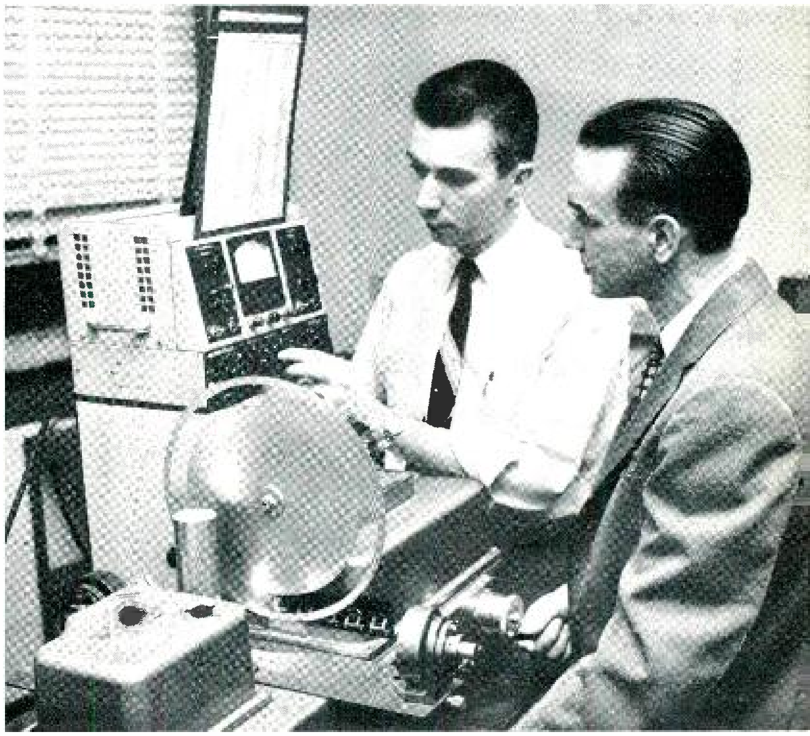
The Bell Solar Battery



Right — W. F. Flood (left) and G. L. Pearson using spectrometer to determine response of silicon solar cell.

D. M. CHAPIN, C. S. FULLER, and G. L. PEARSON

Transmission Research, Chemical Physics, and Transistor Physics

The sun is the ultimate source of all the power which man has at his disposal. For this reason, science has long searched for an efficient method of converting solar energy into a more usable form. The Bell Solar Battery converts as much as 11 per cent of the energy it receives from the sun directly into electrical power — a performance greatly superior to those of other types of photo-sensitive cells. The potential usefulness of such a device marks it as an achievement of great significance, not only in communications, but in many other aspects of modern technology.

The Bell Solar Battery consists of a number of individual silicon solar cells, each of which can convert sunlight into electrical power with a much higher efficiency than has been achieved with any previous photovoltaic device. Since its announcement in April, 1954, it has attracted considerable interest and commentary and it will therefore be necessary to give only a brief summary of its principles of operation, before we present a few of the more pertinent facts concerning its construction and its electrical characteristics. It should be mentioned, however, that the Bell Solar Battery is as yet strictly a laboratory device constructed from costly raw material by means of a complex technology.

The heart of a solar cell is the p-n junction*, or boundary between different electrical conductivity types in a semiconductor crystal. Such junctions were discovered in the 1930's by R. S. Ohl and J. H. Scaff of the Laboratories, who also noticed that the junctions were photosensitive – a property that has since been used in the construction of phototransistors.† Photons of light energy, when they strike a

* Record, *August*, 1950, *page* 337.
† Record, *June*, 1954, *page* 203.

Fig. 1 — D. M. Chapin inspecting Bell Solar Batteries exposed to sun for long term storage battery charging tests.

semiconductor, will often split off an electron from its normal position in the crystal lattice, leaving a positively charged "hole" or vacant space. Both the electron and the hole will then be available for the conduction of electricity — if they can be prevented from recombining and thus neutralizing each other. The p-n junction provides a built-in electric field that pulls the electrons into the n or negative side of the junction and the holes into the p or positive side before many of them recombine. The electrons and holes are said to be "collected" by the junction. With suitable contacts and leads to the two sides, the resultant current can be used in an external circuit. The actual conversion of light energy into electrical energy is therefore seen as occurring in the creation of "electron-hole pairs", a process that becomes significant under the influence of the electric field of a p-n junction.

The solar cell, a representation of which is shown in Figure 2, is thus simply a p-n junction designed to take the best advantage of these phenomena. The junction is made very large and is oriented to face the sun, and the top layer is made very thin so that as many as possible of the effective photons may penetrate to the vicinity of the junction.

With silicon, the effective parts of solar energy are absorbed in the outer 1/1000 inch layer, and to be collected, the electron-hole pairs must be produced within about 1/10,000 inch of the junction. In addition to these fine tolerances, we also have the requirement that the surface must have a high conductivity; otherwise much of the electrical power would be lost through heat generated from the internal resistance of the cell. These considerations suggest the type of construction shown in Figure 2, and the question is how to produce it.

The answer to this problem grew out of a fundamental study of diffusion into solids. Diffusion methods proved to be ideal both for controlling the depth of the outer layer and for achieving high surface conductivity, and boron was found to have many advantages as the diffusing element. In this particular case, temperatures must approach the melting point of silicon (1400°C), and the relationship between diffusion time and depth of diffused layer must be precisely known.

One method of forming the p-layer is to heat a plate of n-type silicon to a high temperature in the presence of a gas containing boron. The boron is broken out of its chemical compound and diffuses into the silicon. The depth of diffusion is determined by the temperature and by the length of time the diffusion process is allowed to proceed. This process results in a decreasing concentration of boron with increasing depth. Right at the surface, the silicon is very heavily "doped" with boron. Further into the crystal the concentration decreases until, at about 1/10,000 inch, it gets so low that the n-type, arsenic-doped silicon of the body of the crystal predominates. This change in conductivity type defines the position of the junction. Deeper into the crystal

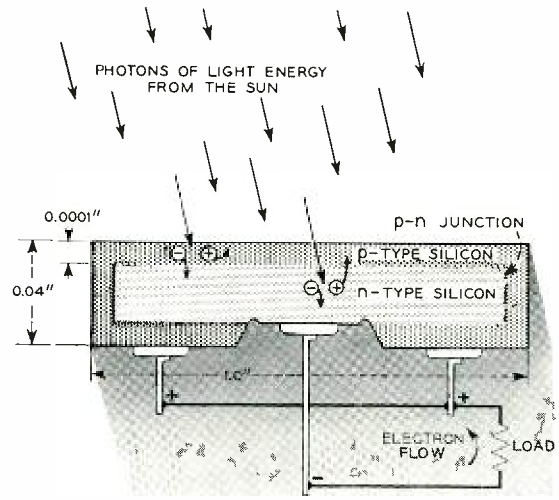


Fig. 2 — Cross-sectional view of a plate of silicon prepared as a solar cell, illustrating creation of electron-hole pairs by photons of light energy.

Six Important Facts About the Bell Solar Battery

1. The Bell Solar Battery is an experimental device that converts sunlight directly into electrical power, with no intermediate steps.

2. It is at least fifteen times more efficient than the best previous solar energy converter, which makes it the first real solar power supply.

3. It has no moving parts or corrosive chemicals, and therefore should last indefinitely.

4. Its efficiency of conversion of available light remains essentially constant even in poor light where other types of converters will fail.

5. It charges a storage battery at constant voltage, and a solar battery-storage battery combination can thus average a steady power output through days and nights, over periods of good and bad weather.

6. It is a result of the same research and development effort that produced the transistor at Bell Laboratories, and it is particularly adaptable to modern transistor circuitry.

beyond the junction, boron concentration drops to zero. The different numbers of arsenic and boron atoms at the various depths create an electric field gradient which as mentioned earlier collects the electron-hole pairs.

After the diffusion process, there still remain the important problems of providing suitable contacts and of encasing the entire structure to protect it against rough treatment and weathering effects. Both problems must be solved in such a way that the cell will show good electrical characteristics over a long period of time. By returning to Figure 2, we see that the diffusion process has left us with a piece of silicon that has the p-layer on all sides. As implied by the drawing, we then remove the p-layer from a portion of the bottom surface and make contact to the body of the crystal. Contact to the p-layer then completes the electrical arrangements.

The thin p-layer is so easily penetrated that making contact by alloying or welding techniques is impracticable. The original solar cells were constructed merely by brushing layers of metallic lacquers on top of copper-plated sections of the cell, but such contacts tended to deteriorate with time. Subsequently, many other methods were tested – for example metallic layers produced by oven firing, electroplating, and metallic vapor deposition. Additional work and long-term testing will be required before the best type of contact is determined, and the same may be said of the problem of encasing the structure. To date, cells have been encased in solid blocks of clear plastic and in blocks of plastic with liquid and gas-filled centers. Various shapes and sizes have been used, some with the clear plastic molded into the shape of lenses in attempts to get the best focusing of solar energy on the surface. Development work has resulted in several promising methods of making contacts and of providing encasements, so neither problem is expected to be serious.

With all these variables entering into the functioning of solar cells, we are able to get a rather wide range of electrical characteristics. Figure 4, however, shows a few of the more important theoretical facts that must be considered in designing for best

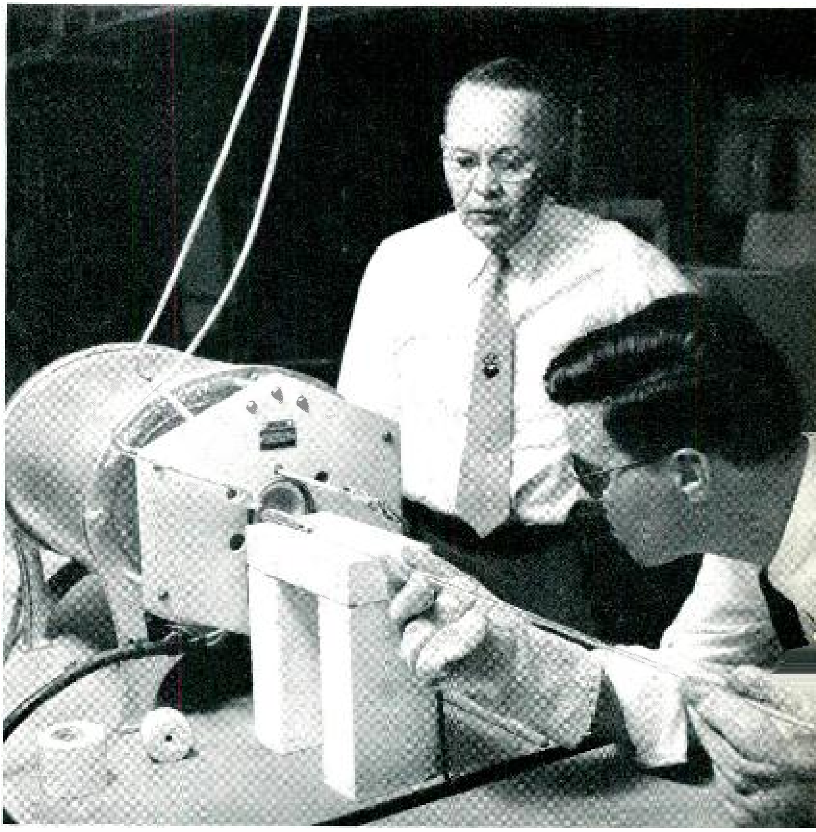


Fig. 3 — C. S. Fuller (left) and J. A. Ditzenberger engaged in a diffusion experiment. Mr. Ditzenberger is shown inserting into a furnace a tube containing silicon plate and boron compound.

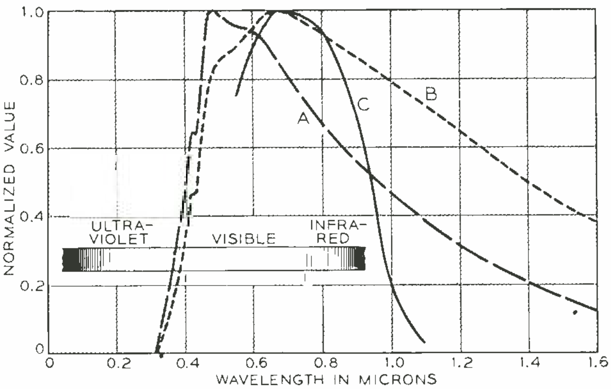


Fig. 4 — (A) solar energy distribution, (B) photon distribution and (C) short-circuit response curve for a silicon solar cell.

performance. On this graph are plotted three curves: Curve A represents the distribution of solar energy at the various wavelengths, relative to an arbitrary maximum of 1.0. This curve was plotted from published data taken in clear weather with the sun at its zenith, and with perpendicular incidence of the light. Curve B shows the relative number of photons at the different increments of these wavelengths, and was derived from curve A simply by multiplying by the wavelength. Curve C is a short-circuit response curve for a silicon solar cell; it was derived by using a spectrometer adjusted to deliver equal amounts of energy at the different wavelengths, and by adjusting the response values to correspond to the amount of energy available from sunlight. Both curves B and C are again referred to maxima of 1.0. The approximate limits of the visible spectrum are included for reference.

To interpret Figure 4 accurately, we need to keep the following facts in mind. At the left of the diagram the photons have high energies, so there are fewer of them for a given amount of energy. Conversely, at the right of the diagram more photons are necessary for the same amount of energy. This is apparent from the diagram: for example, at a relative energy of 0.6, curve B showing the number of photons is below the solar energy curve A on the left and above it on the right.

It will be noticed that the solar cell does not respond to photons having wavelengths greater than about 1.1 microns (0.00011 cm corresponding to an energy of about 1.0 electron-volt). These lower energy photons pass right through silicon and do not create electron-hole pairs. All photons to the left of 1.1 microns on the scale will have more than enough energy to create electron-hole pairs, and this excess of energy is wasted in the form of heat. Additional energy is wasted because some of the higher energy photons create electron-hole pairs very close to the surface, some of them too far from the junction to be collected. Conditions are such, however, that in this cell a maximum number of electrons and holes is collected (i.e., the cell shows maximum response) at about 0.75 micron, near the boundary between the visible and the infra-red regions.

It should be noted in this respect that the value of 0.75 micron is quite close to the wavelength at which a maximum number of photons are available from sunlight, shown by curve B. This fact illustrates that silicon is near to the ideal material for solar energy conversion. The p-layer here was about 1/10,000 inch in depth. With thinner layers, the peak response occurs at wavelengths less than 0.75 micron, toward the violet end of the spectrum, but if we are primarily interested in maximum conversion of solar into electrical energy, we can see the reason for obtaining a peak response near the infra-red region.

Since hazy or partly cloudy skies are more transparent to infra-red than to ultra-violet, the sensitivity to infra-red also shows that poor light condi-

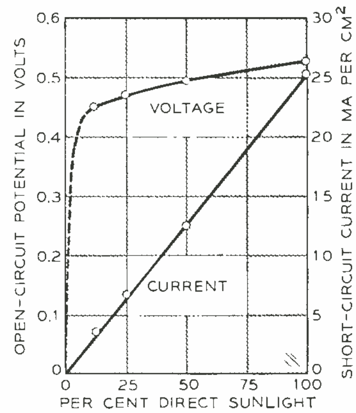


Fig. 5 — Open-circuit voltage and short-circuit current for different percentages of sunlight, at an operating temperature of 25°C.

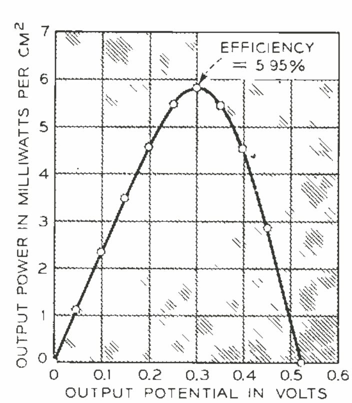


Fig. 6 — Solar cell power output for various external loads, at an operating temperature under full sunlight of 25°C.

tions are not necessarily a deterrent to the cell's utility. If a day begins with a dark overcast and then gradually improves to admit progressively larger amounts of sunlight, we notice the changing characteristics illustrated in Figure 5. Here we have plotted a cell's short-circuit current and open-circuit voltage against percentage of total sunlight. The current rises linearly, but the voltage quickly jumps to its maximum value.

The curves of Figure 5 represent only the extremes of open- and short-circuit conditions. In between, for different external loads, we can plot a power curve of the sort seen as Figure 6. Under full sunlight, the cell's power reaches a peak at a voltage somewhat lower than the best open-circuit response. This optimum power point is the one used to determine the cell's efficiency, here about 6 per cent. This value was obtained at an operating temperature of 25° C. At higher temperatures the output voltage drops off but the current increases, so that the change in efficiency is not very great over a reasonable range of operating temperatures.

For sunlight values less than 100 per cent, power curves similar to Figure 6 are obtained, with the peak power always occurring at about the same

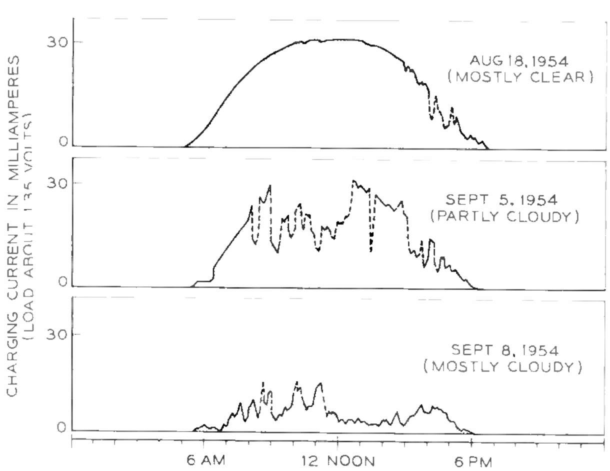


Fig. 7 — Storage battery charging current on clear, partly cloudly, and mostly cloudy days.

voltage — that is, at about 0.3 volt per cell. This means that a constant voltage device, such as a storage battery, is almost the perfect load for a solar battery over a wide range of sunlight values. It means that although the total power is reduced in poor light, the efficiency remains essentially unchanged, in contrast to solar converters that depend upon an initial transfer to heat. This fact will be very important in many applications. In experiments

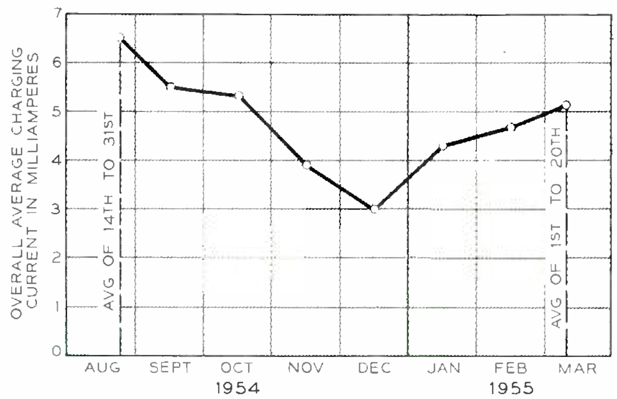


Fig. 8 — Average monthly charging current.

with the P-carrier rural telephone system, for example, the Laboratories plans to use a solar battery to charge a storage battery, which in turn will provide power for a complete terminal of the system.

Up to this point we have been describing characteristics that are observed soon after fabrication. So far as practical uses are concerned, however, the chief interest is in how a battery will perform over a long period of time. Since only a relatively short time has elapsed since the invention of the device, no exact information on length of life can be presented. It may be of interest, however, to note that in one of the first demonstrations of the cell, a solar battery was used to power a motor turning a small disk, and that this disk has been spinning continuously under ordinary indoor lighting for the past year. More germane to the subject, however, are the curves of Figures 7 and 8. A solar battery, consisting of five cells connected in series, with a total area of about 10 square centimeters, was mounted in an exposed location and arranged to charge a storage battery. Charging current was then recorded continuously over a period of several months. Figure 7 shows records for three days with different weather conditions. The general trend from morning to noon to night is clearly discernible, along with the sharp peaks and valleys caused by changing cloud conditions. Curves of this type have shown that occasionally certain cloud formations, by reflecting sunlight, actually result in a response higher than that achieved under cloudless skies. For Figure 8, the charging current was averaged over half-month and full-month periods. Here we again notice irregularities due to changes in average weather conditions. We can also see how the response decreases as days get shorter in the autumn and increases after the winter solstice. Additional information of this kind must be collected before we can make accurate determinations of how large a solar battery will have to be to do a particular job.

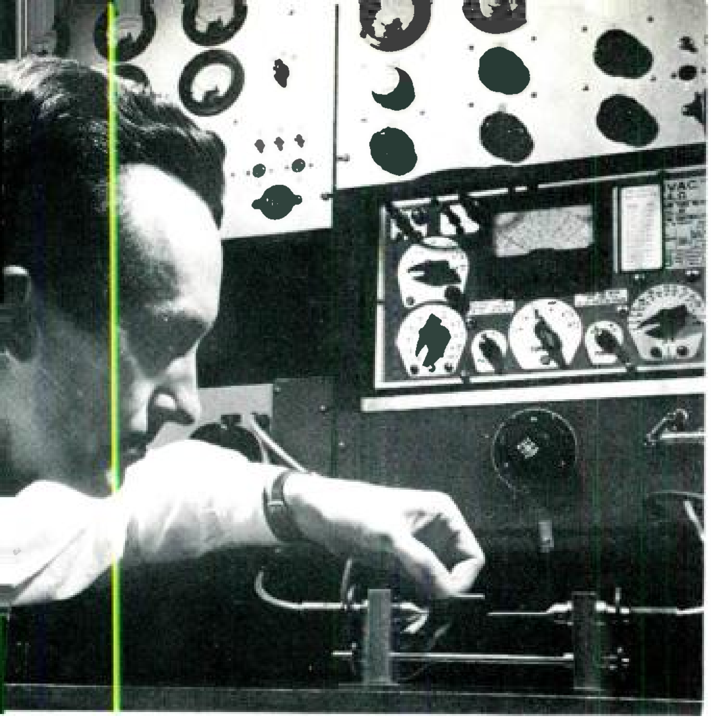
Although we have included this information on recent tests, and although the other figures in part represent a certain amount of data accumulated during the past year, this discussion has been based mainly on preliminary work. Since the invention of the solar battery, the development departments at Bell Laboratories have made much better cells than the early experimental models. The best of the original cells had an efficiency of about 6 per cent. The efficiency of the newer units has been raised consistently to around 8 per cent, and some cells have reached 11 per cent – a phenomenally good performance considering the inherent difficulties of the task.

THE AUTHORS

Daryl M. Chapin received the A.B. (1927) degree from Willamette University and the M.S. (1929) degree from the University of Washington. A member of the Laboratories since 1930, he was first concerned with magnetic materials and, during World War II, with underwater acoustics. Following three years of work on magnetic recording, he turned his attention to special projects such as magnetic measurement, simulated speech, miniaturization, and pulse code transmission. Early in 1953, as a part of the study of new sources of power for low-power transmission systems, he investigated direct conversion of solar energy into electrical energy and applied the new techniques of semiconductor research to the invention of the solar battery. More recently, his work has been concerned with further improvements in the solar battery and tests of its use in relation to the sun's daily and seasonal changes.

Calvin S. Fuller received the B.S. (1926) and Ph.D. (1929) degrees in chemistry from the University of Chicago and joined the Laboratories in 1930. Following several years of research on organic insulating material, he turned his full attention to studies of plastics and synthetic rubber, including investigations of the molecular nature of polymers and the development of plastics and rubber for telephone and associated apparatus. Since 1948 Mr. Fuller has concentrated on semiconductor research and the development of semiconductor devices. His work led to a technique of diffusing impurities into the surface of a silicon wafer, a preparation basic to the solar battery and other silicon devices.

Gerald L. Pearson received A.B. (1926) and M.A. (1929) degrees in physics from Willamette and Stanford Universities, respectively. He became a member of the Physical Research Department in 1929, spending his early years at the Laboratories on studies of noise in resistors, vacuum tubes and carbon microphones. Except for a brief period during World War II, when he was engaged in work on military projects, he has since concentrated on semiconductor research. In this field he has been concerned with thermistors, transistors, and silicon rectifiers which led to the invention of the solar battery. More recently, he has been engaged in work on the silicon alloy diode and power rectifier.



A Miniature Transistor Amplifier

H. M. STRAUBE *Transmission Research*

A new midget amplifier constructed in the Research Department at Bell Laboratories combines a transistor with several other miniature components to achieve extraordinary electrical performance suitable for very wide band services such as television transmission. Although this amplifier, little more than 1½ inches long and ⅛ inch in diameter, is an experimental model, it represents an important step toward the eventual use of transistor amplifiers in broadband transmission networks.

The Bell System provides a network of communication channels over which voice, television, and other signals may be transmitted from point to point throughout the nation. In the general effort to improve this network and make it more economical, study is continuously given to possible improvements in the associated repeaters — devices that amplify decaying signals at regular intervals along a route.

Existing repeaters depend on conventional electron tubes to provide the desired amplification. However, since the advent of the transistor, new avenues to improved repeaters have been opened. The transistor is small, rugged, and efficient. In combination with other circuit elements it may provide the basis for significant advances in repeater design. A preliminary exploration of such possibilities has been made in the Laboratories' Research Department where an experimental transistor amplifier has been constructed for possible use between sections of miniature coaxial cable.

The completed experimental amplifier, shown in Figure 1, is cylindrical in form, approximately 1½ inches long and 1/8 inch in diameter. A unit of this size suggests the possibility of a future transmission system in which repeaters may be fabricated as an integral part of a transmission line. Ordinarily the diameter of a repeater is many times as large as that of the associated cable. While it seems likely that amplifiers of this size will eventually encourage the use of miniature cables (bottom, Figure 1), performance references in this article will be stated in terms of the more familiar 3/8 inch coaxial cable.

Despite its small size, the amplifier provides more than enough gain to offset signal loss in 1½ miles of present-day coaxial cable. Since it produces 22 db gain, signals leave the amplifier with a strength about 160 times their input value. Moreover, this performance is provided over a wide band of frequencies extending from about 0.4 to 11 megacycles per second, as shown in Figure 2(a). The resulting ten megacycle channel is more than adequate for two present-day television programs or could conceivably provide 2,500 one-way telephone circuits. Alternatively, this frequency band could be used for future high quality theater television programs.

The distortion and noise performance of the present experimental unit would allow about ten of

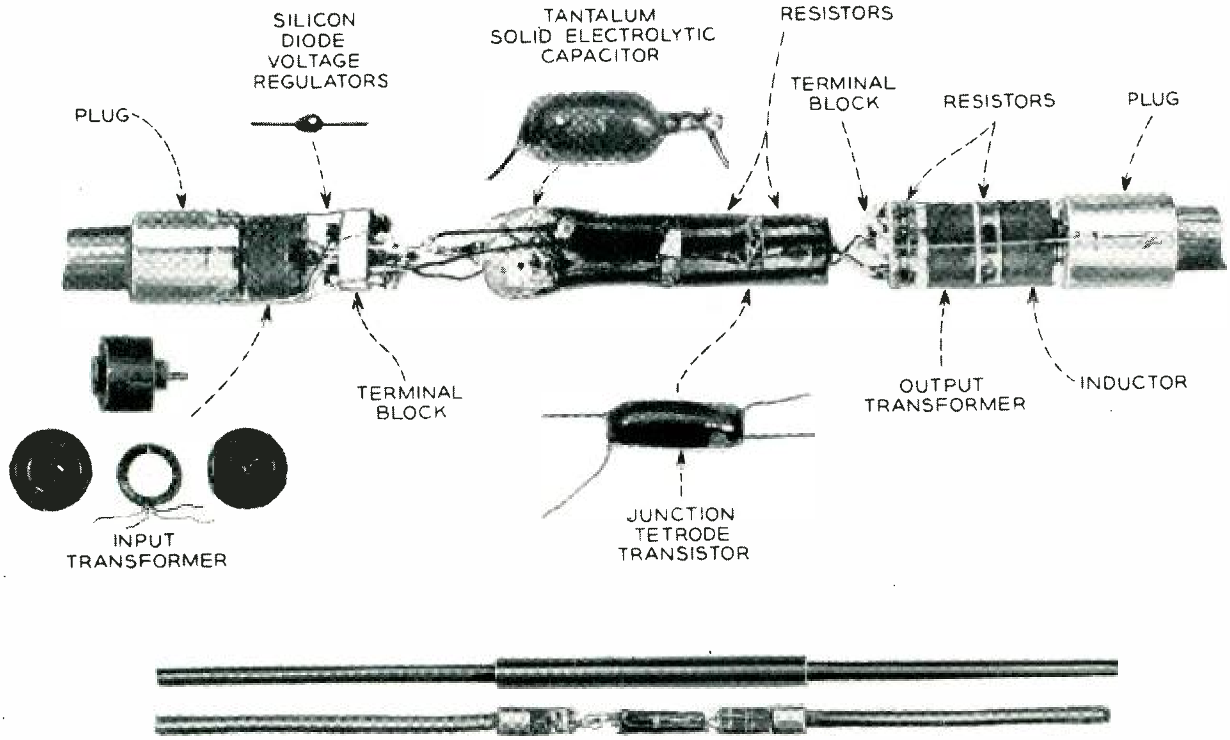


Fig. 1 — An enlarged view of the amplifier unit with components is shown at the top. Actual size views of the amplifier, with and without cover, are shown below. The unit is shown inserted between lengths of experimental 0.1 inch coaxial cable.

these amplifiers to operate in tandem. High quality television, or other broadband transmission, could thereby be provided over 3/8 inch coaxial circuits some 15 miles in length. When the amplifier is delivering 1/4 milliwatt of output power, the desired signal overrides the non-linear distortion by 50 db [Figure 2(b)] and overrides the noise by 60 db (the noise figure of the unit is less than 10 db).

In keeping with its small size, the unit requires only about 1/10 watt of dc power – 5 milliamperes at 22 volts – about half of which is consumed by the included voltage regulation circuits. Although the initial model was designed to be powered by an extra wire outside of the coaxial cable, it could easily be modified to obtain power via the signal conductors of the coaxial itself.

An enlarged photograph of the amplifier assembly with its cover off appears in Figure 1. As shown, the unit contains three subassemblies that are interconnected at terminal blocks. A total of eleven electrical components plus supplementary terminal blocks and plugs are included. At the stage of construction shown, only the middle assembly had been partially impregnated with plastic. The entire assembly was subsequently impregnated and enclosed in a 0.15-inch-diameter brass tube.

In the amplifier electrical circuit, shown in Figure 5, a new 4-electrode transistor is used in a "common emitter" configuration; that is, at signal frequencies, the emitter electrode is effectively grounded. The unit is biased by 22 volt dc power. Critical voltages are regulated by the silicon diodes labeled Z1 and Z2 in the figure, and the emitter current is stabilized by negative dc feedback via emitter resistor Re. Negative ac feedback through resistor Rf and inductor Lf is used to stabilize the gain and control the frequency characteristic of the over-all amplifier. Both input and output transformers are tightly-coupled broadband devices designed to provide a reasonably good impedance match between the transistor and transmission line.

Perhaps the most vital component in the miniature amplifier is the four-electrode transistor used to provide power amplification. Particular emphasis has been placed on achieving high-frequency response and small size in this unit* which otherwise corresponds to the "junction tetrode" type.† Superior high-frequency operation is attained not only by virtue of the fourth electrode associated with such tetrodes, but also by the extreme reductions achieved

* Fabricated by E. Dickten. † RECORD, *April*, 1955, *page* 121.

in physical dimensions. Essentially, the unit consists of a bar of "single crystal" germanium metal 1/10 inch long. Near the middle of the bar, where the cross-section is only about 0.008 inch square, a very thin region of one electrical type separates the two adjoining end regions of different electrical type. The separating layer is only about 0.0003 inch thick – less than 1/10 the thickness of this printed page. After electrical connections are made to two opposite edges of the thin region and to the ends of the bar, a protective coating is applied. The final result, shown in Figure 1, is a small zeppelin-shaped bead that is about 1/4 inch long and less than 1/10 inch in diameter.

The input and output transformers and the feedback inductor are, in themselves, impressive examples of extreme miniaturization. Although less than 1/10 inch long and 1/8 inch in diameter, these units provide very acceptable electrical characteristics, with tight coupling and broadband operation achieved by surrounding fine-wire coils with a ferrite material. The general construction is illustrated in Figure 1, where a double-winding coil appears between the two cores that will eventually enclose it. Shown above the coil is an assembled unit that will provide the loss-versus-frequency characteristics displayed in Figure 4.

Silicon diodes* that provide both dc voltage regulation and ac coupling are the smallest components in the amplifier. Each diode, consisting of a p-n junction prepared by alloying appropriate electrodes to a silicon crystal, is contained in a protective sphere only 40 thousandths of an inch in diameter. To fit within the space, the crystal volume of each unit shown in Figure 1 had to be reduced to about one-tenth its usual value. When such a diode is operated in the proper region of its static characteristic it provides a substantially constant dc voltage, the magnitude of which may be chosen at will in the initial design. In addition, since the diode impedance is only a few ohms at signal frequencies, it may be used to provide low-impedance ac coupling. Both of these functions are performed by the diode Z2 in Figure 5.

The amplifier contains a tantalum solid electrolytic capacitor, a Laboratories' development that is particularly useful in low-voltage applications requiring a large capacitance in a small space. The specific unit used has a capacitance of about 5 micro-

* G. L. Pearson and B. Sawyer, Silicon p-n Junction Alloy Diodes, Proc. I.R.E., vol. 40, pp. 1348-1352, Nov., 1952.

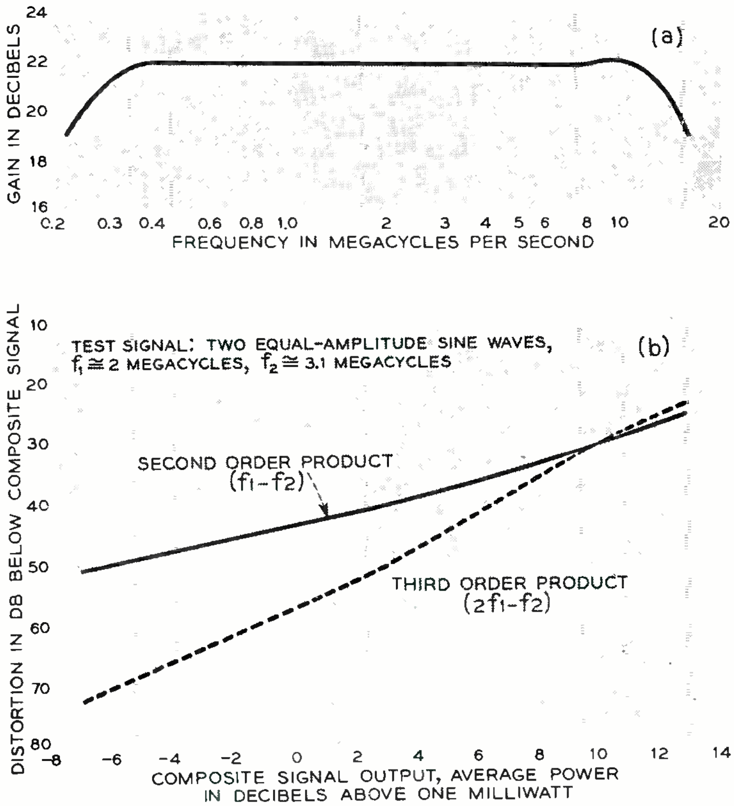


Fig. 2 — (a) Amplifier gain-versus-frequency, and (b) intermodulation distortion characteristics.

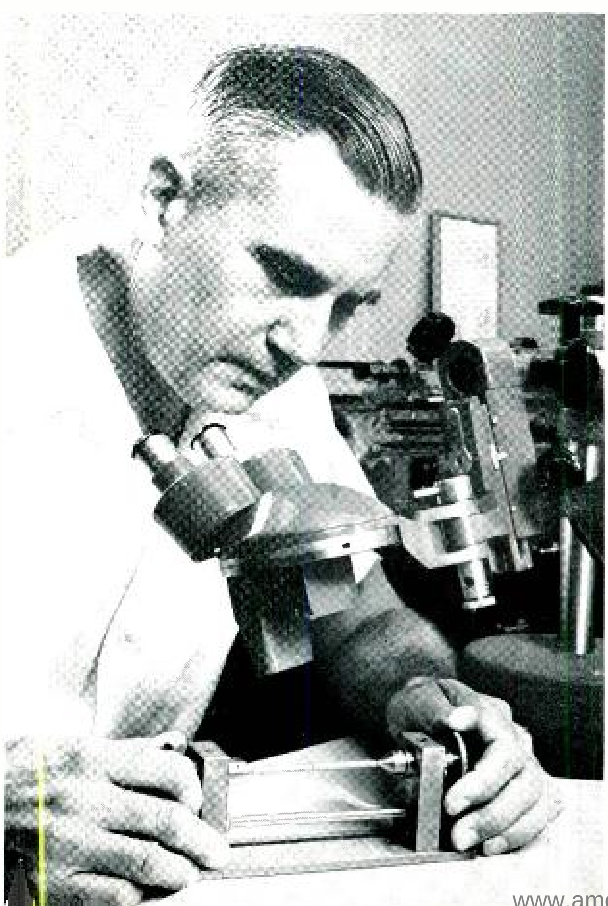


Fig. 3 — W. F. Kallensee examining the finished amplifier under the microscope that he used in fabricating and assembling many component parts.

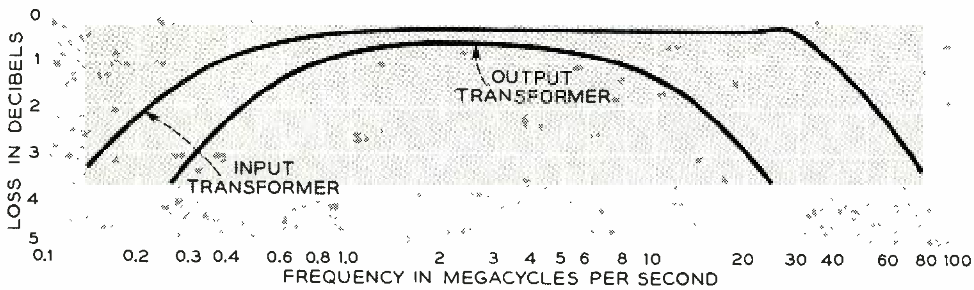


Fig. 4 — Transformer loss-versus-frequency characteristics.

farads, and yet it occupies a cylindrical volume only 3/16 inch long and 1/8 inch in diameter. A typical capacitor of this type is shown in Figure 1.

All four resistors included in the new amplifier were made by winding several turns of nickel-chromium alloy wire 0.001 inch in diameter into space that would otherwise have been wasted. The resistors Re and Rs, shown in Figure 5, were wound around the insulated form of the transistor; resistor Rd was wound around the periphery of the output terminal block; and resistor Rf was wound on a thin insulated disc located between the output transformer and the feedback inductor.

To facilitate interconnection of the amplifier subassemblies, two insulated terminal blocks were provided. Each block, in the form of a disc 1/8 inch in diameter and 0.04 inch thick, is pierced by six terminals. Amplifier-to-cable connections are conveniently made by means of small phosphor-bronze coaxial plugs located at the extreme ends of the assembly.

Although small in size and electrically proficient, the completed experimental amplifier still lacks some of the refinements associated with most practical repeaters. For example, it does not contain the equalization and regulation features necessary in long transmission systems to compensate for frequency and temperature variations. Also, the distortion or "modulation" is too great for systems including more than about ten repeaters in tandem. Although there are still many questions concerning the best physical and electrical form for such units in complete transmission systems, the results achieved in this experimental model predict a promising future for transistor repeaters.

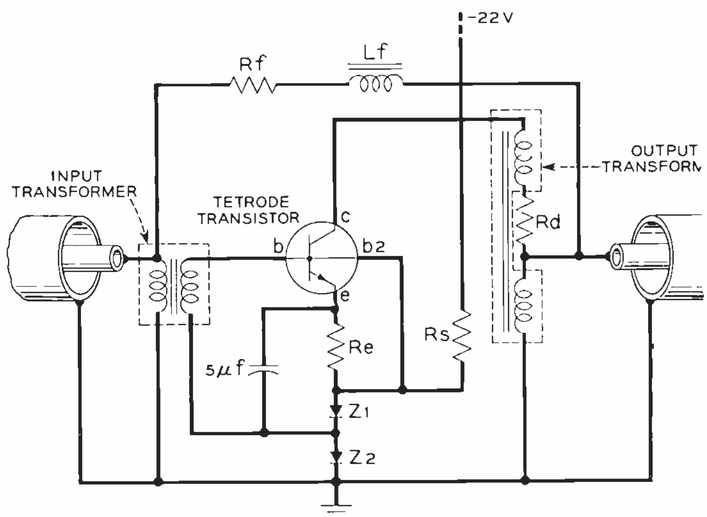
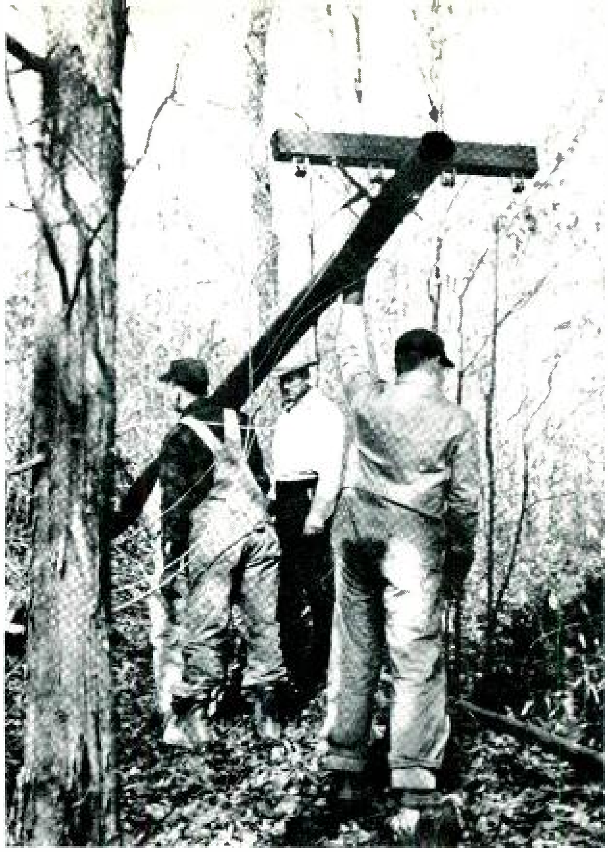


Fig. 5 — The amplifier electrical circuit.

THE AUTHOR

Harold M. Straube joined the Laboratories in 1941, and was at first associated with the development of panoramic receivers, underwater range devices, and television test equipment. During World War II he worked on radar test equipment. In 1946 he transferred to a group concerned with electronic switching, and in 1950 was engaged in television studies. Since then he has devoted his time to transmission research and high frequency transistors. Mr. Straube received his B.S. degree (1939) in E.E. from the University of Michigan, and studied at Northwestern University for the M.S. degree. He is a member of Sigma Xi and a senior member of the I.R.E.

Outside Plant Field Trials



MISS B. J. HENDERSON

Systems Engineering
formerly Outside Plant Development

Since a laboratory in many instances is not suitable for evaluating equipment that is to be installed outdoors, Bell Laboratories conducts and participates in many trials that take place under operating conditions. Typically, a new unit of outside plant equipment is first given preliminary tests in the laboratory, and then is brought to an advanced state of development at the Laboratories' outdoor test location at Chester, New Jersey, or at other outdoor test plots. Finally, before the unit is standardized, the Operating Companies evaluate it in a field trial.

Cable, wire, poles, and conduit are the major items of equipment in the Bell System outside plant. This plant can be aerial (as in the case of pole lines), underground or buried (like conduit or buried cable), or it can be submarine (as in the case of cable running under lakes, rivers, or harbors). Because of its location out-of-doors, it is more subject to the deteriorating effects of weather and to man-made troubles than is inside telephone plant. Maintenance is complicated by the spread-out nature of the plant, and this places emphasis on portability of test and repair equipment. Simplicity and ease of handling of tools and equipment are important, too.

Consider, for instance, some of the conditions to which outside plant is subjected. Outdoor temperatures vary from about —40 F. to 120° F. In some parts of the country equipment is exposed to heavy rains, high humidity, snow, and ice; while in hot, dry areas it is subjected to intense sunlight. Winds sometimes reach hurricane force; also along coastal areas there is salt spray to contend with and in large cities the fumes and gases from industries. Poles and wood products have to be protected against fungi and insects, and buried cable is sometimes attacked by rodents. There is variation in soil composition, and some soils are corrosive to buried structures. All these conditions have to be kept in mind when designing new outside plant.

The preliminary work in developing new equip-

Above — Chesapeake and Potomac Telephone Co. workmen installing test section of new rural line constructed entirely from the ground. To test suitability of construction under difficult terrain conditions, field trial line here was run through wooded area near Spotsylvania, Va., at site of Civil War Battle of the Wilderness.

Fig. 1—Installing field trial section of new urban wire near Atlanta, Ga. Sites were chosen to test the wire under various distribution conditions, including service to new housing development shown here.

ment is done in the laboratory, but an indoor laboratory is not conducive to building and testing outside plant. Designs are moved as soon as practicable to the Laboratories' 100-acre outdoor plot at Chester, N. J., where facilities are available for constructing and testing under conditions similar to those prevailing in Operating Company areas. Here the development is brought to an advanced stage. This usually involves building life-size experimental models by skilled plant craftsmen working under the direction of Laboratories' engineers. If design defects are found during this phase of work, necessary modifications are made and incorporated in the experimental models. When the design has passed detailed inspection and test at the Chester laboratory, it is prepared for field trials in Operating Company locations to see how it stands up under actual conditions in different areas.

There are two types of outside plant field trial: a Laboratories field trial, usually of limited scope, in which the special apparatus, tools, and materials are either furnished by the Laboratories or purchased from the Western Electric Company by the participating Companies; and a general field trial in which all of the Operating Companies ordinarily participate, using trial lots of a new item purchased from the Western Electric Company.

Currently there are 130 Laboratories field trials in progress in thirty-six states and the District of Columbia, in addition to eight general field trials in which the items involved are available on a countrywide basis. The Laboratories trials include: (1) newly developed plant items, (2) life tests of poles in sections of pole line in Operating Company or Long Lines plant, and (3) atmospheric and soil corrosion tests in selected test locations.

A map dividing the United States into Bell System Operating Company areas, used to keep an up-to-date record of these field trials and test lo-

Fig. 2 — T. E. Edwards, now returned to the New Jersey Bell Telephone Company, installing a mechanical splice case at the Chester Laboratories. This case was subsequently tested in a general field trial and has become standard

cations is shown in Figure 3. Numbered pins, colored to indicate the type of trial, mark the locations where trials are in progress. The numbers on the pins refer to cards that contain a brief description of each trial and its progress.

When trials are of such a nature that their location cannot otherwise be pin-pointed, the map pins are placed at the location of the Company or Area headquarters. This accounts in part for the large cluster of pins in the metropolitan New York area, which includes the headquarters of the New Jersey Bell Telephone Company, the Manhattan-Bronx-Westchester, and Long Island Areas of the New York Telephone Company, and the Long Lines Department. Pins indicating general field trials are also included in this group.

The field trials cover a wide variety of studies. For example, in New Orleans, La., the corrosive effects of acid muck soil are being studied; in San Francisco, Boston, Baltimore, and St. Louis, splicers are testing a new tool for slitting the sheath on polyethylene covered cable; because of its wind conditions, Lubbock, Texas, was chosen for a study of "dancing" cables – cables that swing through a relatively large amplitude in strong winds. In Omaha, Neb., test sections of lodgepole pine and jack pine poles have been set in one of the pole lines to be inspected periodically.

The first step in initiating a Laboratories field trial is to select a location in consultation with the

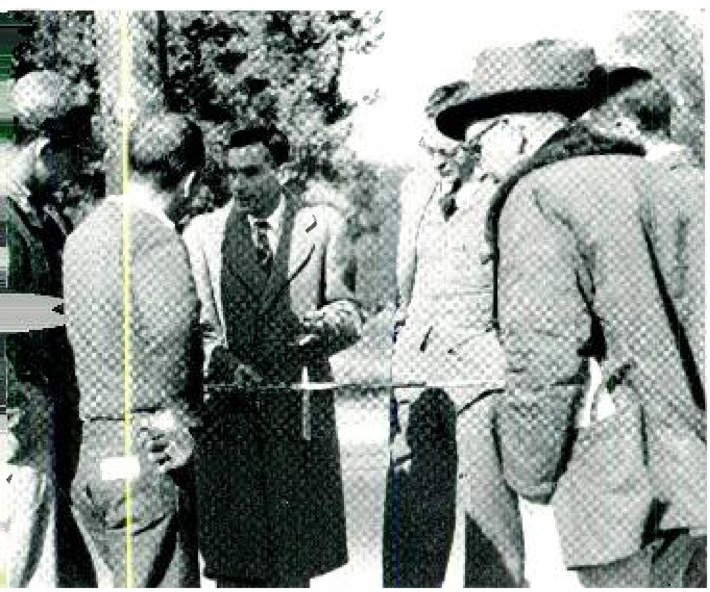


Fig. 1 — F. E. Pawel of the Laboratories (third from left) instructing Southern Bell installers in the procedures for field trial installation of 105A wire terminals. E. J. Bonnesen of the A.T.&T. Co. is to the right of Mr. Pawel.

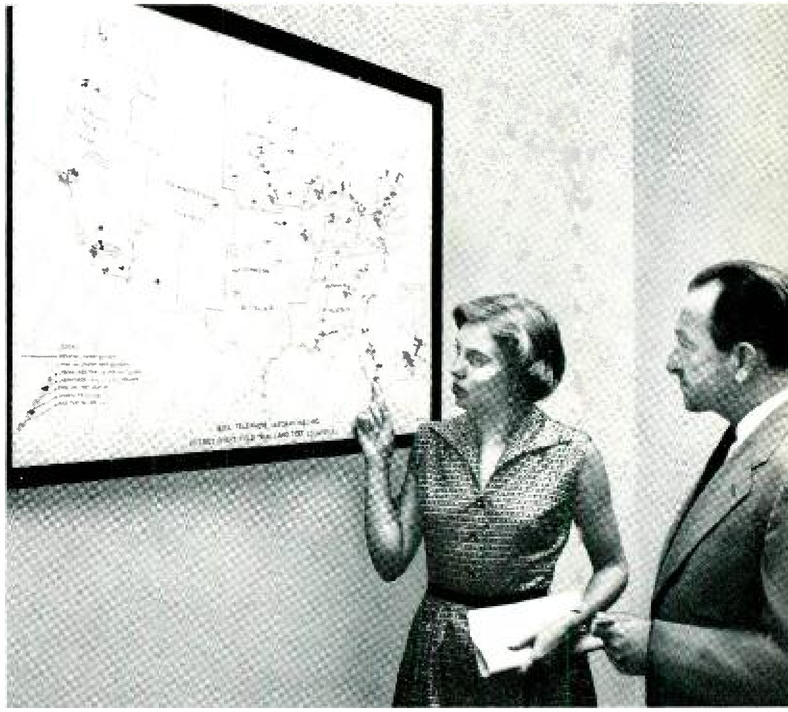


Fig. 3 — T. C. Henneberger and the author examining map showing locations of field trials of outside plant equipment.

American Telephone and Telegraph Company. This selection is made chiefly on consideration of the type of plant, terrain, and outdoor exposure needed for a representative test. Next, a letter is sent to the Chief Engineer or Outside Plant Engineer of the Operating Company or Companies to arrange for the field trial. After these arrangements have been made, the trial equipment and detailed instructions on its use are sent. Often, on installation work, especially of new kinds of plant, Laboratories engineers go to the participating areas to aid in the planning of the work and to acquire first-hand knowledge of conditions and results.

An example of a Laboratories field trial is the recently completed trial of mechanical splice cases and associated terminals for aerial cable.* These cases were designed to eliminate the difficulty of splicing alpeth and stalpeth sheath cable.† Since these trials have proven the cases to be very worthwhile, they are now being manufactured for all the Companies to use. At present, a trial of mechanical splice cases for underground cables is also in progress.

A previous Record article discussed a field trial of the new suspension type rural open-wire line.‡

* Record, *November,* 1954, *page* 405. † *November,* 1948, *page* 441; *August,* 1951, *page* 353. ‡ *April,* 1954, *page* 121.

Fig. 5 — Engineering inspection of a field trial pole; left to right, J. G. Sullivan, New Jersey Bell Telephone Co., E. Weller, A.T.&T., and A. H. Hearn, Bell Telephone Laboratories. Mr. Hearn is prodding ground line section of pole prior to taking core sample to determine internal condition.

This line employed new methods of construction, and new tools and hardware were developed to facilitate this construction. Before field trials were held in Operating Company areas, a trial line was constructed at the Chester laboratory. As this proved satisfactory, Laboratories field trials were set up in several areas (Virginia, Colorado, and Louisiana) to test the construction methods and compare the construction costs with costs for standard methods.

The arrangements for a general field trial are made by the American Telephone and Telegraph Company through a Plant Engineering Letter or Plant Engineering Memorandum, and the participating Companies place their orders with the Western Electric Company on a commercial basis. The general field trial is usually started after a Laboratories field trial has been held but before the item is standardized. New pole preservatives are often tested this way.

Another way to test newly developed preservatives, and also to check on the performance of currently used preservatives, is the pole test section. Treated poles are sent to areas with a variety of conditions to provide a representative long range test of the preservative. The Operating Companies are requested to set the poles as a test section — either using them as replacements in existing pole lines or using them in new pole lines — and to keep a record of their locations. Periodic inspections are made by Laboratories engineers to determine the effectiveness of the preservative.

In one such test section, several hundred pressure-creosoted Douglas fir poles were set as replacements in the Springfield-Wendling line in Oregon. This line was selected as being in an area which was typical of those normally using Douglas fir poles.

The exposure test location provides the same sort of information for the other kinds of outside plant that the pole test section does for poles and preservatives. It acts as a long range test of equipment, supplementing accelerated weathering tests in the laboratory. A plot of ground owned or rented by the Laboratories is used for burying cable, stringing wire, planting test posts or stakes, or for similarly installing other samples of plant. The plant is subjected to severe exposure conditions for varying lengths of time, and periodic inspections are made

Fig. 6 — A. H. Hearn (left) and J. Leutritz (right) of the Laboratories assisting in a periodic inspection of stakes in the Gulfport, Mississippi, exposure plot. Stakes have been treated with various preservatives and are inspected to determine resistance of wood to decay, insect attack, and other forms of deterioration.

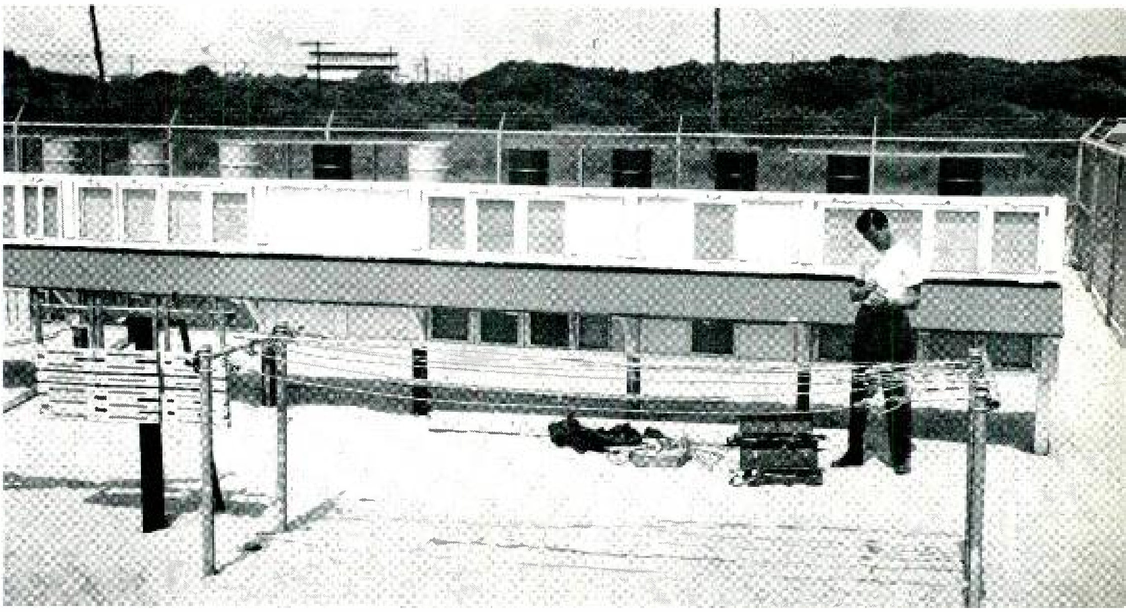


Fig. 7 — A. Mendizza examining samples of strand, lashing wire, and cable sheathing for indications of corrosion at the exposure test plot at Kure Beach, North Carolina. Plot is close to the ocean so that materials are subjected to salt water spray.

to determine the extent of deterioration, if any, including such factors as damage from corrosion and insect attack. Four of the eighteen exposure test locations were chosen chiefly for their soil conditions, these being acid, alkali, clay, and salt marsh. Three other areas are in large industrial cities so it is possible to observe how the plant reacts to industrial gases and fumes. Other plots were chosen for their insect-infested, humid, or corrosive conditions.

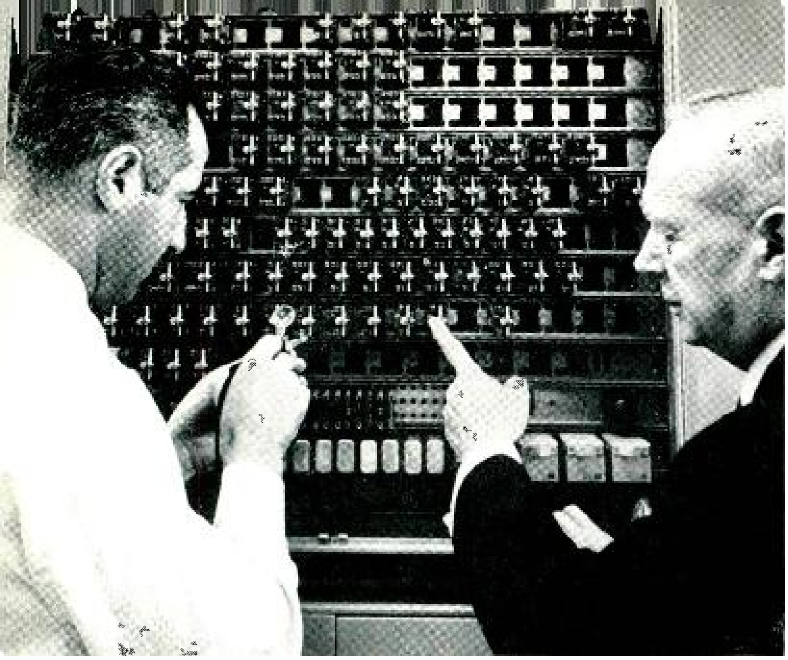
One exposure test of weathering effects on insulated wires is being conducted in Miami, Florida.* This is an ideal location for a study of this sort, because the high temperatures and heavy rains are hard on the life of the insulating materials.

* RECORD, *November*, 1953, *page* 444.

The success of outside plant field trials as a means of early evaluation of new equipment is due in a large degree to the wholehearted participation of the Operating Companies. They appraise and comment on the performance of the equipment or plant on the basis of their observations while working with it. Newly developed items which have met field trial conditions satisfactorily are recommended to the A. T. & T. Co. for standardization, while those showing deficiencies are given further development attention. Additional trials are conducted until acceptable results are achieved. The field trial system has proven to be an invaluable aid in the development and design of outside plant apparatus, tools, and materials required to meet the technical needs of the Bell System Companies.

THE AUTHORS

BARBARA J. HENDERSON was graduated cum laude from Mount Holyoke College in 1953 with a Bachelor of Arts degree in mathematics. She joined the Outside Plant Development Department in the fall of the same year. Besides making economic studies of outside plant, Miss Henderson had charge of collecting and organizing information from the numerous trials of outside plant equipment conducted by the Laboratories and the Operating Companies in various test locations throughout the country. In May, 1954, she was transferred to the newly organized Outside Plant Engineering group in the Systems Engineering Department where she is also working on cost-analysis studies of wire, cable, terminals, and other items of outside plant equipment.



Traffic Load Control in Toll Crossbar Systems

C. H. McCANDLESS *Switching Systems Development II*

Telephone calls, like automobiles, sometimes encounter "roadblocks," traffic tie-ups, and delays. Because of the high usage of equipment, they meet these conditions more frequently in a long-distance, or toll, office than in local offices. To prevent the building up of such situations to serious proportions, and to assure good, fast service to toll customers, special circuits have been incorporated in toll crossbar switching systems. Control of the traffic load is taken care of automatically in three different ways, and heavy traffic loads, such as those occurring on Christmas and other holidays, create little difficulty.

When a telephone customer makes a long-distance call, he expects the same rapid service as on his local calls. If his call is delayed for any reason, the customer not only receives less desirable service but the efficiency of the intervening operators and equipment is lowered. Aside from delays caused by human errors and occasional equipment failures, the longest and most annoying delays, from the customer's standpoint, are due to overloads. These overloads may sometimes cause delays of several hours, especially on such days as Christmas or Mother's Day when the number of calls is exceptionally high.

All telephone office equipment, whether manual or automatic, is furnished in quantities sufficient to handle a certain maximum load. Each piece of automatic equipment has some average holding time. When either the number of offered calls or the holding time exceeds its engineered limit, the excess calls must wait until busy equipment becomes idle. How to handle these excess calls, in both local and toll automatic telephone systems, is one of the telephone engineer's most difficult problems.

Above — The author, right, discusses a feature of a sender link controller with S. J. Argerie of A. T. & T. as he inspects a relay contact.

In the nationwide dialing network of toll crossbar offices, the effects of an overload in any one office are not confined to that office alone but may cause overloads in connecting offices. Figure 1 shows a 4A toll crossbar office "A" serving a toll switchboard, which may or may not be in the same city as office A, and also serving another 4A office "B" in another city. To get a call through office A, it is always necessary to obtain the use of an incoming sender. To obtain a sender, the call must have the services of a sender link controller and a controller connector for approximately one-half a second. Incoming trunks are located on sender link frames in groups of one hundred per frame, with each group having access to a maximum of forty senders.

A call from the toll switchboard enters office A on an incoming trunk, and is connected to a sender by the combination of a link controller and controller connector. When all forty senders are busy, or the link controllers and controller connectors are all busy, the process of setting up a connection through office A is delayed until these circuits become available. If this delay becomes too long, the operator at the switchboard will tell the customer that no circuits are available.

A call through office B, on the other hand, uses 4A crossbar equipment in that office instead of an operator. If the call is unduly delayed by busy equipment in office A, the 4A equipment in office B times out and connects to a reorder trunk, telling the customer or operator to try again. If all trunks in office B are busy, the 4A equipment connects to a "no circuit" (NC) trunk. This then automically sends a signal to the local office that all circuits are busy.

It is economical for senders in office B to wait several seconds for idle equipment in office A before connecting to reorder, particularly if the senders in office B are not being used to capacity. This "time-out" interval is normally in the order of twenty to thirty seconds. If, however, the senders in office B are all busy, then waiting for equipment to become idle in office A aggravates the overload condition in office B. For this reason, whenever a group of forty senders of one type all become busy, the time-out interval of twenty to thirty seconds in each such incoming sender is automatically reduced to approximately five seconds, minimizing the effect of an overload in a connecting office.

As indicated in Figure 1, six link controllers and six controller connectors handle the incoming traffic from approximately twenty-seven hundred trunks through twenty-seven sender link frames. These twenty-seven sender link frames are usually served by four groups of forty senders each. The way the four groups of senders, called key-frame groups, are distributed over the sender link frames is shown in Figure 3. Each group of forty senders first appears on sender link frames 0, 1, 2, and 3, called "key" frames. To simplify the office cabling, additional sender link frames are then added in groups of four, multipled to the four key frames. Frame 4 ties to frame 0, frame 5 to 1, 6 to 2, and so on. Frames 0, 4, 8, 12, etc., then become key frame group 0, frames 1, 5, 9, etc. become key frame group 1, and so on. Thus each key frame group may consist of several frames, but always bears the number of its key frame, 0, 1, 2, or 3.

This still does not explain how only a few link controllers and controller connectors can handle twenty-seven hundred trunks. Six controller connectors are so arranged that each of the six has access to six link controllers. Each connector may serve up to three link frames in each key frame group as shown in Figure 3, but each sender link frame has access to only two of the six connectors.

When a call appears on a sender link frame, an idle connector is found and it in turn finds an idle link controller. Since only two connectors are available to any given link frame, the call waits until one of them is free. If a call came in on link frame 12, for example, it could use either connector 0 or 3 and whichever of the six controllers that was called in by the connector. In any event, this

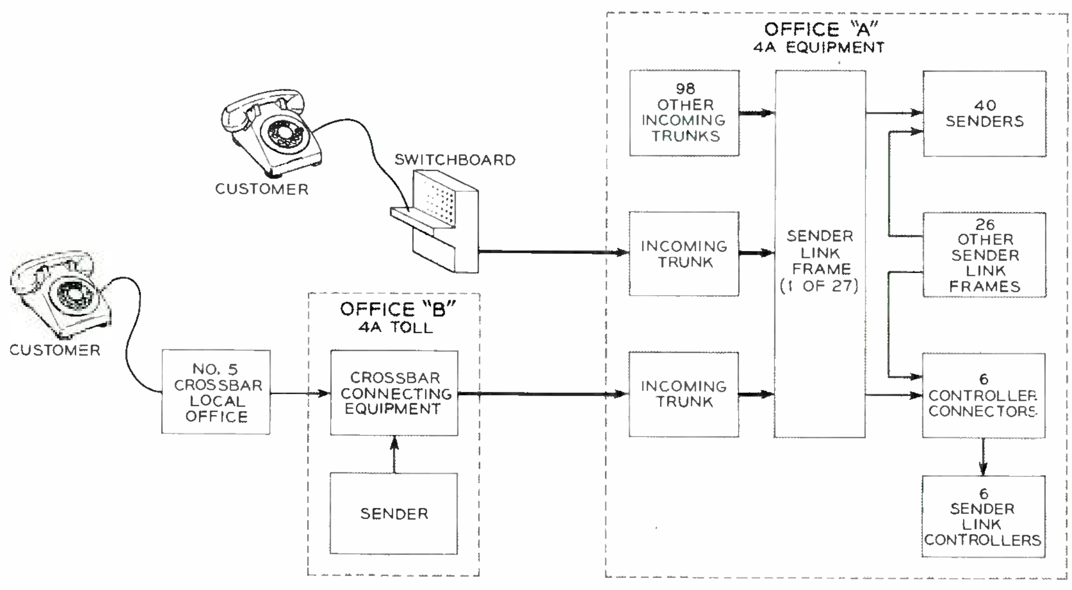


Fig. 1 — A toll switchboard and a 4A office "B" both connect to another 4A office "A". The various functions provided by the switchboard operator are automatically provided by the 4A equipment at office "B".

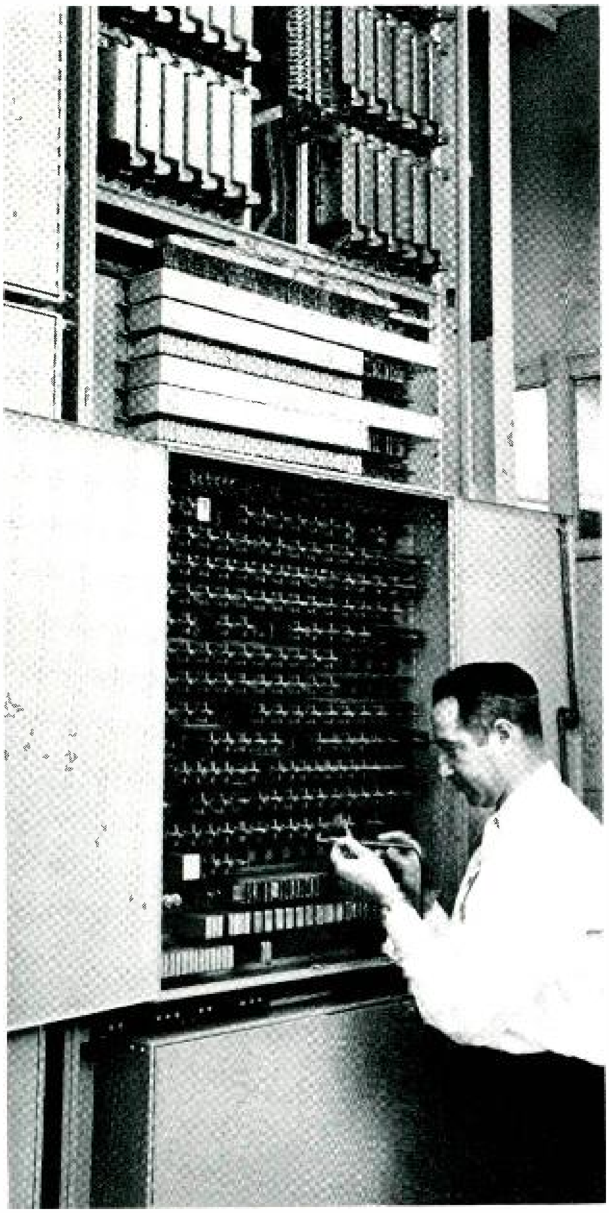


Fig. 2 — S. J. Argerie is shown checking the relays of a sender link controller. The controller connector is in the top half of the bay, with some of the associated senders in the bay to the left.

call on frame 12 must be served by one of the forty senders appearing in key frame group 0. When all calls waiting on sender link frame 12 have been served by connector 0, all other calls waiting on link frames 0, 24, 9, 21, 6, 18, 3, and 15, will be served before the connector is free to again serve sender link frame 12. This "gating" feature prevents any one sender link frame from "hogging" a connector so that it cannot serve other frames which may be waiting.

What happens if traffic is heavy and all forty senders in key frame sender group 0 are busy when a call comes in? A circuit has been designed to recognize this "all senders busy" condition and to initiate a "hold-back" feature in all associated sender link frames. Obviously, it would be a waste of time for the connectors to attempt to serve any calls on sender link frames where all associated senders are busy. Frames 0, 4, 8, 12, 16, 20 and 24

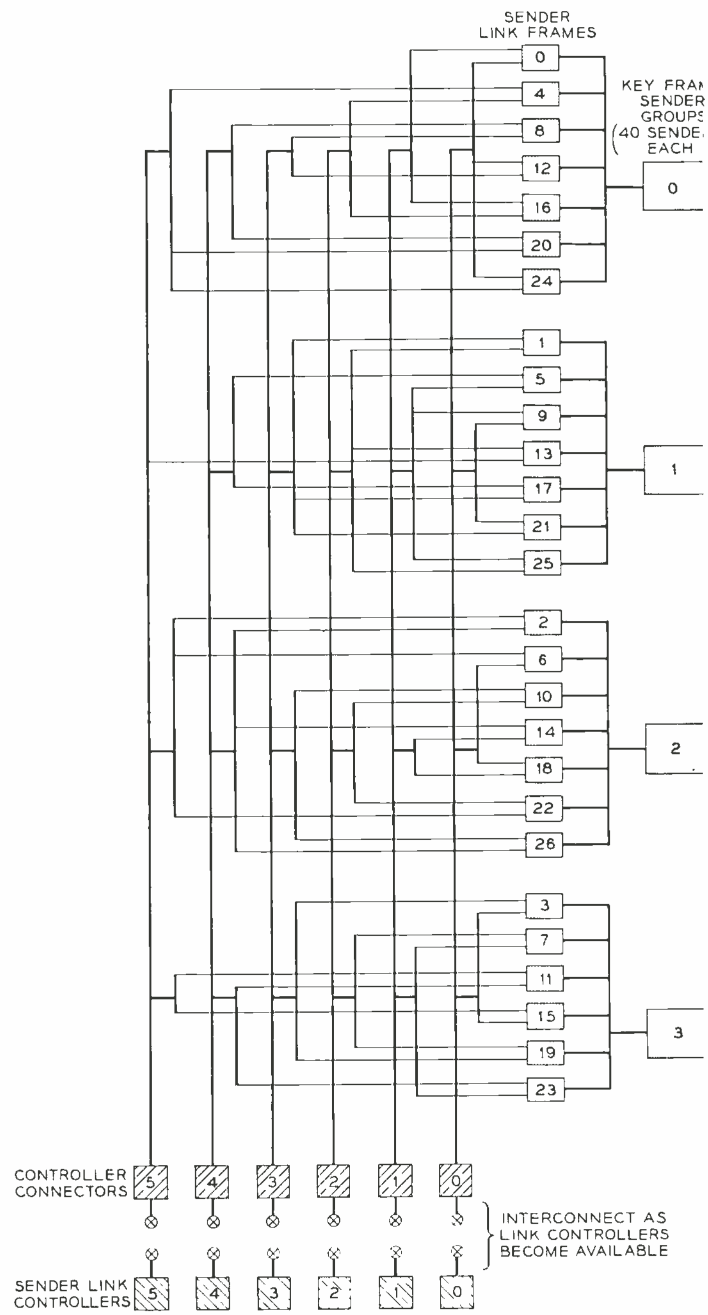


Fig. 3 — How senders may be distributed among the various link frames is shown in this diagram. Six link controllers and six connectors can direct traffic from approximately 2,700 trunks.

in key frame group 0 are, therefore, held back from the services of the connector until one or more of the forty senders serving those frames becomes idle. The connectors are then free to serve all sender link frames having idle senders, in accordance with the preference and gating circuits.

An effort is made to serve the various toll lines in the order in which calls on them were originated, considering the availability of equipment for each call. When all the senders in a group of forty become busy, all associated sender link frames having very recently been served are locked out of service by the "service gating" feature. This permits other sender link frames with calls waiting to be served in rotation. For example, if sender link frame 0 in Figure 3 had been served by the last idle sender, it could not be served again as soon as a sender became idle, as long as sender link frames 12, 24, 9, 21, 6, 18, 3, or 15, had calls waiting. Thus a preferred sender link frame is prevented from hogging connectors 0 and 1, which serve it. This feature, of course, applies to all sender link frames.

There are, then, three separate overload control features: (1) the "holding back" of all sender link frames in key frame groups having no idle senders; (2) the transferring of the "service gate" of the sender link frames from the connector to the sender traffic control circuit when the associated sender group is busy; and (3) reduced sender timing. Whenever all senders of a key-frame group become busy, all three features are effective immediately and remain in effect at least as long as the "all senders busy" condition exists.

The hold-back feature must be released immediately so that waiting calls may be served with a minimum of delay. Release of control of the "service gate" – rotation of service to awaiting calls – is delayed slightly to allow time for the regular control to become effective. Reduced sender timing, however, is maintained for approximately twenty seconds in all senders of one type – multifrequency-pulse or dial-pulse – after all groups of forty senders of that particular type have idle senders. This arbitrary interval, twenty seconds, lets traffic conditions "die down" before the normal sender waiting time is again brought into operation, making the over-all effect on other offices more uniform and preventing needless wear of equipment.

THE AUTHOR

C. H. McCandless received an A.B. degree in 1917 from the College of Emporia, Kansas, and a B.S. in Electrical Engineering in 1921 from the Kansas State Agricultural College. He then joined the Engineering Department of Western Electric in New York City, which subsequently became the Laboratories. His activities have included supervising the design, analysis, and testing of various circuits in panel and crossbar systems. Mr. McCandless conducted two schools on No. 1 crossbar for the Operating Companies in 1939, and another school on No. 4 toll crossbar in 1940. He is at present concerned with the development of an automatic switching system for teletypewriter exchange (TWX) circuits.

Electrical Contacts for Transistors and Diodes

M. C. WALTZ *Transistor Development*

In the design of semiconductor devices one should not become so preoccupied with questions of structure as to lose sight of what might appear to be a very simple matter, namely, making physical and electrical contact to the device element. Making such contacts is an important design problem, and the reader may be surprised at its magnitude and at the amount of knowledge and ingenuity involved in its solution.

Making good electrical contact to semiconductors is essential in fabricating semiconductor devices such as diodes and transistors, but establishing a completely satisfactory contact is not so simple as it first appears. A device designer can make an intelligent decision on a particular type of contact for a particular device only in the light of considerable knowledge about contacts and contact properties. He must know, for example, exactly what the contact is supposed to do. He must know also how much departure from ideal contact behavior can be tolerated in his device. Finally, he must know the individual peculiarities of the various contact types available to him.

The contacts in a semiconductor device are the means of connection between the external terminals and the internal electrically charged carriers in the semiconductor. If this important communication link causes attenuation of the signal, or if it introduces undesirable distortion in the signal, the semiconductor device fails to operate properly. In general, the contact will result in loss to the signal if the impedance between the lead and the semiconductor is high, and it will distort the signal if there is rectification at the contact. It is thus very important in making low-loss or ohmic contacts to semiconductors, that the contacts shall not rectify or exhibit high impedance.

In principle, the function of a contact differs from that of a rectifying junction* in the device element in that, while both are employed to communicate with charge carriers, an ohmic contact controls the behavior of the majority carriers in the semiconductor element, while a rectifying junction controls the behavior of minority carriers. As the designations imply, majority carriers are those present in excess in a particular specimen of semiconductor. Thus, in n-type material, electrons are the majority carriers and holes are the minority carriers; in p-type material the holes are majority carriers while the electrons are the minority carriers.

When a voltage is applied across a junction in one direction, the junction will collect the minority

* Record, *June*, 1954, *page* 203.

carriers in its neighborhood, while with opposite polarity of the applied voltage, the junction introduces or emits minority carriers into the neighboring semiconductor. The action of most transistors is basically dependent upon the emitting and collecting of minority carriers at their active junctions. In an ohmic contact, on the other hand, it is desired to suppress these minority carrier activities. Even though a contact may fulfill the aforementioned requirements of low resistance and absence of rectification, it may nevertheless act somewhat like a junction by introducing minority carriers into the semiconductor. If such charges are present in the vicinity of one of the active junctions of the device, such as the collector of a junction transistor, these minority carriers will be collected, the reverse leakage current of the junction will be increased, and the rectifying properties of the junction will be degraded.

Two general types of ohmic contacts are used in transistor and diode fabrication. One of these might be called a "fast recombination contact" and the other a "non-injecting contact." These names are descriptive of the manner in which the contacts interact with the minority carriers in the semiconductor.

The fast-recombination contact is shown in Figure 1(a). It can be seen that the contact is like a sandwich, with a "disturbed" layer between the semiconductor and the metal. This mechanically disturbed layer is produced by sandblasting, grinding, or otherwise abrading the surface of the semiconductor before applying the metal contact. Such mechanical working has the effect of producing disruption of the crystal lattice structure for a short distance below the surface. Submicroscopic cracks are generated, and the previously continuous crystal is broken up into a mosaic of tiny blocks, misoriented with respect to each other and to the parent crystal.

Such a disturbed layer furnishes many "recombination centers" where excess minority carriers may recombine with the majority carriers. In this layer, any minority carriers introduced from the metal are rapidly absorbed. This sandwich is effective in transmitting voltages from the metal to the semiconductor without rectification or distortion, and it presents only a minimum of impedance to the flow of current across the contact. Unfortunately, however, a good absorber is also a good radiator. This absorbing layer for minority carriers acts also as a generator of new minority carriers, many of which may diffuse away to a nearby collector junction and give an undesired increase of collector current. For this reason, the fast recombination contact cannot be used in the neighborhood of a rectifying junction in either a diode or a transistor.

Wherever a transistor or diode requires a contact close to a rectifying junction, the "non-injecting" contact must be used. As can be seen in Figure 1(b), the non-injecting contact is also in the form of a sandwich. In this case, however, the filling in the sandwich is a layer of semiconductor having very high conductivity. This region contains impurities

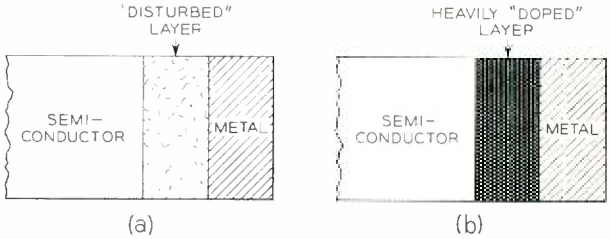


Fig. 1 — Top: "fast recombination" type of contact; bottom: "non-injecting" type of contact.

of the same type as those present in the main body of the semiconductor element, but the concentration of the impurities is greater. The sandwiched layer is said to be heavily "doped." This contact does not always have as low impedance as does the fast-recombination contact, and slight rectification may occur at the boundary between the metal and the heavily doped layer. However, it does have the property of suppressing the flow of undesired minority carriers from the metal into the semiconductor, and it does not generate minority carriers

Fig. 2 — J. N. Borges electroplating a fast recombination contact to a slice of germanium.

itself. It may therefore be used in close proximity to a rectifying junction. Non-injecting contacts are formed in several different ways which will be described later when devices using such contacts are discussed.

Several types of semiconductor devices using the fast recombination contact are shown in Figure 3. It should be noted that in each case the contact is located some distance away from the active junction or junctions, so that injection of minority charge carriers is not troublesome. After abrasion or sandblasting of the semiconductor surface to create the disturbed layer, the metal is attached by the use of solder. In some cases the abraded surface is electroplated with either copper, nickel, or gold before soldering. The plated layer is more readily wet by the solder, permitting the contact to be made at a lower temperature with a less active flux. When a plated layer is used, it is generally applied while the semiconductor material is still in the form of a slice and before it is diced to the final size used in a diode or transistor.

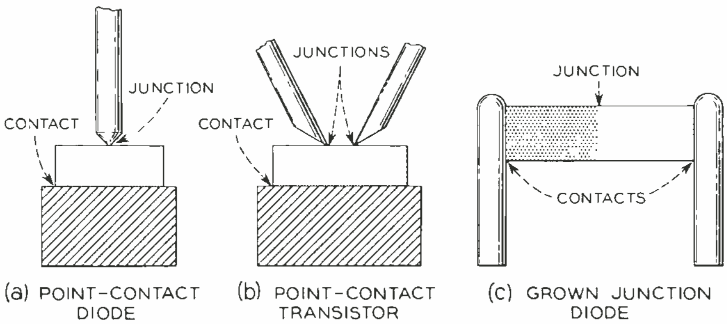


Fig. 3 — Three uses of fast recombination contacts.

Examination of Figure 4 will show that in each of the devices illustrated the contact may be relatively close to a junction. This is especially true of the central contact in the grown junction transistor in Figure 4(a). To avoid the deterioration of junction properties in such close-spaced devices, non-injecting contacts must be used.

In the case of the base or central contact to the grown junction transistor, the contact is made by placing the end of the base lead wire in position against the edge of the base layer and attaching it by a welding process in which a pulse of current through the lead wire bonds it to the semiconductor. The lead material is chosen to contain some impurity of the same type as that responsible for the conductivity of the base layer. During the welding operation, a small volume of melted metal and semiconductor is formed at the contact. When this volume resolidifies, the semiconductor retains enough of the impurity in solid solution to be heavily doped,

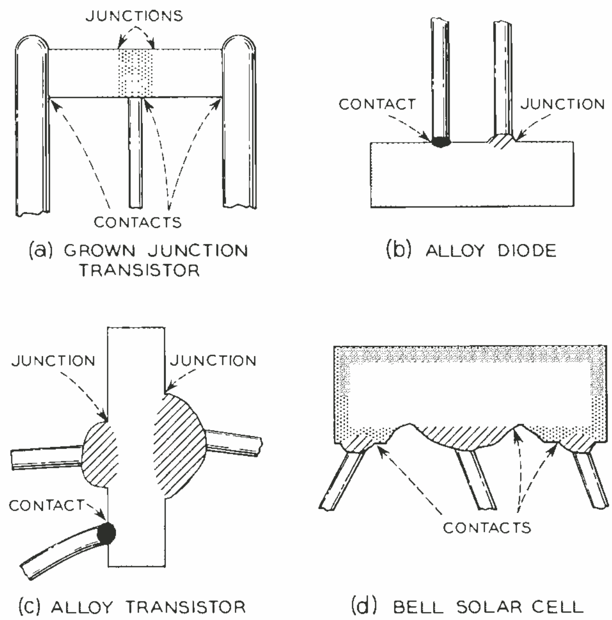


Fig. 4 — Four uses of non-injecting contacts.

THE AUTHOR

MAYNARD C. WALTZ is engaged in electronic apparatus development at the Laboratories, especially that work related to germanium and silicon varistors. Mr. Waltz was graduated from Colby College in 1938 with a B.A. degree in Physics and two years later received the M.A. degree in Physics from Wesleyan University. From 1940 to 1942 he taught Physics at Wesleyan, and from 1942 to 1946 worked in the Radiation Laboratory at the Massachusetts Institute of Technology. In 1946 he joined the Laboratories. Mr. Waltz is one of the authors of *Radar Receivers*, a volume in the Radiation Laboratory Series. He is a member of Phi Beta Kappa, Sigma Xi, and Sigma Pi Sigma.

and it thus comprises the non-injecting sandwich layer. The contacts for the alloy diode and the alloy transistor are made by similar processes.

In the Bell Solar Cell* shown in Figure 4(d), the photo-electric junction is created by a high temperature process, in which impurities are diffused into the surface of the semiconductor wafer, thus converting the outer layers of the wafer to material of opposite conductivity type. The nature of this diffusion process provides that the outermost layer of the converted shell is more heavily doped than the underlying material. It therefore constitutes the heavily doped sandwich layer required for the non-injecting contact. The metal part of the contact may then be applied by plating and soldering.

Still another way of making a non-injecting contact is to attach the lead wire to the semiconductor with a solder which is alloyed with a doping impurity. During the high temperature cycle of the soldering operation, enough of the doping material diffuses from the molten solder into the surface layers of the semiconductor to produce the sandwich layer of highly doped semiconductor. Such soldered contacts are sometimes used in the fabrication of p-n diode bars, Figure 3(c), where, for reasons of keeping the forward resistance as low as possible, the p and n type sections on either side of the rectifying junction are made as short as practicable.

As new types of transistors and diodes are developed, it will be a continuing problem to determine what types of contact can best be used, and what processes should be employed to fabricate them. Information on contacts and contact behavior is thus an important ingredient in the semiconductor device designer's store of knowledge.

* RECORD, *June*, 1954, *page* 232.

Military Radio Control Terminal

A recent development of the Laboratories is a four-wire radio control terminal designed for the Signal Corps, to interconnect radio links (usually over water) to other telephone facilities. Standard telephone equipment is used, together with some new circuits developed especially for use in the terminal.

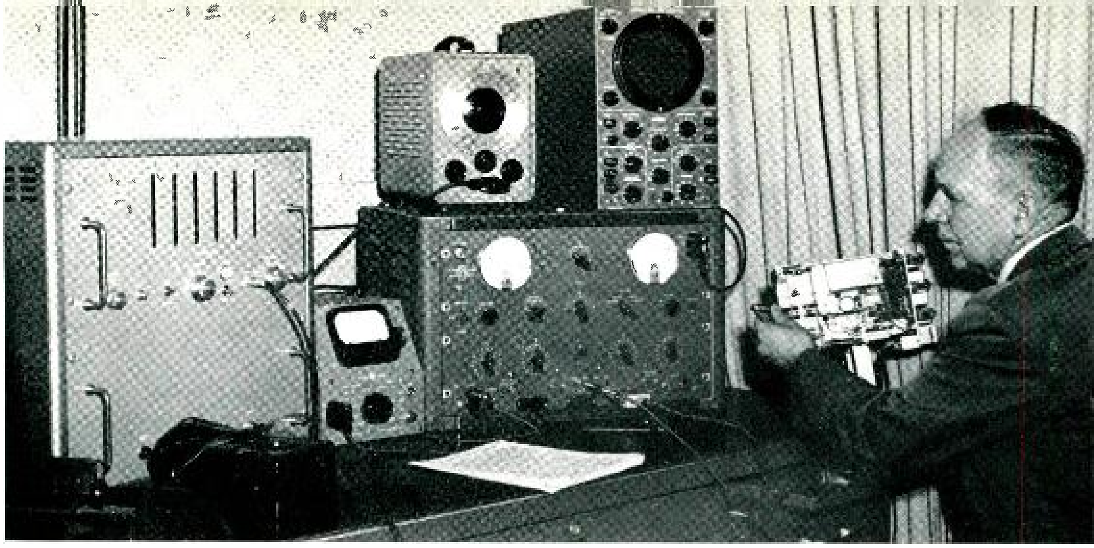
The terminal uses four-wire circuits throughout, including the subset, eliminating certain anti-singing devices normally used with 2-wire terminals. A standard channel shifter is used to stack two voice-frequency channels one above the other frequency-wise; this requires a radio-frequency band of 6 kc. One channel is for facsimile transmission, the other for voice. The radio terminal uses only one 6-kc sideband of the radio signal; the other sideband is for telegraph purposes. Fading and other amplitude variations are minimized by the use of a manual gain control together with a volume limiter in the transmitter, and a vogad (voice operated gain adjusting device) in the receiver, in addition to the usual radio receiver automatic gain control.

Two recorders are included, permitting one-minute recordings to be transmitted continuously for tests or other purposes and hour-long recordings to be made of any information desired.

When telegraph signals are being transmitted, a special control circuit automatically inserts a 3-db pad in the output of the control terminal; this keeps the overall output of both sidebands nearly the same as that from the control terminal only.

A telephone set is available to the operator, for transmitting orders or information directly over the air. In addition, an operator at the terminal can use the telephone to converse with a remote operator.

H. G. JORDAN
Transmission Systems Development



Servicing Center for Short-Haul Carrier

A. L. BONNER *Transmission Systems Development I*

To achieve economy of both cost and space, carrier systems such as N, O, and ON are unitized. In the three systems, there are some forty different plug-in equipment units to be tested. Since some of the units in any one system are either identical or similar to those in the other systems, certain basic tests are common to all three systems. To expedite maintenance a test set was developed — around which a servicing center may be set up — for testing all units in the three systems.

An important and desirable characteristic of any telephone equipment is ease of maintenance. One of the principal advantages of the plug-in feature of N,* O,† and ON carrier system equipment is that it facilitates normal maintenance of these systems. Faulty units may be replaced by good ones to restore service quickly, the trouble then being cleared at a more convenient time — and more efficiently — at a centrally located telephone company servicing center. In addition, Western Electric offers complete repair service for these systems at their repair shops. All three carrier systems are designed for short-haul use, and have other features in common besides plug-in units. For this reason, it was desirable that a servicing center be capable of testing equipment of all three systems.

There are, of course, major differences between the systems, and even between units of the same system. Type-N is a four-wire, twelve-channel system for cables. It uses an 8-kc frequency band for double-sideband transmission, with inexpensive and fairly simple filters. Type-O, on the other hand, is a two-wire system for open-wire lines. It actually consists of four separate four-channel systems operating in different frequency bands, but which are otherwise very similar. It uses single-sideband transmission in a 4-kc band, and the filters are necessarily rather complex. A more recent development, type-ON, uses both N and O equipment plus some units specially designed for ON. It uses the 4-kc bandwidth of type-O to provide twenty channels on four-wire cable circuits and on circuits combining both cable and open wire. A servicing center for all three systems must be quite versatile to provide facilities for testing such a variety of equipment.

Essentially, the servicing center developed for these carrier systems simulates factory test conditions for all of the plug-in equipment. Test equipment consists primarily of a 5U servicing-center test set, oscillator, vacuum-tube voltmeter, and a volt-ohm-milliameter. An oscilloscope and a frequency counter are also available at large servicing

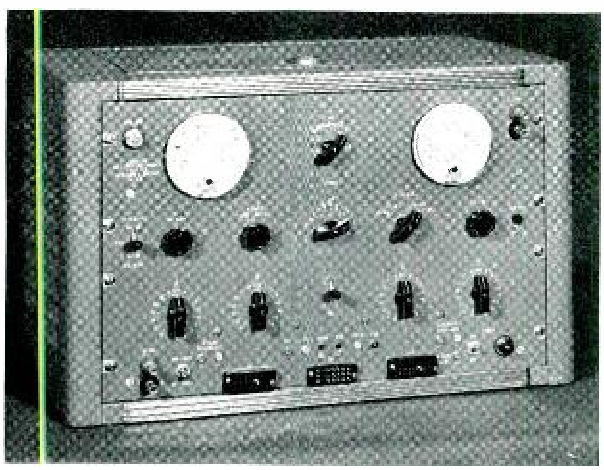
* RECORD, *July*, 1952, *page* 277. † *June*, 1954, *page* 215.

centers. The specially designed test set, Figure 1, can be used to set up about one hundred different test conditions for about forty different units.

The unit being tested is held by an adjustable clamp, and connected by a test cord. Any of the test conditions required for the unit can be obtained by turning the switch dials on the test set to the proper position. If trouble is indicated, it can usually be localized by measuring the voltages at certain strategic points in the unit. Generally, for such work the input power is applied continuously while the vacuum-tube voltmeter is used to measure the voltages. Charts show just where to physically locate the strategic points, where they are in the circuit, and what the voltages should be. The volt-ohm-milliameter is a valuable aid in locating nearly all kinds of trouble. An oscilloscope is particularly valuable in locating trouble in circuits where waveform is important, such as the signaling circuit. The principal use of the frequency counter is to check the frequency of the O and ON carrier-supply and signaling oscillators.

Test equipment in the 5U test set includes two nearly independent switching circuits, a loop-back amplifier, a crystal oscillator, and apparatus necessary for testing carrier system signaling circuits. Figure 3 shows the test set chassis removed from its cabinet and turned on its side. The built-in test equipment is located on the shelf. Switches A and B, Figure 1, can set up 36 different test conditions for N, O, and ON channel units and their subassemblies. The switching circuits are made simpler and more flexible by having each switch perform a separate function. Switch A is used only to connect leads from the built-in and any external test equipment to the unit under test. Switch B sets up the particular conditions required for the test. For example, it puts the correct termination on the vacuum-tube voltmeter and sets up the different signaling test conditions. Switches C and D, in like manner, can set up about 60 different test conditions for group, repeater, oscillator, and filter units.

Fig. 1 — The test set used at the servicing center.



The method of making transmission tests is shown in Figure 2. Test power from the external oscillator

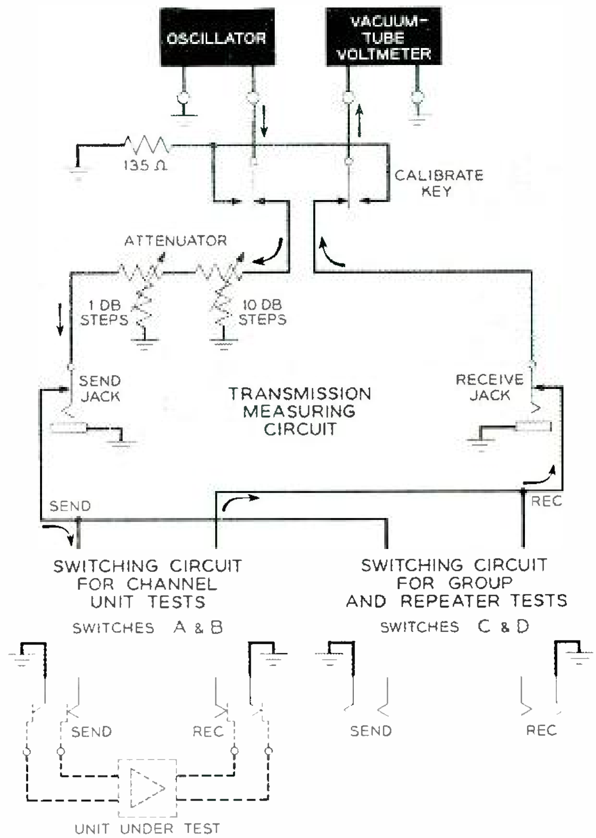


Fig. 2 — The test set arranged for transmission tests.

is connected by the appropriate switching circuit to the input of the unit under test and the resulting output is connected to the vacuum-tube voltmeter.

Tests on channel unit signaling equipment are made in a similar manner, except that the test signal is a source of dial pulses and the capability of the unit under test to reproduce the dial pulses is measured by a "per cent break" meter. When over-all transmission or signaling tests are made on a complete channel unit, a loop-back amplifier is connected between the transmitting and receiving sections of the unit so that they can be tested in tandem.

An interesting problem in the design of the test set was that of reducing the coupling between the low-level input and the high-level output leads of the switching circuits. Since coaxial wire is used and only the center conductor is switched, the shields are connected together by permanent ties

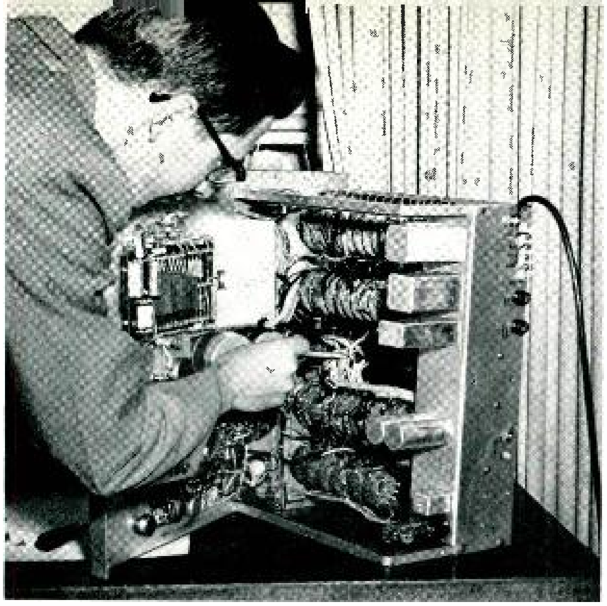


Fig. 3 — J. C. Donaldson points out the close grouping of ground leads in the test set.

permitted a more complicated switching design.

To keep the ground impedance low in the 5U test set, the 50 ground leads are connected in 28 holes in a bus bar area 2½ inches by ⅜ inches. The leads involved in the critical tests are kept within a ⅜-inch length on the bus bar. Thus the 200-kc coupling from this source is held to a loss of at least 90 db when the terminating impedances are 135 ohms. The ground leads have some impedance, and currents returning to ground through them could possibly cause some crosstalk. To prevent this, the ground leads themselves are also shielded wires, one end of each shield being connected to the common ground point. The over-all crosstalk coupling is thus held to about 90 db.

to complete the ground return paths. This complicates things because the different carrier units utilize the jack terminals in different ways; a conductor and its associated ground return paths may be in the high-level part of the switching system in one test and in the low-level part in another.

Figure 4 shows that the ground return paths were completed by connecting each end of each shield individually to a common low impedance ground point. Thus each individual coaxial shield and its associated ground leads are isolated from all the others. Regardless of how the switches are set, the high level ground return current from the voltmeter will return to its starting point at the amplifier output without flowing through any input ground return paths. This is important because the coaxial shields have appreciable impedance at the higher frequencies and any stray current would build up a crosstalk voltage. The effective isolation of the input circuits and of the output circuits

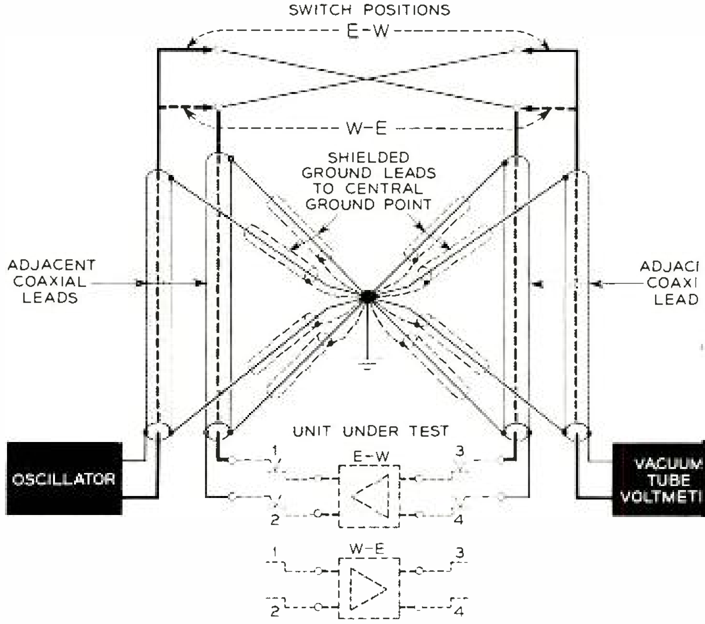


Fig. 4 — Final arrangement of coaxial cables and shielded ground leads in the test set.

THE AUTHOR

Arthur L. Bonner received the degree of B.S. in E.E. from the University of Minnesota in 1927 while working for the Northwestern Bell. He then joined the Laboratories where he spent a year in the switching development group concerned with step-by-step switching. Since that time Mr. Bonner has been in transmission development, engaged in the development and testing of voice-frequency and radio program circuits, radio telephone circuits transmission features of four-wire switching circuits, and carrier equipment. He holds patents on a circuit for reducing signaling interference into carrier channels and on a circuit now being used in automatic toll testing. Another patent has been filed on the method of reducing crosstalk in the system described in this article.

CAMA: Transverter and Billing Indexer

R. P. FOLTZ and G. F. SOHNLE *Switching Systems Development*

By permitting more people to dial their own long distance calls, Centralized Automatic Message Accounting is aiding the expansion of nationwide customer dialing. When accounting equipment is centralized, however, the number of different combinations of billing situations is multiplied many times. Transverter and billing indexer circuits reduce these combinations to a workable number and cause to be punched on the AMA tape a single digit indicative of the rate used in charging for a call.

As a step toward nationwide dialing of telephone calls by the customer, the telephone system must provide equipment for automatically recording information about the call for billing purposes. This is in addition to its primary function of establishing connections between customers. Automatic Message Accounting (AMA) for local crossbar offices was introduced several years ago as the first phase of the over-all plan, and its use is now quite widespread. More recently, AMA on a centralized basis, or CAMA,* has been developed. With CAMA, the recording equipment is placed at a central point so that it can be used by a large number of local offices, an advantage where the traffic is not sufficient to warrant individual office AMA facilities.

The transverter and billing indexer are links in the complex switching network necessary for the recording of CAMA calls (see Figure 2 for a simplified version). A "transverter" is used to "transmit" and "convert" the information involved in the eventual billing of the call. This information is received from the sender and includes the calling and called customers' numbers. By means of the "billing indexer," the transverter derives information about the calling office, directions concerning the amount of information to be recorded on the AMA paper tape, and the message-billing index. This index is used in the accounting center to aid in choosing the proper formula for billing the customer. For example, the call may be one which is to be charged for on a message-unit basis – perhaps three message units for the first five-minute talking period plus one unit for each three-minute additional period – or the call may require detailed billing on a toll statement. In any case, the billing index as determined aids the accounting center in properly billing for each completed call.

The functions of the transverter and billing indexer are so closely related that the two units could be regarded as a single entity. However, the operating time of the billing-indexer function is short compared to that of the transverter, and for reasons of economy the billing indexer is therefore made a separate unit and is connected to the transverter for a comparatively brief period. In this way only three billing indexers are required per tandem office, whereas up to twelve transverters may be necessary. In actual amount of equipment saved, the difference is even more striking, since the billing indexer is about two or three times as large

* RECORD, *July*, 1954, *page* 241; *October*, 1954, *page* 371; *May* 1955, *page* 193, *and June*, 1955, *page* 223.

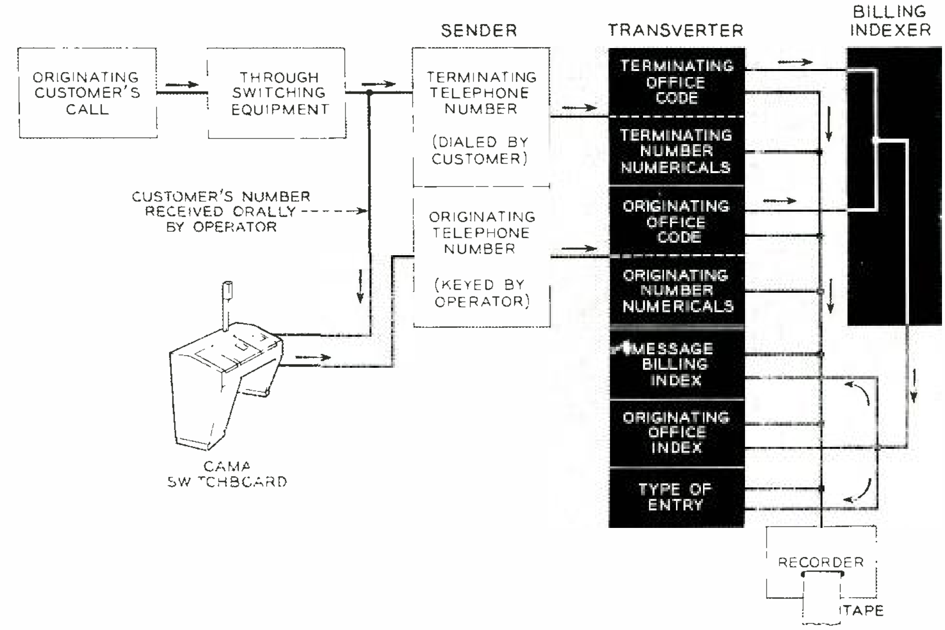


Fig. 1 — Diagram showing flow of information through the transverter and billing indexer.

as the transverter, depending upon the type of traffic to be handled in the CAMA tandem office.

The transverter and billing indexer frames have been designed along the lines of other frames in crossbar tandem offices. In some cases, an additional frame is used to supplement the billing indexer frame. The transverter is equipped with relay casings on the front, and with removable steel covers to provide protection on the rear. Relay protection on the billing indexer is provided by individual steel covers on each mounting plate.

In many respects the function of the transverter in CAMA is similar to transverters used in No. 1 crossbar and No. 5 crossbar systems; that is, the transmission of the information to be recorded on the tape is essentially the same. Obtaining the billing information is more complex, however.

Local office AMA equipment is required to obtain the message billing indexes of calls originating in a maximum of ten offices in the same building. A CAMA tandem office, however, may handle calls originating in a maximum of two hundred offices. These offices may be located in as many as three different numbering-plan areas and may place calls through crossbar tandem to offices in the same three areas on a message-unit or detailed-billing basis as required. Other terminating areas may be reached through CAMA on the detailed-billing basis only.

In more detail, the circuits function as indicated in Figure 1. The customer dials the called number

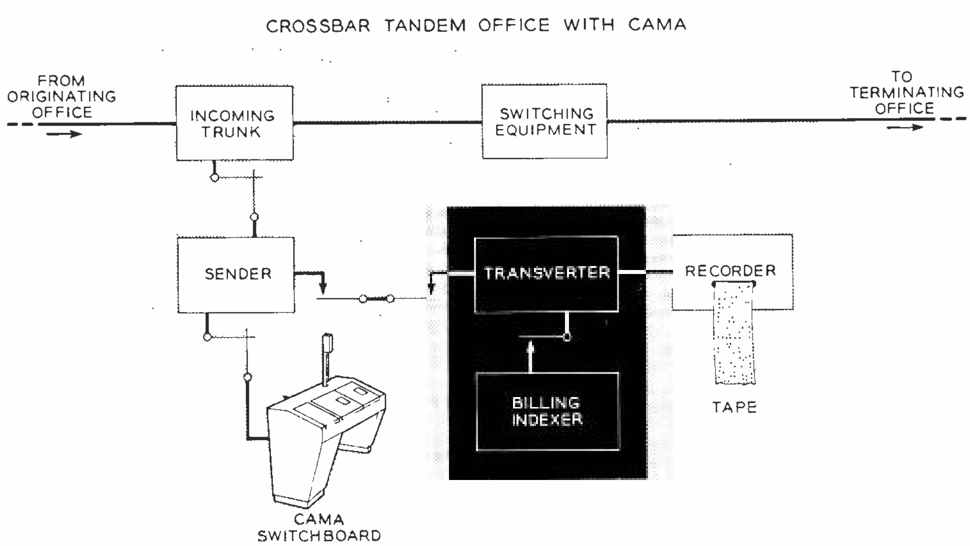


Fig. 2 — Block diagram showing position of transverter and billing indexer in a crossbar tandem CAMA office.

and gives his own number to the CAMA operator, who in turn keys the calling number into the sender. The sender then passes the calling and called numbers to the transverter, together with the number of the recorder that will perforate the tape.

The transverter summons the billing indexer through the billing indexer connector and transfers to it the calling and called office codes and the recorder number. From this information the billing indexer calculates the *message billing index*, the *originating office index*, and the *type of initial entry*. The transverter in turn engages the appropriate recorder and causes it to perforate the initial entry on the tape.

The *message billing index* is a single-digit number (0-9) that is perforated on the AMA tape for aiding in the determination of the charging rate for AMA calls. The flow of information on Figure 1 indicates that the billing indexer combines the calling office code and the called office code to determine the message-billing index for the call. Since there may be as many as two hundred originating office codes completing calls to terminating offices on a message-unit basis, the number of possible combinations of originating and terminating office codes could be very large. Therefore, to provide a reasonable limit to these combinations, a grouping arrangement composed of a maximum of fifty originating rate treatments and seventy-five terminating rate treatments is provided. Thus the maximum number of rate treatment combinations is limited to 3,750, which is considered to be adequate.

The originating and terminating rates are combined by means of cross-connecting "jumpers" and relay operations as shown graphically in Figure 3. In this illustration, jumper A serves to connect a terminal representing the originating office code to one of the fifty terminals corresponding to the originating rate treatment (ORT). Likewise, jumper B connects a terminal representing the terminating office code to one of the seventy-five terminals corresponding to the terminating rate treatment (TRT). A relay corresponding to the originating rate treatment operates to combine the ORT and TRT points into one of the possible 3,750 combination rate treatments (CRT). Jumper C then cross-connects the proper CRT terminal to one of the message billing index terminals for eventual perforation on the tape as a digit 0-9. This number is used by the accounting center machinery in its final billing computations.

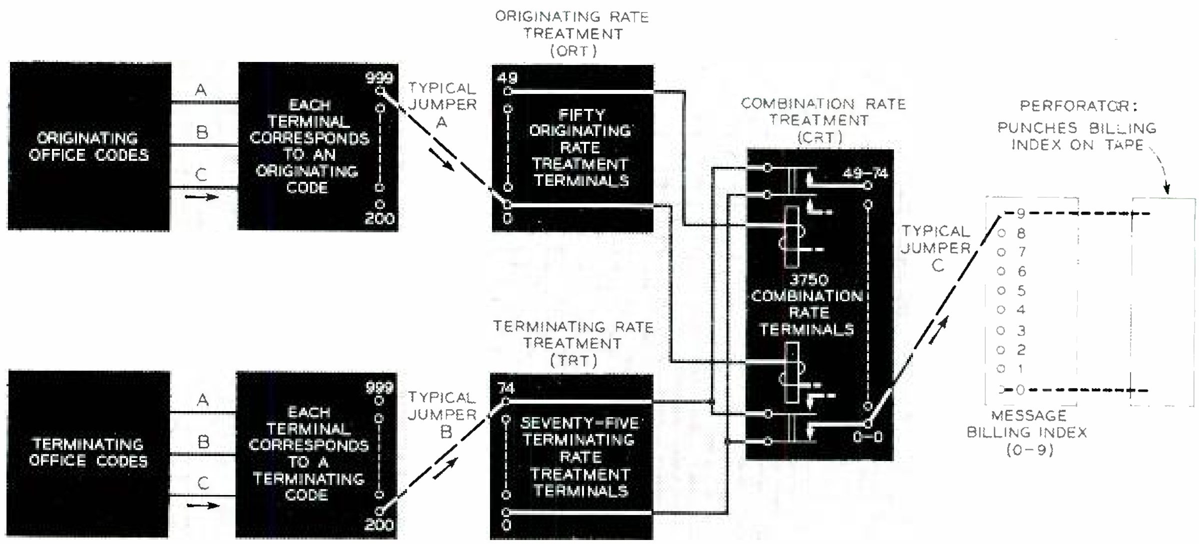


Fig. 3 — Diagram showing method of deriving billing index.

The *originating office index* is a single-digit number perforated on the AMA tape, and, when combined with the number of the recorder group, it identifies the originating office code. Each group of recorders can handle up to ten originating offices. If, for example, trunks from office CHelsea 3 are assigned to recorder group 12, and if the office index is 8, the combination of 12 and 8 on the tape serves to identify the office to the accounting center machinery. Likewise, office CHelsea 2 could be identified as 12 and 7, and so on.

The billing indexer, from the kind of call being processed, also tells the transverter the *type of initial entry* required on the tape. Message-unit calls require two lines, and detailed-billed calls, because of the additional details involved, require four lines on the tape. Both the *office index* and *type of entry* are derived in the billing indexer by cross-connecting methods similar to the one illustrated in Figure 3. The answer and disconnect entries necessary to complete the record of the call are made without further use of the transverter and billing indexer.

To ensure that correct billing information is perforated in the initial entry on the AMA tape, the transverter, billing indexer, and recorder circuits also function to detect troubles that may occur within these circuits as well as in the information received. If trouble is detected by the transverter, billing indexer, or recorder circuits, the transverter will block the call and engage the transverter trouble indicator circuit, which is arranged to record, by lamp indications, information that will enable the maintenance people more easily to trace the trouble. Upon completion of a trouble record, the transverter requests a release from the transverter connector, which in turn arranges for a call to be given a second trial, usually with a different transverter.

If a call encounters trouble on a second trial, the transverter may take either of two actions, depending upon the information it has received from the billing indexer. First, if the transverter receives a detailed-bill initial entry indication or does not receive any initial entry indication from the billing indexer, it provides a signal to the sender indicating that the call should not be established. Second, if the transverter determines from the billing indexer that the call requires a message-unit type of entry, it provides a signal to the sender indicating that the call should be completed.

In addition, the transverter causes the recorder to perforate a "cancel entry" in all cases where partial perforation of the initial entry was made prior to the detection of trouble. This cancel entry notifies the accounting center equipment that an incomplete initial entry should be expected.

Equipment performing functions similar to those of the transverter and billing indexer will undoubtedly be required when CAMA is extended to other switching systems.

THE AUTHORS

Ralph P. Foltz received his B.S. degree in Electrical Engineering from Rose Polytechnic Institute in 1948, and in the same year joined the Engineering Department of the Illinois Bell Telephone Company. During the period 1951 to 1953 he was with the Laboratories in the Switching Systems Development Department, where he worked chiefly on circuit design for the CAMA billing indexer. In April of 1953, Mr. Foltz returned to Illinois Bell, where he has held positions in the Plant Extension Engineering Department and in the Equipment Engineering Department. Mr. Foltz is an associate member A.I.E.E.

G. F. Sohnle joined the Systems Development Department of the Laboratories in 1921. After completing a training course for technical assistants, he transferred to Equipment Development as a trial installation engineer and later as an analyzation and PBX equipment development engineer. During the war years he engaged in the development of long transmission lines for the armed forces and in the development of airborne radar. Following the war he resumed PBX development and then participated in the development of automatic message accounting center equipment. At present he is engaged in the application of centralized message accounting and toll facilities to crossbar tandem offices. Mr. Sohnle received the E.E. degree from Polytechnic Institute of Brooklyn in 1933.

Broadband Test Oscillator for the L3 Coaxial Carrier System

J. O. ISRAEL
Transmission Systems Development—II

To guarantee the best possible service to its customers, the Bell System constantly inspects, checks, and tests its telephone and television plant. Frequently, this job can be done with readily available equipment. As new, complex systems are developed, however, it is often necessary to design special testing apparatus. A versatile broadband oscillator for direct testing of the L3 coaxial carrier system and for calibrating other test equipment is one such development.

As new carrier systems are developed and put into use in the Bell System, complete testing apparatus must be provided for systems maintenance. Since the operation of many of these testing units is based on the measurement of a frequency or frequencies, in one way or another, some means must also be provided to calibrate the units quickly and accurately. This is done by a special test oscillator developed for each system. Such oscillators are also use directly in testing sections of the coaxial line by transmitting selected tones of precise frequency along the segment in question.

With the development of the broadband L3 coaxial carrier system, a new oscillator with a range of nearly ten megacycles – 50 to 10,000 kilocycles – was required. The 56A oscillator was designed to answer this need.

Although there were signal generators available that covered the desired frequency range, a number of auxiliary requirements made it necessary to develop this new type. Since the voice channels in the L3 system extend from one end of the carrier frequency band to the other, and since all voice channels are of uniform band width, no one part of the frequency spectrum is more important than any other. This condition makes it desirable for the test oscillator to have a linear rather than the more usual logarithmic scale.

The oscillator output frequency is designed to be stable to ±20 cps over a ten-second interval to facilitate testing. Also, the generated frequencies are essentially free of harmonics which could cause incorrect results. Additional requirements are placed on the output level of the oscillator. Since power level differences as small as 0.01 db must be measured in carrier calibration, the output of the oscillator must be held constant to within 0.005 db. For convenience in testing, the output level must be adjustable to ±2 db from the normal output – zero dbm – by intervals as small as 0.01 db.

To meet these requirements as well as several others, the 56A oscillator, illustrated in Figure 1, was designed as a heterodyne type, equipped with a film scale 200 inches long. A block diagram of this oscillator is shown in Figure 2. Basically, the circuit consists of two local oscillators, two high-frequency

Above — R. P. Muhlsteff, right, who did the mechanical design of the oscillator, checks the operation of a laboratory model with the author.

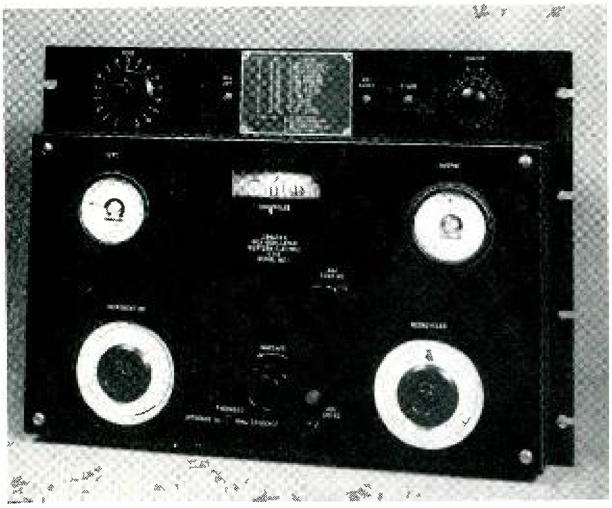


Fig. 1 — Panel view of 56A Oscillator showing arrangement of meters and operating controls.

amplifiers, a modulator and a power amplifier. One local oscillator is adjustable in frequency from 80 to 90 mc and the other is fixed at 90 mc. After amplification, the outputs of these two oscillators are intermodulated to provide a number of modulation products including the difference frequency. This difference frequency is selected by a filter, amplified, and used to provide the oscillator output. The output frequency then varies from zero to ten megacycles as the variable oscillator frequency is changed from 90 to 80 mc.

To obtain the desired frequency output, the operator first sets the pointer on the megacycle dial shown at the lower right of Figure 1. He then operates a switch that controls a motor which drives the oscillator to the approximate preset value at the rate of 500 kc per second. A closer setting to the desired frequency is then obtained on the film scale by operating the tuning knob marked INCREASE located near the lower center of the figure. Calibrated offsets from this frequency can be made by the INCREMENT KC dial shown at the lower left. This dial has a range extending from -5.5 to +10.5 kc. The output level is indicated in dbm on the meter at the upper right. This level is adjusted over the indicated ±2 db range by means of the control knob located above the meter. The test meter and switch in the upper left corner are provided to facilitate maintenance on the oscillator itself.

Since the output frequency of the oscillator is the difference between the two local oscillator frequencies, these local oscillators are made as nearly identical as possible so that variables such as temperature change effects will cancel out. The variable local oscillator tuning inductors consist of two short-circuited coaxial tubes having a total inductance of approximately 0.03 microhenries and a Q of 1,000 or more. The tuning capacitor, encased in a heavy brass casting to minimize the effects of short-time temperature changes, consists of two sets of interleaved fixed plates with a set of rotor plates between them. The capacitance is varied from approximately 100 mmf to 140 mmf to vary the frequency from 90 to 80 mc.

The fixed 90-mc local oscillator is similar to the adjustable oscillator except that the capacitor does not contain a rotor. A small variable air capacitor is connected to the frequency determining network, or "tank" circuit, of this oscillator to provide the INCREMENT KC adjustment. At the time of their manufacture, these oscillators are adjusted to 90 mc ±1 kc. Experience with a number of oscillators of similar construction has indicated that this frequency will shift less than 50 kc over a period of years.

To keep an oscillator of this type in adjustment, two frequency checks are required: one near the lower end of the scale, and one about two-thirds of the way to the higher end. An adjustment at 100 kc was chosen to take care of the low-frequency check and another at 7,266 kc for the high-frequency end. The latter value was selected because it corresponds to the frequency of a pilot tone used in the L3 system, and hence adds to the usefulness of the oscillator. Any small change in the frequency of the fixed local oscillator due to aging, can be compensated for by adjustments at 100 and 7,266 kc.

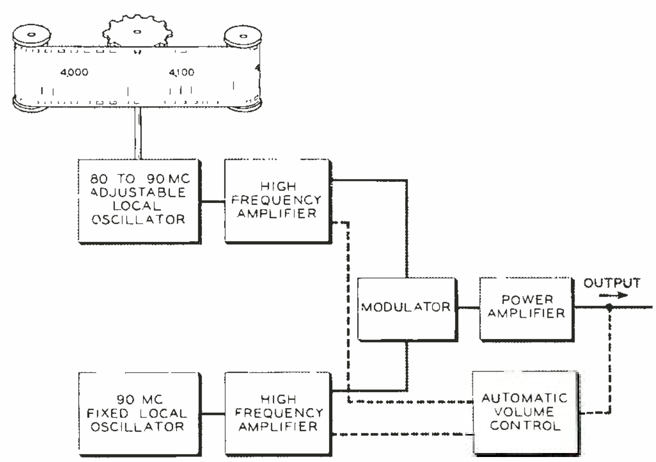


Fig. 2 — Principal components of broadband test oscill

The 100-kc adjustment controls a small capacitor in the variable oscillator tank circuit. Since at 100 kc the frequencies of the two local oscillators are very nearly equal, this can be considered a 90-mc adjustment. Actually, this adjustment establishes the difference between the two local frequencies rather than their true values. As the oscillator frequency is changed to 7,266 kc, the frequency check indication may not occur at the indicated frequency on the film. This means that a "stretching" or "shrinking" of the range is required, and the 7,266-kc adjustment is provided for this purpose. This adjustment produces small changes in both the capacitance and inductance of the variable oscillator tank circuit, and is so designed that it has very little effect on the oscillator frequency at 100 kc. This facilitates adjustment. The frequency checks are made against a 100-kc tuned circuit and a 7,266-kc quartz crystal, built into the oscillator.

The output level is controlled automatically to remain constant within 0.1 db over the entire frequency range, and within 0.005 db at any single frequency. This is done by means of the automatic volume control circuit that serves to diminish any changes in the output level by about 60 db.

A test meter is used to maintain the broadband oscillator. This meter, together with a 17-position switch, measures supply voltages, space currents of the oscillator and amplifier tubes, and the action of the automatic level control. It also acts as a frequency check indicator. By means of this meter it is possible to monitor the operation quickly without checking inside the oscillator.

In addition to its use in L3 system testing and maintenauce, the 56A oscillator has served as the prototype for a wider band oscillator operating from 50 kc to 20 mc. This offspring of the 56A has been used in transmission and phase measuring sets that were important in experimental and production testing of L3 component apparatus.

The 56A oscillator is now in production by the Western Electric Company. Seven models have been in operation for the L3 installations and will remain at strategic locations for maintenance purposes.

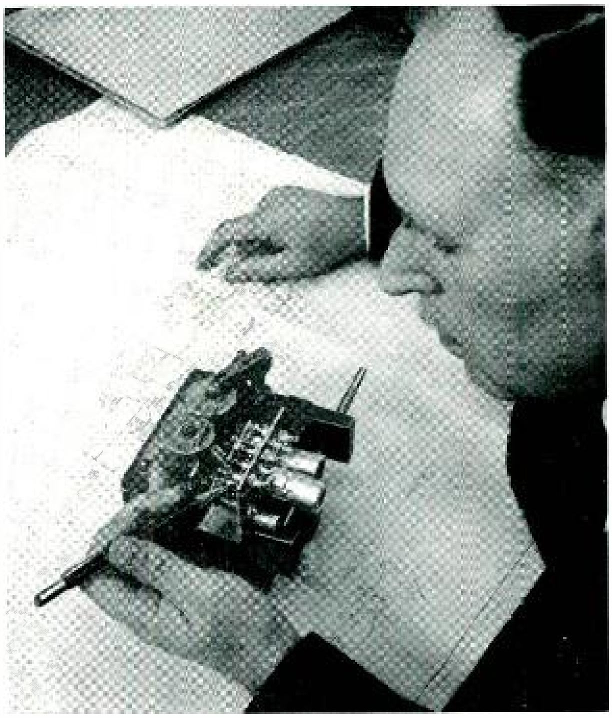
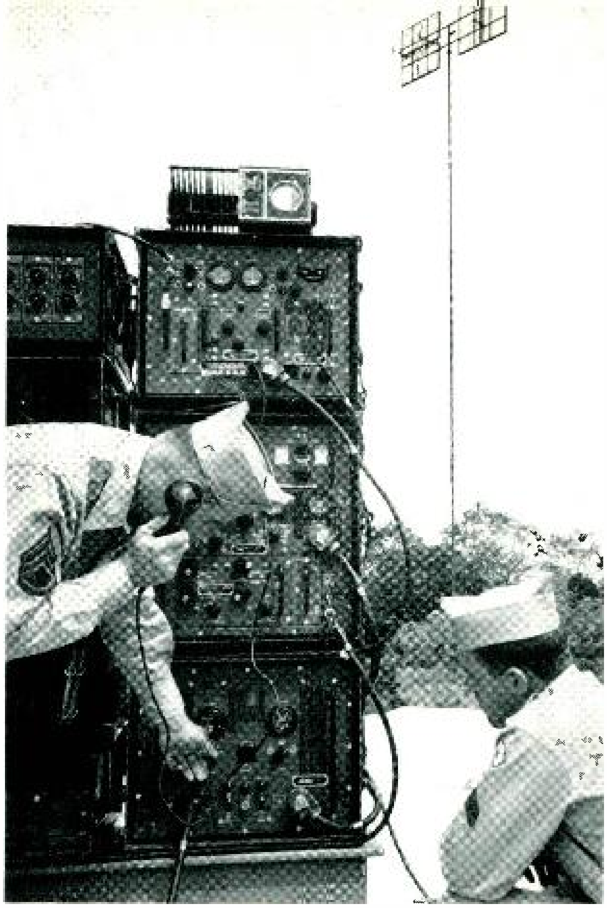


Fig. 3 — K. F. Rodgers, who did the mechanical design of the local oscillators, checks the wiring on an experimental unit.

THE AUTHOR

J. O. Israel joined the Laboratories in 1928 and was engaged in the development of filters and networks for carrier telephone systems until 1942. During World War II, he worked on a submarine detection device (the Magnetic Airborne Detector), and other war jobs. Since 1945 he has been active in the development of heterodyne oscillators and a high-precision crystal oscillator. He is currently engaged in work on frequency-control systems. Mr. Israel received the degree of B. S. in electrical engineering from Lafayette College in 1927, and spent the following year doing graduate work at Yale University, for which he received the Master's degree in 1930.

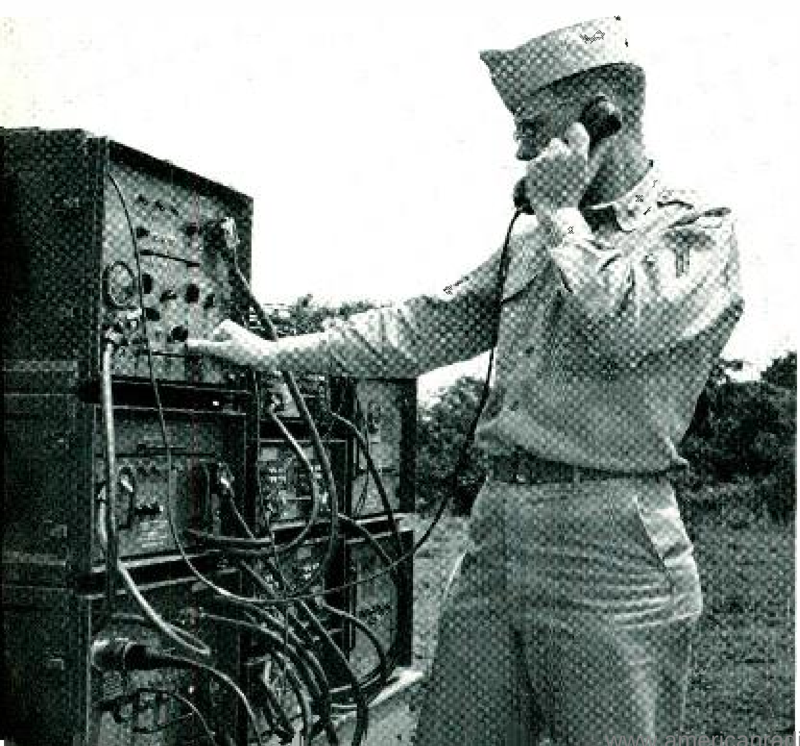
New Military Carrier Telephone System



Bell Telephone Laboratories has recently announced a new combination radio and cable carrier system designed for the Signal Corps. The radio equipment is designated the AN/TRC*-24, and the cable units bear the labels AN/TCC†-3, 5, 7, 8, and 11. All are now in production by the Western Electric Company.

Interconnected radio and cable carrier communications are not new to the military, but this is the first time that carrier and radio systems were developed simultaneously to insure that adequate performance is obtained using both transmission media.

* "Army-Navy/Transportable Radio Communications."
† "Army-Navy/Transportable Cable Communications."



Vital military messages can now be telephoned over the system via terminals and both attended and unattended cable repeaters, and, where conditions merit, transferred at will to radio portions of the overall network. Various lengths of cable and various numbers of radio stations can be quickly interchanged or interspersed. By proper grouping of equipment, communications distances of 800 to 1,000 miles and greater can be achieved.

The design stressed integration between the cable carrier and radio, ruggedness, reliability, and portability. None of the individual portable cases exceeds 120 pounds in weight, and all have withstood severe vibration and physical shock tests.

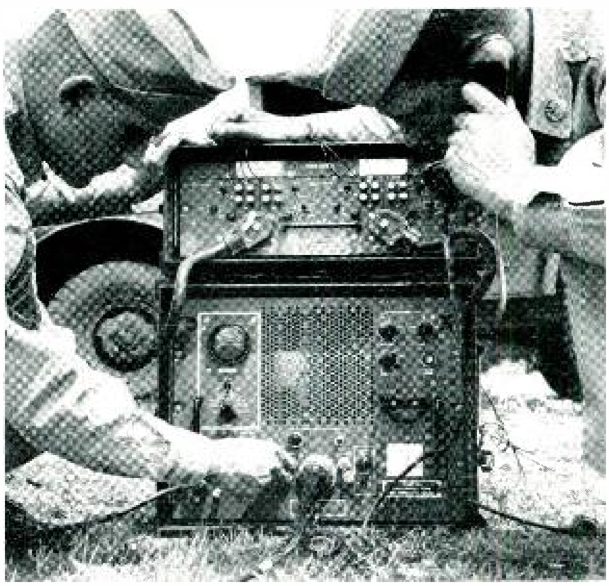
The radio equipment, including a 45-foot mast for the transmitting and receiving antennas, is transported in eighteen cases. In combination with the carrier terminals, it provides either four or twelve telephone message channels and one maintenance channel on a radio frequency located anywhere in the 100- to 400-mc range. Complete radio sets with antennas are placed at intervals of about 25 to 30 miles for line-of-sight transmission. As many as eight radio links may be used in tandem.

The cable sections use a new type of "spiral-four" cable developed for the Signal Corps. This cable

Twelve-channel cable system terminal, AN/TCC-7.

Lowering AN/TRC-24 antennas: gin-pole and block-and-tackle gear permit quick raising and lowering of entire assembly.

consists of four insulated copper conductors spiraled around a very small central polyethylene core and jacketed with a vinyl compound in which is imbedded a stainless steel braid. It is laid in quarter-mile lengths. The four-channel system, using terminals AN/TCC-3 and repeaters AN/TCC-5, pro-



Four-channel cable terminal, AN/TCC-3.

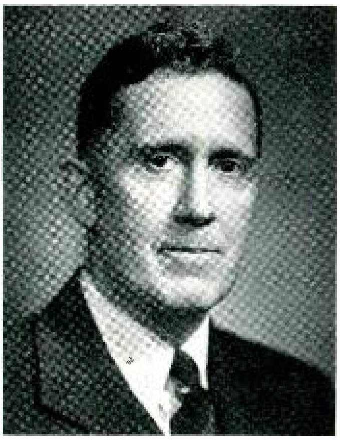
vides four message channels and one maintenance channel. This system uses loading coils at the junctions between cable sections. It may be operated at distances up to 100 miles between terminals with repeaters spaced at intervals of 25-35 miles. A terminal is housed in two carrying cases and a repeater in a single case.

A longer-haul, twelve-channel cable carrier system was also designed. Distances up to 200 miles between terminals are possible with non-loaded cable sections. AN/TCC-7 terminals are separated by AN/TCC-8 attended repeaters at 40-mile intervals and by AN/TCC-11 unattended repeaters at 6-mile intervals. The twelve-channel routes will ordinarily be used for heavy long-haul traffic, with four-channel routes as branch circuits to outlying terminals. Transmission quality over an 800-1,000-mile circuit is as good as that over the longer distance Bell System circuits. Nine cases of equipment comprise the twelve-channel terminal; five are used for the attended repeater; and the unattended repeater is enclosed in a single cylindrical housing.

The accompanying illustrations show a recent demonstration of the new system. All components, including the antennas and mast of the radio system, can be quickly assembled by a crew of three or four men. Twelve message channels operating in such a versatile manner should constitute a major contribution to better military communications.

G. Rodwin and G. H. Huber
Military Communication Development I

Testing unattended repeater for twelve-channel cable carrier system.



E. I. GREEN

J. B. FISK

J. B. Fisk, E. I. Green Elected to New Posts

Other Organization Changes Announced

James B. Fisk, Vice President in charge of Research of the Laboratories, has been elected Executive Vice President with direct responsibility for all of the Laboratories' technical activities, and E. I. Green, Director of Military Communication Systems, has been elected a Vice President of the Laboratories and heads a new vice-presidential area with responsibility for Systems Engineering. The appointments became effective June 1.

As a result of the re-allocation of the work, several new general department heads have also been named.

In his new post Dr. Fisk continues to report to Dr. M. J. Kelly, President of the Laboratories. J. E. Dingman, Vice President and General Manager, continues his direct responsibility for all non-technical activities of the Laboratories. All other Laboratories Vice Presidents report to Dr. Fisk, who also continues in his present position as Vice President in charge of Research.

JAMES B. FISK

Dr. Fisk joined the Laboratories in 1939. At the beginning of World War II he was selected to head a group in the Laboratories to develop the newly discovered microwave magnetron for radar use. After the war, he was placed in charge of electronics and solid state research. It was work in this area that resulted in the transistor inventions at the Laboratories and the greatly increased interest in and importance of solid state science and technology.

In 1947 he became Director of Research of the newly created U. S. Atomic Energy Commission and simultaneously Gordon McKay Professor of Applied Physics at Harvard University. He is now a member of the General Advisory Committee of the Atomic Energy Commission as well as the Science Advisory Committee of the Office of Defense Mobilization.

In 1949 when he returned to the Laboratories from the Atomic Energy Commission and Harvard, Dr. Fisk was placed in charge of research in the physical sciences.

Dr. Fisk received his bachelor's and doctor's degrees at M.I.T. From 1932 to 1934 he was a Proctor Travelling Fellow at Cambridge University, and from 1936 to 1938 a Junior Fellow in the Society of Fellows at Harvard. He served as Associate Professor of Physics at the University of North Carolina.

Dr. Fisk has served on government committees and other advisory boards, both during and since the war. He is a Fellow of the American Physical Society, the Institute of Radio Engineers, and the American Academy of Arts and Sciences, and was recently elected a member of the National Academy of Sciences.

ESTILL I. GREEN

Estill I. Green has had a long and varied career that includes nearly thirty-five years with the Bell System. Before his appointment as Director of Military Communication Systems in 1953, he had served as Director of Transmission Apparatus Development since 1948.

Mr. Green received an A.B. degree from Westminster College (Fulton, Missouri), engaged in graduate studies at the University of Chicago and returned to Westminster College as Professor of Greek. During World War I he saw overseas service as a captain of Infantry and after the war received the degree of B.S. in Electrical Engineering (summa cum laude) from Harvard University.

Joining the Development and Research Department of the A. T. & T. Co. in 1921, he became concerned with Systems Engineering work on multiplex telephone and telegraph systems. In 1934 he was transferred to Bell Telephone Laboratories, becoming Carrier Transmission Engineer in 1938.

During World War II, Mr. Green was responsible for the development of microwave test equipment for radar systems, radio monitoring and jamming equipment. Following that war he was named Assistant Director of Transmission Development with responsibilities including short-haul carrier, general carrier and broad-band carrier terminals, voice-frequency systems, and various types of transmission testing systems.

Mr. Green is a Fellow of the American Institute of Electrical Engineers and of the Institute of Radio Engineers.

Other Organization Changes

New general department heads reporting to Mr. Green are M. L. Almquist, named Director of Systems Engineering I, P. W. Blye, named Director of Systems Engineering II, and F. J. Singer, named Director of Systems Engineering III.

Heading a new general department reporting to Vice President G. N. Thayer is J. A. Morton, with the title of Director of Device Development. M. B. McDavitt continues as Director of Transmission Development. Also in Mr. Thayer's area, G. W. Gilman has been appointed Director of Telegraph, Signaling and Special Systems Development and heads a new general department for the development of special systems, including telegraph, data, signaling and control systems.

In Vice President W. C. Tinus' area of work for the military, R. R. Hough heads a new general department as Director of Military Electronics Development II.

P. S. Olmstead Appointed by Rutgers

Paul S. Olmstead, statistical consultant for the Laboratories, has been appointed an Honorary Professor of Statistical Quality Control in the Mathematics Department of University College, Dr. Lewis Webster Jones, Rutgers president announced recently.

Dr. Olmstead, who has been a pioneer in the development and operation of statistical quality control, joins Walter A. Shewhart of the Laboratories in serving as an Honorary Professor of Statistical Quality Control at Rutgers. He will serve on committees in connection with the graduate program in Applied Statistics, give special lectures, and advise on research problems and new courses in that program. Dr. Olmstead has been associated with the Laboratories since 1925, most recently as a consulting analyst on major military projects.

Patents Issued to Members of Bell Telephone Laboratories During the Months of March and April

Anderson, A. B. – *Cutaneous Signaling* – 2,703,344.

Anderson, A. E. – *Gas Discharge Transmit-Receive Switch* – 2,706,263.

Anderson, A. E. – *Storage Tube Circuit* – 2,706,264.

Babcock, W. C. – *High Gain Antenna* – 2,706,779.

Best, F. H. – *Method of Constructing A Helix Assembly* – 2,706,366.

Bjornson, B. G. – *Two-Step Lockout System* – 2,706,221.

Bjornson, B. G. – *Transistor Lockout Circuit* – 2,706,222.

Brewer, S. T. – *Electromechanical Switch* – 2,706,756.

Goss, F. A., Jr. – *Mechanical Stabilizer for Supporting Radar Antenna* – 2,706,781.

Haskell, F. V., Sutton, S. M., and Walter, O. L. – *Method and Apparatus for Installing Aerial Cable* – 2,703,218.

Hensel, W. G. – *Crystal Controlled Oscillators* – 2,706,783.

Holden, L. T. – *Coin Signal for Telephone Pay Stations* – 2,705,472.

Kleimack, J. J., and Trent, R. L. – *Semiconductor Signal Translating Devices and Method of Fabrication* – 2,705,768.

Krom, M. E. – *Testing Small Private Branch Exchange Trunk Groups* – 2,706,749.

Lewis, W. D. – *Directive Antenna Systems* – 2,705,754.

Lovell, C. A., and Murphy, O. J. – *Polytonic High Speed Calling Signal Generator* – 2,706,223.

Mason, W. P. – *Polarization Process for Pseudocubic Ferroelectrics* – 2,706,326.

Miller, R. L. – *High Speed Continuous Spectrum Analysis* – 2,705,742.

Mills, J. K., and Ross, W. S. – *Voltage Testing Circuit* – 2,706,258.

Mumford, W. W. – *Broad Band Microwave Noise Source* – 2,706,782.

Mumford, W. W. – *Noise Source* – 2,706,784.

Murphy, O. J., see Lovell, C. A.

Ross, W. S., see Mills, J. K.

Sutton, S. M., see Haskell, F. V.

Taylor, E. R. – *Scanning Panoramic Receiver System* – 2,704,325.

Teal, G. K. – *Method of Producing a Semiconductor Element* – 2,703,296.

Townes, C. H. – *Frequency Selective Systems* –2,707,235.

Townes, C. H. – *Frequency Stabilization of Oscillators* – 2,707,231.

Trent, R. L., see Kleimack, J. J.

Walter, O. L., see Haskell, F. V.

Wrathall, L. R. – *Pulse Regeneration* – 2,703,368.

Fellowship Program Announced

The Laboratories announced recently the establishment of a fellowship program through which it will grant funds for students doing graduate study in electrical communications.

To be known as Bell Telephone Laboratories Fellowships, the awards are for study of one or two years, leading to a doctorate. Each fellowship carries a grant of $2,000 to the fellow, and an additional $2,000 to cover tuition, fees and other costs to the institution at which he chooses to study.

Recipients of the fellowships will not be required to limit their study to electrical engineering, although the field of study and research must have a bearing on electrical communications. They may, for example, pursue various branches of mathematics, physics, chemistry, engineering mechanics and mechanical engineering. Fellows may choose any academic institution within the United States.

The new awards continue a ten-year program of the Bell System in aiding graduate study. The program now being concluded is known as the Frank B. Jewett Fellowships awarded since 1945 to post-doctoral students in the physical sciences. The Jewett awards were set up to honor the late Dr. Frank B. Jewett, who retired in 1944 from Bell Telephone Laboratories, which he had headed from its organization in 1925. Dr. Jewett had also served as Vice President of the American Telephone and Telegraph Company, where he was in charge of development and research. A trust fund, administered by Bell Laboratories, has provided for the fellowships. In the last ten years, 51 one-year awards have been made to 41 students, ten awards having been made to the same persons for a second-year continuation of their research.

Their researches have been carried on at 14 separate institutions. Five Jewett Fellows are currently completing their final fellowship year. Of the others, all but one have entered university teaching, and several are now full professors. The Jewett awards were about evenly divided among the fields of chemistry, mathematics and physics.

Talks by Members of the Laboratories

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

I.R.E. – U.R.S.I. (Union Radio Scientifique Internationale)
National Bureau of Standards, Washington, D. C.

Beck, A. C., and Mandeville, G. D., Microwave Traveling Wave Tube Millimicrosecond Pulse Generators.

Crawford, A. B., and Hogg, D. C., Measurement of Atmospheric Attenuation at Millimeter Wavelengths.

DeLange, O. E., The Regeneration of Binary Microwave Pulses.

Fox, A. G., Wave Coupling by Warped Normal Modes.

Hogg, D. C., see Crawford, A. B.

Mandeville, G. D., see Beck, A. C.

Mumford, W. W., and Schafersman, R. L., Data on the Temperature Dependence of X-Band Fluorescent Lamp Noise Generators.

Robertson, S. D., The Ultra-Bandwidth Finline Coupler.

Schafersman, R. L., see Mumford, W. W.

Other Talks

Anderson, A. E., Large Area Silicon Rectifiers and Solar Converters, A.I.E.E. Middle Eastern District Meeting, Columbus, Ohio.

Becker, J. A., Seeing Individual Atoms and Molecules Adsorbed on a Tungsten Surface, Sigma Xi, St. Louis University, St. Louis, Mo.

Bozorth, R. M., Some Magnetic, Electrical and Optical Properties of Electrolytic and Evaporated Films, University of Algiers, Algeria.

Brangaccio, D. J., see Sullivan, J. W.

Brattain, W. H., The Role of Surfaces or Phase Boundaries in Semiconductor Electronics. Solid State Seminar, Department of Physics, University of California, Berkeley.

Brattain, W. H., see Garrett, C. G. B.

Bridgers, H. E., Transistor Chemistry, Scientific Research Society, Lever Brothers Research Laboratories, Edgewater, N. J.

Buck, T. M., and McKim, F. S., Depth of Surface Damage Due to Abrasion on Germanium, Electrochemical Society, Semiconductor Symposium, Cincinnati.

Dacey, G. C., Unipolar, Analog, and Field-Effect Transistors, Electronic Components Conference, Los Angeles.

Darlington, S., An Introduction to Time-Variable Networks, Symposium on Circuit Analysis, University of Illinois, Urbana.

Dewald J. F., Experiments on the Formation of Anode Films on InSb, Electrochemical Society, Semiconductor Symposium, Cincinnati.

Dodge, H. F., and Torrey, Miss M. N., A Check Inspection and Demerit Rating Plan, American Society for Quality Control, Ninth Annual Convention, New York City.

Early, J. M., The Intrinsic Barrier Transistor, I.R.E. Professional Group on Electron Devices, National Bureau of Standards Auditorium, Washington, D. C.

Early, J. M., Junction Transistors for Very High Frequencies, A.I.E.E. Middle Eastern District Meeting, Columbus, Ohio.

Ebers, J. J., Junction Transistors for Switching Applications, A.I.E.E. Middle Eastern District Meeting, Columbus, Ohio.

Eigler, J. H., see Sullivan, M. V.

Elliott, S. J., Solderless Wrapped Connections, National Security Industrial Association, Improved Electrical Connections Subcommittee, Long Island City.

Fagen, M. D., A Method for Highly Precise Frequency Measurements on Quartz Crystal Units, Signal Corps Frequency Control Symposium, Asbury Park, N. J.

Ferrell, E. B., New Techniques in Control Charting, American Society for Quality Control, Albany Section, Albany, N. Y.

Fleckenstein, W. O., Electronic Switching Techniques, Engineering Department, Pennsylvania Bell Telephone Company, Pittsburgh.

Fleckenstein, W. O., Mechanized Intelligence, A.I.E.E.-I.R.E., Pittsburgh Sections, Pittsburgh.

Fox, A. G., Behavior of Ferrites in Waveguides, I.R.E. Monmouth Section, Little Silver, N. J.

Fuller, C. S., Bell Solar Battery, Thiokol Technical Club, Trenton, N. J.

Galt, J. K., Ferromagnetic Resonance Losses in Nickel-Iron Ferrites, Symposium on Relaxation and Remagnetization Processes in Ferromagnetic Materials, Armour Research Foundation, Chicago.

Garrett, C. G. B., The Science Behind Reliability of Semiconductor Devices, Electronic Components Conference, Los Angeles.

Garrett, C. G. B., and Brattain, W. H., Holes and Electrons in Germanium Electrodes, Electrochemical Society, Semiconductor Symposium, Cincinnati.

Goeller, L. F., Jr., A Rainfall Rate-Meter, Virginia Academy of Science, Madison College, Harrisonburg, Va.

Haynes, J. R., Fundamental Experiments in Transistor Physics, Physics Colloquium, University of Kentucky, Lexington.

Hayward, W. S., Jr., A Practical Method of Solving Markoff Chain Traffic Problems, American Statistical Association, Section on Physical and Engineering Sciences, New York University, New York City.

Herring, C., Electronic Transport Phenomena in Semiconductors, Physics Colloquium, Johns Hopkins University, Baltimore.

Herring, C., Surface Energy of Crystals and Its Role in Sintering, Washington Philosophical Society, Washington, D. C., and Edison Laboratory, West Orange, N. J.

Keister, W., Digital Control, University of California, Berkeley.

Keister, W., Mechanized Intelligence, Du Pont Company, Philadelphia.

Koerner, L. F., Methods of Obtaining Reduced Tolerances in Crystals Over a Wide Temperature Range, Signal Corps Frequency Control Symposium, Asbury Park, N. J.

Kohman, G. T., The Migration of Silver Through and on the Surface of Insulating Materials, Electronic Components Conference, Los Angeles.

Kompfner, R., High Frequency Tubes, U. S. Naval Reserve, Electronic Company, New York City.

Kompfner, R., Recent Advances in Microwave Tubes, I.R.E., Evansville-Owenboro Section, Evansville, Ind., and I.R.E. Louisville Section, Louisville, Ky.

Kramer, H. P., Perturbation of Differential Operators, Spectral Theory Seminar, Yale University, New Haven.

Landgren, C. R., A Review of the Theories of the Kinetics of Nucleation and Crystal Growth, American Institute of Chemical Engineers, Houston, Texas.

Law, J. T., and Meigs, P. S., The Effect of Water Vapor on Germanium and Silicon Junctions, Electrochemical Society, Semiconductor Symposium, Cincinnati.

Lewis, W. D., The Role of Computers in Automation, Centennial Symposium, Michigan State College, Lansing.

McKim, F. S., see Buck, T. M.

Meigs, P. S., see Law, J. T.

Moll, J. L., Silicon Transistors, A.I.E.E. Middle Eastern District Meeting, Columbus, Ohio.

Murphy, R. B., Problems of Selective Assembly, American Society for Quality Control, Ninth Annual Convention, New York City.

Paterson, E. G. D., An Overall Quality Assurance Plan, American Society for Quality Control, Ninth Annual Convention, New York City.

Pearson, G. L., The Bell Solar Battery, Sigma Xi Lecture, University of Utah, Salt Lake City.

Pearson, G. L., Silicon in Modern Communications, Pacific Telephone and Telegraph Company, San Francisco, and Stanford Research Institute, Stanford, Calif.

Peterson, J. W., The Intrinsic Barrier Transistor, Electronic Components Conference, Los Angeles.

Pietenpol, W. J., Survey of Recent Reliability Studies, A.I.E.E. Middle Eastern District Meeting, Columbus, Ohio.

Ryder, R. M., Transistors Today, A.I.E.E. Middle Eastern District Meeting, Columbus, Ohio.

Schlaack, N. F., The History of Overseas Radio Telephone Operation and Operating Techniques, I.R.E. Subsection, Burlington, Vt.

Sears, R. W., A Regenerative Binary Storage Tube, Electronic Components Conference, Los Angeles.

Shackleton, S. P., Opportunities in Engineering, Morris Township Junior High School, N. J.

Shockley, W., Transistor Physics, Societe Royale Belge des Ingenieurs et des Industriels, Brussels, Belgium.

Smith, K. D., The Bell Solar Battery, Ninth Annual Battery Research and Development Conference, Asbury Park, N. J.

Sullivan, J. W., and Brangaccio, D. J., Broadband Oscilloscope Tube, Electronic Components Conference, Los Angeles.

Sullivan, M. V., and Eigler, J. H., Hydrides as Alloying Agents on Silicon, Electrochemical Society, Semiconductor Symposium, Cincinnati.

Terry, M. E., Examples of Quality Control of Residuals in Analysis of Variance, American Society for Quality Control, Ninth Annual Convention, New York City.

Thurber, E. A., A New Sintered Tungsten Matrix Cathode, Electrochemical Society, Electronics Division, Cincinnati.

Torrey, Miss M. N., see Dodge, H. F.

Tukey, J. W., Conclusions versus Decisions, American Statistical Association, Physical and Engineering Sciences Section, New York University, New York City.

Vacca, G. N., The Chemical Industry and You, Kiwanis Club, Cranford, N. J.

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:

Achenbach, C. H., Power Equipment for Telephone Central Offices, Telephony, **148**, Apr., 1955.

Beck, A. C., Measurement Techniques for Multimode Waveguides, Proc. I.R.E., MTT-3, pp. 35-41, Apr., 1955.

Bemski, G., Nierenberg, W. A., and Silsbee, H. B., Cosine Interaction in CsF and RbF, Phys. Rev., **98**, pp. 470-473, Apr., 1955.

Benes, V. E., On the Consistency of an Axiom of Enumerability, J. Symbolic Logic, **20**, p. 29, Mar., 1955.

Best, F. S., see Harrower, G. A.

Bittrich, G., see Compton, K. G.

Boyle, W. S., Self-Propagating Intermittent Discharge, J. Appl. Phys., **26**, pp. 584-586, May, 1955.

Boyle, W. S., and Germer, L. H., Arcing at Electrical Contacts on Closure Part VI – The Anode Mechanism of Extremely Short Arcs, J. Appl. Phys., **26**, p. 571, May, 1955.

Burns, F. P., and Quimby, S. L., Ordering Processes in Cu_3Au, Phys. Rev., **97**, pp. 1567-1575, Mar. 15, 1955.

Compton, K. G., Ehrhardt, R. A., and Bittrich, G., Brass Plating, J. Am. Electroplaters Soc., **41**, p. 1431, Dec. 1954.

Darlington, S., An Introduction to Time-Variable Networks, Proc. of Symposium on Circuit Analysis, pp. 5-1 to 5-25, May, 1955.

Ehrhardt, R. A., see Compton, K. G.

Feher, G., and Kip, A. F., Electron Spin Resonance Absorption in Metals, I – Experimental, Phys. Rev., **98**, pp. 337-348, Apr. 15, 1955.

Felch, E. P., and Israel, J. O., A Simple Circuit for Frequency Standards Employing Overtone Crystals, Proc. I.R.E., **43**, pp. 596-602, May, 1955.

Frost, H. B., Cathode Interference Impedance Desimplified, Trans. P.G.R.Q.C. **5**, pp. 27-33, Apr., 1955.

Geller, S., Crystal Structure of RhTe and $RhTe_2$, Am. Chem. Soc. J., **77**, pp. 2641-2644, May 5, 1955.

Germer, L. H., see Boyle, W. C.

Harrower, G. A., Best, F. S., and Machalett, A. A., Coaxial Electrical Connection Into Vacuum, Rev. Scientific Instruments, **26**, p. 404, Apr., 1955.

Hochgraf, Lester, and Watling, R. G., Telephone Lines for Rural Subscriber, A.I.E.E. Commun. and Electronics, **18**, pp. 171-176, May, 1955.

Hohn, F., First Conference on Training Personnel for the Computing Machine Field, Am. Math. Monthly, **62**, pp. 8-15, Jan., 1955.

Holden, A. N., Matthias, B. T., Merz, W. J., and Remeika, J. P., New Class of Ferroelectrics, Phys. Rev., Letter to the Editor, **98**, p. 546, Apr. 15, 1955.

Hooton, J. A., and Merz, W. J., Etch Patterns and Ferroelectric domains in $BaTiO_3$ Single Crystals, Phys. Rev., **98**, pp. 409-413, Apr. 15, 1955.

Israel, J. O., see Felch, E. P.

Karnaugh, M., Pulse-Switching Circuits Using Magnetic Cores, Proc. I.R.E., **43**, 570-583, May, 1955.

Keywell, F., Measurements and Collision – Radiation Damage Theory of High-Vacuum Sputtering, Phys. Rev., **97**, pp. 1611-1619, Mar. 15, 1955.

Kohn, W., and Luttinger, J. M., Theory of Donor Levels in Silicon, Phys. Rev., Letter to the Editor, 97, p. 1721, Mar. 15, 1955.

Luttinger, J. M., see Kohn, W.

Machalett, A. A., see Harrower, G. A.

Malthaner, W. A., and Vaughan, H. E., Control Features of Magnetic-Drum Telephone Office, I.R.E. Trans. P.G.E.C., **4**, pp. 21-26, Mar. 1955.

Matthias, B. T., see Holden, A. N.

McSkimin, H. J., Measurement of the Elastic Constants of Single Crystal Cobalt, J. Appl. Phys., **26**, pp. 406-409, Apr., 1955.

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

Merz, W. J., see Hooton, J. A.

Morrison, J., and Zetterstrom, R. B., Barium Getters in Carbon Monoxide, J. Appl. Phys., **26**, pp. 437-442, Apr., 1955.

Newhouse, R. C., Feedback Relations in Military Weapon Systems, I.R.E. Trans. P.G.A.N.E.-1, **3**, pp. 24-27, Sept., 1954.

Pfann, W. G., Continuous Multistage Separation by Zone-Melting, J. Metals, **7**, pp. 297-303 (Part 2), Feb., 1955.

Pierce, J. R., Interaction of Moving Charges with Wave Circuits, J. Appl. Phys., **26**, pp. 627-638, May, 1955.

Prince, M. B., Silicon Solar Energy Cells, J. Appl. Phys., **26**, pp. 534-540, May, 1955.

Quimby, S. L., see Burns, F. P.

Remeika, J. P., see Holden, A. N.

Rose, D. J., and Brown, S. C., High-Frequency Gas Discharge Plasma in Hydrogen, Phys. Rev., **98**, pp. 310-316, Apr. 15, 1955.

Smith, B., and Boorse, H. A., Helium II Film Transport, I – The Role of Substrate, Phys. Rev., **98**, pp. 328-336, Apr. 15, 1955.

Tukey, J. W., Unsolved Problems of Experimental Statistics, Am. Stat. Assoc. J., **49**, pp. 706-731, Dec., 1954.

Van Roosbroeck, W., Injected Current Carrier Transport in a Semi-Infinite Semi-conductor and the Determination of Lifetimes and Surface Recombination Velocities, J. Appl. Phys., **26**, pp. 380-391, Apr., 1955.

Vaughan, H. E., see Malthaner, W. A.

Walker, L. R., and Wolontis, V. M., Large Signal Theory of Traveling-Wave Amplifiers, Proc. I.R.E., **43**, pp. 260-277, Mar., 1955.

Watling, R. G., see Hochgraf, Lester

Wolontis, V. M., see Walker, L. R.

Zetterstrom, R. B., see Morrison, J.