

Single-Crystal Germanium



H. E. BRIDGERS *Chemical Physics*

As recently as ten years ago, the metallic element germanium was virtually unknown. Today it is probably the best understood—and most widely used—of those unusual and exciting materials known as semiconductors. This vastly increased knowledge has come primarily through Bell Telephone Laboratories' broad integrated research program on semiconductors—a program that has already yielded such significant inventions as the Transistor and the Bell Solar Battery, and a number of other interesting and highly promising devices. A major step in this program was the development of techniques for growing large, single crystals of incredibly pure germanium. Here is the story of that basic contribution.

Many of us recall the early days of radio when crystal detectors were used almost universally in receiving sets. In this application, satisfactory reception required frequent and seemingly haphazard adjustment of the "cat-whisker" on the crystal surface. More often than not it was a tedious and exasperating procedure to locate a "sensitive" spot. Once this was accomplished, however, the operator was rewarded—for a time at least—by reception of a broadcast that may have originated many miles away. The crystal was a semiconductor, and with the fine point of a metallic wire bearing on its surface, it formed a rectifier. A new and more reliable detector was provided by the thermionic tube, and its development made the crystal rectifier obsolete in radio receivers.

Following this development, use of crystal rectifiers was confined almost exclusively to detection at ultra-high frequencies where their performance was superior to that of thermionic tubes. Early in World War II, however, extensive research and development programs were begun to produce military

systems. One of the most important of these—radar—required microwave detection, and this revived wide-scale interest in crystal rectifiers.

At the end of the war, the major research laboratories of the nation continued programs designed to investigate these semiconducting crystals. From the point of view of technological development as well as that of fundamental understanding, Bell Telephone Laboratories has played a prominent role in this study. It was, in fact, from a Laboratories program directed toward obtaining an understanding of semiconduction that the transistor emerged.

Germanium used in the early manufacture of crystal rectifiers, as well as that used in fabricating the first transistors, was polycrystalline. A polycrystalline solid is one in which many small crystals fit neatly together much like the stones of a stone wall. As shown in Figure 1, a polished surface of

Above — The author examining typical germanium single crystals grown by members of the Chemical Physics Department at Murray Hill.

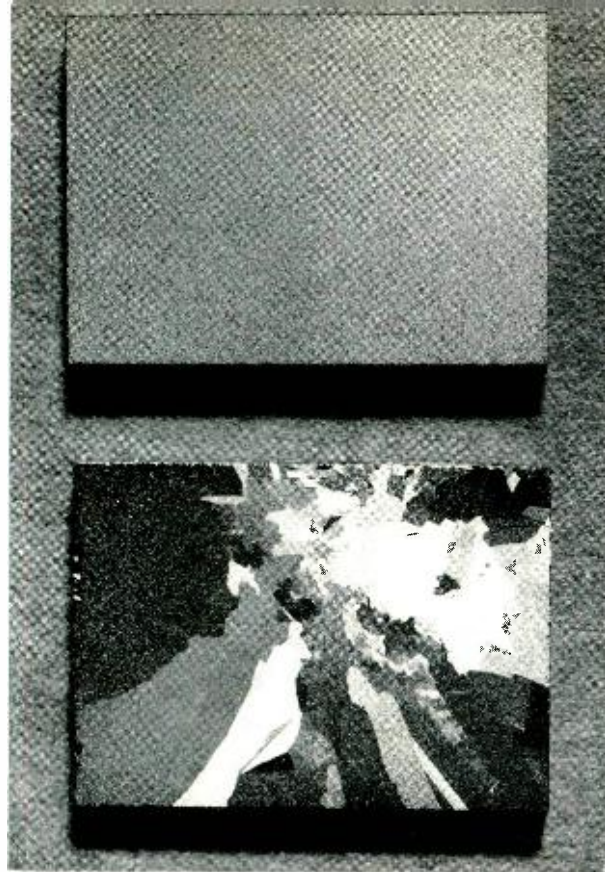


Fig. 1—Germanium plates; the polycrystalline sample below exhibits grain-boundaries that are absent in the single-crystal sample above.

polycrystalline germanium gives an appearance similar to that of camouflage patchwork. Each small crystal is a regularly ordered array of atoms, and although the pattern is identical in each crystal, the relative orientations are different. For this reason, the pattern does not match where two crystals join, and a "grain-boundary" results.

It has long been recognized that these grain-boundaries seriously affect the electrical properties of the material. In fact, their presence was one cause for the erratic behavior of the galena crystals used in early radio detection. Although germanium and silicon rectifiers* had been mass-produced with material from which these grain-boundaries had not been totally eliminated, with the advent of the transistor it became imperative to obtain large single crystals of germanium. Such crystals are essential to insure that the electrical properties will be completely reproducible.

In the growth of germanium crystals many difficulties are encountered. Its melting point is about 1,700° F and the difficulty inherent in performing any controlled process at this temperature is further increased by the fact that germanium will react vigorously with oxygen, even to the point of

* RECORD, April, 1948, page 152.

removing oxygen from water vapor. This necessitates the exclusion of all but inert gases. The problem of contamination is a vital one. As we have already seen, even minute traces of a wide variety of impurities have deleterious effects on conductivity. Not only must extreme precaution be taken to avoid contamination, but only polycrystalline germanium of the highest purity can be used as the starting material.

Germanium of exceedingly high purity has been made available through the efforts of the metallurgical group at the Laboratories. This in itself was a major contribution to the general effort that led to single-crystal production. As measured in terms of conductivity, the purity of the starting material corresponds to about one foreign atom for every billion atoms of germanium.

The growth of large single crystals illustrated in the headpiece of this article was first accomplished through the efforts of G. K. Teal and his associates in the Chemical Physics Department. The crystal-growing machine and its associated equipment, as pictured in Figure 3, is the product of several earlier designs, and although it is a rather complicated mechanical and electrical assembly, its function is quite simple. The process can be best described by considering the schematic diagram of Figure 2. The heart of the apparatus is a carbon

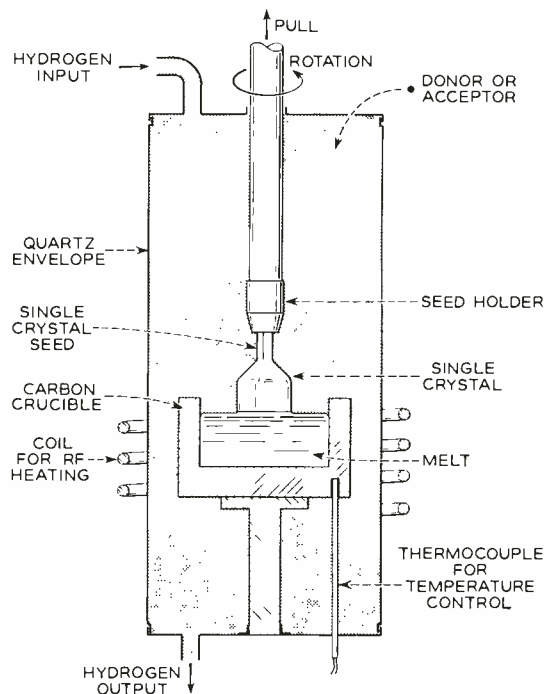


Fig. 2—Schematic diagram of the crystal-growing machine shown in Figure 3.

crucible which contains a molten charge of germanium. Radio-frequency power is fed to a surrounding coil, and currents induced in the crucible walls produce temperatures in excess of the melting point of germanium. A thermocouple, situated in the crucible wall, is used to measure and control the temperature.

A transparent quartz envelope encloses the crucible and confines a flow of hydrogen gas that bathes both crucible and germanium melt. This hydrogen flow serves two purposes. Not only does it provide an inert atmosphere, thereby protecting the hot germanium from chemical reaction, but it also serves as a cooling medium. For rapid temperature control, it is necessary to have adequate cooling in addition to readily available power.

A small single-crystal "seed" of germanium, supported by a shaft extending into the system, dips into the melt. As the shaft is slowly withdrawn, the seed grows out in diameter and a large single-crystal is produced. Crystal growth occurs at the interface between crystal and melt. The crystal diameter depends critically on the control temperature and the rate of withdrawal. This behavior is primarily due to the fact that the transition from liquid to solid germanium is accompanied by a release of energy called the latent heat of fusion. The rate at which this heat is generated is proportional to the rate of crystal growth. Hence, by proper adjustment of the control temperature, for a given rate of withdrawal, the desired crystal diameter can be obtained. Although the interface temperature is essentially at the melting point of germanium, the control temperature in the crucible wall ranges from about 40° to 90° F higher, depending on the rate of withdrawal. This withdrawal rate is usually from two to ten inches per hour.

Elaborate control circuits are used to maintain constant temperature and withdrawal rate. As the crystal is withdrawn it is also rotated to stir the melt. The stirring action provides thermal symmetry in the melt and aids in mixing added impurities. Facilities are available for the addition of controlled amounts of either donor or acceptor impurities, to obtain either n-type or p-type germanium of the desired resistivity.

Procedure for the growth of a single crystal begins with a thorough cleaning of the growth chamber. This is done with suitable chemical reagents, and if necessary, by baking the crucible at high temperatures for long periods in flowing hydrogen. The oriented seed crystal and the germanium charge are chemically etched and dried. The cham-

ber is sealed, flushed with hydrogen, and the germanium melted. The seed is then dipped into the melt, and the temperature and withdrawal rate adjusted to grow a crystal of suitable diameter.

Most acceptor and donor impurities are considerably less "soluble" in solid than in liquid germanium. To produce a desired concentration of impurity atoms in the crystal, it is therefore necessary to provide a considerably larger concentration in the melt. For purposes of purification, this is most fortunate, because the first solid frozen will contain much less impurity than does its parent liquid. This property is not uncommon, and evidence of it is seen in large cakes of commercial ice with discoloration at their centers. The center of



Fig. 3 — E. D. Kolb operating a machine used to grow single-crystal germanium.

the block, being the last portion to freeze, is discolored by impurities that were initially present throughout the water. As ice is formed, the impurities concentrate at the center. As a result of this, the outer portion of the ice cake is much purer than the initial water. It is this behavior that provides the means for extensive purification of germanium. On the other hand, this same behavior makes it difficult to grow germanium crystals with constant impurity content and consequent constant resistivity. As the melt is depleted by crystal growth, its impurity concentration continually increases. This increasing melt concentration is re-

flected in the crystal, so that each successive increment of crystal contains more and more impurity.

The effective solubility of an impurity in the crystal also depends on the crystal growth rate. In particular, at a given melt concentration, more impurity is incorporated in the solid at faster growth rates. Therefore, by growing the crystal at a constantly decreasing rate, it is possible to counteract the effect of the increasing impurity content of the melt. Single-crystal germanium with the desired level of constant resistivity is produced in this way. This does not necessarily represent the ultimate in methods for growing such crystals and, in fact, other methods have achieved considerable success. That it produced excellent results, however, is borne out by the examples illustrated in this article.

Single-crystal germanium of n- or p-type conductivity is used in the fabrication of point-contact devices. In these devices, as in the early crystal rectifiers and the first transistors, the fine points of one or more metallic wires bear on the surface of a small piece of single-crystal germanium. More recent devices derive their characteristic electrical properties from a conversion of conductivity type within the body of the single crystal. The boundary between regions of different conductivity is called

a "junction" and devices that incorporate such boundaries are called junction devices.* A p-n junction crystal can be produced by first growing a portion of crystal from a melt to which an acceptor impurity has been added. Following the growth of a suitable amount of this p-type crystal, a donor impurity is added in sufficient excess to compensate for the acceptor impurity and produce n-type crystal. In a similar fashion, by three impurity additions, more complicated structures can be grown with two junctions spaced very close together. These and other techniques have been employed in the crystal-growing machine illustrated in Figure 3.

The science and technology of solid state electronics is advancing rapidly. Future realization of other devices and applications will ultimately depend upon the production of various materials with controlled crystalline imperfections. The work at Bell Telephone Laboratories which led to the production of single-crystal germanium will play a significant role in guiding present and future efforts toward this controlled production of other materials vital to solid state electronics.

* RECORD, June, 1954, page 203.

THE AUTHOR

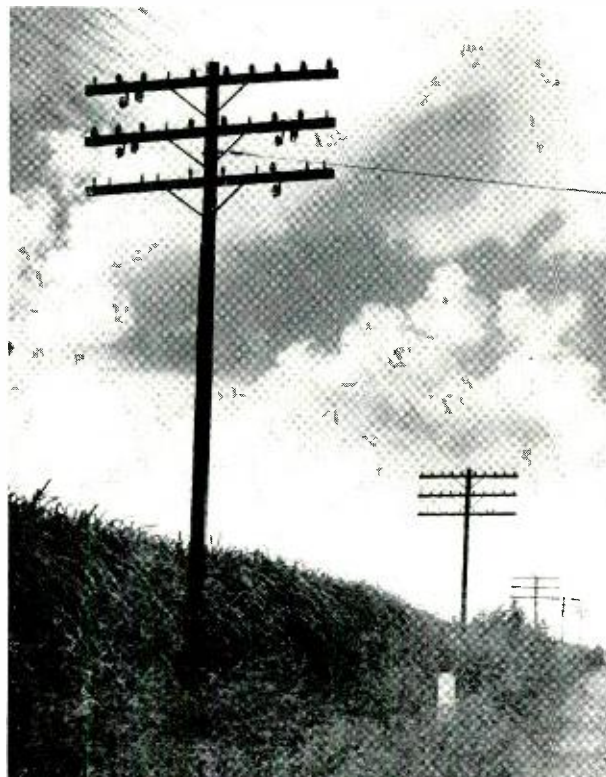


HENRY E. BRIDGERS received a B.S. degree from the College of William and Mary in 1943. Following three years of service with the Army Air Corps, where he served as an aerial navigator and radar operator, he taught in the Hampton, Virginia, public school system. From 1948 to 1953 he was a graduate instructor in chemistry at Ohio State University, and he received the Ph.D. degree from the same institution in 1953. Dr. Bridgers joined the Laboratories the same year and has been concerned with research in techniques of growth of single crystals of germanium for semiconductor device applications.

The Type-O1 Transposition System

ESTHER RENTROP

Transmission Engineering



The Bell System uses many different means for telephone communication, but open-wire lines still provide much of the service in some parts of the country. One of the difficulties encountered with such lines is the presence of noise and crosstalk. To reduce this interference, wires are periodically interchanged in position along the line following the pattern of a transposition system. To permit the use of type-O carrier on existing lines with the least possible line rearrangement, the new type-O1 transposition system was developed.

Telephone communication in areas of our country away from cities and congested surroundings is largely provided over open-wire lines. Pairs of wires supported by insulators on one or more crossarms, and strung from pole to pole, make up an open-wire line such as in the headpiece. An observant person driving along the road might wonder about the steel brackets fastened to some crossarms at intervals along the line. Known as drop brackets, they extend below the crossarm; some drop brackets, Figure 1, extend both above and below. Others, called point type brackets, can be seen on the top crossarm in Figure 1. They have four insulators, but only two are visible in the picture.

These brackets are not placed on the line for decoration, to break the monotony of the mile-upon-

mile of wire and poles, or to furnish targets for passing hunters. Neither are they intended to be convenient places for birds to build nests, as is sometimes the case. Instead, they serve as a means of transposing or interchanging the wires of a pair, or interchanging two pairs, in carefully prearranged patterns along the line as prescribed by a particular transposition design. Transposing, or interchanging, the wires reduces mutual coupling, and thereby the crosstalk, between the various circuits on a line.

One form of crosstalk,^o which almost every telephone user has experienced at some time, is speech on one circuit heard on an entirely different circuit. Very infrequently the speech is intelligible; at other

^o RECORD, November, 1934, page 66.

times, though audible, it cannot be understood. The coupling between the two circuits that causes cross-talk results from electric and magnetic fields surrounding the wires. Transpositions placed at specific points along the wires annul to a great extent this electric and magnetic coupling.

Either a drop bracket, Figure 2, or a point-type bracket, Figure 3, may be used when the individual wires of a pair are transposed. When a drop-bracket is used, the left wire of a pair goes to the top pin of the bracket, and the right wire goes to the bottom pin, Figure 2. The interchange is completed at the following pole, where the wire originally on the left takes the position on the right, and vice versa. Thus, two spans are required to transpose a pair of wires with a drop bracket. With a point-type bracket, the wires of a pair are transposed within a few inches, or at a "point." Other types of brackets, Figure 4, are also used in transposing the wires of a pair.

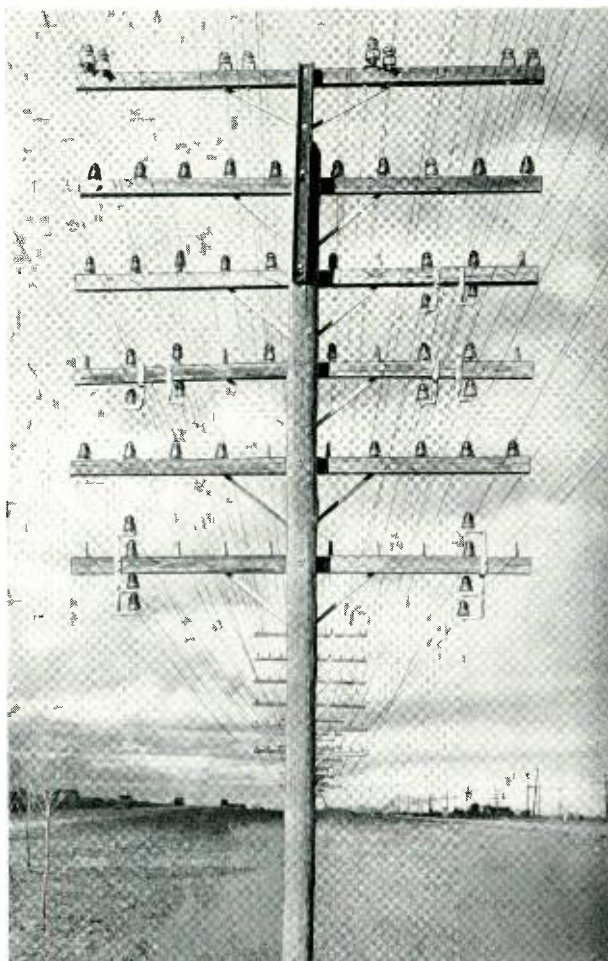


Fig. 1—A test line used in the evaluation of various transposition systems. Three types of transposition brackets may be seen.

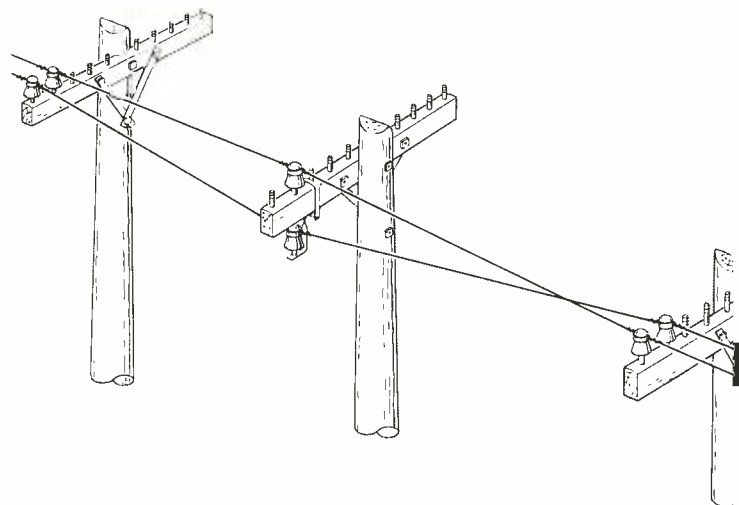


Fig. 2—Two pole spans are required for a transposition with a drop bracket.

Sometimes a transposition design calls for interchanging the positions of two adjacent pairs of wires. Such a transposition is required where each pair of wires is used as one side of an additional circuit known as a "phantom" circuit. The brackets for two phantom transpositions appear on the bottom crossarm in Figure 1. Often a transposition design calls for a transposition in one or both of the pairs at the same time that a phantom transposition is made. Thus four types of phantom transpositions are possible, depending on how the wires of the individual pairs are treated.

A transposition design is a collection of transposition patterns for a specified number of open-wire pairs in a particular length of line. Developing a transposition design—that is, selecting the transposition patterns for the various pairs of an open-wire line—much akin to chess playing, is a long and

TABLE I—THE FOUR SEPARATE CARRIER SYSTEMS OF TYPE-O

<u>Carrier Systems</u>	<u>Frequency Band (kc)</u>	<u>Open-Wire Line Application</u>
OA	2-36	Voice-Transposed pairs (3-kc) (Restricted Use)
OB	40-76	C-Carrier Transposed Pairs (30 kc)
OC	80-116	C-Carrier Transposed Pairs (30 kc) (Restricted Use)
OD	120-156	C-Carrier Transposed Pairs (30 kc) (Restricted Use)

involved process. The designer must take into consideration the maximum permissible crosstalk, the frequency band required by the voice or carrier system that will be operated on the pairs, and the wire-spacing, pole-spacing, and wire-sag requirements for the line. He must consider each pair to every other pair from the standpoint of near-end, far-end, and interaction crosstalk,* and also crosstalk that may result from line irregularities. The patterns finally selected are those that will satisfy the design objectives most economically. Samples of short lengths of such patterns for a few pairs of different transposition systems are shown in Figure 5.

A transposition system usually consists of designs for a definite number of pairs (or phantom groups) covering several different lengths of line. The long, or basic, transposition section (256 spans) varies in length from 6.4 miles to 8 miles, depending on pole spacing. Other designs are used for shorter sections ranging from 0.2 mile to 4 miles in length.

All crosstalk between open-wire pairs is not eliminated through the use of transpositions; there is always residual crosstalk at the end of a transposition section. To reduce the accumulation of this crosstalk from section to section, transpositions are placed in some of the pairs at the end of each section. These are called junction transpositions, and designs for them are provided with each transposi-

* A. G. Chapman, Open-Wire Crosstalk, Bell System Technical Journal, 13, pp. 19-58, January, 1934, and pp. 195-238, April, 1934.

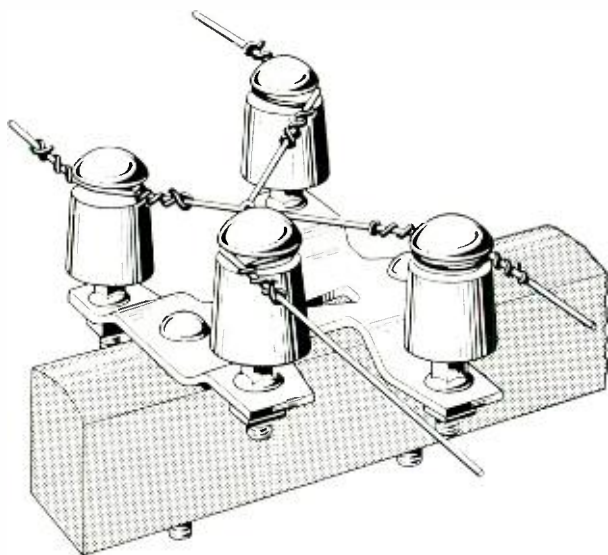


Fig. 3—A point-type bracket permits a transposition to be made at a single pole within only a few inches.

tion system. The Bell System employs a dozen or more open-wire transposition systems that have been developed through the years. Among these transpositions are short-haul voice-frequency systems. Normal pair spacing on such lines is 12 inches, and the crossarm separation is 24 inches. Transpositions on voice-frequency lines are usually made on drop brackets, and requirements for uniformity of wire-sag and pole-spacing are lenient for such lines.

Among the transposition systems designed for



Fig. 4—W. R. Kelly of the New York Telephone Company checks the wires on a tandem bracket. This is a point-type bracket with only two insulators, used on voice-frequency lines; a double-skirted insulator at the right takes the place of a drop bracket.

specific carrier-frequency applications are those for type-C (up to 30 kc) and type-J (up to 142 kc). Wire spacings for C-carrier lines are the same as those for voice frequency lines and transpositions are also made on drop brackets, but wire-sag and pole-spacing requirements are a little more exacting. Lines transposed for J-carrier, however, require 6-inch or 8-inch pair spacing, 36-inch crossarm separation, and point-type transposition brackets. Pole-spacing deviation and wire-sag requirements for J lines are much more stringent than those for C-carrier lines.

The latest transposition system to be standardized is the non-phantomed type-O1 for operation up to 156 kc, designed to obtain full use of type-O carrier* on existing short-haul open-wire lines. These are at present transposed mainly for voice

* RECORD, June, 1954, page 215.

frequencies or for carrier frequencies up to 30 kc.

Type-O comprises four separate carrier systems, OA, OB, OC, and OD, with frequency allocations and applications to existing lines as shown in Table I. These O-carrier systems achieve about 20 db less crosstalk than older carrier systems, through the use of companders^o in each channel. This permits using 36-kc OA carrier on some existing 3-kc voice pairs without prohibitive crosstalk. It also permits the use of OB carrier on nearly all existing type-C pairs, and OB systems have been applied to many C-carrier lines throughout the Bell System without line rearrangement. However, the 20-db crosstalk advantage is not sufficient for OC and OD to be used on all C-carrier pairs. Measurements have shown that, because of excessive crosstalk, OC can be operated on only about 20 to 30 per cent, and

^o RECORD, November, 1953, page 452.

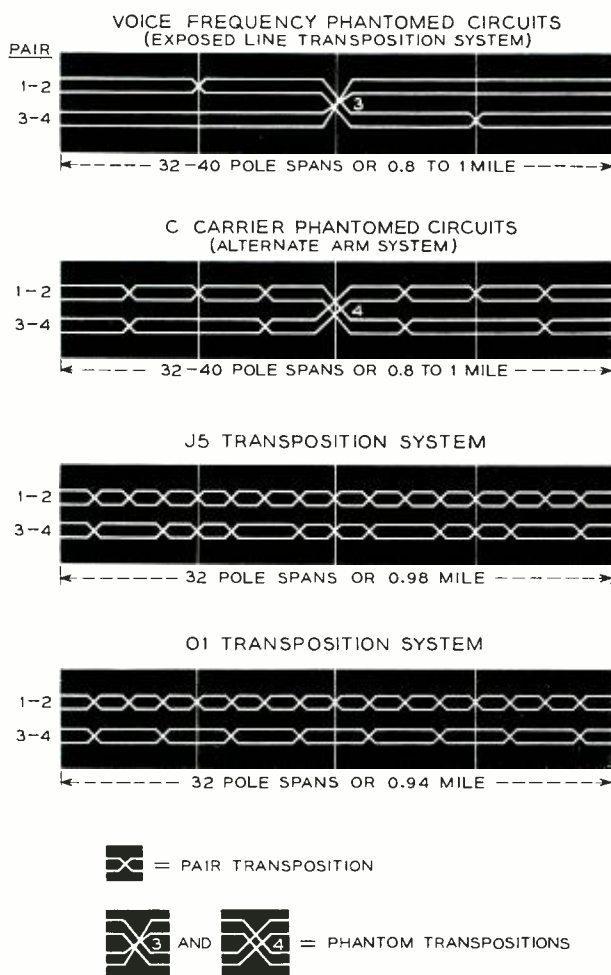


Fig. 5—Transposition patterns for a voice frequency and several carrier systems. Pair 1-2 is the outside pair, with pair 3-4 nearer the pole.

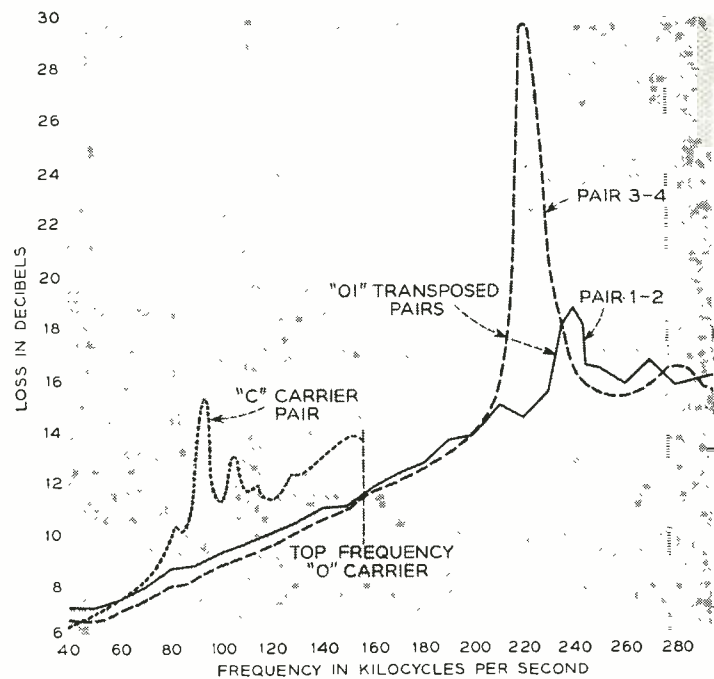


Fig. 6—Absorption peaks in lines transposed for type-C and type-O carrier. The peak in the C-carrier pair falls in the OC range, making the pair unsuitable for OC use

OD on 15 to 20 per cent of these pairs. Usable pairs can be determined only by means of crosstalk measurements.

The chief reason that OC and OD can be used on so few existing C pairs is that attenuation, or "absorption," peaks and high crosstalk occur in some of these pairs above their transposition design frequencies. An absorption peak is caused by high crosstalk into surrounding wires being coupled back again so as to oppose original transmission on the pair, and is a function of the transposition pattern. Absorption peaks and excessive crosstalk are avoided within the design frequency range through careful selection of transposition patterns. Figure 6 includes an example of an absorption peak in the OC band between 80 and 100 kc, well above the design frequency of 30 kc for the pair. Excessive loss and resulting high crosstalk in the frequency range of the peak render this and similar pairs unsuitable for OC operation. Similar peaks in the OD range on some C pairs also interfere with the operation of OD. This situation made it evident that to realize full use of OC and OD carrier, the C-carrier pairs would have to be retransposed to a new design.

A crosstalk objective was set up for the type-O transposition system of at least 30 db equal-level

coupling loss between pairs in 150 miles of line over the frequency range from 2 to 156 kc. Another requirement called for type-O carrier pairs on at least five crossarms per pole. Further stipulated was the operation on these pairs of either the non-compandored type-C or the new OA systems, in the frequency range below 36 kc.

As finally evolved, the O1 transposition system provides for non-phantomed pairs on five crossarms. These pairs meet the design requirements in all respects except that on lines where fewer than 40 poles per mile are used, the performance of the top two OD channels of one pair is slightly poorer than desired. The transposition patterns of the O1 design are similar to those of the J design for long transposition sections, Figure 5. Existing voice-frequency pole-pairs* and phantoms can be retained on a line otherwise transposed to the O1 designs, although crosstalk between some of the type-O pairs is less when these pole-pair circuits are removed. Absorption peaks on O1 pairs occur well above the type-O frequency range, Figure 6.

Type O1 designs call for 8-inch spacings with the wires transposed on point-type brackets, as do the J designs. The 12-inch spacing usually found on existing short-haul lines, on which type-O will be used, results in excessive crosstalk when pairs are transposed to the O1 designs. Respacing pairs from 12 inches to 8 inches to get lower crosstalk is costly; therefore, a less expensive technique has been developed. The usual 12-inch spacing is retained at non-transposition poles and a new 4-

* A pole-pair consists of the two wires in the middle of a crossarm, one on each side of the pole.

inch point-type bracket is used at transposition poles. The spacing of those pairs not transposed at the transposition poles is also reduced to 4 inches on a special bracket. Thus, the spacing between wires of a pair tapers uniformly from 12 inches at one pole to 4 inches at the next, returns to 12 inches at the third pole, and repeats the process throughout the section. This results in an average spacing of about 8 inches as desired, and makes the conversion from existing 12-inch pairs to the equivalent of 8-inch pairs easier and less expensive.

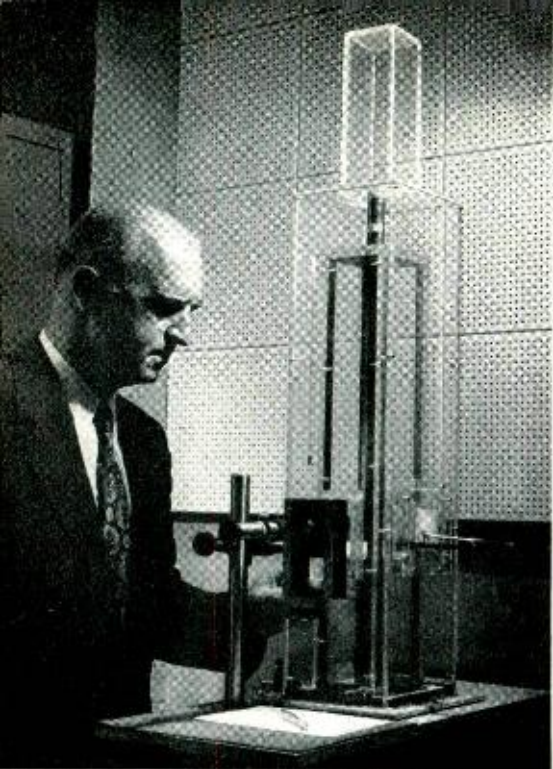
The O1 transposition design has the usual series of sections of different lengths, ranging from 0.24 to 7.5 miles, to facilitate the coordination of type-O pairs with existing voice-frequency or C-carrier pairs. The O1 design also provides junction transpositions; these are most effective for a series of similar sections without intervening sections of other lengths. Type-O1 transposition patterns are not necessarily compatible with existing C-transposed pairs, and when one or more C phantom groups are retransposed to the O1 design, modifications may be necessary on certain of the remaining C phantom groups.

Since the OB system was made available first, much of its use has been on existing pairs already transposed for C-carrier operation. However, a few open-wire lines have been retransposed to the O1 design and satisfactory crosstalk performance has been obtained. Additional lines are expected to be transposed to the O1 design as the number of OC and OD systems increase, thus providing satisfactory crosstalk for up to 16 carrier channels per pair of wires.

THE AUTHOR



ESTER RENTROP received her B.S. degree from Louisiana State Normal College in 1926 and later studied at Louisiana State University, Tulane University, and Peabody College. She joined the transmission group of the Development and Research Department of the American Telephone and Telegraph Company in 1928, transferring to the Laboratories in 1934. In both companies she has been engaged principally in control of crosstalk, both in field studies and transposition design work. During World War II, she assisted in problems of the Wire Section, Eatontown Signal Corps Laboratory at Fort Monmouth, and later she worked on other military projects at the Laboratories for the duration of the war.



Relay contact erosion is usually determined by visual examination of contacts through a microscope. However, more accurate results can be obtained by measuring small weight changes in the contacts. To weigh relay contacts, a special spring-type micro-balance was designed and built by the Laboratories. This balance permits weights in the range from 0 to 20 milligrams — less than 1/1000 of an ounce — to be measured with a probable error of only 1.5 micrograms, or roughly 50 billionths of an ounce.

Spring-Type Micro-Balance

M. S. BURGESS *Switching Apparatus Development*

The Bell System spends several million dollars annually for precious-metal relay contacts that open and close talking and signaling circuits. It is essential to the operation of the telephone system that these contacts give reliable performance for millions of operations. For this reason, continuing studies are made of the effects of circuit conditions and relay operation on contact performance. Most important are those factors affecting the rates of mechanical wear and electrical erosion, which limit the useful contact life.

Previously, evaluation of contact erosion has been an estimate based on visual examination of contacts through a microscope. A recently developed technique uses measurement of the change in weight of a contact after many operations. Since the contacts to be studied — on wire-spring relays — are welded to their supporting wires, special demountable contacts had to be devised. These demountable contacts, Figure 1, simulate the standard welded type in size and weight, yet are easily removed and replaced. Two types of contacts are used, differing in size and shape. Both types, how-

Above — The author makes an adjustment on the balance before a measurement.

ever, are mechanically secured by force-fitted wedges as shown in Figure 1. The wedges fit into slots in the twin wires and the single-contact block, and may be removed to demount the contacts with little chance of contact abrasion. The combination of demountable contacts and weight measurements at intervals during their operation gives a more precise evaluation of contact erosion than is possible with the visual method.

These demountable contacts range in weight from 5 to 7 milligrams. To determine small changes in their weights requires the use of a balance with an accuracy on the order of a few micrograms. The spring-type balance developed for this purpose has as its essential element a helical spring with a small pan fastened at the lower end to hold the weight being measured. A weight on the pan causes the spring to elongate, and the deflection of the pan is proportional to the weight. This deflection is observed through the traveling microscope seen in the headpiece. Although this balance is less accurate than the torsion balance^o developed by Haworth and Reitter, it permits measuring much larger differences in weight. This greater range of

^o RECORD, June, 1953, page 215.

measurements is desirable for weighing the demountable contacts.

In accelerated tests without contact protection,* electrical erosion of a contact may remove one milligram of metal in a few million operations. Measuring the weight within 10 micrograms gives an accuracy of 1 per cent for such a loss, or about a 20-fold improvement over the accuracy of visual estimates. Protected contacts, however, may lose as little as 1 microgram in 4 million operations, requiring 40 million operations for a loss of 10 micrograms. In tests of reasonable duration, measuring such small changes requires an accuracy on the order of 1 microgram. The new spring balance can be used to measure weights up to 20 milligrams with a probable error† of only 1.5 micrograms.

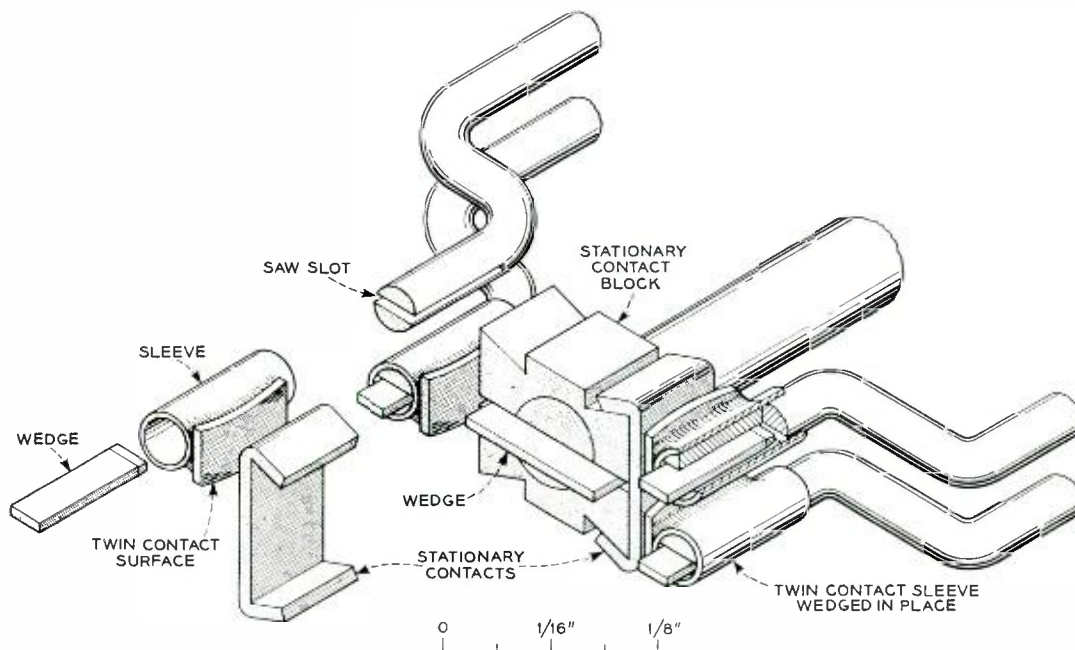
The accuracy of a spring balance is limited by

— deflection per unit weight — of 0.5 inch per milligram weight.

With this high compliance needed for sensitivity, the capacity of the balance is limited by the elongation of the spring; for a weight of 20 milligrams, this amounts to about 10 inches. It was desired to keep the balance to less than 3 feet in height. After allowing for a pan rest and spring support, the extension of the spring under its own weight had to be less than 1 foot. Furthermore, since elongation of the spring reduces its diameter and hence changes the compliance, the length of wire in the spring should preferably be about ten times the elongation that is caused by the load, or roughly 100 inches.

To meet these requirements, the wire must have a very small diameter. The actual spring, Figure 4,

Fig. 1 — The demountable wire-spring relay contacts used in tests of contact erosion.



the precision with which the pan deflection — spring extension — can be measured. The traveling microscope, Figure 2, selected as a convenient means of deflection measurement has a probable error of 0.1 mil-inch (0.1 thousandth of an inch). To keep the total weighing error less than 1 microgram, 0.2 microgram was chosen as the limit for the probable error from the deflection measurement. This required a deflection of at least 0.1 mil-inch for a weight of 0.2 micrograms, or a spring compliance

has 62 turns of phosphor-bronze wire 0.002 inch in diameter. The principal fabrication problem in constructing the balance was to form a uniform helix of such fine wire. An annealing procedure was developed that gave a uniform helix with adequate spring temper; the wire was close-wound on a brass mandrel, placed in an oven, annealed for an hour, and then slowly cooled to room temperature.

The resulting helical spring has a compliance that varies from 472 to 452 inches per gram weight — about 4 per cent — over the weight range from 0 to 20 milligrams. Actual measurements are usually over only a small part of this range, and com-

* Contacts are protected from electrical arcing by various combinations of resistance and capacitance.

† Probable error is that error for which greater or smaller errors are equally likely.

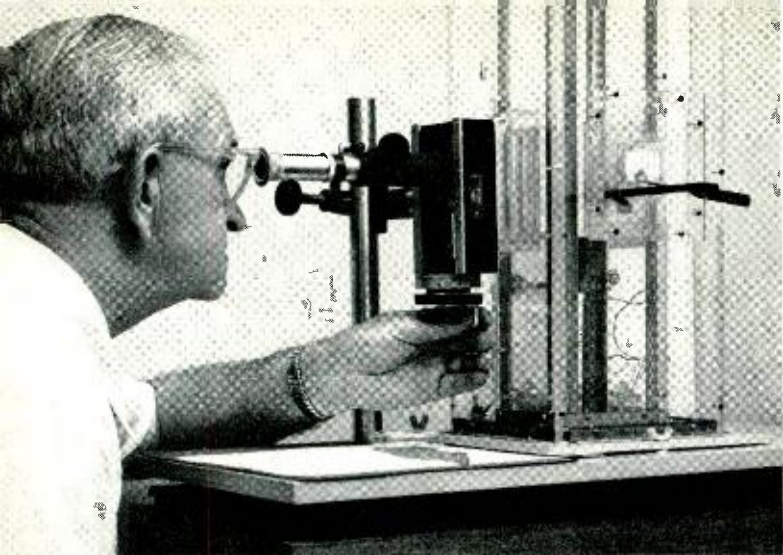


Fig. 2—W. E. Stephens measures the pan deflection through the traveling microscope.

pliance changes are then negligible. The over-all accuracy, however, is subject to other factors such as temperature changes, air currents and vibration. Normal room temperature changes affect the spring compliance only slightly, but may have a considerable effect on the length of the spring support. Since these changes occur slowly, their effect is minimized by making all measurements on a comparative basis. Air currents in the weighing chamber can cause serious errors. An air velocity of 0.2 millimeters per second — only 0.0022 miles per hour — produces the same deflection as a 0.5 microgram weight!

To reduce the possibility of air currents, a double housing of lucite, seen in the headpiece, surrounds

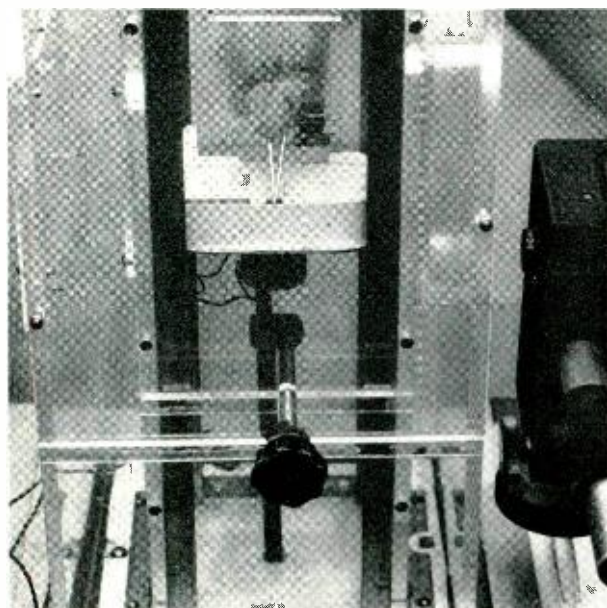


Fig. 3—While contacts are moved on or off the pan, the movable magnetized platform holds the pan steady.

the balance. Optical glass windows in the side toward the traveling microscope provide clear vision for the observer. Weights are moved in and out of the chamber on a sliding tray, and a pair of forceps is used to put them on and take them off the pan. The tray enters the chamber through two hinge-type trap-doors on the inside of each housing wall, Figure 3, and a flexible plastic mounting around the forceps maintains the air

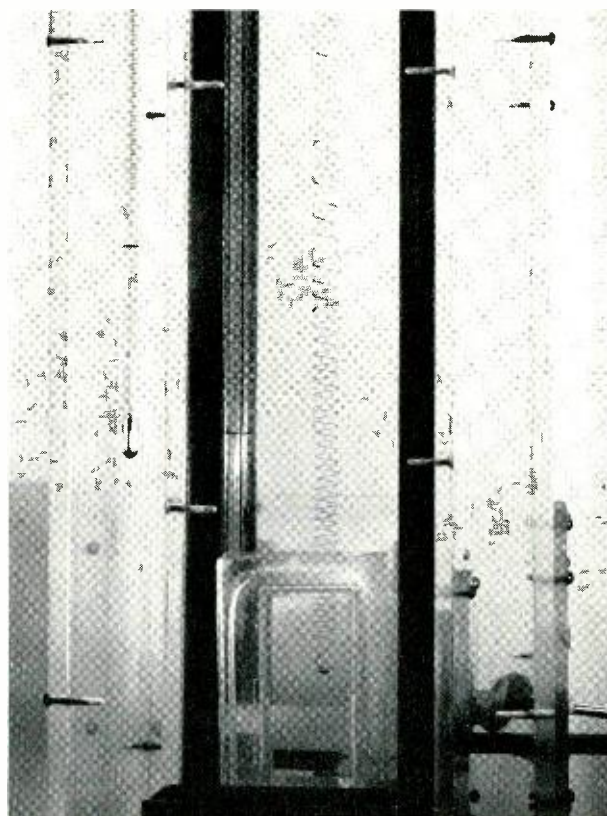


Fig. 4—The helical spring of the balance is elongated by its own weight.

seal. The balance is insensitive to high-frequency vibration, but requires some seconds to come to rest after shock excitation. To reduce this possibility, the entire balance with its housing is mounted on a heavy plate with sponge-rubber supports.

A close-up of the balance, Figure 3, shows a platform that can be raised and lowered by means of the knob at the side of the balance. Beneath the platform is an electromagnet, the upper end of its core forming a rest for the pan. When it is desired to locate the pan while contacts are being handled, a battery is connected to the electromagnet and the magnetic pan is held tight to the pan rest.

To load the pan, the movable platform is raised

so that the pan can be magnetically locked to the pan rest when the magnet winding is energized. The platform and pan are lowered to a convenient level where the contacts are introduced into the chamber on the sliding tray and placed on the weighing pan. With the contacts on the pan and the magnet current disconnected, the weight is supported only by the spring; its deflection can then be measured.

Since the range of the traveling microscope is only 2 inches, corresponding to a weight range of 4 milligrams, the initial setting of the spring must be adjustable to give the full weighing range of 20 milligrams. The upper end of the spring is soldered to a brass rod that extends upward through a hollow brass cylinder and is clamped at the top by a set-screw. This spring support rod may be adjusted by removing the lucite sub-compartment on top of the balance and loosening the set-screw. This adjustment is unnecessary for most contact measurements, since they fall within the weight range of 4 milligrams.

When weighing a contact, a standard is weighed first, then the contact, then the standard again. The deflection readings of the standard are averaged and subtracted from the unknown reading. This difference divided by the compliance, plus the weight of the standard, gives the weight of the unknown. If two succeeding standard weighings differ by more than 1.5 mil-inch (3 micrograms), the readings are discarded and new ones taken. This procedure largely corrects for errors resulting from drift from the zero position, and eliminates readings taken during sudden environmental



Fig. 5 — A test contact is transferred from its storage bottle to a dish for handling by Miss V. M. Kind.

changes such as air currents from open doors.

Experience with this balance indicates that the probable error could be reduced to a few tenths of a microgram by fully shielding the spring from air currents, or by mounting it in a thermostatically-controlled evacuated chamber. This would require complicated apparatus for moving contacts in and out of the chamber and for putting them on and taking them off the pan. Such elaboration of the balance is not warranted, since the present accuracy is entirely adequate for use in contact studies.

THE AUTHOR

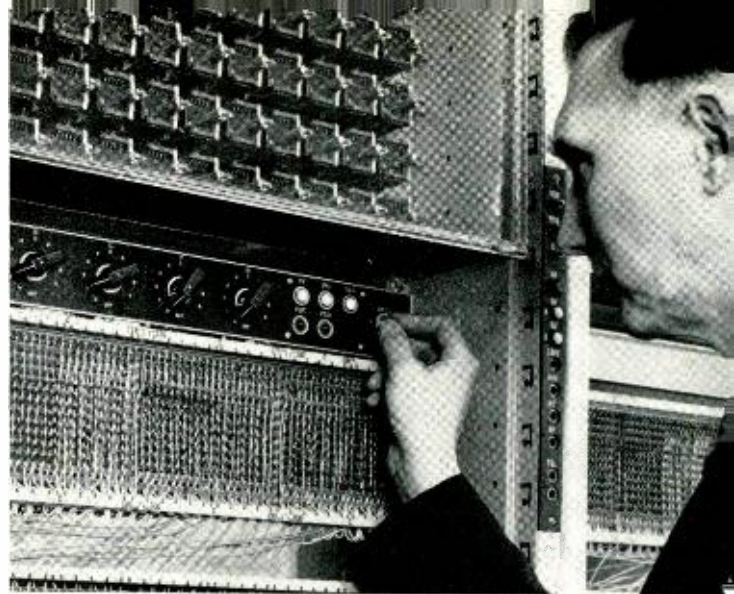


M. S. BURGESS received the degrees of S.B. and S.M. in Electrical Engineering from M.I.T. in 1928 and 1929, respectively, after completing the co-operative course in conjunction with General Electric. He worked in the Development and Research Department of the A. T. & T. Co. until he transferred to the Laboratories in 1934. He was first concerned with transmission studies relating to carrier and coaxial systems, telephotography and television. In 1937 he engaged in the design of transmission apparatus for carrier and radio frequency. Four years later he worked on high- and low-voltage transformers and retardation coils for regulated rectifiers, aircraft and radar equipment. He also developed static frequency generators using non-linear magnetic coils. In 1948 he transferred to electro-mechanical studies of switching apparatus, which included the testing and analysis of new and improved switching equipment. He has recently been concerned with contact erosion studies of wire spring relays using demountable contacts and the spring-type micro-balance to estimate contact performance.

Foreign Area Translation in No. 5 Crossbar

C. F. KNEPPER

Switching Systems Development



In some situations where numbering-plan boundary lines separate areas of mutual telephone interest, roundabout trunking might occur in switching a call from one area to another. To provide more efficient and economical trunking in such situations, "foreign area" translators have been designed for No. 5 crossbar offices. The first six digits of a ten-digit number are examined to determine whether a local cross-boundary situation exists and whether a more direct trunk group is available.

Limited customer dialing of toll calls is in use in a number of communities, and where such service is now provided, it has been well received.* Further expansion of this service to other communities is contemplated or actual installation work is in progress. The long-term objective is to remove present limitations and make it possible for a customer to be connected to any one of millions of telephones in the United States or Canada, merely by dialing a ten- or eleven-digit number. Any one of these numbers must, of course, represent some one telephone somewhere in the United States or Canada, and there can be no duplication of the number. To provide this individual numbering, the "area numbering plan"† is used in which one or more area codes in the XOX-XIX series are assigned to each state in the United States and to the political subdivisions of Canada. Some states require more than one area code because of the large number of telephones in use.

As an example, the state of New York is assigned area codes 212, 315, 516, 518, 716, and 914, each representing a particular area of the state. The Laboratories' telephone number, using the area numbering plan, is 212-CH3-1000. The 212 is the area code, CH3 is the code of the Chelsea 3 central office, and 1000 is the number within the

* RECORD, *January, 1954, page 11, and April, 1954, page 153.* † RECORD, *May, 1951, page 197.*

office assigned to the Laboratories. A telephone customer located outside the New York 212 area may call the Laboratories by dialing the above ten-digit number. The state of New Jersey is assigned area code 201. If it is assumed that the calling customer's telephone number in New Jersey under the area numbering plan is 201 B1gelow 3-1000, then the need for the numbering-area codes becomes evident, for in both cases the calling central-office code digits and number and the called central-office code digits and number are 243-1000.

In the No. 5 crossbar system, the marker is required to translate only the first three digits of a seven-digit number to determine the routing to the called office, and it can translate the first three digits of a ten-digit number in a similar manner. However, the first three digits of a ten-digit number is an area code, and its translation determines only one routing into the area in which the called telephone office and number are located. Further translation of the called office code digits must then be made in the called area to determine the routing to the central office. Another way of looking at the marker operation is to consider it as rather indifferent to any of the digits except the first three. It is only required to check and to forward other digits to an outgoing sender. This arrangement is satisfactory for most uses, and pro-

vides a simple method of handling customer dialing of long distance calls, except as noted below.

As our country has grown, telephone traffic has also grown, and now there are communities in adjacent states between which a considerable volume of telephone traffic exists. In some cases the traffic is sufficient to warrant the installation of direct trunks between local telephone offices in different numbering areas. The original No. 5 crossbar system marker arrangements do not provide for translation of the office code digits when numbering area codes are used. Consequently it has not been economical to use direct trunks between two local offices in different numbering areas even though they are directly adjacent.

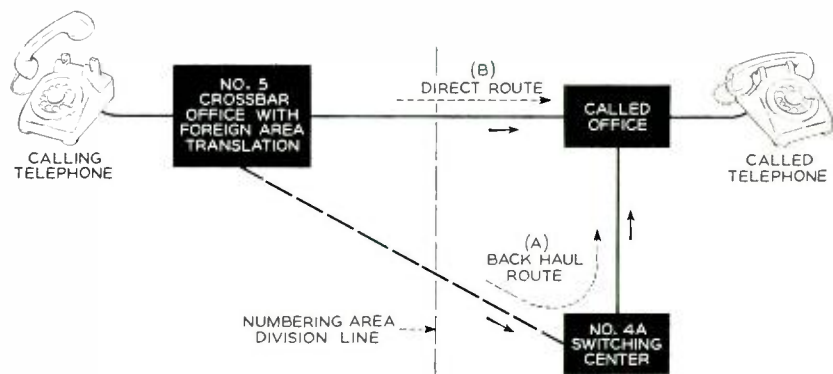
A more flexible arrangement, to permit the use of direct trunks, requires that the area code or a directing code be translated to determine the numbering area, and in addition, the central office code must be translated to determine which one of the trunk groups should be used to complete the call.

foreign area translation provides for the translation of the called office code digits in the calling office, and the information obtained by this translation is used to determine the trunk group into the called area. With foreign area translation it is also possible to use direct trunks between an office in one numbering area and an office in another, and thus eliminate the intermediate switching and back haul trunking.

The foreign area translator is arranged to provide translation for tandem and long distance calls switched through a No. 5 office. The translator may also be used to determine the proper billing treatment for Automatic Message Accounting (AMA) use, where one trunk group is provided into a foreign numbering area and where two or more billing treatments are required.

The equipment necessary for translation involving three numbering areas is shown in simplified form in Figure 2. This equipment consists of one connector unit per marker, and one translator frame for all markers. Eight connector units are

Fig. 1—Possible arrangement of offices involving “back haul” traffic (A). Foreign area translator causes more direct route (B) to be found.



A study of this situation led to the development of foreign area translation for the No. 5 crossbar system. This new feature is arranged to translate the office codes of any six numbering areas, which is sufficient for all presently known requirements.

As mentioned before, the No. 5 crossbar system was originally arranged to handle customer-dialed calls to other numbering areas without foreign area translation, but only one trunk group into any other numbering area could be used. With one trunk group, calls from one area to another are routed to a central point in the called area and distributed as required by the called office code digits. This arrangement may result in undesirable trunking, as illustrated in Figure 1, where the geographical locations of the calling office, the intermediate office, and the called office are such that “back haul” trunking is required. The addition of

shown mounted on one connector frame to provide service for eight markers. If translation involves more than three numbering areas, an additional connector unit per marker and an additional translator frame for all markers are required. The translator consists of a double-bay frame containing duplicate equipment in the two halves of the frame. These duplicates are provided for service protection. A marker requesting translation may use either translator A or B of the pair, depending on availability and on a predetermined order of preference. The A and B translators are further divided into three individual area translators. The marker determines which area translator is to be used.

The block diagram, Figure 4, shows the relationship of the marker to the foreign area translator connector and translator. The marker receives the called number from a register or sender and

uses the first three digits to determine the proper foreign area translator connector and the proper foreign area translator. It then indicates to the connector whether the first three or second three digits of the called number are involved in the call. This indication is also used to signal the translator that the called number consists of either seven or ten digits.

Seven-digit entry into the translators is sometimes used, for example, to find the most convenient routing to certain distant offices in the home area over a trunk group to a switching center located in other than the home area. The translator examines the three digits and determines the proper billing, and for switching reasons signals the marker to add an area code to the seven digits dialed by the customer.

The translator connector seizes the indicated area translator and forwards into the translator the three code digits to be translated, together with signals indicating the area, class of call, and number of digits. There are three class signals, one for customer-originated calls, one for incoming tandem trunk calls, and one for incoming long distance trunk calls. The translator uses the ABX code digits to cause the grounding of a terminal called a code point. The code point is cross-connected in the translator to produce an area route indication as directed by the area, class of call, and number-of-digits signals. This area route indication is forwarded from the translator through the connector to the marker, where it is used in the same way that other marker code points are used to determine the routing.

The translator is provided with a "relay tree"

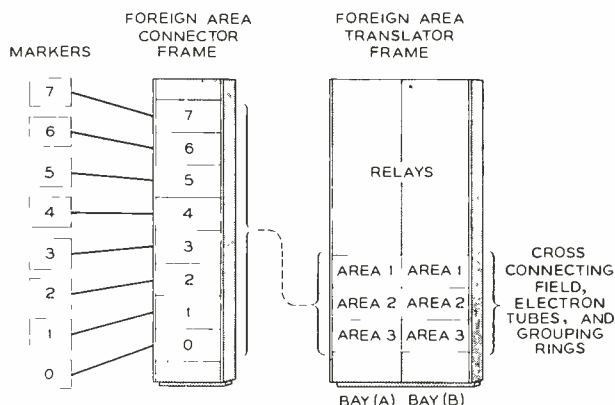


Fig. 2—Block diagram showing equipment arrangements used for foreign area translation involving three numbering areas.

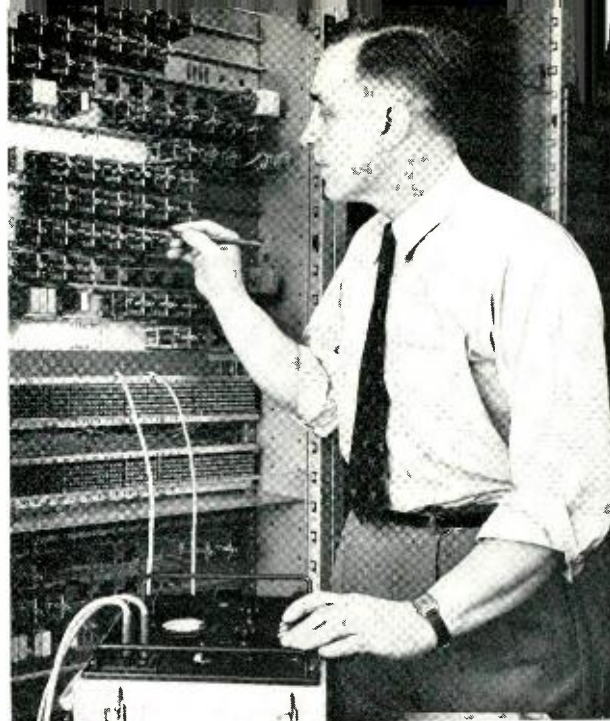


Fig. 3—F. C. Kuchas checking the operation of foreign area translator connector circuits.

type translation device to translate the office code digits into one of a thousand code points. This device serves all three area translators. The complete translator also includes three other translation devices, and they may be used either individually or in common to obtain the required route indications. The first of the three devices is the direct route translator, which may be used where direct trunks are provided between offices in different numbering areas. It is primarily intended to be used for a small number of codes having few variations in routings, or it may be used to serve one area if only one area translator is equipped. The second device is the grouping "ring" transla-

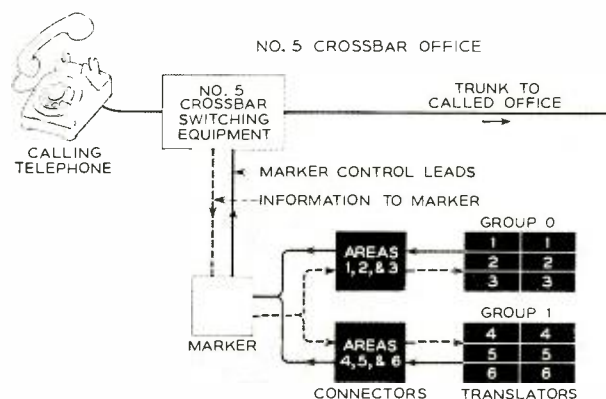


Fig. 4—Block diagram showing relationships between marker, foreign area translator connectors, and foreign area translators.

tor,^o used for translations of large numbers of codes having many variations in routings. These routings usually will be through tandem or toll centers in the called numbering area. The third device is the code-screening controller. It is used where different route indications are required for called offices that may be reached by using either seven- or ten-digit called numbers. It permits proper completion and billing of calls if customers incorrectly dial ten digits when they should dial seven digits. Each individual area translator (maximum of 3 per translator group) may be provided with any or all of the above devices as needed.

An actual situation, as illustrated in Figure 5, will explain the use of foreign area translators. The figure is a map of portions of the states of Ohio, Pennsylvania, and West Virginia. East Liverpool, situated in Ohio and geographically adjacent to Pennsylvania and West Virginia, is equipped with No. 5 crossbar equipment arranged to use foreign area translation. The office names used in this installation are FULTON 5, FULTON 6, ROCKWELL 4, and EVERGREEN 7. Some of the customers who use this equipment are located in Ohio (area 216), some in Pennsylvania (area 412) and some in West Virginia (area 304). The majority of the telephone calls made by the nearby customers in Pennsylvania and West Virginia terminate in the Ohio or 216 area. To permit seven digit dialing for these calls, the Pennsylvania and West Virginia customers are considered to be in the 216 area. For calls to other numbering areas where customer dialing is permitted, customers will dial a ten-digit number.

In situations of this nature, where the numbering area division lines run between communities having interests in common, No. 5 crossbar offices can

^o RECORD, February, 1951, page 62.

use the flexibility in trunking, switching, and billing provided by foreign area translation. Where a roundabout route might ordinarily be required to connect an East Liverpool customer to, say, a

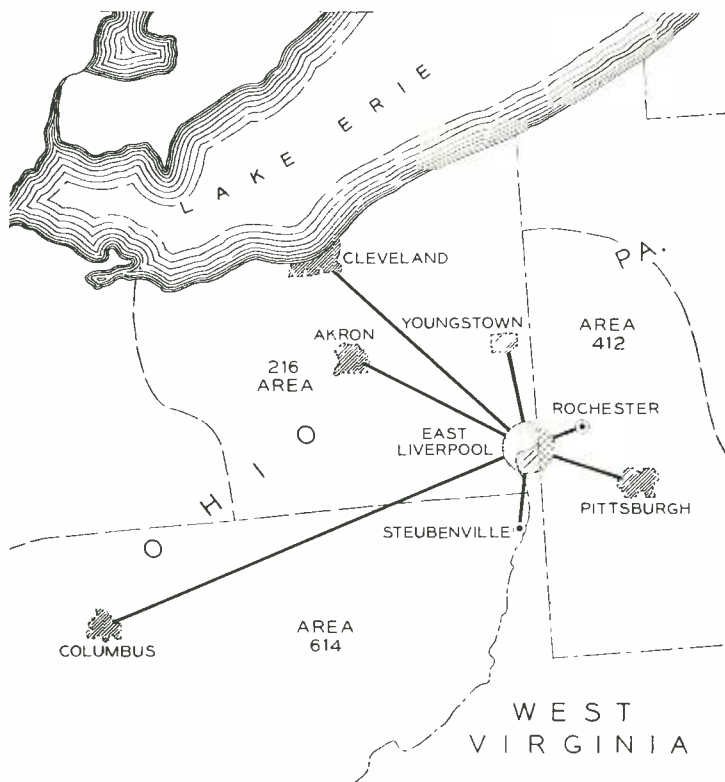


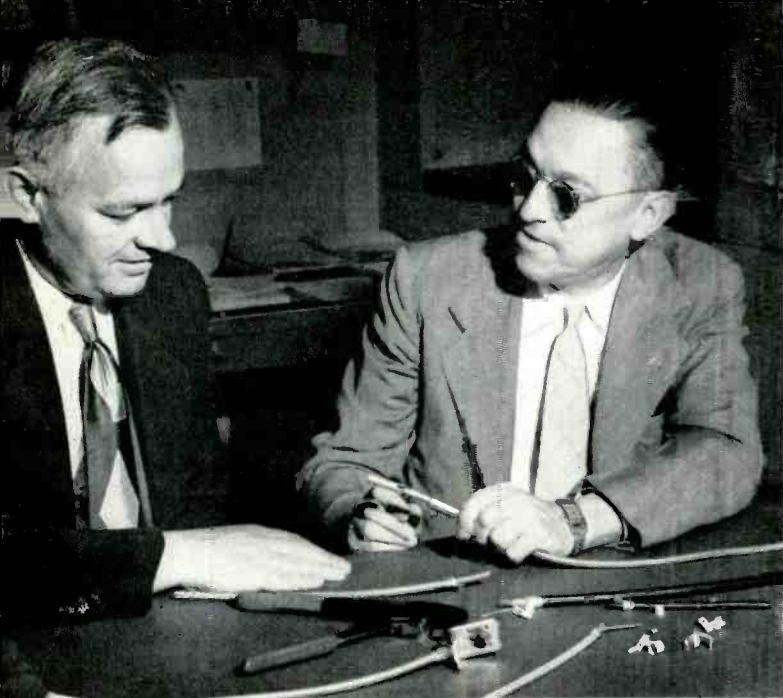
Fig. 5— Map showing boundary situation where foreign area translation can be used for more efficient trunking.

customer somewhere in Pennsylvania, the foreign area translator will examine the dialed number and find a more direct route. The addition of foreign area translation to the No. 5 is another step taken to extend customer dialing of long distance calls.

THE AUTHOR



CHARLES F. KNEPPER entered the Bell System in 1923 when he joined the Bell Telephone Company of Pennsylvania, serving as chief switchman on central office equipment maintenance. In 1946 he transferred to the Laboratories to help organize and act as an instructor in the first No. 5 crossbar maintenance training school. Later, Mr. Knepper was concerned with experimental work on the original version of markers for the No. 5 crossbar system. In 1952 he was engaged in the layout and design of laboratory equipment for foreign area translators. Mr. Knepper is presently concerned with the re-design of the No. 5 crossbar switching system using wire spring relays.



F. W. Koller (left) and A. J. Wier examining a crimped connection of a 724-type cable on a 358-type coaxial plug.

When low-loss, office-type shielded cables, both coaxial and balanced pair types, were introduced into the broadband carrier, television, and microwave radio systems, an efficient means was needed to connect to the metallic shield of these cables.

The soldering methods previously used to make connections often caused the polyethylene inner insulation to soften or even to flow. The connection presented a poor appearance and was sometimes unsatisfactory at high frequencies.

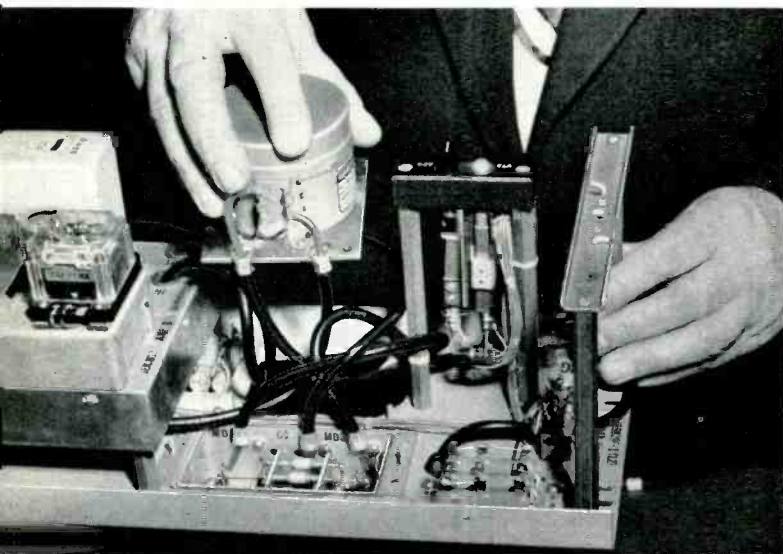
The use of crimp-type connectors, like those il-

Connectors for Cable Shields

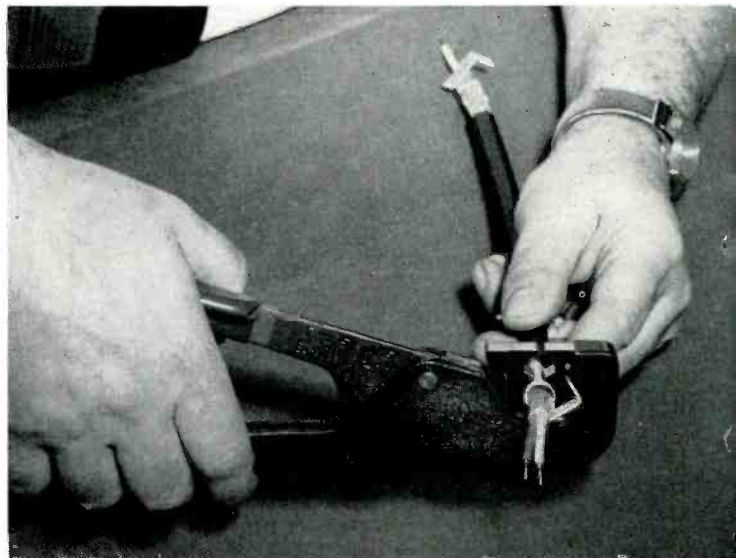
lustrated, not only overcomes these difficulties but also produces a cheaper, more uniform connection. Artificial aging and salt spray tests showed that such connections are indistinguishable electrically from soldered connections.

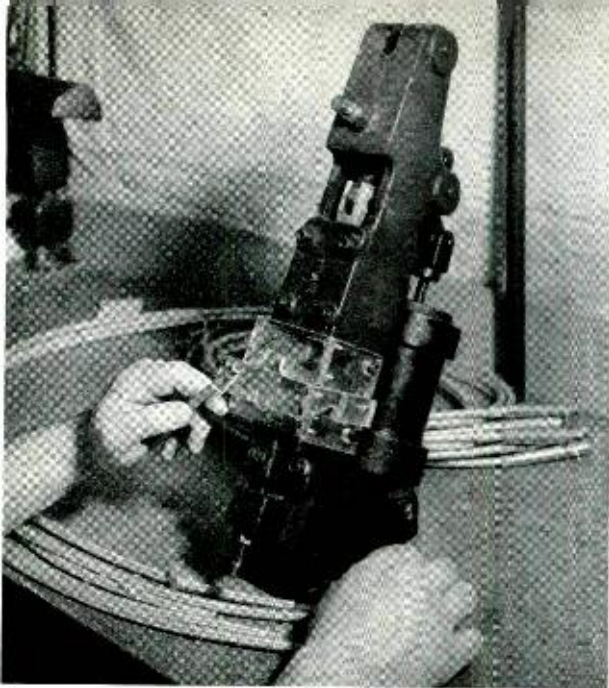
These connections are made by crimping the cable shield between two tin-plated copper sleeves. The inner sleeve, which is almost incompressible, is placed over the inner insulation and under the shield braid. The outer sleeve is placed over the shield braid and crimped to a hexagonal shape.

Utilization of crimped-type connectors on a panel of the L3 carrier terminal equipment.



GSF 405 flag-type connector being applied to 754-type cable using a hand-operated tool.





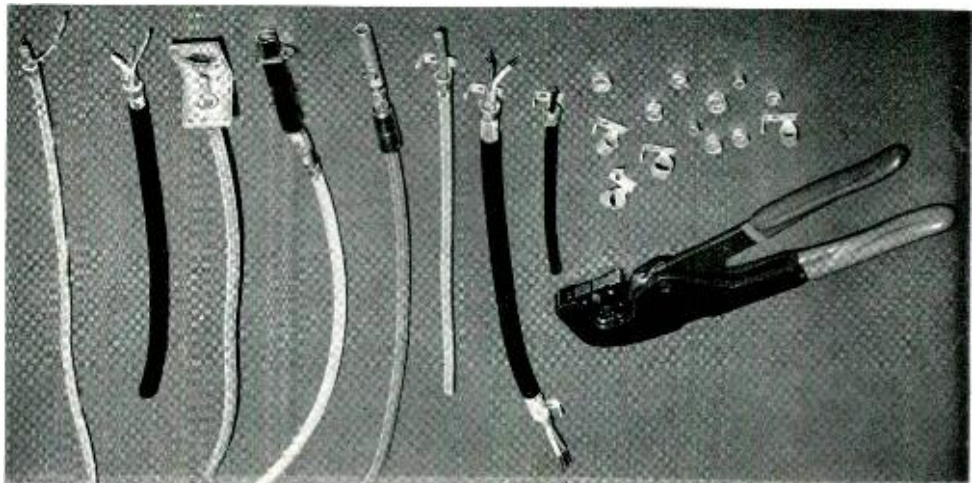
GSF 327 flag-type connector after application to 724-type cable by means of an air operated bench tool used for quantity production in the factory.

where the end of the cable is to hang free. When a connection to the shield is required, a short length of wire or pigtail is usually inserted with the shield braid between the inner and outer sleeves, before crimping. This type of outer sleeve is also used for connecting cable shields to coaxial jacks or plugs.

A hand-held, hand-operated crimping tool is provided for field or installer use. This tool is equipped with a mechanical interlock which makes it necessary to close the hexagonal die shapes all the way, or, in other words, to complete the crimping operation before the tool can be reopened. This insures uniformity of all crimped connections.

An air-operated bench tool is used in the factory where large quantities of cable subassemblies are being manufactured. This tool is provided with adequate guards to protect the operator's hands. An associated foot-operated valve actuates the crimping mechanism.

Crimping tool, assorted sleeves and flag-type connectors, with connections made on several types of cables, jacks, and plugs.



Thus the shield braid is held between the two sleeves, with great pressure applied at six points equally spaced around the cable.

Two types of outer connectors are being used in relatively large quantities. One, called a flag-type connector, provides a means of mounting a cable end and simultaneously grounding the cable shield. A soldering lug is also provided for additional wire or pigtail connections to the shield. These multiple functions make the flag-type connector a very useful component, especially in high-frequency equipment. The other type of outer connector is a simple sleeve used for terminating cable shields

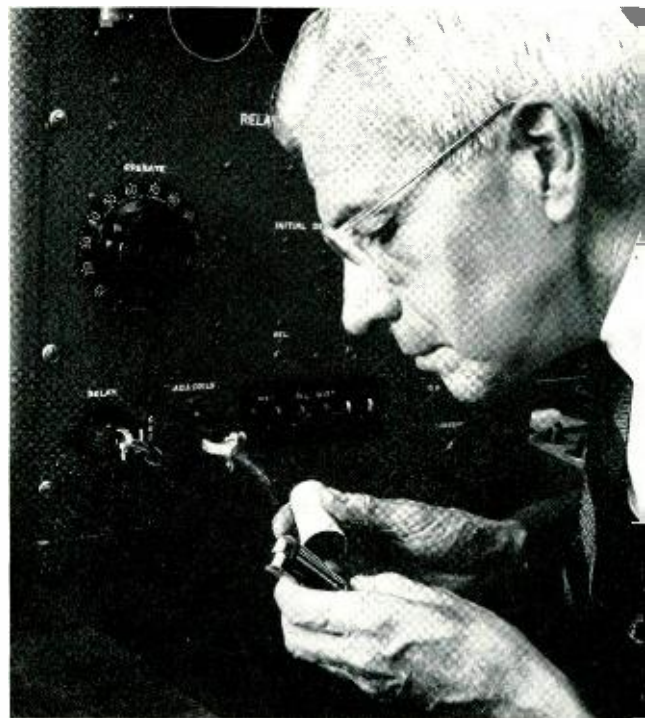
Collaborating on the development of these devices and their introduction into equipment designs were A. J. Wier and F. W. Koller, of the Transmission Systems Development Department. W. T. Westaway of the Western Electric Company, Engineer of Manufacture Organization, participated in the application aspect of the project and developed the production methods used in the Kearny shops.

F. W. KOLLER

Transmission Systems Development

The new 291 mercury-contact relay is especially adaptable to a variety of uses by adjustment of its operate and release sensitivities. Since the adjustment process is a complicated one when performed manually, a circuit has been designed that permits an unskilled operator to adjust these relays quickly and automatically at a rate of two or more per minute.

J. T. L. BROWN *Switching Apparatus Development*



Automatic Relay-Adjusting Circuit

Relays used in telephone switching and for other purposes must be so designed and adjusted that a specified range of current values applied to the winding of the electromagnet causes the armature to move and thus operate the contacts involved in an electrical connection. The adjustment process in manufacture is typically a "cut-and-try" manual process requiring some degree of skill on the part of the operator. For most common relays, the adjustments are mechanical, and involve the changing of spacings and spring forces to compensate for minor variations in materials and manufacture.

Relays like the 276 type mercury-contact relay* are also adjusted manually. The working parts of this relay, however, are sealed in glass, and such mechanical operations as changing spring tensions are therefore not feasible. Instead, requirements for the 276 relay are met by adjusting the magnetization of a two-element magnet assembled in its housing. An operator first fully magnetizes this

* RECORD, September, 1947, page 342, and April, 1949, page 132. † RECORD, October, 1953, page 392.

magnet, and then demagnetizes it to the point where the correct currents will just operate and just release the relay. This sequence of full magnetization followed by controlled demagnetization gives maximum stability of magnet strength.

The recently developed 291 type mercury-contact relay, however, has two independent magnets assembled in its housing. This two-magnet arrangement permits a wide range of currents at which the relay will just operate and release. The two current values can be the same or opposite polarity, and the difference between the two magnetomotive forces may range from about 4 to about 100 ampere-turns. Thus the relay is expected to be a possible replacement for polar relays like the 280 type,† which operate on about plus or minus 3 ampere-turns. It can also be used in places where high speed is required when driven from a uni-

Above—The author examining the two permanent magnets of a 291 type mercury-contact relay, from which the cover has been removed. The relay-adjusting circuit is in the background.

polar source with a limited power output, such as a transistor.

The new relay uses the mercury-contact switch shown in Figure 1(a). It is a symmetrical structure, with an armature in the form of a reed operating between platinum-alloy contacts welded to pole pieces. These pole pieces extend out of the glass envelope at the top. In the surfaces of the armature are grooves that feed mercury to the contacts from a reservoir at the bottom. Figure 1 shows the assembly of the switch into a relay. Two magnets are soldered to the pole pieces and also to perm-alloy side plates outside of the operating coil. The assembly is placed in a steel can filled with wax. The operate and release sensitivities are then adjusted on the completed structure.

Because of the two-magnet structure of the 291 type relay, the process of arriving at a particular combination of sensitivities is more complicated than that for the 276 type. Since manual adjustment in the manufacturing process would be unsuitable, a circuit has been built which simplifies the process by making it automatic. A similar magnetization-demagnetization cycle is used, but is carried out by the equipment itself.

A model of this equipment is shown in Figure 5. The principal element is a circuit cabinet, with a number of dials and keys on its front panel. In front of this is a connecting fixture which holds the relay to be adjusted. Magnetization and demagnetization are obtained with the electromagnet fixture, which is shown being put in place over a relay. Figure 2 is a diagram showing how the electromagnets are placed with respect to the permanent magnets of the relay when the adjustment is made.

Most of the dials and keys seen in Figure 5 are used for setting up the circuit for adjustment of various relay types. When this has been done, the routine procedure for adjusting a batch of relays of a given type is fairly simple. With the machine set up, the operator plugs a relay to be adjusted into the connecting fixture and slips the electromagnet fixture over it. He operates a key on the panel for a few seconds to magnetize the relay and then shifts the same key to a position that starts the demagnetizing process. He can follow this process by watching two lamps on the panel labelled "operate" and "release". In about fifteen seconds these lamps go into a rapid oscillation, indicating that the adjustment is completed.

Thus it is possible for an unskilled operator to adjust relays at the rate of two or more per minute.

The precision typically obtained corresponds to a deviation of less than one ampere-turn from the desired operate and release values.

Compared to the operator, the circuit has quite a lot to do. A block diagram illustrating the operations of the circuit is shown as Figure 3. In the initial magnetization of the relay a strong magnetic flux is applied directly across the relay magnets by the electromagnet fixture. The electromagnets in this fixture are energized together by half-cycle pulses from a 60 cycles-per-second ac power source. The flux from them is sufficient to fully magnetize the permanent magnets of the relay. In the fully magnetized condition, the relay just operates in each direction on relatively large current values, which are about equal numerically but opposite in polarity. That is, the algebraic difference value between the two currents is relatively large.

After this magnetization, the armature will be fully operated to one side or the other, and the

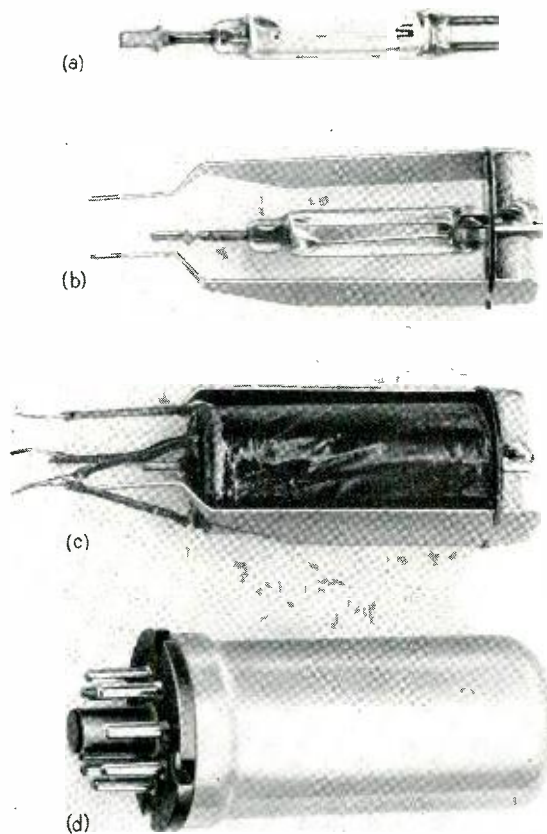


Fig. 1—Mercury-contact relay: (a) switch element; (b) magnets, spool, and side plates added; (c) coil added; (d) the complete relay.

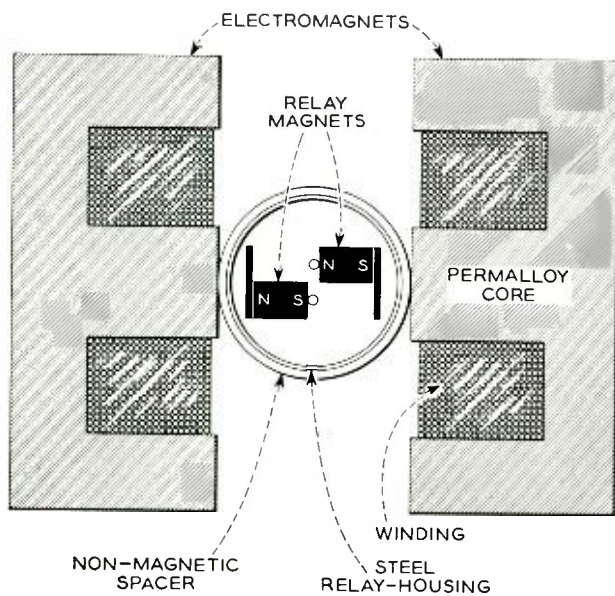


Fig. 2 — Diagram showing how the magnets of the electromagnet fixture are positioned with respect to the permanent relay magnets.

adjustment process starts by applying the first demagnetization pulse to that side. This initial demagnetization pulse, however, may shift the armature to the other side. To ensure that the armature is restored to the correct position, the relay is given a "reset" current. Then the relay is tested with the current value specified for operation from that side. This cycle is repeated with progressively increasing demagnetization pulses until the relay responds to the test current by

operating to the other side. The demagnetization input is in the form of a half-cycle pulse applied to the electromagnet on the side being adjusted, but of reverse polarity to the initial magnetization. The cycle of alternate demagnetization and test is adjustable to various submultiples of 60 cycles per second, usually about five per second.

At the end of this first demagnetization series, the relay will just operate on the final current value desired for operation in one direction. The difference value between the operate and release currents will also have been reduced from that corresponding to full magnetization. The magnet that has just been operated on, however, is not yet at its proper final strength, because the other magnet, not yet reduced in strength by adjustment, is aiding it.

Now, with the armature starting on the other side, the above adjustment process is repeated. Pulses are applied to the electromagnet on that side, and the relay magnet is tested with respect to the second specified current value. This leaves the relay adjusted to the second current value, with the difference current value still further reduced.

The process is repeated alternately on the two sides until both the current value being adjusted and the difference value are those specified. Actually, because of the finite size of the steps, the final operate and release currents are slightly inside of the test currents used. That is, they have a slightly smaller difference value. This is compensated for by corrections applied to the test currents that are set up.

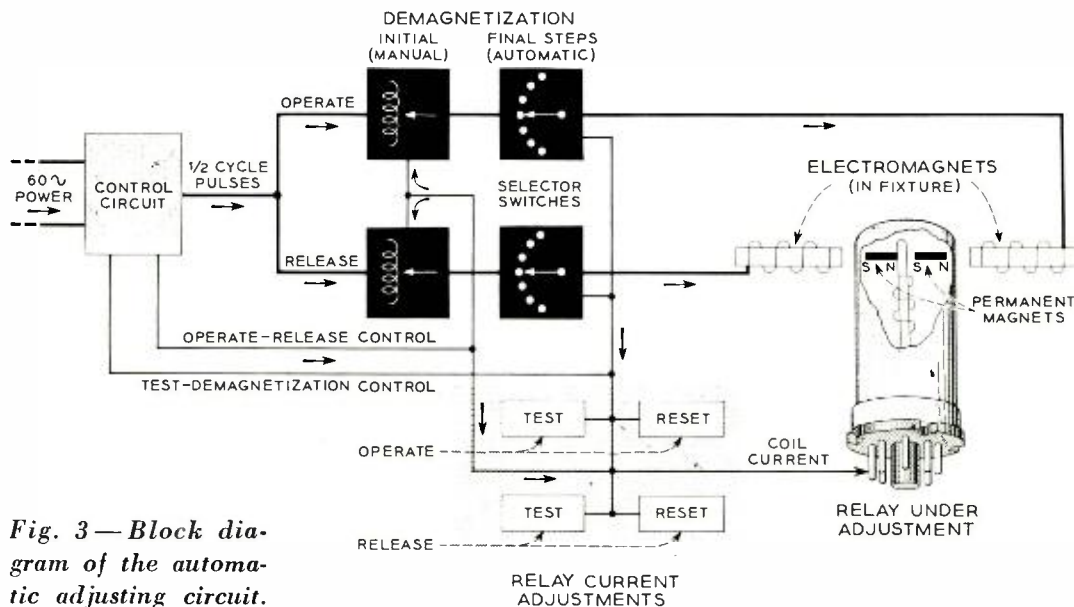


Fig. 3 — Block diagram of the automatic adjusting circuit.

Figure 6 shows a typical progression of these adjustments on alternate sides, ending in the final adjustment on both sides. The initial magnetization, it will be noted, resulted in a "just operate" value of +50 ampere-turns and a "just release" value of -56 ampere-turns. The corresponding difference value is 106 ampere-turns. After nine preliminary adjustments on alternate sides, the relay was adjusted to operate on +45 ampere-turns and to release on +24 ampere-turns, the difference being 21 ampere-turns. Each of the adjustments is about 1 ampere-turn inside of the test values used.

The circuit shown in Figure 3 employs two selector switches and several relays for its automatic switching functions. The control section switches periodically between the test and demag-



Fig. 4—Western Electric Company equipment for adjusting 223-type switch.

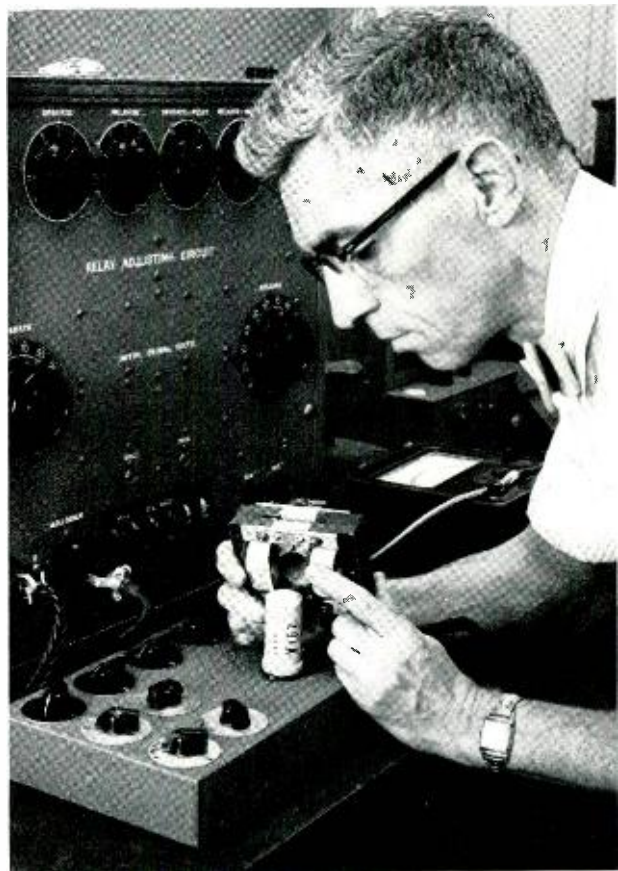


Fig. 5—C. E. Pollard placing the electromagnet fixture over a 291 type relay. Thereafter, the operation of a single key completes the adjustment.

netization conditions, and it also switches between the operate and release conditions in response to the test currents of the relay being adjusted. In addition, it selects the half-cycle ac pulses used for magnetization and demagnetization. For magnetization, the full line voltage is applied to the electromagnets, the peak current reaching fifteen amperes. Then, when the operator switches his key to the demagnetization position, voltage is applied with reverse polarity in progressively increasing steps to one electromagnet at a time.

Two demagnetization sections are provided: one for adjusting operate sensitivity and the other for adjusting release sensitivity. Each section includes a manual voltage control, the setting of which determines the initial demagnetization voltage applied to the electromagnets. Each section also includes an automatic voltage control, in which a selector switch progressively increases the demagnetization voltages as the adjustment proceeds. The range of voltages provided is wide enough to cover the variations among relays of a given type.

The remainder of the circuit provides adjustable test and reset currents. Test currents are set at the final adjustment values required, except for the small corrections already mentioned. The reset currents are set at values high enough to ensure that the relay armature will always be in the correct position after each demagnetization impulse. When the relay responds to the test current after a progression of alternate demagnetization pulses and tests, the circuit switches from the "operate" to the "release" side, or vice versa. When the test conditions are reached on both sides, the circuit oscillates between the operate and release conditions. Figure 4 shows a model of the adjusting equipment built by Western Electric to adjust the 223-type switch. This switch is a combination of four relays using the same mercury-contact switch element as the 291. It is used for switching in high-frequency coaxial circuits. Except for its physical arrangement, the circuit is the same as that described above. The larger size of this "console model" is partially due to a dc power supply in the lower part of the cabinet.

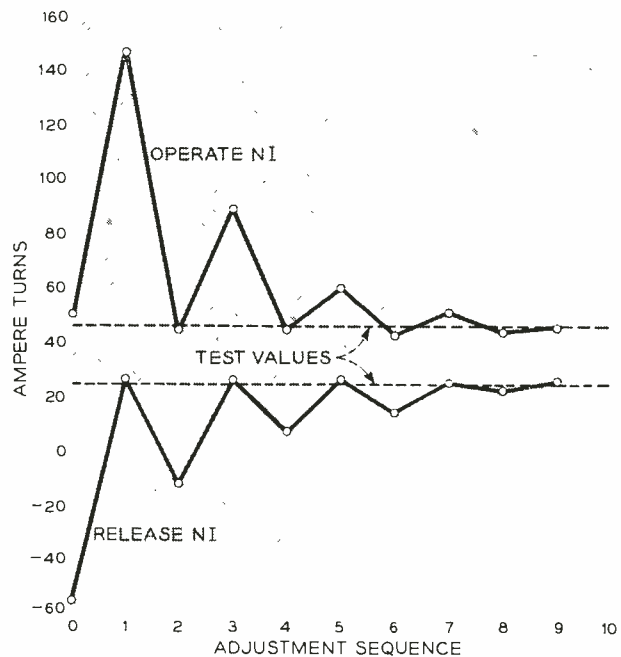
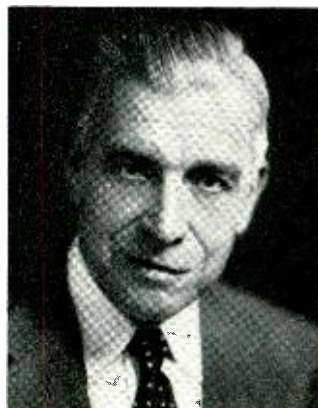


Fig. 6 — Curves showing automatic progression of adjustments on alternative sides, ending in adjustment on both sides of a 291 mercury-contact relay.

THE AUTHOR



J. T. LINDSAY BROWN received a B.S. degree from the College of the City of New York in 1915, and joined the Laboratories the same year. For 25 years Mr. Brown was concerned with the development and testing of telephone instruments, including such allied apparatus as loudspeakers, microphones, and earphones. In 1940 he transferred to work on the development of glass sealed magnetic switches. Mr. Brown is currently in charge of a group which is responsible for developing high-speed mercury-contact relays. He is a member of the A.I.E.E., I.R.E., and the Acoustical Society of America.



Connectors in 4A Toll Crossbar

M. E. ESTERNAUX

Switching Systems Development II

Little known and seldom discussed, connector circuits are important parts of modern common-control switching systems. Instead of interchanging pieces of information between major circuit units in sequence, modern systems interchange large blocks of information at one time. This requires “connector” circuits capable of associating major circuit units over many leads at once. In addition, these connectors include preference and gating arrangements to prevent any major unit from monopolizing any other unit, and to prevent similar units being inadvertently connected together.

Automatic dial telephone systems, such as 4A Toll Crossbar, use large common-control circuit units — senders, decoders, translators, and markers — to set up a talking path through an office.* To obtain the necessary flexibility in associating these major circuit units with each other, “connecting” circuits are provided. These smaller units, commonly referred to as “connectors,” temporarily obtain the exclusive use of larger circuit units, and establish many simultaneous connections between them for the interchange of information as required. Collectively, they also determine the order in which waiting calls are to be handled, and prevent the monopolizing of connected circuits by any one or any group of units. These connectors, when called in by major circuit units, connect them to other major units only when needed. Although several different types of connectors are used in 4A offices, only those that interconnect the major common-control circuits will be discussed.

One of the very important connectors in the 4A office is the decoder connector. This connector has two jobs — it establishes many connections for the interchange of information between a sender and a decoder, and later also between the same sender and a marker. Provision is made for a maximum of seventy-six decoder connectors in a 4A office, and each connector provides a group of five senders with access to a maximum of eighteen decoders and twenty markers.

When a sender has received and stored enough information (a minimum of three digits) to require a decoder for translation of the code,† it signals its decoder connector to establish connections to an idle decoder. This signal is battery applied to the “start” lead of that particular sender’s preference relay *SP* in the decoder connector. The connector may receive up to five such requests

* *Record*, Dec., 1953, page 481. † Aug., 1954, page 295.

simultaneously, one from each of the five senders it serves. The connector determines which sender is to be served first and then proceeds to lock out the remaining senders by means of a simple "lock-out" and preference circuit. A five-sender preference circuit is illustrated in Figure 1.

Although all five senders may signal their connector at the same time, it is unlikely that all SP relays will operate because their operating speeds are not identical and because the operating ground for higher-numbered relays is routed through the unoperated lower ones. Any SP relay may operate at any time providing no lower-numbered relay is operated. However, only one sender "cut-in" relay

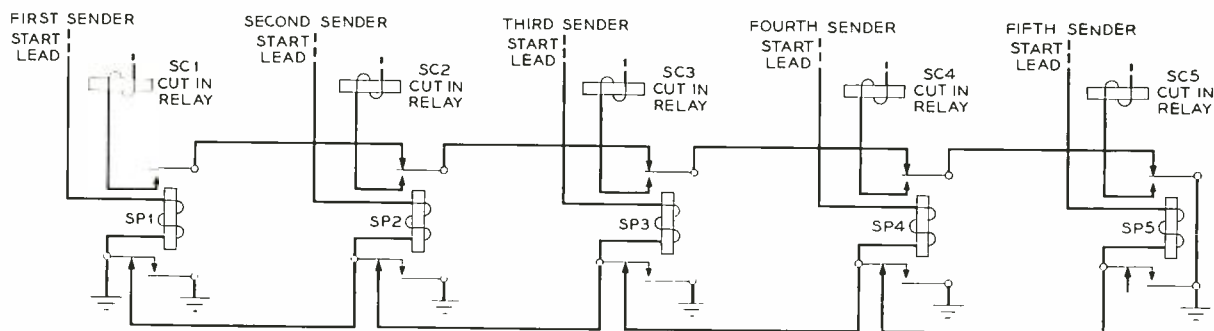


Fig. 1 — A five-sender preference circuit as used in a 4A toll crossbar system.

SC can operate because operating ground for the lower numbered SC relays is routed through contacts of unoperated higher numbered SP relays. If the SP5 relay is operated, its associated SC relay will operate. All others are locked out. When the connector has completed its task of serving the fifth sender, its associated SP5 relay releases and makes the connector available for other senders. Release of an SP relay transfers the SC operating ground to contacts of the next lower numbered SP relay. Thus, if all five SP relays are operated, their associated SC relays will operate in descending order. Figure 1 shows these cut-in relays simply as coils; actually each is several multi-contact relays that complete most of the connections between senders, decoders, and markers. The rest of the connection is established by operation of the decoder and marker cut-in relays.

A decoder connector that has selected a sender and locked out the other four senders then bids in competition with other connectors for an idle decoder. In selecting a particular sender, five senders are bidding for just one decoder connector. However, in selecting a decoder, many connectors (76 maximum) are bidding for many decoders (18 maximum). Figure 2, where four connectors have

access to three decoders, illustrates part of a typical checking and lockout circuit used in 4A toll crossbar offices. Here, each of the three decoders is first choice to one of three different connectors, the second connector being a repetition of the first connector. Additional connectors and decoders follow the same basic pattern.

Each connector, besides having the necessary cut-in relays DC, is equipped with two relays CB and DP for every decoder to which it has access. The CB relays form a preference circuit for the decoders, while the DP relays do the same for the connectors. Two interlocking preference chains thus provide a "many-to-many" preference and

lockout circuit. Whenever a decoder is busy, its CB relays are operated in all connectors except in the connector that is holding the decoder busy. Connectors with bids for a decoder will attempt to operate the DP relay of their first-choice decoder. Should that decoder be busy, as recognized by the operated CB relay, the connector will attempt to operate its next-choice DP relay. Assuming that only one decoder is idle, and all four connectors bid for that decoder simultaneously, each connector will have operated its DP relay associated with the idle decoder. However, only the preferred connector will have a circuit for operating its decoder cut-in relay DC.

Referring to Figure 2, and assuming that all DP relays for DECODER 0 are operated, it can be seen that the preferred connector is CONNECTOR 3 and its decoder cut-in relay DC0 will operate. As soon as exclusive occupancy of the decoder is established, its CB relays will operate in all connectors except CONNECTOR 3. The operated CB relays open the circuits of all DP relays for the occupied decoder except the one in the successful connector. With all decoders now busy, the connectors wait for another decoder to become idle; the decoder will then permit its DP relays to operate.

Once a connector has served a sender, a "gate" circuit prevents that connector from handling another call until all other connectors with waiting calls are served. Again referring to Figure 2, each connector's operating circuit for DP relays is routed through a normal contact of its gate relay CR. This relay operates whenever the connector successfully establishes a connection between a sender and decoder, as evidenced by operation of the decoder

cut-in relay DC. The gate relay is held operated until all waiting connectors have been served. The last connector used releases all other connector CR relays, permitting a new line up of waiting calls to be served. A timing circuit is provided so that if any connector is delayed for an unreasonable time in securing a decoder, all CR relays will release, closing all connector start leads.

After obtaining for a sender the exclusive occu-

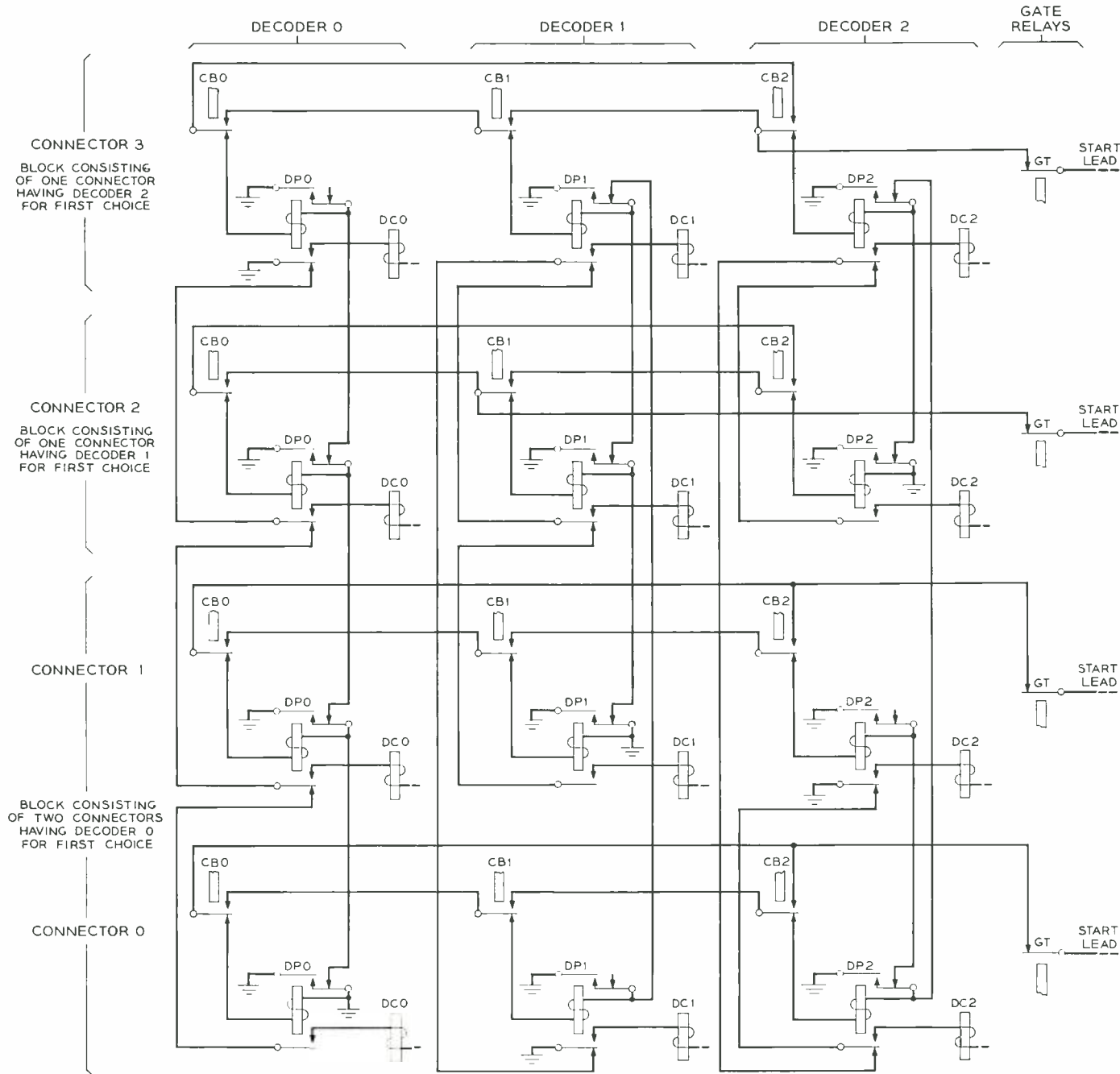


Fig. 2—Four connectors gain access to three decoders through two interlocking preference circuits. The CR relays form a preference circuit for the decoders and the DP relays do the same for the connectors.

pancy of a decoder, the decoder-connector closes fifty-three connections between these circuit units. In most connector units, it would now have completed its task—connecting two major units together. In the 4A system, the decoder connector must still connect sender and marker together. There may be as many as twenty markers; the decoder connector, however, selects the particular marker which the decoder is using. Figure 3 illustrates the relationship of the various units. In this illustration, SENDER NO. 4 has been connected to DECODER NO. 2 through its decoder connector, and MARKER NO. 8 has been connected to the decoder through a marker connector (to be described later). The marker connector signals the decoder connector that DECODER NO. 2 is associated with MARKER

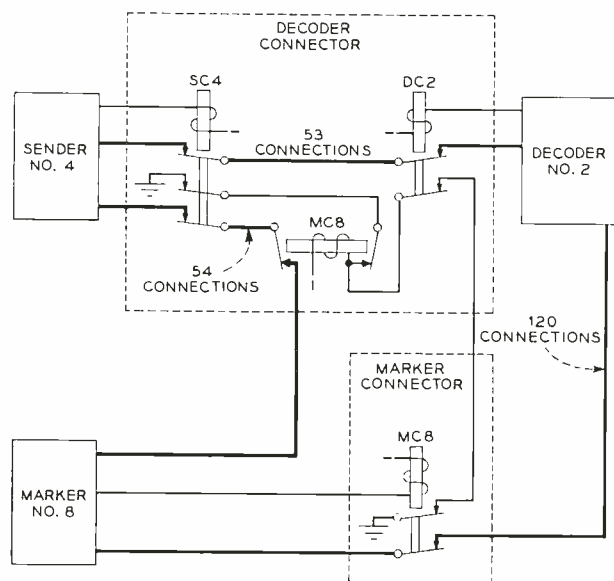


Fig. 3 — A sender is associated with a decoder and marker through decoder and marker connectors.

NO. 8. Marker cut-in relay MCS in the decoder connector then operates, connecting SENDER NO. 4 to MARKER NO. 8 through fifty-four connections. With these connections established, the sender is now connected to both the decoder and marker.

The decoder, on completing its job, signals the decoder connector to release it from the sender, but to continue to hold the connections between sender and marker. Once released, the decoder releases the marker-connector and both these circuit units become available for use by other waiting decoder connectors. The marker, after setting up the talking path, transmits certain information to the sender, enabling it to proceed with passing the

call to the next office. On completion of its functions, the marker signals the sender to release the decoder connector; when this is accomplished, the marker and connector may be re-seized to make another call.

Troubles that prevent either the decoder or marker from completing their tasks result in a trouble record being taken and a signal being sent to the decoder connector to release both decoder and marker. The sender remains associated with its connector, and while temporarily locking out the just-released decoder to prevent its re-selection, the connector chooses a new decoder, and later connects another marker to the sender in the normal manner.

A signal is sent by the connector to the new decoder that this is a second trial call; this information is stored in the decoder and passed on to the new marker. In the event that the same, or another, trouble prevents this second trial from being completed, a trouble record is again taken and the connector is again signaled to release the decoder and marker. This time, however, in selecting a new decoder, the connector specifies that no further attempts to complete the call are to be made and that the incoming call is to be set up to a reorder circuit. If a connection to reorder cannot be established, a third failure is recorded and the sender is notified to release the decoder connector and abandon the call.

Area or office codes transmitted to a decoder that result in a "no card" indication from a translator may either be due to a "vacant code," where the card had been intentionally omitted, or to an actual trouble. In any event, the decoder is unable to complete its tasks when no card with that code is found, and so it forwards a request for a second trial to the decoder connector. The connector stores the information that "no card" is available and proceeds with a second trial as previously described. If a card is found by the decoder handling the second trial, the progress of the call is momentarily blocked and a trouble record is made, indicating that some other decoder had a card failure on the particular code wanted. If, however, the new decoder also finds no card, the connector is again requested to release the decoder and to specify that a third trial should route the call to reorder. This reorder signal then informs the originating operator that the code being called is probably a vacant one.

A second connector, the marker connector, is also required in 4A offices. One of these connec-

tors is associated with each decoder and provides lockout and selection arrangements necessary to connect any one of twenty markers to a given decoder. The lockout circuit used in this connector is similar to the one shown in Figure 2, since many connectors may be bidding in competition with each other for many markers. Once a marker connector has established connections between a decoder and marker, it assists in closing a circuit to the decoder connector. This enables the decoder connector to connect its sender to the same marker, as shown in Figure 3. One hundred and twenty connections are then closed for the interchange of information between decoder and marker. Some of this information is used to permit the marker to set up a talking path between the incoming and outgoing trunks. Other information is stored in the marker and later is transmitted to the sender. The marker connector is released after the decoder completes its functions. However, the marker is still held connected to the sender through the decoder connector until all of the marker functions are completed.

There is one other connector that connects major circuit units together in the 4A system. When a translation is required from one of the foreign area translators in a common pool to which all decoders have access, a translator connector is used. One of these connectors is associated with

each translator in the pool. There are a maximum of nineteen foreign area translators and their associated connectors. In addition, to prevent degradation of service when a translator is non-operative for any reason, an emergency translator and connector are provided in each 4A office. This emergency translator and its connector can be used in place of any translator in the office.

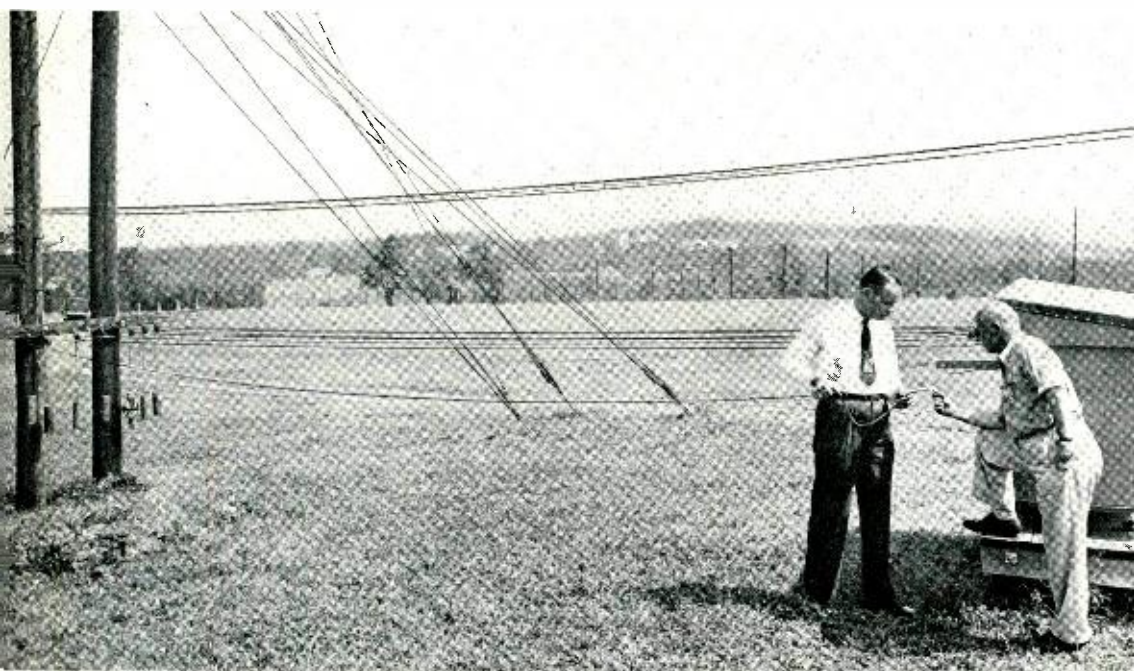
Since many decoders may be bidding for one translator in the common group, a lockout and preference circuit of the same type as shown in Figure 1 is used to regulate the flow of traffic from all decoders. Decoders and translators are only connected together for a brief interval of time. During this time the translator connector establishes 195 simultaneous connections required by the decoder-marker combination. After the decoder and marker have stored all necessary information, the translator connector is released, permitting re-seizure of the translator by another decoder.

There are other connectors in the 4A system, such as sender link connectors, trunk block connectors, and incoming and outgoing link connectors. These perform similar functions, but some of them utilize crossbar switches as well as multi-contact relays. However, in general, these connectors use one of the two lockout and preference circuits illustrated in Figures 1 and 2.

THE AUTHOR



MAX E. ESTERNAUX entered the Bell System in 1921 when he was employed by the New York Telephone Company. He remained with the New York Company until 1943 when he was granted a leave of absence to work with the Army and Air Force on the design and installation of message centers and communications systems in the Pacific Theater of Operations. Mr. Esternaux returned to the New York Company briefly in 1945 and was later temporarily assigned to Western Electric's Hawthorne Works. He has been with the Laboratories since 1946 and has been concerned with circuit designing and crossbar toll systems in connection with senders and marker design. He attended New York University and is a member of the Essay and Proof Society.



H. A. Wells (left) and W. C. Sturzenegger inspecting a drop wire clamp after test at the Chester Laboratory.

Drop Wire Clamp Testing Machine

More than fifteen million drop wire clamps are used each year to support the familiar drop wire running from the telephone pole to the customer's house. Two types of clamp are standard in the Bell System. One is made of copper and brass with a copper tail wire. The other, essentially similar in design except for materials employed, is made of aluminum with a stainless steel tail wire. The aluminum clamp is somewhat cheaper, but its use is limited to areas where corrosion is not severe. This clamp, shown in Figure 1, consists of three

parts which are assembled on the wire as follows: The drop wire is placed in the shell at the middle left of Figure 1. The shim at the middle right is placed against the wire, and when the narrow end of the wedge (bottom of Figure 1) is pulled into the shell, the wire is tightly grasped. The tail wire attached to the wedge can then be dropped over a hook on the telephone pole. The drop wire is suspended between this and a similar attachment on the customer's premises.

From a mechanical standpoint the tail wire is the most vulnerable part of the drop wire clamp. It must be relatively resistant to corrosion, able to withstand abrasion and fatigue stresses caused by swaying of the drop wire, must be strong enough to hold the drop wire to its breaking point, and must be soft enough to form around various attachment fittings. It was to test materials for this use that the machine shown in Figure 2 was designed.

This testing machine has ten testing positions, to each of which may be strung a drop wire held by a clamp at one end, and dead loaded by means of weights at the other end, to obtain the desired tension. Extra clamps, attached to the drop wire as seen at the left in Figure 2, are threaded with a wire completing the electrical circuit to the motor.



Fig. 1—Drop wire clamp gripping the wire. The disassembled parts are seen in the lower part of the photograph.

Failure of any test clamp pulls this wire loose and shuts off the machine so that readings may be readily taken.

This machine attempts to duplicate the effect on the drop wire clamp of the gentle swaying of a drop wire span under the influence of wind. Instead of the line swaying, however, the supporting fixtures, onto which the tail wires are hooked, swing back and forth through an angular amplitude of 45° at a frequency of 25 cycles per minute. The attachment chosen for testing the clamps is a galvanized steel hook such as is used in regular service. Under load, the friction between tail wire and hook causes high-frequency vibrations to be set up as the wire changes its position around the hook, resulting in fatigue stresses in the tail wire. This simulation of sway friction is accomplished with a minimum of other effects. The rubbing on the tail wire is continuous in the machine testing, whereas in actual service, wear occurs only when the wind sways the drop wire. At the normal machine rate of about a million cycles per month, the machine will duplicate in a month or two the amount of wear a tail wire will receive in several years of service under the worst of field conditions.

Tests made in this machine showed 100-fold variation in durability of different kinds of tail wires. Aluminum wires, for example, failed between 50,000

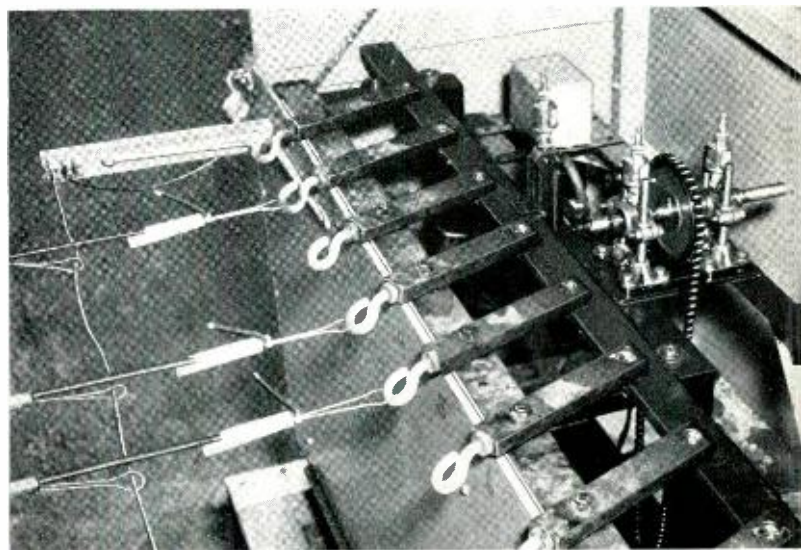


Fig. 2 — Mechanism causes hooks to swing back and forth, thus simulating wind action on drop wire clamps.

and 150,000 cycles, copper wires failed at about 1,500,000 cycles, and the stainless steel wires reached 3,000,000 to 4,500,000 cycles before failure. These tests were a major factor in the choice of a copper tail wire for the copper clamp and of a stainless steel wire for the aluminum clamp.

H. A. WELLS, *Outside Plant Development*

Papers Published by Members of the Laboratories

Following is a list of the authors, titles, and places of publication of recent papers published by members of the Laboratories:

Anderson, O. L., and Stuart, D. A., The Calculation of the Activation Energy of Ionic Conductivity in Silica Glasses by Classical Methods, *J. Am. Ceramic Society*, **37**, pp. 573-580, Dec., 1954.

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Uhlir, Arthur, Jr., The Potentials of Infinite Systems of Sources and Numerical Solutions of Problems in Semiconductor Engineering, *B.S.T.J.*, **34**, pp. 105-128, Jan., 1955.

Weiss, M. T. see Fox, A. G.



Carrier Terminals for the L3 System

D. B. PENICK

Transmission Systems Development I

The function of a terminal in a carrier system is, fundamentally, to combine the original signals with the carrier frequencies for transmission over the system, and to faithfully translate the received signals to their original frequencies. In the latest coaxial carrier system, the L3, the great number of telephone channels involved—either 1,860 in each direction on a pair of coaxial tubes, or 600 channels and a 4.2 mc television channel—have made necessary extremely complex terminals. These require carefully designed and engineered components to provide the required high-quality telephone and television service.

A carrier terminal is primarily a means for building up a wide frequency spectrum from small blocks of frequency space, each of which is capable of carrying information. It must also separate these blocks from an incoming spectrum and restore them to their original form. Yet, between the building up or transmitting, and the separating or receiving operations, the whole spectrum may be transmitted as a unit over any medium that can accommodate its bandwidth.

Although a terminal usually bears the name of the type of line for which it is originally designed, it may also be useful for other types. The L1 terminal, for example, is also the terminal for TD-2

radio circuits. Similarly, parts of the L3 terminal are already being considered for use with TD-2 and possible future radio relay systems. In modified form, the L3 terminal may even be used for L1 because of its more efficient use of the frequency spectrum between two and three mc.

The basic building blocks for which the L3 terminal is designed are telephone speech channels each four kilocycles wide. Standard arrangements are available for combining two or three speech channels to form one high-quality channel for program transmission or for further dividing a speech channel to form a number of telegraph channels. Alternatively, large blocks of message

channels may be omitted and the frequency space used for television transmission.

The general method for translating a block of frequency space from its original location to a desired position in the spectrum is similar to that used in radio broadcast studio transmitters and home receivers. A pair of carrier terminals may be thought of as a set of individual transmitters and receivers, fixed-tuned to a series of assigned frequencies, with transmission confined to a chosen route instead of being broadcast in all directions.

Briefly, the method consists of applying both the original signal and a carrier with a chosen frequency to a modulator (or demodulator). Such a device produces an entire spectrum of combination products of the two input signals and their harmonics. At this point, however, there is an essential difference between radio broadcasting and the operation of most carrier terminals. The radio broadcaster transmits the carrier and both upper and lower sidebands. The carrier is always present at a constant amplitude, which to minimize distortion must be greater than the highest sideband amplitude. Such a signal is easily retranslated to its original frequency band.

The economics of long-haul carrier transmission, however, require that each channel use the minimum possible frequency space and transmitted power consistent with faithful reproduction of the original signal. Such a minimum is realized in a single sideband which contains all the frequency and amplitude information present in the original signal. This use of one rather than both sidebands doubles the number of channels that can be transmitted in a given frequency space. The carrier is completely suppressed at the transmitting terminal and is resupplied from an independent oscillator at the receiving terminal. In this way, as much as 90 per cent of the required power-carrying capacity of the amplifiers is saved. For single sideband (but not for double sideband) transmission, a moderate difference between the transmitting and receiving carrier frequencies does not produce a noticeable change in transmission quality.

Single sideband transmission has been used successfully in the Bell System for many years in such systems as the type J open-wire carrier, type K cable carrier and type L1 coaxial carrier. Table 1 shows the capacities of these systems. For L3, single sideband transmission is used, but with a number of extensions and refinements of many circuit design features in the terminals to meet the objectives for transcontinental service.

It is necessary, for example, to maintain a frequency shift no greater than two cycles per second in any high-quality program circuit. Since such a circuit may be transmitted over several carrier links in tandem, any individual link should have a maximum deviation no greater than 0.6 cycle per second. In type J and K circuits this requires that the carrier oscillator frequency be stable to about four parts per million; this objective is attained commercially by tuning forks or crystal control of the oscillators together with semiannual checks with the Bell System reference frequency.^o

To achieve the correct stability required for type L1 transmission at three megacycles — 0.2 parts per million — automatic frequency control has been added. This normally maintains frequency differences between transmitting and receiving oscillators at values less than one part in 30 million. This performance is more than adequate not only for L1 but also for the corresponding L3 requirement of 0.08 parts per million at eight mc.

A transmission requirement of the L3 system makes it necessary to rearrange the frequency spectrum at 400- or 800-mile intervals along a route. This means that a signal will pass through parts of at least five or ten pairs of carrier terminals in a 4,000-mile circuit. The long-time variation of the over-all circuit is to be kept below 2 db, and the variation of transmission amplitude from all causes must not exceed about 0.4 db per terminal if the causes are random, or about 0.1 db if the causes

TABLE 1 — CHANNEL CAPACITIES

<i>Type of System</i>	<i>Channel Capacity</i>
H	1
C5	3
J2	12 ^o
K2	12 ^o
L1	600 ^o
L3	1860 ^o

^o Broadband systems.

are systematic. Since the most persistent cause of variation is that of office temperature, and widely scattered offices are subject to similar but not identical daily and seasonal changes, temperature variation is considered a semi-systematic cause, justifying a terminal stability objective of 0.2 db. Careful study of each modulator and demodulator at each carrier frequency has resulted in attaining this objective.

^o Record, July, 1951, page 338.

Use of carrier frequencies up to 18.2 mc has required the development of many new techniques. For example, in circuits where only a single frequency is involved, a simple resonant circuit using slug-tuned adjustable inductors^o is used in place

of the more conventional two-winding transformer to provide controlled impedance and voltage transformations.

The process of building up a carrier frequency spectrum has been described as though each channel were modulated in a single step to its ultimate position in the line spectrum. Although this is

^o RECORD, August, 1953, page 301.

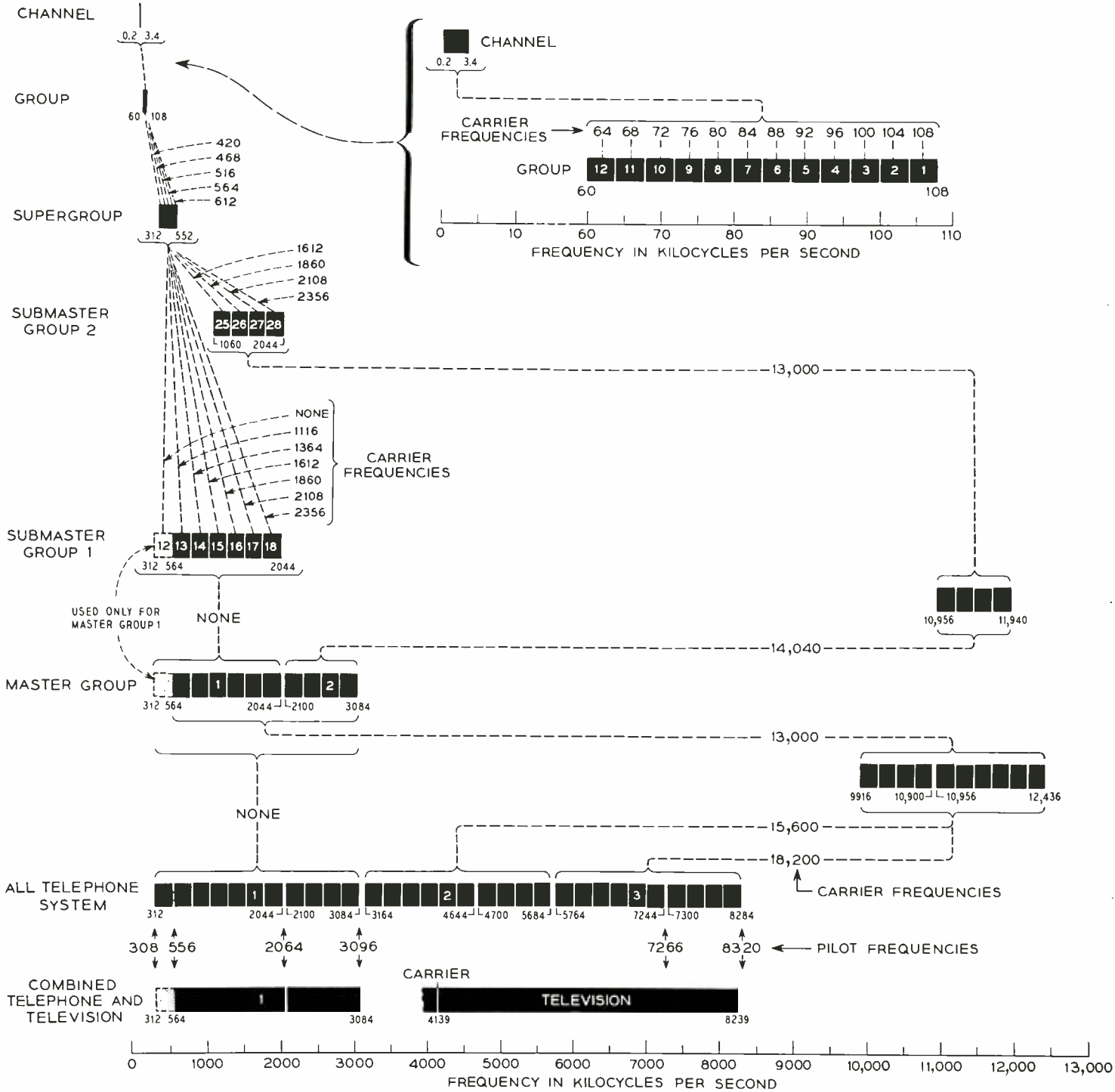


Fig. 1 — Modulation steps used in building up the L3 carrier frequency spectrum.

feasible in theory, the costs and physical limitations of the circuit components make it expedient to use several steps of modulation as charted in Figure 1. In the first step, each of 12 channels is modulated to an assigned position in the 60- to 80-kc spectrum. A guard space of about 20 per cent of the total is allowed between the bands to reduce interference between adjacent channels; since the carriers are spaced one every 4,000 cycles, this guard space is about 800 cycles wide, and the useful width is about 3,200 cycles. This step of modulation, basic to all "broadband" carrier systems, meets the objective that nothing in the long-distance connection between the shorter local portions of a telephone circuit should contribute appreciably to the over-all distortion.

In the second step, each of the resulting 12 channel groups is treated as a unit, and five such units are group modulated to adjacent positions in a super-group spectrum that extends from 312 to 552 kc and accommodates 60 channels. In the third step, a super-group is either transmitted directly without modulation, or it is modulated to one of six other positions separated by 8 or 12 kc guard spaces.

These three steps of modulation and the corresponding equipment units are identical with those used in L1 carrier or TD radio terminals except that in the L3 arrangement some of the super groups provided in the other systems are omitted



Fig. 3—R. F. Morra checking the operation of a pilot signal transfer and control circuit.



Fig. 2—A. J. Uminowicz adjusting meters in an L3 terminal amplifier at the Laboratories. One such meter in each electron tube circuit is adjusted to read 1.0 arbitrary units of plate current when a new tube is inserted. As the tube loses emission with age and the current drops below 0.65 of its original value, a contact on the meter pointer closes, actuating an alarm that indicates the end of the useful life of the tube. This feature supplants the routine periodic tube tests required in other circuits to prevent total failures that would interrupt service.

in building up submaster groups 1 and 2. The remaining steps of modulation are new. First, submaster group 2 is modulated up and down again in the frequency spectrum as indicated in the chart. This band is then added to the unmodulated submaster group 1 to form a master group, leaving a 56-kc guard space between the two submaster groups. Three master groups so produced are used to form the final spectrum. Of these, one is transmitted without modulation, and the other two groups are double modulated to adjoining positions in the spectrum, with 80-kc guard spaces left between them.

These guard spaces facilitate the design of blocking filters which make it possible to break into a circuit in a chosen block of channels for local use at any intermediate station without disturbing through transmission of the rest of the spectrum. Such branching circuits have an important place

in system layout. They provide needed operating flexibility at small offices along a main route, without either the expense or transmission distortion of terminal equipment in through channel paths. Such guard spaces are also required at pilot signal frequencies because of practical design limitations in filters used to isolate them.

Circuits required to perform the steps of modulation fall naturally into banks in which each circuit is distinguished from the others chiefly by a small difference in operating frequency. The method of grouping these circuits into banks is

shown in Figure 4. Such banks form equipment units of convenient size which may be duplicated as needed to fill the requirements of particular offices up to the full capacity of the system.

All carriers are derived as harmonics of a carefully controlled 4-kc base frequency. This base frequency is generated as a subharmonic of 128 kc produced by an oscillator similar to that in the Bell System primary frequency standard. Both the 4- and 128-kc outputs of this oscillator are utilized to generate four master and submaster carriers ranging in frequency from 13.0 to 18.2

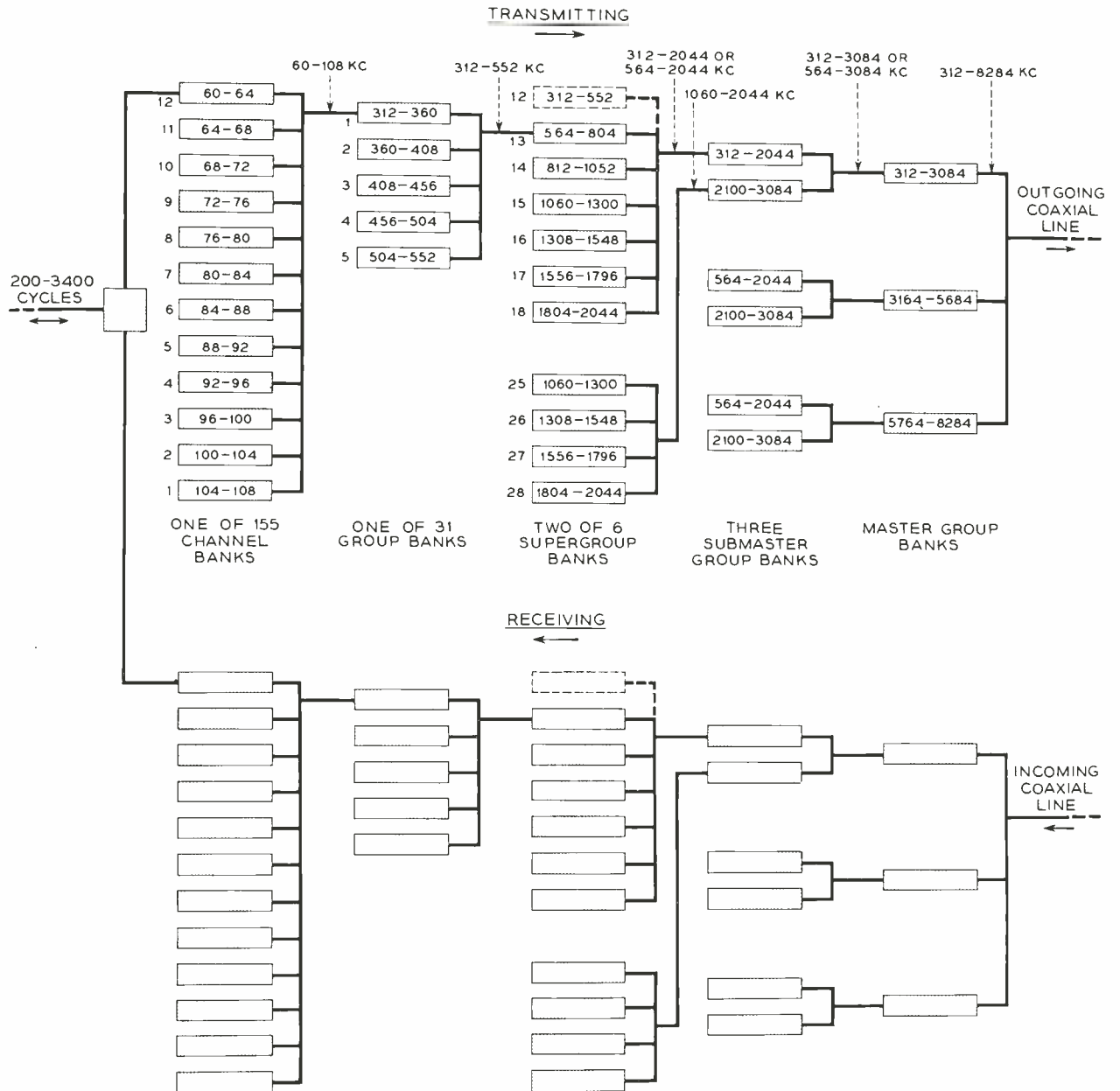


Fig. 4 — Arrangement of L3 terminal modulating circuits into banks.

mc. One carrier supply can provide for the carrier and pilot requirements of two eight-tube coaxial cables.

To overcome the practical difficulty of generating high order harmonics, this operation is performed in two steps. The first step produces a 520-kc signal and the second step generates the carriers themselves which are harmonics of the 520-kc frequency. These harmonics, the 25th, 27th, 30th, and 35th are selected from the generator output, amplified, and distributed to the modulators. The 520-kc frequency, although a harmonic of the 4 kc base frequency, is actually produced in a specially designed saturable inductor modulator energized by both the 4- and 128-kc outputs of the frequency supply.

Pilot frequencies used to regulate the line are not directly connected with the terminal modulation process, but are a natural by-product of terminal operation, since the carrier supply circuits contain many of the elements needed for pilot supply, and have similar frequency stability requirements. For example, the same modulator that supplies the 520 kc furnishes outputs of other frequencies that are combined in auxiliary circuits to form fourth or sixth harmonics of the six pilot frequencies. Each pilot frequency is generated from its subharmonic in a varistor circuit that multiplies the frequency. This circuit is also capable of delivering a constant output with input variations over a range of several decibels. Actually it reduces the normal carrier variations several per cent, to less than one-half of one per cent; 0.05 decibel for the pilot frequencies.

The resulting constancy of pilot output is im-

portant in meeting television requirements on a long system. Any change in the transmitted pilot frequency is interpreted by the automatic regulators along the line as a change in line characteristics, and is counteracted, falsely in this case, by an equal and opposite change in the over-all transmission.

Since an equipment failure in the terminal might interrupt a large number of circuits, every effort is made to insure continuity of operation. The improved performance of newer types of electron tubes, for example, is sacrificed for the longer expected life of the 310A and 311B types — about 45 and 20 years respectively. This and the conservative specifications for other components in such repeaters as capacitor voltage ratings and resistor power ratings, combine to minimize the number of equipment troubles.

All active circuits are provided in duplicate with automatic transfers that operate when carrier or pilot levels become abnormally high or low. In older systems, the non-working duplicate circuits were merely standby circuits. They were normally disabled by applying a bias at a convenient point until a transfer put them in operation. If trouble developed in a standby circuit it might be undetected until a transfer occurred and resulted in a circuit failure. In the L3 master group carrier and pilot supplies, however, both the regular and emergency circuits are kept in operation and continuously monitored by bridged rectifiers which hold relays operated when the outputs are normal. Thus any failure in either circuit is indicated immediately and is accompanied by an automatic transfer if that is necessary to maintain service.

THE AUTHOR

DIXON B. PENICK joined the Engineering Department of the Western Electric Company in 1924, where he worked on special problems in the development of vacuum tubes. In 1937 he transferred to the Systems Development Department and has since been engaged in development work on carrier telephone systems, including open-wire carriers, cable carriers, and high quality program circuits. Mr. Penick received his B.S. degree in Electrical Engineering from the University of Texas in 1923, and a B.A. degree from the same institution the following year. In 1927 he received his M.A. degree from Columbia University. He is a member of the Institute of Radio Engineers and Tau Beta Pi.



Significant Advances In Communications Marked 1954

The Bell System made significant advances in the art of communications during 1954, according to a year-end statement issued by Cleo F. Craig, President of the A. T. & T. Company.

It started work on the first underseas voice cable between this continent and Europe, it produced a revolutionary device to change sunlight directly into useful energy, and it provided network facilities to transmit color television throughout the country.

Manufacture of the cable to connect this country and Canada with Great Britain was begun. Cable laying will start next summer. In places between Newfoundland and Scotland the cable will lie in water three miles deep. It will contain 104 repeaters which are designed to operate without maintenance for at least 20 years. By late 1956 the cable is expected to be in commercial operation, carrying 36 simultaneous conversations and supplementing the present radiotelephone service.

During the year the invention of the Bell Solar

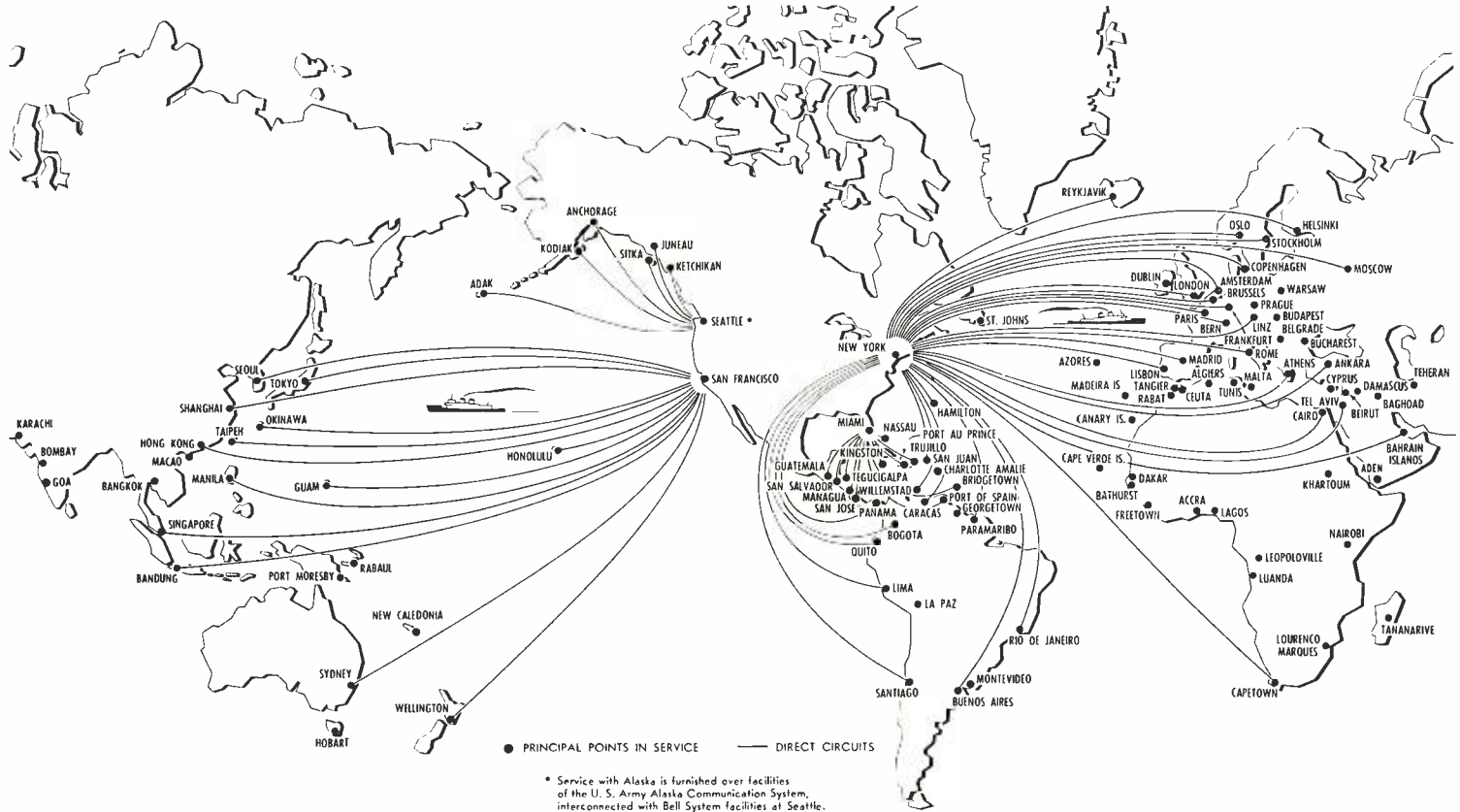
Battery was announced by the Laboratories. It is the first successful device to convert the sun's energy directly into useful amounts of electricity. Mr. Craig said that experimental models, while small in total energy produced, already are yielding eight per cent efficiency, which is comparable to that of steam or gasoline engines.

Color television became a part of commercial broadcasts, and through the nationwide network of telephone cables and radio-relay beams it reached 139 stations in 101 communities.

Bell System business improved substantially in the latter months of 1954 and should make further gains in 1955, Mr. Craig said. "In 1954 we added more than 1,900,000 telephones, slightly more than in 1953. During the next year we expect a gain of two million or more," he reported. "The number of long distance calls now is running about 10 per cent above a year ago, and in 1955 we foresee a further rise of from 5 to 10 per cent," he added.

The greatest service restoration job in telephone

BELL SYSTEM OVERSEAS TELEPHONE SERVICE DECEMBER 1954



history took place in 1954 as three hurricanes within seven weeks put more than a million telephones out of service temporarily. Mr. Craig said it was a good test of Bell System readiness to concentrate its resources swiftly where needed in emergencies.

The operating companies began aggressive selling of their services during 1954 as the period of shortages appeared to be ending. To find and fill customers' needs and wants, the companies are preparing for an active year of merchandising in 1955, he said. The number of share owners continued to increase and, as a result of a 35,000 net gain, passed the 1,300,000 mark late in the year. In a further employees' stock plan offer, employees subscribed for 1,450,000 shares offered to them on a pay-roll deduction basis.

"The System's expenditures for new construction totaled nearly \$1.4 billion in 1954, and may be slightly higher in 1955," Mr. Craig continued. "We are going ahead with this big program in order to meet present customers' wants, care for needs of

new customers, provide more dial service, and move along toward the goal of direct distance dialing on a nationwide basis," he said. Of close to 43,300,000 Bell System telephones, almost 84 per cent are the dial type.

An average of 159 million local and long distance conversations a day were handled. "The quality of service was at or higher than the best levels previously achieved," Mr. Craig asserted. The number of telephones in rural areas served by the Bell System passed the 3.1 million mark, the highest number on record. This represented a gain of about 275,000, almost 10 per cent, for the year.

"We have an ever-improving service," Mr. Craig concluded. "Our sales efforts are proving very effective. Looking forward to good, substantial, healthy progress, we are going to continue to invest in the future. That is what all our experience and study tell us is right and necessary, to meet the tremendous growth that is surely ahead in this country of ours."

Patents Issued to Members of Bell Telephone Laboratories During the Month of November

- Anderson, J. R. — *Ferroelectric Storage Devices* — 2,695,396.
 Anderson, J. R. — *Ferroelectric Storage Circuits* — 2,695,397.
 Anderson, J. R. — *Ferroelectric Storage Circuits* — 2,695,398.
 Armitage, L. — *Vibrating Reed Selector* — 2,694,119.
 Bachelet, A. E. — *Pulse Counting and Registration System* — 2,694,801.
 Baker, G. H. — *Duplex Radio Telephone System* — 2,694,196.
 Beckham, C. L. — *Apparatus for Measuring Usage of Equipment* — 2,693,912.
 Bond, W. L., Sparks, M., and Teal, G. K. — *Semiconductor Bodies for Signal Translating Devices* — 2,694,024.
 Caruthers, R. S. — *Two-Way Multichannel Carrier Wave Transmission* — 2,695,332.
 Caruthers, R. S., and Van Tassel, F. K. — *Multichannel Carrier Telephone System* — 2,695,927.
 Chase, F. H. — *Current and Voltage Regulation* — 2,693,568.
 Chase, F. H. — *Current and Voltage Regulation* — 2,693,572.
 Coleman, R. E., Jr., and Kingsbury, E. F. — *Optical System for Card Translator* — 2,693,734.
 Davis, G. W., and Waltz, M. C. — *Methods of Selectively Plating p-Type Material of a Semiconductor Containing a p-n Junction* — 2,694,040.
 Dunlap, K. S. — *Dialing or Signaling System* — 2,695,334.
 Feldman, C. B. H. — *Scanning Antenna System* — 2,694,147.
 Gilman, G. W., and Pflieger, K. W. — *Selection of Low Interference Radio Channel* — 2,694,140.
 Harrison, C. W. — *Cathode Crystal Coupled Oscillator* — 2,695,960.
 Joel, A. E., Jr. — *Calling Line Identification* — 2,695,928.
 Kingsbury, E. F., see Coleman, R. E., Jr.
 Kingsbury, E. F. — *Card Translator Optical System* — 2,694,154.
 Kinzer, J. P., Marshall, R. W., and Wilson, I. G. — *Wave Filter* — 2,694,186.
 Laidig, J. F. — *Signal-to-Noise Energy Detection Unit* — 2,694,142.
 Leed, D., and Smith, N. D. — *Servo-Mechanism Stabilization* — 2,695,980.
 Lewis, W. D. — *Directive Antenna Systems* — 2,695,958.
 Loman, G. T. — *Thermally Sensitive Resistors* — 2,694,050.
 Mallinckrodt, C. O. — *Gating Circuit* — 2,695,956.
 Marshall, R. W., see Kinzer, J. P.
 Meacham, L. A. — *Transistor Amplifier with Conjugate Input and Output Impedances* — 2,694,113.
 Meacham, L. A. — *Push-Pull Transistor Amplifier with Conjugate Input and Output Impedances* — 2,694,115.
 McKay, K. G. — *Amplifier Utilizing Bombardment Induced Conductivity* — 2,694,112.
 Mills, J. K. — *Ringing Current Supply System* — 2,694,106.
 Mitchell, D. — *Radiant Energy Signaling System* — 2,694,141.
 Mohr, M. E. — *Frequency Dividing Circuit* — 2,695,959.
 Pflieger, K. W., see Gilman, G. W.
 Pierce, J. R. — *Microwave Amplifier* — 2,694,159.
 Rea, W. T. — *Expandable Straight Line Trajectory Radar and Sonar Indicator* — 2,694,160.
 Rounds, P. W. — *Equalizer* — 2,694,184.
 Shuhart, J. H. — *Vibration Damper for Transmission Lines* — 2,694,101.

Patents Issued to Members of Bell Telephone Laboratories, Continued

- Smith, D. H. — *Electromagnetic Control Apparatus* — 2,694,178.
Smith, N. D., see Leed, D.
Sparks, M., see Bond, W. L.
Sparks, M. — *Fabrication of Semiconductors for Signal Translating Devices* — 2,695,852.
Stone, J. R. — *Frequency and Voltage Control Apparatus* — 2,694,174.
Teal, G. K., see Bond, W. L.
Van Tassel, E. K., see Caruthers, R. S.
Wallace, R. L., Jr. — *High-Frequency Transistor Circuit* — 2,695,960.
Waltz, M. C., see Davis, G. W.
Wilson, I. G., see Kinzer, J. P.
Wirsching, R. E. — *Solderless Wire Terminal* — 2,694,189.
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Talks by Members of the Laboratories

During December, a number of Laboratories people gave talks before professional and educational groups. Following is a list of the speakers, titles, and places of presentation:

- Ardis, R. B., Patent Law as a Profession, Student Branch of A.I.E.E. and I.R.E., University of Michigan.
Baker, W. O., Dynamics of Polymer Liquids, A.S.M.E. National Meeting, New York City.
Biskeborn, M. C., The Transatlantic Telephone Cable, Third Annual Signal Corps Wire and Cable Symposium, Asbury Park, N. J.
Fleckenstein, W. O., Common-Control Switching Systems Chicago Section of A.I.E.E.
Foster, F. G., Ray Paths of the Compound Microscope, New York Microscopical Society, American Museum of Natural History, New York City.
Fuller, C. S., Bell Solar Battery, New York Chapter of the Armed Forces Communications Association, New York Telephone Company.
Garrett, C. G. B., Physical Properties of Germanium Surfaces, Division of Electron Physics Meeting of the American Physical Society, University of California, Berkeley, Cal.
Hamming, R. W., Use of Analog and Digital Computers in Engineering Work, Western Electric Company, Kearny.
Ingram, S. B., How Modern Scientific Developments Will Affect Undergraduate Engineering Curricula, Winter Meeting of the Middle Atlantic Section of American Society for Engineering Education, Polytechnic Institute of Brooklyn.
Jensen, A. G., Color Television, Eta Kappa Nu Society, New York City.
Keister, W., Mechanized Intelligence, Association of Mathematics Teachers of Philadelphia, Philadelphia, Pa., and Swarthmore College, Swarthmore, Pa.
Knowlton, A. D., Some New Developments at Bell Laboratories, Joint Meeting, Telephone Company and Power Company representatives, Dallas, Texas.
Koliss, P. P., Mechanical Splice Closures for Telephone Cables, Third Annual Signal Corps Wire and Cable Symposium, Asbury Park, N. J.
McMillan, B., History of a Problem, Society of Industrial and Applied Mathematics, Pittsburgh, Pa.
McNally, J. O., Tube Reliability, Institute of Radio Engineers Branch Meeting, Poughkeepsie, N. Y.
Merrill, J. L., Recent Developments in Negative Impedance Repeaters, New York Section of A.I.E.E., New York City.
Moll, J. L., Applications of Junction Transistors as Switches, Southern Methodist University, Dallas, Tex.
Owens, C. D., Modern Magnetic Ferrites and Engineering Applications, New York Section I.R.E., New York City.
Pearson, G. L., The Bell Solar Battery — A Silicon p-n Junction Photovoltaic Device, Eta Kappa Nu Society of C.C.N.Y., and National Association of Manufacturers, New York City.
Raisbeck, G., Bell Solar Battery, Joint I.R.E.-A.I.E.E. Meeting, Philadelphia, and Student Sections of I.R.E.-A.I.E.E. and American Physical Society, Rensselaer Polytechnic Institute, Troy, N. Y.
Read, W. T., Dislocations in Germanium, Columbia Metallurgical Colloquium, New York City.
Rowen, J. H., Ferromagnetism in Ferrites and Application to Microwave Devices, Long Island Chapter of I.R.E., New York City.
Slepian, D., Information Theory, Sigma Xi Society, Lehigh University, Bethlehem, Pa.
Smith, K. D., Silicon Solar Batteries, Rectifiers, and Voltage Limiters, New Jersey Section of A.I.E.E., Newark, N. J.
Sobel, M., Statistical Problems in Life Testing, Third Symposium on Mathematics, Statistics and Probability, University of California, Berkeley, Cal.
Sparks, M., Transistor Chemistry, American Chemical Society, East Tennessee Section, Knoxville, Nashville and Memphis Sections, all in Tennessee; Wilson Dam Section, Sheffield, North Alabama Section, Decatur, Alabama Section, Birmingham, and Auburn Section, all in Alabama; and Georgia Section, Atlanta, Ga.
Thatcher, W. H., Nike, Stevens Metropolitan Club, New York City.
Thayer, G. N., Research in Industry, Sunday Breakfast Club of Philadelphia, Pa.
Thomas, D. E., Semiconductor Devices, Naval Reserve Composite Company 3-6, Chatham (N. J.) High School.
Thomas, D. E., Transistors, A.I.E.E. and I.R.E. Student Sections, Cornell University, Ithaca, N. Y.
Van Uitert, L. G., Correlation of the Solution Stabilities of the Chelate Compounds of Ligands Coordinating Through Nitrogen and Oxygen, General Chemistry Seminar, Rutgers University, New Brunswick, N. J.
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