operate or just-latch current value. The just-operate current for any crosspoint is defined as the minimum value of peak current required to successfully close both contacts of the

crosspoint. A histogram of the just-operate currents for a typical universe of 1280 remreed crosspoints is presented in Fig. 11. These data are representative of the final crosspoint design released for production. The distribution presented in Fig. 11 shows an interval of approximately 1 A between the highest just-operate values and the 4-A field pulse requirement. This interval does not represent margin with respect to crosspoint operation, but rather the overcurrent required to guarantee that the field pulse not only operates a crosspoint but magnetically saturates the reed material as well. That is, crosspoints closed with their just-operate currents are not saturated and, as a result, do not provide a completely stable operate condition. However, the interval between the upper end of the just-operate distribution and the 4-A field pulse is utilized in practice to permit a manufacturing test pulse safely below the field requirement. The test pulse amplitude specified for the switch manufacturer is 3.6 A. Switches tested in this fashion should perform satisfactorily in the field environment even when trouble conditions may occasionally result in pulses of less than 4 A.

The effect of the OREO sequence on the just-operate current values is shown in Fig. 12. The solid curve is a repeat of the standard operate distribution shown previously in Fig. 11, while the dashed curve

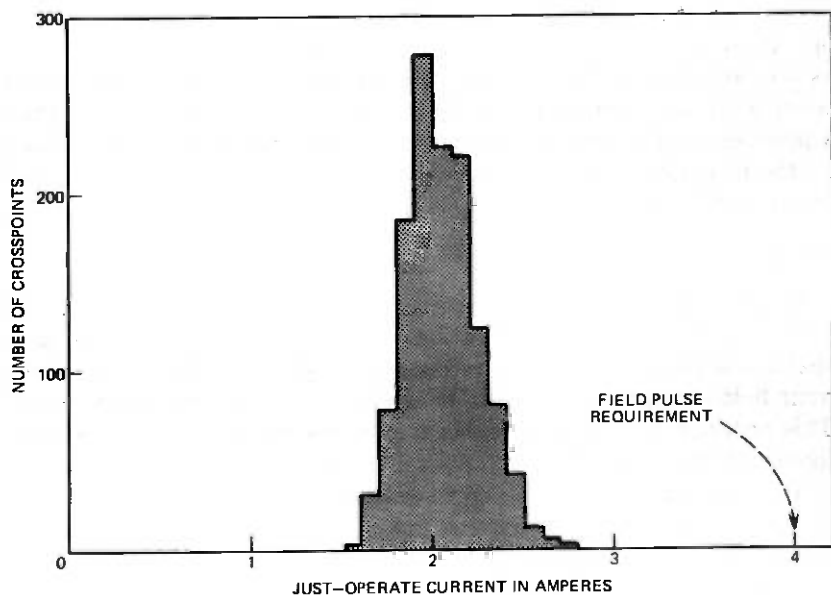


Fig. 11—Just-operate current histogram.

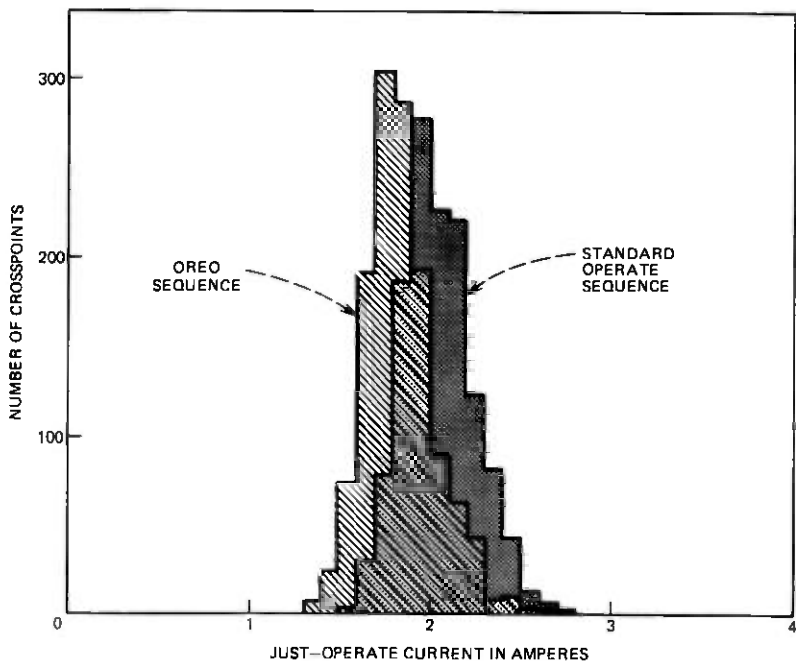


Fig. 12—Effect of OREO sequence on just-operate histogram.

represents the just-operate results for the same crosspoints when utilizing the OREO sequence.

As can be seen, the net effect of the initial reed motion developed with the OREO sequence is to reduce the average value of the just-operate current by approximately 0.2 A.

In a similar fashion to the above, the effect of various crosspoint design proposals were quantified using the just-operate current values. For example, the epoxy-coated steel planes used to support the flexible circuits were found to decrease the average just-operate current by 0.2 A when compared to various nonmagnetic support planes. This improvement results from the magnetic return paths created by the steel core.

The most important use of the just-operate current as a crosspoint design aid was in the determination of the 238A contact sensitivities which would be acceptable for remreed switches. Early in the development of the switch, it was empirically determined that the just-operate current of any particular crosspoint could be correlated with the release sensitivity of the sealed contacts used in that crosspoint. In general, the lower the release ampere turns (NI) of the contacts utilized, the higher the just-operate current. This correlation can be

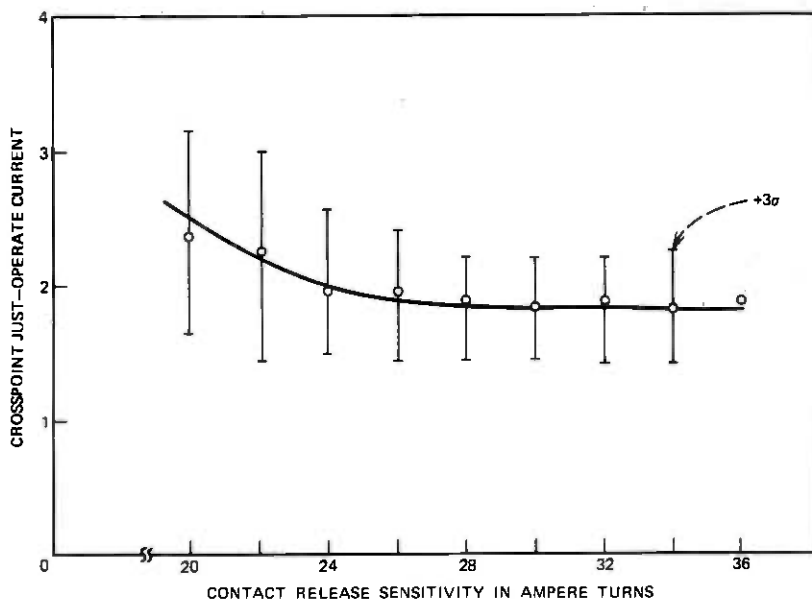


Fig. 13—Crosspoint just-operate current vs contact release sensitivity.

seen in Fig. 13. The increased just-operate currents for crosspoints having contacts with low values of NI release can be understood with the aid of the contact hysteresis loop shown in Fig. 14.

Contacts with low NI release values correspond generally to contacts with release flux levels approaching the remanent flux limit. Therefore, to operate such contacts, the field produced by the crosspoint coils has to essentially saturate the reed material since, for successful operation, the final flux developed by the reeds must exceed the release flux. A plot similar to the one shown in Fig. 13 was instrumental in selecting the 20-NI lower bound for the 238A contact-release sensitivity range.

The operate time of remreed crosspoints controlled with a pulse such as that shown in Fig. 8 is relatively fast. Data taken on many crosspoints indicate the reed bounce or chatter has ceased 3 ms after the start of the operate pulse. However, a low and stable contact resistance cannot be ensured until the ongoing reed vibrations induced by the initial impact have dampened appreciably. For this reason, the crosspoint resistance test performed by the switch manufacturer is made 50 ms after the initiation of the operate pulse.

The actual acceptance level for the terminal-to-terminal resistance test made on a remreed switch varies with the switch code. The need

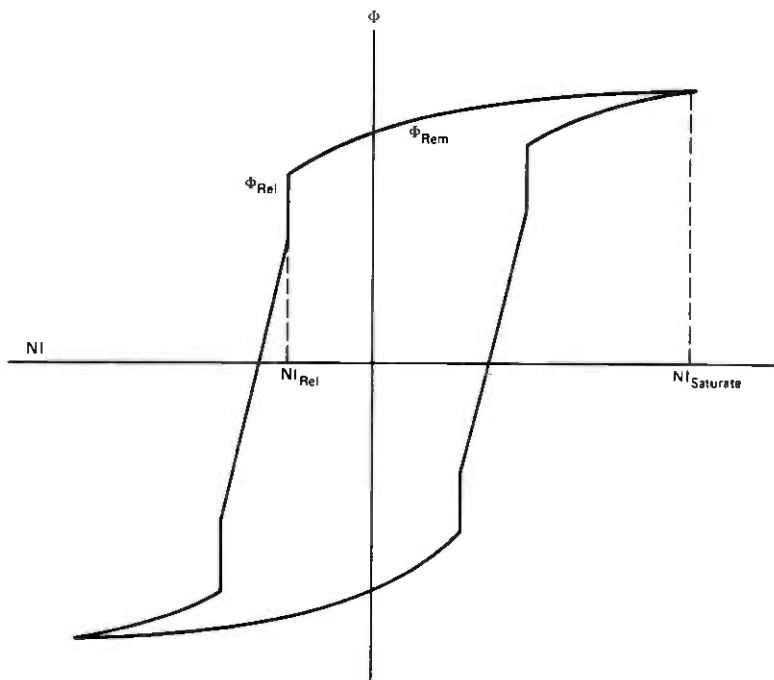


Fig. 14—Hysteresis loop for remreed contact.

for various acceptance levels is due to the difference in the length of the printed-wiring paths required to interconnect the particular configuration of crosspoints contained in each code. In general, however, the terminal-to-terminal resistance requirement applied to remreed switch tip-and-ring paths is in the several-hundred milliohm range.

3.2 Release

When any crosspoint in an array is operated, all other crosspoints in the same row and column are simultaneously released. Those in the same row are released by horizontal windings, while those in the same column are released by vertical windings. The final magnetization states that result from these two windings are shown in Fig. 15.

Any previously operated contact in the same row or column will be switched into one of the above states. In either case, only one reed of each operated contact is reversed and it is the secondary coil of the winding utilized that actually produces the magnetization reversal. The associated primary coil on the opposite side of the shunt plate merely reinforces the magnetization direction of its associated reeds.

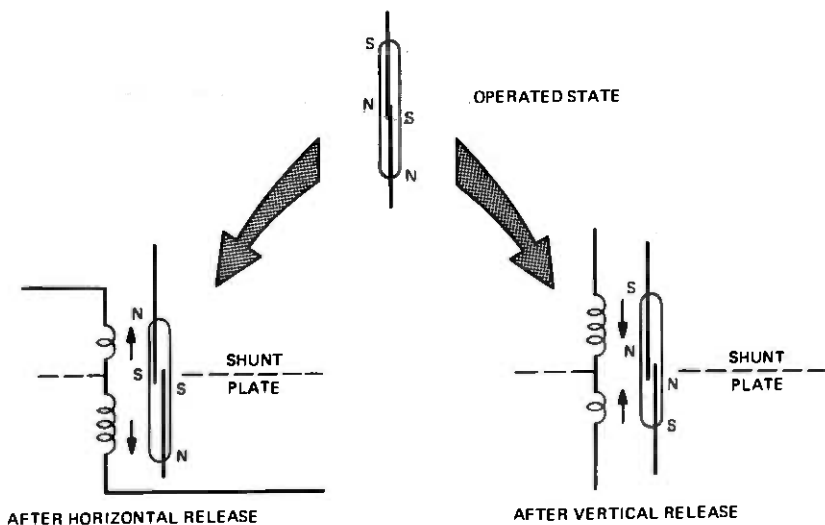


Fig. 15—Magnetic configuration of a contact after horizontal release pulse and after vertical release pulse.

This standard situation is deviated from only in the case of switching from one release state to the other, that is, from a horizontal release to a vertical release state or vice versa. In this case, the magnetization direction of both reeds is switched.

The just-release current is the minimum current pulse that will successfully release both contacts in a crosspoint from a saturate-operate state. A histogram of the just-release currents for a random universe of 1280 crosspoints is shown in Fig. 16. These data were taken using the vertical windings of the crosspoints to effect the release. The just-release current of a crosspoint depends primarily on the release sensitivity of the sealed contacts utilized at the crosspoint. The release-sensitivity range allowed for the 238A contact is from 20 to 36 NI. Contacts with release values approaching the 36 NI upper limit are the most difficult to release in a crosspoint. The distribution of contact release values is essentially gaussian, peaking at approximately 28 NI. This accounts for the relatively normal shape of the crosspoint data shown in Fig. 16.

A plot of the crosspoint just-release current versus the release sensitivity of the particular contacts utilized in the crosspoint is shown in Fig. 17, which is a partial plot in that it covers only the contact range above 33 NI. As can be seen, the higher the NI release value of the contacts, the higher the pulse amplitude needed to release the crosspoint. A plot similar to the one shown in Fig. 17 was used to

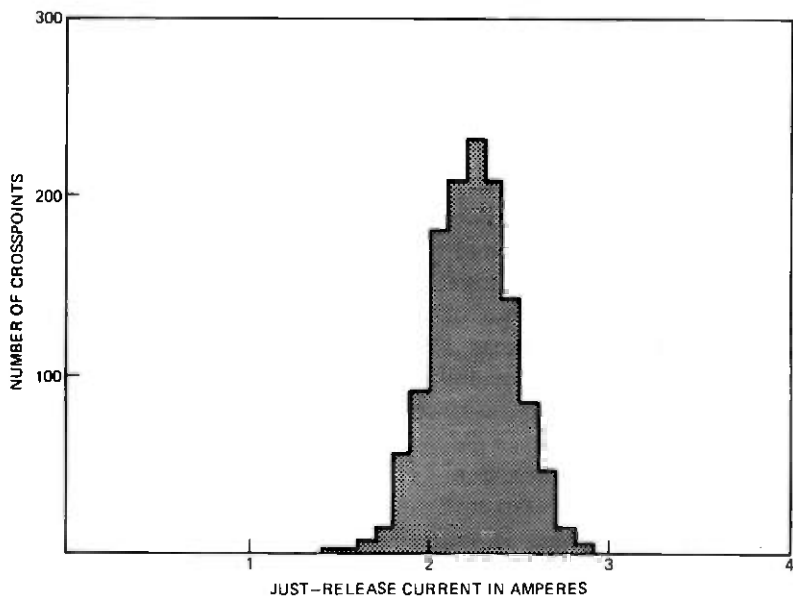


Fig. 16—Just-release current histogram.

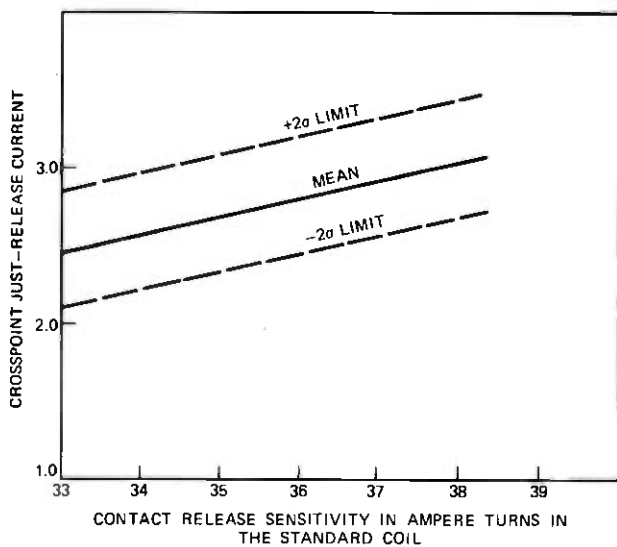


Fig. 17—Crosspoint just-release current vs contact release sensitivity.

determine the upper limit (36 NI) for the release sensitivity of the 238A sealed contacts used in remreed switches.

As stated previously, Fig. 16 gives the distribution of just-release currents for a random universe of crosspoints as measured with the vertical release windings. A similar distribution developed from readings taken with the horizontal windings shows a shift to the left of approximately 0.2 A resulting from the slightly different magnetic interference pattern generated with the horizontal windings. The coil-winding pattern used in remreed switches alternates the winding directions between each column of crosspoints. This alternating column pattern was selected because it reduces the hazard of magnetic walk-down when operating diagonally adjacent crosspoints. However, as a result, the horizontal release windings at any crosspoint are aided slightly by the interference fields of neighboring row crosspoints while the vertical release windings are opposed by the interference fields of neighboring column crosspoints.

Successfully releasing a crosspoint with either its horizontal or vertical windings can be affected by the position of the sealed contacts with respect to the central shunt plate. As stated previously, it is the N turn or secondary coil of the particular winding (horizontal or vertical) that is actually responsible for reversing the magnetization direction of one reed of each contact at a crosspoint. If the gaps of the contacts are mislocated in the direction away from the active secondary coil, releasing the crosspoint becomes more difficult. The testing requirements for remreed switches were selected to provide allowance for up to 0.020 in. of displacement of the sealed contact gap.

A second effect that can be enhanced by contact displacement is the phenomenon of momentary closure. A momentary closure is a transient closure that can occur to an already released crosspoint that receives a second or subsequent release pulse. As a result of the unbalanced primary and secondary coil system, the magnetic field of the primary coil normally dominates in the region occupied by the gaps of the sealed contacts. This is true despite the isolation intended by the shunt plate. Any displacement of the contact gap toward the primary coil aggravates this situation. Hence, when a release pulse is applied to an already released crosspoint, the transient field at the contact gap is not zero and, depending on the displacement, the gap field can be large enough to cause the contact to momentarily close. However, a lower bound of 92 NI on the operate sensitivity of the 238A contact as well as positioning requirements on the contact minimize the hazard of momentary closures. In addition, the final testing requirements on all remreed switch codes include a check for momentary closures.

3.3 Magnetic interference

Remreed crosspoints are spaced on 0.450-in. centers. As discussed in Section 2.6, this intercrosspoint spacing was the minimum allowed by various mechanical factors such as the coil design and winding limitations. To ensure the compatibility of remreed crosspoints spaced on 0.450-in. centers, all magnetic interaction effects were studied in detail.

A remreed crosspoint is not a completely closed magnetic structure. As a result, both the static and transient fields created by a particular crosspoint permeate the surrounding matrix and influence the magnetic states of nearest neighbors. The extent of this interaction between crosspoints depends primarily on the magnitude of the stray fields produced.

The stray magnetic fields produced by a remreed crosspoint are significantly less than those created by a ferreed crosspoint. The primary reasons for the reduction are the following. First, the coercive force of the Remendur alloy used in a remreed crosspoint is 30 percent less than the coercive force of the ferreed Remendur. As a result, fewer ampere turns are required to switch the material. Second, the volume of Remendur utilized at each crosspoint is significantly less in the remreed design.

The effects of magnetic interference on the performance of a remreed switch are reflected primarily in the release current and the residual contact flux. For each of the above parameters, a worst-case interference pattern maximizes the effect. Considering these worst-case interference patterns, it was experimentally determined that reductions in holding flux of about 3 percent could occur. Also, it was found that the nominal release current for a given crosspoint could be elevated approximately 0.1 A due to interference. These rather mild effects do not appreciably affect the overall switch performance.

IV. CODING

A total of seven remreed switch codes were designed to produce No. 1 ESS line link and trunk link networks. A listing of these codes and their basic crosspoint configurations is given in Table I. The seven remreed switch designs are used in combinations to manufacture four codes of larger switching units called grids. These grids, coded the 10A, 11A, 12A, and 13A, are two-stage switching units that form the basic building blocks of No. 1 ESS trunk link and line link networks. The 10A and 11A grids are used in TLNs, the 10A and 12A in 2:1 LLNs, and the 10A and 13A in 4:1 LLNs.

The use of seven distinct remreed switch codes for No. 1 ESS evolved after a detailed study of many possible alternatives for partitioning

Table I — Basic crosspoint configurations for No. 1 ESS remreed switch codes

Code	Crosspoint Configuration
296C-1A	2—8 × 8's
296C-1B	2—8 × 8's
296C-1C	2—8 × 8's
296-2A	4—8 × 4's
296-3C	4—4 × 4's plus 16 cutoff crosspoints plus 16 ferrod sensors
296-4C	1—16 × 4/8 plus 16 cutoff crosspoints plus 16 ferrod sensors
296C-5D	32 test vertical crosspoints

the larger grid units. For example, partitioning schemes resulting in switch designs having a portion of both grid stages were compared to plans that called for switches containing only crosspoints from a particular stage. Although the plan finally selected did not minimize the number of switch codes necessary, it was nevertheless accepted as a result of valuable economic input from the Western Electric Company. Their concurrence was based on the fact that the manufacture of the proposed switch codes would be simplified because of the high degree of piece part commonality achieved in the design of the seven switches.

The quantity and location of the semiconductor control components included in each of the seven switch codes varies. The components required in the switches results directly from the exact scheme adopted for partitioning each grid.

4.1 Trunk link network codes

Four remreed switch codes were developed to produce the 10A and 11A grids required in No. 1 ESS trunk link networks. They are the 296C-1A, 296C-1B, 296C-1C, and 296C-5D. These switches are used in specific combinations to form the larger two-stage grids. As shown in Table I, the 296C-1A, 296C-1B, and 296C-1C codes all contain two 8 × 8 crosspoint arrays. These codes are almost mechanically identical, utilizing the same shunt plate, printed-circuit boards, terminal blocks, etc. The differences exist in the control components included in each.

The 296C-1A is used in the input stage of both 10A and 11A grids. As such, it was designed with steering diodes in each vertical coil path. The 296C-1B is used in the output stage of 10A grids and requires steering diodes in each horizontal coil path. The 296C-1C code has diodes in both vertical and horizontal coil paths. It is used to form the output stage of 11A grids. Actually, in the case of the 296C-1B and 296C-1C, a single code (296C-1C) would have sufficed. However, the economic penalty of having superfluous diodes in the output stage of

10A grids was deemed severe enough to justify a separate 296C-1B code.

The remaining TLN code, the 296-5D, contains only 32 crosspoints. These crosspoints are controlled as four separate 1×8 arrays, although the tip-and-ring strapping actually forms a 1×32 selection. Two 296C-5D switches are utilized in the output stage of 10A grids to provide test access to each of the grid's individual output ports. As a result of the unique control scheme required in the 10A grid, over 100 steering diodes are associated with the windings of the 296C-5D switch. These devices are mounted on the 5D circuit boards and, from a design viewpoint, they offset the low crosspoint count and create a relatively dense switch package.

The 296C-5D switch was designed to use the same molded shunt plate employed in the 296C-1 type codes except that only 32 of the total of 128 coil forms are wound. In addition, the support planes, terminal blocks, and all miscellaneous hardware from the 296C-1 designs are utilized. The flexible circuit boards of the 296C-5D design are the only piece parts not common to the 296C-1 type codes.

4.2 Line link network codes

The switch codes developed specifically for the line link networks of No. 1 ESS are the 296-2A, 296-3C, and 296-4C. They are used to produce 12A and 13A grids which are 2:1 and 4:1 concentrators, respectively.

The 296-2A switch is quite similar to the 296C-1 type codes discussed in Section 4.1, except that the field of 128 crosspoints is interconnected as four 8×4 arrays rather than two 8×8 arrays. This is accomplished by way of the printed-wiring boards utilized in the 296-2A code. One 296-2A switch forms the complete output stage of both the 12A and 13A grid units.

The two other LLN codes, the 296-3C and 296-4C, are utilized to produce the input stages of 12A and 13A grids, respectively. The 296-3C and 296-4C both contain 64 crosspoints and service 16 customer lines. The 296-3C crosspoints are interconnected as four 4×4 arrays, and the 296-4C is interconnected as a $16 \times 4/8$ array. In addition to the 64 switching crosspoints, each switch also contains 16 ferrod sensors and 16 associated cutoff crosspoints for connecting and disconnecting the sensors to each of the 16 switch inputs. By including cutoff crosspoints and ferrod sensors together with an appropriate portion of the input stage of switching and interconnecting them via the switch circuit boards, a significant amount of external frame wiring was eliminated.

The ability to design functional line packages such as the 296-3C and 296-4C codes was made possible by the development of the minia-

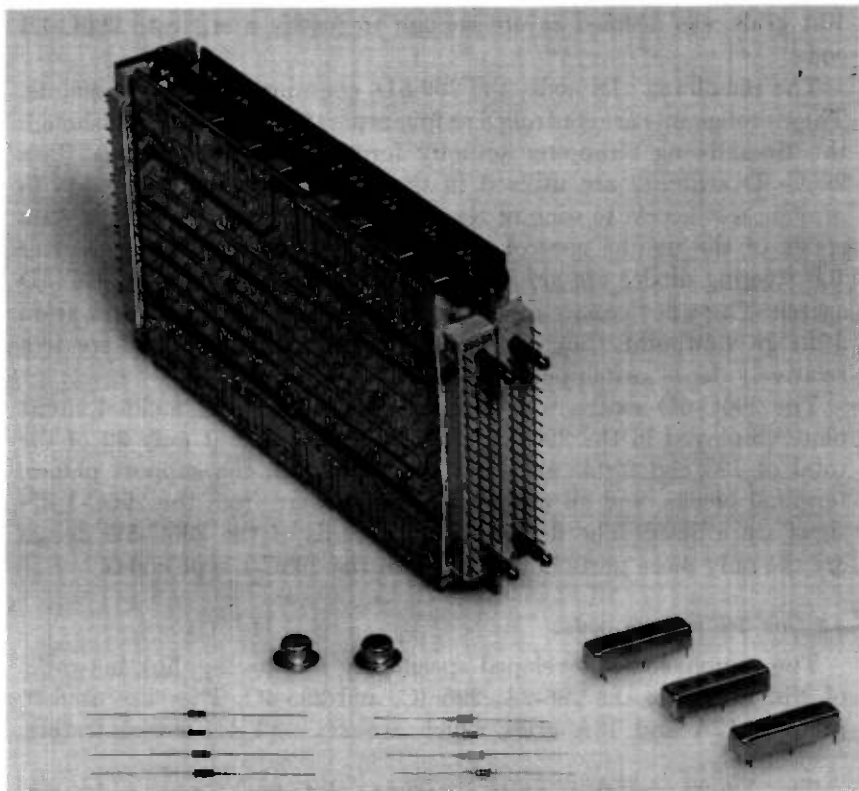


Fig. 18—296-3 type remreed switch.

ture 2A ferrod sensor. This new ferrod design is electrically equivalent to the 1B ferrod used in ferreed LLNs; however, it is a factor of 6 smaller and designed for mounting on a printed-wiring board. The 2A ferrod makes use of many manufacturing techniques common to reed relay devices, employs the identical ferrite stick piece partly utilized in the older conventional designs, and has a significantly lower cost. The RC contact protection networks required for each sensor and cutoff cross-point combination are separately mounted on the switch printed-wiring boards. Figure 18 is a photograph of a 296-3C switch. Eight of the included sensors are partially visible along the top edge of the near printed-wiring board. Several loose sensors are shown in the lower right-hand corner of the photograph.

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Remreed Switching Networks for No. 1 and No. 1A ESS:

Remreed Network Electronic Control

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The new remreed network was designed to reduce the cost and the size of the No. 1 ESS network. It uses a new self-latching sealed contact and a new switch-package design. This new package includes components directly related to the control of the switch. Remreed network control, the subject of this paper, is all electronic. It uses a mixture of silicon integrated circuits and discrete circuits to accomplish its control functions.

The network topology and modularity has not been changed. The design was undertaken with the goal of complete compatibility with all existing system programs, including fault-recognition and diagnostic programs. This has permitted the addition of remreed networks to existing No. 1 ESS offices with no program changes or modification of ferreed networks. The resulting remreed-ferreed mix is operated and maintained by the same software.

The new network offers reduced manufacturing costs, simplified installation, improved reliability and maintainability, and a 3:1 to 4:1 space reduction.

I. INTRODUCTION

A new technology has evolved in designing and assembling central office equipment. This new technology has reduced the cost and size of a No. 1 ESS office. The remreed controller uses low-level, high-speed, integrated-circuit logic for all its information-processing functions. Higher-voltage integrated and discrete circuits interface with PNP transistors in the network control path. Standard 24-V central office battery is the primary source of power. It is converted locally to low voltage levels to provide power for the integrated circuits.

Automatic machine wiring is used to interconnect circuit packs and construct wired backplanes. Other interconnections are made using connectorized cables and flat ribbons. Flexible circuits are used in switch packages and will also be used in grids and concentrators. The remreed network has become fully connectorized.

A dramatic size reduction has been achieved. One fully equipped trunk link network can now be assembled in one shippable unit compared to eight separate frames required for one ferreed trunk link network.

The new network controller has been designed and organized to be compatible with all existing No. 1 ess programs. This requirement determines how much network fabric is assigned to one controller. It determines the method a controller must use in reporting its normal and diagnostic functions and also the sequence of events that must take place during an operating cycle.

II. ELECTRICAL DESIGN

2.1 Basic features

The remreed network is made up of four different switching circuits. These are the 2:1 line-switching circuit which uses 12A concentrator grids, the 4:1 line-switching circuit which uses 13A concentrator grids, and the trunk- and junctor-switching circuits that use 11A and 10A grids, respectively.¹ These four circuits are all different in size and organization, but basic control functions are common.

Figure 1a illustrates a remreed crosspoint.^{2,3} The figure shows the reed contacts and two pairs of differently wound windings. One pair is associated with a vertical control path and the second pair is part of the horizontal control path. The reeds will close and latch if a current pulse passes through the vertical and horizontal control winding simultaneously. Pulsing through either the vertical or horizontal windings alone magnetizes the reeds opposing and, thus, releases the contact.

The remreed crosspoint has the same destructive mark feature as the ferreed crosspoint. The choice of 64-31 turns of 29-gauge wire is an electrical and physical compromise. The crosspoint will be in an all-electronic-control environment. From an electrical control standpoint, it is desirable to have a large number of turns of heavy-gauge wire to minimize both current and voltage. The opposite is true from a physical design standpoint. The chosen number of turns and wire gauge is therefore a compromise. The impedance of the pulse path is dominated by the ohmic resistance of control windings. A typical path through a grid has about 23 ohms resistance and requires 96 V of driving potential.

The flux through the ferreed contact during operate pulsing is opposite to the holding flux. Each time a closed ferreed contact is pulsed, the flux through the contact will reverse. The flux will go through zero and cause the contact to open momentarily. The reversal of flux does not take place in the remreed crosspoint. The contact

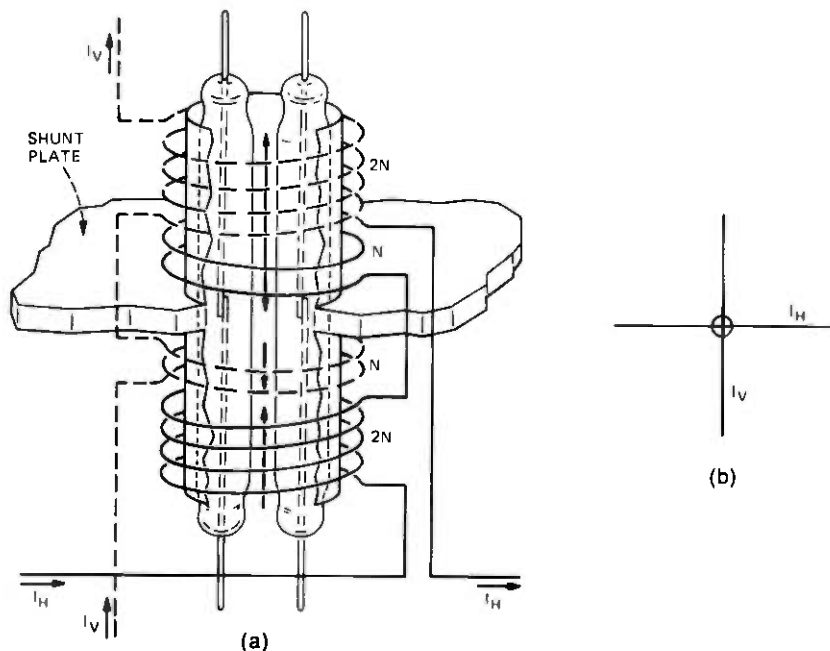


Fig. 1—(a) Remreed crosspoint. (b) Schematic symbol.

members contain the magnetomotive force for latching and, during reoperate of a closed contact, the flux density will change but the direction of the flux will remain the same and the contact will remain closed. This modulated flux density will cause magnetostrictive elongations of the reeds. This motion produces scrubbing of the contact surfaces which can cause cold welding. The retractile forces available may not be enough to overcome the bonds and the contact will stick. Therefore, a standard remreed operating cycle will initially deliver a prerelease pulse to ensure that the crosspoint is open prior to the operate pulse.

A 4-A, 1-ms-wide prerelease pulse will be steered along the vertical column of control windings to release the contacts that the subsequent operate pulse will close. This prerelease action is performed simultaneously in both stages of a concentrator or grid. The operate pulse has an amplitude of 4 A and a width at the base of about 4 ms. Figure 2 illustrates the events.

2.2 Basic control functions

A remreed switch package is assembled by forming a matrix of crosspoints. The vertical control windings are interconnected to form

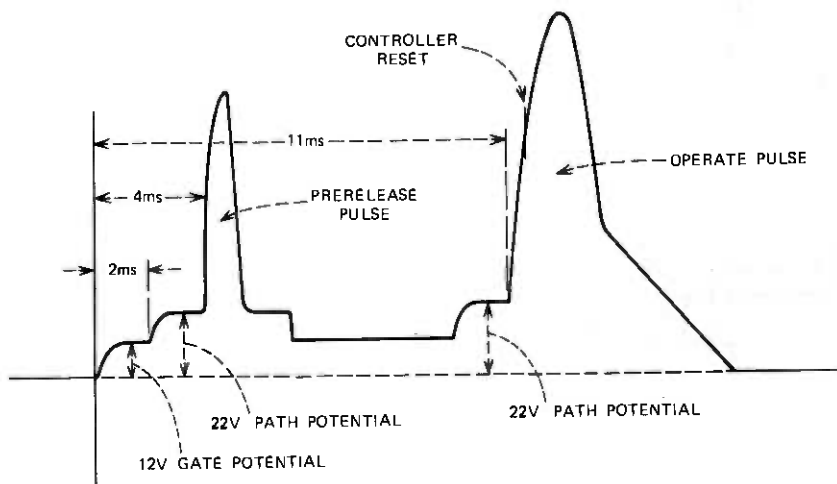


Fig. 2—Voltage at positive pulser terminal.

columns and the horizontal windings are interconnected to form rows. The reed contacts are interconnected to form a contact matrix that corresponds to the control-pulse-path matrix. Such an interconnected matrix is referred to as a switch. More than one switch may be assembled in one switch package. Switch packages are interconnected to form larger arrays called either concentrators or grids. The concentrators and grids have the same dimensions and topology as in the present ferreed network.⁴

PNPN transistors are used in pulse-path arrays and also external to the arrays to select a unique pulsing path. Both concentrators and grids are two-stage arrays. Stage 0 contains input switches and stage 1 contains the output switches. PNP transistors used to select an input or output switch are located inside the switch package. All vertical columns and horizontal rows contain series-connected diodes that are also part of the switch package.

A unique pulse path is established by selectively "turning-on" PNP transistors. A path normally consists of an input level, input switch, output switch, and output level. Some pulse paths through a concentrator or grid are partial paths. The remove-cutoff and restore-cutoff functions are examples of orders requiring partial paths through a concentrator. Operate no-test and remove no-test are examples of partial paths through a junctor grid.

A PNP transistor and some associated control components are used in all stages of selection. These components are located inside switch

packages and on external circuit packs. Figure 3 illustrates the PNP transistor and its control components.

This group of components is used in every stage of selection. It provides means for detecting any component failure. Any number of these groups of components may be connected in series for multistage path selection. In this description the N-emitter will be referred to as the cathode and the P-emitter as the anode. The two diodes connected to the base provided access to the PNP-transistor from two sources. In this case two controllers may have access to this transistor. The PNP transistor chosen requires a minimum gate current of 5 mA and it has a maximum latch current of 16 mA.

The 430-ohm resistor provides terminations for the gate current. The diode in series with the cathode permits the formation of merging pulse-path nodes. The cathode may drive expansion nodes where each driven member of the node contains a diode.

A PNP transistor is selected when a positive potential (+12 V) is applied to one of the gate diodes and the associated cathode resistor is terminated to circuit ground. The cathode resistor is terminated to ground through one or more saturated transistors. This gate-drive and cathode-terminating scheme permits using the PNP transistor as a selection device in a two-dimensional selection matrix. Gates are interconnected along one dimension and cathode resistors are interconnected along the second dimension.

The gate-current path is perpendicular to the pulsing or holding path as shown in Figs. 3 and 4. This combination of PNP transistors and associated components is used in all concentrators and grids for selecting a unique path. This scheme permits cascading any number of these combinations in series without the familiar voltage ladder problem. In

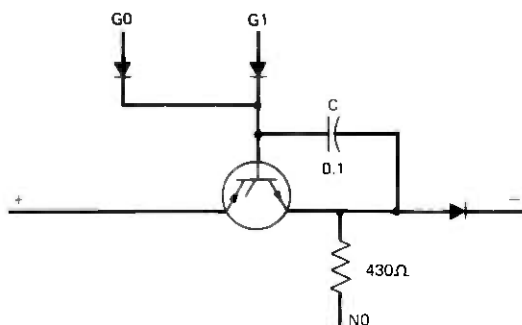
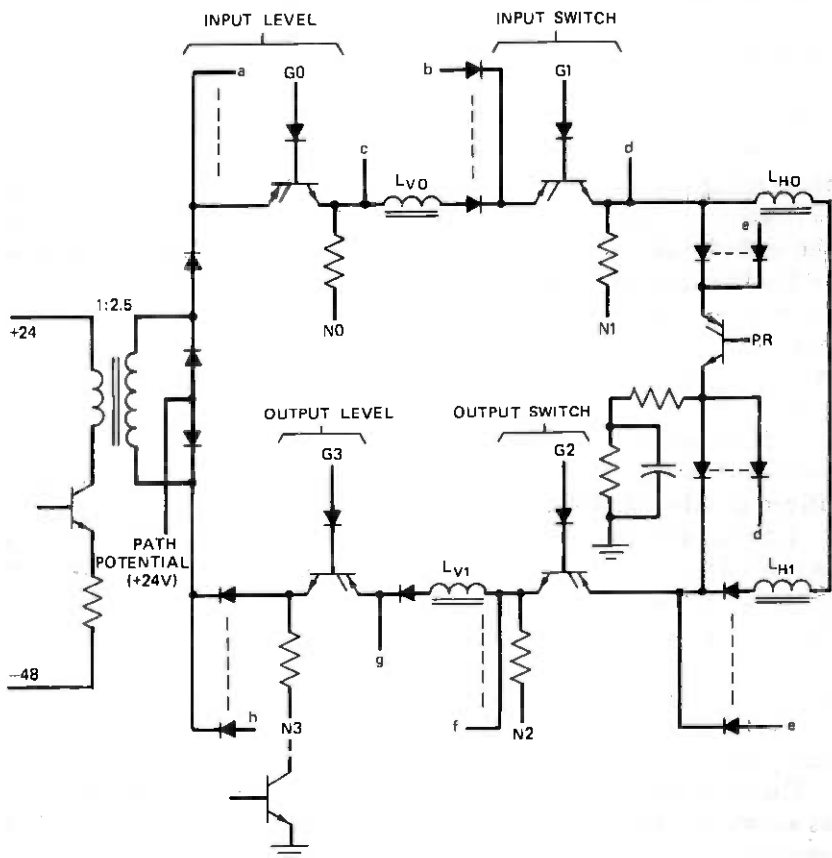


Fig. 3—PNP transistor and associated control components.



- a - TO OTHER INPUT LEVELS IN THE SAME GRID
- b - TO OTHER INPUT LEVELS OF THE SAME INPUT SWITCH
- c - TO CORRESPONDING INPUT LEVEL OF OTHER INPUT SWITCHES
- d - TO OTHER OUTPUT SWITCHES IN THE SAME GRID
- e - TO OTHER INPUT SWITCHES IN THE SAME GRID
- f - TO OTHER OUTPUT LEVELS IN SAME OUTPUT SWITCH
- g - TO CORRESPONDING OUTPUT LEVEL OF OTHER OUTPUT SWITCHES

Fig. 4—Basic pulse path.

addition, this scheme provides the means for detecting component failures or physical problems such as shorted conductors or open paths.

2.3 Gate drive and group check

Each select group is driven by a current-limited voltage source. Each controller has six such voltage sources. The voltage applied to the gate of any PNP transistor is limited to 12 V and the voltage source is designed to deliver a maximum of 34 mA. Figure 5 illustrates the circuit. The voltage source is turned on at the beginning of each

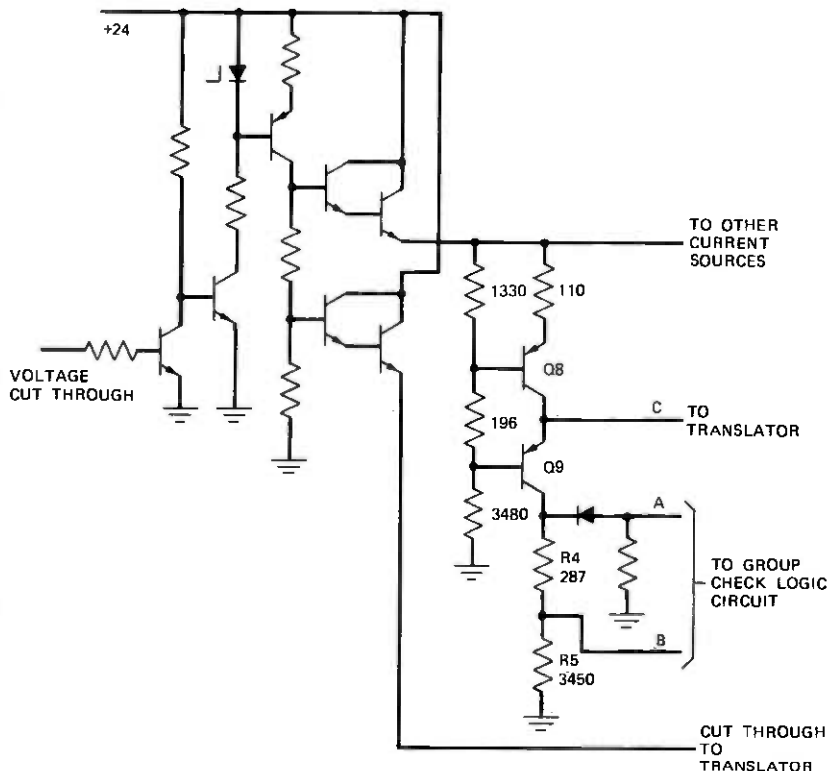


Fig. 5—Current-limited voltage source.

network cycle and turned off during the operate pulse. Only one PNP transistor in each select group should be activated. This will draw 24 mA from each voltage source over the C lead and the remaining 10 mA flow through resistors R4 and R5. An excessive demand of current on any of the C leads will cause a "more-than" failure. A translator failure or addressing error that will attempt to select more than one PNP transistor in any select group will demand more current from the gate driver than is available. A component failure in the pulse-path fabric, such as shorted components or shorts between components, will cause the same controller failure.

Similarly, a failure or error that fails to select any device in a select group will cause a "less-than" failure. There will be no demand for current on the C lead and all the current will go through R4 and R5. A connection logic circuit monitors the A and B leads in each group for failure states. It will indicate the type of failure and indicate the select group that has the failure. Strobing for group-check failure takes place about 2 ms into the network cycle. At this time all gate currents

should have reached their final value. If a failure is detected, the network cycle is aborted.

When the group-check test passes, it indicates that the address received is valid, the translators are giving valid outputs, and all transistors, diodes, and PNP transistors involved in selecting a pulse path are functioning properly. As previously mentioned, the control path or gate-current path of a PNP in this scheme is perpendicular to the pulse path, and the group check does not, therefore, indicate continuity in the chosen pulse path. A separate path check will sense for continuity between stages of the pulse path.

2.4 Path check and pulsing sequence

Figure 4 shows four select points interconnected to form a four-stage pulse path. This method of forming and selecting a unique pulse path is basic to all remreed circuits. Gate potential (+12 V) has been applied to all four PNP transistors and gate current flows through the four cathode resistors. Since the voltage source for all gates is the same, gate current cannot flow forward into the succeeding stage. The forward voltage drop of the pulse-path diode and PNP transistor prevents current from flowing between stages.

Checking for a pulse path starts after a successful group check. A +24-V path potential is applied to both the positive and negative terminal of the pulser circuit. The path-check circuit is part of the pulser circuit. The path potential will propagate forward through each selected stage, and path current will flow to ground through each of the cathode terminating resistors. The higher level of the path potential will back-bias the gate diodes and shut off the gate current.

Each PNP transistor in the path changes from a gated state to an avalanched and forward-conducting state. The path-sensing circuitry in the pulser circuit will trigger at a path current of 120 mA and initiate the pulsing sequence. The path potential maintains the negative pulser terminal at +24 V. The pulser circuit is a constant-current pulser. Voltages along the path are determined by the impedances and voltage drops across PNP transistors and diodes. Figure 2 illustrates the voltage waveforms at the positive terminal of the pulse and the sequence of events during an operating cycle.

The first event in the pulsing sequence is the prerelease pulse. The desired operate path remains selected; gate potential, path potential, and cathode-resistor terminations remain active. A 0.5-ms pulse is given to the gate of a prerelease PNP transistor. This PNP transistor (PR), shown in Fig. 4, shorts half the chosen operate path.

The prerelease current flows only along the vertical control windings of both stages and releases all closed contacts in those two verticals.

This release path shuts off after the 1-ms pulse. The R-C network in the cathode shuts the path off. In addition, the path potential is temporarily removed. The path potential is later reconnected. The initial operate path is again turned on and the operate-pulse sequence starts. The controller remains in its active state during the initial rise of the operate current. As the current goes through half its peak value, the controller will reset. Gate and path potential and cathode resistor terminations are removed. The pulse path becomes a semifloating path. The source of the path potential supplies the current that flows to ground through the cathode resistors during prerelease and the initial part of the operate pulse.

The control point in Fig. 3 shows a 0.1 μ F capacitor connected between gate and cathode. All PNP transistors in the pulse path have this capacitor. In the switch packages and in the assembled concentrator and grids, tip-ring conductors are carefully balanced to achieve crosstalk and impulse noise requirements.⁵ This careful balance solves the problem of pulse-path-to-transmission-path impulse noise. The reverse is not true. The pulse path is an unbalanced segmented single conductor. It is susceptible to impulse noise coupling from the transmission path. The gate-to-cathode capacitor reduces the dynamic sensitivity of the PNP transistor to any type of impulse noise.

2.5 Frames and circuits

A ferreed line-switching circuit is mounted in a double-bay frame. A ferreed trunk-switching circuit is also mounted in a double-bay frame. The system refers to these circuits as frames in its input and output message nomenclature. A remreed line-switching circuit occupies less than half a single-bay frame and a remreed trunk-switching circuit occupies less than one-quarter of a single-bay frame. The system message nomenclature is in this sense not compatible with the remreed physical design.⁶ The office craftsperson needs to make a mental translation of frame into circuits and bay into mounting plate.

The remreed network frame has one peripheral bus circuit per bay. This circuit converts the system ac bus to a dc bus within the bay. All circuits in the bay connect to the common bay bus. In the trunk-link network the number of peripheral cable receivers has been reduced by a factor of four. Similarly, each bay has one diagnostic bus-access circuit.

In the remreed network, the concentrators and grids are the smallest functional and physical units of the switching fabric. In a fabric sense, these are functionally identical to their ferreed counterparts. These units are the smallest replaceable fabric unit in the field. A 6-foot, 6-inch, double-bay frame contains a fully equipped and

factory tested 1:1 test link network. It contains a factory wired and tested connectorized B-link cable. It is the largest shippable network unit.

Remreed network topology and control partitioning is the same as in the ferreed network. Functional names and abbreviations in the remreed network controller design are the same as those used for similar functions in the ferreed controller.

One important objective of the new network design has been compatibility with the existing system programs and general system structure. All operating instructions are received over the peripheral bus. This bus is fixed both in number of information bits and in the coded format of the information. The number of bits on the bus and the information format was initially determined by the ferreed network electromechanical pulse-path-selection scheme. The information format is different for the different network circuits. The information is folded to achieve efficiency in the use of relay contacts in the ferreed pulse-path selectors.

2.6 Power

Standard central office +24-V and -48-V power is used. Each bay terminates duplicated feeders of the two voltages into 32,000- μ F filters. Each controller converts some +24-V power to +3.0 V using a dc-to-dc converter. This provides a single-point power source for all low-level integrated and discrete circuits within a controller. Each switching circuit dissipates about 50 W. The -48 V power is used primarily as a source of pulsing power.

III. REMREED CONCENTRATORS AND GRIDS

This section examines the four types of network circuits and describes the use of the basic control principles introduced earlier in the article.

3.1 The 2:1 concentrator

A 12A concentrator is a 2:1 concentrator. It has 32 inputs and 16 outputs. It is assembled from three switch packages, two 3C packages and one 2A package. These are interconnected either by a machine-wired backplane or a double-sided, flexible-circuit backplane. The 3C stage 0 switch package contains four 4-by-4 switch arrays and a pair of cutoff contacts* associated with each input level. In addition, the package contains a new reduced-size line ferrod for each input level.⁷

* The cutoff contacts are the same as any other fabric contact. Only the control windings are different to provide for individual crosspoint control.

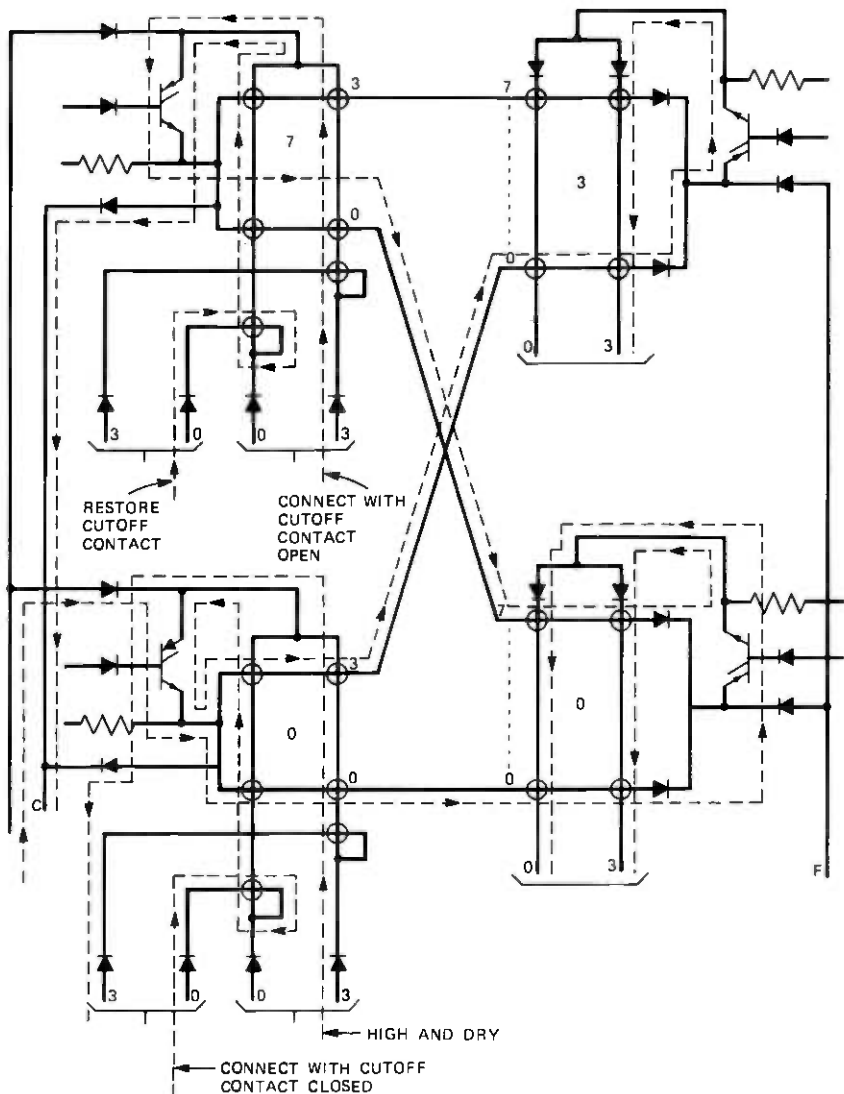


Fig. 6—12A concentrator.

Figure 6 illustrates the control path for a 2:1 concentrator. The PNPN transistors and other control components are part of the switch package. Four 16-conductor connectorized cables are connected to the rear of the concentrator to provide for all network control access. Same numbered input and output levels are interconnected and level selection is performed external to the concentrator.

Figure 6 illustrates typical paths the operate-current pulse will follow as a function of the order. The order group is a select group that determines the kind of path to be established. The other select groups determine the location of the path. Input level, input switch, output switch, and output level are path-select groups. The control of the cutoff contacts is determined by which group of input-level-control windings is chosen. With reference to Fig. 6, the right-hand group of inputs will cause the cutoff contacts to open. If the selected input level is in the left group, the cutoff contacts will close.

The prerelease path in a concentrator consists of two parallel paths. One path enters the selected input level in the right group and follows the vertical control winding of the selected input switch and exits over output C. The second prerelease path enters the selected output switch over input F and follows the vertical control windings that correspond to the selected output level.

The connect-with-FCG (OR2) prerelease path consists of only the output switch vertical control winding path. This order does not require closing the stage 0 crosspoints and the stage 0 prerelease path is not used. The operate pulse in this order opens a crosspoint in stage 0.

3.2 The 4:1 concentrator

Figure 7 illustrates the 13A concentrator. This 4:1 concentrator has 64 inputs and 16 outputs. The input switch is a limited-access switch. Each input level has access to four of the eight outputs. The 13A concentrator is assembled from four 4C switch packages and one 2B switch package. The switch packages are interconnected either by machine-wired or flexible-circuit backplanes. Each of the 4C switch packages contains one 16-by-4-out-of-8 switch, 16 cutoff switches, and their associated line ferroids. The switch is controlled as two separate 16-by-4 switches. Figure 7 shows two PNP transistors associated with each input switch. One PNP selects the even-numbered outputs and the other selects the odd-numbered outputs. The four physical input switches are controlled as eight electrical switches. Control path and prerelease paths are the same as for the 2:1 concentrator. All same-numbered input and output levels are interconnected. One set of 16 input-level-control paths are used with all orders that require the cutoff to open. The other set, the left-hand group in Fig. 7, is used to close the associated cutoff contacts.

3.3 Trunk and junctor grids

Figure 8 illustrates the control path of the familiar 64-by-64 octal trunk grid. The grid is assembled from four 1A and four 1C switch

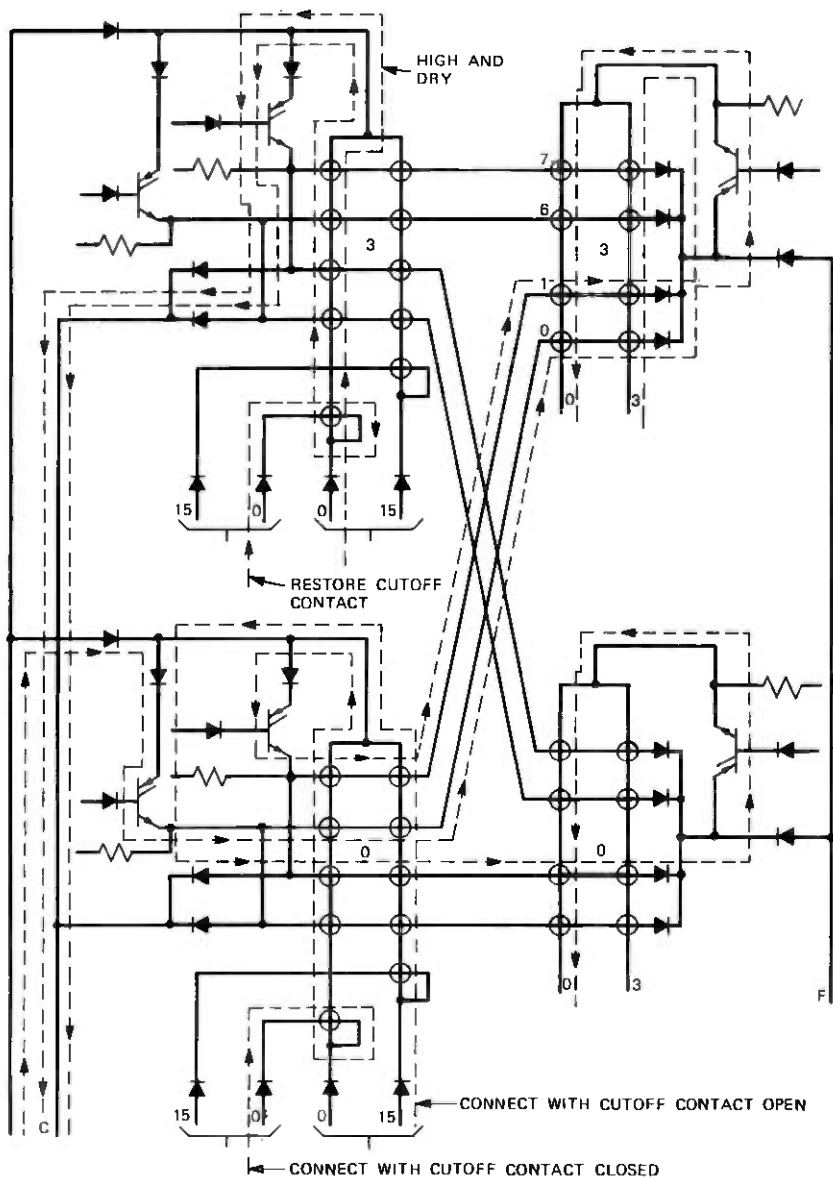


Fig. 7-13A concentrator.

packages. The switches are interconnected by either a machine-wired or flexible-circuit backplane. The interconnected unit is apparatus coded as the 11A grid. Four connectorized 16-conductor cables attach to a connector location in the backplane. These cables provide all the

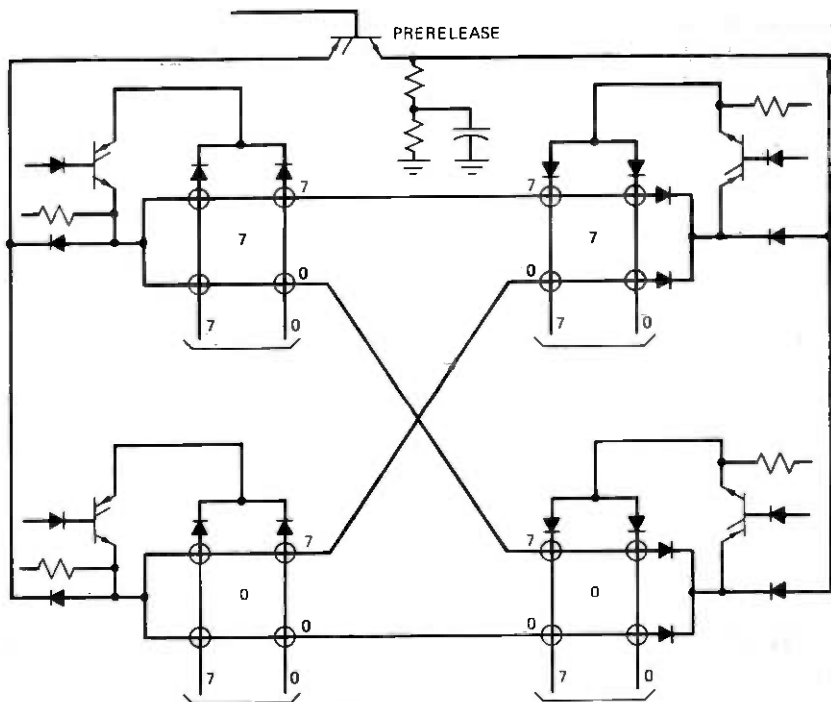


Fig. 8—11A trunk grid.

control connections for the grid. A unique pulse path through the grid is established by selecting one of the eight input and one of the eight output switches. Input and output levels are selected externally to the grid.

The prerelease path utilizes the PR PNP transistor. This path effectively short-circuits the interconnected horizontal control winding of both stages. The prerelease pulse current will enter the grid along the stage 0 vertical control winding determined by the selected input level and switch, and it will exit the grid along the vertical control windings of stage 1 determined by the selected output level and switch. Most of the prerelease pulse current will follow the external short-circuiting PR path. Only "connect" instructions can be executed in this grid.

The 10A grid contains two additional switch packages. These packages each contain four 1-by-8 crosspoint arrays. The crosspoint control windings are connected to provide for individual control. The contacts and control windings are otherwise the same as all other fabric crosspoints. Figure 9 shows these F-contact or test-vertical access-control windings connected in series with each of the output-level-control

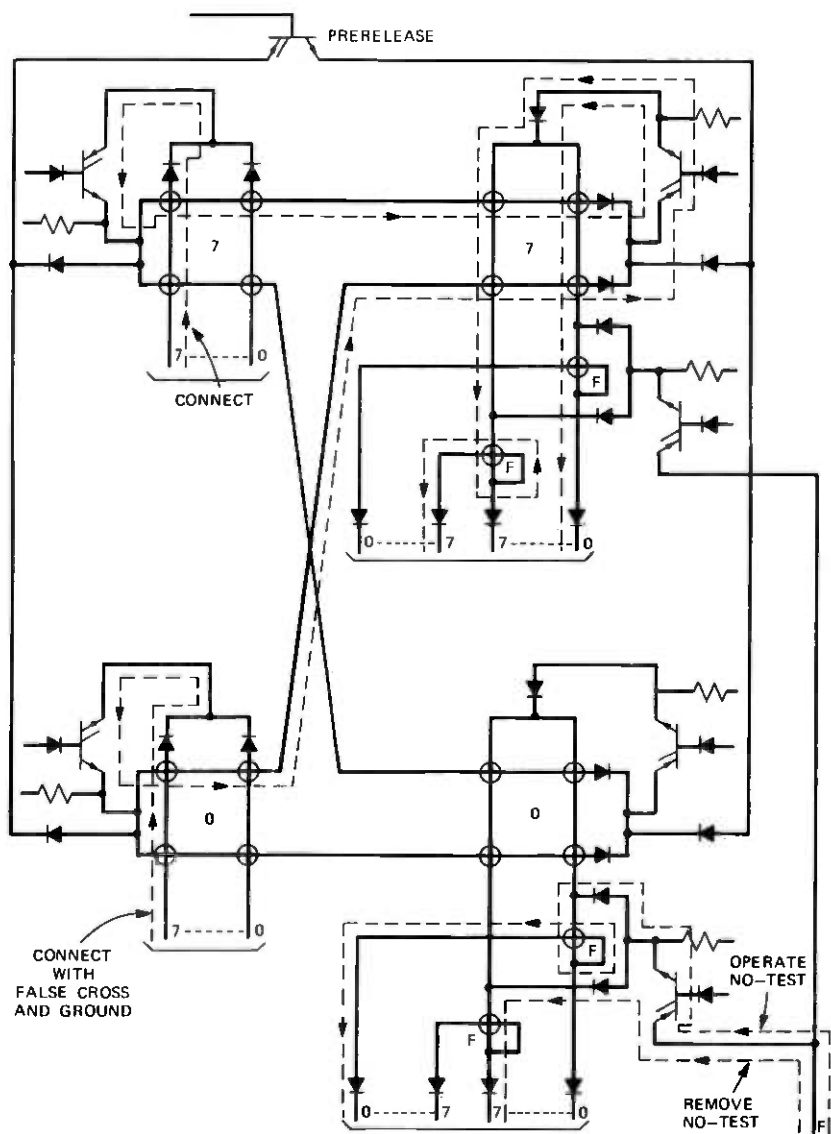


Fig. 9—10A junctor grid.

windings of the grid. When the operate pulse is applied to the terminal designated F, the access contacts can be controlled individually.

A path through a junctor grid can either close or open the F contacts associated with the chosen output level. The two eight-output level-control groups determine the state of the associated test-vertical

crosspoint. In Fig. 9, the F-contact will open if the operate-pulse current exits the grid on a level that belongs to the right-hand group and close it if it exits on a level in the left-hand group.

The prerelease path is the same as in the 11A grid. In addition, the prerelease pulse is forced to exit on an output level that is a member of the release group.

The output switch and the corresponding F-switch PNP transistor have their gate diodes interconnected. All output switch PNPNs have their cathode resistors interconnected and, similarly, the F-switch PNP cathode resistors are interconnected. External termination to ground of one of these two resistor groups will cause the selection of either an output switch or an F-switch.

IV. REMREED NETWORK CONTROL

4.1 Introduction

The different types of network circuits differ mainly in their internal organization and the network fabric they control. This results in differences in the information processing. The basic scheme, control components, and apparatus are the same for all circuits. The general partitioning of functions and sequence of events are the same as in the ferreed controller. The actions or reactions of the remreed controller must be similar to those of the ferreed controller in order to make the remreed switching circuits compatible with existing diagnostic programs, as well as with call-processing programs. Functional names have been maintained. The few items that are not directly compatible with existing programs are primarily physical. Some sensing and monitor functions that are unique to the ferreed electromechanical controller have been added to the remreed controller as artificial monitor points to maintain program compatibility.

The cycle time (20 ms) in the ferreed controller is primarily determined by the operate time, chatter characteristics, and release times of the wire-spring relays. In the remreed electronic controller, the minimum cycle time is dictated by the remreed crosspoint. The need to prerelease and the need to maintain operate current for 3 ms to ensure contact closure and latch consume 5 ms of cycle time. Addressing, testing of the selected path, and circuit restoration consume another 5 ms. An electronic remreed controller could reduce the network cycle time to 10 ms.

A remreed controller performs two types of checks before transmitting its operate-current pulse into a concentrator or grid. The group-check circuitry determines if the state of the translator is valid or not. A nonvalid combination of bits on the peripheral bus or some faults in the buffer register or translator will cause the controller to stop

processing the information. The PNP transistors and diodes in the pulse-path fabric are part of the translator. Component failures and other pulse-path faults will be detected by the group check. In comparison, the ferreed controller terminates in relay windings and is disjunctive from the contacts that form the pulse path. Shorts in the ferreed pulse path are not detectable by the ferreed controller as they are in the remreed network. While group check protects against double pulse-path connections, the controller path check tests for pulse-path continuity and protects against pulse-path opens.

Each controller connects to the central control over the familiar F, S, and T monitor points, used to report failures to the system fault-recognition programs.

The two 38-pair peripheral unit-address busses connect the central processor with each network bay. The peripheral bus-receiver circuit is the interface between the system bus and the local bay bus. The peripheral bus-receiver circuit is an independent circuit in each network bay. It converts the balanced ac system bus to an unbalanced information bus shared by all circuits in the same bay. Similarly, one diagnostic bus-access circuit is provided per bay.

4.2 Circuit organization and information format

Both line-switching circuits and the trunk- and junctor-switching circuits are organized to match the peripheral bus-information format. The existing format was prepared to be efficient for the ferreed electro-mechanical control.

The 36 information bits on the bus are pretranslated into several 1-out-of-4 groups. The different circuits use different group sizes. A line-switching circuit has 16 concentrators. Concentrators 0 through 7 are associated primarily with controller 0, and concentrators 8 through 15 are associated primarily with controller 1. The terms "home" and "mate" are used to indicate control configuration. Concentrators 0 through 7 are home concentrators for controller 0 and mate to controller 1. Each controller contains enough circuit redundancy to control all 16 concentrators in case the mate controller is out of service.

Figures 10 and 11 illustrate in a block diagram the eight 2:1 and eight 4:1 concentrators associated with a controller. The diagrams show P- leads that are gate-driver leads and SN- leads that are cathode-resistor nodes. The peripheral bus path information for the line-switching circuits is all in multiple 1-out-of-4 format. Four bits are used to identify one out of four input switches in a switch group. Another four bits are used to identify a concentrator pair and a third group of four bits identifies the switch group in the pair. This selects the input-switch PNP transistor by providing simultaneous gate-drive and

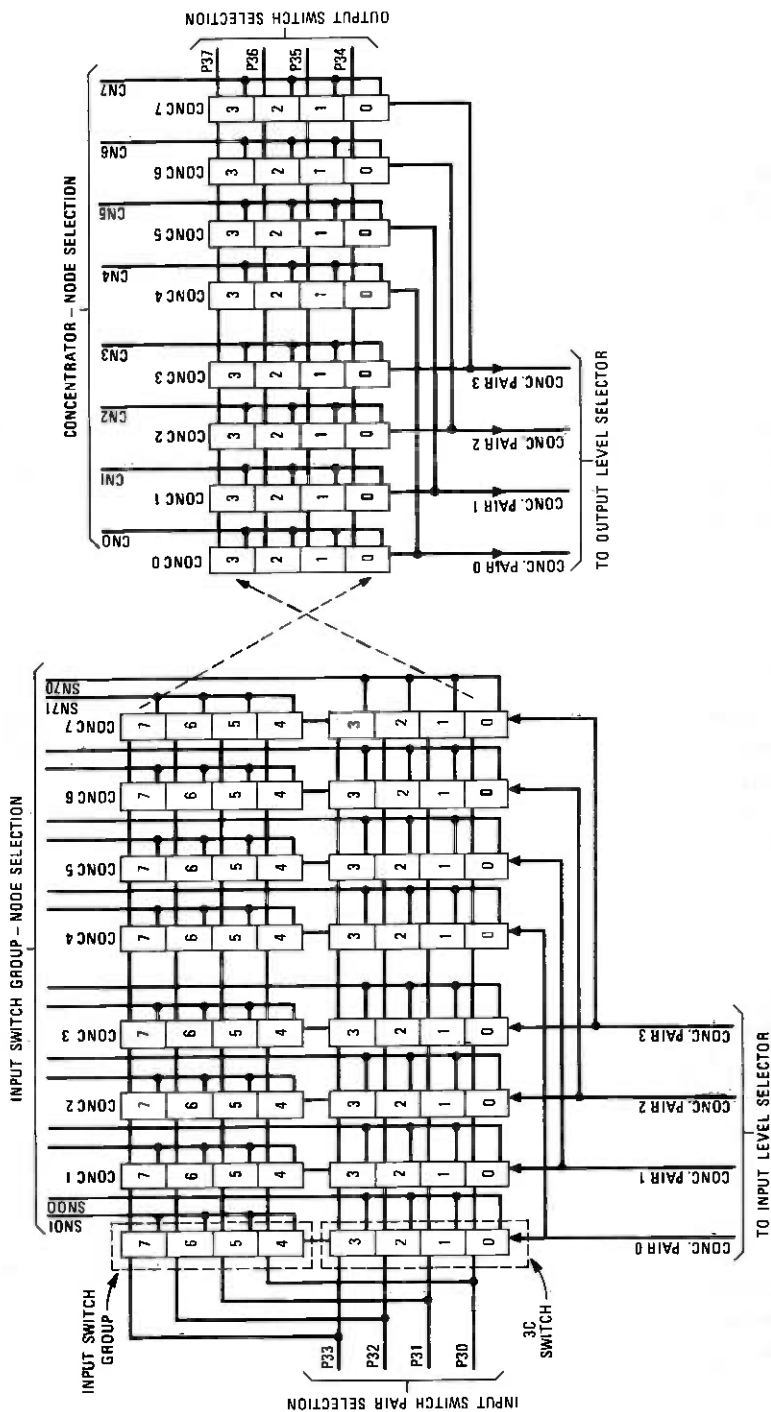


Fig. 10—12A concentrators, concentrator pairs, and input-switch groups.

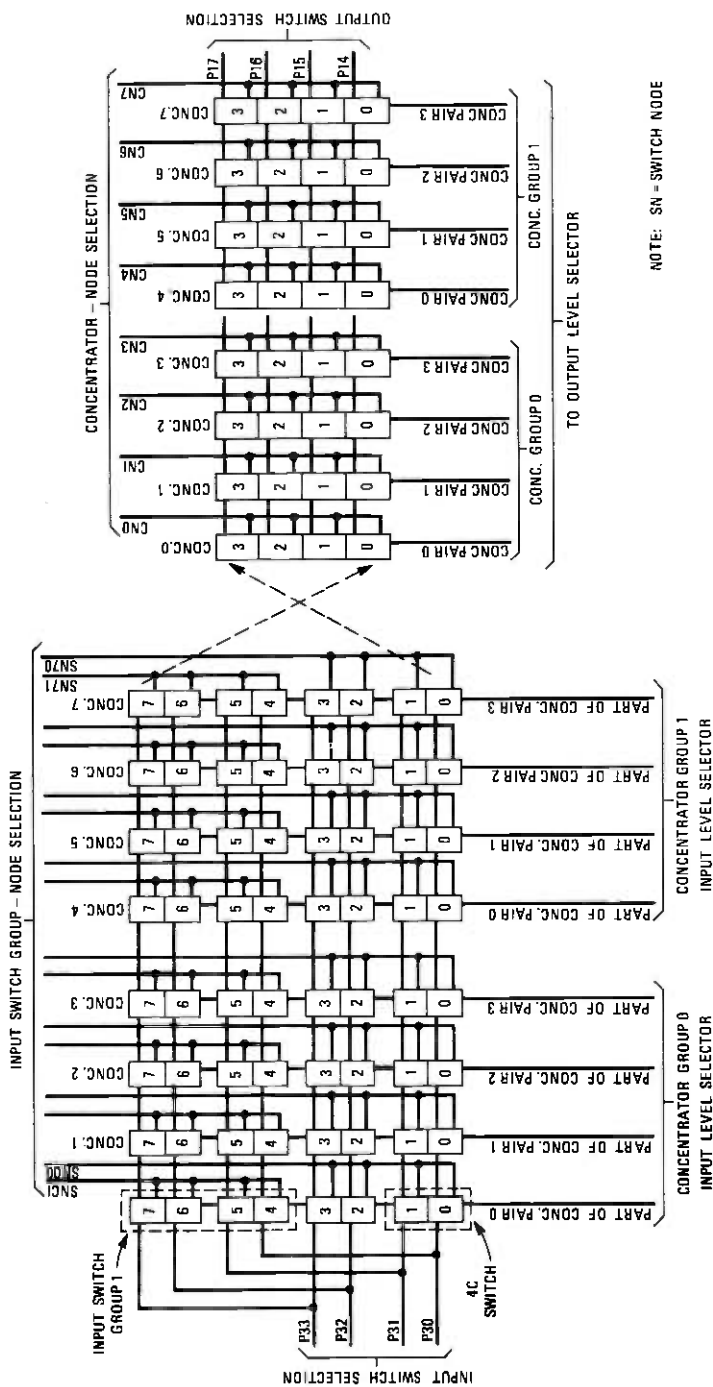


Fig. 11—13A concentrators, concentrator group, concentrator pair, and input-switch group.

cathode-resistor termination. The same information is used to identify the concentrator-node termination (CN-) and an additional four bits identifies the output switch. Selection of input level and output level each require four bits and this selection is illustrated in Fig. 6.

The 4:1 line concentrator has 16 input levels compared to 4 inputs in the 2:1 concentrator. This requires an additional four bits. In the electromechanical ferreed pulse-path selection, the peripheral bus-path information had to be folded to minimize the need for relay contacts. Figure 11 shows the eight remreed concentrators grouped into two concentrator groups; the peripheral bus-path information is folded between the two groups. This means that part of the bus information has a different meaning from another part in relation to the concentrator group selected.

The peripheral bus information for the trunk- and junctor-switching circuits has a multiple 1-out-of-2 and 1-out-of-4 format. This information is translated by the controller into multiple groups of 1-out-of-8 information.

4.3 Register, translator, and buffer circuit

Figure 12 illustrates the register and translator used in the trunk- and junctor-switching circuits. The circuit connects directly to the two local dc bay busses. A 1-out-of-2 and 1-out-of-4 bit combination is registered and translated to a 1-out-of-8 output by a pair of parallel-connected translators. One translator is designated H for home and the other is designated M for mate. This circuit portion is assembled

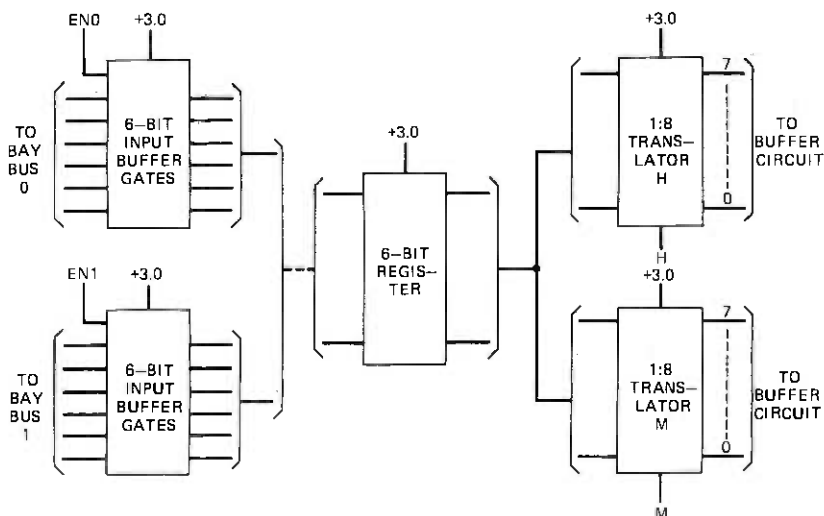


Fig. 12—Register and translator circuit.

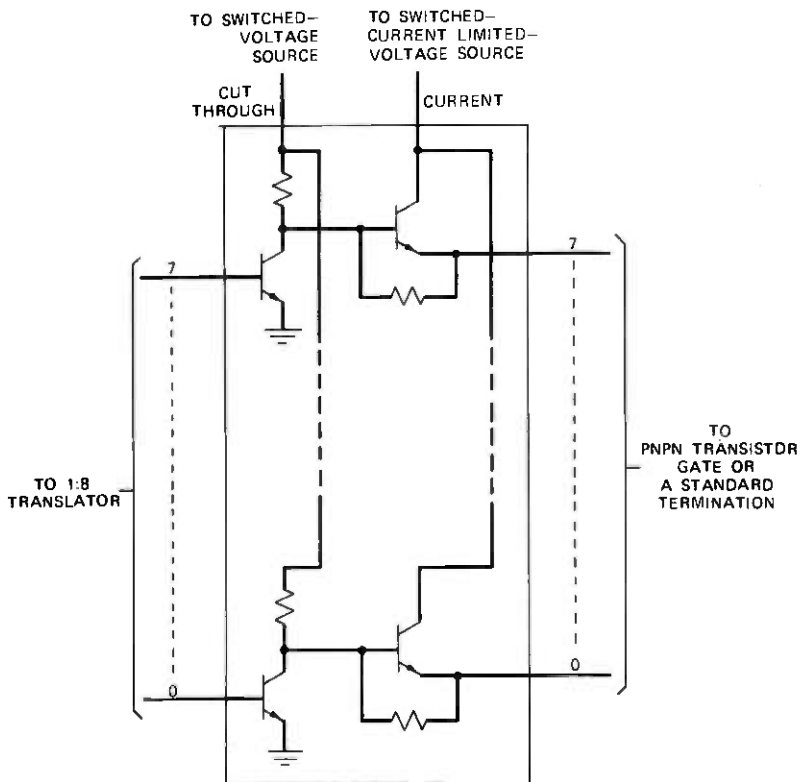


Fig. 13—Buffer circuit.

from integrated-circuit chips. The same ceramic circuit pack contains the output buffer interface shown in Fig. 13. This interface is assembled from junction-isolated-monolithic (JIM) chips that will handle the 12-V gate-driver potential. This interface circuit is connected to an external switched-voltage source which is the group-check circuit. The current in the collector lead designated C is monitored by the group-check circuit, which will report a failure whenever the current demand deviates significantly from the expected value. Cause of such failure can be invalid information on the bus, malfunction of the translator, or a component failure. Failure of pulse-path components in concentrators or grids or physical failures such as opens or shorts are detected as group-check failures.

Four such 1-out-of-8 groups are required to select a path through a grid and each of these groups is monitored by the group-check circuit. These groups select input level, input switch, output switch, and output level.

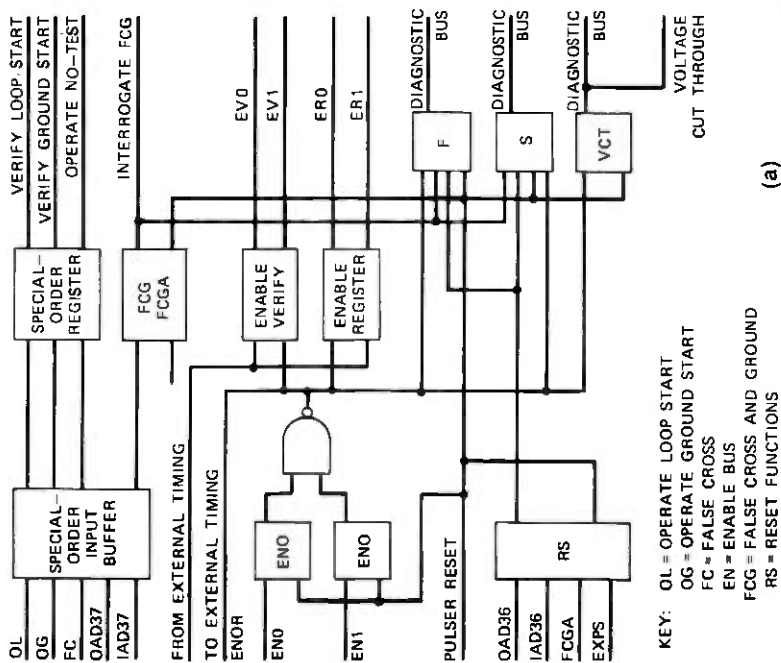
In the line-switching circuits, the 1-out-of-4 information groups are registered without any initial translation. The information is gated directly to the PNP transistor gates in the concentrators and to discrete transistor translator circuits that terminate the cathode-resistor nodes.

4.4 Sequence control

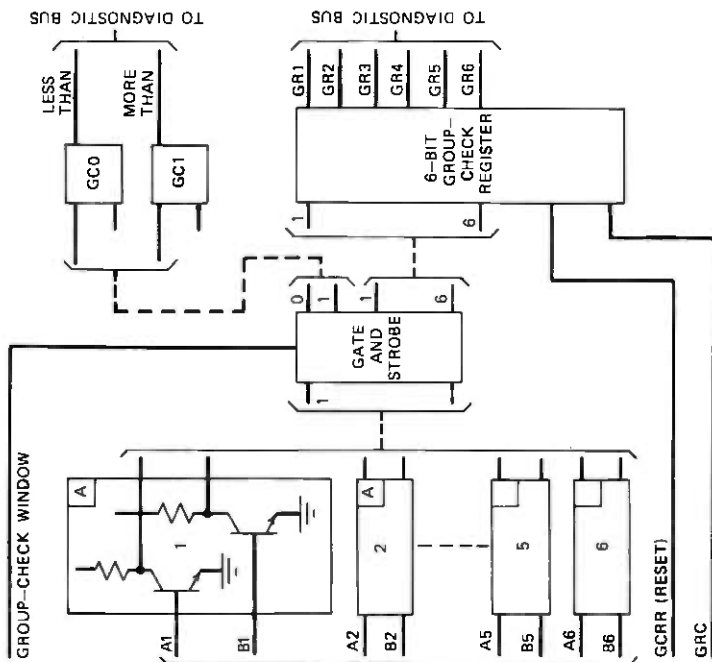
One code of ceramic circuit pack is common to all remreed switching circuits. It contains the controller low-level logic and digital portion of the group-check circuit. It contains 38 integrated-circuit chips and about 900 crossovers. It interfaces with connecting discrete circuit packs where the low-level logic has to convert into 24-V signal levels. External discrete circuits perform differentiations and integration where timing functions are needed. Figure 14a shows this circuit as a functional block diagram.

All inputs are high (+1.0 V) in their idle states. The circuit receives its enable signals from the peripheral bus circuit and enables the register and translator circuit to read information from either bus 0 or 1. It generates and stores the F, S, and vcr signals. vcr stands for voltage cut-through. This is the signal that will start the gating sequence. The circuit further administers the special functions such as: connect with rcc, restore verify loop start, and ground start and operate no-test.

The digital portion of the group-check circuit is shown in Fig. 14b. It connects to the A and B monitor leads associated with the group-check current source. Six such A and B pairs, one pair for each monitor group, are monitored. Two milliseconds after cut-through and the application of gate drive, a strobing signal designated GW reads the state of these monitor pairs. A more-than or less-than failure will cause the GC1 or GC0 flip-flop to become set (GC stands for group check). Both types of failures may occur among the six groups. The group-check logic contains a 6-bit register. Each bit is assigned to a monitor group. The GC1-GC0 pair of flip-flops indicate the type of failure while the other six indicate the location of the failure. The content of this register can be gated onto the diagnostic bus if stg is set. stg stands for "short to ground." It is a special test function in the ferreed controller. In the ferreed network, the stg tests for shorts to ground in the pulse path formed by the wire-spring-relay contacts. stg has no similar meaning in the remreed pulse path. A short in the remreed pulse path will cause group-check failure. However, stg action must be maintained to satisfy the diagnostic program. Therefore, the diagnostic stg action has been made an artificial function that will generate the expected state on the diagnostic bus when the remreed



(a)



(b)

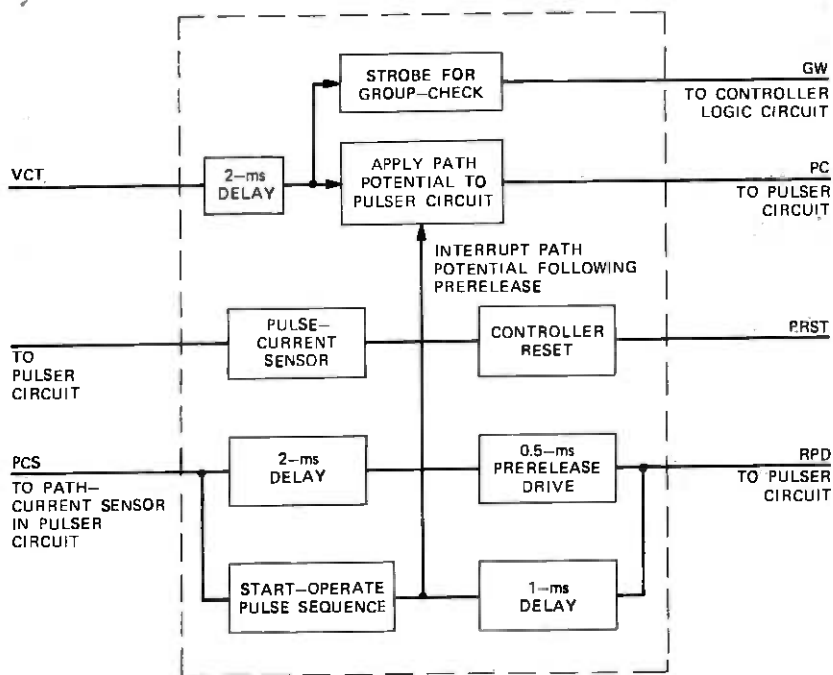
Fig. 14(a) Control diagram. Fig. 14(b) Group-check register.

controller receives a set STG instruction. The set STG has been expanded to also mean: gate the six failure-location bits onto the diagnostic bus. While this is of no use to the present generic diagnostic program, installation test programs have been modified to take advantage of this feature, which aids in locating faults.

All other controller functions are similar to the ferreed controller logic. This one ceramic circuit pack contains the same logic functions as 14 discrete ferreed controller circuit packs.

4.5 Pulser-driver sequence

The pulser-driver sequence starts after strobing for group check is complete. Figure 15 illustrates in a block diagram the actions and sequences that follow VCT. Strobing for group check takes place 2 ms after VCT and the application of all PNP transistor gate drives and cathode-resistor node terminations. This sequence circuit supplies the path potential and the connecting pulser circuit senses the path cur-



KEY: VCT = VOLTAGE CUT THROUGH
 GW = GROUP CHECK WINDOW
 RPD = RELEASE PULSE DRIVER
 PRST = PULSER RESET

Fig. 15—Pulser-driver sequence.

rent. If the path-current sensor detects the pulse-path continuity, the pulse-current-sensor (PCS) input will go high and initiate the pre-release-and-operate pulsing sequence. The controller sequence will stop if the pulser fails to detect a path. The path potential is interrupted for about 1 ms following the prerelease pulse. This is to ensure that the prerelease path has been released prior to the start of the operate pulse. The release-pulse-driver (RPD) signal is used to drive the prerelease pulse in the connecting pulser circuit. The same RPD signal is also used to temporarily remove some of the cathode-resistor terminations during the prerelease pulse. This avoids draining off some of the active pulse current into cathode-terminating resistors.

4.6 Pulser circuit

The pulser circuit provides the power in the pre-release-and-operate pulse. The frame filter stores the energy. Each bay filter serves as many as eight controllers and each intra-bay +24- and -48-V power feeder is supported by a 32,000-mF filter. The remreed network requires only one-fourth as many feeders of half the gauge as does the ferreed network. The energy per pulse is the same in both networks. The pulser circuit and associated path-sensing circuit is shown in Fig. 16. The circuit is a constant current-pulsing source. Voltages of +24- and -48-V are used as the primary driving potential. The pulser is coupled to the pulse path by means of a 1:2.5 step-up transformer. This voltage step-up provides for the pulsing voltage across pulse-path semiconductors and an ohmic resistance of up to 24 ohms. Furthermore, the transformer provides compensation for the primary voltage losses. These losses include ohmic drops in power feeders, power relay contacts, fuses, and connectors, and can become significant, since the primary peak currents are nominally 12 A.

The pulser circuit action starts as the input path current (PC) reaches +24 V. This applies path potential to both output terminals of the pulser. The circuit expects to see a forward termination to ground through the terminated cathode resistor of selected PNP transistors. A forward path current of 120 mA will cause current to flow into the PCS terminal of the sequence circuit through transistor Q6. This current is initially limited by the high input impedance of the sequence circuit. Relay CR (cut-through) will not operate at this time.

The detection of 120 mA of path current starts the pre-release-and-operate-pulse sequence. The path potential and current shut off the gate current to all PNP transistors in the path and the path is held on by the path current. The negative terminal of the pulser remains at the path potential (+24 V). This gives the pulse path a reference termination that is at a voltage higher than any gate potentials. This

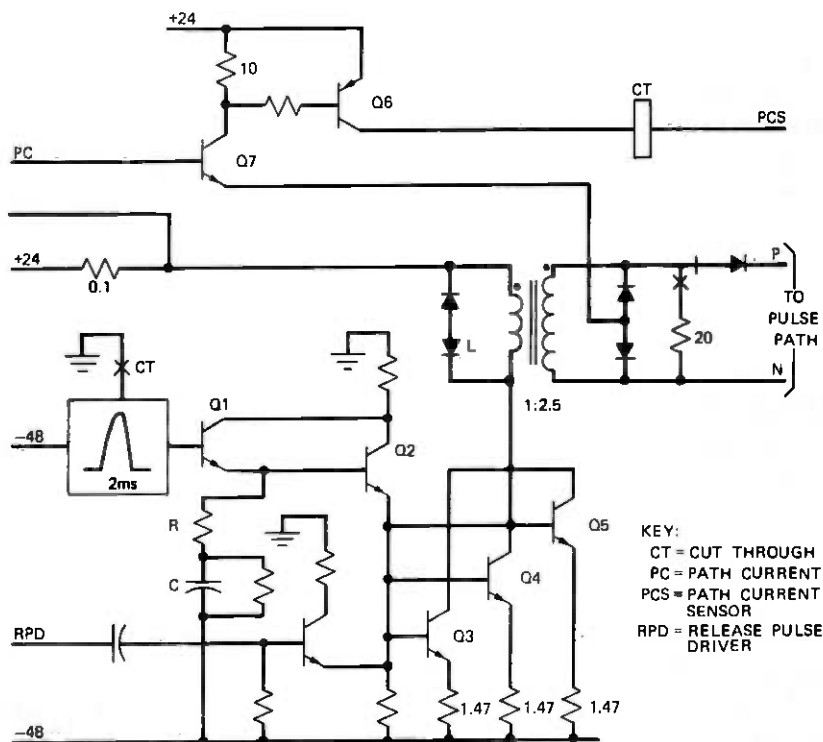


Fig. 16—Pulser circuit.

reference path potential ensures that other gated PNP transistors in the pulse-path fabric will not be "pulled on." The operate pulsing sequence follows the prerelease and interruption of the path potential. The path potential is reapplied and the pulser sequence circuit changes the impedance on the pcs terminal from 10 kilohms to 1000 ohms. This permits the current in the pcs lead to increase and operate relay ct. The ct relay contact will cause a half-wave-sinusoidal voltage wave to be applied to the base of the Q1-Q2 Darlington pair. The sinusoid measures 2.0 ms at the base. The Darlington pair drives three current sources connected in parallel. The rc network associated with emitter of Q1 will modify the trailing edge of the half sinusoid and cause an almost straight-line decay of the operate pulse as indicated in Fig. 2. This gives the operate pulse the required width, minimizes the eddy-current losses, and provides holding and damping forces on the closed contact.

The pulse-current amplitude is regulated to provide 4.2 A at maximum and minimum battery. The maximum expected pulse-path im-

pedance is 24 ohms in series with 1.2 mH. The pulse-path voltage is not affected by the inductance since the pulsing power is all in a frequency band below 1000 Hz.

4.7 Input- and output-level selection

Input level, output level, prerelease, and order-group-pulse steering is performed externally to the concentrators and grids. PNP transistors and their associated standard control components (Fig. 3) are mounted on circuit packs. Figure 17 illustrates the selection scheme used in the 2:1 line-switching circuit. The scheme is the same in the 4:1 line-switching circuit except that the input-level dimension is four times as large.

The selector illustrated in Fig. 17 works directly with the 12A concentrator shown in Fig. 6. The input levels are numbered from 0 to 7. The four lower-numbered levels are used with all orders that require the cutoff contacts to be opened. The four higher-numbered levels are used with all orders that require the cutoff contacts to close. In this example, the concentrator pair 0 is used and consists of concentrators 0 to 4. These circuits are dedicated to the concentrators and can be accessed by both controllers. The cathode-resistor nodes have been given a designation that contains one or more digits. The digits correspond to the order number that will cause the node to be terminated to ground.

These groups of four PNP transistors are preceded by an order-group pulse-steering stage. PNP transistors OR1 and OR4 steer the pulse to all input-level-select groups that will cause the cutoff contacts to open. Transistors OR5 and OR7 connect to groups that will close the cutoff contacts. OR2 does not require an input-level selection and only orders 1, 2, and 5 require an output level to be selected.

For orders 1 and 5, the prerelease path consists of two parallel paths. Half of the pulse current will enter the release cutoff path, follow the selected input-level vertical-control windings, and exit through OR47 PNP transistor. OR4 is made active during the prerelease interval. The second half of the prerelease pulse enters the concentrator at the anode of the selected output switch through PNP PRI and exits the concentrator along the vertical in the output switch associated with the selected output level.

For all orders that require the cutoff contacts to close, the input-pulse-steering path is modified to add the release path in parallel. The resistor in series with the operate path will ensure that most of the prerelease current will follow the cutoff release path to the concentrator.

The line-switching circuits use this split prerelease path scheme rather than the horizontal shunt path used in the trunk- and junctor-

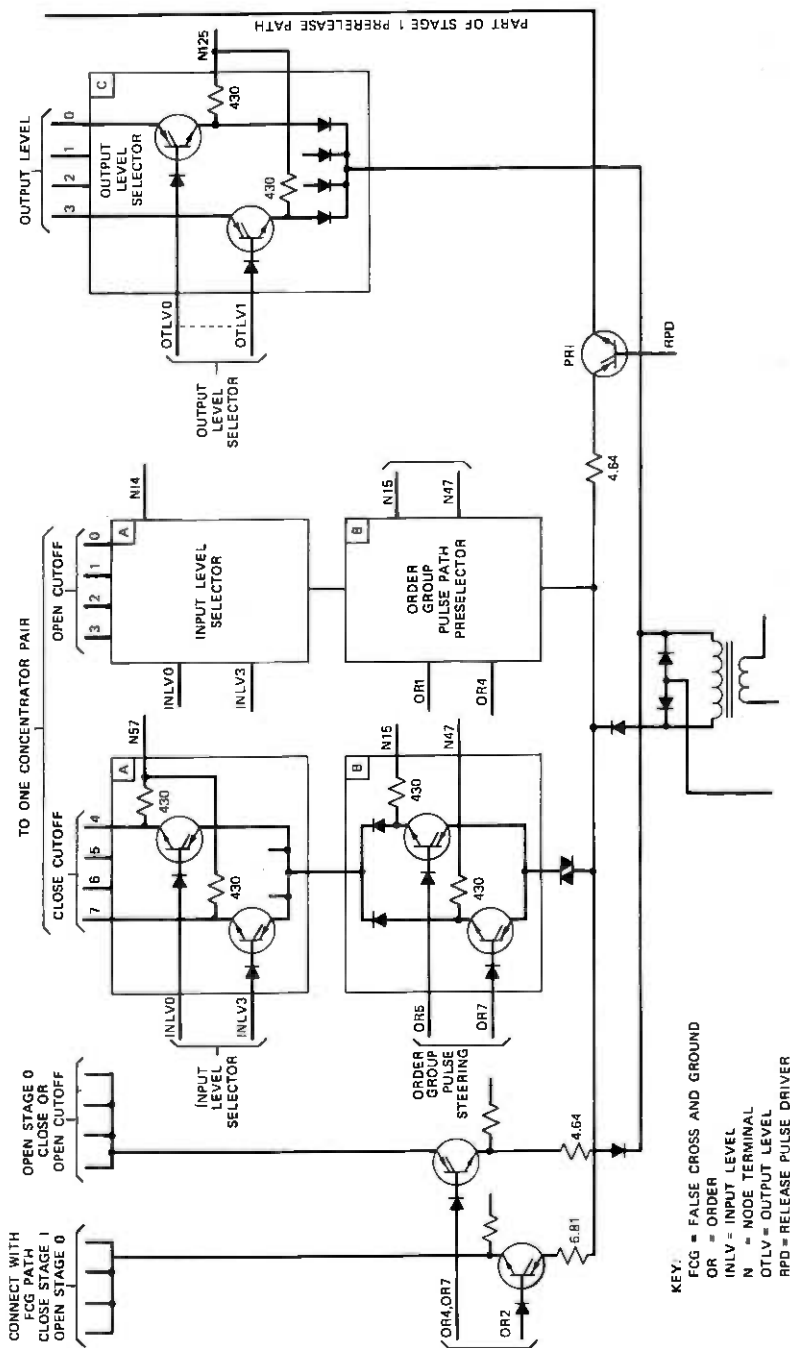


Fig. 17—Line-switching circuit: input-output path selection for 2:1 concentrators.

switching circuits. The horizontal-pulse-path impedance in the concentrators is too low to make a horizontal shunt practical.

4.8 Test-vertical functions

Figure 18 illustrates the familiar test-vertical-access function. A test vertical is common to a pair of 10A grids. A pair of 5D switch packages in each 10A grid provides access to all junctor terminals. The access contacts can be controlled as part of a path through the grid or individually. The loop-start-restore and ground-start-restore verify functions use reed relay contacts to apply the two resistive terminations.

The false-cross-and-ground test is used during call processing to test the integrity of each network path prior to the application of talking battery. Battery and ground are applied in the reverse sense (battery on tip, ground on ring) on the test-vertical pair which are connected to the network path through the contacts of the 5D switch.

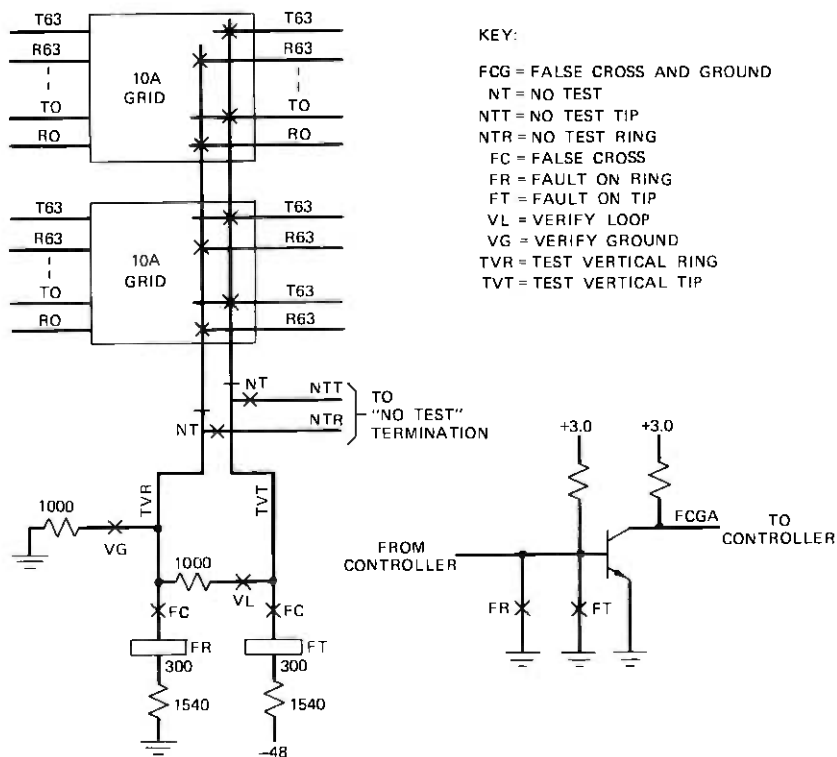


Fig. 18—Test-vertical access for one pair of grids.

A pair of relays, *FR* and *FT*, wired in series with the test vertical are used to detect the current which flows in the event of a cross to an active path or a ground in the path under test. The *FCG* test fails when either relay operates.

V. SUMMARY

The remreed network and its electronic control is a merger of both old and new electrical and physical technologies. The physical partitioning has been made to agree with a logical partitioning of the controller functions. The remreed network controller was designed from standard, available, Bell System devices. No special chip or device was designed specifically for this project. This permitted the design, construction, evaluation, and introduction into the field to be made in a very short time. With all control functions defined, the door has now been left wide open for on-going cost-reduction efforts. This is taking place both at the device and *IC* level. The initial choice of a pulse-path fabric diode has been replaced by a diode designed specifically for this use at one-quarter the cost. The *PNP* transistor has been given a new encapsulation to reduce its cost. The relatively complicated and expensive 36-chip ceramic circuit pack used in the register and translator circuit has been redesigned using a new integrated-circuit technology. This new equivalent circuit pack contains four chips mounted on a one-quarter size piece of ceramic at one-third the cost. Other functions that presently are performed using discrete devices are candidates for eventual replacement by integrated circuits, which will result in considerable reduction in material cost.

VI. ACKNOWLEDGMENTS

The authors wish to thank Mr. G. Haugk and Mr. R. W. Ketchledge for their continued support and technical contributions. The development of the remreed network was an integrated effort involving all of the authors of this issue's articles. Their assistance in formulating the electrical and mechanical requirements, in evaluating the designs, and in solving a number of problems encountered in the design is deeply appreciated by the authors.

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Remreed Switching Networks for No. 1 and No. 1A ESS:

Remreed Line Scanner

By J. C. KENNEDY, W. A. LISS, and J. R. SMITH

(Manuscript received October 29, 1975)

A new line scanner design was undertaken as part of the No. 1 ESS remreed network development. The new design reduces frame and unit wiring, improves maintenance, lowers manufacturing cost, and occupies less space. The new scanner has been designed to be completely compatible with all existing No. 1 ESS system programs to permit its use in growth applications as well as in new machines.

I. INTRODUCTION

The No. 1 ESS line scanner is used to detect originations on subscriber lines. The original design, used in ferreed line link networks, is described in Ref. 1. The new scanner design takes advantage of the remreed network packaging and interconnection technologies to achieve a significant reduction in frame and unit wiring, manufacturing costs, and floor space by integrating the line supervisory element with the connectorized network fabric. Additional cost and space savings, reduced wiring, and improved reliability are achieved through the use of an integrated-circuit controller. The new scanner is referred to as the remreed line scanner because of its physical packaging with the remreed network fabric.

1.1 Scanner function

Most of the No. 1 ESS scanning logic is built into the scan programs. A scan request is generated in the central control in small offices or in the signal processor in large offices and transmitted to the scanner control over the peripheral unit-address bus. Each scanner in an office monitors the state of 1024 scan points, organized in 64 rows of 16 scan points in a particular row specified by the order. The scanner interrogates the 16 points specified by the order received over the peripheral unit-address bus and responds with a 17-bit message on the scanner-

answer bus. The first 16 bits in this message give the states of the scan points in the selected row with the convention of 0 indicating off-hook and 1 indicating on-hook. The seventeenth bit, called all-seems-well (ASW), provides the principal scanner-maintenance function. An ASW of 1 indicates successful scanner-control operation.

1.2 The 2A ferrod

The scan element in the new scanner design is the 2A ferrod, basically a repackaged version of the 1B ferrod (used in the existing scanner) to permit its mounting within the remreed-network first-stage switch package.² The 2A ferrod, like its predecessor the 1B, consists of a ferrite rod (or stick) around which is wound a pair of control windings. The control windings are wired in series with the subscriber's loop in such a way that sufficient loop current magnetically saturates the ferrite rod.

The ferrod state is determined by a single-turn interrogate winding and a single-turn readout winding threaded through a pair of holes in the center of the ferrite rod. The ferrod functionally acts as a transformer whose magnetic coupling between the interrogate and readout windings is controlled by current in the control windings.

Interrogation is accomplished with a bipolar current pulse through the interrogate winding. If the subscriber line is on-hook, only loop leakage current, less than 5.5 mA, should flow through the control windings. This permits energy from the interrogate pulse to couple through the unsaturated ferrite rod to the readout winding where an output is detected as a logical 1 by the detector circuit. The bipolar current pulse consists of a reset portion and an interrogate portion of opposite polarities. This assures full magnetic switching of the ferrite material during interrogation.

When the subscriber goes off-hook, loop current in excess of 10 mA flows through the control windings, magnetically saturating the ferrite rod. The interrogate pulse energy is no longer coupled to the readout winding, and a logical 0 is detected.

1.3 Subscriber-loop wiring

The line ferrod is wired to the subscriber's loop through a pair of remreed cutoff contacts. These contacts are closed whenever the line is in the idle state, enabling the line scanner to detect a service request. Once the service request has been detected (line off-hook) and reported to the system, the cutoff contacts are opened and supervision is transferred through the network to a trunk scanner.

There are two methods of wiring subscriber loops to their line ferroids. The normal method, called loop start, is used on most ESS

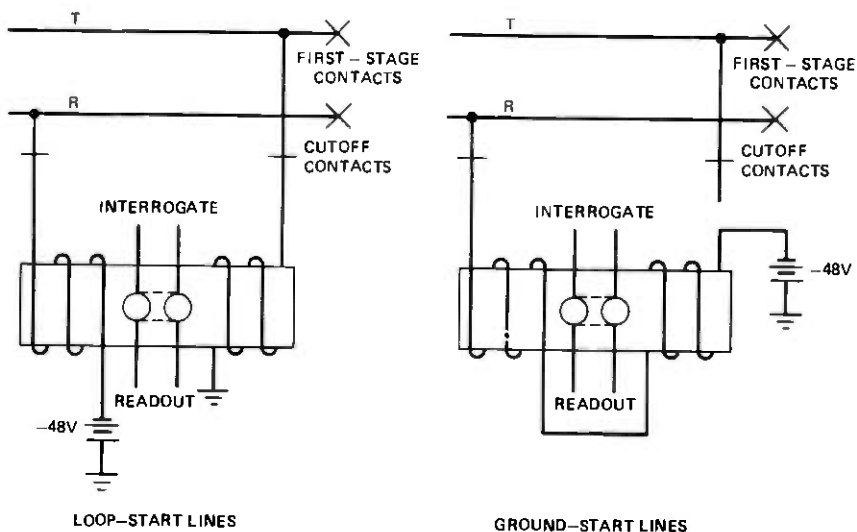


Fig. 1—Ferrod wiring options.

lines. In this arrangement, the line ferrod supplies battery to the ring and connects the tip to ground (see Fig. 1). Loop-start lines make use of the balanced ferrod windings to prevent the scanner from responding to longitudinal currents that may be induced in the outside plant.

Some coin and PBX lines require ground-start wiring of their line ferrods. In this arrangement, both ferrod windings are connected in series with the ring conductor, the tip conductor being left open in the idle state. On originating calls, the PBX line equipment grounds its ring conductor, saturating its line ferrod. On terminating calls, the line is switched by ESS to a loop-supervised trunk circuit, which furnishes a ground on the tip conductor, signaling seizure to the PBX.

All line ferrods are wired loop-start initially. The ground-start wiring option is provided on half the lines and is applied where needed during installation.

1.4 Scanner organization

The functional arrangement of the scanner controller and ferrods is shown in Fig. 2. The 2A ferrods are the elements of a 1024-point array. The matrix is arranged in 64 rows of 16 ferrods. The interrogate windings of the 16 ferrods in each row are wired in series to a pulse transformer from which the bipolar reset-interrogate pulse sequence is delivered when that row is selected. The readout windings of the 64 ferrods in each matrix column are wired to a readout circuit.

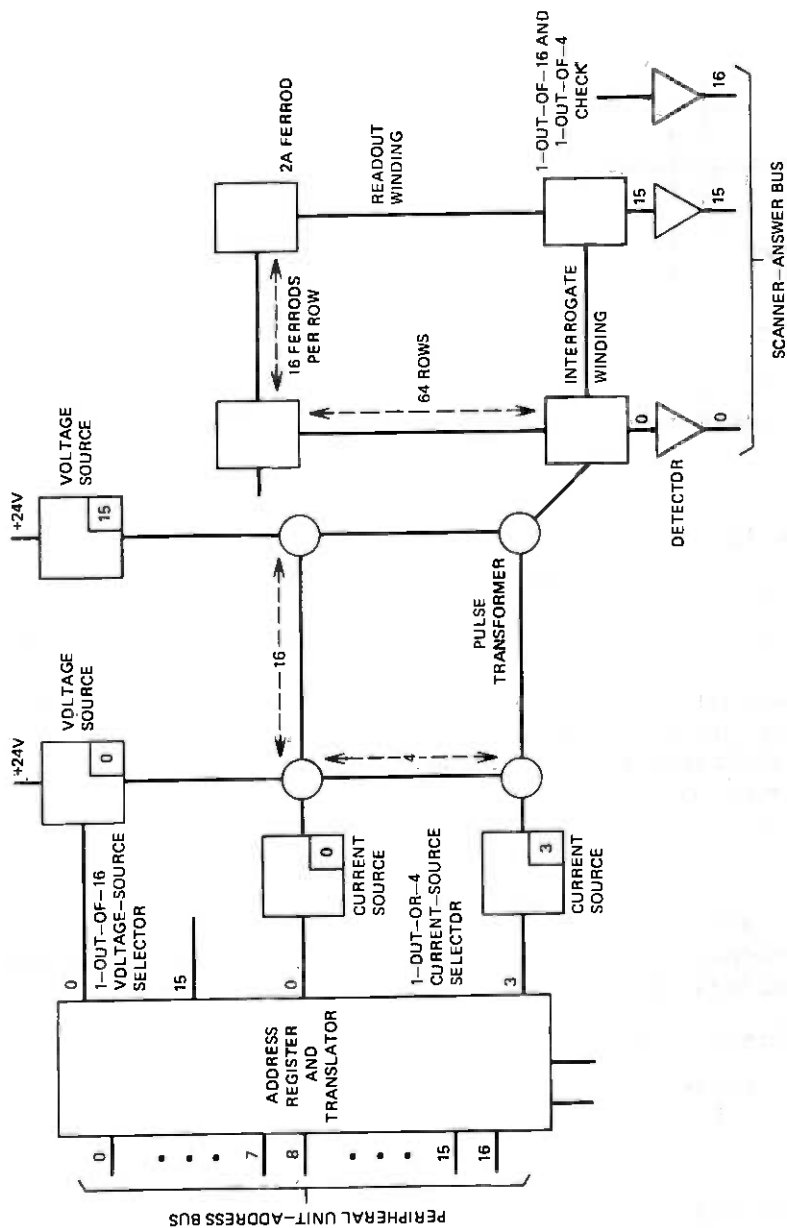


Fig. 2—Scanner block diagram.

The ferrod matrix itself is the only part of the scanner that is not duplicated. Each row contains the scan elements for the 16 lines that share the same first-stage switch. The line concentrators (12A or 13A grids*) are arranged so that their removal affects only the two or four rows of lines equipped in the concentrator.

The interrogate and readout circuits are completely duplicated. Under normal conditions, one scanner controller is active and the other is standby. Four enable circuits from the central pulse distributors are provided to select the peripheral unit-address bus and scanner controller. The enable pulse is used to open an address window, during which address information is received over the peripheral bus. The received address is stored and translated by the controller.

Each controller is also equipped with 16 readout circuits that receive information from the ferrod matrix readout windings. The readout information is then gated from the active controller to both scanner-answer buses.

II. PHYSICAL DESIGN

Many manufacturing economies achieved in the new scanner design are the result of new approaches to mounting and interconnecting the scanner components.

2.1 The remreed line-switch package

In the ferreed line-switch frames, the first stage of switching and line-cutoff switches are mounted in the same equipment unit and connected by unit wiring. The ferrod elements are mounted in a separate unit and connected to the various lines by frame cable. The remreed line-switch frames are organized so that the first stage of switching, cutoff contacts, and line ferrods for 16 lines are equipped within the switch package, replacing the unit and frame wiring with printed-circuit interconnection technology. To accomplish this, the 2A ferrod was packaged as an individual unit and is mounted and soldered in the switch-package circuit board.

Half the line ferrods are wired in the loop-start configuration on the switch printed-circuit board. The remaining half may be externally strapped in either the loop-start or ground-start configurations.

2.2 Connectorization

Since the 2A ferrods are mounted in the line-switch package, they are a physically integral part of the switching fabric. The 32-line 12A concentrator used for high-traffic applications and the 64-line 13A concentrator used for regular-traffic applications are fully connectorized

* References 3 and 4 describe the line concentrators.

replaceable modules. Bypass resistors are provided in the connectors to maintain the integrity of all readout loops while a concentrator is being replaced. The remaining scanner circuits are equipped on completely duplicated plug-in circuit packs.

2.3 Frame physical design

Two remreed frame designs use the new scanner. The 2:1 remreed line-switch frame contains two 2:1 concentration-ratio line-switching circuits and a line-scanner circuit. This frame provides the line scanner, cutoff contacts, and first two stages of switching for 1024 lines. It is used in high-traffic applications (exceeding about 4 ccs/line) where an overall 2:1 or 3:1 concentration ratio is needed.

The 4:1 remreed line-switch frame contains two 4:1 concentration-ratio line-switching circuits and two line-scanner circuits equipping 2048 regular traffic lines with their scanner, cutoff contacts, and first two stages of switching. This frame is used where an overall 4:1 or 6:1 concentration ratio is called for (usually below 4 ccs/line). In either case, a single bus unit, mounted at the top of the frame, provides the interface between the peripheral unit-address busses, scanner-answer busses, central pulse distributors, and the scanner and network controllers on the frame.

III. SCANNER-CONTROL CIRCUITS

As illustrated in Fig. 2, the scanner-control functions are divided into four sections: address register and translator, interrogate circuits, readout circuits, and maintenance functions.

3.1 Address register and translator

Scanner address information is sent from the processor to a scanner controller over a peripheral unit-address bus. The scanner controller and bus choice is made by selecting one of four enable pulses from the central pulse distributor. The arrival of an enable pulse at a scanner opens an address window gating information from the selected bus into the selected control register. A normal scan order contains 16 bits consisting of two 1-out-of-8 codes. These data are translated into a 1-out-of-4 and a 1-out-of-16 selection used to drive the analog portion of the scanner. The register and translator circuits associated with one controller are located on a single circuit pack consisting of 1A (137-type) silicon-integrated circuits interconnected with thin-film technology on a ceramic substrate.

3.2 Interrogate circuit

The interrogate circuit (functionally illustrated in Fig. 2) consists of 16 voltage sources, 4 pairs of current sources, and a 16-by-4 array

of 64 three-winding transformers, each corresponding to a ferrod row. The 1-out-of-16 selection from the translator activates one of the voltage sources, while the 1-out-of-4 selects one of the pairs of current sources. The details of the voltage source, current source, and pulse transformer are shown in Fig. 3. One current source in the pair generates the first or reset portion of the current pulse which is driven through a single transformer winding and delivered to one of the 64 ferrod rows, resetting the magnetic state of the ferrite rod. The second current source in the selected pair then generates a similar current pulse through the second winding of the same transformer. The sense of this winding is opposite that of the first, and the result is an opposite-polarity, interrogate current pulse delivered to the ferrod row. Any of the 16 ferrods in the selected row that is not saturated (by loop current corresponding to an off-hook line) is thus switched, producing an output signal across its readout loop.

3.3 Readout circuit

The readout circuit has the function of detecting an output from an interrogated, unsaturated ferrod and delivering a logical 1 over the scanner-answer bus to the processor. The circuit consists of two analog detector-amplifiers and a digital integrated-circuit logic chain that strobes the detector outputs, stores the resulting 1 or 0, and then gates the result onto both scanner-answer buses. The readout circuit of a controller is illustrated in Fig. 4. As previously mentioned, the readout circuits are duplicated. The strobing technique prevents noise present during the switching of interrogate and readout currents from being falsely interpreted as logical 1s.

3.4 Maintenance functions

The principal scanner fault-detection mechanism is the all-seems-well (ASW) detector. This feature, used on every scanner order, verifies that one, and only one, scanner row has been selected, reset-pulsed, and interrogate-pulsed. Failing to reset or interrogate a row, or resetting or interrogating multiple rows, inhibits the generation of the ASW signal. The ASW signal is normally delivered, along with the 16 information bits (corresponding to the state of the 16 interrogated ferrods), to the processor over the scanner-answer bus.

A seventeenth bit is also provided in the address field (in addition to the 16 address bits) to permit the system to check all readout circuits. This maintenance bit is sent during diagnostic testing to activate special circuitry that generates a current pulse in each readout loop. The 16 readout circuits should detect current flow and report logical 1s back on the scanner-answer bus. An open readout loop or a

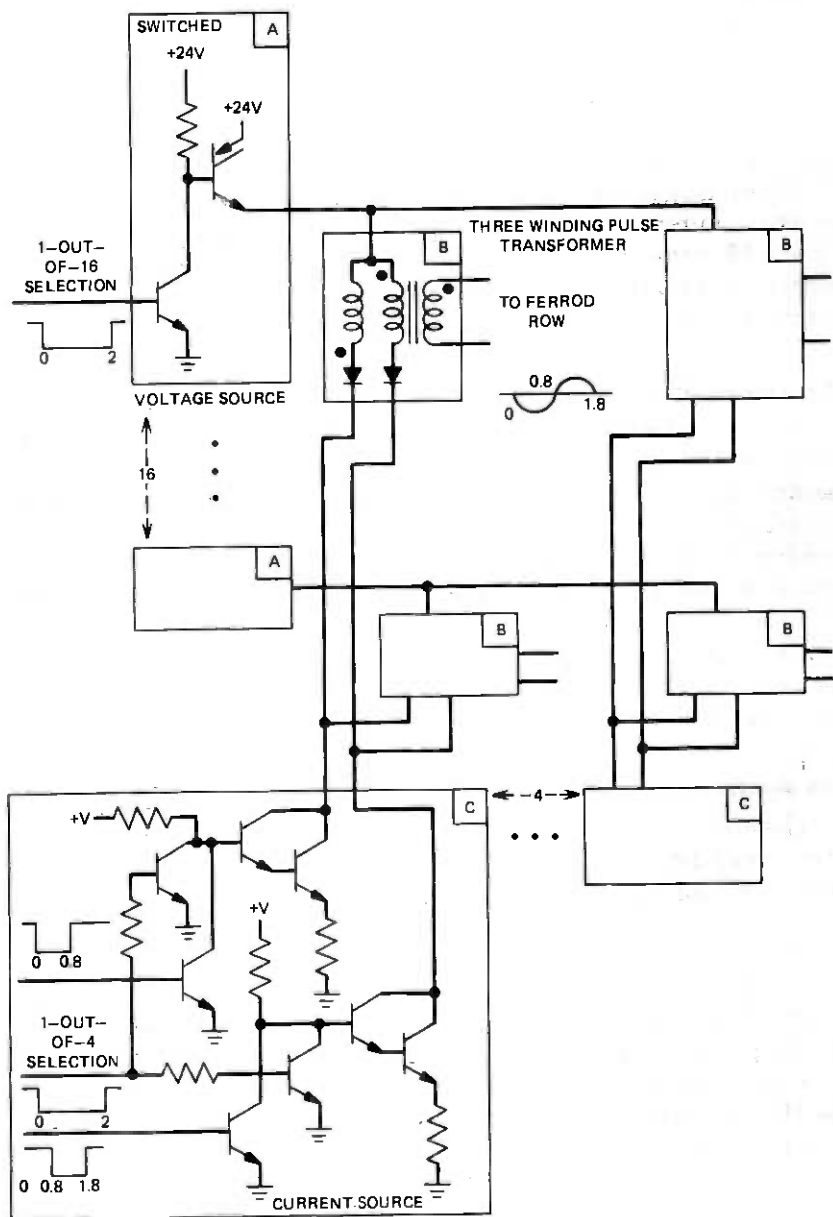


Fig. 3—Interrogate circuit.

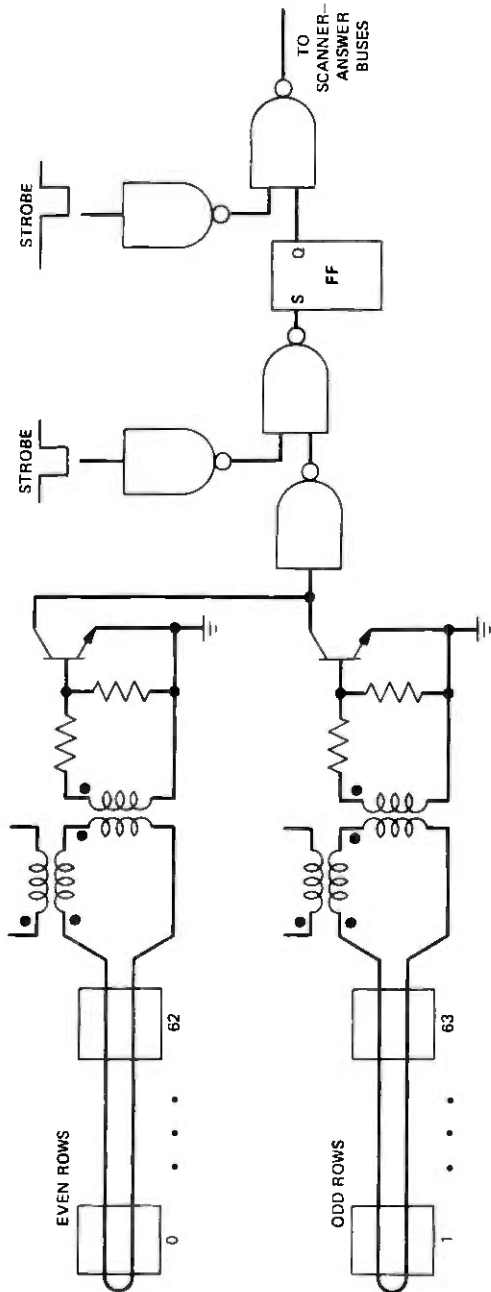


Fig. 4—Readout circuit.

faulty detector results in a logical 0 being returned on the scanner-answer bus.

IV. ADDITIONAL SCANNER FEATURES

In addition to the original design objectives stated at the beginning of this paper, the new scanner provides improved noise margin and higher-speed operation than the existing scanner, both enhancing system performance.

The existing scanner resets the ferrod rods in a scanner row after completion of an interrogation. The interrogate-reset sequence has the disadvantage that essentially all changes of state take place in the interval between a reset and the following interrogation. An off-hook to on-hook transition removes the control winding current that held the ferrod saturated in the off-hook state, but does not switch the ferrite rod. Consequently, the rod is left in an intermediate state. The following interrogate pulse partially switches the rod, producing a low-amplitude output. The detector threshold in the existing scanner is adjusted to be able to detect this low-amplitude output signal.

The new scanner uses a reset-interrogate sequence, always resetting immediately prior to interrogation. As a result, every unsaturated ferrod makes a full transition on interrogation, generating a full-amplitude output signal. This permits the detector threshold to be set at full amplitude in the new scanner, enhancing the noise margin over that in the existing scanner.

The new scanner was also designed for a worst-case response time (the longest time from receipt of address to scanner answer) of 2.3 μ s and a recovery time of 4.5 μ s to permit its use at the 7- μ s scan interval planned for 1A ESS. This improvement in the scan rate over the 11- μ s scan interval used in No. 1 ESS will help increase system call capacity.

V. ACKNOWLEDGMENTS

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Remreed Switching Networks for No. 1 and No. 1A ESS:

Physical Design of Remreed Switching Networks

By H. J. KLEIN

(Manuscript received November 11, 1975)

Five new switching frames have been designed for use in No. 1 and No. 1A ESS central offices. These new frames utilize the recently developed remreed sealed contact and are equipped with electronic network controllers. The new remreed switching frames occupy approximately one-quarter the floor space required for the ferreed switching frames that they replace. Other design features include improved maintainability, reduced installation interval, and reduced cost. This paper describes some of the more significant physical design features incorporated in these five new frame designs.

I. INTRODUCTION

Manufacture of the ferreed switching frames originally designed for use in No. 1 ESS central offices^{1,2} is being phased out in favor of the new remreed switching frames. These five new codes of remreed frames are shown in Figs. 1 through 5 and provide the basic building blocks from which all line link and trunk link network configurations are constructed. These new frames make use of the recently developed remreed sealed contacts,³ new all-electronic network controllers, and the new 1A technology packaging hardware.^{4,5} Basic line link and trunk link network switching functions performed by the remreed frames were constrained⁶ to be identical to those performed by the ferreed frames they replace.

Basic physical design concepts for the line link network configurations were developed at the same time the remreed trunk link network was being designed. This approach enabled us to take advantage of the commonality of apparatus and hardware piece-parts such as circuit packs, control units, mounting plates, grid-support hardware, wiring troughs, etc. The apparatus and piece-part commonality achieved be-

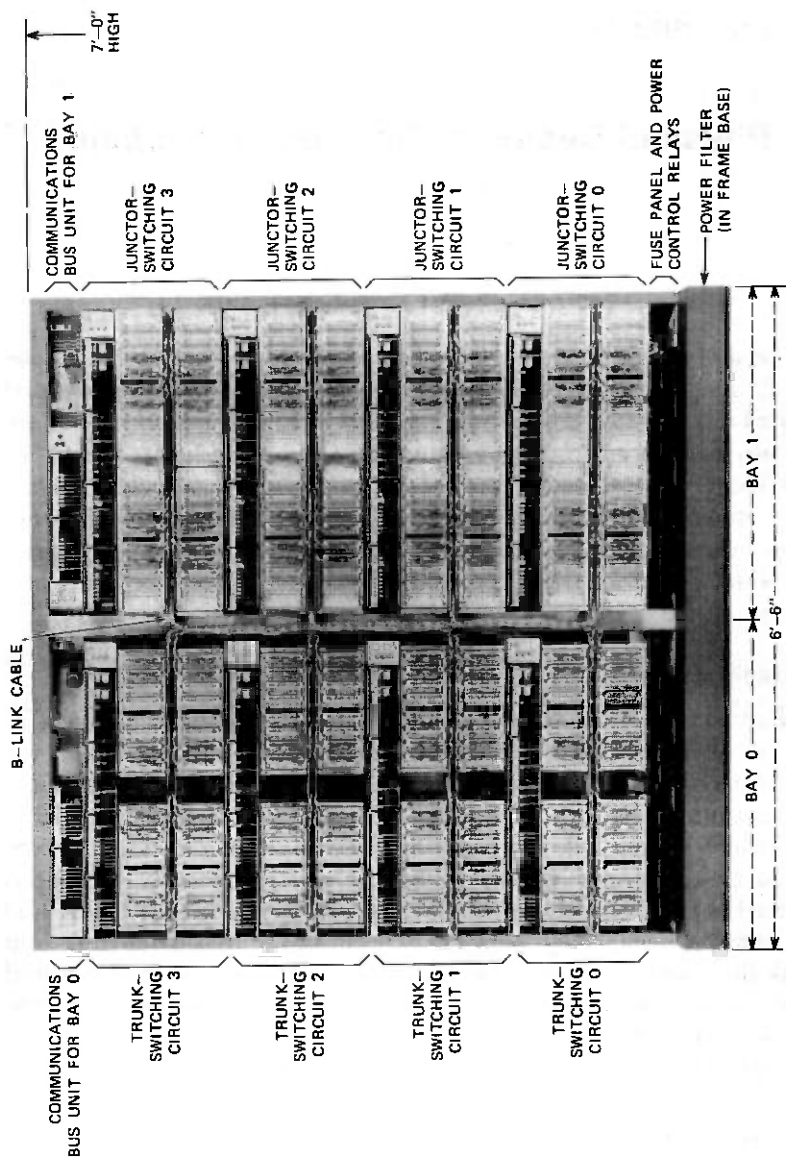


Fig. 1—Trunk link network frame (1024 trunks with 1:1 trunk-concentration ratio).

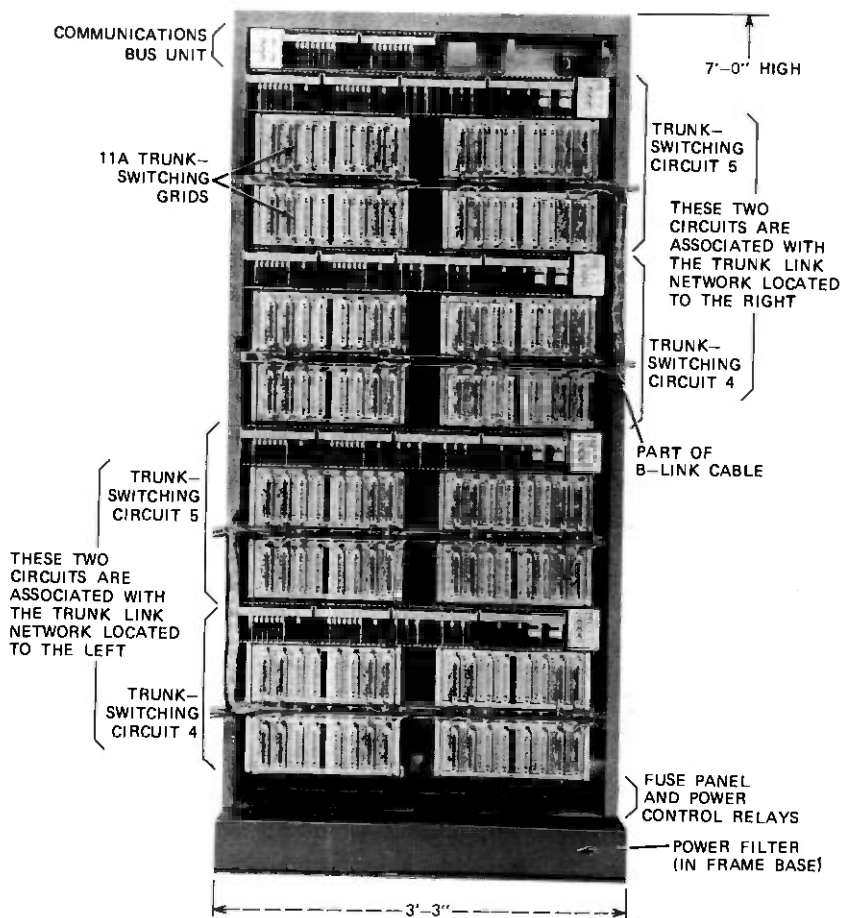


Fig. 2—Trunk-switching frame (shown fully equipped to provide additional trunk-switching circuits required for two different $1\frac{1}{2}$:1 trunk link networks).

tween the five remreed frame codes becomes quite obvious when Figs. 1 through 5 are compared.

II. TRUNK LINK NETWORKS

2.1 Trunk link network frame

Remreed trunk link networks are available in three basic configurations. These are the 1024 two-wire trunk link network with a 1:1 concentration ratio, the 1536 two-wire trunk link network with a $1\frac{1}{2}$:1 concentration ratio, and the 2048 two-wire trunk link network with a 1:1 concentration ratio.¹ The remreed trunk link networks represent a 4:1 space saving over the ferreed networks they replace. Other

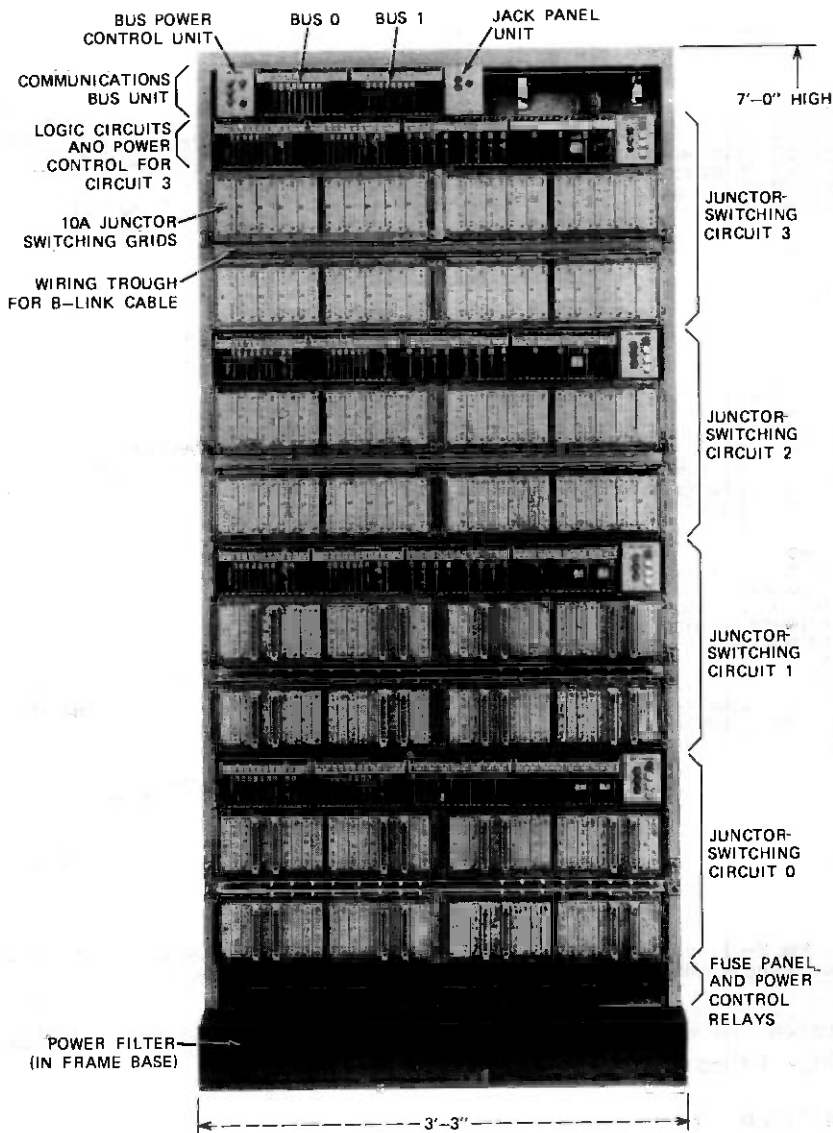


Fig. 3—Junctor-switching frame.

design features include improved maintainability, reduced installation interval, and reduced cost. The 6-ft, 6-in. TLN frame shown in Fig. 1 is the basic building block for the three trunk link network configurations. Some more significant physical design features incorporated in this equipment unit are as follows.

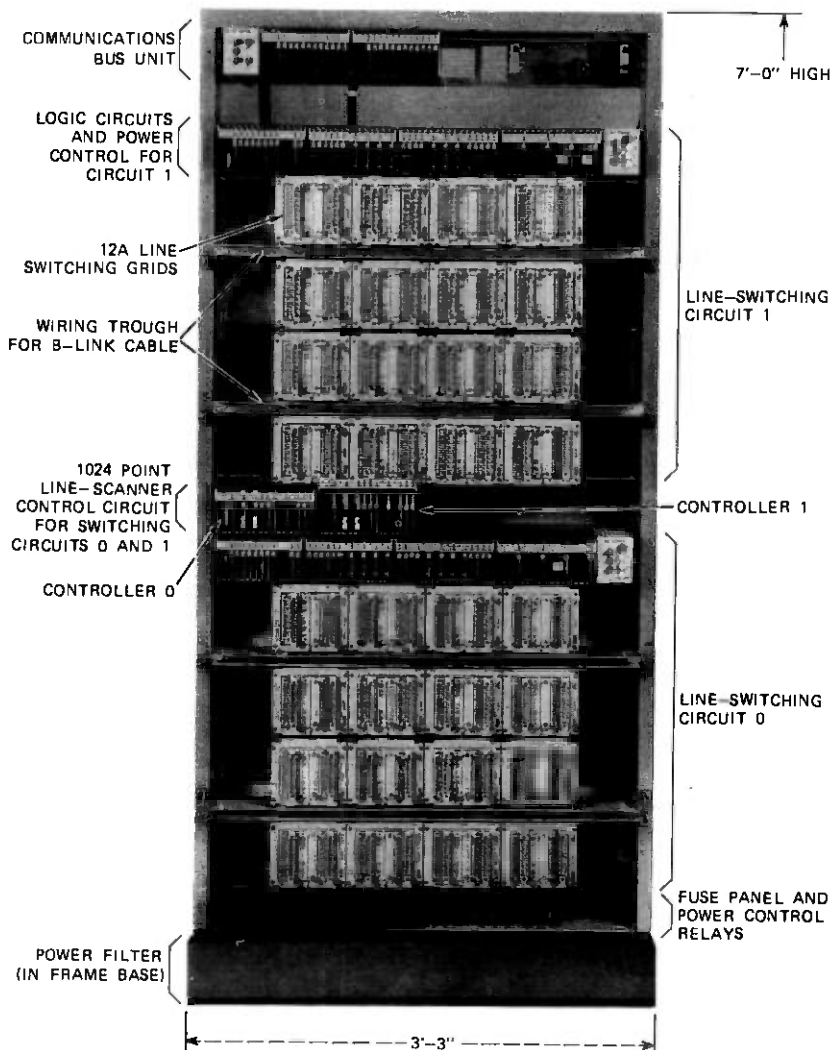


Fig. 4—Line-switching frame (for 2:1 line-concentration ratio).

2.2 Frame organization

A standard double-bay framework 7 ft high by 6 ft, 6 in. wide by 1 ft deep is used to provide the necessary frame-mounting space for the control, switching, power-filtering, fusing, alarm, and maintenance circuits. Equipment arrangement on the frame is, for the most part, in keeping with the standard pattern used on all No. 1 ESS frames. Communication bus circuitry, terminal strips, and power feeders are

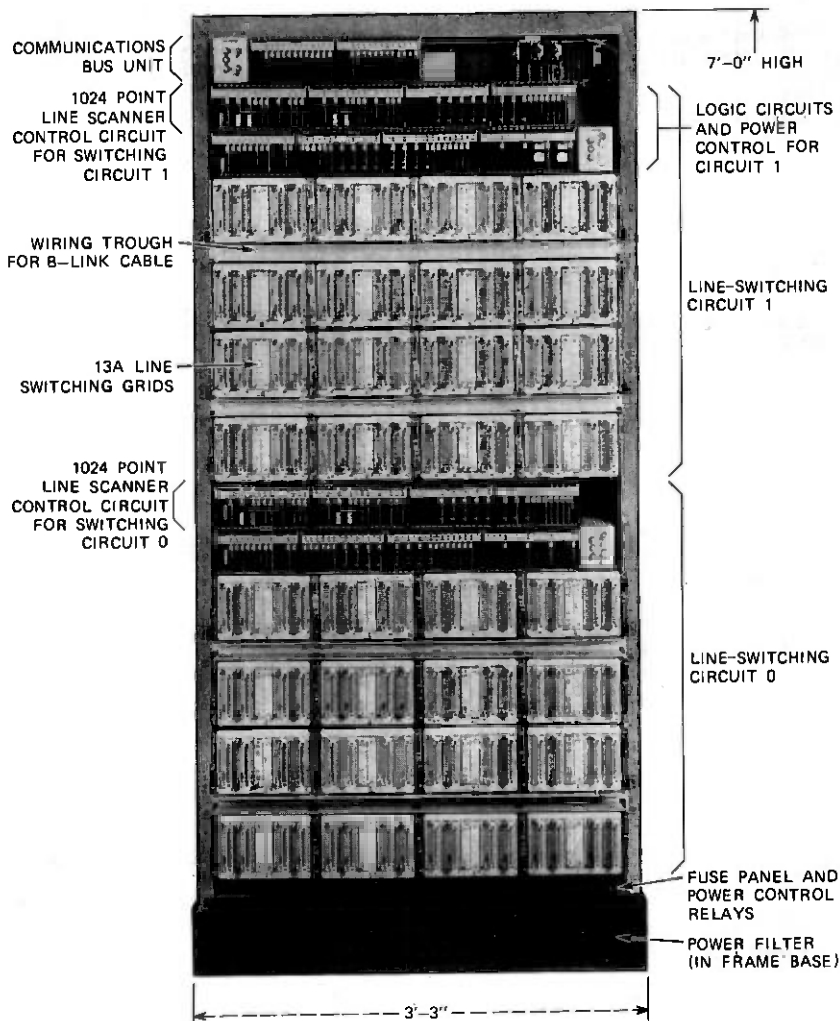


Fig. 5—Line-switching frame (for 4:1 line-concentration ratio).

located at the top of the frame and the power filters, fuses, and power-control relays are located at the bottom of the frame. The remaining frame space is utilized to support the switching and control circuits as outlined in Fig. 1.

Four identical trunk-switching circuits are provided in bay 0 and four identical junctor-switching circuits are provided in bay 1. Each switching circuit occupies 17 in. of frame-mounting space and consists of a 4-in. switching circuit control unit and a 13-in. mounting plate

which supports the four switching grids associated with each control unit. Figure 15 provides a more detailed view of a junctor-switching circuit. Physical design aspects of the switching grids are described in Section IV.

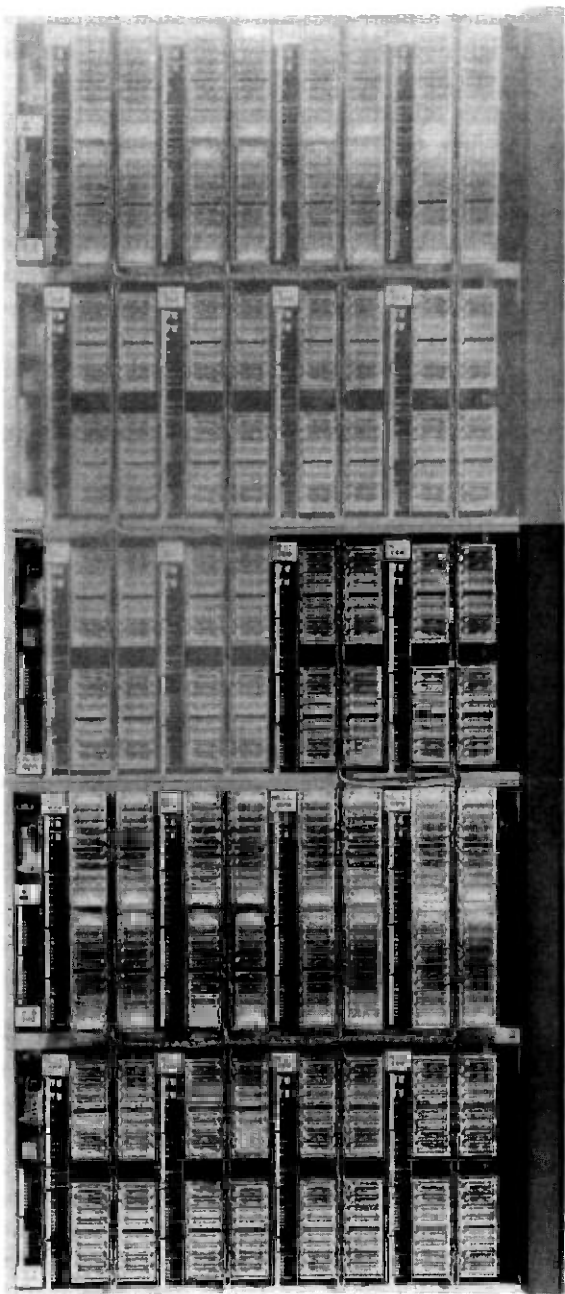
A total of four stages of switching are provided by the trunk link network circuits, the first two stages by the trunk-switching circuits and the last two stages by the junctor-switching circuits. Each switching circuit accommodates 256 tip-and-ring pairs, or a total of 1024 pairs on a per-frame basis. The 1024 output pairs from the trunk-switching grids in bay 0 are wired to the 1024 input pairs of the junctor-switching grids in bay 1 via a 1024-pair connectorized cable. These wired links between the trunk and junctor circuits are referred to as the B links.¹ Advantages of the connectorized B-link cable used on all the remreed frames are reviewed in Section 5.1. One complete trunk link network frame provides any of its 1024 input pairs access to any of its 1024 output pairs.

2.3 Trunk-switching frame

Trunk link network configurations with a $1\frac{1}{2}$:1 concentration ratio and the 2048 network are made up of two frames as shown in Figs. 6 and 7, respectively. The 2048 network consists of two 1024 trunk link network frames which are interconnected by a 2048-pair B-link cable. No other hardware changes are required for the 2048 configuration.

The $1\frac{1}{2}$:1 trunk link network configuration is achieved by adding two additional trunk-switching circuits and multiplying their outputs (B links) to the four junctor-switching circuits located in the trunk link network frame. These additional trunk-switching circuits are provided on the trunk-switching frame. This single-bay frame, 3 ft, 3 in. wide, contains the identical hardware arrangement as contained in bay 0 of the trunk link network frame. Each trunk-switching frame, as shown in Fig. 2, can be equipped with either two or four trunk-switching circuits. When the frame is equipped with four circuits, the bottom two are associated with the trunk link network frame on the left and the top two are associated with the trunk link network frame on the right (when viewed from the front). In offices that have an odd number of $1\frac{1}{2}$:1 trunk link networks, the trunk-switching frame would only be equipped with the bottom two circuits. In these cases, a 6 ft, 6 in. space is reserved to the right of the trunk-switching frame in the floor plan layout for the future addition of another trunk link network frame. The two associated trunk-switching circuits are easily added to the partially equipped trunk-switching frame during office growth.

IN OFFICES EQUIPPED WITH AN ODD
NUMBER OF 1½-TO-1 TRUNK LINK NETWORKS,
THIS SPACE IS RESERVED FOR FUTURE GROWTH



6'-6" TRUNK LINK NETWORK FRAME
3'-3" TRUNK SWITCHING FRAME
9'-9" 1½-TO-1 TRUNK LINK NETWORK

Fig. 6—Trunk link network frame combination for a 14:1 trunk-concentration ratio.

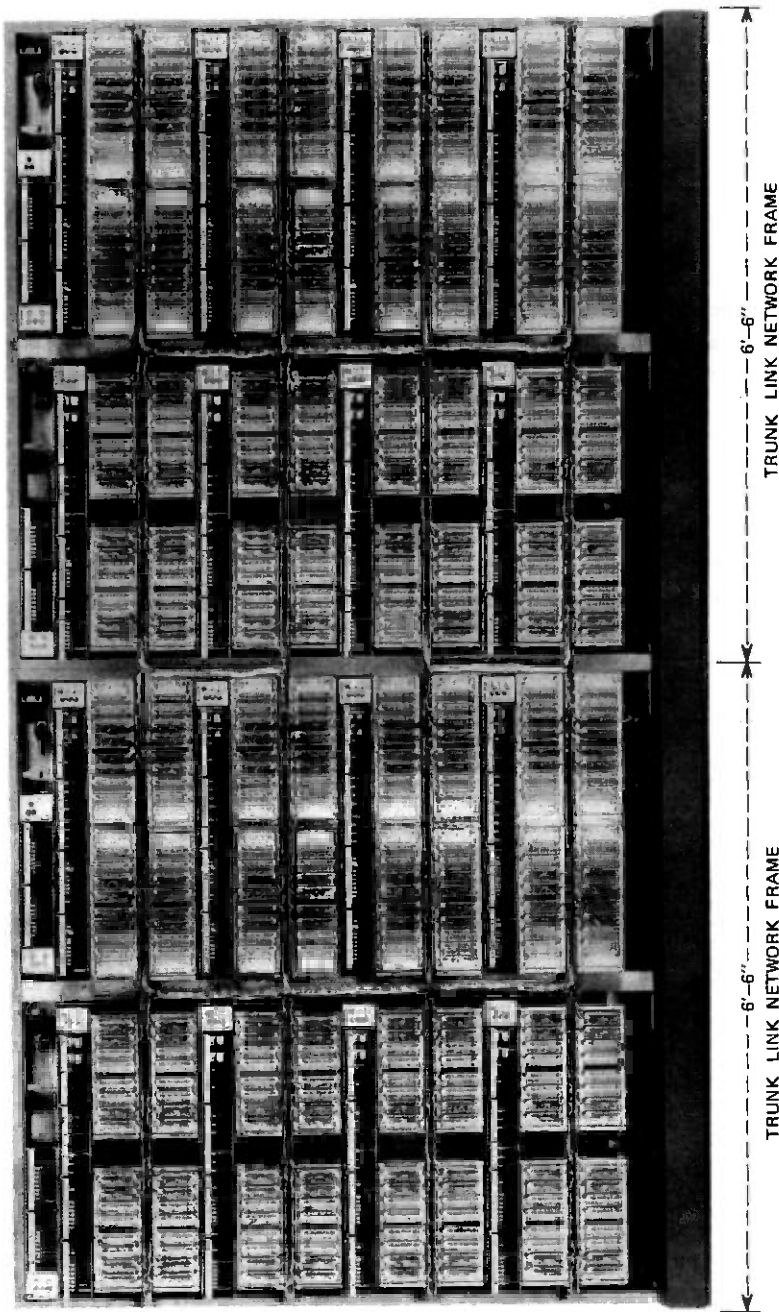


Fig. 7—Trunk link network frame combination (for a 2048 network with a 1:1 trunk-concentration ratio).

III. LINE LINK NETWORKS

3.1 Junctor-switching frame

Remreed line link networks are available which provide four basic concentration-ratio configurations. There are 2:1, 3:1, 4:1, and 6:1. Any of these four network configurations may be provided by the proper selection and interconnection of three basic remreed frames designed for this purpose, i.e., the junctor-switching frame, the 2:1 line-switching frame, and the 4:1 line-switching frame, as shown in Figs. 3, 4, and 5, respectively.

Each line link network provides four stages of switching. The first two stages of switching are performed by the line-switching circuits, and the last two stages of switching are performed by the junctor-switching circuits. As in the case of the trunk link networks, a connectorized B-link cable is used to link the outputs from the line-switching circuits to the inputs of the junctor-switching circuits.

The junctor-switching frame is common to all line link network configurations and contains 16 junctor-switching grids as described in Section 4.2. A standard single-bay framework 3 ft, 3 in. wide supports the associated junctor-switching frame equipment and is, in fact, identical to the equipment in bay 1 of the trunk link network frame. As in the trunk link network frame, the 16 junctor-switching grids provide access to a total of 1024 junctor-output pairs.

3.2 Line-switching frame (2:1 line-concentration ratio)

The 2:1-type line-switching frame shown in Fig. 4 contains two complete line-switching control circuits, one 1024-point scanner-control circuit, one communication bus circuit, and the associated switching grids, power filter, fusing, and alarm circuits. The 36 plug-in circuit packs required for one line-switching control circuit occupy a 4-in. high by 3-ft wide mounting plate. The 16 associated switching-grid packages are located directly below the control circuit. A standard single-bay framework 3 ft, 3 in. wide is equipped with two line-switching circuits and provides the first two stages of switching for 1024 incoming line pairs.

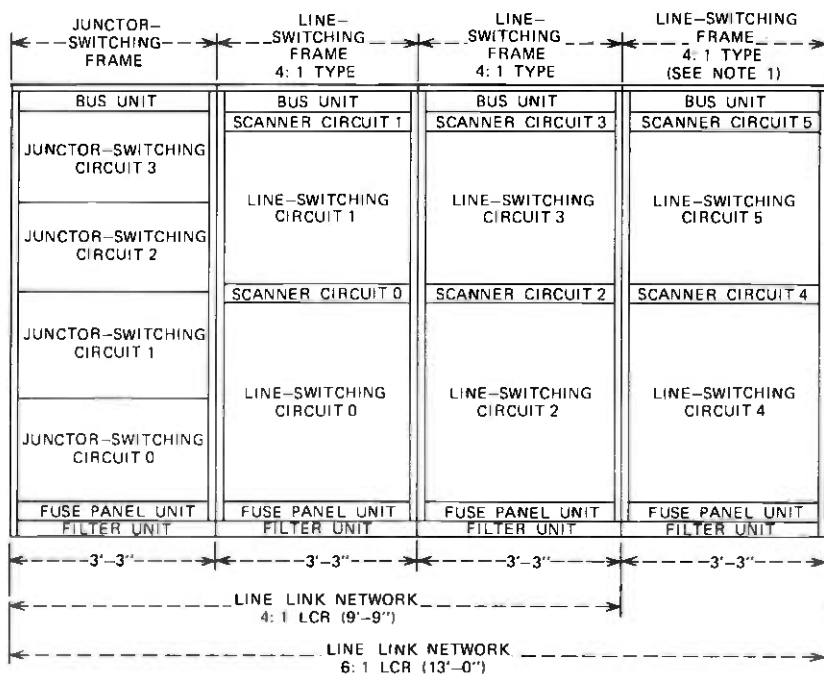
The 1024 line-scanner ferroids that monitor the state of each incoming line pair are provided as part of the remreed switch package. These line-scanner ferroids are controlled by the 20 circuit packs (10 for controller 0 and 10 for controller 1) located on a 4-in. mounting plate between the two switching circuits. Scanner-control circuitry⁷ is duplicated, and both controller 0 and 1 have access to all 1024 line-scanner ferroids on the frame.

Communications bus circuits are located at the top of the frame and are described in Section 5.9. The power filters, fuse panel, and

power-control relays are located at the bottom of the frame. Interconnections between the communication bus, line-switching circuits, and line-scanner controllers are accomplished using flat, flexible tape cables as described in Section 5.6.

3.3 Line link network (2:1 and 3:1 line-concentration ratios)

A complete line link network with a 2:1 line-concentration ratio consists of two 2:1-type line-switching frames and one junctor-switching frame. These three frames are arranged as shown in Fig. 8. Frames are interconnected by a 1024-pair, connectorized, B-link cable which is shipped with the frames. This network configuration terminates a total of 2048 incoming line pairs and provides access to 1024 junctors. Half-equipped networks can be provided that will accommodate 1024 incoming line pairs. In this arrangement, the frame equipped with line-switching circuits 2 and 3 is omitted at initial installation, but space is provided in the floor plan layout for future growth to a full



NOTES:

1. THE ADDITION OF THIS FRAME CONVERTS THE 4:1 LCR NETWORK TO A 6:1 LCR NETWORK.

Fig. 8—Front view of line link network configurations with 2:1 and 3:1 line-concentration ratios (LCR).

network. Connectors on the B-link cable that terminate on line-switching circuits 2 and 3 are secured to a supporting structure provided for this purpose until such time as the complete network is required.

Line link networks with a 3:1 line-concentration ratio consist of one junctor-switching frame and three line-switching frames of the 2:1 type arranged as shown in Fig. 8. B-link interconnections for these frames are accomplished by the use of a 1536-pair, factory-formed, connectorized cable that is shipped to the field with the frames. In this arrangement, half the 1024 B links are multiplexed to the outputs of the 32 additional 12A grids provided on line-switching circuits 4 and 5. A wiring pattern for these multiple connections has been designed that minimizes traffic blocking on the multiplexed B links. A full line link network with 3:1 line-concentration ratio terminates 3072 incoming line pairs and provides access to 1024 junctors. Partial equipment arrangements that permit growth steps of 1024 and 2048 line pairs are permissible and are handled in the same manner as described above for the 2:1 line link networks.

3.4 Line-switching frame (4:1 line-concentration ratio)

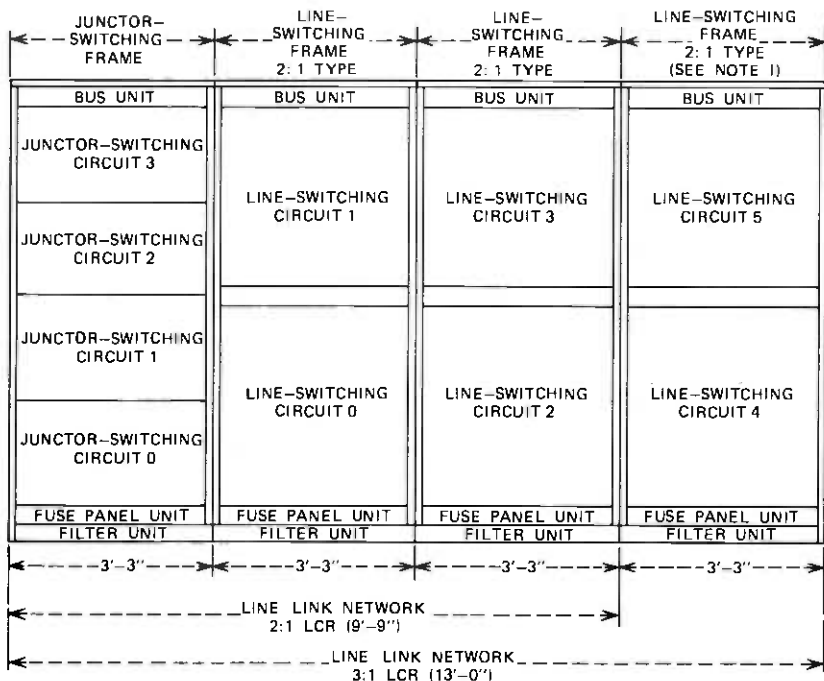
The 4:1-type line-switching frame is shown in Fig. 5. Sixteen switching grids and the associated control circuit provide for the interconnection and concentration of 1024 incoming line pairs to the 256 B-link output pairs and constitute a complete 4:1-type line-switching circuit. A 1024-point ferrod scanner-control circuit is provided for each 4:1-type line-switching circuit. A scanner ferrod associated with each incoming line pair is incorporated in the remreed switch packages on which the incoming line pairs are terminated.

A single-bay framework 3 ft, 3 in. wide supports two complete 4:1-type line-switching circuits and associated scanner-control circuits. Power filters, fuses, communication bus, and alarm circuits are also located on the frame.

3.5 Line link network (4:1 and 6:1 line-concentration ratios)

A complete line link network with 4:1 concentration ratio is illustrated in Fig. 9. Connections between the 1024 output pairs on the two line-switching frames and the 1024 input pairs on the junctor-switching frame are made using a connectorized B-link cable which is plugged onto the frames during installation. This three-frame complex provides the means of connecting any one of the 4096 incoming line pairs to any one of the 1024 junctor output pairs through four stages of switching.

By adding one additional line-switching frame to the 4:1-type line link network and multiplying its 512 output pairs to half of the 1024 B



NOTES:

1. THE ADDITION OF THIS FRAME CONVERTS THE 2:1 LCR NETWORK TO A 3:1 LCR NETWORK.

Fig. 9—Front view of line link network configurations with 4:1 and 6:1 line-concentration ratios (LCR).

links, a line link network with a 6:1 concentration ratio is obtained as shown in Fig. 9. The 6:1 line link network is capable of switching any one of its 6144 incoming line pairs to any one of its 1024 output junctor pairs.

IV. SWITCHING GRIDS

Four different switching-grid units have been coded for the remreed switching application: the junctor-switching grid (10A grid), the trunk-switching grid (11A grid), the 2:1 line-switching grid (12A grid), and the 4:1 line-switching grid (13A grid). These grids are illustrated in Fig. 10.

Each of the four switching grids contains a prewired number of remreed switch packages⁸ and a terminal field for access to the controlling circuit. The switch packages and terminal field are supported by two picture-frame-type mounting brackets tied together by two

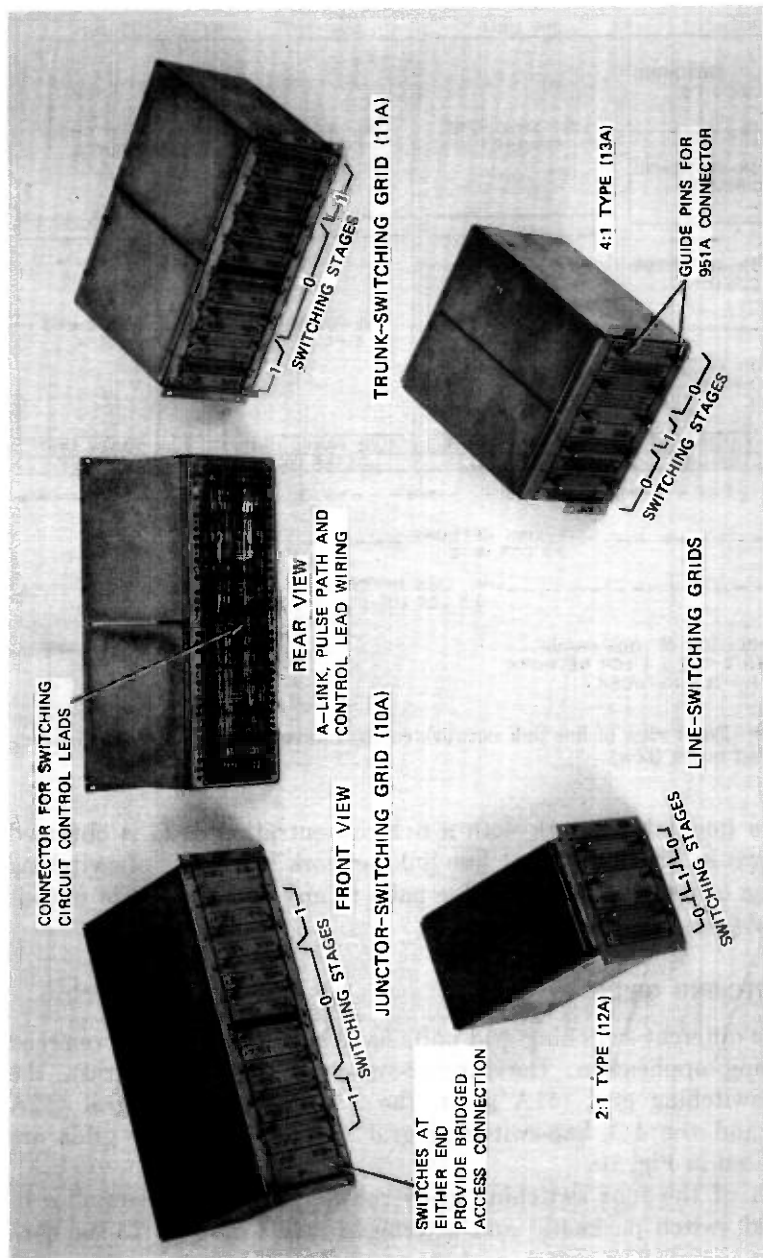


Fig. 10—Remreed switching grids.

cover details. These mounting brackets are designed to provide the necessary means to support the grids in the frame, to protect the switch packages from physical damage, and to allow switch-package alignment within the grid as required for automatic wire wrapping or flex circuit application.

The outputs from the switch packages in the first stage of switching are linked (wired) to the inputs of the second-stage switches. These links (A links) are wired on the rear of the grid in a specific pattern that permits each input terminal pair of the stage-0 switches to gain access to each output terminal pair of the stage-1 switches. One important design constraint of the switch packages and grid assembly was the optimization of the A-link, pulse-path, and control-lead wiring. Early in the design period, it was decided that the terminals for these leads should be arranged in a manner to facilitate their interconnection by means of either a double-sided flexible printed circuit or automatic wire-wrapping machinery. This decision, as well as the decision to provide a plug-in switching grid rather than a wired-in version similar to that used in the ferreed networks, dictated to a large extent the final design parameters.

Close cooperation between Bell Laboratories designers and Western Electric manufacturing and installation engineers resulted in the present design. For example, the output terminals of the stage-0 switches and the input terminals of the stage-1 switches were located at the rear of the switch packages. Pulse-path and control leads for both types of switches were also brought out on the rear terminals. Thus, all leads that control the switches or were required to interconnect the two stages of switching were constrained to terminate on terminals located at the rear of the switch packages. (See the rear view of the 10A grid in Fig. 10.)

4.1 Trunk-switching grid

The trunk-switching grid is a two-stage switching array that has 64 input pairs and 64 output pairs. Any input pair of this array may be connected to any output pair to provide a metallic two-wire path through the grid.

The trunk-switching grid shown in Fig. 10 contains eight remreed switching packages and associated mounting hardware. Four of these switch packages are used to provide the first stage of switching (stage 0) and four are used to provide the second stage of switching (stage 1).

Terminals on the front of the stage-0 switch packages are dedicated to the tip-and-ring inputs from the connecting trunk and service circuits. Front terminals of the stage-1 switch packages are reserved for the output tip-and-ring leads that are wired directly (via the B-link

cable) to the input of the junctor-switching grids where the last two stages of switching are performed.

4.2 Junctor-switching grid

Junctor-switching grids are somewhat more complicated than the trunk-switching grids because of the two additional switch packages required for the bridged-access connection to the 64 switchable tip-and-ring pairs. These two-stage switching grids (Fig. 10) permit the interconnection of any one of 64 input pairs to any one of 64 output pairs. Four such grids are associated with each junctor-switching circuit. Each line or trunk link network is equipped with four junctor-switching circuits that provide a total of 1024 individual tip-and-ring terminal pairs, half of which may contain two connections.

The 1024 input pairs (or 1536 where multiple connections are provided) to the junctor-switching grids are connected to the outputs of either the 2:1 or 4:1 line-switching grids via a connectorized B-link cable as described in Section 5.1.

4.3 Line-switching grids, 2:1 type

Two basic types of line-switching grids have been coded for the line link networks. The 2:1 line-switching grid (12A grid) consists of three remreed switch packages and associated mounting hardware as shown in Fig. 10. Two switch packages are used to provide the first stage of switching and contain the line-scanner ferros and cut-off contacts. The third switch package provides the second stage of switching.

In addition to providing two stages of switching, the 12A grid also provides a traffic-concentration function in the ratio of 2 to 1. Thus, the 32 incoming line pairs that terminate on a 12A grid have access to only 16 outgoing B-link pairs, which connect directly to the inputs of the junctor-switching grids. One complete line-switching control circuit¹⁰ has the capability of controlling a total of 16 of the 12A grids that collectively provide 512 line pairs access to 256 B links.

4.4 Line-switching grids, 4:1 type

In most residential calling areas where a large number of low traffic lines are to be terminated, it is more economical to further concentrate the lines to ratios of 4:1 or 6:1. Line link networks with these higher concentration ratios are equipped with the 13A grids shown in Fig. 10. This grid code consists of five remreed switch packages and appropriate mounting hardware. Sixteen incoming line pairs are terminated to each of the four first-stage switches in the grid. The fifth switch package provides the second stage of switching as well as the traffic-

concentration function. As in the case of the 12A grid, the line-scanner ferroids are incorporated in the stage-1 switch packages. Terminals on the front of the stage-0 switch packages are reserved for the incoming line pairs.

The 16 pairs of outputs from the grid appear on the front of the stage-1 switch package located in the center of the grid. As is the case with all the grid codes, terminations to the front of the grids are made on 951A-type connectors described in Section 5.2. Each 13A grid has the capability of connecting any one of its 64-input line pairs to any one of its 16-output B-link pairs. Each line-switching control circuit controls 16 grids that collectively provide 1024 line pairs access to 256 B links.

V. APPARATUS AND EQUIPMENT

5.1 Connectorized B-link cable

Outputs from the line- and trunk-switching grids are linked to the inputs of the junctor-switching grids via a connectorized B-link cable. Each line and trunk link network configuration has a unique B-link wiring pattern.¹ This wiring pattern provides a wired access between each of the line- or trunk-switching grids in the associated network and its corresponding 16 junctor-switching grids. The B-link cables plug directly to the front of the switching grids. Wiring troughs located between the grids provide a means of support for the B-link cable as well as allow grid removal without disturbing the B-link connections to other grids. This design scheme resulted in a standard cable configuration that could be fabricated, tested, and, in the case of the trunk link network frame, installed in the factory. For line and trunk link network configurations that are made up of two or more frames, it is more convenient to install the factory-formed-and-tested B-link cable after the individual frames are erected in place.

Another advantage of this approach is the elimination of the B-link cables from the overframe cable rack as required for the ferreed networks. For the 1:1 trunk link networks (both 1024 and 2048), this resulted in a 33-percent reduction in the number of leads required to be run in the cable rack and a 50-percent reduction in the number of wire-wrap connections that had to be made during field installation. Similar savings were realized for the line link networks and account for a significant portion of the reduced installation interval achieved by the introduction of the remreed networks.

5.2 B-link cable connector

To implement the connectorized B-link cable design for the remreed frames and to achieve the plug-in grid design objectives, it was neces-

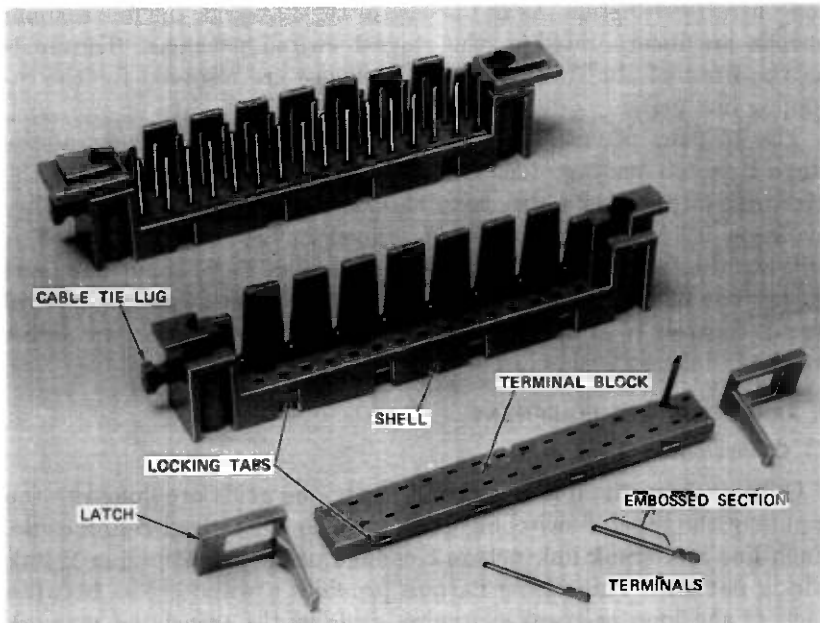


Fig. 11—B-link cable connector.

sary to develop an appropriate connector. The connector developed for this purpose is shown in Fig. 11. This connector provides the pluggable interface between the terminals on the front of the remreed switch packages and the switchboard and B-link cables. Although the B-link cables are factory-wired, the subscriber lines and trunk- and service-circuit leads (inputs to the line- and trunk-switching grids) and the junctor links (outputs from the junctor-switching grids) must be wired in during field installation.

The connectors on which these field-installed leads are terminated are shipped in place on the grids. During installation, the craftsman forms, ties, and terminates the leads on these connectors. The wiring trough that supports the B-link cable is also used to support these field-installed cables. Tabs located on the wiring trough secure the cable as shown in Fig. 15 and are positioned to allow the cable to twist rather than bend when the connectors are disengaged for grid removal. This twisting motion permits the use of the solid wire required for wire wrap, while at the same time it provides the flexibility that is inherent in stranded wire.

Each connector provides 32 terminals designed to accept two 26-gauge wire-wrap connections. Terminals are assembled into the molded terminal block that is then locked securely into the molded shell by

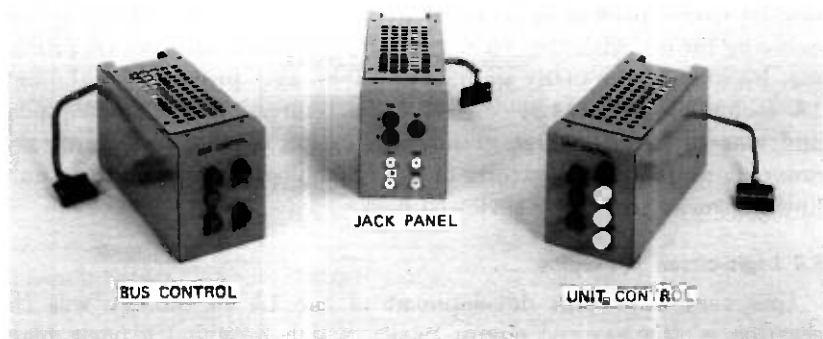


Fig. 12—Jack panel and manual power-control units.

the tabs provided for this purpose. The two latches are trapped in between the block and the shell during the connector assembly operation. Each switch package is equipped with two guide pins (shown in Fig. 10) which align the connector to the 32-terminal pin field during engagement. When the connector is properly seated, the two molded latches engage the groove on the guide pins and complete the locking feature.

5.3 Power-control panel unit

Each communication bus and line-, trunk-, and junctor-switching circuit has its own individual power-control panel unit. These basic units (Fig. 12) are designed to share many of the same piece parts and differ only in their front panel assembly and associated umbilical cable wiring. The connectorized umbilical cable plugs directly into the frame circuit it controls.

These units permit the craftsperson to manually remove power from either duplicated controller during maintenance operations. A mechanical interlock arrangement provided on the pushbutton key assembly prevents simultaneous power removal from both controllers. A lamp array provided on the power-control unit indicates the operational status of the circuit it controls. A separate jack-panel unit provides telephone jacks and convenient access to the frame power supply via the test voltage supply jacks. Telephone jacks are multiplied to all frames in the office and facilitate communication between craftspeople during maintenance and/or routine test operations.

5.4 Control-circuit hardware (1A technology)

Implementation of the 4:1 space reduction for the remreed networks could not have been achieved as a result of the switch-package minia-

turization alone. Independent of the remreed switch development, a new hardware-packaging scheme referred to as the 1A technology was evolving for use with the No. 4 ESS toll application and the 1A processor. Because of the many significant advantages provided by the new 1A technology, it was selected for the remreed frame development and was in fact the first major application of this new hardware. Some more important features of this technology as used on the trunk-link networks are briefly reviewed below.

5.5 Logic-circuit packaging

One very important development of the 1A technology was the creation of the FA-type circuit packs, which provided a basic high-density logic-circuit packaging method. FA-type circuit packs consist mainly of an aluminum heat sink, a ceramic circuit, and an 82-pin connector as shown in Fig. 13. The ceramic circuit provides bonding sites for up to 52 beam-leaded devices. The fixed geometrical location of these bonding sites as well as the standardization of the placement of power, ground, and crossover arrays makes it possible to generate the required interconnections between devices by computer programs. This computer-aided design philosophy has resulted in extremely fast turnaround time between design concept and artmaster generation.

Assembly of the ceramic to the aluminum heat sink is designed to provide intimate contact between the two. This large area of contact provides the necessary heat sinking required to fully utilize the 52 bonding sites when required. The aluminum heat sink is also used to support the 82-pin connector plug as well as guide the plug into its mating receptacle via the slots provided in the apparatus mounting.

Leads of the connector plug are thermocompression-bonded to the ceramic to establish electrical contact between the two. During the final stage of assembly, the beam-leaded devices that are bonded to the ceramic are encapsulated with an RTV compound, and a metal cover is provided to protect the ceramic assembly from physical damage during handling.

Two FA circuit-pack codes are used in the switching-control circuits¹⁰ provided on all the remreed network frames. One pack contains the register and translator circuits which receive information from the communication buses. Each ceramic contains a total of 36 beam-leaded silicon-integrated-circuit devices that are required to implement this circuit function. The other circuit pack contains the controller-logic and group-check circuits. One such pack is provided in each of the two duplicated control circuits.

The packaging of discrete circuit components using the 1A technology has also resulted in tremendous improvements in circuit

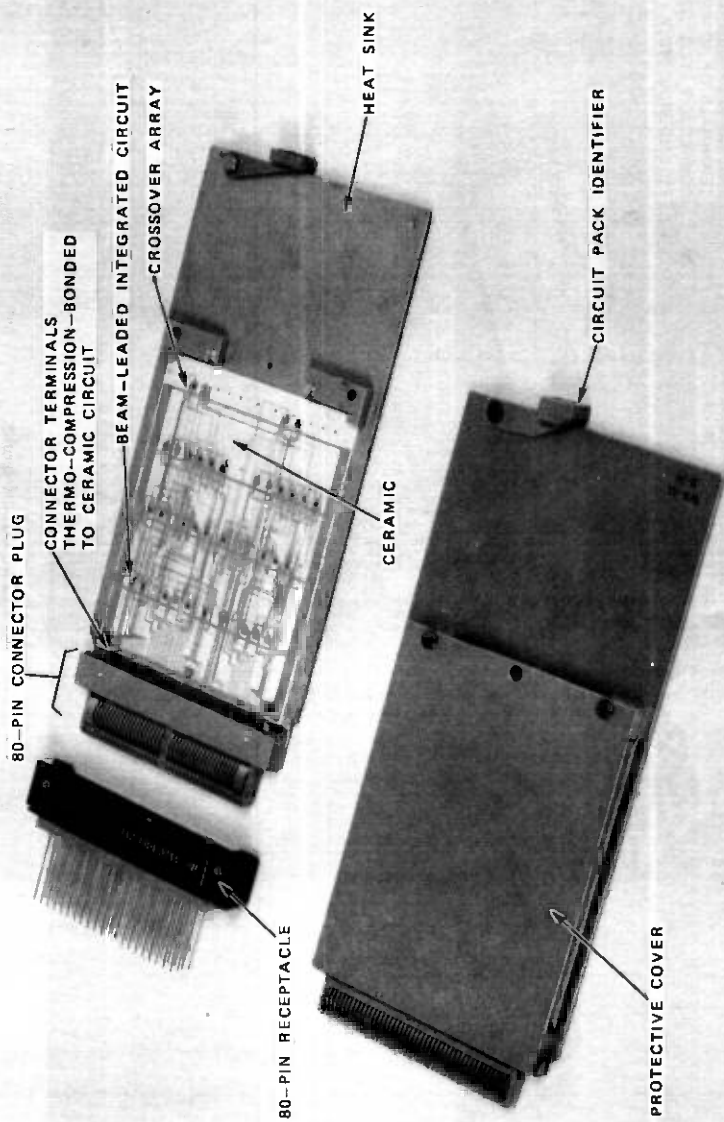


Fig. 13—FA circuit pack.

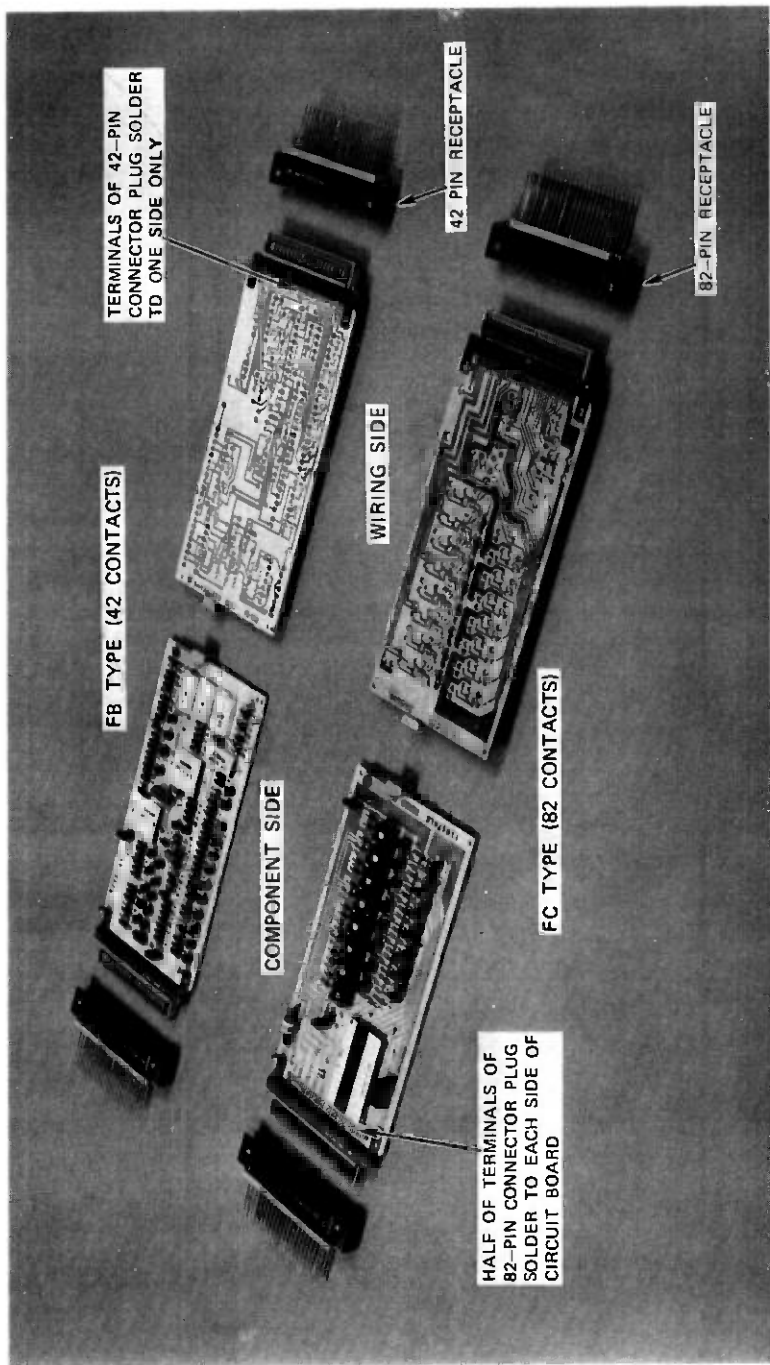


Fig. 14—FB and FC circuit packs.

density per pack and enables the designer to take full advantage of the board space provided. Two basic types of discrete-component circuit packs are available. These are coded as the FB and FC types, and provide either a 42-pin or 82-pin contact arrangement, respectively, as shown in Fig. 14.

Partitioning the circuits into discrete circuit packs was done in a manner to minimize the number of codes required and maximize the usage of the codes between the various line- and trunk-switching circuits. As a result, 26 of the 33 codes are used in more than one application.

5.6 Circuit-pack housing (apparatus mounting)

To accommodate the increased heat dissipation associated with this high-density packaging, a new apparatus mounting (Fig. 18) was developed. The open construction of this new mounting is designed to optimize the air flow around the circuit packs. Associated designation strips and circuit-pack identifiers are also designed to minimize the restriction of air flow and allow for sufficient circulation of natural convection currents to cool the packs even under extreme office conditions. The two apparatus mounting codes used in the remreed frames provide space for 14 or 16 circuit packs. These two codes permitted a frame-packaging scheme that utilized to full advantage the available frame space and also provided some physical grouping of the more important duplicated control functions shown in Fig. 15.

5.7 Flat, flexible tape cables

The communications bus circuit provides the interface between the central processor and the four switching circuits in the equipment bay. Information from the bus circuit is multiplied to each circuit in the bay by means of flat, flexible tape cables, as shown in Fig. 16. The tape cables provide a controlled impedance and minimize crosstalk between adjacent signal leads. Each tape cable contains 8 signal leads and 16 ground leads. Each signal lead is located between two ground leads. Use of the backplane connectors described in Section 5.8 permits automatic mass termination of the 24 leads. Another design feature of the connector permits the termination of two cables to each connector to achieve the required multiple effect.

5.8 Backplane connectors

The connector used for the flat, flexible cable is just one of a family of connectors that were designed as part of the 1A technology hardware package. Each connector in this family utilizes the same 10-terminal

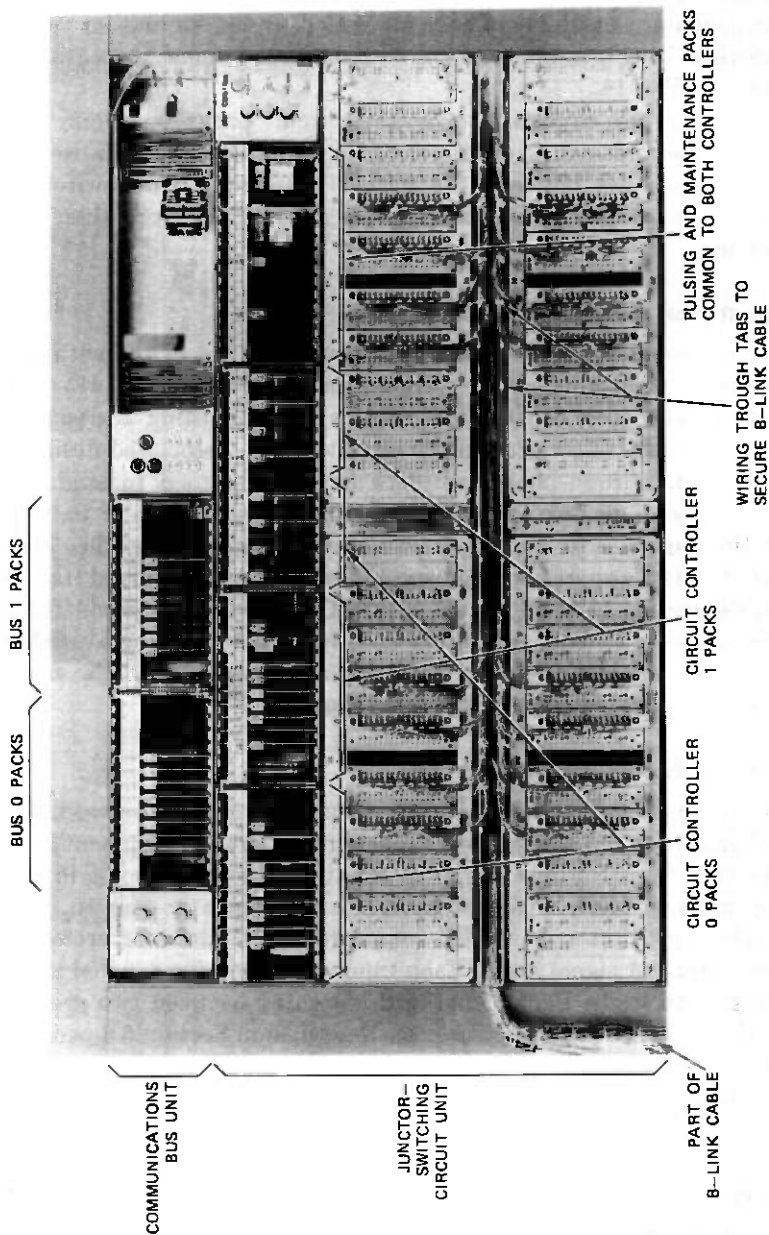


Fig. 15—Communications bus and junction-switching circuit units.

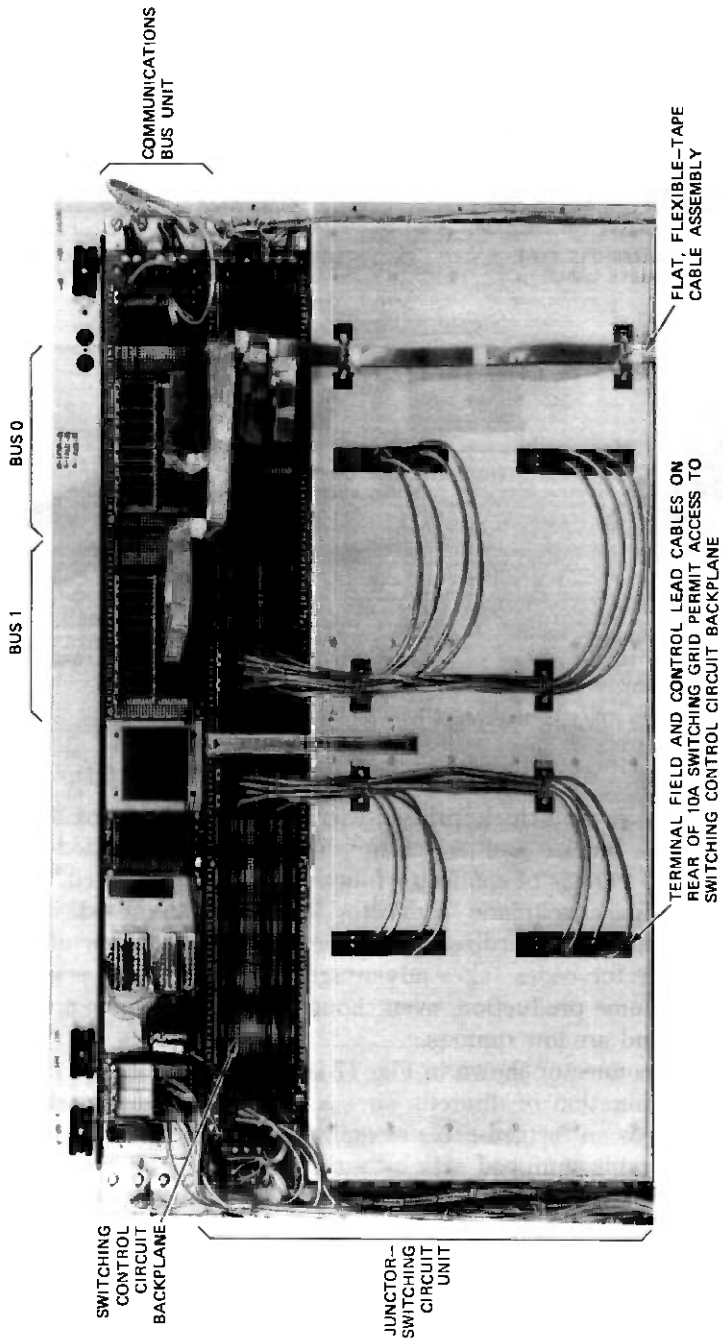


Fig. 16—Rear view of communications bus and junctor-switching circuit units.

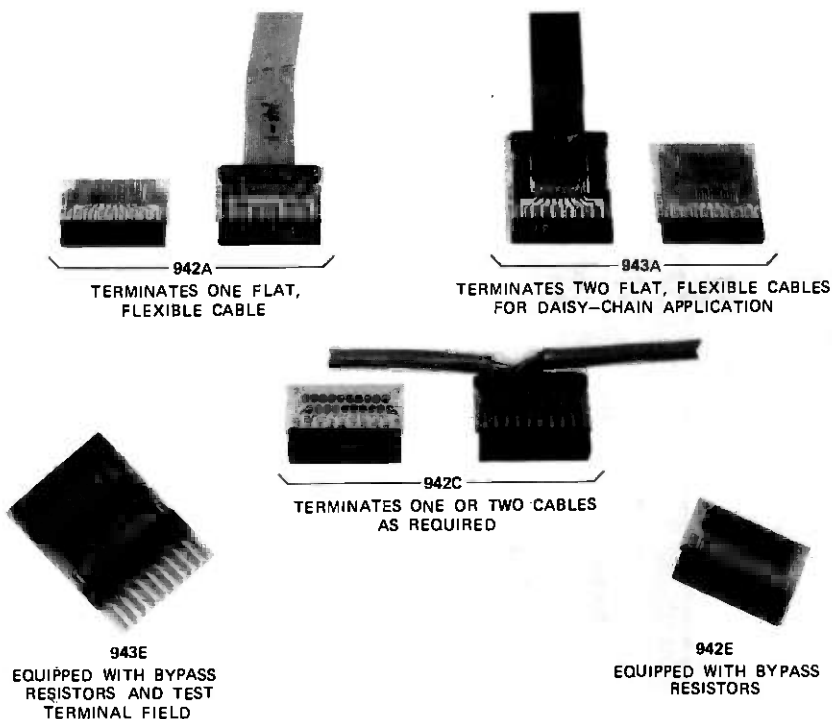


Fig. 17--Typical backplane connectors used on remreed frames.

block and a $\frac{1}{32}$ -inch-thick printed-wiring board. By using one or two terminal blocks and selecting an appropriate printed-wiring board, a wide variety of connector functions can be generated. Figure 17 shows some backplane connector configurations used on the remreed frames. Standardization of the common features of these various connector codes takes advantage of the economy associated with high-volume production, even though some codes have a unique application and are low runners.

The 942C connector shown in Fig. 17 is widely used. This code permits the termination of discrete wires and is used with switchboard cable as well as on formed-cable assemblies. For example, a length of switchboard cable equipped with a connector at each end provides the interconnecting link between the switching grids and the switching-control circuitry on the trunk link network frame shown in Fig. 16. Four such cables are used for each grid to connect its 64 control leads. This technique greatly simplified the task of achieving the plug-in grid-design objectives.

5.9 Control-unit plug-in feature

The additional connectorization of the few maintenance and power leads that connect to the switching-circuit control units resulted in a completely connectorized control unit. This design feature permits the field craftsperson to completely remove and replace a control unit of any switching circuit without jeopardizing the operation of the other switching circuits in the frame. This feature was originally provided with the intent that, if any major redesign or rewiring of the control unit was required, it could be more economically done in the factory than in the field. In such a case, the field craftsperson would remove the unit, replace it with a new unit, and return the old unit to the factory for modification. A craftsperson can remove and replace a unit in approximately 1 hour. As a result of the comprehensive frame tests performed by the Western Electric Company prior to shipment to the field, this unit-replacement option has been infrequently used. This option has, however, proven its worth on units that were physically damaged in shipment and required extensive factory rework.

5.10 Plug-in frame concept

The duplicated communication buses (address and answer leads to the central processor) are multiplied from frame to frame. Information from the bus is picked off by a transformer located on the bus circuit packs. This new bus circuit pack was designed for use with the 1A processor and replaces the scheme formerly used in which the bus leads were hardwired to the transformers on each frame. This design permits the interconnection between frames to be achieved by means of a double-ended connectorized switchboard cable. Use of these bus packs on the remreed frames and the connection of the tip-and-ring leads to the 951A grid connectors resulted in an almost complete frame plug-in arrangement. Only the dc power feeders and ground return which serve the frame are hardwired during installation. This frame plug-in feature has been used to advantage on numerous occasions both in the field and in the test-and-evaluation laboratory. Less than 4 hours are required to completely remove and replace a remreed trunk link network frame.

5.11 Circuit-pack receptacle

A very important feature of the 1A technology is the design flexibility available through the use of the circuit-pack receptacle. These receptacles, as shown in Fig. 14, are available in two basic pin configurations (the 42-pin and the 82-pin) and are designed to mount directly to the frame mounting plates. Connectors are generally lo-

cated on $\frac{1}{2}$ -in. centers or multiples thereof on the mounting plate. The opening of the receptacle is designed to mate with the circuit pack plug. Overall connector dimensions are such that, when connectors are placed on $\frac{1}{2}$ -in. centers on the mounting plate, the terminal field of adjacent connectors falls on a 0.125-in. by 0.125-in. grid which is acceptable for automatic wire wrapping. Terminals on the rear of the connectors are designed to provide a soldered connection to a multi-level printed-wiring board, two wire-wrap connections using 30-gauge wire, and an optional third wire wrap or the contact space for a backplane connector.

5.12 Machine-wrapped 30-gauge backplane connections

A terminal density of 64 terminals per square inch can be achieved by using the 1A hardware. This density precludes the use of hand-wiring techniques except for very limited repair work or minor wiring modifications. As a result, semiautomatic and/or fully automatic wire-wrapping equipment is used for the manufacture of the remreed units. Electrical characteristics of units wired by this equipment are uniform from unit to unit. Automatic wire-verification techniques check for missing or misplaced wires and provide a convenient method of monitoring the performance of the automatic wrapping machines. Machine wiring is fast, economical, and essentially error-free and permits the designer to control path routing as well as wire density in localized areas.

The ability to specify the path routing of machine-applied wires on the switching grids made it possible to meet the stringent crosstalk and transmission design requirements. In this case, the tip-and-ring leads of a pair were controlled to run in the same horizontal and/or vertical wiring channel, i.e., the space between adjacent rows of terminals. Electrically noisy leads such as the pulse leads were routed in selected wiring channels which were dedicated to such leads. Using this technique, a grid wiring pattern was developed that not only satisfied the transmission requirements but provided adequate margin.

5.13 Power and ground backplanes

A highly reliable low-impedance ground-return path is essential for proper circuit operation. The backplane technique developed for use on the remreed control units satisfies this grounding requirement and in addition provides a power-distribution point that permits power wiring to individual circuit packs to be applied by automatic machine techniques. A typical backplane board is shown in Fig. 18. The grounding scheme consists of an etched copper path around the perimeter of the rear of the backplane board to which pins pressed into the board

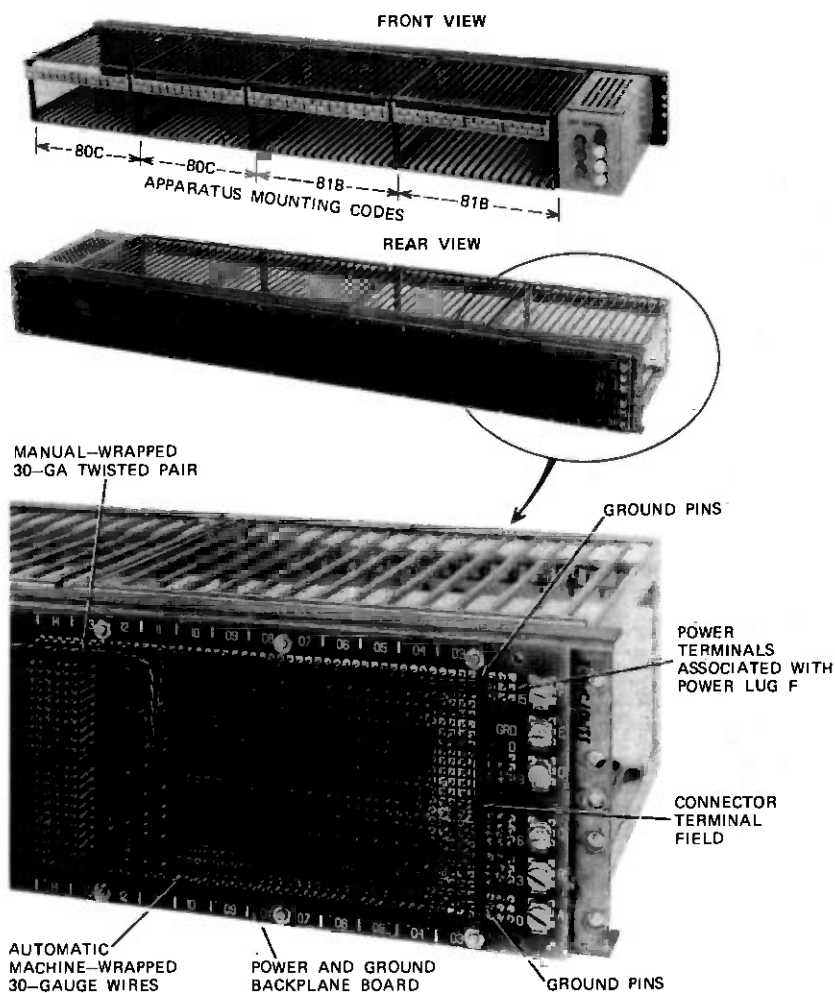


Fig. 18—Junctor-switching control unit (less circuit packs).

are soldered. Ground pins are located above and below all possible circuit-pack connector locations. Ground leads are machine-wrapped between these ground pins and the dedicated ground pins of the 947-type connectors as required.

Circuit packs which require multiple ground connections are also easily accommodated by this technique. A screw-type terminal lug is pressed into the board and soldered to the copper ground circuit along one edge of the backplane board. A ground wire connected to this terminal is routed to the ground side of the power filter located in the base of the frame to complete the ground-return path.

Power connections are handled in much the same manner. In this case, the screw-type terminal lug, the power portion of the printed circuit, and the 25-mil-square pins dedicated for power are localized along the edge of the board. Leads from the screw-type terminal lugs are routed directly to the controlling power relay or associated fuse located at the bottom of the frame. This technique is illustrated in Fig. 18. Connections between the circuit-pack terminals and the power pins are machine wrapped. Multiple power connections to a particular circuit pack are easily accommodated when required.

VI. ACKNOWLEDGMENTS

Design of the 1A technology packaging hardware and the subsequent physical design of the remreed network frames are the direct result of the combined efforts and talents of many other members of the technical staff and technical assistants whose contributions I wish to acknowledge. The individual contributions of many of my colleagues who were associated with this development effort are detailed in the companion papers in this issue.

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Remreed Switching Networks for No. 1 and No. 1A ESS:

Transmission Design and Environmental Protection of Remreed Networks

By C. H. KLOSTERMAN and J. E. UNRUE, Jr.

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The transmission characteristics of remreed networks have been designed to support a wide variety of switched services. These include local- and toll-switched voice-message and voiceband data services. Also, looking toward the future, the remreed network has the capability of supporting wideband services such as analog Picturephone® service and T1 bit streams. In a class of space-division networks, it approaches being an ideal noninteractive extension of the switching-office cabling.

This article discusses the transmission and environmental protection aspects of remreed networks. The objectives and requirements used to control the transmission and protection design for remreed networks are given and the resulting performance characteristics are described.

I. INTRODUCTION

The switching network of a telephone central office serves the function of interconnecting the many lines and trunks of the office with each other and with service circuits such as tone sources, signal transmitters, signal receivers, etc. For the duration of the connection, the switching network constitutes a portion of a transmission channel over which communication takes place.

The remreed network for No. 1 and No. 1A ESS is a space-division metallic network. The transmission channels are formed by interconnecting metallic conductors with metallic contacts, and electrical isolation of different channels is achieved by physical separation in space. The remreed network is also classified as a two-wire network since, for each connection, two independent metallic-conductor paths are established: the so-called tip (T) and ring (R) conductors.

In the ideal case, the T and R conductor paths of a remreed network would form a noninteractive extension of the office cabling appearing at the network terminals. The electrical isolation between channels would be complete (infinite coupling loss), and the transmission channel would contain no internal noise sources. Furthermore, this would ideally be true at all frequencies. Of course, this cannot be achieved in practice but can be approached sufficiently by careful design.

The T and R conductors of the remreed network are extended into the outside plant of a telephone exchange area by cables. As a result, the remreed network is exposed to an electrically hostile environment. The system design must assure that the network will survive hazards such as lightning strikes, power-line crosses, and other electrical fault conditions. This requires a certain degree of ruggedness of the remreed network and the use of other external means of providing protection.

In this paper, we discuss the transmission and environmental considerations in the design of remreed networks and we focus primarily on the T and R conductors. General design objectives are discussed in Section II. Design factors affecting transmission are covered in Section III, followed by the measured transmission characteristics in Section IV. Section V covers the environmental protection aspects of the design.

II. GENERAL DESIGN OBJECTIVES

2.1 Transmission

To enjoy the economies of high-volume production, it is desirable for the apparatus and equipment used in remreed networks to support a wide variety of present and future services. Therefore, the transmission design has been guided not only by the requirements of the present applications, but with an eye toward future applications as well.

Some of the future applications would increase the bandwidth requirements of the network. Others would involve changes in the transmission mode in which the T and R conductors are used to obtain an "equivalent four-wire" switching capability.

2.1.1 Transmission modes

As previously noted, each connection establishes two independent conductor paths: the T and R conductors. In most applications, these conductors are used to form a single communication channel, as shown in Fig. 1. In this case, the conductors are usually balanced with respect to ground and the interconnecting equipment has source and

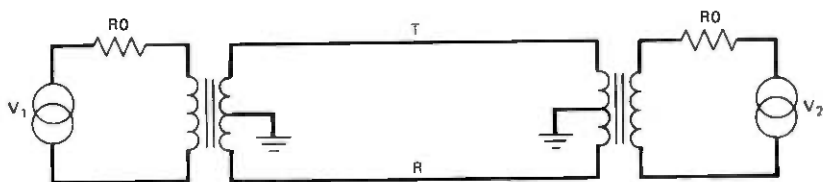


Fig. 1—Properly terminated balanced mode.

load impedances that approximate the characteristic impedance of the channel. We refer to this as the properly terminated balanced mode.

In some applications, the T and R conductors are used in separate circuits, each having common-ground return, to form two independent communication channels, as shown in Fig. 2. Such unbalanced circuits tend to be susceptible to crosstalk and other sources of interference unless certain precautions are taken. When such circuits are used in conjunction with remreed networks, the transmission mode is changed to the so-called HILO mode¹ to control crosstalk and other types of noise. In the HILO mode, the connecting equipment presents a very high source impedance and very low load impedance. This impedance relationship gives rise to the name HILO and reduces the interference susceptibility of the unbalanced circuits.

The properly terminated balanced mode is usually used in bilateral circuits where information propagates equally well in both directions. These are the so-called two-wire switching applications. In the HILO mode, each circuit is inherently unilateral, i.e., signals propagate in only one direction. The two HILO circuits of each connection are used to obtain an equivalent four-wire switching capability where one

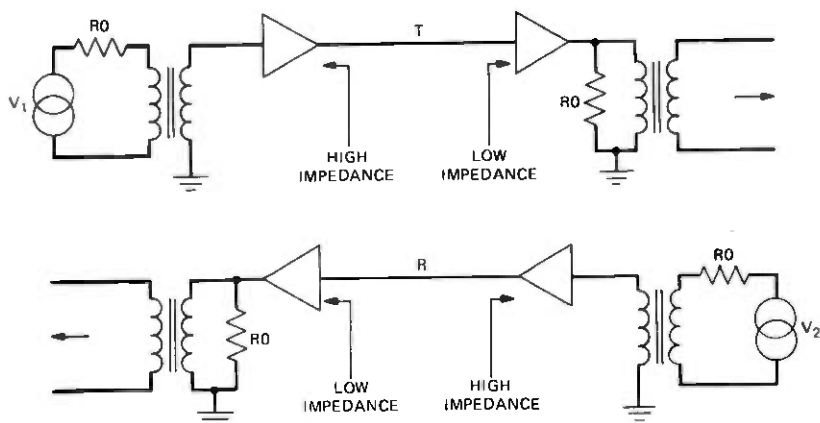


Fig. 2—HILO unbalanced mode.

circuit is used for "east-to-west" communications and the other for "west-to-east."

2.1.2 Applications

The initial and predominant use of remreed networks is for two-wire voiceband switching in local, tandem, and toll offices. The properly terminated balanced mode is used in these applications. The HILO mode will be used for equivalent four-wire voiceband switching in No. 1 ESS and No. 1A ESS in toll and other special applications.

Looking toward the future, remreed networks are expected to be used for wideband switching applications. These include such services as Picturephone® service and various analog and digital data applications. In most of these cases, the nature of the service requires an equivalent four-wire connection, which may be obtained using a single connection and the HILO transmission mode, or by establishing two connections and using the properly terminated balanced mode.

2.1.3 Transmission objectives

In the ideal case, from a transmission point of view, the T and R conductors of remreed networks would be equivalent to a section of multipair cable. As in cable, the transmission parameters of primary importance are the insertion characteristics, crosstalk characteristics, and susceptibility to external noise sources. Design objectives were established for each of these parameters, taking into account the many switched services for which the remreed networks may ultimately be used.

In the case of wideband services, several were studied for the purpose of establishing meaningful transmission objectives. These include analog Picturephone service, 64-kb/s digital data, and 1.544-Mb/s digital data (equivalent to a T1 line signal). It is presumed that these are representative of a wide class of analog and digital signals that may be switched in the future.

The design objectives applied to the remreed network were derived from transmission objectives established for local and toll switching offices as a whole. The remreed network is a subsystem in the office. Therefore, it was necessary to allocate the office objectives among the various subsystems: trunk and junctor circuits, remreed networks, and interframe cables. Also, it proved desirable to further allocate these objectives to the network apparatus level since it is at this level that one can exercise design control. In this manner, objectives were established for concentrator grids, trunk grids, and junctor grids.^{2,8} These subsystems are similar from a transmission viewpoint since each includes two switch stages. Therefore, they each received the

Table I — Grid transmission objectives

1. Single-disturber equal-level crosstalk objectives:

Frequency (kHz)	Minimum Coupling Loss (dB)		
	Balanced (a)	HILO Interchannel (b)	HILO Intrachannel (c)
3.4	90	90	90
32	45	50	35
400	65	—	—
750	45	50	35

a. Between any two T-R conductor pairs.
 b. Between any two T or R conductors except mate conductor.
 c. Between T and mate R conductors.

2. Impulse noise: less than 11 mV into 110-ohm terminations.
3. Minimum 3-dB bandwidth (balanced mode): 5 MHz.
4. Maximum T or R conductor resistance: 1.5 ohms @ 20°C.
5. Maximum unbalance resistance between T and mate R conductors: 200 milliohms @ 20°C.

same allocation, which we will refer to as grid objectives. The grid objectives that were established are summarized in Table I.

In the case of the HILO mode, we distinguish two different types of crosstalk couplings: interchannel and intrachannel. As previously noted, the HILO mode is used for equivalent four-wire applications so that each connection establishes two communication channels. Crosstalk between the two channels of the same connection is called intrachannel coupling. Crosstalk between channels of different connections is called interchannel coupling. Intrachannel coupling is more difficult to control since these two channels are in close proximity to each other throughout the entire connection. This fact must be recognized when allocating objectives.

In most of the wideband cases, it is not the single disturber crosstalk that is important, but the crosstalk in a particular channel that is the sum of all disturbers. Design control can be reasonably exercised only for the worst disturbers. The objectives allocated to a grid, which apply to the single worst disturbers, were chosen so that the more pertinent objectives for the sum of all disturbers would be guaranteed.

A crosstalk objective was not established for the HILO mode at 400 kHz. This frequency is pertinent to vestigial sideband modulated analog Picturephone signals. Remreed grids are under consideration for line-concentration functions in Picturephone switching applications.

However, the HILO method of equivalent four-wire switching cannot be used in this case due to the large difference in signal levels between the east-to-west and west-to-east channels. Instead, the balanced mode would be used, with the transmission directions segregated into different grids.

2.2 Environmental protection

2.2.1 Environmental hazards

In normal system operation, the T and R conductors of remreed networks will be subjected to a number of electrical stresses. Table II indicates some common operational voltages that appear in local exchange area network applications. Also shown are estimates of the cumulative duration over a 40-year design life that particular conductors may reasonably be expected to have the given voltage impressed.

We can observe from Table II that the simultaneous presence of coin voltage and range-extended ringing on adjacent conductors will result in a peak potential difference of 362 V between the conductors.

In many applications, the T and R conductors of the network are extended directly by other metallic conductors into the outside plant of an exchange area. As a consequence, the remreed network can be subjected to a number of natural and man-made electrical fault conditions caused by lightning strikes, power-line crosses or ground faults, and incorrect maintenance and repair actions. When these fault conditions occur, the voltages can exceed the values given in Table II by a considerable amount.

Lightning strikes can, in rare cases, result in voltage transients that approach 1000 V peak with respect to ground.⁴ Improper use of cable-fault-locating equipment can result in 600 V dc being impressed on the network conductors. Ground faults in power-distribution lines can induce voltages on the T and R conductors which range from negligible values to several hundred volts as a function of such variables as the

Table II — Normal operational voltages

Source	Voltage	Estimated Cumulative Duration Per 40 Years, Per T-R Pair
Line battery	± 52 Vdc	50,000 hours
Coin voltages	± 135 Vdc	6,000 hours
Range-extended ringing	149 V peak 20 Hz superimposed on -78 Vdc	2,000 hours

power-distribution voltage, location of the ground fault, and proximity of the telephone plant.

2.2.2 Environmental protection objectives

In the case of the normal system operational stresses, the design of the remreed networks must be such as to withstand these stresses over its design lifetime (40 years). This, of course, is true also for all other equipment in the connecting complex of the system, such as trunk and junctor circuits. However, it is not economically practical to design all central office equipment to withstand every possible fault condition without damage. Nevertheless, catastrophic service-affecting failures cannot be tolerated. To minimize the service effect under fault conditions, a preferred order of failure has been established as follows:

- (i) Trunk- or junctor-circuit failures.
- (ii) Network switch-contact failures.
- (iii) Network link-wiring failures.

When this order of equipment failure is maintained, the probability of multiple equipment failure is minimized, restoral effort is minimized, and switching network traffic-carrying capacity is maximized.

Most No. 1 ESS trunk circuits are plug-in units and are easily replaced. Single network crosspoint failures can be tolerated because excessive traffic blocking will not occur until multiple crosspoint failures accumulate, at which point an individual grid can be replaced. A single network link-wiring failure will eliminate from service the accessibility of eight stage-0 crosspoints and eight stage-1 crosspoints in a grid and will reduce the traffic-handling capacity of a remreed grid sooner than, for example, individual crosspoint failures.

To achieve the above preferred failure order, the failure limits of trunk and junctor circuits were studied along with the characteristics of protection devices such as carbon blocks. Also, the action which the system takes in response to each failure was determined. (These studies are discussed in Section V). The design objectives for electrical faults for the remreed network apparatus were established. These objectives were to sustain without damage the following:

- (i) 900-V peak; 10- μ s risetime \times 1000 μ s fall time transient.
- (ii) 800-V peak 60-Hz ac for 1 second.
- (iii) 600-V dc for 1 second.
- (iv) 3 A rms for 2 minutes.
- (v) 2 A rms for 10 minutes.
- (vi) 1.5 A rms continuously.
- (vii) 5 A rms for 1 second (link wiring only).

III. TRANSMISSION DESIGN

3.1 *Constituent parts of remreed networks*²

In this section, we describe the constituent parts of remreed networks from a transmission point of view. More complete descriptions can be found in Refs. 2, 3, and 5.

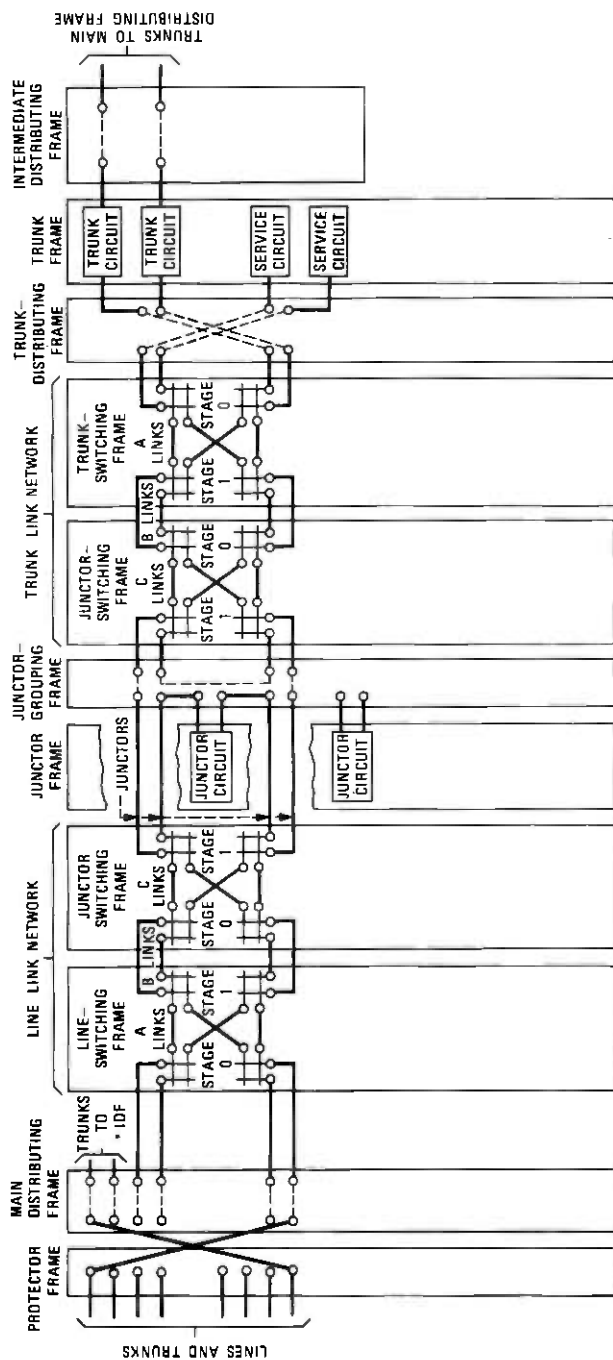
The equipment organization for transmission through remreed networks is shown in Fig. 3. A connection can involve different equipment units, depending on the switching function of a call—intraoffice, interoffice, or tandem.

The connections through the network consist of several path segments in either a line link network (LLN), trunk link network (TLN), or both. The link networks are further broken down into frames. The LLN consists of line-switching frames and junctor-switching frames, while the TLN consists of junctor-switching frames and trunk-switching frames.

The line-switching frames give rise to two stages of switching in the interconnecting process, connecting line terminals at their inputs to B links at their outputs. The line-switching frames perform a basic network function of concentration. Two types of line-switching frames have been provided: one concentrates by a ratio of 4 to 1 between input lines and B links and the second concentrates by a ratio of 2 to 1. Associated with the line-switching frames are junctor-switching frames. The junctor-switching frame also performs two stages of switching: it interconnects B links and junctors. Junctors are the central link of every network connection. The final type of network frame is the trunk-switching frame, which also performs two stages of switching, interconnecting B links and trunk terminals. The basic junctor- and trunk-switching frames have 1-to-1 concentration ratios.

Each type of switching frame consists of apparatus called grids, which contain the stage-0 and stage-1 switches and their associated interconnecting A or C link wiring as indicated in Fig. 3. Four types of grids are used. The line-switching frames use the 13A-type grid to provide 4-to-1 concentration and the 12A-type grid for 2-to-1 concentration. The junctor-switching frame uses a 10A-type grid and the trunk-switching frame uses an 11A-type grid.

The above grids contain different types of switches. The switches in turn contain a basic component of the remreed networks, the 238A, miniature, sealed-reed contact.⁶ These sealed contacts are physically associated in pairs, one used for the T-conductor path and the other for the R-conductor path. These contact pairs and their associated control elements are called crosspoints and are packaged and interconnected in the remreed switches to form spatial arrays. There are several switch types, each providing either a unique T-R array con-



*INTERMEDIATE DISTRIBUTING FRAME

Fig. 3—Equipment schematic.

Table III — Switch types

Switch Code	Array Configuration	Used-In-Grid Code
296-1A	2— 8×8	10A, 11A
296-1B	2— 8×8	11A
296-1C	2— 8×8	10A
296-2A	4— 4×8	12A, 13A
296-3C*	4— 4×4	12A
296-4C*	1— $16 \times 4/8$	13A
296-5D†	4— 1×8	10A

* Switch also contains 16 cutoff crosspoints and associated line ferroids.

† Contains 32 crosspoints used to give the junctors access to a common test vertical.

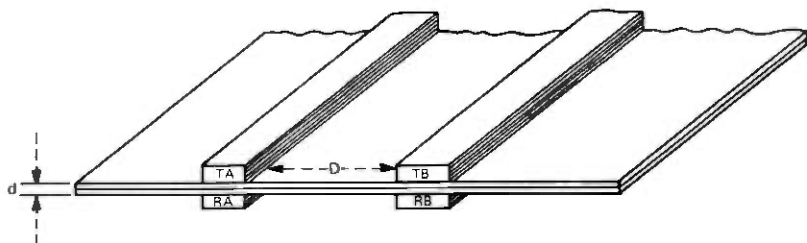
figuration or crosspoint-control function. Table III lists the different types of switches, the number of and type of array patterns provided, and identifies the type of grid in which it is used.

The interconnection of the switching frames is by switchboard cables whose transmission characteristics are well understood. Therefore, the remaining discussion will focus attention on grids and switches.

3.2 Physical design

Miniaturization places a greater importance on physical design to control and minimize factors which affect transmission, such as crosstalk and other types of noise. A remreed switch package can contain up to 128 crosspoints and associated electronic control devices. These components are interconnected with flexible printed wiring to form the arrays in the switch package. On each switch, two flexible printed-wiring planes are used: one that forms the horizontal interconnection plane and a second that forms the vertical interconnection plane for each array. Each flexible printed-wiring plane is a double-sided circuit containing the T-R conductors and associated pulse and control conductors. The flexible printed-wiring planes are cemented to epoxy-coated steel boards, which are part of the crosspoint support structure. The steel core of these boards is grounded. To provide maximum crosstalk isolation, the physical relationship between the T-R conductors and ground planes was controlled to minimize the capacitive unbalance to ground of the T-R conductor pairs. The T and R conductors of a pair were oriented on opposite sides of the circuit in a vertical colinear geometry. The advantage of this orientation is shown in Fig. 4a and the method used to equalize capacitance to ground is shown in Fig. 4b.

When mounted in a grid, the switch packages are interconnected to permit each input T-R terminal pair of the stage-0 switches to have access to each output T-R terminal pair of the stage-1 switches. These interconnections are called links, and are identified as A links in the



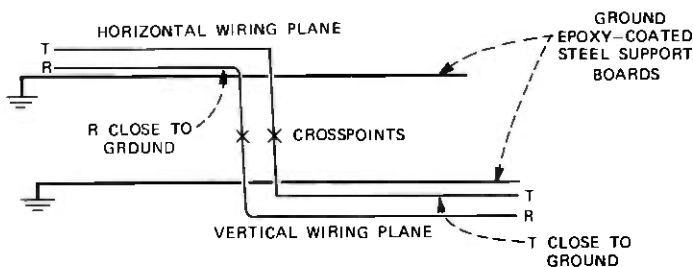
$$\text{UNBALANCE CAPACITANCE: } C_U = [C_{TATB} - C_{TARB}] + [C_{RARB} - C_{RATB}]$$

$$\therefore C_U \text{ SMALL WHEN } \frac{d}{D} \leq 0.1$$

$$\text{SINCE } C_{TATB} \approx C_{TARB}$$

$$C_{RARB} \approx C_{RATB}$$

(a) T AND R CONDUCTOR GEOMETRY



(b) METHOD FOR EQUALIZING CAPACITANCE TO GROUND

Fig. 4—(a) Tip- and ring-conductor geometry. (b) Method for equalizing capacitance to ground.

11A, 12A, and 13A grids and C links in the 10A grids. The A- and C-link wiring patterns are shown in Figs. 5 through 7 for the 10A, 12A, and 13A grids. The 11A-grid, A-link wiring pattern is similar to that of the 10A grid shown in Fig. 7 except that the test-vertical cross-points are not present.

The A- and C-link interconnections were originally made with 30-gauge insulated wires applied by automatic wiring machines. Special care was taken here to define the routing of the T-R pairs between the stage-0 and stage-1 switches. The intent of the routing specification was to keep close physical proximity between the two wires which form a T-R pair. Based on a consideration of the economics associated with the automatic wiring machines, it was determined that the link wiring should be applied such that the vertical T-R route lengths would be minimized at the expense of lengthening the horizontal T-R routes. This was done to maximize T-R pair adjacency over the longer horizontal route and thereby reduce capacitive unbalance between different T-R conductor pairs. Shown in Fig. 8 is the terminal field of the

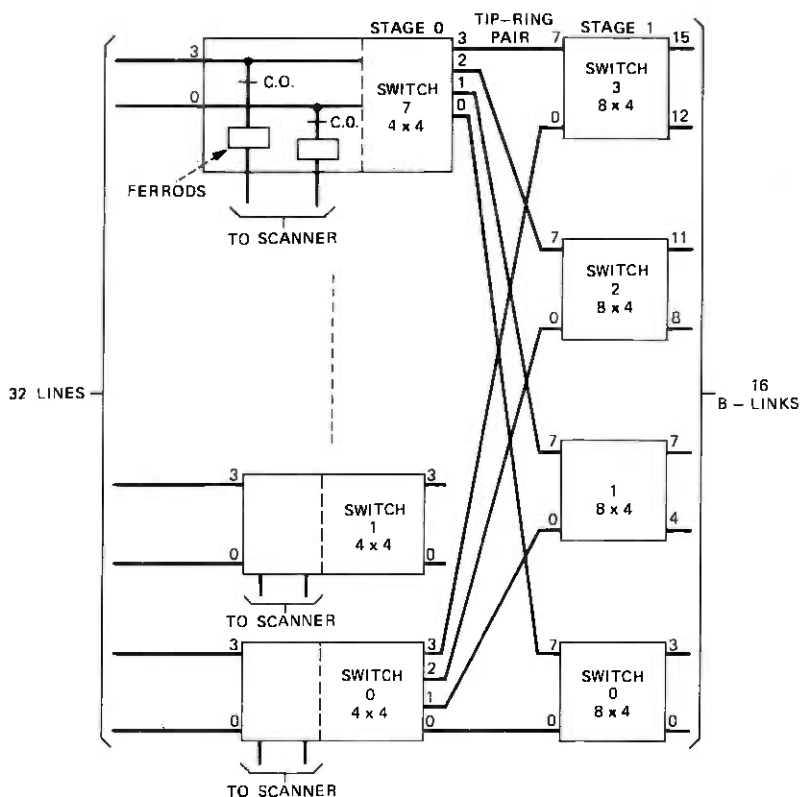


Fig. 5—Line-switching frame—tip-ring block diagram of a 2-to-1 concentrator.

stage-0 and stage-1 switches in a grid. The T-R pairs can be routed in the same terminal channels in the horizontal plane but cannot be routed economically in the vertical plane.

As a substitute method, grid-A and C-link backplane interconnections by means of flexible printed circuits have also been developed. Unlike the switch flexible circuits, on which the T-R conductor pairs are oriented in a vertical colinear geometry, in the backplane flexible circuitry, the T-R conductor geometry is similar to that designed for the wired grids. This follows the practice of requiring the T-R conductor pairs to lie in the same terminal channels when routing in the longer horizontal plane and allowing one terminal channel separation in the shorter vertical plane. It should be noted that for both the wired and the flexible backplanes, the longest T-R pair horizontal route is 11 inches while the longest vertical T-R pair route is only 3 inches.

Grids mounted in a switching frame must be interconnected with other grids in the associated switching frame to form a complete link

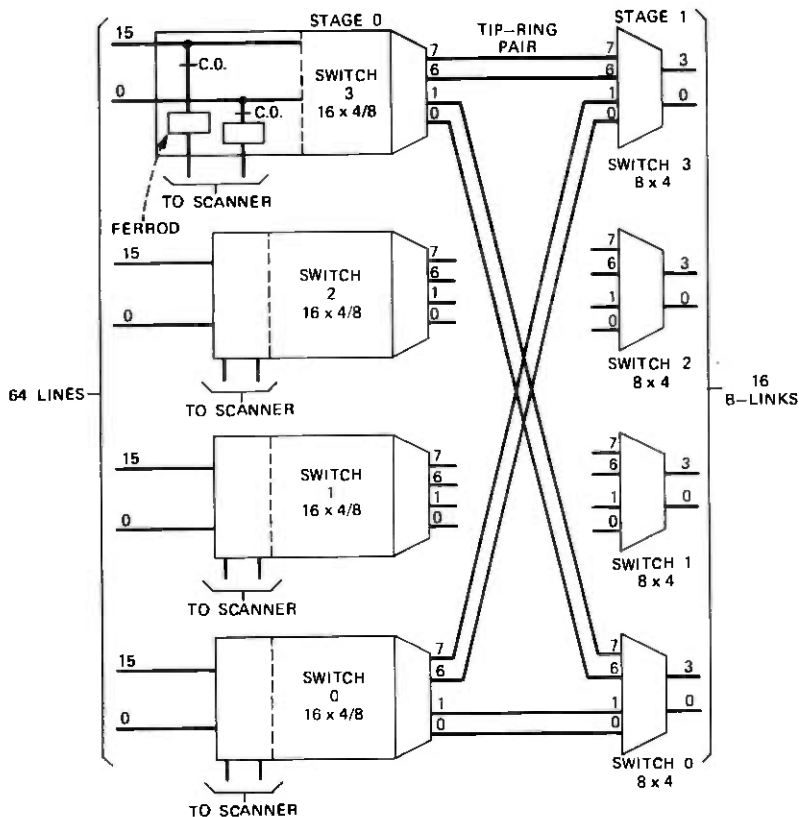


Fig. 6—Line-switching frame—tip-ring block diagram of a 4-to-1 concentrator.

network. The purpose of this interconnection is to enable any input T-R line or trunk terminal to be connected to any junctor T-R terminal. This interconnecting link is the B link and is a formed connectorized cable utilizing standard pvc, insulated, 26-gauge twisted pairs. The length of the B-link cable for a maximum-size 2048 TLN is 10 feet \pm 7.5 feet. The number 2048 signifies the number of trunk and junctor T-R terminal pairs available.

The final interconnecting links are the juncctors. These links connect the LLN's and TLN's together. They are formed from standard 800-type switch-board cables connected to a junctor-grouping frame.

3.3 Network topology

Further control of crosstalk and other types of noise is obtained from the network topology of the remreed network. Maximum crosstalk-coupling exposure, the total length two independent T-R paths are

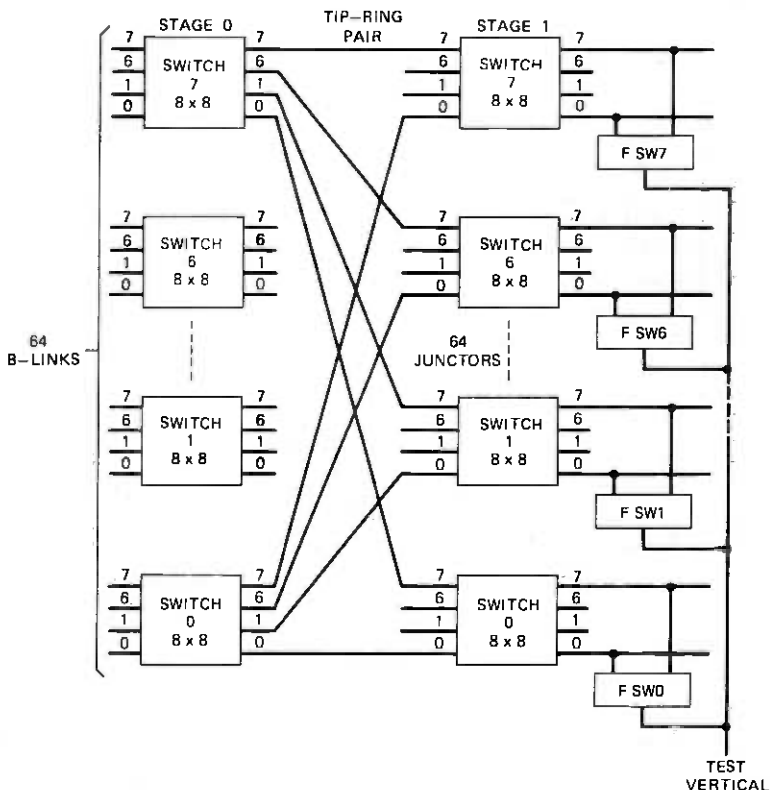


Fig. 7—Juncture-switching frame—tip-ring block diagram of a grid with test-vertical access.

in close proximity, is limited due to the topology of the network. For example, if two paths enter the same input switch of a grid, they cannot leave the grid through the same output switch. This example is valid for all switches except those used in the 4-to-1 line concentrator

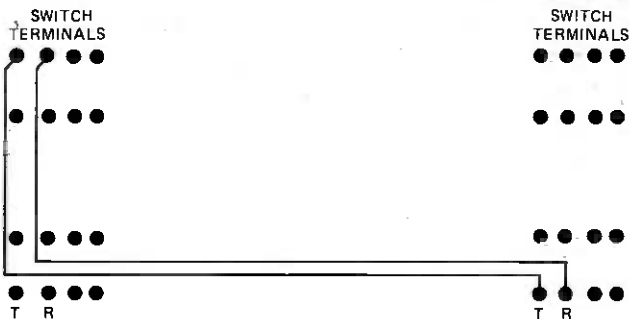


Fig. 8—Backplane wiring.

where a maximum of two paths can enter and leave the same switch. This can be seen by examining Figs. 5, 6, and 7. The B link T-R distribution pattern also reduces the possibility that the paths will ever be adjacent again. The importance of the network topology on crosstalk and other noise interference is that it breaks adjacency between two particular channels within the network and even minimizes adjacency in the office cabling external to the network.

IV. TRANSMISSION PERFORMANCE OF REMREED NETWORKS

The control of crosstalk and impulse noise were of primary concern in the design of remreed networks since miniaturization reduces conductor separations. The crosstalk requirements stated in Section II have been met for all planned and future switching applications, as indicated in Table IV. The measured crosstalk values stated are worst-case measurements. The average balanced mode and HILO interchannel crosstalk loss for a grid is 20 dB better. The average HILO intrachannel crosstalk is 3 dB better. The measurements shown apply to the 10A grid. This is the worst-case grid, due to the extra wiring associated with the test vertical. The other grids are generally 1 to 2 dB better.

In the HILO mode, intrachannel crosstalk becomes limiting as frequency increases. This crosstalk is dominated by the capacitive and magnetic coupling between the T and mate R conductors on the flexible printed circuits of the switch packages. As seen in Fig. 4A, this tight coupling is a direct result of the vertical colinear geometry

Table IV — Transmission performance

Grid Crosstalk Performance:

Frequency (kHz)	Minimum Coupling Loss (dB)		
	Balanced	HILO Interchannel	HILO Intrachannel
3.4	93	117	93
32	88	95	72
400	67	60	45
750	61	50	35

Impulse Noise: 0.7 mV into 110-ohm termination.

Grid Resistance Characteristic—T or R Conductor—Ohms @ 20°C:

	Longest Path	Shortest Path
Wired backplane	0.57	0.47
Flexible circuit backplane	0.82	0.76

that was chosen. A different geometry could improve the intrachannel coupling loss, but would impair the balanced mode crosstalk by increasing the unbalance capacitance. Due to the close proximity of the grounded support plane in the switch, it was more advantageous to use the geometry that minimized the unbalance capacitance.

The internal noise sources of remreed networks are thermal noise, impulse noise due to mechanical vibration, and impulse noise due to electrical coupling between the crosspoint-control circuitry and the T-R conductors. Thermal noise is negligible, as is impulse noise due to mechanical vibration. The worst-case impulse noise due to crosspoint operation is 0.7 mV when the T-R conductors are terminated in 110 ohms. This is well under the 11-mV objective. A number of design factors led to this good performance. The crosspoint structure of the switch packages includes a steel plate between the control windings and the T-R conductors that acts as a magnetic shield. Also, care was taken in the routing of switch flexible circuits and grid backplanes to achieve maximum separation between T-R conductors and conductors used for crosspoint pulsing and control.

The maximum resistance objective was met with margin, partly because the requirement imposed for current-carrying capacity controlled the design in this regard. This will be discussed in the next section. New grids generally do not display resistance unbalance greater than 10 milliohms. Over the lifetime of the grid, some unbalance can develop due to aging of the 238A, miniature, sealed-reed contact. However, this should stay well within the 200-milliohm objective.

The insertion loss characteristic of the 10A grid is shown in Fig. 9a and the phase response in Fig. 9b. The 10A grid is the limiting case for these characteristics, since it includes the additional wiring associated with the test vertical. Two curves are shown for each characteristic: one applicable to wired backplanes and the other applicable to flexible-circuit backplanes. The flexible-circuit backplane is somewhat more limiting because of the higher capacitance between T and R conductors, although both types of backplane meet the bandwidth objectives.

The above insertion characteristics apply to a grid. On an overall basis, the small physical size of the remreed network results in relatively short electrical and physical lengths of the T-R conductors through the network. For example, in a 1024 trunk link network, composed of four junctor-switch frames and four trunk-switch frames interconnected by B link cables, the maximum T-R length is approximately 18 feet and the minimum is approximately 7 feet. This makes the network contribution to office loss and loss contrast nearly insignificant.

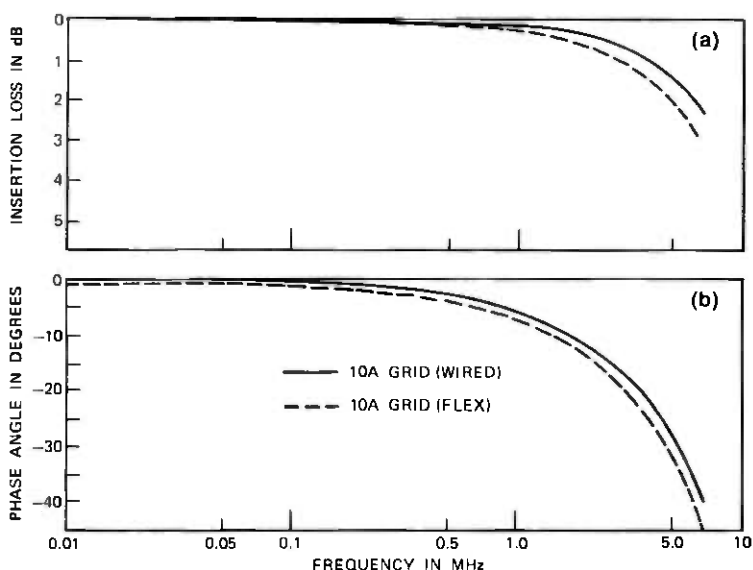


Fig. 9—(a) Insertion-loss characteristic of 10A grid. (b) Phase-response characteristic of 10A grid.

V. PROTECTION FOR REMREED NETWORKS

5.1 General

The remreed switching network provides the means for making interconnections between lines and trunks to be served by the No. 1 ESS system and also provides access to various service circuits required in handling telephone calls. For the duration of the call processing, the T and R conductors are exposed to outside plant and subjected to the operational and fault stresses that were identified in Section 2.2.

Protection for the remreed network T and R conductors is external to the network equipment frames but is associated with the network T and R conductors. The protection that is afforded depends upon the following items:

- (i) Carbon block characteristics.
- (ii) Central office cable resistance.
- (iii) Central office foreign-potential-detection circuits.
- (iv) Trunk- or junctor-circuit component-failure characteristics.
- (v) 238A-contact current-carrying characteristics.
- (vi) System-controlled actions associated with supervisory component-failure characteristics.

These items work in combination to prevent catastrophic network failures by limiting the damaging effects of electrical stress voltages and currents in both magnitude and time.

5.2 Voltage and current limiting for remreed networks

All remreed LLN network T and R conductors terminate on an office protector frame⁷ before interfacing with outside plant. At this point, 3-mil-gap carbon protectors are connected to the T and R conductors. These devices spark-over (break down) to ground when impressed by high voltages. The results of recent breakdown characterizations⁸ for the protector are given in Table V. These protector breakdown data indicate that the remreed network T and R conductors can be subject to voltages as high as 707 V rms, 60 Hz or 900 V peak for surges.

Carbon-block protectors are the only external protective devices required in Nos. 1 and 1A ESS and, from the above discussion, it is apparent that significant foreign-potential levels can enter the switching office. The carbon blocks connected to a T and R conductor pair are not selected for breakdown symmetry. Therefore, foreign potentials which exceed the lower bound of carbon-block breakdown voltages may appear on a T-R pair as a longitudinal (same voltage on T and R) or metallic (voltage differential due to one block breakdown) voltage.

As additional protection, office wiring and trunk service circuit components are designed to limit current through remreed network T and R conductors and contacts. Interframe T and R conductor wiring is 26 gauge, with a nominal resistance of 8.4 ohms per 100 cable feet. Switched connections between office distributing frames are limited to 1200 cable feet maximum to control the office insertion loss. This resistance, in addition to the impedances of trunk and service circuits, limits the current which can flow through the remreed T and R conductors.

5.3 Foreign-potential detection

Power-line-cross tests are made on lines during the initial stages of call processing.⁹ The tests are performed by certain service circuits.¹⁰

Table V — Three-mil-gap, carbon-protector breakdown characteristics

Condition	Mean Breakdown	Standard Deviation	Measured Maximum
60 Hz (rms) Surge (peak)	519 volts 707 volts	84 volts 89 volts	707 volts 900 volts

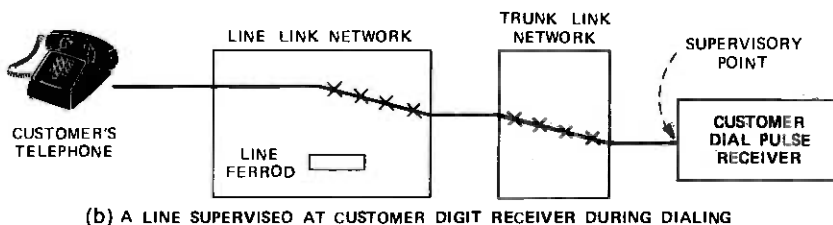
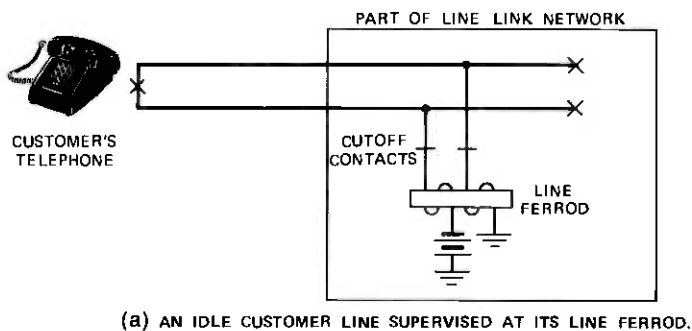


Fig. 10—(a) An idle customer line supervised at its line ferrod. (b) A line supervised at customer digit receiver during dialing.

For example, when a customer's line is on-hook, a 2A line ferrod^{5,11} is connected to the line through cutoff contacts, as shown on Fig. 10a. When a customer requests service (station set off-hook), the origination is detected by the line ferrod. The system then opens the cutoff contacts which removes the line ferrod from the line and, in turn, sets up a network path to the customer dial pulse receiver (CDPR), as shown in Fig. 10b. After the network path to the CDPR has been established, the initial action in the CDPR trunk circuit is to make a foreign-voltage test. If a foreign voltage of sufficient magnitude is detected, the call-processing procedure is abandoned. First the CDPR is released and then the first-stage network contacts are opened. The cutoff contacts associated with the line ferrod for the affected line are not restored. In addition, a trouble indication is printed on the office local-maintenance or the automatic-line-insulation-test teletypewriter.

A similar procedure is followed when ringing a line. In both cases, the actions followed ensure that the remreed network T and R contacts are switched dry. However, there is a possibility that the cutoff contacts and associated 2A line ferrod, located in the 296-3C and 296-4C remreed switch packages, could be damaged. The damage to the cutoff contact is related to the amount of current it breaks or passes in the presence of the foreign voltage. The possible damage to the 2A line ferrod is discussed below.

The ferrod¹² is a current-sensing device operating on electromagnetic principles. It consists of a ferrite rod around which is wound a pair of solenoidal control windings. In addition, a single-turn interrogate winding and a single-turn readout winding are threaded through two holes in the center of the ferrite rod. The two single-turn windings are physically separated from the pair of control windings by a plastic bobbin. The plastic bobbin is so constructed that the pair of control windings are also separated from each other. In normal operation, the ferrod is energized by the flow of dc current through its control windings, however, it can also be energized by ac current in the control windings.

The 2A line ferrod is used to detect call originations. It supplies battery and ground to the tip and ring of all loop-start lines through remreed cutoff contacts. In the case of coin or PBX ground-start lines, the line-ferrod control windings are connected in series, and supply battery power to the ring conductor through the cutoff contacts. The nominal dc resistance of each control winding, part of a pair of control windings, is 685 ohms. The guaranteed control-winding energizing current is 10 mA dc and the nonenergized current is 5.5 mA dc. The ferrod does not respond to longitudinal currents when wired in a loop-start configuration.

5.4 Foreign potential on idle lines

When a longitudinally applied foreign potential exists on an idle line arranged for loop-start operation, the 2A line ferrod shunts the foreign current to ground. The current through the ferrod winding decreases with time because the control-winding resistances increase due to heating. This proceeds until the windings short. As the windings begin to short, the current increases rapidly to a level where the windings open (blow out). The failure characteristics of the 2A line ferrod is shown on Table VI. The blow-out current of the 2A line ferrod is approximately 3.2 A.

Table VI — Typical 2A line-ferrod failure characteristic

Foreign Potential (V, 60 Hz rms)	Initial Current in Control Winding Before Shorting (A, 60 Hz rms)	Shorting* Time (s)	Blow-out† Time (s)
120	0.18	35	185
140	0.21	23	57
220	0.33	9	15
380	0.58	4	8

* After 100 s ferrod appears energized.

† Blow-out at approximately 3.2 A (rms).

It has been observed that for longitudinal power crosses in which the time to shorting is greater than 100 seconds, the current through the control windings causes the ferrite magnetic structure to heat. When its Curie temperature is reached, it loses its switching characteristics, and appears energized. When this occurs, the system identifies the power cross as an origination and the cutoff contacts operate and break whatever power cross current is flowing. In a case of this type of false origination, the power cross will be detected by the CDPR.

If the power cross is metallic, and thus flows only through one winding (which is also applicable to ground-start operation), the ferrod will energize and register a false origination request within approximately 100 to 200 ms.

5.5 Foreign potential on active lines

When a power cross occurs, it can be assumed that many of the lines affected are active. Figure 3 shows the No. 1 ESS equipment units in an active connection for intra- and interoffice calls that are vulnerable to damage.

In both types of calls, line supervision is derived from a 1C-type ferrod associated with either the junctor or trunk circuit. Fault currents due to power crosses will be carried by the office cabling, network contacts and link wiring, and junctor- or trunk-circuit battery-feed inductors in series with their associated ferrod sensors to ground. Figure 11 shows the components in junctor and trunk circuits. The major current-limiting factors in an active connection are the dc resistances of the office cabling, battery-feed inductor, and ferrod sensor.

When a battery-feed inductor and ferrod sensor are subjected to carrying fault currents of sufficient magnitude, they will heat and short. When this happens, the only impedance that limits the fault current is the office cabling resistance. The maximum allowable office cabling resistance in No. 1 ESS is 100 ohms, 50 ohms in both the tip and ring conductors. Therefore, after the battery-feed inductor and ferrod sensor windings short, the minimum rms fault current flowing, due to a 267-V rms potential, is approximately 5 A. The lower 3-sigma breakdown limit of the carbon-block protector is 267 V rms. This current will flow in both the T and R conductors. The power-cross shorting characteristics of No. 1 ESS battery-feed inductors and associated ferrod sensor windings are shown in Table VII, and their blow-out characteristics in Table VIII.

5.6 Remreed-contact-failure mode

When closed, the 238A remreed contact has a quiescent remanent-flux level. The effects of passing high-fault currents, ac, dc, or surge,

TRUNK CIRCUIT
(SHOWING FERROD SUPERVISORY FEATURE)

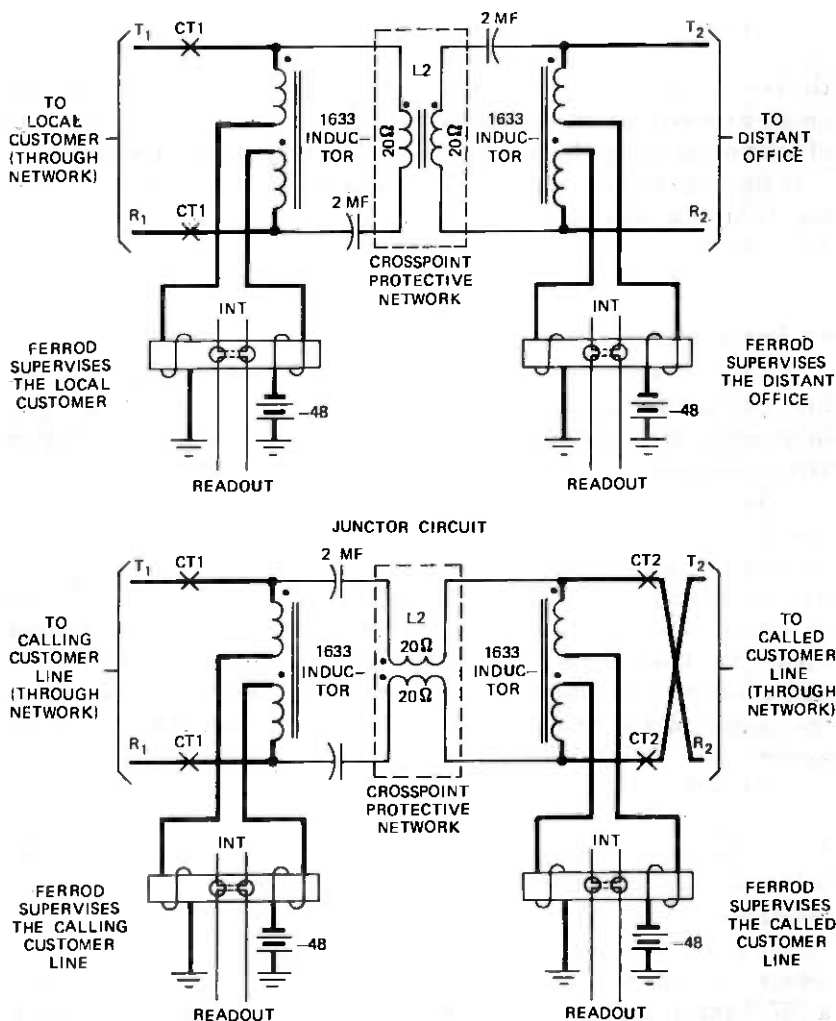


Fig. 11—Trunk circuit showing ferrod supervisory feature.

tend to reduce the remanent-flux level to a value equal to or less than the release-flux level and, therefore, cause the contact to open. Arcing, which occurs during opening, causes contact damage. In an active connection, there are eight contacts in series in both the T and R paths. The action of any one contact opening, due to high-current stress, will remove the fault-current return path and protect the remaining contacts. This action is significantly different from that

Table VII — Coil-shorting characteristic of line-supervision inductor and associated ferrod

Initial Fault Current (A, 60 Hz rms)	Shorting Characteristics	
	Longitudinal Cross Time (s)	Metallic Cross Time (s)
0.5	>100	—
0.6	40	250
0.7	30	70
0.8	25	55
0.9	20	40
1.0	16	32
1.1	13	25
1.2	10	20

experienced on sealed contacts, which are held closed by external remanent-flux fields, as is the case for ferreed crosspoints. These types of contacts would tend to repeatedly open and close and then weld when passing high-fault currents and this failure mode could propagate to all contacts in series. The remreed contact offers an improvement in this regard. In the case where the power-cross fault-current flows through remreed network contacts, the maximum fault current is limited to 3.2 A rms, which is the current magnitude where the contact opens.

Fortunately, the combined action of the remreed contact, transmission, and supervision components subjected to a power cross, taken as a whole, and the corresponding operational characteristics of the Nos. 1 and 1A Ess systems prevent fault currents of high magnitude from flowing in the network links and office cable for the relatively long periods required for the individual trunk components to blow out. The maximum fault current flowing in the network T and R conductors

Table VIII — Blow-out characteristics of line-supervision inductor and associated ferrod

Current (A, 60 Hz rms)	Blow-out Characteristics	
	Longitudinal Cross Time (s)	Metallic Cross Time (s)
2.5	—	—
3	1000	—
4	100	—
5	20	—
6	4	200
7	1	7

and contacts is 3.2 A rms and the maximum time this current flows is 42 seconds. The 3.2 A limit is controlled by the action of the 238A contacts. When open, the fault current stops. The 42-second time interval is related to the shorting time of the trunk- or junctor-circuit supervisory ferrod. When its control winding shorts (this occurs before the 3.2-A current level is reached) or the battery-feed inductor windings open, the ferrod deenergizes. The system will recognize this as a disconnect. Depending on system load, it will take from 11 to 42 seconds to open the cut-through contacts of the trunk or junctor circuit, removing all current paths to ground.

In addition to the current-carrying capability just described, the 238A remreed contact is designed to support, when open, a 900-V peak surge transient and 800-V peak, 60-Hz potential without breakdown.

5.7 Remreed switch and grid-link wiring

In the previous section, the remreed contact-failure characteristics were described. The remaining parts of the remreed network T-R paths are composed of switch printed-wiring planes and grid-link wiring. These interconnecting T-R links have been designed to carry foreign-potential currents in excess of 3.2 A rms without damage. They also are capable of supporting 900-V peak surge transients and 800-V peak, 60-Hz potentials without breakdown between T-R pairs or T-R conductors to ground.

VI. SUMMARY

In designing the remreed networks, special attention was given to the resulting transmission characteristics, and to assuring that they were sufficiently rugged to withstand the electrical stresses which they could encounter.

The geometries of the T and R conductors were carefully controlled to minimize susceptibility to interference, maintain a good balance to ground, and minimize insertion loss and distortion. As a result, the remreed networks provide excellent transmission quality in all present applications and are capable of supporting wideband analog and digital switching applications as they may arise in the future.

The design also assures that the remreed networks can withstand the normal operational stresses over their design lifetime and that they will survive most fault stresses without damage. Under very severe fault conditions, the design assures that failures will occur in an order which minimizes the loss of switching capability.

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Remreed Switching Networks for No. 1 and No. 1A ESS:

Remreed Contact and Switching Network Evaluation

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The performance evaluation of the remreed switching network begins with a study of failure modes of the remreed contact and ends with a discussion of results from a field study. Remreed contact-reliability test results show low early failure rates due to high contact resistance and contact sticking. High contact resistance, which characterizes the wear-out mode of failure, is discussed. Remreed switch evaluation results are given. Finally, early field performance of the remreed switching network is assessed in a study using in-service trunk link networks as the source of data.

I. INTRODUCTION

During the development of new switching hardware, many evaluations and tests are performed. The broad objectives of these tasks are to prove and assure that the performance and reliability of the new equipment will meet Bell System needs. High on the priority list of objectives are (i) a reliable method of manufacture, (ii) an in-service life of 40 years, and (iii) maintenance-free performance during operation. This paper summarizes the work conducted at Bell Laboratories on the remreed contact, switch, grid, and frame design to meet these objectives.

To show that the broad objectives could be met by the remreed design, several specific goals had to be achieved. They are:

- (i) The adequacy of the new hard-gold contact surface had to be established. The ferreed sealed contact, predecessor to the remreed sealed contact, has a diffused gold-silver plated contact surface.

- (ii) The ruggedness of the sealed contact in the new switch package had to be established to assure that high initial failure rates, induced by handling and shipping, did not occur.
- (iii) The point where the failure rate of the sealed contact begins to increase, i.e., where the contact begins to wear out, had to be determined. At this point, a mechanism of contact erosion from small arc discharges leads to the high-resistance failure mode. The design goal regarding this failure mode was to produce contact surfaces that exhibited failure rates the same as or lower than the failure rates of the ferreed contact.
- (iv) The reliability of the control circuits and hardware had to be determined. The remreed network represents the first application of 1A processor technology,¹ including the 946/947 circuit pack connector family and 3-volt collector diffusion isolation (CDI) integrated circuits. Additionally, many of the functions accomplished electromechanically in the ferreed network are replaced in the remreed design with discrete semi-conductors (i.e., PNP transistors and diodes).
- (v) The establishment of low failure rates for remreed networks in service was needed to verify many assumptions made during the design phase. This was achieved by a field study conducted in various central offices.

Several evaluation methods were used to study remreed equipment. The remreed sealed contacts were "screened" on a computerized data acquisition system. Screening is a term used to describe a testing technique that determines early failure rates of the sealed contact. In general, application of this technique requires very large sample sizes—5000 to 50,000 contacts per test—which are tested for only 1000 operations.

Remreed switch packages and grid assemblies were examined for their ability to withstand levels of shock and vibration normally encountered in shipping via rail and motor freight. In addition to these tests, the switch package underwent exposure to elevated levels of temperature and humidity in an effort to induce early failure. Throughout all of these tests, the operational performance, contact resistance, and sticking behavior of the equipment was measured and/or monitored.

In April 1974, a remreed quality study was initiated. Study offices selected were among those first manufactured. Considerable manufacturing experience had been gained by this time since several hundred trunk link networks (TLNs) containing over 30 million remreed sealed contacts had been shipped to the field. Some of these net-

works were selected and included in the study. The primary objective of the quality study is to measure the failure and replacement rates of in-service remreed apparatus. The study is fault-oriented, that is, attempts are made to analyze and understand each failure, why it occurred, how it was identified, and how it was corrected.

In an effort to offer a snap-shot view of the usefulness of the evaluations, studies, and surveys, a few results are summarized here. The quality study completed in October 1975 indicates that the remreed sealed contact in this application achieved a very low failure rate. The upper 95-percent confidence interval on the FIT rate is 2.4 while the observed rate is 1.5 FITs. (Here the term FIT is used in its usual sense: 1 FIT is equal to one failure in 10^9 device hours.) The quality study is described in more detail in Section IV.

Another point should be made now regarding the use of a FIT rate. In this paper, the sealed-contact failure rates resulting from laboratory tests are expressed in terms of failures per contact per operation. Then, by estimating the number of times the contact is operated per year, the failure rate is converted to a FIT rate. This is different from the common use of a FIT rate because the failure modes are operation-dependent rather than time-dependent.

The low FIT rates didn't just happen, they are the result of a long, involved, and complex evaluation program that identified several problem areas. When a problem was identified, steps were taken to redesign hardware when it was appropriate and to implement new requirements and tests where necessary.

II. REMREED SEALED CONTACT

The objectives of the sealed-contact evaluation work focused on (i) determining early failure rates and failure mechanisms of the hard-gold plated contact surface and (ii) determining when wear-out mechanisms caused the sealed contact to become unreliable. Two important failure modes exist for the sealed contact. These are the high contact-resistance mode and the failure-to-release or stuck-contact mode. Both early life and end-of-life performances exhibit these modes.

Reliability theory states that device performance generally fits a "bathtub" curve similar to the one sketched in Fig. 1 (shown on a linear grid). The bathtub curve is a plot of failure rate or hazard against time and has three regions: early or premature failure, useful life or constant hazard, and wear out. The first or initial portion of the curve is the result of early failures which ultimately can be traced to a defective part or an improperly performed step in the manufacturing process. This portion is examined by contact screening tests. The

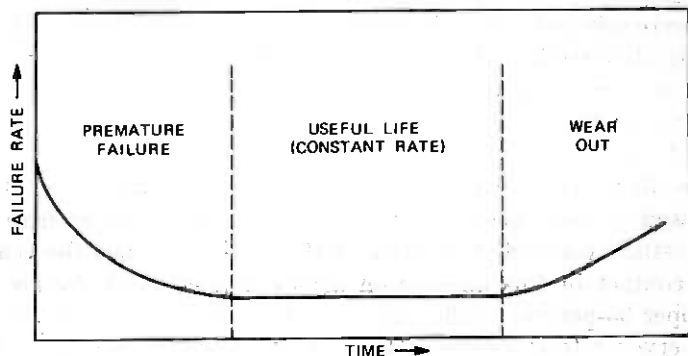


Fig. 1—Typical "bathtub curve."

useful life portion of the curve is a measure of the long-term failure rate and reflects the design reliability of the device in its application. This portion is examined in a field study. If the hazard is truly constant in time, then the reliability can be described mathematically by the exponential distribution and a FIT rate can be determined. The wear-out portion of the curve is, as the name suggests, the time when devices begin to fail as the result of normal use. This part of the curve, examined by life testing, indicates that the stress of use and/or device degradation increases the hazard.

2.1 Data collection

The remreed sealed contact was subjected to many different tests during its development. This section briefly describes one of the tests used to evaluate the 238A sealed contact. The testing facility is a computer-based, data-acquisition system² capable of testing 114 sealed contacts at the rate of eight cycles (operate and release) per second. The system does on-line data analyses as it collects the data because of memory-size limitations (both core and disk). During each cycle, the contact is electrically interrogated two times, once to measure its resistance in the operated state and once in the release state to determine whether it failed to release (a stuck contact). Throughout the test, the computer maintains a counter which indicates the number of test cycles completed (number of contact operations completed).

The on-line data analyses are performed quickly enough so that data from succeeding measurements are not lost. The resistance measurements are compared, contact by contact, to eight software-set resistance-threshold values. (These have been chosen to include all possible resistance measurements.) As the test proceeds, counters assigned to each threshold value by contact accumulate data and, when

these data are displayed, the result is a histogram for each contact. In addition, three of the eight threshold values have associated tables used to record the current operation number when the contact-resistance measurement first exceeds the assigned threshold value. The contact measurements for failure to release are treated in a similar manner to the resistance data except that there is only one threshold value and its associated first-failure table.

After the test is complete, the resistance histograms and first-failure table data are written from core memory to disk memory and are ready for off-line analyses.

2.2 Early life

In evaluating the remreed sealed contact to determine its early life characteristic, the test data are converted to a hazard statistic using the following formula.³

$$z_d(x_i) = \frac{N(x_i) - N(x_i + \Delta x_i)}{N(x_i)\Delta x_i}, \quad (1)$$

where

$z_d(x_i)$ = empirical hazard or failure rate in failures per contact per operation.

x_i = the operation number at the beginning of the i th interval.

$N(x_i)$ = the number of contacts that have not failed by the beginning of the i th interval.

$N(x_i + \Delta x_i)$ = the number of contacts that have not failed by the end of the i th interval.

Δx_i = length of the i th interval in operations.

Using this relationship, $z_d(x_i)$ is calculated for various intervals and plotted at the midpoint of the interval. Figure 2 shows the 238A remreed sealed-contact hazard functions for stick failures and 150-milliohm and 100-ohm resistance failures versus operation number on log-log graph paper. (Two widely separated resistance levels are shown; however, in general, circuit reliability depends on many different levels of resistance. Higher reliability (lower failure rates) accompany greater tolerance to contact-resistance changes.) It is interesting to note that each failure mode produces a straight line with a negative slope. The three hazard curves can be fitted to the equation

$$z(x) = Kx^m, \quad (2)$$

where K and m are constants. This equation, for $m > -1$, is the hazard function for the Weibull distribution with a probability density func-

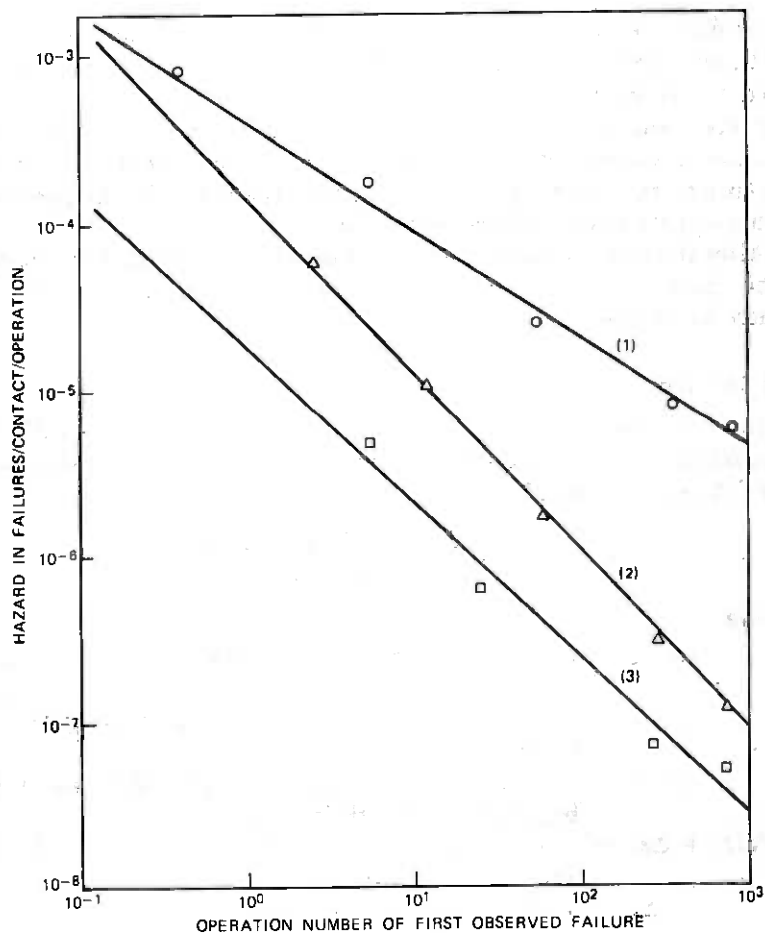


Fig. 2—Screening data for remreed sealed contact: (1) 150-milliohm failure level, (2) 100-ohm failure level, (3) release failures (stuck contacts). Sample size: 158,738 contacts. Data are plotted at midpoint of selected interval.

tion written in the form:⁴

$$f(x) = Kx^m \exp \left[-K(x^{m+1}) / (m + 1) \right] \quad (3)$$

Mode	m	K
Resistance > 150 milliohms	-0.68	4.34×10^{-4}
Resistance > 100 ohms	-1.1	1.56×10^{-4}
Sticking	-1.0	3.12×10^{-5}

The Weibull distribution was not used in two of the three cases shown because the requirement for m was not satisfied.

Before continuing, some additional information about Fig. 2 would be useful. In the first place, a contact resistance which just exceeds 150 milliohms probably will not be detected by the No. 1 ESS system and, hence, it will not be removed from the system. In fact, in some cases, the 100-ohm contact could go undetected. However, the hazard is that such high contact resistances are prone to generate noise from mechanical disturbances and this could impair service. An additional point is that the interpretation of the hazard statistic assumes that once a contact failure is observed, that contact remains a failure for each succeeding operation. Data showing persistence of failure of sealed contacts indicate that this assumption is violated a high percentage of the time. Presently, software and data-handling routines are being developed to gather and analyze multiple-failure data. For the present, and since the first-failure event does not imply failure on all succeeding operations, this assumption is believed to be a good approximation and will be used.

Sealed-contact failure due to sticking is another matter. When a sealed contact sticks, it produces a circuit malfunction which is detected and an error message is printed on the No. 1 ESS teletypewriter. A sealed contact which persists in the stick-failure mode will cause an error message each time the system detects the circuit malfunction. Under these conditions, the sealed contact will probably be replaced.

This evaluation leads to the conclusion that the early failure modes describe a type of early failure behavior of the contacts with decreasing hazard as a function of contact operations. A study of the number of expected contact operations as a function of contact-circuit application yielded a wide-ranging distribution which had its 50-percent point at 1.25×10^4 operations per year. This result, together with the above test results, means that after six months of service, the expected hazard for the two resistance levels and the stick modes are 1.1×10^{-6} , 1.04×10^{-8} , and 5×10^{-9} failures per contact per operation, respectively.

A study of the effect of the large range of the expected number of contact operations together with the decreasing hazard shows very little difference in the performance of the sealed contacts after the first six months of service. The reason that this result is obtained is that the higher hazard (due to fewer operations after six months) is multiplied by a lower yearly operation rate.

2.3 End-of-life

Life testing was conducted in such a way as to accelerate wear-out mechanisms. Two types of failure modes existed during these tests: high resistance due to contact erosion and failure to release (or stick-

ing). Contact erosion was accelerated by using a charged, twisted-pair cable to produce a low-energy-arc discharge, which causes a transfer of metal from one reed to the other. The acceleration results from a discharge occurring on each operation, and since the polarity of the charging voltage is fixed, the metal transfer is always in the same direction. In service, arcing does not occur every operation and the polarity direction tends to be random. After thousands of discharges, sufficient metal has been transferred so that the contacting surfaces become base-metal surfaces. The result is an increase in contact resistance.

The stick-failure mode is accelerated by magnetostrictively scrubbing the contact surfaces every 2000 operations. This is accomplished by operating each contact and then cycling the coil-drive current between a full saturate value of 210 ampere-turns and zero ampere-turns. Five cycles at one cycle per second are used.

Figure 3 shows a hazard plot for three contact-resistance-failure levels as a function of contact operations. The contact-resistance curves in the wear-out region have the characteristic shape of the log-normal distribution and in the early-life portion of the curve, the Weibull distribution. The useful-life portion of the curve lies below a failure rate of about 1.6×10^{-8} per operation for the 1.0-ohm level.

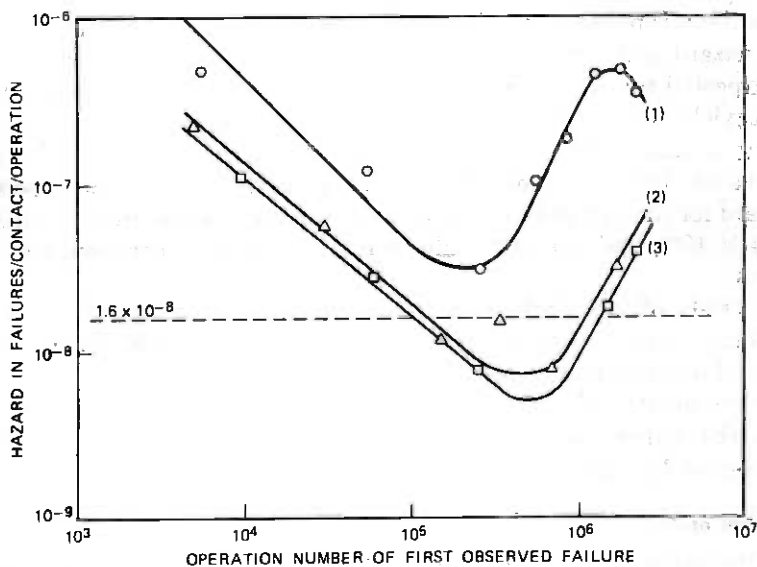


Fig. 3—Life test data for remreed contact: Failure rate vs operation number of first-observed failure for (1) 150-milliohm resistance level, (2) 500-milliohm resistance level, and (3) 1 ohm resistance level. Sample size: 456 contacts.

Since, in the field, erosion does not occur on every contact operation, the above rate is a conservative estimate. Nevertheless, these data lead to an estimated failure rate of about 18 FITs per contact during most of the life of the contact. It should be pointed out that even at the higher expected operation rates, the 1-ohm-failure data suggest that several years of use are required to reduce the failure rate to this level. No estimate of failure rate for the contact-stick mode was made from the data gathered during contact tests, because the magnetic field distribution of the test coil does not simulate the magnetic field found in the remreed switch crosspoint.

III. REMREED SWITCH

The remreed switch was evaluated with respect to thermal and mechanical environments. The purpose of the evaluation was to determine if the structural integrity and performance of the switch are satisfactory with respect to the extremes of these environments. Such conditions can occur during handling, transit, and service conditions. During testing, the limits of the expected environments were increased in an effort to accelerate the processes of degradation and aging. In all cases, caution was exercised such that unreasonable changes or new failure modes were not introduced.

Finally, in addition to thermal and mechanical evaluation, the remreed contact was investigated for sticking tendencies within the normal crosspoint environment. The sticking mechanism was accelerated by frequent magnetostrictive scrubbing.

3.1 Mechanical environment

The mechanical environment to which equipment may be subjected consists of shock pulses and vibrational stresses induced during handling and transit. Generally, the maximum shock and vibration inputs occur in the nonoperating condition during commercial transportation.

To simulate the shock pulses and vibrational stresses that may be encountered in transit, the shock and vibration levels⁵ listed below were employed.

Vibration	Frequency	Acceleration	Displacement
	7-500 Hz	Constant 1.5 g	Variable
Shock	Amplitude	Duration	Shape
	15 g	0.011 s	$\frac{1}{2}$ sine wave
	30 g	0.011 s	$\frac{1}{2}$ sine wave

During the vibration testing, a remreed switch was vibrated in each of its three mutually perpendicular axes at a frequency sweep rate of one octave per minute. The response to the excitation was monitored with accelerometers placed on the switch. All resonant frequencies were sustained for fifteen minutes.

During the shock-testing portion of the evaluation, a packaged switch was tested six times in each direction of its three mutually perpendicular axes.

The samples tested were the 296-1B and 296-1C codes of remreed switches.⁶ To determine structural and electrical stability of the designs, initially and throughout the study, visual examinations as well as measurement of the following electrical parameters were performed.

- (i) Operate sensitivity.
- (ii) Release sensitivity.
- (iii) Contact resistance.

Studies of the remreed switch vibrated at the prescribed level revealed a fundamental resonant frequency of 75 Hz and a peak acceleration of 24 g's. This occurred when the switch was mounted with the shunt plate positioned horizontally and the excitation in a vertical direction. No damage of the switch components, including the contacts, was found after the vibration tests and there were no significant changes in the electrical parameters.

Next, the remreed switch was placed in its Styrofoam* shipping container and was subjected to the specified levels of shock and vibration. Accelerometer responses showed a reduction in peak amplitude to 8 g's due to the damping effects of the shipping container. No significant changes were observed in either the structure of the remreed switch or in the measured electrical parameters.

3.2 Thermal environment

The environments used consisted of temperatures and humidities which represented conditions beyond those normally encountered during transit and in service. The purpose of the test is to determine the ability of the remreed switch to withstand extreme environmental conditions as well as to accelerate potential failure mechanisms.

The environmental exposure was an accelerated test using the temperature and humidity extremes listed below. To restate for emphasis, these conditions are higher than those occasionally encountered.

*Trademark of Dow Chemical Company.

1. Room Condition*
2. 150°F @ 5% R.H.
3. Room Condition
4. -40°F @ 5% R.H.
5. Room Condition
6. 150°F @ 95% R.H.
7. Room Condition
8. 35°F @ 95% R.H.
9. Room Condition

The remreed switch test samples remained at each of the conditions listed until the electrical parameters being measured had stabilized.

Results of tests conducted with early, nonproduction samples indicated that some areas of thin plating on the ferrous metal parts led to corrosion spots. This was investigated and corrected in production samples.

Exposure of a 296-1C code remreed switch to the prescribed temperature and humidity caused no serious degradation of the materials of the switch. With respect to the electrical parameters of the switch, no problems were observed as a result of exposure to the experimental conditions; however, because of the possibility of changes in contact resistance at the low-temperature condition, operation of the switch below 32°F is not recommended.

3.3 Contact sticking in the remreed switch

This section documents results of a contact-stick evaluation of five 296-7A preproduction remreed switches. This particular switch design was used because of the ease of detecting and identifying a stuck contact. The design, called the 7A package, was intended for a signal-distributor application and has one lead of each contact brought out to a front or rear connector pin such that a one-for-one correspondence exists between connector pins and sealed contacts. The package contains two 8 × 8 arrays of crosspoints with two contacts per crosspoint and, as far as the contacts are concerned, it is identical to the other remreed switches.

To perform this evaluation, a special computerized test set was constructed. It contained a parallel 16-input solid-state scanner which was used to measure contact release time, a measure of sticking tendencies, to verify contact operation, and to sense stuck contacts. During the life test, every crosspoint of one 8 × 8 array was operated simultaneously with an LRC discharged current pulse. Next,

* Typically 74°F @ 40 percent R.H.

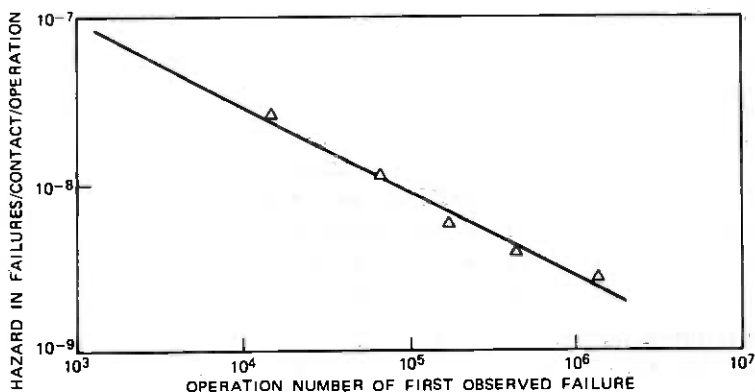


Fig. 4—Life test data for remreed switch: stick-failure rate per contact per operation vs contact operation number. There were three magnetostrictive contact scrub operations per operation. Sample size: 1280 contacts.

three more operate pulses were executed and the scanner was used to verify that all contacts had been operated. The three additional operate pulses produce magnetostrictive scrubbing. Finally, a release pulse was executed, one row at a time, and the release time was simultaneously measured for each of the 16 contacts in the row. If, after 5 ms, the contact was still not released, it was recorded as a stuck contact.

The stick data, plotted as stick failures per operation versus the number of contact operations, are shown in Fig. 4. The shape of this curve does not indicate that a wear-out mechanism might be commencing. Each of 1280 contacts was tested for 2×10^6 operations. A conservative estimate of the failure rate for the stick mode is 2.8 FITs. This is conservative because the remreed circuit design does not permit a crosspoint to be driven by consecutive, multiple operate pulses.

IV. CIRCUIT DESIGN

The circuit design adhered to a number of design principles aimed at ensuring that the devices were operated within their capabilities in order to maintain the validity of the reliability forecasts. These design principles include:

- (i) Worst-case circuit design taking into account minimum and maximum battery and minimum and maximum temperature conditions as well as maximum circuit occupancy.
- (ii) Derating of power and tolerance ratings of components to assure margin between the worst theoretical conditions and actual operating conditions.

The initial remreed controller design used only existing components and devices that had already undergone laboratory life testing to forecast reliability and, in many cases, had the benefit of considerable field experience in other systems. Subsequent design activity aimed at achieving further cost reduction has introduced some new devices designed specifically for remreed application. These are undergoing similar laboratory life tests prior to their introduction.

Laboratory tests were conducted with prototype and early production models to verify the margin and integrity of the design. These tests included simulated installation and traffic load runs in a No. 1 ESS system lab at elevated temperature (aisle ambient of 120°F) and minimum battery. The results of these tests were used by the designers to identify weaknesses and "fine tune" their designs.

Once the first remreed networks went into service, an extensive reliability study was undertaken to closely monitor performance. The study and some early results are reported in Section VI.

V. NETWORK MAINTAINABILITY

While failure rate is a measure of reliability, maintainability is also a measure of the ability of the design to provide the expected service. There are three principal techniques used in the remreed design to enhance network maintainability, given the forecasted device reliabilities described in Section IV. These are duplication, partitioning, and connectorization. The use of these techniques permits the system to meet its dual maintainability objectives: a loss of less than one call in 5000 and less than one hour of accumulated downtime per line in 40 years.

In general, all portions of the remreed network control that affect service to more than 64 lines or trunks are duplicated. Care has been taken in the design to assure that a failure occurring in one controller is isolated so that the system's fault-recognition-and-maintenance program can correctly switch in a working, mate controller.

The switching fabric (i.e., sealed contacts, switches, and associated wiring), as well as most of the pulse-steering PNP transistors and diodes, are not duplicated. The approach taken here is to partition the fabric in order to minimize the effect of a fault on service. Most sealed-contact failures, for example, affect only isolated paths in the network and, therefore, create only a slight reduction in the network traffic capacity. Diode and PNP transistor failures affect at most 64 lines or trunks.

All remreed apparatus is connectorized to facilitate replacement and minimize downtime. Most of the controller circuits, including all of the system bus interface, translators, and timing circuits, are mounted on

plug-in circuit packs. The unduplicated switching fabric, pulse-steering diodes, and PNP transistors are mounted in fully connectorized grid units.

VI. FIELD RESULTS

When the remreed quality study began on April 1, 1974, several hundred remreed trunk link networks (TLNs) had been shipped to the field. These networks contain over 30 million remreed sealed contacts, 1 million 1A silicon integrated circuits (sics), 6 million 446F diodes, and 0.5 million 59A PNP transistors.

The primary objective of the study was to measure the failure-and-replacement rates of in-service remreed apparatus. The study is fault-oriented, that is, attempts were made to analyze and understand each failure, why it occurred, how it was identified, and how it was corrected.

Secondary objectives included an evaluation of maintainability, identification of design weaknesses, and establishment of procedures for further studies on line link networks. Maintainability includes the effectiveness of diagnostic aids. One measure of diagnostic resolution is the number of packs replaced to clear a single fault.

The number of offices in the study was limited to seven to establish and maintain a good person-to-person working relationship with central office personnel. It was recognized at the time the study was organized that office-to-office variations probably existed and to measure this effect, offices of various sizes should be studied. Instead, for economic reasons, and since hardware variations were of greater importance, large offices were favored. In this way, it was hoped that a responsive arrangement to provide credible failure data would develop. Therefore, the following criteria were used to select study offices:

- (i) The offices had to have large number of TLNs to maximize the total sample of TLNs in the study.
- (ii) The offices had to have been in service at least five weeks to allow an operating base free of outside plant, trunk, and other system problems that might make it difficult to get reliable data on network performance.
- (iii) The office had to have a history of good system performance (i.e., a sufficiently low level of error messages) to ensure that nonreliability problems had been cleared during the five-week period after cutover.

The study required a distinct sharing of responsibilities by Bell Laboratories, Western Electric, and the operating companies. Bell Laboratories furnished replacement parts, consulted with the operating

company on special problems, and performed and coordinated analyses on all failed parts. Bell Laboratories then published reports on all data obtained.

The data-collection procedure used is shown in Fig. 5. Under this procedure the initial trouble is identified and cleared by the operating company craftsperson using normal procedures. Once a trouble has been cleared, the craftsperson prepares a trouble report and contacts the Bell Laboratories engineer. A parallel form is filled out at Bell Laboratories and a trouble number is assigned. The operating company then sends the suspect apparatus directly to Bell Laboratories and a

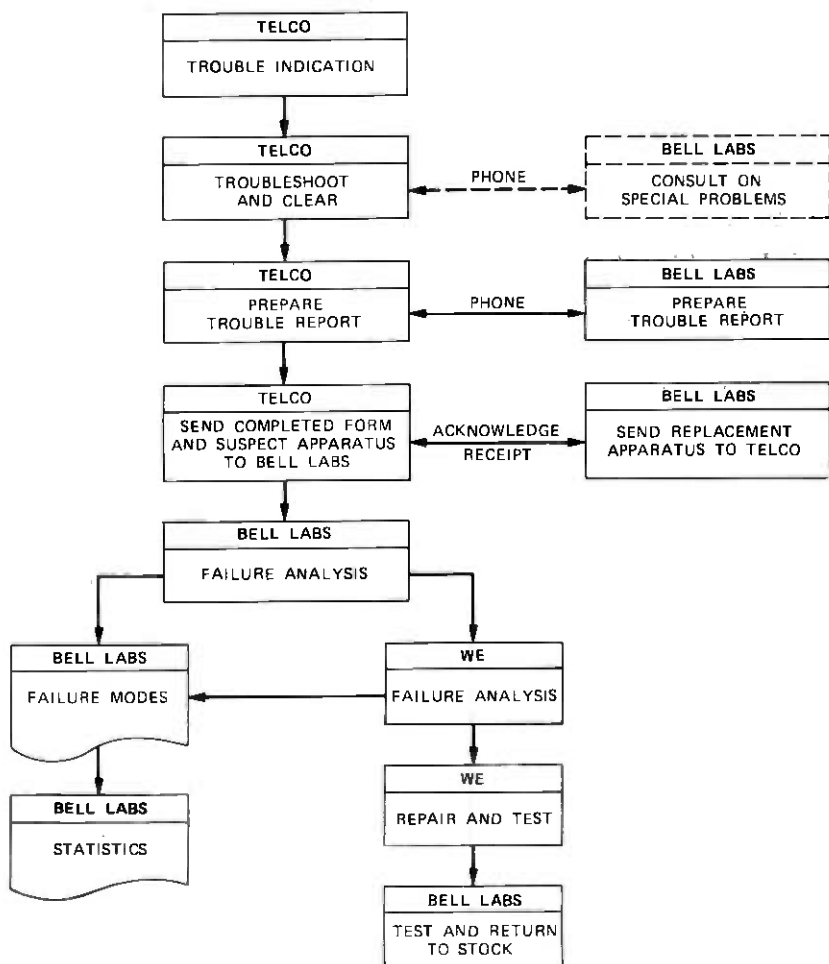


Fig. 5—Trouble analysis and evaluation procedure.

replacement is sent to the operating company. (This procedure ensures Bell Laboratories' participation in the failure analysis.)

The returned apparatus is matched up with its trouble report and tested in Bell Laboratories' systems laboratory and by Western Electric on standard factory test facilities. If the reported trouble is reproduced under test, the failing device is removed and sent to the responsible device organization for a more detailed analysis. In the case of multiple replacements, a careful analysis of the trouble report and the returned apparatus identifies the cause of failure. In such cases, the identified cause is counted as a failure, with the remaining apparatus counted only as a replacement whether damaged or not.

The detailed trouble report was valuable when difficulty was encountered in reproducing the reported trouble. Where the trouble report pointed to a device, a parametric analysis was conducted. In the case of grid failures, the trouble report enabled an individual sealed contact or printed wiring path to be analyzed. This practice led to a minimum number of "no trouble found reports". In the few cases where the problem could not be identified, the suspected apparatus was returned to the operating company and retested in its original location.

Table I lists observed failure rates and 90-percent-confidence intervals along with other pertinent information after 18 months of field monitoring for several devices. The study showed that the confidence intervals for the 446F diode, the 59A PNP transistor, the 66S transistor, and sic_s fell below the expected failure rate. The observed confidence interval of the 238A sealed contact matched the expected failure rate. However, the observed rate is lower than predictions based on accelerated laboratory tests. (The expected failure rate of one to two FIT_s is taken from a previous field study of 237B sealed contacts in No. 1 ESS working systems.)

Since the quality study produced failure-rate estimates periodically through the term of the study, time-dependent reliability information was obtained. An example of such information for 238A sealed contacts

Table I — Results of the trunk link network quality study

Device	Cumulative Device Hours	Expected* Failure Rates	Study Results		
			Observed	Lower 95% Confidence Limit	Upper 95% Confidence Limit
1. 238A Remreed Contact	3.1×10^{10}	1-2 FIT	1.6	1.3	2.0
2. 446F Diode	5.4×10^9		0.2	~0	0.9
3. 59A PNP Transistor	5.3×10^8	20	5.7	1.5	14
4. 66S Transistor	8.6×10^8	30	14	8	23
5. sic _s (137 type)	7.7×10^9	10	2.6	0.5	8

* Design information.

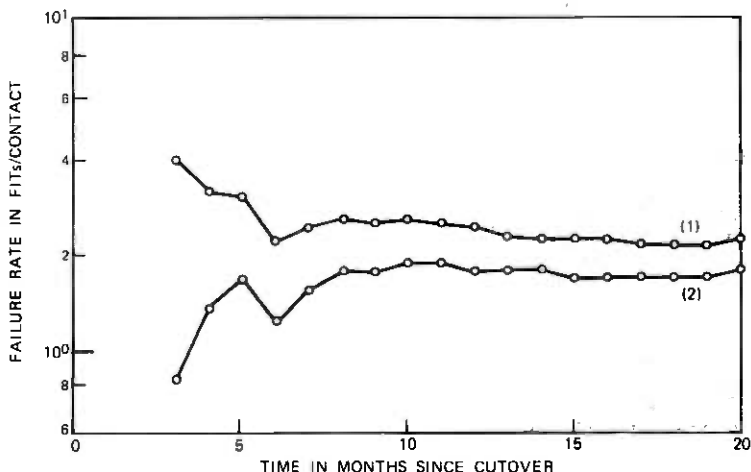


Fig. 6—Field-survey results of remreed contacts: time vs (1) upper 95-percent confidence level and (2) observed failure rate.

is shown in Fig. 6. Further analyses of the contact failures indicate that approximately 30 percent were due to sticking and 70 percent were due to high-contact resistance or contacts that failed to operate.

VII. SUMMARY

We have described in part some of the methods and philosophies of the evaluation program for the remreed contact and associated apparatus and equipment. For purposes of brevity and conciseness, the details of the tests were held to a minimum; additionally, many of the experiments performed in the course of remreed hardware evaluation were not mentioned. The several techniques used in these evaluations have been instrumental in achieving our high-reliability objectives: (i) large sample sizes were used to improve confidence, (ii) simulation procedures were employed to model the real world, and (iii) failure-mechanism acceleration was designed into the experiments in an effort to reduce study and testing times to manageable levels. In addition, a remreed quality study was instituted to verify that these objectives had been met.

VIII. ACKNOWLEDGMENTS

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to the many operating company people at Bell of Pennsylvania, Illinois Bell, Michigan Bell, Northwestern Bell, Ohio Bell, South Central Bell, and Southern Bell who tirelessly offered their time and assistance during the field evaluation.

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Contributors to This Issue

W. E. Archer, B.S. (Physics), 1966, and M.S. (Physics), 1968, University of Akron; Bell Laboratories, 1968—. Mr. Archer has been working on the development of electromagnetic contacts and crosspoints.

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R. J. Gashler, B.S. (Physics), 1963, Fairleigh Dickinson University; M.S. (Physics), 1965, Stevens Institute of Technology; Bell Laboratories, 1963—. At Bell Laboratories, Mr. Gashler first worked on the development of sealed contacts for No. 1 ESS and later on the vacuum deposition of magnetic materials. Currently, he is supervisor of the dry reed relay, ferrod, remreed, and ferreed switch group.

T. G. Grau, B.A., 1960, Ohio Wesleyan University; M.S., 1962, Ohio State University; Bell Laboratories, 1960—. Mr. Grau has worked on studies of wire-spring relays to determine the effects of proposed design changes. He holds a patent describing a flux-limiting technique in magnetic-latching relays. He has designed a family of magnetic-latching, miniature, wire-spring relays and applied several of these relays to circuits. He has been responsible for testing exposed- and sealed-contact switching apparatus and connectors. Mr. Grau is presently supervisor of the Connector Evaluation and Reliability Group.

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James C. Kennedy, B.S.E.S., 1967, Pennsylvania State University; M.S.E.E., 1968, Stanford University; Ph.D. (E.E.), 1971, Stanford University; Bell Laboratories, 1967—. Mr. Kennedy did the basic planning and design of the No. 1 ess remreed line scanner including the evaluation of alternative scan elements and control schemes. He is currently working on hardware architectures to implement new No. 1 ess switching features. Member, Phi Beta Kappa, Tau Beta Pi, Sigma Xi, Pi Mu Epsilon.

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Warren A. Liss, B.S.E.E., 1961, City College of New York; M.S.E.E., 1963, New York University; Bell Laboratories, 1961—. Mr. Liss did the design and development of the No. 1 and No. 2 ess centrex attendant's console lamp control circuit and was responsible for the basic maintenance plan on the Electronic Community Dial Office

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R. I. Narney, Associate Degree of Electrical Technology, 1967, Ohio Institute of Technology; Bell Laboratories 1969—. Mr. Narney is currently responsible for the operation and maintenance of a computerized data acquisition system that is dedicated to evaluation of sealed contacts.

K. M. Olsen, B.S. (Chemistry), 1935, Cooper Union; M.S. (Metallurgical Engineering), 1942, Columbia University; Bell Laboratories, 1929-1975. At Bell Laboratories, Mr. Olsen was a supervisor in the Metallurgical Department responsible for alloy development and metallurgical processing. He was responsible for the development of the high-purity nickel alloys used as cathode materials in the long-lived vacuum tubes used in the repeaters in early submarine cables. He was also responsible for the development of the first commercial quality superconducting niobium-tin wire.

R. N. Rath, Diploma, 1966 (Electronics and Instrumentation Technology), Penn Technical Institute; Bell Laboratories 1966—. Mr. Rath has worked on life testing of wire-spring and flat-spring relays and has been involved in environmental testing of the miniature cross-bar switch and the remreed switch package. Currently, Mr. Rath is a member of a team involved in a field study of connectors used in the Bell System.

P. W. Renaut, B.S. (Physics), 1960, City University of New York, M.S. (Physics), 1963, New York University; Bell Laboratories, 1960—. Mr. Renaut's early work at Bell Laboratories consisted of various studies of dry reed sealed contacts. His work in the area of sealed contact development culminated in the development of the remreed contact. Currently, as supervisor of the connector contact development group, his work is directed toward a reduction in the amount of gold used by the Bell System for connectors. Member, Phi Beta Kappa.

James R. Smith, B.E.E.T., 1970, DeVry Institute of Technology; Bell Laboratories, 1970—. Mr. Smith worked on the circuit design of the No. 1 ESS wideband switching network and later took over the development of the No. 1 ESS remreed line scanner.

D. E. Tompsett, B.S. (Mechanical Engineering), 1967, Michigan State University; M.S. (Mechanical Engineering), 1968, Purdue University; Bell Laboratories, 1967—. Mr. Tompsett has worked on fluidics and holds a patent on an electric-to-fluidic transducer. He has also worked on mercury contacts and relays. For the past two years, he has worked on evaluation and reliability studies of the remreed switch. Currently, Mr. Tompsett is working on several connector-evaluation programs.

John E. Unrue, Jr., B.S.E.E., 1963, University of Toledo; M.S.E.E., 1965, New York University; Bell Laboratories, 1963—. Mr. Unrue is presently responsible for the design of new trunk circuits used in No. 1 ESS four-wire toll applications. He also has general responsibility for No. 1 ESS transmission. Member, Tau Beta Pi, Eta Kappa Nu, Phi Kappa Phi.

Edward G. Walsh, B.Ch.E., 1940, Cooper Union; Bell Laboratories, 1935—. Mr. Walsh has worked on new switching devices, which included work on push-button telephones and solderless connections, on development of antiaircraft gun control computers, and on electromagnetic fuses for mines and depth charges. He has been responsible for the development of the wire-spring multicontact relay for the No. 5 Crossbar System, for the development of processing and packaging of semiconductor devices, and for the development of sealed-contact apparatus, including ferreed and remreed switches. He is presently head of the department responsible for the development of connector technology.

N. Wasserman, Brooklyn Polytechnic Institute; Bell Laboratories, 1955—. Mr. Wasserman first worked on the development of keys, jacks, tube sockets, and separable connectors. He has more recently been concerned with the physical design of ferreed and remreed switches for No. 1, No. 2, and No. 3 ESS, as well as PBX systems.

R. G. Whitfield, B.S.E.E., 1966, University of Pittsburgh; S.M.E.E., 1968, Massachusetts Institute of Technology; Ph.D. (Industrial and Systems Engineering), 1975, Illinois Institute of Technology; Bell Laboratories, 1966—. Mr. Whitfield has been working on statistical problems involving field reliability and quality testing of remreed switching networks. He has recently been engaged in traffic engineering for local/toll applications. Member, ORSA, Eta Kappa Nu, Sigma Tau, Sigma Xi.

D. H. Yano, M.S. (M.E.), 1964, Lehigh University; Bell Laboratories, 1968—. Mr. Yano first worked on the exploratory development of fluidically controlled metallic crosspoints. Currently, he is engaged in the development of remreed switches.

R. C. Zolnoski, B.S. (E.E.), 1967, Polytechnic Institute of Brooklyn; M.S. (E.E.), 1969, Ohio State University; Bell Laboratories, 1963—. Mr. Zolnoski first worked on the design and development of vibrating reed selectors. Currently, he is involved with the development of ferreed and remreed switches.

The following is a list of the names of the
 persons who have been appointed to the
 various offices of the Board of
 Education for the year 1875-76.
 The names are arranged in alphabetical
 order.

Abstracts of Papers by Bell System Authors Published in Other Journals

CHEMISTRY

Dielectric Anisotropy in Amorphous Ta₂O₅ Films. P. W. Wyatt, *J. Electrochem. Soc.*, **122** (December 1975), pp. 1660-1666. The capacitance of Ta-Ta₂O₅ thin-film capacitors varies in an asymmetric way with dc electric field. This asymmetry suggests that an interface effect might be involved, but measurements with different oxide thicknesses show that at low temperature the interfaces are not the cause. Therefore, the asymmetry must be due to anisotropy in the bulk oxide, which is surprising in view of its amorphous structure.

The Diffusion of Ion-Implanted Arsenic in Silicon. R. B. Fair and J. C. C. Tsai, *J. Electrochem. Soc.*, **122** (December 1975), pp. 1689-1696. Secondary ion mass spectrometry and differential conductivity measurements of implanted-diffused As layers in Si have been performed to study the diffusion and electrical quality of these layers. The effects of diffusion ambient and surface pile-up of As are discussed.

Osmium Dioxide Trifluoride OsO₂F₃: Synthesis and Some Properties. W. E. Falconer, F. J. DiSalvo, J. E. Griffiths, F. A. Stevie, W. A. Sunder, and M. J. Vasile, *J. Fluorine Chem.*, **6** (December 1975), pp. 499-520. Osmium dioxide trifluoride, OsO₂F₃, has been synthesized for the first time. The yellow-green substance is isomorphous with one phase of OsO₂F₂, and a fluorine-bridged polymeric system is likely. The free molecule is polar, and disproportionates readily at temperatures required to obtain its mass spectrum.

ELECTRICAL AND ELECTRONIC ENGINEERING

The Gettering of Boron by an Ion-Implanted Antimony Layer in Silicon. R. B. Fair and P. N. Pappas, *Solid State Electron.*, **18** (December 1975), pp. 1131-1134. Secondary ion mass spectrometry has been employed to reveal the gettering of implanted B by an annealed, implanted Sb layer. It is shown that the gettering of B is significant, and may be caused by electric-field-enhanced diffusion of the B as well as by solubility enhancement of the electrically-active Sb.

Heterojunction Band Discontinuities. J. L. Shay, S. Wagner, and J. C. Phillips, *Appl. Phys. Lett.*, **28** (January 1, 1976), pp. 31-33. The discontinuity $\Delta E_c = 0.56$ eV in the conduction band edge at *n*-CdS/*p*-InP junctions is reported. This discontinuity and others are compared with photoemission data and with Van Vechten's extension of these data to many tetrahedrally coordinated semiconductors. Agreement between measured discontinuities and theoretical predictions is very good. Predictions are made for band parameters pertinent to interfaces involving A^{III}B^{IV}C^V compounds with zinc blende, chalcopyrite, or wurtzite crystal structures.

Ion Milling (Ion-Beam Etching), 1954-1975: A Bibliography. D. T. Hawkins, *J. Vacuum Sci. Technol.*, **12** (November/December 1975), pp. 1389-1398. The ion milling (ion-beam etching) process has recently been exploited for a wide variety of applications. This bibliography of 215 references attempts to collect references on ion milling and to classify them by application. A brief review of the process and an author index to the bibliography are included.

A Modified Novel Frequency Multiplication Technique. R. K. Even, *IEEE Trans. Circuits Syst.*, *CAS-22* (December 1975), pp. 954-959. Langham proposed a frequency multiplier that uses two oscillators and a simple digital processor. The

multiplication factor of this multiplier is equal to the ratio of the frequencies of the two oscillators. The modification proposed here involves discarding one of the oscillators at the cost of adding to the complexity of the digital processor. One thus retains the advantages of the Langham circuit while getting rid of its main disadvantage: the direct dependence of the accuracy and stability of the multiplication factor on the tracking characteristics of two oscillators.

A Note on Painted Reflecting Surfaces. T. S. Chu and R. A. Semplak, *IEEE Trans. Ant. Propag.*, *AP-24* (January 1976), pp. 99-101. Microwave depolarization in the process of oblique reflection from a painted surface has been found insensitive to the dielectric constant of the paint and not negligible for higher frequencies if polarization requirement is stringent. Approximate reflection coefficients suggest lenient tolerance for uniformity of paint layer on reflector antennas of large F/D ratio.

A Theory of Software Reliability and its Application. J. D. Musa, *IEEE Trans. Software Eng.*, *SE-1* (September 1975), p. 312. A theory of software reliability is developed and its successful application to four projects described. The theory permits estimation before a project, and reestimation during test, of the amount and duration of testing required to achieve a specified reliability goal. Managers can use the estimates to predict schedules and monitor progress.

Transistors with Boron Bases Predeposited by Ion Implantation and Annealed in Various Oxygen Ambients. T. E. Seidel, R. S. Payne, R. A. Moline, W. R. Costello, J. C. C. Tsai, and K. R. Gardner, *International Electron Devices Meeting, Technical Digest*, IEEE, December 3, 1975, pp. 581-584. When integrated circuit bases are fabricated on (001) oriented Si using ion implantation, special annealing processes are required to avoid defect formation and transistor degradation. A systematic study which examines the transistor degradation and establishes margins for oxygen in the annealing ambient is described.

PHYSICS

The Molecular Cloud Sagittarius B2. N. Z. Scoville, P. M. Solomon, and A. A. Penzias, *Astrophys. J.*, *201* (October 15, 1975), pp. 352-365. The structure of the Sgr B2 molecular cloud has been studied by detailed mappings of the CO, ^{13}CO , CS, and H_2CO (2-cm) transitions. The dynamics of the gas in the cloud are found to be dominated by large-scale systematic motions with velocity not a monotonic function of radius.

CW Tunable Laser-Sideband Generation From 5.5 μm to 6.5 μm by Light Scattering From Spin Motion in a Spin-Flip Raman Laser. V. T. Nguyen and E. G. Burkhardt, *Appl. Phys. Lett.*, *28* (February 15, 1976), pp. 187-189. CW laser sidebands are generated at wavelengths tunable from $\sim 5.5 \mu\text{m}$ to $\sim 6.5 \mu\text{m}$. Behavior of the power output of about $10 \mu\text{W}$ is described quantitatively by using the equivalence between four-photon mixing and Raman scattering from coherent spin motion in a spin-flip Raman laser. High-resolution spectroscopy with new source is shown by the spectrum of NH_3 , which indicates a linewidth $\leq 0.01 \text{ cm}^{-1}$.

High-Performance Solar Cell Material: n-AlAs/p-GaAs Prepared by Vapor Phase Epitaxy. W. D. Johnston, Jr. and W. M. Callahan, *Appl. Phys. Lett.*, *28* (February 1, 1976), pp. 150-152. Solar cells with measured sea-level-sunlight power-conversion efficiencies of 13 to 18% and areas of several cm^2 have been prepared by vapor-phase epitaxial growth of n-AlAs on p-GaAs substrates. Cells have an anti-reflective passivating anodically grown coating and have much improved stability in the laboratory atmosphere.

Optical and Electronic Properties of Thin $\text{Al}_x\text{Ga}_{1-x}\text{As}$ -GaAs Heterostructures. R. Dingle, *Crit. Rev. in Sol. State Sci.*, *5* (1975), p. 585. A brief survey of very recent optical investigations of molecular-beam-grown multilayer $\text{Al}_x\text{Ga}_{1-x}\text{As}$ -GaAs structures in which layer thicknesses as small as 50 \AA is given. Confined carrier quantum effects produce new detailed structures in the above-gap GaAs absorption spectra. Properties of the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ -GaAs interface are discussed.

Optical Fiber Modes Using Stimulated Four Photon Mixing. R. H. Stolen and W. N. Leibolt, *Appl. Opt.*, **15** (January 1976), pp. 239-243. Phase-matched, stimulated, four-photon mixing was used to excite separately and photograph all the modes of a 10-mode optical fiber. Measured mode intensities agreed well with intensities calculated for a step-index guide. Interactions between different Stokes:anti-Stokes pairs were also observed.

Optical Investigation of Stress in the Central GaAs Layer of Molecular-Beam-Grown $\text{Al}_x\text{Ga}_{1-x}\text{As-GaAs-Al}_x\text{Ga}_{1-x}\text{As}$ Structures. R. Dingle and W. Wiegmann, *J. Appl. Phys.*, **46** (October 1975), pp. 4312-4315. From the analysis of exciton splittings and shifts in the 2K absorption spectra of central GaAs layers in molecular-beam-grown $\text{Al}_x\text{Ga}_{1-x}\text{As-GaAs-Al}_x\text{Ga}_{1-x}\text{As}$ structures, the magnitude and sign of the layer stress is deduced. Annealing at 850°C has little influence on the layer stress, although large changes in photoluminescence efficiency are observed.

Room-Temperature Operation and Threshold Temperature Dependence of LPE-Grown $\text{In}_x\text{Ga}_{1-x}\text{As}$ Homo Junction Lasers. R. E. Nahory, M. A. Pollack, D. W. Taylor, R. L. Fork, and R. W. Dixon, *Appl. Phys.*, **46** (December 1975), pp. 5280-5282. $\text{In}_x\text{Ga}_{1-x}\text{As}$ homo junction lasers prepared by liquid phase epitaxy have been operated from below 77°K to room temperature. Lowest thresholds were $J_{th} = 2000 \text{ A/cm}^2$ at 77°K and 290,000 A/cm^2 at room temperature. The variation of threshold with temperature can be fit by either $J_{th} \sim T^3$ or $J_{th} \sim \exp(T/67^\circ)$ above $\sim 150^\circ\text{K}$, and by $J_{th} \sim T^{2.3}$ at lower temperatures.

Tunable CW Difference-Frequency Generation in Tellurium at $\sim 11 \mu\text{m}$. T. J. Bridges, V. T. Nguyen, E. G. Burkhardt, and C. K. N. Patel, *Appl. Phys. Letters*, **27**, No. 11 (December 1 1975), pp. 600-602. Difference frequency mixing in tellurium between a tunable CW spin-flip Raman laser at 5.3 μm and a 10 μm fixed frequency CO_2 laser has given CW tunable output near 11 μm . Spectroscopy of ammonia indicates a source linewidth $\leq 0.01 \text{ cm}^{-1}$. Use of other fixed frequency lasers could provide a high resolution CW tunable source from 5-30 μm .

SYSTEMS ENGINEERING AND OPERATIONAL RESEARCH

Time Variations and Harmonic Content of Inductive Interference in Urban/Suburban and Residential/Rural Telephone Plants. D. N. Heirman, *IEEE Trans. Commun.*, **COM-23**, No. 12 (December 1975), pp. 1484-1495. The time variations and harmonic content of longitudinal (common-mode) interference present on a wide variety of telephone lines in both urban/suburban and residential/rural environments are presented. This data will aid telephone equipment designers to reduce adverse inductive interference effects of the telephone operating environment on their designs.

Office of the Secretary of Defense
Washington, D. C. 20301
Attention: Mr. [Name]

Dear Mr. [Name]:

I am pleased to inform you that your application for [Position] has been reviewed and your qualifications are considered excellent.

We are currently reviewing all applications and will contact you again once a final decision has been reached.

Thank you for your interest in the Department of Defense.

Sincerely,
[Signature]

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