Zone-Melting

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Significant advances in science and technology are frequently made by adapting simple and well known physical laws to the solution of a problem. Faced with the challenge of supplying single-crystal germanium of ultra-high purity for the transistor, metallurgists at the Laboratories devised a new approach to the centuries-old method of segregating impurities by repeated crystallization. The new method, known as zone-melting, is based on the same physical law that explains the formation of salt-free ice in the saline waters of the Arctic Ocean. It is now being used extensively in the commercial production of ultra-pure germanium, and it is being applied on a laboratory scale to a host of other materials.

Attainment of perfect purity in elemental substances and compounds has been a continuing challenge to science and technology, for impurity is like a veil which hides the true properties of a substance. Only after the last traces of impurity have been removed can the intrinsic qualities of a substance be revealed. Break-throughs in the search for purity have often led to new scientific discoveries or to the birth of new industries.

A general technique for the purification of crystalline solids, which is almost as old as chemistry itself, is that of repeated fractional crystallizations. It has been widely used in the past and has important uses in the present day. Nevertheless, it has the disadvantage that it requires a troublesome, repeated sequence of manipulations, namely: melting or dissolving the impure crystals, slow freezing-out of a fraction of the melted crystals, removal of the pure crystals from the remaining impure liquid, and recombination of the removed fraction with other fractions. Although many difficult separations have been made in the past, such as the isolation of radium by the Curies and the separation of the rare earths by James and co-workers, these are more a tribute to the perseverance of the workers than to the efficiency of the method.

Now, a fresh outlook is in the offing for this centuries-old technique. By means of a new method, known as *zone-melting*, repeated crystallizations can be performed with a minimum of effort, and as a result, the impractical has become feasible.

Zone-melting was invented in the Metallurgical Research Department to purify germanium for transistors, and in this task its success has been spectacular. The method is not restricted to germanium, however, but can be applied to silicon and other semiconductors, metals, organic and inorganic compounds. In fact, it is useful for any crystalline substance which can be safely melted and in which there exists an appreciable difference

Above — D. Dorsi operating a small, general purpose zone-refiner used in studies of the purification of metals and chemicals.

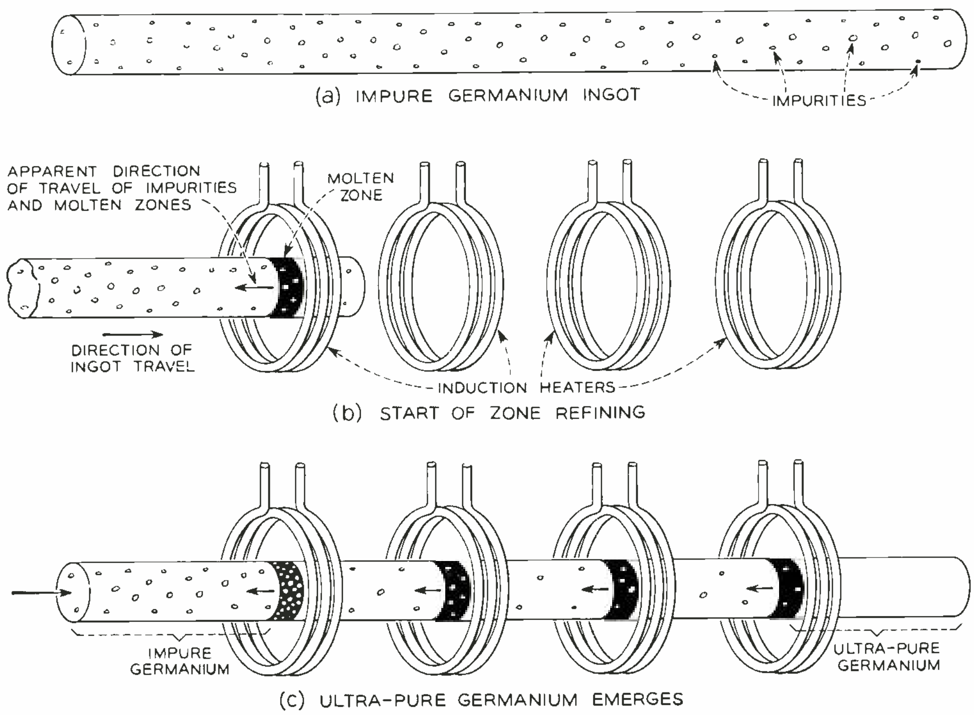


Fig. 1 — Zone-refining technique. As the molten zones travel through the ingot, each carries a fraction of the impurities toward the end of the ingot, leaving purified material in the remainder.

in impurity concentration between the freezing solid and the liquid from which it freezes.

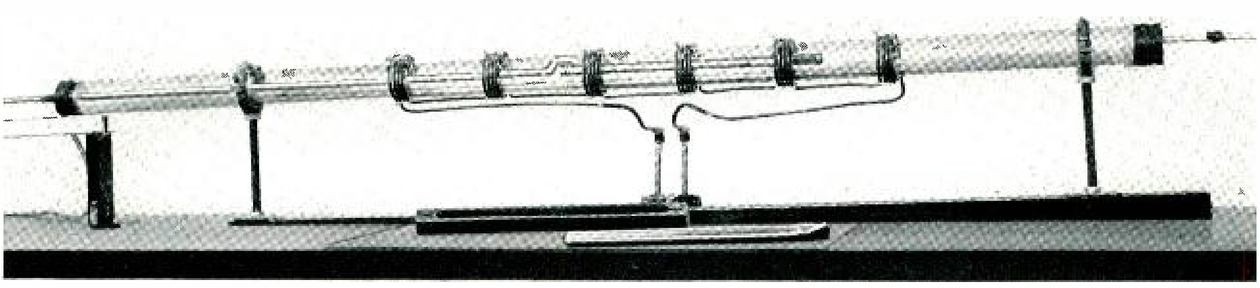
Further, zone-melting has important uses other than purification. For example, it can be used to distribute a desired constituent uniformly throughout a crystalline solid. It can also be used to produce p-n or n-p-n junctions – the basic building blocks for junction transistors and diodes.

In this article we discuss the use of *zone-refining* to remove impurities from germanium and the use of *zone-levelling* to produce highly uniform single-crystal ingots of germanium. Other variations of zone-melting will be touched upon briefly.

The method of *zone-refining* consists of slowly passing a series of molten zones through a relatively long charge or ingot of impure solid. The zones can be produced by external, ring-shaped heaters, as shown schematically in Figure 1. As a molten zone advances, impure solid melts at its leading interface and purified solid freezes at its trailing interface. Each molten zone which passes through the charge carries a fraction of the impurity toward the end of the charge. The purification increases with the number of zone-passes, approaching a finite limit after a large number of zone-passes have been made. Thus, the repeated sequence of troublesome steps heretofore used for fractional crystallization is reduced to a very simple operation.

Germanium purified by zone-refining is probably the purest known manufactured material. Germanium for transistor use is available, already in high purity, as germanium dioxide powder. The dioxide

Fig. 2 — Induction-heated zone-refining apparatus used for the purification of germanium. An impure germanium ingot in a graphite boat passes through six 4-turn induction coils connected in series, each of which produces a molten zone that traverses the ingot.



is reduced in hydrogen, forming germanium powder which is then melted and solidified in the form of an ingot which may be from 12 to 20 inches long and an inch or more in diameter. The ingot is placed in a long graphite container and slowly pulled through a series of induction heating coils, as shown in Figure 2, each coil producing a molten zone which travels through the ingot. This simple operation reduces the concentration of impurities throughout most of the ingot to less than one part in 10,000,000,000 parts of germanium.

The zone-refining method for purification of germanium has been widely adopted by the transistor and diode industries. It has eliminated batch-to-batch variations in incoming germanium by raising all of it to extremely high purity. It can also be used to recover scrap germanium that has not been too contaminated by impurity.

With pure raw material in hand, the next step in fabrication of a transistor or semiconductor diode is usually to prepare a single crystal ingot of the desired electrical conductivity. The conductivity is produced by adding an element of Group III or Group V of the Periodic Table, such as indium or antimony. The amount of additive is

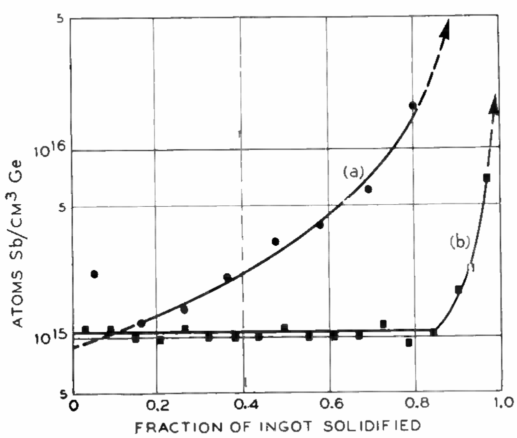


Fig. 3 — Curves showing antimony concentration throughout lengths of two germanium ingots: (a) conventionally solidified ingot, (b) zone-levelled ingot. The antimony concentration is much more uniform in the latter.

quite small, about 1 atom per 100,000,000 atoms of germanium.

A number of *zone-levelling* techniques have been devised for this purpose, the object being to introduce solute (a soluble element) as uniformly as possible throughout a solidified ingot. In one such technique a long ingot of zone-refined germanium, which is usually polycrystalline, is placed in a boat. A single crystal seed is placed at the lead end of the ingot to ensure single crystal growth. A small pill of addition alloy, containing antimony for example, is placed in a groove at the lead end of the ingot to provide the desired level of electrical

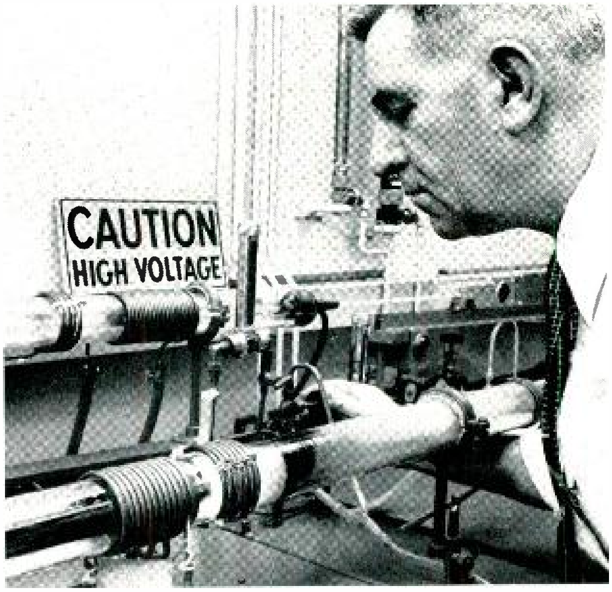


Fig. 4 — C. F. Larkin operating the zone-levelling apparatus. In this operation a desired addition-agent (antimony) is placed in a single molten zone, which then traverses the ingot, producing a large single crystal of a uniform antimony concentration.

conductivity. A molten zone is formed by an induction-heating coil at the juncture of seed and ingot and is made to traverse the ingot by pulling the ingot through the coil. The apparatus is shown in operation in Figure 4. The reason why a uniform concentration of antimony is produced may be seen as follows:

As the molten zone travels through the ingot there freezes out behind it a solid whose antimony concentration is always proportional to that in the zone. But the proportionality constant for antimony is very small, about 0.007. Hence little antimony is lost by the travelling zone and therefore the antimony concentrations in the zone and in the solid freezing from it remain essentially constant. When the zone reaches the end of the ingot it begins to contract, causing the antimony concentration to rise. However this deviation from uniformity is limited to a short region at the end of the ingot.

Before the introduction of zone-levelling, it was impossible by simple means to produce a germa-

Fig. 5 — J. J. Gillich measuring electrical resistivity along the length of a zone-refined germanium ingot, using an apparatus which automatically brings 4 electrodes down on the ingot at 0.1 inch intervals as it traverses the ingot.

nium ingot having a substantially uniform resistivity over a major portion of its length. Hence, much expensive germanium had to be reprocessed, because uniformity of transistor and diode properties requires corresponding uniformity in the conductivity of the germanium. A comparison of zone-levelled and conventionally solidified ingots of germanium alloyed with antimony appears in Figure 3. The concentration of antimony is uniform in about 85 per cent of the length of the zone-levelled ingot. A photograph of a single crystal ingot of zone-levelled germanium appears in Figure 7, together with a polycrystalline ingot of zone-refined germanium.

The large, highly perfect and highly uniform single crystal shown in Figure 7, which is now a product of manufacture, did not appear overnight.

Fig. 6 — Miss L. C. Lovell measuring carrier lifetime of a sample cut from a zone-levelled germanium single-crystal. Such measurements indicate purity, crystalline perfection, and suitability of the germanium for transistor use.

It represents the culmination of much painstaking exploratory development. The work has been accompanied by an unexpected scientific dividend, namely the proof that a particular type of crystal imperfection known as an edge dislocation does exist in real crystals.* And this has led to fruitful scientific studies of dislocations – an example of how pure research and development often complement and reinforce each other at the Laboratories.

A number of new zone-melting techniques have been devised and are under development. The object of *zone-remelting* is to produce p-n or n-p-n junctions. In this process a single crystal of germanium is prepared containing uniform concentrations of two carefully-chosen solutes, one producing n-type and the other p-type conductivity. When

Fig. 7 — A polycrystalline zone-refined ingot of germanium at the left, exhibiting grain boundaries, compared to a highly perfect and highly uniform single crystal zone-levelled ingot.

both are present, the observed conductivity-type corresponds to the solute whose concentration is greater.† A portion of a block cut from such a crystal is next melted and then refrozen. By this simple operation, the solutes are redistributed in such a way that p-n or n-p-n junctions result.

In another technique, known as *temperature-gradient zone-melting*, moving heat sources are un-

* RECORD, *March*, 1954, *page* 104. † *August*, 1954, *page* 285.

necessary, as the molten zones are moved by means of a stationary temperature-gradient. A feature of this technique is that molten zones of extremely small dimensions can be caused to move about in a solid crystal. A sheet of aluminum 0.003-inch thick sandwiched between two silicon slabs can be made to migrate in molten form through one of the slabs of silicon by applying a temperature-gradient at right angles to the sheet. The reason why the molten layer moves may be seen as follows:

When the aluminum sheet is heated it forms a low-melting-point alloy with silicon by dissolving silicon from the slabs. Because of the impressed temperature-gradient, one interface of this thin layer is hotter than the other. Hence more silicon dissolves there. This sets up a concentration-gradient of silicon across the layer, causing silicon to diffuse from the hot interface to the cooler interface, where it freezes. The continued solution of silicon at the hot interface and freezing at the cooler interface results in movement of the molten layer through the hotter slab. This technique provides a method for fabricating new types of semiconductor devices. It has many other uses as well, now being explored.

While the method of zone-refining, described at the beginning of this article has many virtues, it is a batch operation and as such has certain disadvantages inherent in batch operation. To avoid these, a *continuous zone-refining* process has been devised in which impure material continuously enters at the midpoint of a column through which molten zones are travelling, while pure product leaves at one end and impure waste leaves at the other end. Advantages of the continuous process are that it eliminates handling of successive batches of material and that it can produce a large yield of purified material per unit of time.

All of these zone-melting techniques stem from one well-known fact — that a freezing crystal differs in composition from its liquid — and from one simple idea, the idea of melting *part*, rather than all, of an ingot or charge at a given time. In general, the charge may be regarded as a medium and the molten zone as a distributor of solutes in the medium. Depending on the arrangement of solutes in the starting charge, and on the size, number, and direction of travel of the zones, many useful distributions can be achieved.

THE AUTHORS

WILLIAM G. PFANN received the 1955 Mathewson Gold Medal Award of the American Institute of Mining and Metallurgical Engineers for his invention of the zone-melting process of refining germanium and other materials as described in three papers in the Institute's publication "Journal of Metals." Associated with the Laboratories' Metallurgical Research Department since 1936, Mr. Pfann was engaged in work on microscopy, silicon rectifier development, and electrical contact studies, and, since 1948, in research on transistor materials and processes. He received a B.Ch.E. degree from Cooper Union in 1940 and is a member of the American Institute of Mining and Metallurgical Engineers, the American Physical Society, the American Society for Metals, and Tau Beta Pi.

KARL M. OLSEN joined the Laboratories in 1929 and was first engaged in studies on cable sheathing materials. During World War II he was active in the Manhattan Project, and until 1949 he worked on the processing of silicon and germanium and on the preparation of semiconductor rectifiers. The author of numerous articles on semiconductor materials, he has been granted several patents for processes he developed in this field. More recently, he has devoted his time to general metallurgical processing studies, including zone-melting and ferrite core preparation. Mr. Olsen received the degree of B. S. in chemical engineering from Cooper Union in 1936 and the M. S. degree in metallurgical engineering from Columbia University in 1942.

Analysis of No. 5 Crossbar Trouble Recorder Card

G. H. DUHNKRACK *Switching Development*

Diagnosing trouble in a common-control switching system, such as No. 5 crossbar, can be compared to diagnosing trouble in the human nervous system. Like the psychiatrist, who may be a trouble-shooter in the subconscious, the telephone craftsman is an electrical and mechanical trouble-shooter in a No. 5 crossbar central office. The psychiatrist, by analyzing what the patient tells about himself, can often isolate the source of trouble in the subconscious. Similarly, the telephone craftsman, by studying the information given by trouble recorder cards, can usually isolate the source of trouble in No. 5 crossbar. Fortunately, in telephone equipment, when the source of trouble is located, it is usually a routine task to correct it.

When irregular operating conditions develop in No. 5 crossbar dial central office equipment, they are usually reported on cards perforated by the trouble recorder apparatus that forms part of the master test frame.* These cards are then analyzed by maintenance craftsmen who use the card information and a set of charts and sketches to locate the troubles, usually in a relatively short time. Necessary remedial measures are then applied to clear the operating difficulties.

The trouble recorder cards have two sections that provide space for a total of 1,080 punch indications – 18 rows of 60 each. The actual number of holes appearing on a particular card, however, varies widely with the type of trouble being reported. Moreover, only portions of the card are used for troubles of a particular type. The card illustrated in Figure 1(a), for example, was punched because a marker seized the trouble recorder and brought in an alarm when it encountered trouble while establishing a connection to an outgoing trunk. The parts of the card that are not used in recording a trouble in such a connection are indicated by shading in Figure 1(b). Reporting this particular trouble required a total of 134 punches.

The letter-number designations R0 to R8 and S0 to S8 appearing at both ends of the card are used to label the rows. These designations, combined with the numerals (0 to 59) across the top of the card, form a precise coordinate system for the various punch positions. The coordinates, S8-0, for example, refer to the perforation T1 in the upper left-hand corner of the card, and similarly any punch position can be identified.

Each trouble recorder card is divided by heavy lines into seventeen major divisions and these divisions have been arbitrarily assigned the letters A through Q as shown on the card in Figure 1(b). All the punch indications in one of these major divisions supply related information. Division A, for example, indicates the class of record being made, the type of connection being established, and the type and number of the circuit that reported the trouble; Division I contains punch indications that show the progress of a call through a marker; Division Q tells the date and time that the card

* Record, *May*, 1950, *page* 214.

was perforated. Each of these major divisions is divided into a series of subdivisions indicated on the card by the light lines. Within Division A, the position SS-0 forms one subdivision, SS-1 to SS-4 another, and SS-5 to SS-8 a third, etc. Each of these subdivisions contains closely allied information of a specific nature. One of the subdivisions, SS-14 to SS-18, for example, identifies the type of circuit that called in the trouble recorder to make the record.

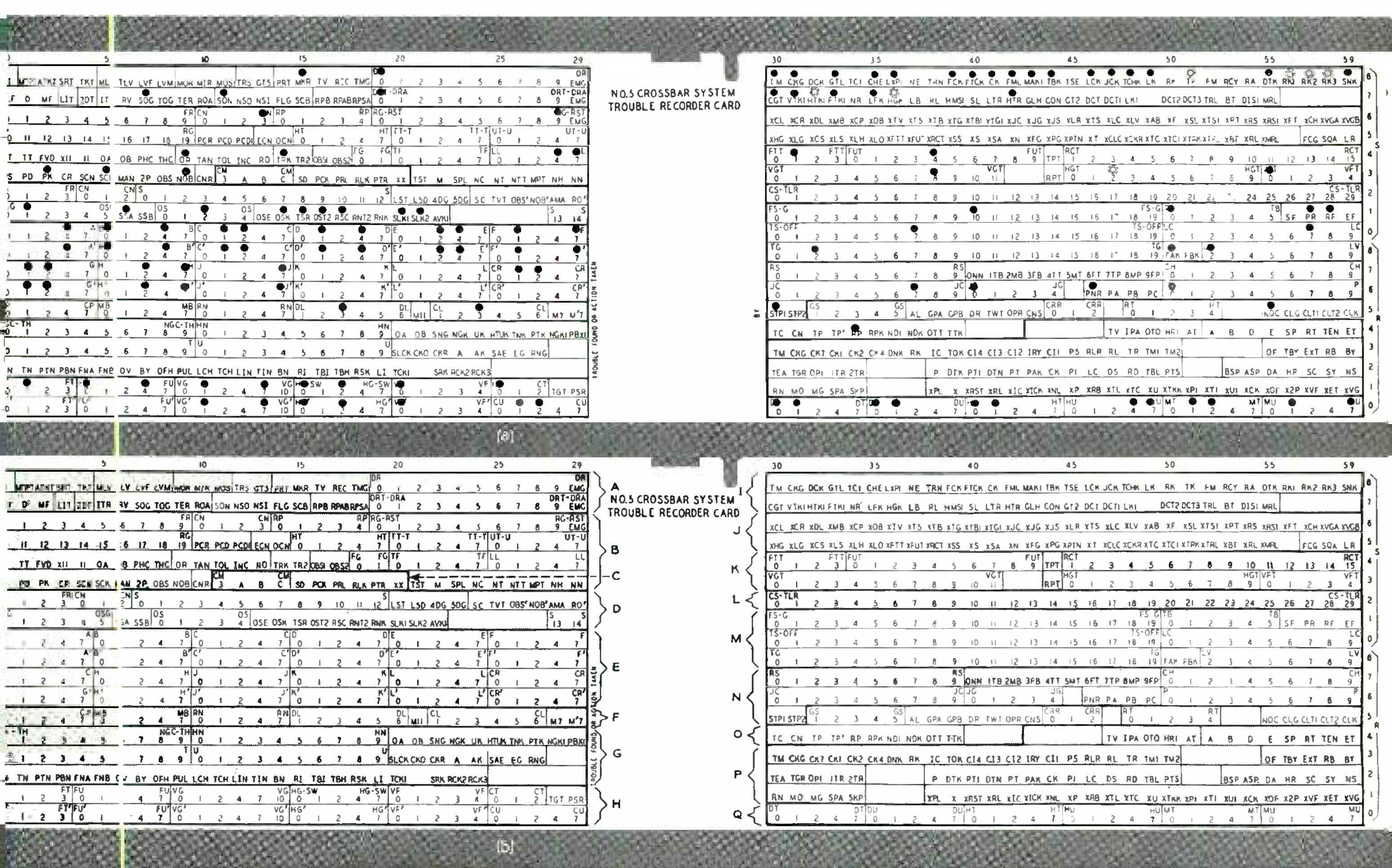
In analyzing a trouble, a maintenance craftsman first learns from the card the type of connection being established and the circuit that reported the trouble. He then checks the progress perforations in Division I of the card. These indicate the operation of key relays in establishing a connection, and if any are missing, the failure of the associated relay provides a clue to the nature of the trouble condition. Since the order of these punch positions on the card does not necessarily correspond to the order in which the various associated relays operate, the maintenance man next consults a sequence chart.* There is one such chart for each type of call, and the chart for the call indicated on the trouble card is selected. The appropriate relays and punch indications are illustrated on these charts in such a way that the sequence of operation can be determined easily.

After the sequence of operation has been established, one of the missing punch indications is selected and an index is consulted in reference to this punch indication. The index provides the number of the circuit sketch containing the electrical path for the relay that controls the particular punch in question. The operating path in this sketch is studied, and the elements in this path are then tested to locate the trouble. The headpiece of this article shows a telephone craftsman at the No. 5 crossbar office in Englewood, New Jersey, analyzing a trouble in this way. The binder in his hand contains circuit sketches, and the sequence chart binder is open at the right of the picture. The master test frame appears in the background.

In the trouble example shown in Figure 1(a), the punch at SS-15, labeled MKR, indicates that the trouble recorder was called in by a marker. A punch at SS-14 would have indicated that the process was initiated by a pretranslator; SS-16, a transverter; SS-17, an AMA recorder; and SS-18, a master timer.

* RECORD, *December*, 1953, *page* 492.

Fig. 1 — Trouble recorder cards. (a) Card punched as a result of a trouble encountered by a marker in attempting to establish a connection to an outgoing trunk. An open circle above the punch designation indicates missing perforation. (b) Shaded areas represent parts of card not used in reporting troubles of the type indicated above.



In analyzing the trouble reported by this card, a craftsman first learns some basic facts about the trouble from the punches in Division A, Figure 1(b). The punch at S8-0, for example, tells him that the trouble was encountered on a regular service call. If the connection had been for a test or monitored call, a punch would also have appeared in that this connection required the use of a sender.

Since the maintenance craftsman now knows that the call was for an outgoing trunk connection, he uses the sequence chart for this type of connection to assist him in analyzing the trouble. A portion of this chart is illustrated in Figure 2. This chart is actually a graphic representation of the sequence

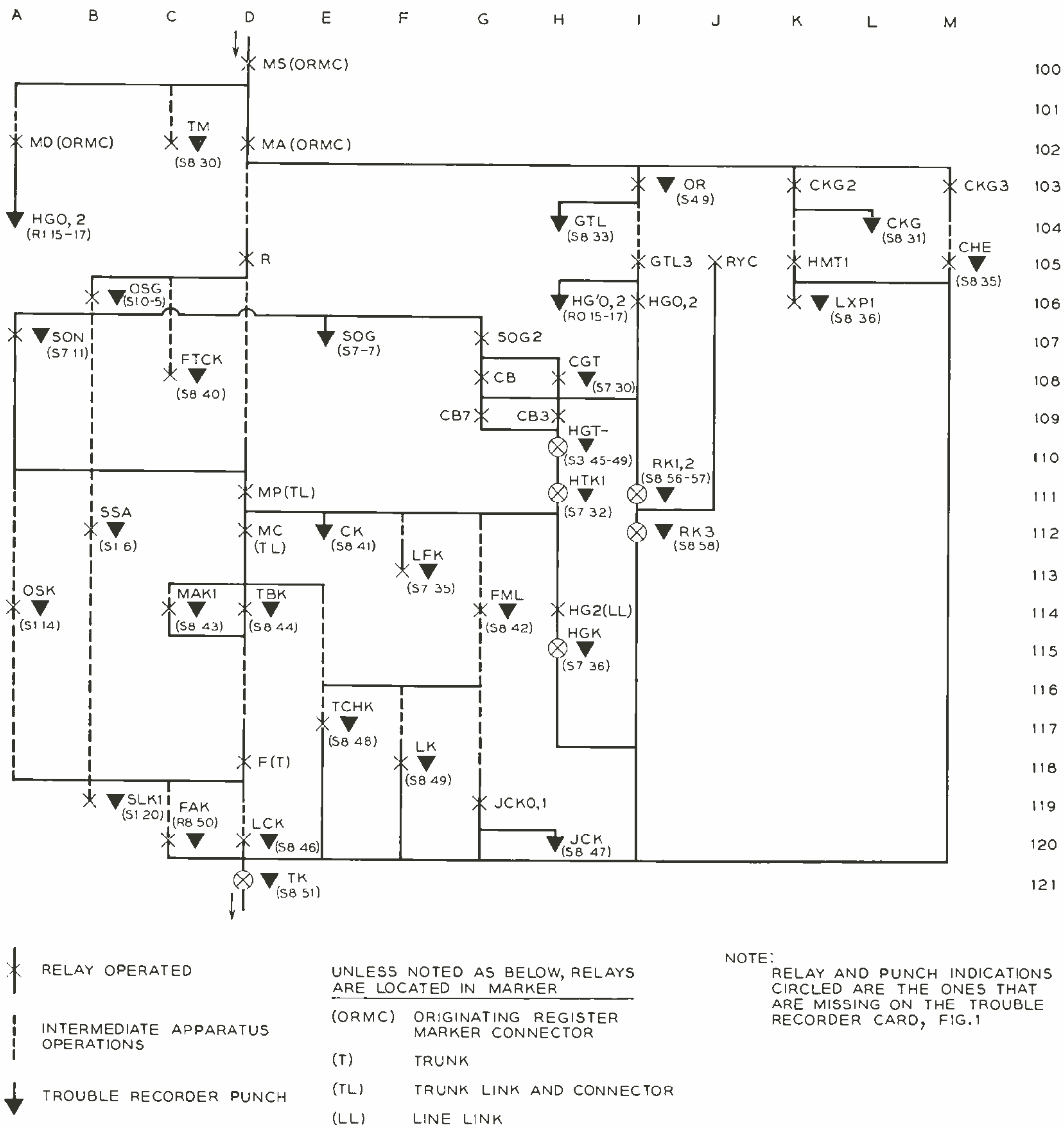


Fig. 2 — Portion of a sequence chart for an outgoing trunk connection that assists the maintenance man to analyze trouble.

one of the positions S8-1 to S8-11. As previously mentioned, the punch at S8-15 tells him that the trouble recorder was called in by a marker. The combination S8-19 and S7-19 gives him the marker number — in this case, No. 0. The two remaining punches in Division A, SOG (subscriber outgoing) at S7-7 and SON (sender outgoing) at S7-11, indicate that the marker was establishing an outgoing trunk connection when the trouble was encountered, and of operation of the relays and other components involved in a part of the marker operation. The relay designations are arranged in a relative time order on the chart from the top down, and are connected by appropriate lines to show the interdependence of successive operations. For example, relays HMT1 (coordinates K-105) and CHE (M-105), shown in Figure 2, operate simultaneously and are preceded by the operation of relays CKG2 (K-103) and CKG3 (M-103). This chart also indicates that the operation of any relay is dependent on the action of the preceding relays in all associated branches of the circuit. The way in which these relays are interdependent can be seen in detail by following the electrical operating paths given in the circuit sketch. This means that not only does the operation of LXP1 (K-106) depend on HMT1 (K-105), but it also depends on the operation of CHE (M-105).

After the sequence chart has been consulted, the marker progress points in Division I on the trouble recorder card are compared with the chart, and it is noticed that several punches that should have appeared for an outgoing trunk connection are missing. These missing punches are indicated in Figure 1(a) by an open circle above the punch designation. One of the missing punches is in the position labeled TK (coordinates SS-51) and this locates an important check point in the progress of the call. A punch at this point would indicate

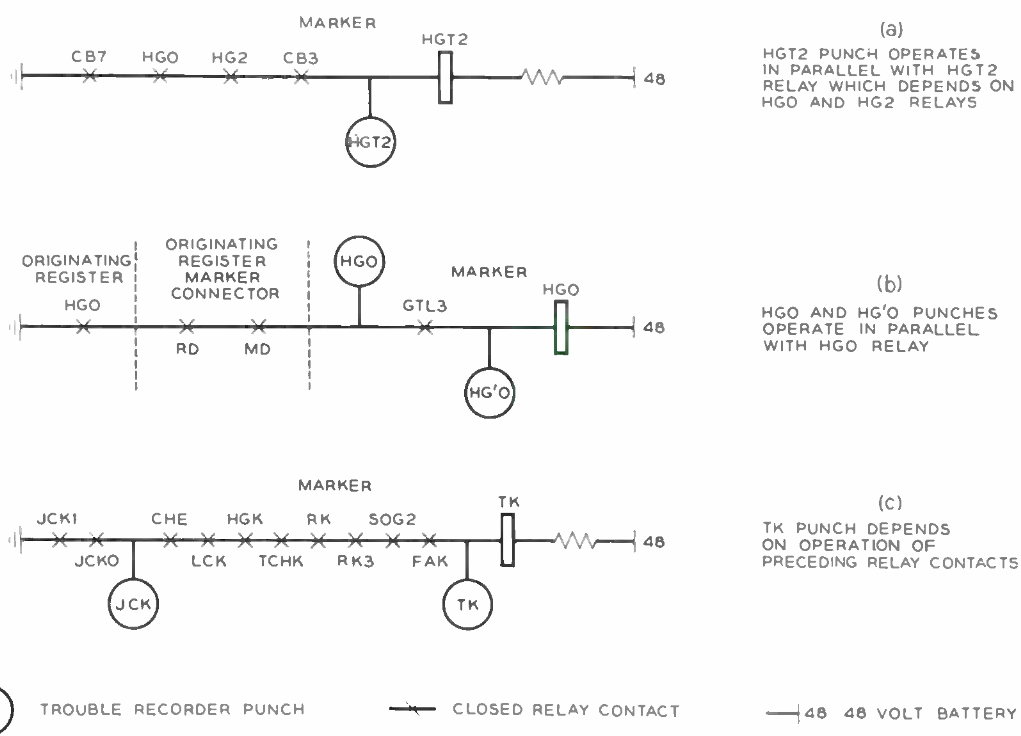


Fig. 3 — Part of a circuit sketch showing the paths for relays governing missing punched holes on the card in Figure 1.

that all the relay operations necessary for one phase of the marker operation had been completed.

The next step is to locate the TK relay on the portion of the sequence chart illustrated in Figure 2 (coordinates D-121) and notice that its operation depends on the operation of relays in several preceding branches of the chart. The relays immediately preceding TK in each branch of the chart are checked against the trouble recorder card and it is found that the punches corresponding to the relays FAK(C-120), LCK(D-120), TCHK(E-117), LK(F-118), JCKO,1(G-119), and CHE(M-105) are present, but HGK(H-115) and RK3(I-112) are missing. Coordinates for these punches on the trouble recorder card are given near each punch position on Figure 2. The trouble then must be in the branch of the circuit containing the HGK(H-115) *and* RK3(I-112) punches and relays. Further checking on the sequence chart (Figure 2) shows that the operation of the HGK(H-115) relay depends on that of the HG2(H-114) relay in the line link frame, which in turn depends on HTK1(H-111) in the marker. The operation of HTK1 further depends on HGT(H-110); and RK3(I-112) depends on RK1 and RK2(I-111). These punches are also missing from the card and hence, the location of the trouble is narrowed to this area.

At this point, it is necessary to consult a circuit sketch to study the paths for the relays corresponding to the missing punches. In these sketches, as illustrated in Figure 3, the boundaries of the conventional schematic diagram are completely disregarded. For simplicity, relays and their contacts are detached, and the operating paths for all relays and other apparatus are shown completely from 48 volt battery to ground.*

From a study of the sequence chart, the crafts-

* RECORD, *July*, 1954, *page* 261.

man decides that the HGT-relay (H-110) is a logical starting point in his search for the trouble, since it represents the first missing punch in the sequence. There are, however, 10 HGT relays and to determine which one of them is applicable in this case, the craftsman checks the trouble recorder card and notes that the calling line is located in horizontal group 2 in the line link frame as indicated by the presence of the HGO and HG2 punches (coordinates R1-15, 17) on the card. This indicates that the operating path for the HGT2 relay should be examined. The number of the circuit sketch containing the path for this relay is obtained from an index and the proper sketch is found to be the one illustrated in part in Figure 3.

As shown in line (a) of the figure, the missing HGT2 punch operates in parallel with the HGT2 relay. The operation of this relay, however, depends on the closure of contacts on relays CB3, HG2, HG0, and CB7. To determine which of these relays did not operate, the craftsman tests their contacts for closure in the actual circuit. The check indicates that the HGO contacts did not close and hence the path for the operation of that relay is to be checked. This path, as illustrated in line (b), shows that the HGO relay operates in parallel with the HGO and HG'O punches. Since these punches are present on the trouble recorder card (R1-15 and R0-15), the operating path from ground is complete up to the winding of the HGO relay.

The sequence chart shows that the operation of RK1, RK2, and RK3 depends upon the operation of the HGO relay (Column I, Figure 2) and hence, these RK- punches are also missing on the trouble recorder card. Line (c) of Figure 3 illustrates the way the missing TK punch that formed the basic clue to locating this trouble condition depends on the operation of the preceding relays in various branches of the sequence chart. Failure of any one of the relay contacts shown would prevent the TK punch indication from being perforated.

At this point, the craftsman locates the faulty HGO relay on the marker frame from information given in the reference material and an operational check is made. This check can be made in two ways. A head receiver can be used to test the continuity of the operating path, or the same call that caused the marker to seize the trouble recorder can be simulated on the master test frame, and the operation of the relay observed when the remote control start key at the marker frame is depressed. If the latter method is used, it is noticed that the HGO relay does not operate. The head receiver is then used to check the continuity of the operating path through this relay winding and this path is found to be open. After the faulty relay has been replaced, the same call is again checked on the master test frame, and if the call is completed without bringing in the trouble recorder, the difficulty has been satisfactorily cleared.

When the trouble recorder card is first received by the craftsman, it is dated and the name of the central office recorded in the space provided for this information. After the trouble is cleared, a record of the difficulty found and the action taken is made at the center of the card, and it is signed by the people who took the action. Any additional facts pertinent to the trouble condition are entered on the back of the card which is then filed to provide a permanent record of the trouble encountered and the action taken.

Since No. 5 crossbar is a complex common-control switching system, the procedure for locating faults actually amounts to a diagnosis and a craftsman must be trained in these techniques of maintenance. As experience is gained in these techniques, faults or trouble conditions are quickly analyzed, located and corrected.

THE AUTHOR

G. H. DUHNKRACK joined the Laboratories in 1923 after six years with the Western Electric Company. Until 1940 he was engaged in work on design and construction of long-distance central office equipment, and supervised analyzation of local and long-distance circuit design. During World War II he helped design remote control radio transmitter circuits for military use and conducted tests on groundwave and skywave radio transmission. More recently he has supervised the preparation of training and maintenance material for the No. 5 crossbar system.

Dr. Kelly Recommends Graduate Training in Creative Technology for Engineers

Nothing is more important in keeping the nation strong than an adequate supply of scientists and engineers trained in modern creative technology, Dr. M. J. Kelly, President of the Laboratories, told the American Society of Mechanical Engineers recently.

"In the contest of the free world with Russian inspired communism, there is no action for increasing the Nation's strength of greater continuing importance than that of providing an adequate number of sufficiently trained scientists and engineers to meet the expanding and ever more exacting needs of creative technology," he said.

Dr. Kelly spoke on "Training Programs of Industry for Graduate Engineers" before the A.S.M.E.'s 75th Anniversary Meeting at Stevens Institute of Technology.

The area of creative technology — applied research, development, and systems and design engineering — is uniquely the area where the graduate engineer is inadequately prepared for the professional career on which he embarks, Dr. Kelly said.

The recent tremendous expansion in basic research, with the accompanying dynamic progress in technology and engineering, is probably the chief cause of this difficult problem facing both engineering educators and industrialists. Pure research has increased the scope and depth of knowledge about matter and the laws governing its behavior. This expanded knowledge has provided creative technology with a vast reservoir of opportunity to develop new and more efficient facilities for both military and civilian use.

"The young man of 1955, entering his career in creative technology in electronics and communications, is presented with a widely different vista from the young man of 1940," Dr. Kelly said. "A maturity in the physical sciences of a new order must be integrated with his engineering and technical background."

To develop this maturity in its engineering graduates, Bell Laboratories initiated its Communications Development Training Program. This three-year, part-time program emphasizes increasing depth in the physics, chemistry and mathematics essential to modern technology, with advanced courses in communications and electronic technology.

"We consider this educational experiment a success," Dr. Kelly said. "Our experience in this program, accompanied by collateral observations, has led to some general conclusions about educational requirements and the training to meet them for creative technology. These conclusions may be summarized as follows:

(a) "Four-year engineering training, independent of the nature of the curriculum, is inadequate for a professional career in creative technology.

(b) "The larger the basic science (physics, chemistry, mathematics) content of the curriculum, the better is the course for those preparing for creative technology.

(c) "For the specific development, design, and engineering areas of creative technology, an industry can well provide the four-year engineer with the additional training required.

(d) "For the research and fundamental development areas of creative technology, training to the doctorate level in science or engineering is most desirable. A man, planning to enter these areas, can hardly afford, in his own interest, to have less training.

(e) "Training to this level is best done in an academic institution. Industry cannot provide the environment and stimulation of a graduate school.

(f) "While there is need for more men trained to the doctorate level in both science and engineering, the shortage in engineering is much more pronounced. Increased training to the doctorate level in engineering is a national need of major importance.

(g) "The enticing opportunities for graduate engineers, occasioned by our present relatively low engineering school enrollment and the ever-increasing demands for engineers, do not provide a good national environment for graduate training in engineering. The needs for the added training to the doctorate level should be more generally recognized, especially by our engineering faculties.

(h) "The projected increase in college enrollment, almost double by 1970, coupled with the effort to increase the percentage of entrants choosing science and engineering, does not provide a good environment for increasing the basic science content of engineering curricula or for markedly increasing the number of engineers continuing to the doctorate level."

Safer Testing Aids

J. T. SCHOTT *Military Engineering*

(Formerly Transmission Systems Development)

Although the Bell System has won the National Safety Council's highest award for the past several years, the entire system, including the Laboratories, is constantly striving for ways to further decrease the number of accidents that may occur. In line with this policy, a volt-ohm-milliammeter and several sets of special leads to go with it have been designed to provide a maximum degree of safety to the user. These testing aids are now available for use throughout the Bell System.

A general purpose volt-ohm-milliammeter, and several attachments designed to be used primarily with that meter, are now available for general Bell System use. This equipment, designed for electrical testing in general and voltage measurements on electronic apparatus in particular, is convenient to use and provides some important built-in safety features.

The meter, now standard for field use, is shown in Figure 1. It features a number of improvements over previously available models. These include simplified open scales that are easily readable, and a single large-handled switch for changing scales. In addition, there are only two points of connection to the meter. Dc and ac ranges up to 600 volts are provided, with full-scale accuracies of two and five per cent respectively and sensitivities of 20,000 ohms per volt for dc and 3,000 ohms per volt for ac. Current ranges extend to 120 milliamperes. Resistance ranges are in decade steps with the ohmmeter circuit fused to give a degree of protection against burn-out of circuit resistors should the meter inadvertently be connected across a relatively high voltage source with the switch on a resistance measuring position. Connection to the meter can be made only by use of completely insulated connectors, designated KS-14530, which must be inserted into the two recesses in the face of the meter case. To protect the user against accidental shock, no metal part carrying a voltage is exposed on either the meter or the connectors. A pair of conventional test prods complete with leads and the new connectors is furnished with each meter. A simple metal stand is also available for holding the meter tipped up at a convenient viewing angle when it is used for bench testing.

A new safety prod provides a solution to the long-standing problem of improving safety in measuring voltages on "live" electronic equipment; that is, with normal operating voltage applied. Conventional test prods generally have an exposed metal tip of some length. When such a prod slips from the point of contact, as it often does, possible short-circuits between terminals or between a terminal and ground can result in blown fuses or damaged components. Miniaturized equipment has greatly increased the likelihood of this happening. The newly developed safety prod prevents such accidental short circuiting or making improper contact. The possibility of injury to personnel resulting from sudden muscular reactions brought about by surprise flashing or sparking is also minimized.

The safety features of the prod result from the use of a retractable spring-loaded nylon insulating tube to surround the metallic contacting rod. Under normal conditions, this tube completely covers and extends beyond the end of the metallic rod, acting as a guard to prevent any unwanted contact.

To make a voltage measurement, the desired point can be located by counting electron tube socket springs or terminal block punchings, using the end of the white insulating guard tube as a pointer or indicator. The open end of the extended nylon guard is then placed over the particular lug or terminal so as to cover it completely or partially, as shown in the headpiece, which shows J. Reyda using the safety prod to measure a voltage in a "tight" location. The inset illustrates how the insulating guard holds the prod on a terminal and prevents slipping. With the head prevented from slipping, the prod can be held near the tail end, thus moving the hand to a safe distance from voltage exposure.

Electrical connection to the test point is made by pushing the body of the prod toward the terminal, in opposition to an internal spring, until the inner metallic rod makes contact. The face of the rod tip is made of hardened steel which is deeply grooved to produce several sharpened points around its periphery. This contacting rod is supported within the prod so that in the event of a doubtful contact, a slight twist of the prod body will also twist the rod, causing the face to cut through to a clean contact. When the prod is withdrawn, the safety guard again extends to its normal position. The user of the prod can proceed confidently to seek out the test point desired, knowing that there is practically no possibility of accidental short circuiting. After placing the prod guard over the test point, he can devote his full attention to reading the test instrument knowing that the prod is not likely to slip off and cause damage to the instrument or any component of the circuit that is being tested.

The safety test prod is packaged in two different ways: as part of a two-lead combination, and alone. For general voltage-to-ground testing, specifically with the previously described meter, a pair of test leads is available. Both leads are equipped on one end with the special connectors required for connection to the meter, and at the other end, one lead is provided with a safety test prod, and the other with a substantial test clip for a firm ground connection. This combination has been designated "KS-14510 List 6 Safety Test Leads." Where the prod is to be used with other types of meters or circuit checking instruments such as cathode-ray oscilloscopes, the prod alone (List 7) is available to be attached to any desired type of lead.

In future equipment designs, it is expected that, by use of the safety test prod, the pin jacks ordinarily used at meter reading circuit test points can be supplanted by a simpler and smaller detail. In addition, many test points can be brought together in the form of a miniature terminal block, thus saving space and yet permitting contact to each test point with complete isolation from all others.

Two attachments for extending the dc voltage range of the test meter are also available. These consist of two sets of test leads, as shown in Figure 2, each including an appropriate voltage-multiplying resistor housed in a well insulated probe to be held in the hand. Special attention has been given to the

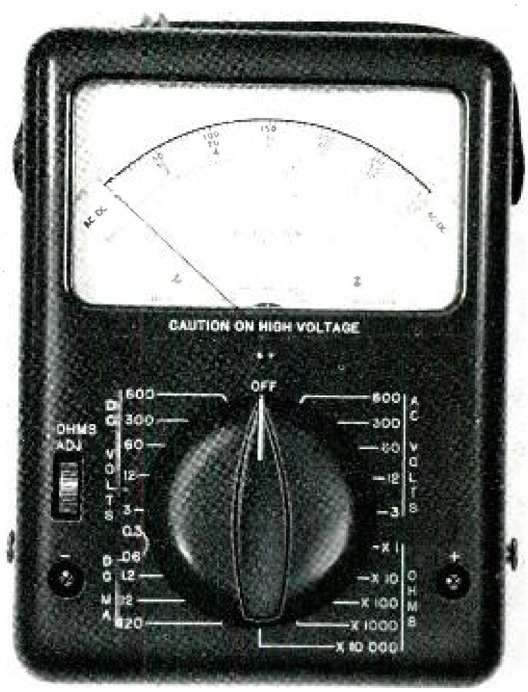


Fig. 1 — Front view of a KS-14510 volt-ohm-milliammeter now available for Bell System use.

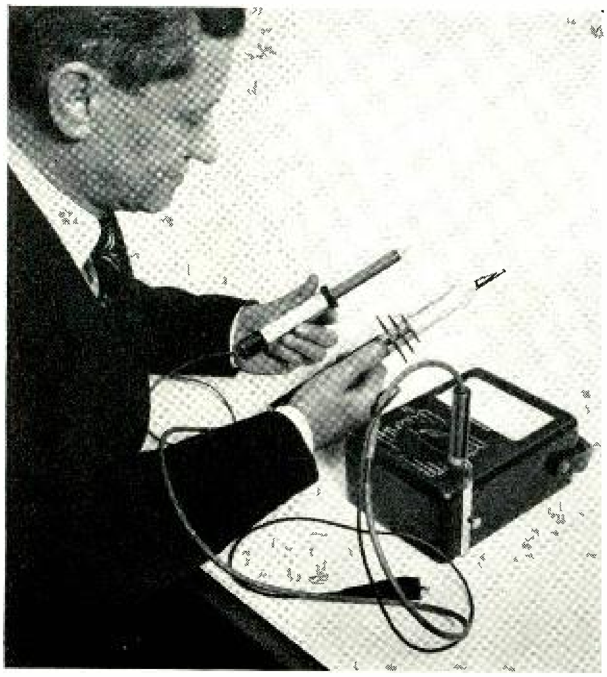


Fig. 2 — The author illustrates the designs of the KS-14709 L1 test leads (3 kv) at left, and at the right, the KS-14708 L1 test leads (12 kv), shown connected to the KS-14510 meter.

lead and connector arrangements to provide a high degree of safety in use. One set, the 12-kv test leads, is intended primarily for maintenance testing of video monitors. It extends the dc voltage scale of the meter to 12 kv. The meter end of the "high" lead is fitted with a safety connector provided with a retractable insulating guard tube similar to the safety prod described earlier. The "high" side connection to the meter can only be made by inserting the insulating guard into the connection recess and depressing the connector body against an internal spring until contact is made. The connector is held in this position by hooking the foot of a metal "L" under the meter as shown in Figure 2. To disconnect the "high" lead, the "L" detail is swung out, permitting the connector spring to extend the guard tube and thus break the connection. Since the "live" parts of the connector are always covered, the user is protected against ordinary contact hazard, and against any injury that might result from surprise sparking in case the probe is connected to a high voltage source while the meter end of the lead is lying free.

The second set of leads is intended for maintenance testing of mobile radio transmitters, video A scopes, and laboratory test oscilloscopes. These leads extend the dc voltage scale of the meter to a full-scale reading of 3 kv. Since voltages in this range are somewhat less hazardous, and since it was desired to have this probe look distinctly different from the 12-kv model, a smaller, simpler probe was designed.

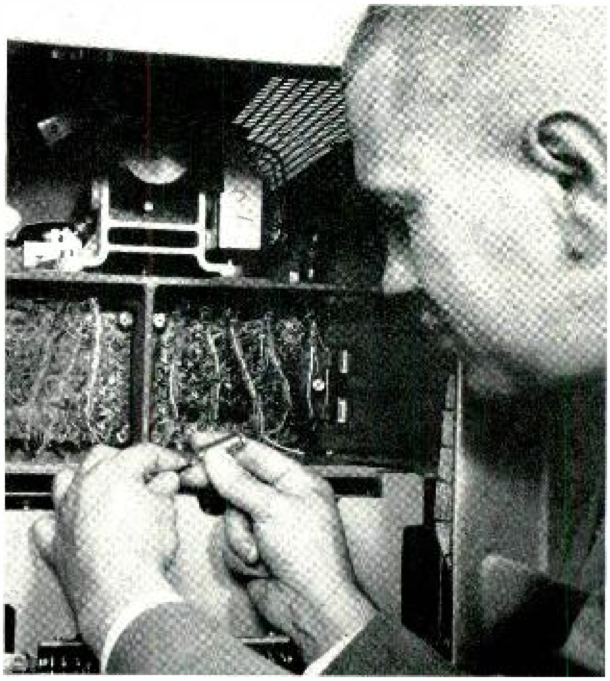
Both 12- and 3-kv probes are used with the meter-switch set on the 3-volt dc position. The 12-volt scale is read as a 12-kv scale in the first case, and the 300-volt scale as a 3,000-volt scale in the second. Both 12- and 3-kv. combinations also have a ground lead equipped with a substantial clip. In each set, the two leads are bound together at a point a short distance from the meter connectors. This compels use of the complete assembly as a high voltage kit and prevents improvising that might occur if the leads were separated and one misplaced. Having a separate harness for special use also serves as a psychological warning to exercise caution in high voltage measurements.

Even though the new high voltage prod arrangements provide improved safety, personnel should continue to observe the usual precautions recommended in higher voltage testing.

THE AUTHOR

After receiving the degree of B.S. in E.E. from the University of Illinois in 1921, J. T. Schott joined the American Telephone and Telegraph Company where he was engaged in the development of telephone repeaters, echo suppressors, and special service toll circuit arrangements. He became a member of the Laboratories in 1934, for a time in the Toll Facilities Department and later in Transmission Development, continuing the same work. In 1942 he became engaged in military projects, particularly in the development of pulse echo type line fault finding equipment. Later he was occupied in the development of sending and receiving devices for use in transmission measurements on television circuits. In 1953, he returned to military project work at Whippany, initially in the Military Systems Development Department and later in the Military Engineering Department.

Transistors in the 4A Crossbar System



P. MALLERY *Switching Systems Development II*

In 1948 Bell Telephone Laboratories announced the invention of the transistor, a tiny electronic device that greatly reduces the size and power consumption of many circuits. Its first large-scale use for telephone purposes is in the card translator, the machine that helps find idle trunks in the 4A crossbar system for switching long distance telephone calls.

In nationwide dialing, routing of calls through a No. 4A crossbar office is automatically determined from information supplied by the card translator. This routing information is registered on metal cards which are selected in accordance with the digits dialed. As described previously* the routing information appears as a pattern of clear and blocked light channels. The conversion of light to the operation of a relay was an important problem in the development of the card translator. The transistor provided a satisfactory answer, and transistor circuits were designed to detect the presence or absence of light in a channel.

Figure 1 is a block diagram of the circuit used to determine whether a particular channel is interrupted or not. Each block, with the exception of the light source, represents a piece of equipment provided individually for each channel. The light source is common to all channels. For those channels not blocked by the selected card, light will pass completely through the stack of cards and fall upon the phototransistor.* The phototransistor converts the light into an electrical signal which is impressed on the transistor amplifier. After being amplified, this signal is used to trigger a cold cathode gas tube. The gas tube, in turn, operates the channel relay. This relay is located in the decoder or marker circuits, which use the information provided by the translator.

In a detailed examination it is convenient to break the channel circuit down into two parts, the optical section and the electrical. The optical section includes

* RECORD, *March*, 1955, *page* 93 and *May*, 1955, *page* 178.

* RECORD, *August*, 1950, *page* 337.

everything up to the point where the light falls upon the germanium of the phototransistor. This part of the channel is shown functionally in Figure 2. The light source is a standard projection-type lamp normally rated at 500 watts. To obtain long life it is part is shown in Figure 3. Those familiar with other transistor circuits will note that the light acts as the emitter of the phototransistor. The collector is of the conventional type for point-contact transistors. It is biased in the high-impedance direction, and varia-

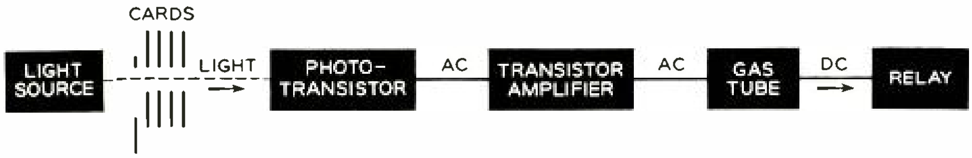


Fig. 1 — Block diagram of circuit that determines whether a card has been dropped in the 4A crossbar translator.

operated in the translator at half voltage. At that level its input is approximately 170 watts. This type of lamp was chosen because of its high concentration of light in a small plane.

The light from the lamp passes through a motor-driven perforated disc. The disc interrupts the light at a 400-cycle rate, and the differential between the light and dark currents of the phototransistor is used as the signal. In this manner, operating margins are greater than those obtained with unmodulated light.

The modulated light beam is collimated (that is, made parallel) by a lens to minimize losses as the beam passes through the holes in the cards. Unless interrupted by a dropped card, this beam will pass through holes in all of the cards and will fall on an

tion of the light intensity causes a variation in the collector impedance. The 3A phototransistor used in the card translator has an impedance of about 10,000 ohms when dark. This is reduced to approximately 3,000 ohms when illuminated.

The phototransistor is coupled to the amplifying transistor by transformer T1. This transformer permits convenient matching of impedances and separation of the dc bias voltages. A voltage-limiting varistor V is connected across the input of the transformer to limit surges which might otherwise damage the amplifying transistor. The input to the transistor amplifier is a minimum of 1.3 volts, positive peak, 400 cycles. The output is limited by saturation of the amplifier to a maximum of about 160 volts positive

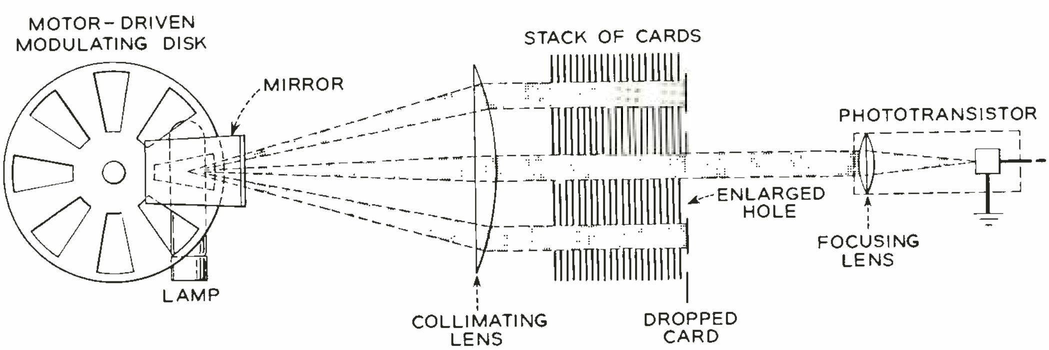


Fig. 2 — Functional diagram of the optical section of the channel circuit.

individual channel-lens, which focuses the light on the sensitive area of the phototransistor. The light intensity at the lens of the phototransistor is 34 foot-candles minimum. This supplies about 12 millilumens to the phototransistor, a figure relatively small when compared with the light intensity required by conventional photoelectric cells.

At the point where light falls on the phototransistor, the optical part of the channel circuit ends and the second, or electrical part, begins. The electrical

peak. To guarantee operation, any phototransistor-amplifier combination whose output voltage tests below 38.5 positive peak will have its weak element or elements replaced. This output voltage breaks down the control gap of the cold-cathode gas tube, and sufficient current flows in this control gap to insure reliable transfer to the main gap. The capacitor and resistor network at the main anode of the tube prevents transients caused by the operation of other channels from falsely breaking down the main gap of a dark channel. The current in the main gap in turn operates the channel relay.

Circuits are so arranged, however, that current will flow in the main gap of the tube only when the card is "checked down". Two holes in the card are never enlarged, and when the card is properly dropped, light will be blocked in these two channels. A special down-check circuit detects this condition, and will permit operation only if a card has dropped.

Figure 5 shows the card "down-check" circuit. Its function is the inverse of the routing-information channel circuits, since it operates a relay when the light is blocked. Therefore the transistor amplifier-gas tube circuit could not be used. Instead, the output of the phototransistor is amplified by the first section of a double triode thermionic emission tube V1. The ac signal at the first plate of V1 is rectified by a conventional full wave rectifier which contains a transformer and another double triode. The rectified voltage is negative with respect to ground, and when it is impressed on the grid of the second section of tube V1, that section is driven past cut-off—that is, current will not flow to the second plate. Therefore as long as light falls on the phototransistor, no current flows through the relay. When a selected card blocks the light, the negative voltage on the second grid disappears and the tube conducts, operating the associated relay. Although the prime purpose of this down-check circuit is to signal that a card is in position to have the routing information determined, another advantage is taken of its ability to distinguish between a light and dark phototransistor. If a card does not drop, or if either the lamp or modulating disc fails, the circuit will operate alarms to bring the failure to the attention of maintenance personnel.

After the card has been checked down, the decoder and later the marker connect positive 130 volts through their channel relays to the main-gap anodes of the gas tubes (Figure 3). All gas tubes associated with illuminated channels will have their control gaps broken down, which will enable their main gaps to break down. As already described, this operates the corresponding channel relays. When operated, these relays lock to ground and extinguish the main-gap discharges, which increases the life of the gas tubes. Those channels which have been blocked will

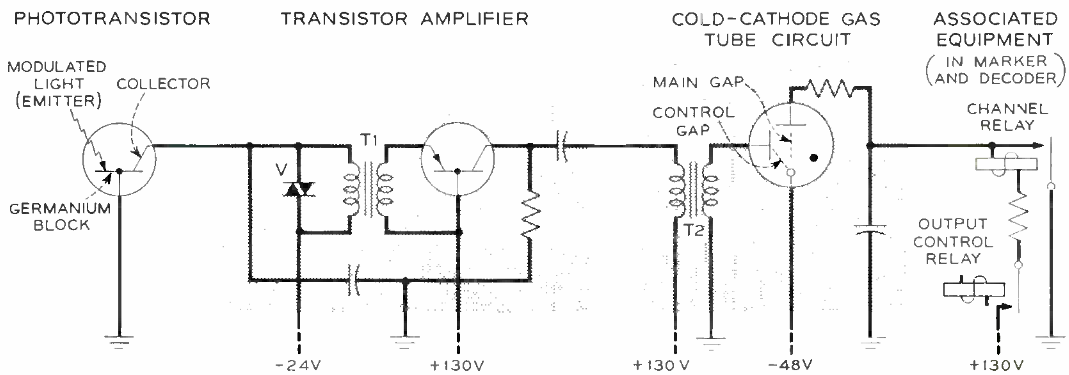
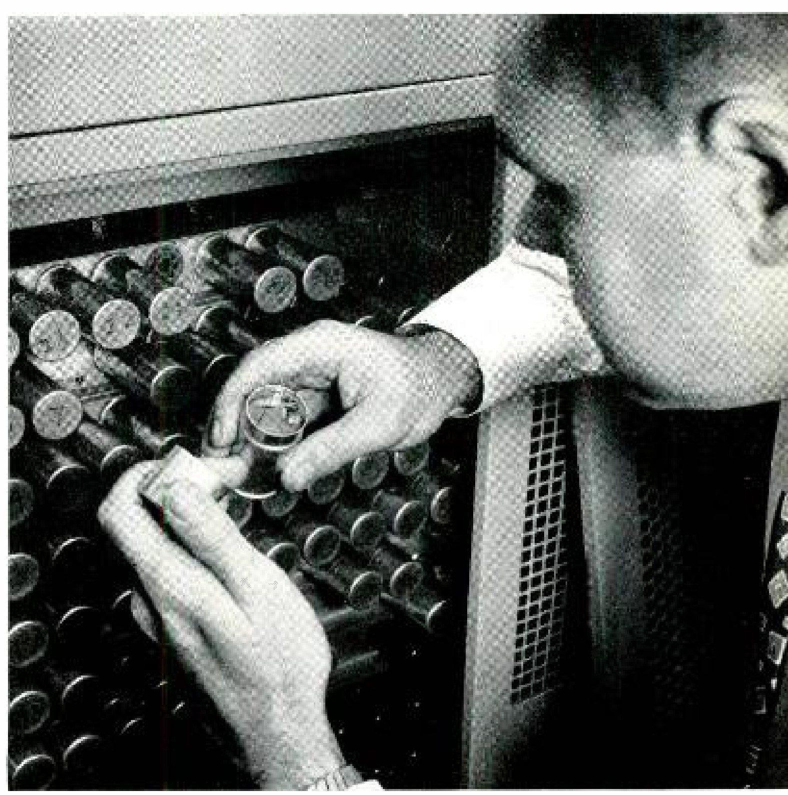


Fig. 3 — Simplified schematic of electrical section of channel circuit.

Fig. 4 — D. A. James inspecting a transistor mounted on top of the amplifier. The entire transistor amplifier is contained in the can, covered by a removable cap.



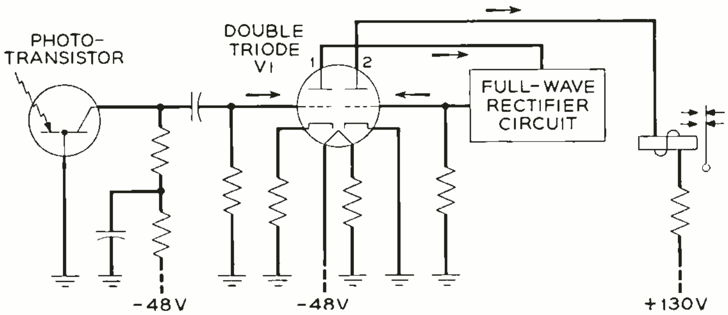


Fig. 5 — Simplified representation of down-check circuit.

not have the control gaps of the gas tubes broken down. Therefore when the 130 volts is applied, the relays associated with dark channels will not operate. The operation or non-operation of the relays in the decoder and marker completes the function of the channel circuits.

For installation in the translator, the phototransistor is mounted in a tube along with a lens that focuses the collimated light on the germanium. Figure 6 is a cutaway view of the phototransistor showing the relationship of the lens to the phototransistor. When being mounted in the translator, the tube is slipped into an accurately positioned hole and clamped in place by means of the slotted ear seen at the right. This mechanical fastening is also the ground connection. The output lead from the collector is attached with a slip-on connector.

The amplifying transistor, transformer T1, varistor V, the resistor and two capacitors of the amplifier are packaged as a convenient plug-in unit. Figure 4 shows one amplifier removed from its socket. As shown, the transistor is mounted under a removable cap on the package so that it may be conveniently replaced if necessary. The gas tube, transformer T2, and the associated resistor and capacitor are also assembled as a packaged unit.

In the development of the translator, the channel circuit and its transistor components were subjected to marginal tests to guarantee that operation would be reliable under extremes of voltage, light intensity and temperature. In addition, three translators

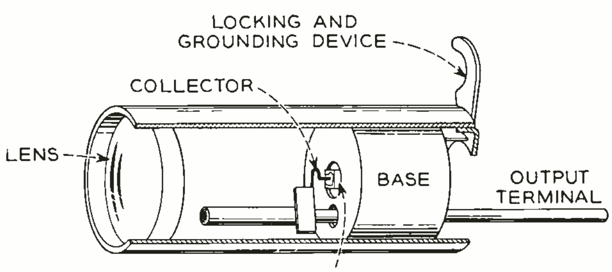


Fig. 6 — Cutaway view of phototransistor.

equipped with a total of 272 channel circuits were installed in the laboratory and connected in a normal service manner to standard associated 4A crossbar system equipment. Then call after call was sent through the system. In all, over 35 million translations were made. Each translation required the proper operation of many channel circuits. In the entire test, there was no evidence of any channel failing to operate because of the transistor elements in the circuits.

Although the reliability of operation by the channel circuits was of prime importance, the life of the transistors is another factor that has a great effect on

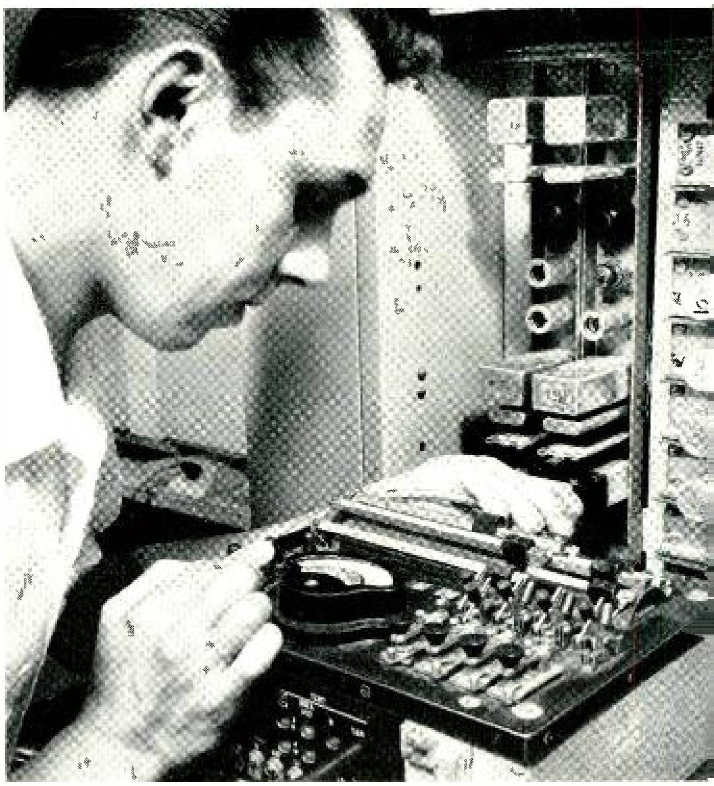


Fig. 7 — M. Ignatowitz measuring output current in index channels of the 4A crossbar card translator.

the cost of apparatus and maintenance. Therefore, 96 channels were subjected to a series of measurements designed to determine the effect of aging on the transistor elements. For this purpose, a test set was used, which was designed to place on the transistor equipment the worst circuit condition that will occur in service. It was equipped to make output voltage measurements of the phototransistors and the transistor amplifiers. This test set is now coded the 100A for use in the field.

The results of the series of output voltage measurements were subjected to the usual statistical analysis. This showed that the performance with age of the transistor elements was as expected and that deviations from the mean were not excessive and were in good control. Figure 8 is an average curve of the outputs of the 96 channels as they change with time. The months in operation represent the time during which the phototransistors were exposed to light and during which operating voltages were applied to the circuit.

When devices are used which approach their end of life gradually, it is important to determine, in advance of service failure, whether any element is becoming weak. In the card translator this can be accomplished by periodically making a marginal test of all channel circuits. For this test, the intensity of the light falling on the phototransistors is reduced and the decoder and marker are used to check for channel operation. No card is dropped for this test; therefore no channel is blocked and every channel relay should operate. By means of the trouble recorder, a record is made showing the channels that operated. An examination by the switchman of this record will disclose any failure under this test condition. The individual components of channels that fail the marginal test are examined using the 100A test set to disclose the weak units.

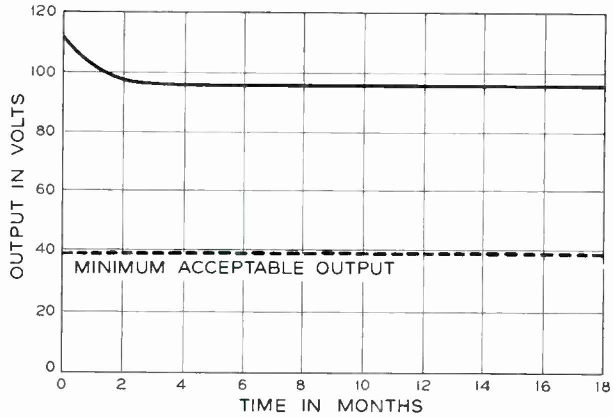
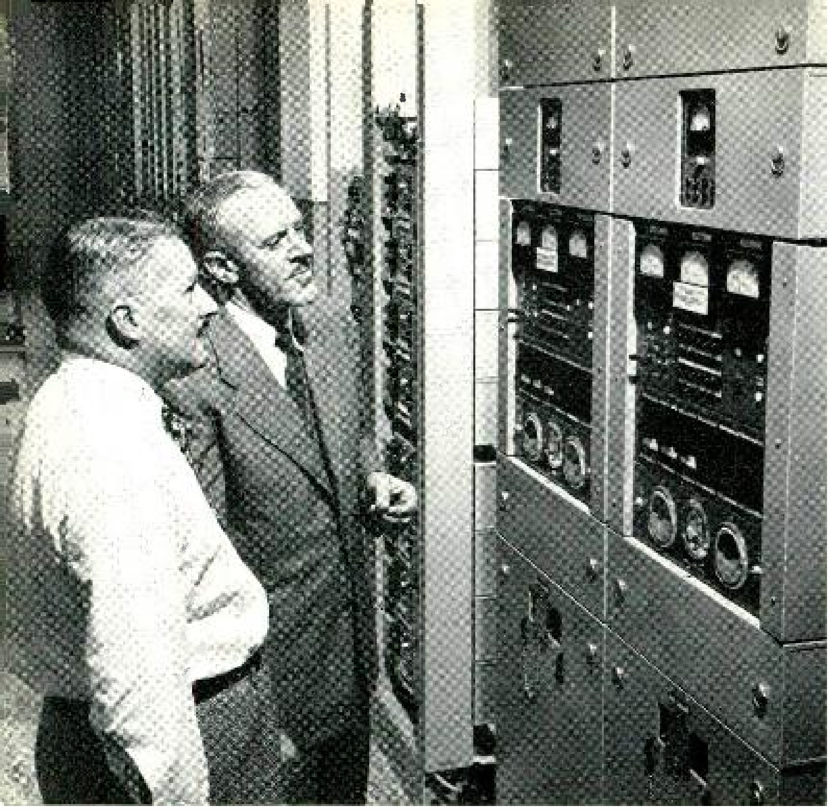


Fig. 8 — Curve showing stability of output voltage of translator channels.

The first card translators were placed in service in March, 1953, in Pittsburgh. The field experience gained on these, and on the many installed subsequently, has shown that the channel circuits are highly reliable. The success of this first large-scale application of the transistor in the Bell System is indicative of the great possibilities of new developments due to this product of telephone research.

THE AUTHOR

P. Mallery joined Bell Telephone Laboratories in 1941 following his graduation from Ohio State University where he obtained a B.E.E. degree. He was concerned with toll systems testing before entering the U. S. Army in 1942 where he served as a radio and radar repair officer in the Southwest Pacific. Remaining in the Army Reserves he is now Chief of Public Facilities of a military government group, the section which controls civilian telephone operation. Following World War II he worked on sender circuit development for manual toll and then on the card translator. He was concerned with the CAMA project for No. 4A toll and is now engaged in the program to develop an automatic switching system for TWX. He is the author of approximately one hundred technical articles and currently has an electrical handbook being published.



Power Supply for the L3 System

H. H. SPENCER *Facilities Development*

No matter how well a telephone transmission system is designed and developed, high quality, uninterrupted service still depends on a highly reliable supply of power. A complete power failure in a part of the L3 system, for example, could affect as many as 1,800 telephone messages. To minimize this possibility, a reliable power supply with a number of emergency facilities has been developed for that system. Provision is included to maintain service in the event of outside power failure, or any foreseeable breakdown within the Telephone Company power plant.

In the L3 coaxial carrier system as in the L1 system, the 60-cycle ac power supplied to auxiliary repeaters along the cable is transmitted over the same coaxials as the carrier signals themselves. The increased power required by each repeater, together with the closer spacing of repeaters in the L3 coaxial system have increased the amount of power that must be generated at the sending stations by seven times that required by the L1 system. In the power supply for the L3 system, greater system stability has been attained through improved control of the rate of change of power. Also, closer regulation of the power and improved protection features result in better system performance and longer tube life.

AC power in the system is furnished by continuously operated two-motor alternator sets. The two motors, one ac and the other dc, are mounted on the same shaft as the alternator and the shunt generator which furnishes current to excite the alternator field. A flywheel is also mounted on this shaft to provide the inertia needed to reduce the dip in load voltage to a negligible amount when it is necessary to transfer the drive from one motor to the other.

One of these motor-generator units is furnished for each cable transmission circuit so that operating difficulties on any one will affect a minimum number of telephone channels. This means that four such regular alternators are used on each standard eight-tube coaxial cable. In addition, an emergency alternator unit is operated continuously at no-load, ready to take over the load if any of the four regular units should fail. This emergency unit, similar in all respects to a regular alternator, is used principally during maintenance of the regular units. One of the most commonly used alternator units, rated at 16 kva, is illustrated in Figure 1. Power is normally supplied to these alternators from commercial ac sources. During ac power failure, the dc motors operate from large 130-volt batteries to provide continuous cable power until a station standby engine-driven alternator takes over the ac drive, or commercial power is restored.

A schematic diagram of a regular and emergency alternator supplying power to repeaters along the cable is shown in Figure 2. At auxiliary repeaters, the primaries of power transformers are connected in line with the inner coaxial conductors to form a series circuit so that a constant line current provides constant power to each repeater.

Two systems of regulation are employed at the source to hold the coaxial line current constant: A coarse control using relays operates a slow-acting motor-driven autotransformer whenever the coaxial current varies more than ±3 per cent from its nominal value of about 1.5 amperes. A faster acting motor-driven variable autotransformer provides a fine control which boosts or bucks the supply from the coarse control. This unit regulates the coaxial current within limits of ±1 per cent. Its range, limited to a maximum buck or boost of 10 per cent of the supply voltage, is more than sufficient to take care of any anticipated alternator voltage changes. Its rate of change has been designed to keep up with that of the alternator supply so that alternator voltage changes are compensated by the fine control unless they exceed its range. The fine control is arranged to servo-control the drive of the coarse unit to keep the fine control at its midpoint so that the latter may always have its full range available for fast correction. Controls are protected so that electronic failure will cut off the fine control and maintain relay coarse control limits until repairs are made.

The voltage required on the coaxial power circuit varies with the number of amplifiers served. Although not indicated in the schematic, the secondaries of the high-voltage transformer are tapped to provide proper voltages for repeater spans ranging from a few auxiliary repeaters up to the maximum of 22 repeaters requiring over 4,000 volts. The resistance, with ground at center, shown between the high voltage secondaries, provides a means of measuring the cable current at near ground potential. It also provides a signal to the current regulating circuits. Power for the main repeater, taken from the primary side of the high-voltage transformer, affords essentially a regulated supply to this equipment without placing it in the cable power transmission circuit and thereby raising the supply voltage above that required for the cable supply. The input to the power control bay for the maximum span of auxiliary repeaters requires about 8.5 kw of 230-volt power. A 10-kw alternator unit provides adequate capacity for this load plus the supply for TV terminal equipment when power is transmitted in one direction only. Units of 16 kva and 21 kva are used when power is supplied in two directions as it is at main repeaters.

The equipment for regulating the cable current is housed in an eleven and one-half foot power control bay located close to the repeater equipment as shown in the headpiece, which shows the author, at the right, and M. H. Artt, Long Lines Central Office

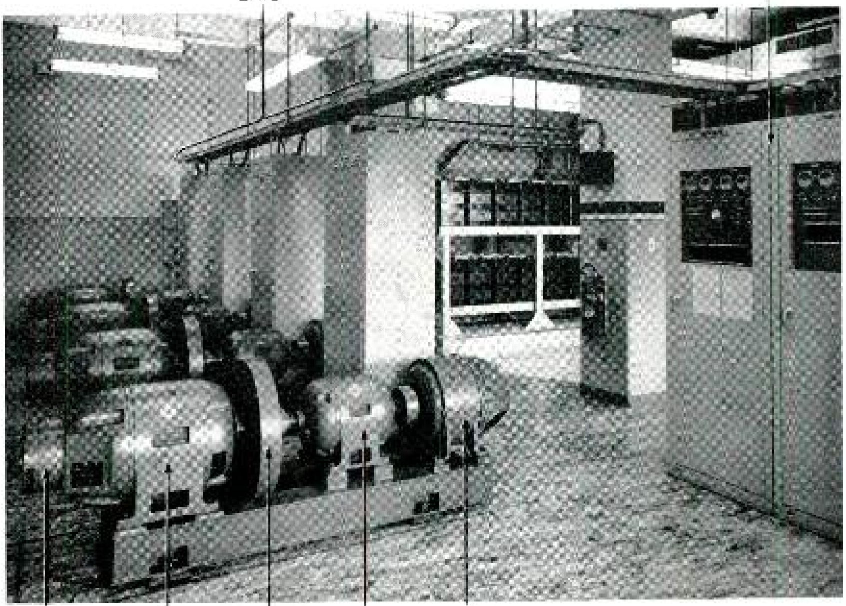


Fig. 1 — Over-all view of a typical power room at an L3 terminal. This one, rated 16 kva, is one of those most commonly used at present.

Chief, at an L3 cable current regulating bay installation. The motor-alternators and their control bays are located near the battery and other power plant equipment as shown in Figure 1. The control is entirely automatic for unattended operation with alarms for transmission to remote alarm control centers to indicate abnormal conditions. These alarms not only indicate troubles in the ac supply to the coaxial equipment, but also provide for the associated power plant. They indicate discharged batteries, outside power failure, failure of the automatic reserve engine alternator, and blown fuses.

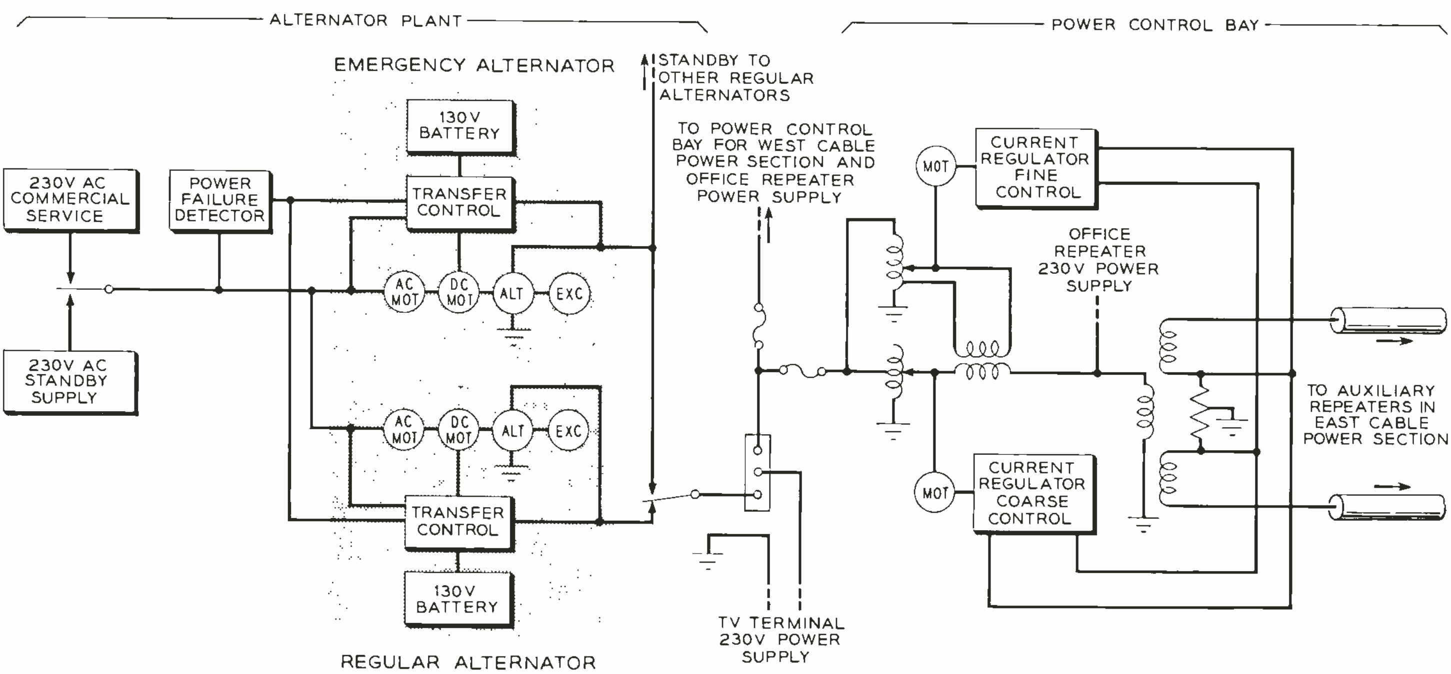


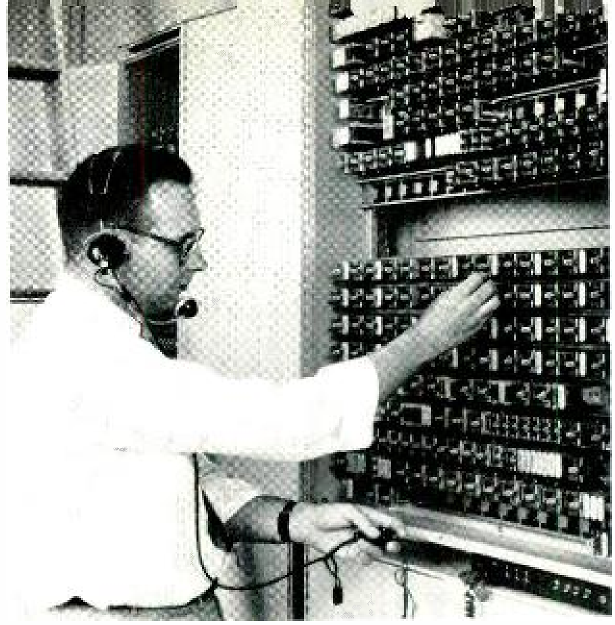
Fig. 2 — Simplified diagram of regular and emergency alternator units.

Power for the terminal equipment used in bringing the telephone messages down from coaxial carrier frequencies to voice frequency is supplied directly from batteries and involves no new problems other than proper distribution to provide a minimum of telephone service interruptions in the event of a fuse failure. A fully equipped L3 cable of eight coaxials with terminal equipment for a maximum of about 5,400 telephone circuits will create problems such as the need for larger 24- and 130-volt battery plants, larger diesel engine plants, and new floor plan arrangements. However, standardized information and plants are available for handling these problems in the same way as they are now being handled for central office and other telephone power plant application throughout the Bell System.

THE AUTHOR

After receiving a B.S. degree in mechanical engineering from the University of New Hampshire in 1923, H. H. Spencer joined the Technical Staff of the Laboratories. He has been engaged primarily in the development of power supplies for broadband carrier, toll, and repeater equipment, including automatic plants for unattended operation on J, K, and L carrier systems and TD-2 microwave radio relay systems. Mr. Spencer is a member of the American Institute of Electrical Engineers.

CAMA – Crossbar Tandem PCI Sender



L. A. WEBER *Switching Systems Development*

Direct-distance dialing for all telephone customers has been brought closer to realization by the development of centralized automatic message accounting. Among the modifications required for CAMA, crossbar tandem offices needed a new type of sender to perform the more complex switching required when details of a call are recorded automatically. Besides working with other parts of the CAMA system, this circuit receives digital information, translates it, and re-transmits it to the distant office.

A tandem telephone switching office acts in a sense as a "central office" for local central offices by providing connections between such local offices, in much the same general way that a local office makes connections between telephone customers. One of the modern tandem offices in the Bell System is the crossbar tandem office, which has recently been adapted to centralized automatic message accounting (CAMA).* Customers served by CAMA may now dial directly to points outside their local exchange area, and the details of the call necessary for billing purposes are recorded automatically. Centralizing this billing information by recording it in the crossbar tandem office opens a wide field for direct distance dialing where traffic does not justify local AMA equipment.

An important new circuit developed to permit automatic recording of billing information at a tandem office is the panel call indicator (PCI) sender, one of which is seen in the above illustration which shows the author at the crossbar tandem PCI sender in the New York City CAMA installation. Three senders are mounted in a bay, and each sender consists of two cabinets that enclose the equipment.

As illustrated in Figure 1, a CAMA call reaches a tandem office over a trunk from a local panel or crossbar office. This trunk requests the sender link equipment to attach a sender, which is used for control purposes while the call is being switched at the tandem office. When the sender is attached and is ready to function, a signal is passed to the originating office to indicate that the tandem office is ready to receive the telephone number of the called customer. This information is then transmitted from the originating office and is registered in the sender. The sender connects to a marker, which in turn closes a path through crossbar switches to an outgoing trunk to the desired terminating office. The marker refers to a built-in information directory, and informs the sender how to handle a call to this destination.

While these actions have been taking place, the sender has been busy seeing to the details of recording the billing information for the call. The sender connects itself to a CAMA operator position and closes a talking path between the operator and the customer. The operator obtains the *calling* number

* Record, *July*, 1954, *page* 241; *October*, 1954, *page* 371; *May*, 1955, *page* 193.

verbally from the customer and keys this into the sender. The sender then summons a transverter and transfers to it all information required for billing purposes. After a certain point in its operation, the transverter determines that the operator is no longer needed, sends a "position release" signal to the sender causing dismissal of the operator, seizes an AMA recorder which perforates an initial entry on the AMA tape, and signals the sender that a billing record has been made. The receipt of this signal causes the sender to release itself from the transverter. During this time, the sender has also transferred the called number information to the distant office. The last or units digit, however, is not sent out until the sender receives a signal that the billing record is complete. After the last digit is transmitted, the sender releases from the call, setting the incoming trunk in a talking condition so that the calling and called customers are connected when the terminating office has connected to the called customer.

This sender differs in two important respects from senders that have been used in crossbar tandem offices in the past. First, it receives the called number by panel call indicator (PCI) pulsing, universally available in all panel and crossbar offices. Revertive pulsing, which is also available in these offices, is restricted in the number of office codes it is able to pulse out. Second, it contains the necessary circuitry to control the operation of the CAMA functions of the system. More about these points later after a brief review of PCI pulsing.

The PCI system* is one of several methods by which a number can be generated and transmitted more rapidly than with a telephone dial. It uses four conditions of direct current on the line: zero current, small negative current, large negative current, and small positive current. These are arranged in a code system (Figure 2) whereby a choice between two of the four conditions identifies either a "mark" or a "space." This is analogous to the familiar "on" or "off" and "yes" or "no" conditions of circuits as used in modern switching and computer theory. The figure shows that each digit of a telephone number is defined by a particular combination of four mark or space conditions. In the first and third positions (or "quadrants" with values of 1 and 4), a space is defined by zero current, and a mark is defined by a small positive current. In the second and fourth positions (quadrants with values of 2 and 5), a space is defined by a small negative current, and a mark is defined by a large negative current.

* RECORD, *November*, 1943, *page* 110.

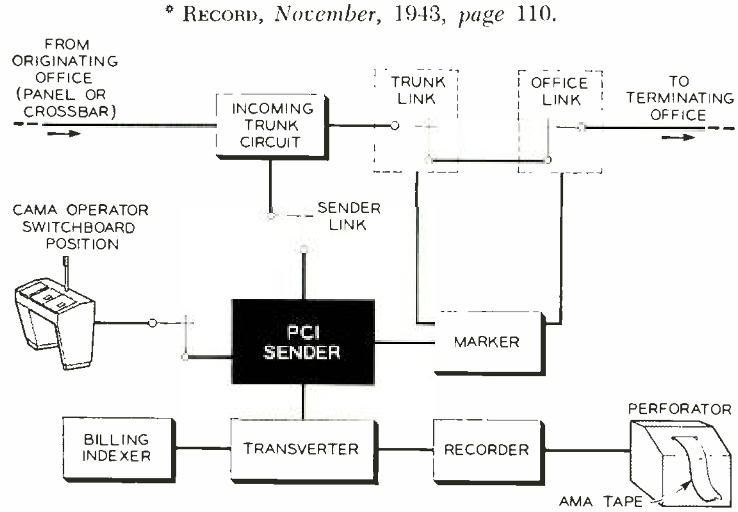


Fig. 1 — Block diagram illustrating role of PCI sender in a CAMA crossbar tandem office.

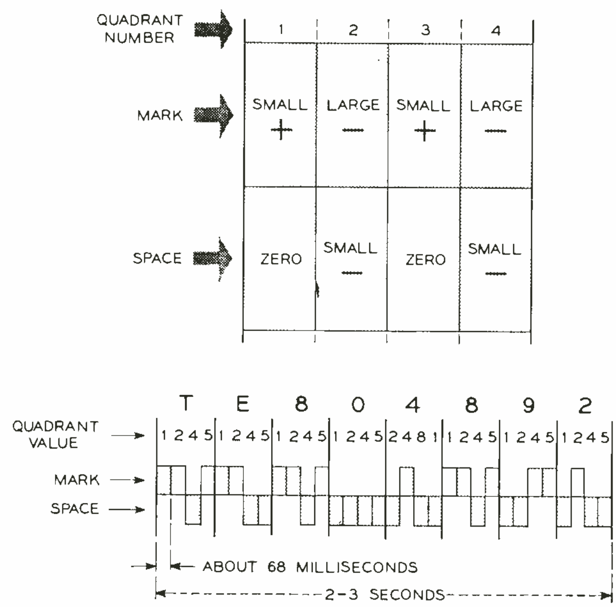


Fig. 2 — The PCI coding scheme for the number TE8-0-4892. The enlarged detail shows current conditions for marks and spaces in the four quadrants.

For the purpose of effecting equipment economies in the original design of the PCI system, an exception was made in the quadrant values for the four positions in the thousands digit of the transmitted number. The code shown in the figure thus represents the telephone number "TE 8-0-4892." (The "0" in this number indicates that the number does not have a party letter; for certain manual office numbers a party letter is necessary and is sent in this space.) A complete breakdown of codes for digits 0-9 is given in Figure 4. When transmitted automatically, the number can be sent in about two to three seconds.

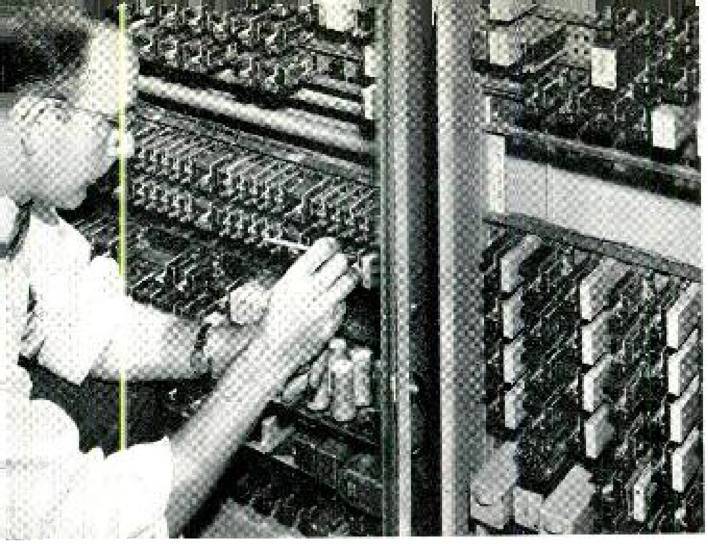


Fig. 3 — PCI sender in Washington, D. C., installation. Vincent L. Van Steamburg, Central Office repairman of C and P, is inspecting relay contacts.

A closer look at the PCI sender is now in order. Figure 5 shows a block diagram of the sender with each block representing a general function of the circuit. The called number register circuit receives from the originating office information determining the ultimate destination of the call. This PCI number is received on polar, marginal and sensitive relays that discriminate between the four current conditions on the line. The marker control determines when a request is to be sent to the marker, transmits to the marker sufficient information for it to do its job, and receives all necessary information from the marker needed by the sender. The AMA control summons an operator, receives the *calling* number information from the operator, summons a transverter, provides information for the billing record, receives notification that this record is satisfactory and complete, and informs the outpulsing control that transmission of the *called* number to the terminating office may be completed.

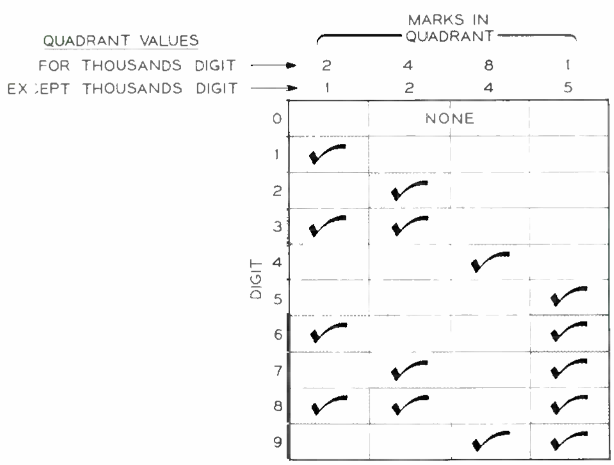


Fig. 4 — Distribution of marks for the digits 0-9.

As illustrated in Figure 5, the outpulsing control transmits the *called* number to the terminating office under instructions that have come from the marker through the marker control. The sender can complete calls by means of any of four types of pulsing, *viz.*, revertive pulsing, PCI pulsing, dial pulsing, and multifrequency pulsing. The type of pulsing needed for a particular destination is indicated to the outpulsing control by the marker. On routes to different destinations, a variable number of digits may be necessary to control switching beyond the tandem office. The sender is therefore arranged to pulse out either, 4, 5, 6, 7, or 8 digits under control of information from the marker. This variable number of digits is effective for both multifrequency and dial pulsing. The office code transmitted may be the same as received, or the marker may inform the sender to send 1, 2 or 3 other digits instead.

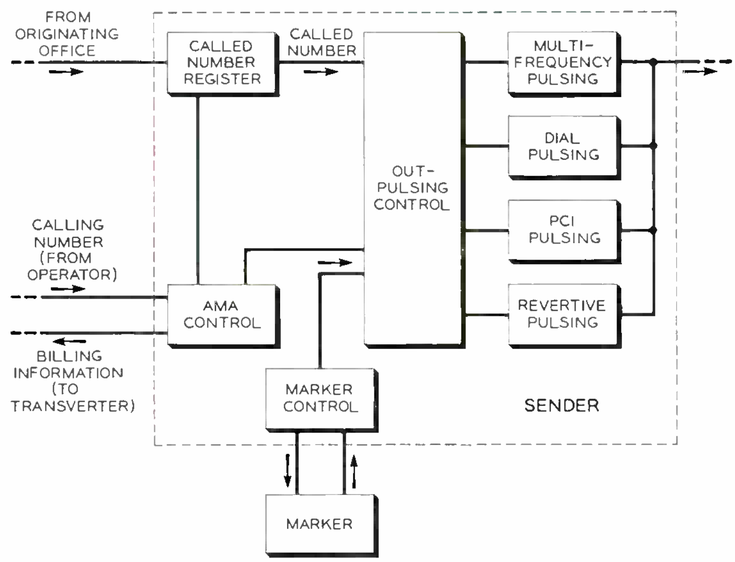


Fig. 5 — Functional elements of a PCI sender.

A method called *recapture registration* is used in controlling the pulsing out of digits. Figure 6 is a further functional breakdown of the outspulsing section seen in Figure 5, and will help to explain the operation and advantages of this scheme. Outpulsing requires that digital information stored on relay registers must be sent out in proper sequence and pulsing language. The outgoing language may not be the same as the language in which the digits are stored internally in the sender, so some form of translation is required. In the recapture scheme a separate group of relays (called "recapture register" relays) is used. Translation networks are provided on the recapture register relays only. In operation (see Figure 6) a digit register, say the A register, transmits its digital information to the recapture register through connector relay contacts "a". This digit is then translated and sent out to the distant office in the required form. Connector relay contacts "a" then open, thus releasing the digital information in the recapture register. Now connector contacts "b" close, allowing the recapture register to respond to the digital information in the B register. This digit is translated and sent out. In a similar manner successive digits are "recaptured" and sent out. The merit of this scheme is that it requires only a single translation network on the recapture registers for all digits. The digit registers then can be designed to use very simple and inexpensive relays, since all they do is "remember" rather than "translate."

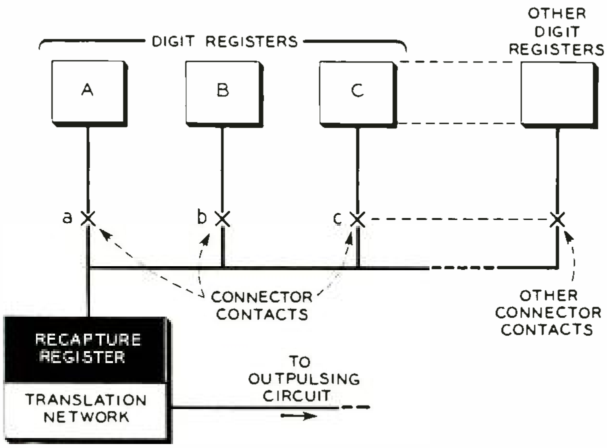


Fig. 6 — Functional elements of the outpulsing control, illustrating "recapture registration."

In addition to the general features applicable to all calls, other features of the sender make its operation reliable and versatile. If for any reason the first request to the marker does not result in the successful setting of the crossbar switches, the sender makes a second trial, generally getting another marker in an attempt to complete the call through the tandem office. Also, the information transmitted from the marker to the sender to indicate what sort of outpulsing is required may be changed by the marker during its operation, if for some reason an alternate route is selected.

If some unusual condition occurs in the attempt to perforate an initial entry for billing purposes, indicating that a transverter trouble has occurred or that the information received by the transverter is unsatisfactory, the sender will connect to another transverter and again attempt to perforate the initial entry. A failure in the second transverter indicates that the information to the transverter is faulty in some manner, and generally the calling customer will be connected to an "overflow" trunk.

If certain checks fail in the transverter, some irregularity is indicated in the information that the operator has keyed into the sender. For this case, the transverter signals the sender to tell the operator by means of a flashing "supervisory lamp" in her switchboard position to erase the information she initially keyed into the sender.* She again obtains the calling number from the customer and rekeys this information into the sender. The supervisory lamp will also flash if she has made an error in her original keying, such as hitting two keys at once or keying too many digits. This will indicate to her that she must rekey the number. If for any reason the operator cannot complete the call in a regular fashion, she may depress a "position disconnect" key, which will release her from this particular call and will also connect the customer to an overflow trunk.

The sender is arranged so that calls not requiring the AMA features may also be handled. For such calls, the sender is told whether to bring in the AMA circuits or not by means of a "class mark" sent to it from the incoming trunk circuit through the sender link equipment.

* Record, *October*, 1954, *page* 371.

THE AUTHOR

L. A. Weber received a Bachelor of Electrical Engineering degree from Cornell University in 1944. Until 1946, he was an electronics radar officer in the U. S. Navy. Joining the Laboratories immediately after being released to inactive duty in 1946, he became engaged in developing alarm and control systems, and subsequently N carrier signaling circuits, in the Switching Systems Development Department. Later he became occupied with arranging crossbar tandem circuits for centralized automatic message accounting, and is now engaged in the design of signaling circuits for trunk carrier systems.

Semiconductor diodes, like transistors, have a rapidly moving history of continuous development through various models and through many improvements. And like transistors, they are finding wide use in the communications industry, especially for high-speed, high-frequency electronic switching circuits.

Semiconductor Diodes

D. K. WILSON *Transistor Development*

Eighty years ago a German experimenter, F. Braun, noted that certain metal compounds like galena (lead sulphide), when contacted by a metal point, could serve as rectifiers. That is, he found that the current for one direction of applied voltage (the "forward" direction) was greater, often by an order of magnitude, than for the opposite or "reverse" direction. This rectifying property of such "cat-whiskered" crystals – the first semiconductor devices – was of subsequent importance in the early stages of radio communication. Eventually, these erratic crystal detectors were superseded by the more stable and efficient vacuum diode.

With the higher and higher frequencies of modern communication systems, however, certain limiting features of the vacuum diode brought about the renaissance of the crystal diode.* As a result of World War II radar work, the temper-provoking cat-whisker device matured into a useful and reliable circuit component. And especially with the tremendous swing in recent years toward high-speed electronic switching, semiconductor diodes are finding even more application.

The immediate outcome of early work on microwave diodes was a point-contact rectifier using p or hole-conductivity type silicon as the semiconducting element. The silicon was "doped", usually with boron or aluminum "impurities", to provide the desired kind of electrical conductivity. Figure 1 illustrates the assembly of such a silicon point-contact diode. A polycrystalline silicon ingot is first cut into slices; one surface of each slice is polished and the other surface is copper plated. The slices are then "diced" into wafers, and each wafer is soldered to a brass stud. This stud is inserted into a ceramic sleeve, and a sharp, 0.005-inch tungsten wire, formed into an "S"-shaped spring, is brought in from the other end of the ceramic cylinder. Metal and semiconductor are then contacted and a small additional pressure is applied. The contact is usually stabilized by mechanical tapping of the cartridge. In the completed unit, the forward or easy current flow direction is with the point negative and the p-

* Bell System Technical Journal, page 1, January, 1947.

Above — The author (left) and P. H. Shearer using automatic equipment to compress and form point to semiconductor during fabrication of diode.

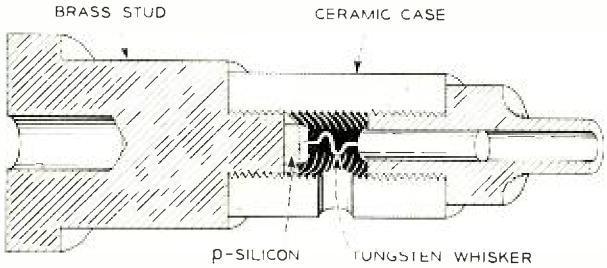


Fig. 1 — Cross-section showing construction of a typical silicon point-contact diode.

type silicon positive. For n-type silicon, these polarities are reversed.

The voltage-current characteristics of the completed unit are shown by the solid line curve in Figure 2. Because the currents in the reverse direction are low, the scales are changed below the origin and to the left. One measure of diode performance is the rectification ratio — that is, the ratio of reverse resistance to forward resistance for a given value of applied voltage (customarily 1.0 volt). For present microwave diodes, the rectification ratio may approach 100. With a very small contact area, they can operate efficiently at 100,000 mc and can detect signals as low as 10^{-15} watts.

The characteristics of such point-contact silicon diodes thus compare favorably with those of vacuum diodes, and in some respects are superior. In particular, the performance with small signals at high frequencies and the elimination of the need for a filament supply represent clear advantages. Vacuum diodes, however, have a higher peak reverse voltage (the maximum reverse voltage that can be applied without damaging the unit), and show better rectification ratios.

Developmental effort was therefore directed toward a second semiconductor diode — the germanium point-contact type — with a new set of properties applicable for different uses. This unit has an improved low-frequency performance in both rectification ratio and peak reverse voltage. It is assembled in much the same way as the silicon point-contact diode except that the semiconductor wafer is normally high-purity n or electron-conductivity germanium; the doping material is arsenic, antimony, or phosphorus.

It was observed in the early work on the germanium point-contact diode that a brief application of high forward current substantially improved the electrical properties, and eventually a "forming" pulse (or series of pulses) became part of the manufacturing process. Apparently a small region underneath the metal contact is heated by this process to a temperature of about 800°C and is thermally converted to p-type germanium. There is formed a small hemispherical p-n junction which results in high rectification ratios and high peak reverse voltages. This diode was one of the first demonstrations of the superiority, in many respects, of p-n junctions over metal-semiconductor contacts.

The dashed curve in Figure 2 shows the improved performance of the germanium point-contact diode, and also shows a region in the reverse voltage condition where the resistance of the unit becomes negative (the backward bend at the left portion of the curve). This type of behavior, in which the

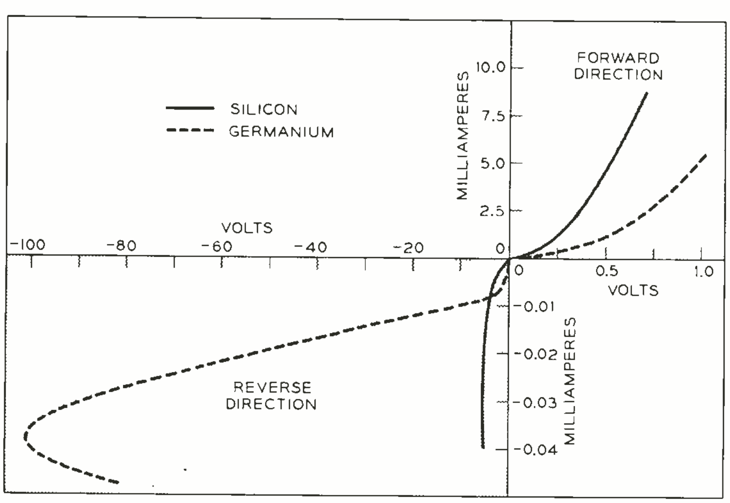


Fig. 2 — Voltage-current characteristics of silicon point-contact diode (solid line) and of germanium point-contact diode (dashed line).

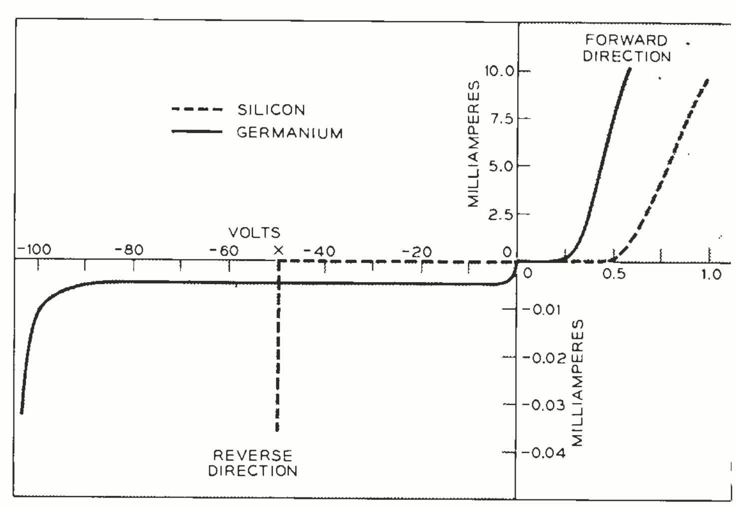


Fig. 3 — Voltage-current characteristics of germanium grown p-n junction diode (solid line) and of silicon alloyed-junction diode (dashed line).

current increases as the voltage decreases, occurs when the power applied to the unit raises the junction temperature substantially. Such germanium diodes are not useful above about 80 C. Units more heavily doped with impurities may be operated at higher temperatures, but these have a lower peak reverse voltage.

In recent years, several new diode structures have been developed.* One of these is the germanium grown p-n junction diode, which is simply a rectangular bar of germanium having p-type material at one end and n-type material at the other end. A p-n junction is formed where the conductivity type changes. Because of the control that can be exercised over physical properties in the crystal-growing process, the electrical characteristics of the diode that are made by this technique are predictable.

The crystal is "grown" by pulling it slowly out of a molten mass of n-type germanium and by dropping pellets of the p-type impurity into the melt at the correct time. Rectangular bars are later

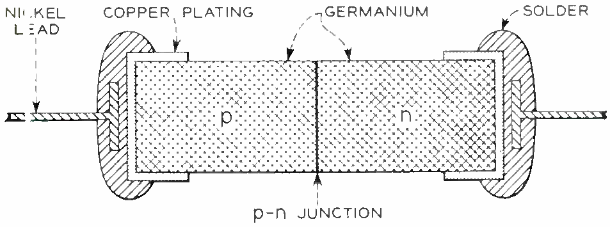


Fig. 4 — Construction of typical germanium grown p-n junction semi-conductor diode.

cut from the cooled crystal, and large area contacts are made to the plated surfaces, as shown in Figure 4. After suitable chemical treatment, the unit is encased.

The solid-line curve in Figure 3 illustrates the current-voltage behavior of a typical grown junction diode. As in Figure 2, the reverse scales have been changed. Since the area of the junction is about 100 times that of the "formed" junction of the germanium point-contact diode, and about 10,000 times the area of a silicon point-contact diode, the junction resistance is reduced and more current flows in the forward direction. This current is further increased by minimizing the so-called "spreading" resistance of the large-area contacts on the two ends. Finally, the reverse resistance is maximized by a chemical processing that reduces the leakage current flowing across the surface of the crystal. Unfortunately, however, the increased

Fig. 5 — Mrs. P. A. Queripel inspecting enlarged image of an "S"-shaped spring used in point-contact diodes. Point is later pressed against semi-conductor wafer.

area of the grown junction reduces the maximum frequency of efficient operation because of the larger junction capacitance and because of an effect known as "minority carrier storage." This effect is caused by a delay in the device's return to the high resistance condition after it has been passing current in the forward direction. Charge carriers that have been pushed across the junction during the previous forward half-cycle do not disappear immediately upon reversal of the voltage. Many of them diffuse backward across the junction, causing a momentarily high value of reverse current. This momentary delay in the recovery of high reverse resistance behaves like an apparent capacitance effect. In fact, the larger part of the junction capacitance effective in high-speed rectification arises from this charge-storage effect, rather than from the small-signal capacitance of the junction.

By properly exploiting these electrical and geometrical variables, rectification ratios of 10,000 can be obtained. Although the reverse current is decreased by the chemical treatment of the surface, there is a certain theoretical limit for the reverse voltage condition. For devices of this type, the reverse current cannot be made lower than about one microampere. It is a characteristic of such junction diodes that this reverse current is "saturated"; that is, it is nearly independent of the magnitude

* RECORD, *June*, 1954, *page* 203; *August*, *page* 285.

of the applied voltage, and the reverse dc resistance therefore increases with voltage.

Though the behavior of but one type of germanium junction has been described, it is possible by changing the doping of the crystal to get an infinite variety. For example, it is possible to make high peak reverse voltage units (greater than 500 volts)

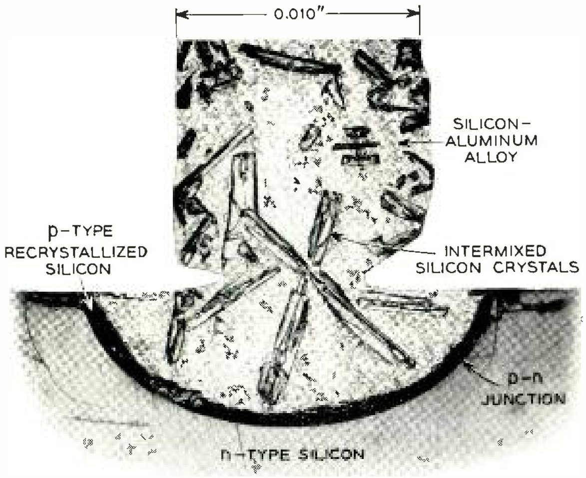


Fig. 6 — Photomicrograph of an alloyed contact.

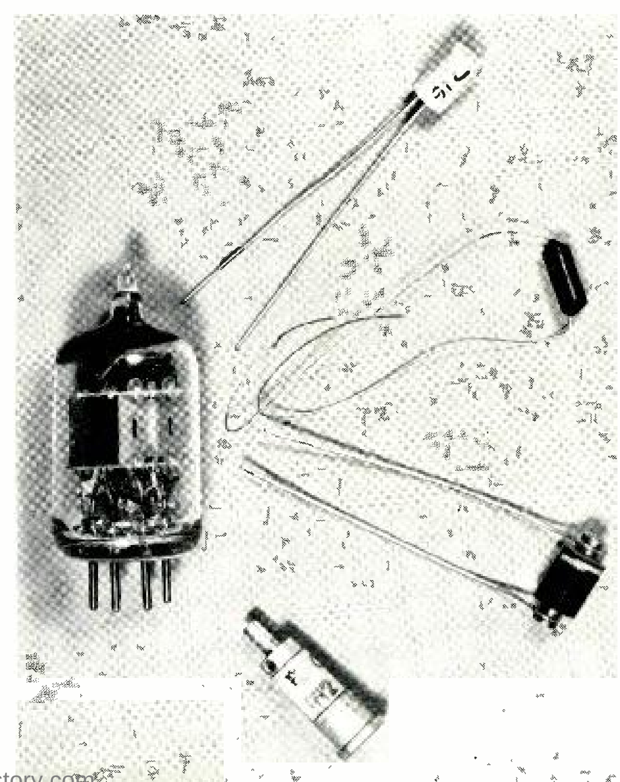
for use as high voltage rectifiers, or high forward current types for use as signal limiters. Since the junction is also remarkably sensitive to light, it can be used to construct photocells* whose current increases proportionally to the light striking near the junction. The junction can also be adapted to high power circuits by further increasing the junction area, decreasing the forward resistance, and attaching the unit to a heat-dissipating surface.

The difficulties of heat sensitivity and particularly of the lower theoretical limit of the reverse current can be very greatly alleviated if the junction is fabricated from silicon. The lower current limit in silicon junctions is one millionth that for a similar germanium junction, and the maximum temperature of operation can be raised to 200°C. The reverse current of course increases with temperature, but even at 200°C it is hardly larger than that of a germanium junction at room temperature. The silicon junction diode is thus a promising addition to the semiconductor family.

The junctions described so far have been either of the "formed" or grown varieties, and another type — the "diffused junction" used in the Bell Solar Battery — has been described in a previous issue of the RECORD.† There remains to be discussed here the fabrication of silicon junctions by what is termed the "alloyed junction" method.‡ By means of this improved technique, a wafer of n-type silicon is heated and a very fine aluminum wire is contacted to it. As illustrated in Figure 6, the aluminum melts and dissolves some silicon, forming a hemispherical region. The aluminum becomes supersaturated with silicon so that when the temperature is reduced, some silicon precipitates onto the original wafer. This recrystallized silicon is of the heavily doped p-type because of the aluminum dissolved in it. Ultimately, the remainder of the alloy solidifies as the lowest melting silicon-aluminum alloy.

In Figure 6, the junction itself is at the lower edge of the hemisphere, and the narrow curved strip above it is the p-type recrystallized silicon. Above this region is a matrix of solidified aluminum-rich silicon alloy containing precipitated crystals of relatively pure silicon. By this technique, a large-area p-n junction is formed, and a large-area, low resistance contact is made close to the junction on the silicon side. A second low-resistance (ohmic) contact is made to the n-silicon side by a similarly alloyed gold wire. The unit is chemically treated to improve the reverse-current properties, and is then covered with a cushioning substance to protect it from thermal and mechanical shocks. Finally,

Fig. 7 — Vacuum diode and, top to bottom, silicon alloy-junction diode, germanium grown p-n junction diode, germanium point-contact diode, and silicon point-contact diode.



* RECORD, *August*, 1950, *page* 337.

† RECORD, *June*, 1954, *page* 232. ‡ RECORD, *September*, 1953, *page* 361.

it is placed in an aluminum can and is encased with a thermosetting plastic.*

The electrical properties of the silicon alloy diode are shown by the dashed curve in Figure 3. The reverse currents are extremely small, sometimes of the order of 10^{-12} amperes. Consequently the rectification ratio may be 10,000,000. In most circuit applications this means, remarkably enough, that the reverse conductance can be entirely neglected. A further consequence of the low reverse current is the rather sharp transition from a high resistance to a low resistance at ½ volt in the forward direction. This characteristic voltage can be used as a reference potential by passing moderate forward current through the diode.

An important and useful property of silicon junction diodes is the reverse breakdown feature shown at "X" in Figure 3. Here the reverse characteristic breaks suddenly from a saturation region where the current is practically independent of voltage to a breakdown region where small changes of voltage produce enormous changes in current. This breakdown, which is non-destructive to the diode, is analogous to the breakdown that occurs in gas tubes. It is due to ionization of silicon atoms in the junction region by rapidly moving holes and electrons. The breakdown voltage can be made to fall anywhere in the range from 5 to 1,000 volts by properly preparing the base silicon. It is nearly independent of temperature. The breakdown feature makes the silicon diode useful for many circuits where gas tubes are now employed but where smaller size, better range of breakdown voltage, and higher frequency operation may be desirable.

The silicon diode provides the circuit engineer of today a new degree of freedom in circuit design.

Fig. 8 — Mrs. P. A. Queripel preparing automatic equipment for alloying p and n wires in the fabrication of silicon alloy semiconductor diode.

More than the germanium types, it approaches the ultimate ideal of a diode as a switch—infinite resistance in the reverse and zero resistance in the forward direction — than any other diode available. Additionally it provides the engineer with a voltage regulator whose voltage can be fixed within reasonable values. There is no doubt that these silicon junction devices will be widely used in the years to come. Not only can they replace most of the other devices described here, but they can also replace many electron tube diodes, copper oxide rectifiers, and selenium rectifiers, and in many cases they can do so with improved results.

* Record, *December*, 1954, *page* 447.

THE AUTHOR

Donald K. Wilson joined the Laboratories in 1951. Until 1953 he was engaged in the development of alloyed junction semiconductor devices and the aluminum silicon diode. Since 1953 he worked on perfecting the alloyed silicon transistor. Mr. Wilson attended Rensselaer Polytechnic Institute and received B.S. and M.S. degrees from Pennsylvania State University in 1950 and 1951, respectively. He is a member of Phi Beta Kappa, Sigma Xi and Sigma Pi Sigma. At present Mr. Wilson is continuing his education, studying Physics at the University of Rochester.

Teletypewriter Billing of Special Toll Cal

W. Y. LANG *Telegraph Engineering*

A receiving teletypewriter makes a true copy of information typed on the transmitting machine, not only word for word but also line for line. Sometimes it is necessary that the receiving machine use business forms instead of plain teletypewriter paper, entries being made at specific places on the form. Ordinarily, the transmitting operator "line feeds" her machine the correct number of times to properly position the form on the receiving machine. A new teletypewriter attachment developed at the Laboratories automatically "line feeds" the correct number of times, insuring that the receiving form is accurately positioned.

One of the many uses of teletypwriters is the transfer of information over a distance, where the receiving machine uses invoices or other kinds of printed business stationery instead of plain teletypewriter paper. In such cases, the information to be typed on the form must go in the particular space provided for it, a requirement that does not exist when messages are typed on plain paper. However, if the sending and receiving machines are equipped with similar forms, and if these are always moved together, the problem is greatly simplified. The sending operator can check her machine to see that the form is properly positioned and may then assume that the information will be typed on the remote receiving teletypewriter in the proper position. In "feeding out" the form paper to position it, the operator usually presses the "line-feed" key more slowly than normal to avoid feeding out the receiving form at the remote machine beyond the desired index point.

If the sending machine is not equipped with form paper, or if the sending form differs from the receiving form, the operator must count the lines of copy that have been prepared for a form. The required number of line-feed combinations are then sent without any way of checking whether the form at the receiving station is fed out the correct distance.

One service where "feed-out" is required is the telephone call billing furnished to hotels in Metropolitan areas. The three-inch form shown in Figure 1 is used on receiving machines at the hotels, and plain paper is used on the sending machine at the telephone central office. A teletypewriter operator at the central office sorts the hand-written toll charge tickets for calls from the various hotels using the service. She then secures a connection to the desired hotel and informs the operator there that she is ready to report the calls on which billing will be made. The hotel operator indexes the first form and signals the central office operator to begin. Figure 2 shows examples of such billing for plain paper at the central office and the forms on the receiving machine.

To meet the needs of this service, the Laboratories has developed an automatic feed-out device that relieves the central office teletypewriter operator of the necessity for counting line-feeds. This device, which may be added to the keyboard of a 15-type page teletypewriter, automatically sends out the correct number of line-feeds to the teletypewriter at the hotel while shorting the line relay contacts of the sending machine to prevent it from feeding. A "form-out" key is added to the keyboard at the right of the line-feed key, and is operated when feed-out is desired. Made for the Bell System by the Teletype Corporation, the "form-out" device consists of two units interconnected by a cord and multicontact plug. The control mechanism unit mounts on the keyboard of a 15-type machine, and the counting mechanism unit in a 105-type apparatus box, may be mounted wherever it is most convenient.

Keyboard modifications consist of adding two snap-action switches operated by the line-feed and form-out key levers, a contact operated by each revolution of the keyboard sending cam, a form-out key lever mechanically linked to both the line-feed key lever and the repeat-space rod, a signal lamp, and a reset key. The counting mechanism unit contains current-limiting resistors, spark protective components, and a 206-type rotary stepping switch used as the selector. A full revolution of the switch wiper-arm shaft provides 44 contacts, the action being continuous. To provide a repeating sequence, the number of line-feeds used plus the necessary control points must be a submultiple of 44.

Two snap-action switches, mounted beneath the keyboard, are operated by the line-feed and form-out key levers. When the line-feed key is operated, its associated snap-switch completes a preparatory circuit from positive battery, through the selector magnet winding, through one set of bank contacts, to a contact to be operated by the sending cam. As the sending cam rotates, to send a line-feed code combination to the teletypewriter circuit, it closes

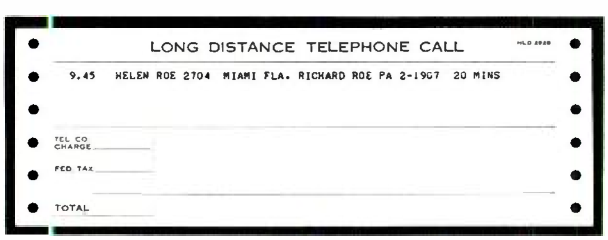

LONG DISTANCE TELEPHONE CALL
9.45 HELEN ROE 2704 MIAMI FLA. RICHARD ROE PA 2-1967 20 MINS
TEL CO CHARGE
FED TAX
TOTAL

Fig. 1 — A typical form used for billing of hotel toll calls by teletypewriter.

its associated cam contact and completes the selector operating circuit to negative battery. When the selector magnet operates to step the selector switch one point, auxiliary selector magnet contacts are closed in parallel with the line-feed switch, insuring operation of the selector magnet during the full time that the sending cam contact is closed. Thus, each time the operator presses the line-feed key, the machine line-feeds as usual and the selector switch steps one point.

After the operator has typed all pertinent information, she operates the carriage-return and line-feed keys, and then holds the form-out key depressed until the signal lamp lights. Since the snap-action switch associated with the form-out key short-circuits the sending machine's line relay contacts,

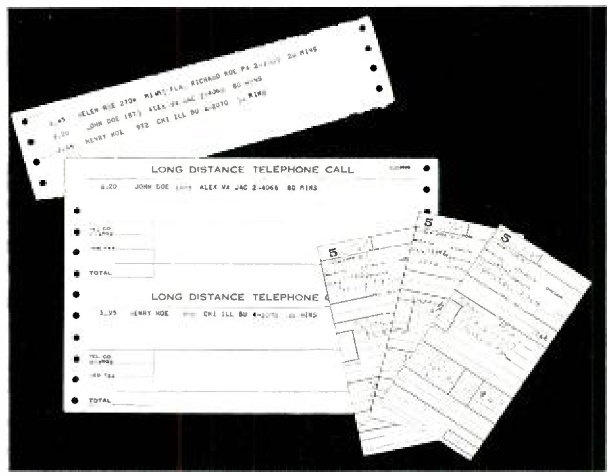


Fig. 2 — Billing information from the charge slips is typed on plain paper but is received on the forms with the entries in proper position.

holding the teletypewriter selecting magnet in an operated condition, the paper in the sending machine does not feed out. At the same time, depressing the form-out key also operates the line-feed key and repeat mechanism of the keyboard through a mechanical linkage, sending repeated line-feed code combinations to the distant machine.

Each time a line-feed combination is sent, the selector switch steps one point. Since hotel billing service uses a three-inch form requiring nine line-feeds and the number of points used must be a submultiple of 44, point 10 is used for preliminary transmission cutoff and point 11 is used as a control point. Similarly, points 21 and 22, 32 and 33, and 43 and 44 perform these same functions. Once the repeated line-feeds have caused the selector switch to step to point 10, the keyboard contacts are shorted to prevent any further transmission of line-feed combinations to the distant machine. On the next revolution of the sending cam, the selector wiper moves to terminal 11 and the following events occur: the contacts remain short-circuited, the signal lamp

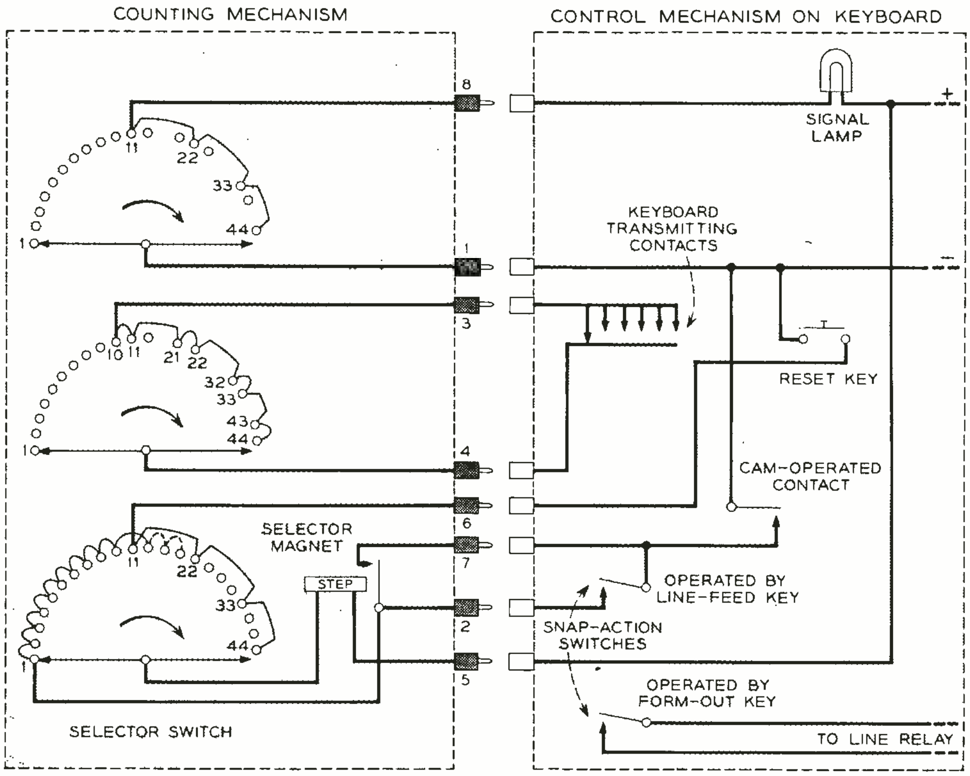


Fig. 3 — A schematic drawing of the two units with their connecting cable.

lights, and the selector switch magnet is transferred from the sending cam circuit to the reset key circuit.

After the operator has held the form-out key until the signal lamp lights, she knows that the receiving machine has advanced to where a new form is properly indexed. She operates the reset key and this advances the selector wipers one point, removes the short-circuit from the sending contacts, routes the selector magnet operating circuit back to the cam contacts, and extinguishes the signal lamp. She then types the next form and repeats these operations.

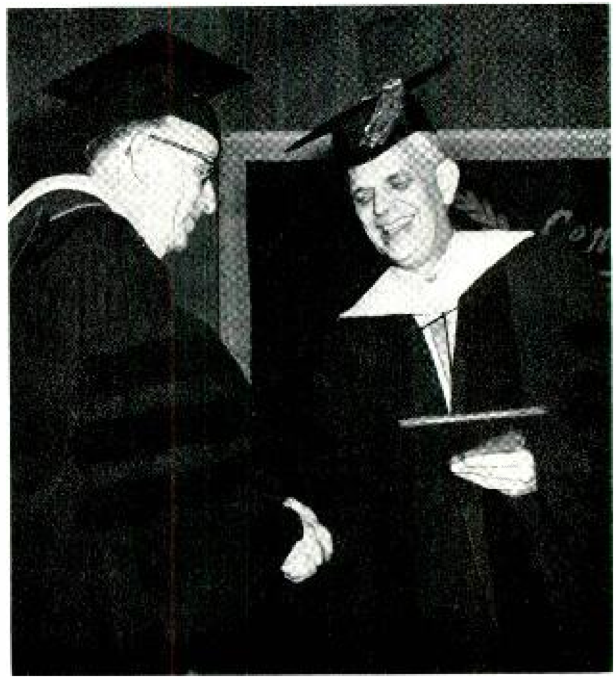
Although the form-out attachment as furnished will only accommodate three-inch forms, the selector switch banks may be rewired for forms of other lengths. However, the multiplicity of dead switch points necessary for certain forms makes use of such forms uneconomical from a time standpoint. Initial trial installations of the automatic line-feed attachment were made in the New York City area and, prior to the completion of that trial, additional installations were made in other cities. The form feed-out is now being used in a number of large cities.

THE AUTHOR

After joining the Laboratories' Design Drafting Department in 1920, W. Y. Lang took the course for technical assistants, meanwhile attending City College and, later, Columbia University. He then spent a year with the Specifications Department and a few years with the Precision Apparatus Laboratory. Since 1927, when he became a member of the technical staff, he has been engaged in the design of printing telegraph apparatus, except for the war years when he worked in sonar development and was responsible for the development of indicator and control units as well as keying and training units. Mr. Lang is a member of the station engineering group of the Telegraph Development Department.

Dr. M. J. Kelly, President of the Laboratories, receiving the honorary degree of Doctor of Engineering at the New York University College of Engineering May 7. In conferring the degree on Dr. Kelly, Chancellor Henry T. Heald (right) of New York University, cited him as follows: "In your renowned professional attainments, you have excited the admiration of a host of contemporary scientists and stimulated the ambition of oncoming generations of those who would follow in your train, for all of which we gladly welcome you into the company of our honorary alumni."

Donald A. Quarles, Assistant Secretary of Defense and former vice president of the Laboratories, also received the honorary degree of Doctor of Engineering at the same ceremony.



John R. Pierce Elected to National Academy of Sciences

Dr. John R. Pierce, Director of Electronics Research of the Laboratories, was elected a member of the National Academy of Sciences at its 92nd annual meeting held in Washington recently.

The National Academy of Sciences, a private, non-profit organization, serves as an adviser to the Federal Government in scientific matters and acts generally in the furtherance of science for the general welfare. The membership of the Academy numbers approximately 500 distinguished scientists in the physical and biological fields.

In addition to Dr. Pierce, President M. J. Kelly, Vice President J. B. Fisk and Dr. W. Shockley of the Laboratories are members of the Academy.

Sloan Foundation Names Dr. Kelly Trustee

On May 5 at the meeting of the Board of Trustees of the Alfred P. Sloan Foundation, Dr. M. J. Kelly, President of the Laboratories was named a trustee of the Foundation.

The Alfred P. Sloan Foundation, established in 1934, administers a private fund for the benefit of the public. It confines its activities to the making of grants for the support of approved projects carried on by educational, scientific and charitable institutions. Up to the present time these grants have been primarily in the field of American economic education and research, and medical research, especially cancer research.

Other trustees of the Foundation include Dr. J. R. Killian, Jr., President of M.I.T.; George Whitney, Chairman, J. P. Morgan & Co., Inc.; Laurance S. Rockefeller, President and Director, Rockefeller Bros., Inc.; Lucius D. Clay, Chairman of the Board, Continental Can Company.

Long Lines, Six Companies Plan $27,000,000 Expansion

Authority to construct new telephone facilities costing about $27,000,000 is being sought by the Long Lines Department of the A. T. & T. Co. and six associated companies in a filing with the Federal Communications Commission. A previous application covering a $10,000,000 portion of the same construction program was filed with the Commission Nov. 1, and approved Dec. 30 of last year.

The new application covers installation of equipment to meet a considerable increase in telephone message traffic. The proposed construction would include facilities to provide about 2,000 additional long distance circuits, and equipment for additional private line telegraph circuits.

The operating companies participating in the program are Illinois Bell, Mountain States, Northwestern Bell, Pacific, Southwestern, and Wisconsin.

The 1955 A.T.&T.
Share Owners Meeting

"We are in a period of the greatest expansion telephone service has ever known," Cleo F. Craig, President of the American Telephone and Telegraph Company, said recently at the annual meeting of share owners in New York City. "In the few years since the war the Bell System has grown about as much as it had during the whole previous 70 years of its existence."

The seventieth annual meeting brought out a record attendance of more than 1,500 share owners. For the first time since 1915 the meeting was moved from A. T. & T. headquarters at 195 Broadway to 50 Varick Street in New York City in order to handle the increased numbers.

"Throughout these years of postwar growth, we in the Bell System have had to accomplish almost the impossible in our efforts to meet the increasing needs and wants of telephone users. All told we have installed about 79 million telephones, including those for subscribers who have moved and the net increase has been approximately 21½ million," Mr. Craig said.

"To do this we have expended $11 billion for new construction . . . or on the average, we have built $500,000 of new plant every working *hour* since the war. A great part of this money has come from share owners whose support has been indispensable to the whole program.

"The Bell System still has a great deal to do to eliminate entirely its backlog of unfilled orders and requests for telephone service from the public but great progress has been made since the war and will continue to be made in the years to come,"

Share owners participate in demonstration of new color telephones.

Mr. Cleo F. Craig, A.T.&T. President, on speakers' platform during the Annual Share Owners Meeting.

Mr. Craig told the share owners. Following this, Mr. Craig described some of the various equipments and services Bell System companies presently have to offer; for example, the new handsfree telephone, the automatic telephone answering set, the various button telephone arrangements, the telephone with a built-in light for easy dialing in the dark, and the volume control telephone set with its simple control button.

"In order to give telephone users what they want – to meet their needs and preferences – we are continuing with a heavy construction program in 1955. It will probably be a little larger than last year's new construction budget of one billion four hundred million dollars," he stated.

Mr. Craig went on to cite the valuable work carried out by the Bell Telephone Laboratories and the Western Electric Company in System expansion.

"All units of the Bell System – research, manufacturing, and operating – work together on the principle of giving the best possible service to the public. This combination of research, manufacturing and operating talents, and the team work of these Bell organizations, make the prospect before us a most encouraging one," he continued.

Another important aspect of the country's telephone network brought out by Mr. Craig in his remarks was the planning of the system to be ready in the event of a national emergency. "There is already great assurance," he said, "in the fact that the network is so tremendous. Coaxial cables and radio relay systems spread over the nation. These and other lines form a vast spider web criss-crossing the country and this makes a large number of routes available for any one call."

Nevertheless, to provide even greater protection, the Bell System is now undertaking to build trunk lines circling the largest cities and still more "express" routes which will travel through open country for most of their length. These will interconnect with existing routes as well as by-pass critical target areas entirely. Thus, if a target area is destroyed we will still have two-way communication through the remaining cities and the rest of the nation.

Speaking of the new proposed transatlantic telephone cable between Newfoundland and Scotland, Mr. Craig described the manufacture of the underwater amplifiers or voice boosters.

"They will be inside the cable sheath and lie on the ocean floor at intervals of 40 miles. Western Electric is making them at Hillside, New Jersey, near Elizabeth, and the procedure is something extra special. To make sure that no dust or foreign particles will get in the room it is slightly pressurized so that air will blow out, not in, when a door is opened."

Mr. Craig further praised Bell Telephone Laboratories developments in color television transmission over radio relay and coaxial cables and in the development of the telephone system so that it may readily be used to perform many different functions, for example, regulating pumps along the routes of oil and gas pipe lines, in tailor-made communication systems enabling power companies to control the flow of electrical energy from a central dispatching point, for toll road and thruway authorities, airways, railroads, state police and other organizational uses. This ability to perform many functions is certainly one of the most important characteristics of modern telephone facilities, Mr. Craig said.

"The military relies on these systems developed at Bell Telephone Laboratories to detect the approach of hostile forces, in the air, on the surface, and under the water. It depends on them to spread warning. But beyond these things it also relies on them to track the enemy, control the aiming and firing of guns, to sight bombs and to guide missiles," he continued.

"Recently the Government has asked the Bell Laboratories and Western Electric to take on still further defense responsibilities," Mr. Craig said. "In the Arctic, along the northern rim of the continent, Western Electric is building for the Air Force the Distant Early Warning Line — called for short the DEW Line. In tropical waters special submarine cables report data on tests with guided missiles. The work center of Bell Laboratories at Whippany, New Jersey, is devoted mainly to research and development on military projects and in North Carolina several Western Electric plants are working full time on production of "Nike" systems and other military equipment."

In conclusion, Mr. Craig said: "Our business is above all a business of people — of men and women in each community who wish to serve their neighbors well — with courtesy and skill and as good fellow-citizens. This spirit of personal and community service is the lasting foundation of all our work and of public understanding and approval."

Over-all view of the fourth floor, 50 Varick Street, as the A. T. & T. annual meeting gets underway.

R. Karl Honaman Appointed to Defense Department Post

R. Karl Honaman, Director of Publication of the Laboratories, was appointed Deputy Assistant Secretary of Defense for Public Affairs, effective April 30, the Department of Defense announced recently. He is on leave from the Laboratories.

Mr. Honaman had been serving in Washington part time as Director of the Office of Strategic Information in the Office of the Secretary of Commerce since October, 1954. In that post, he has been studying complex problems relating to published information which on balance can be inimical to the defense interests of the United States, the announcement said.

R. KARL HONAMAN

In the office of Robert Tripp Ross, Assistant Secretary for Legislative and Public Affairs in the Department of Defense, Mr. Honaman succeeds D. Walter Swan, who is returning to his position as Assistant to the President of the United Air Lines.

Born in Lancaster, Pennsylvania, in 1895, Mr. Honaman obtained his early education in that city and graduated from Franklin and Marshall College in 1916, receiving a master's degree in 1917 after a year of graduate work. He joined the American Telephone and Telegraph Company in the Department of Development and Research in 1919 and transferred to Bell Telephone Laboratories when functions of the American Telephone and Telegraph Company's Development and Research Department were combined in the Laboratories. In 1942 he was made Director of the Laboratories' School for War Training in which officers and technicians of all the Services were trained in newly developed equipment, such as radar and other electronic military devices. In 1945 he was named Director of Publication of the Laboratories.

Wesley Fuller is Acting Director of Publication of the Laboratories during Mr. Honaman's absence on leave.

Talks by Members of the Laboratories

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

AMERICAN PHYSICAL SOCIETY, WASHINGTON, D.C.

Anderson, P. W., Indirect Exchange Coupling of Nuclear Moments by Electrons in Semiconductors and Insulators.

Fuller, C. S., and Reiss, H., The Influence of Holes and Electrons on the Solubility of Lithium in Boron Doped Silicon.

Geballe, T. H., see Hrostowski, H. J.

Holden, A. N., Matthias, B. T., Merz, W. J., and Remeika, J. P., Guanidine Aluminum Sulfate Hexahydrate—A New Ferroelectric Material.

Hoover, C. W., Transient Response of Cavity Resonator.

Hrostowski, H. J., Morin, F. J., Geballe, T. H., and Wheatley, G. H., Hall Effect and Conductivity of InSb.

Lewis, H. W., Surface Energy of Superconductors.

Mason, W. P., Dislocation Relaxations at Low Temperatures and the Determination of the Limiting Dislocation Shearing Stress of a Metal.

Matthias, B. T., see Holden, A. N. and Merz, W. J.

Merz, W. J., Remeika, J. P., Holden, A. N., and Matthias, B. T., Electrical Properties of Guanidine Aluminum Sulfate Hexahydrate and Some Isomorphs.

Merz, W. J., see Holden, A. N.

Morin, F. J., see Hrostowski, H. J.

Prince, M. B., Silicon Conductivity Modulated Diffused p-n Junction Rectifier.

Reiss, H., see Fuller, C. S.

Remeika, J. P., see Holden, A. N. and Merz, W. J.

Schawlow, A. L., Structure of the Intermediate State in Superconductors.

Uhlir, A., Jr., Micromachining with Virtual Electrodes.

Wheatley, G. H., see Hrostowski, H. J.

Augustadt, H. W., Human Engineering Aspects of the Telephone Answering Set, Electrical Contractors Clinic, Wahpeton, and North Dakota Telephone Association, Fargo, N. D.

Bachelet, A. E., Control System to Provide Orientation Correction Automatically for Easy Viewing of Stereo Projection, New York Stereo Club, New York City.

Bennett, W. R., Synthesis of Active Networks, Polytechnic Institute of Brooklyn, Modern Network Synthesis Symposium, New York City.

Compton, K. G., The Interpretation of Underground Corrosion Survey and Test Data, Joint Meeting of Tidewater Corrosion Committee and Tidewater Section of National Association of Corrosion Engineers, Norfolk, Va.

Darrow, K. K., Magnetism in the Atom, University of Virginia, Sigma Xi Society, Charlottesville, Va.

Dimond, T. L., Long Distance Dialing and Automatic Accounting, Railroad Systems and Procedures Committee, Chicago.

Douglas, V. A., An Experimental Mobile Dispatcher System, Johns Hopkins University, A.I.E.E. and I.R.E. Student Branches, Baltimore.

Fisher, J. R., and Potter, J. F., Apparent Density as a Means for Evaluating the Physical Structure of Steatite, American Ceramic Society, White Wares Division, Cincinnati.

Fox, A. G., Measurement Techniques in the Millimeter Wavelength Range, A.I.E.E. and I.R.E. New York Sections, New York City.

Galt, J. K., Ferromagnetic Domain Wall Motion and Ferromagnetic Resonance in Ferrites, University of Illinois, Electrical Engineering Department, Urbana, Ill.

Galt, J. K., Losses in Ferrites, University of Illinois, Physics Department Solid State Seminar, Urbana, Ill.

Garrett, C. G. B., Semiconductor Surfaces, Columbia University, New York City.

Geller, S., see Thurmond, C. D.

Gilbert, E. N., see Morgan, S. P.

Githens, J. A., Digital Differential Analyzers, Stevens Institute of Technology, I.R.E. New York Section, Hoboken, N. J.

Grossman, A. J., Practical Implications of Modern Network Synthesis, Polytechnic Institute of Brooklyn, Modern Network Synthesis Symposium, New York City.

Hagstrum, H. D., Electron Ejection from Metals by Positive Ions, International Symposium on Electrical Discharges in Gases, Delft, Netherlands.

Harvey, F. K., Sound and Microwave Analogies, University of Minnesota, Minneapolis, and University of Wisconsin, Madison.

Herring, C., Phonon Effects in Thermoelectric Power, Princeton University, Theoretical Physics Seminar, Princeton, N. J.

Karlin, J. E., and Pierce, J. R., Measuring a Lower Bound of Information Transmission Through the Human Channel, Eastern Psychological Association, Philadelphia.

Keister, W., Mechanized Intelligence, Newark College of Engineering, A.I.E.E. Student Branch, Newark.

Kelly, H. P., Differential Phase and Gain Measurements in Color Television Systems, I.R.E. Cincinnati Section, Cincinnati.

Kock, W. E., Physics of Speech, Music and Hearing, Franklin Institute, Philadelphia.

Kruger, M. K., Distribution Requirements in Terms of Quality Control Procedures, American Society for Quality Control, Montreal Section, Montreal.

Lloyd, S. P., and McMillan, B., Filtering of Sampled Signals, Polytechnic Institute of Brooklyn, New York City.

McKim, B., Two Nations at Your Fingertips, R.C.A. Laboratories, Princeton, N. J.

McLean, D. A., Capacitors Employing Metallized Organic Dielectrics, Professional Group on Components, Washington, D. C.

McMillan, B., see Lloyd, S. P.

Merrill, F. G., Navarho Single Site Navigation System, N Club, New York City.

Meszar, J., Modern Dial Systems, Morristown Area Chamber of Commerce, Morristown, N. J.

Meszar, J., Digital Machines for Nationwide Dialing, Massachusetts Institute of Technology, I.R.E. Professional Group on Electronic Computers and I.R.E. Boston Section, Cambridge.

Morgan, S. P., and Gilbert, E. N., Optimum Design of Directive Antenna Arrays Subject to Random Variations, Moore Institute of Art, Science, and Industry, Philadelphia.

Nylund, H. W., Special Communication Problems in Connection with Range Instrumentation, American Ordnance Association Instrumentation Symposium, Patrick Air Force Base, Melbourne, Florida.

Pearson, G. L., The Bell Solar Battery—A Silicon p-n Junction Photovoltaic Device, American Physical Society, Southeastern Section, Gainesville, Florida.

Peterson, J. W., High Frequency Junction Transistors, Joint A.I.E.E.-I.R.E. Meeting, Kansas City, Mo.

Peterson, J. W., The Intrinsic Barrier High-Frequency Transistor, I.R.E. Technical Conference, Seventh Region, Phoenix, Ariz.

Pierce, J. R., see Karlin, J. E.

Potter, J. F., see Fisher, J. R.

Rice, S. O., Introduction to Random Noise, Southern Methodist University, Third Annual Southwestern Conference on Feedback Control Systems, Dallas.

Riesz, R. R., Exploratory Study of Human Accuracy for Counting Sound Pulses, Eastern Psychological Association, Philadelphia.

Robertson, S. D., The Ultra-Bandwidth Finline Coupler, I.R.E. Technical Conference, Seventh Region, Phoenix, Ariz.

Robinson, F. N. H., Low Temperature Physics, Bell Telephone Laboratories, Holmdel, N. J.

Rowen, J. H., Ferromagnetism and Its Application to Microwave Techniques, I.R.E. Montreal Section, Montreal.

Ryder, R. M., Transistors Today, I.R.E. Student Section, Princeton, N. J.

Schumacher, E. E., Communications Metallurgy, American Institute of Mining and Metallurgical Engineers, Detroit Section, Detroit.

Shockley, W., Transistor Physics, New York University Colloquium, New York City, and Institution of Electrical Engineers, London.

Talks by Members of the Laboratories, Continued

Singer, F. J., Highlights of Recent Bell Laboratories Developments, Petroleum Industry Electrical Association, Houston, Texas.

Storks, K. H., Application of Instrumental Methods to the Analysis of Metals, American Chemical Society, Milwaukee Section, Milwaukee.

Thomas, D. E., Bell Solar Battery, Connecticut Industrial Arts Association, New Britain, Conn., and New England Radio Electronics Meeting, Boston.

Thurmond, C. D., and Geller, S, Is There a Crystalline SiO?, American Chemical Society, Physical and Inorganic Chemistry Division, Cincinnati.

Townsend, M. A., A Hollow Cathode Glow Discharge with Negative Resistance, Delft Symposium, Delft, Netherlands.

Vogel, F. L., Dislocations in Germanium Crystals, Rensselaer Polytechnic Institute, Metals Science Club, Troy, N. Y.

Warren, C. A., Project Nike, Watchung American Legion, Watchung, N. J.

Wolff, P. A., Avalanche Breakdown in Silicon and Germanium, Cornell University Solid State Seminar, Ithaca, N. Y.

Papers Published by Members of the Laboratories

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

Anderson, O. L., and Bommel, H. E., Ultrasonic Absorption in Fused Silica at Low Temperatures and High Frequencies, J. Am. Ceramic Soc., **38**, pp. 125-131, April, 1955.

Bennett, W., Curtis, H. E., and Rice, S. O., Interchannel Interference in FM and PM Systems Under Noise Loading Conditions, B.S.T.J., **34**, pp. 601-636, May, 1955.

Blye, P. W., Coolidge, O. H., and Huntley, H. R. (A.T.&T.), A Revised Telephone Transmission Rating Plan, B.S.T.J., **34**, pp. 453-472, May, 1955.

Bommel, H. E., see Anderson, O. L.

Bouton, G. M., Heiss, J. H., and Phipps, G. S., Experimental Extrusion of Aluminum Cable Sheath at Bell Telephone Laboratories, B.S.T.J., **34**, pp. 529-561, May, 1955.

Buehler, E., see Fuller, C. S.

Coolidge, O. H., see Blye, P. W.

Curtis, H. E., see Bennett, W.

Ditzenberger, J. A., see Fuller, C. S.

Eder, Miss M., Warner, R., and Keene, F., Statistically Designed Experiment of the Factorial Type Applied to Point-Contact Transistors, Proc. I.R.E. National Symposium on Quality Control and Reliability in Electronics, Nov. 12-13, 1954.

Evans, H. W., see Welber, I.

Fuller, C. S., Ditzenberger, J. A., Hannay, N. B., and Buehler, E., Resistivity Changes in Silicon Single Crystals Induced by Heat Treatment, Acta Metallurgica, Letter to the Editor, **3**, pp. 97-99, Jan., 1955.

Geller, S., Matthias, B. T., and Goldstein, R., Some New Intermetallic Compounds with the "β-Wolfram" Structure, J. Am. Chem. Soc., **77**, pp. 1502-1504, Mar. 20, 1955.

Gilbert, E. N., and Morgan, S. P., Optimum Design of Directive Antenna Arrays Subject to Random Variations, B.S.T.J., **34**, pp. 637-663, May, 1955.

Goldstein, R., see Geller, S.

Hannay, N. B., see Fuller, C. S.

Hearn, A. H., Creosote Retention as Determined by Toluene Extraction of Treated Wood, Annual Proc. Am. Wood. Pres. Assoc., Feb., 1955.

Heidenreich, R. D., Transition Structure in Lead-Silver Alloys and a Dislocation Mechanism, Acta Metallurgica, **3**, pp. 79-86, Jan., 1955.

Heiss, J. H., see Bouton, G. M.

Horton, A. W., Jr., and Vaughan, H. E., Transmission of Digital Information Over Telephone Circuits, B.S.T.J., **34**, pp. 511-528, May, 1955.

Inskip, L. S., and Watson, H. N., Grounding of Portable Electric Equipment, Elec. Engg., **74**, pp. 286-291, April, 1955.

Jaycox, E. K., Spectrochemical Procedure of General Applicability, Anal. Chem., **27**, pp. 347-350, Mar., 1955.

Keene, F., see Eder, Miss M.

Louisell, W. H., and Pierce, J. R., Power Flow in Electron Beam Devices, Proc. I.R.E., **43**, pp. 425-427, April, 1955.

Matthias, B. T., see Geller, S.

McCarthy, John A., Search for Double Beta Decay in Ca^{48}, Phys. Rev., **97**, pp. 1234-1236, Mar. 1, 1955.

McSkimin, H. J., Transducer Design for Ultrasonic Delay Lines, J. Acous. Soc., **27**, pp. 302-309, Mar., 1955.

Morgan, S. P., see Gilbert, E. N.

Phipps, G. S., see Bouton, G. M.

Pierce, J. R., Propagation in Linear Arrays of Parallel Wires, I.R.E. Trans. of Electron Devices, ED-2, pp. 13-24, Jan., 1955.

Pierce, J. R., Orbital Radio Relays, Jet Propulsion, **25**, pp. 76-78, Feb., 1955.

Pierce, J. R., see Louisell, W. H.

Pullis, G. A., see Welber, I.

Raisbeck G., Order of Magnitude of the Fourier Coefficients in Functions Having Isolated Singularities, Am. Math. Monthly, **62**, pp. 149-154, Mar., 1955.

Reed, E. D., A Tunable, Low-Voltage Reflex Klystron for Operation in the 50- to 60-kmc Band, B.S.T.J., **34**, pp. 563-599, May, 1955.

Rice, S. O., see Bennett, W.

Rowen, J. H., Ferro Magnetism at Microwave Frequencies and Its Applications, Radio Elect. Engg, **24**, pp. 26-28 and 40-41, April, 1955.

Talpey, T. E., The Nature of the Uncorrelated Component of Induced Grid Noise, Proc. I.R.E., **43**, pp. 449-454, April, 1955.

Warner, R., see Eder, Miss M.

Vaughan, H. E., see Horton, A. W., Jr.

Welber, I., Evans, H. W., and Pullis, G. A., Protection of Service in the TD-2 Radio Relay System by Automatic Channel Switching, B.S.T.J., **34**, pp. 473-510, May, 1955.