A crucial operation in fabricating semiconductor devices is to introduce into a crystal the right numbers of impurity atoms in the right places — an exceedingly complex problem when we work with minute amounts of impurities distributed in very thin layers of a solid material. Now, however, the technique of diffusing impurities from a gaseous state into the crystal has opened up the possibility of achieving high operating frequencies and high power-handling capacities never before possible with transistors and other semiconductor devices.

MORGAN SPARKS *Solid State Electronics Research*
W. J. PIETENPOL *Solid State Device Development*

Diffusion in Solids—a Breakthrough in Semiconductor Device Fabrication

A large part of the past history of semiconductor research and development has been characterized by attempts to produce single crystals of exceptional purity and to add to these crystals very small amounts of impurities in precisely specified regions. The first of these problems is not easily solved, but crystals are now available that are the purest substances known to man, some of them having less than one significant impurity atom for every ten billion atoms in the semiconductor. It is the second of these problems – the precise control of both amounts and locations of impurities – that is crucial to the fabrication of semiconductor devices.

During the past two years, Bell Telephone Laboratories scientists have succeeded in making a wide range of devices from silicon and germanium by using diffusion for this critical step. The method is basically simple, but a long and painstaking program has been necessary for its achievement. The development of diffusion for making transistors and other semiconductor devices has just begun, but there is good reason to believe that the result will be greater uniformity and reliability, lower cost, and superior performance. One dramatic result of the diffusion technique has already been described, however. The Bell Solar Battery,* a special type of photoelectric device that can be used for converting sunlight directly into electrical power, uses as its light-sensitive element a large-area diffused layer on a silicon crystal.

Diffusion is a special kind of mixing, a mixing which takes place on an atomic scale and which is very slow compared with mixing by stirring or convection. In gases and liquids, diffusion is a common experience. A drop of a colored dye in a glass of still water will mix completely by diffusion in about one hour. In solids, however, diffusion is ordinarily ignored. The reason it can be ignored is not that it doesn't happen, but that it is so very slow. The colored dye would diffuse throughout a cake of ice as well, but it would take millions of years.

All diffusion processes can be greatly speeded up by heat. At room temperature, it would take many thousands of years to perform the diffusion required to make a Bell Solar Battery, but in a furnace at about 1,300°C, one can be made in less than half an hour. The fact that a high temperature is required for such diffusion processes is fortunate; it

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* Record, *July,* 1955, *page* 241.

means that diffused layers of impurities will not change their characteristics under the ordinary conditions in which they are used.

There are additional reasons why diffusion is well suited to the introduction of impurities into a semiconductor crystal. Because the process is slow, the impurities can be moved very small distances with a fine degree of control. Because separate impurities move individually, their concentration and depth of penetration can be controlled and varied over a wide range. Since the impurities are introduced after the crystal is grown, the crystal itself can be grown under the simplest of all conditions – constant rate of growth from a uniform melt.* This is an important practical consideration, because simple conditions of growth lead to greater control of crystal properties. After growth, the crystal is cut into small pieces and exposed in a furnace to an atmosphere containing one or more impurities in small but known concentrations. At high temperatures these impurity atoms bombard the crystal surface and slowly force their way into the interior, following the predictable pattern of diffusion. By varying the amount, the kind and the sequence of introduction of impurities into the crystal, a variety of devices has been made.

The principles of diffusion have long been understood. However, the use of diffusion as a fabrication technique on a wide scale has been rather recent. The difficulty lay in perfecting the method so that only the wanted impurities were introduced during the heating. It is not easy to appreciate the magnitude of this problem, which arises from the fact that extremely small traces of many impurities have a marked influence on the electrical properties of semiconductors. It is necessary to keep all extraneous contamination well below the level of the impurity being purposely introduced, which may itself be so low in concentration that it cannot be detected by the most sensitive chemical analysis. Years of careful research by a number of scientists were required to identify and eliminate, one by one, the subtle causes of uncontrolled changes in the electrical properties of silicon and germanium crystals when they were heated to the temperatures necessary for diffusion applications. The history of this search, during which many preliminary conclusions depended upon indirect evidence and deductive reasoning, reads like a scientific detective story.

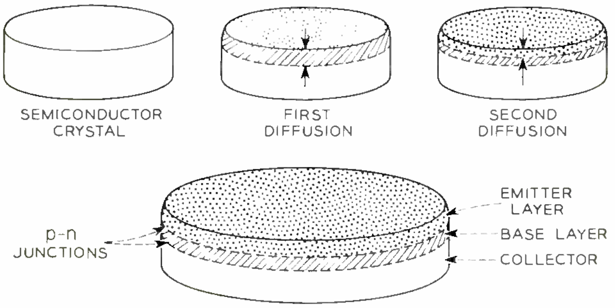

Fig. 1 — Double-diffusion into a semiconductor: first diffusion creates collector junction, second diffusion forms the emitter junction. Depths of diffused layers are greatly exaggerated.

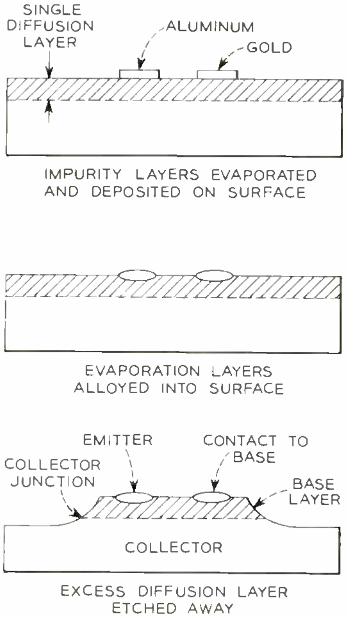

Fig. 2 — Single diffusion used in production of collector junction; emitter junction and base contact are produced by evaporation and alloying. Proportions are not to scale.

The degree of control achieved with diffusion techniques can be illustrated by its application to transistors. The region between the two junctions of a junction transistor is called the base region, and the thickness of this base region is the critical dimension of the transistor. The thinner it is, the higher the frequency to which the transistor will operate. When this region is formed by diffusion of impurities into a crystal, the transistor is called a diffused-base transistor.

As shown in Figure 1, we can make a diffused-base transistor by subjecting a piece of semiconductor crystal to two diffusions. The first and relatively deep diffusion (only about 0.0002 inch, however) is carried out with impurities that are electrically opposite to those already present throughout the crystal. The result of this first diffusion is a single p-n junction very slightly below the surface. This will become the collector junction of the transistor. The second and shallower diffusion is then carried out with impurities opposite to the kind used in the first diffusion; that is, impurities of the same kind as

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* RECORD, *February*, 1955, *page* 41.

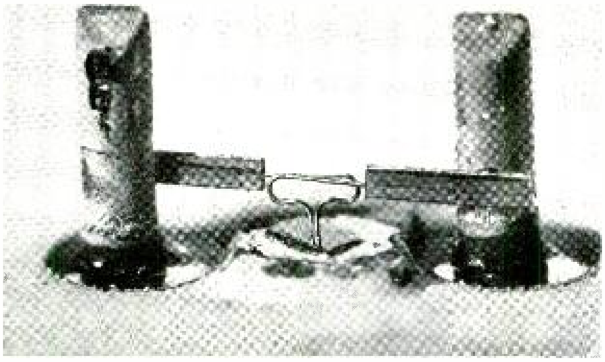

Fig. 3 — Internal structure of single-diffused germanium transistor. Bent wires from posts lead to emitter layer and base contact on surface of crystal.

those in the parent crystal. This second diffusion is performed with a sufficient concentration of impurity to overwhelm those introduced in the first diffusion, but penetration is only about half as deep. In this manner, a second p-n junction is produced at about half the depth of the first junction. This second junction serves as the emitter, and the exceedingly thin layer between the junctions becomes the base region of the transistor.

As an alternative, a similar type of diffused-base structure can be produced by employing only one diffusion and, instead of a second diffusion, using an evaporation and alloying technique to obtain the emitter junction. As indicated in Figure 2, an emitter impurity (aluminum) is evaporated and allowed to deposit in a very thin film on the single-diffused surface. At alloying temperature, the impurity melts into the surface and upon cooling is incorporated into the semiconductor in such a manner as to produce the second or emitter junction. This step requires great care to control the alloying depth, which determines the effective thickness of the base layer in the completed transistor.

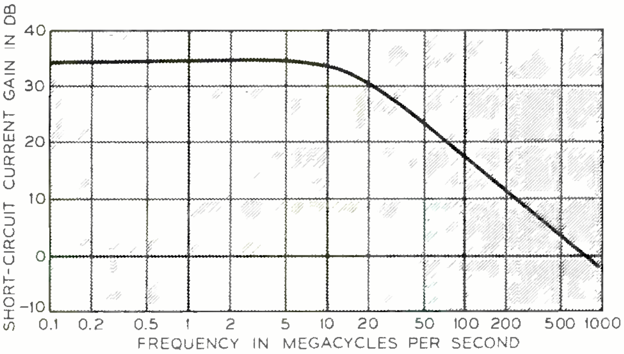

Fig. 4 — Gain-frequency characteristic of a typical Laboratories developmental model diffused germanium transistor (grounded emitter circuit), showing amplification into the 500-mc region.

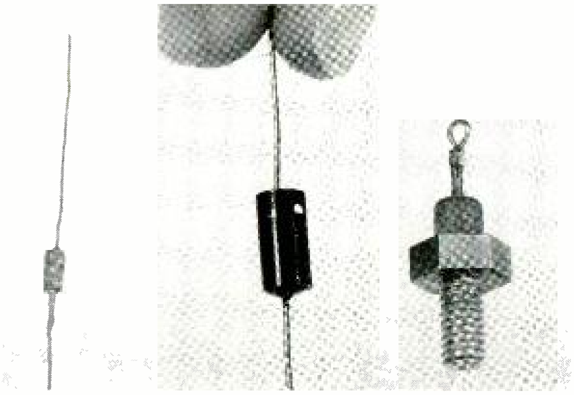

Fig. 5 — Laboratory models of diffused silicon power rectifiers; left to right, 0.25-ampere unit, 1-ampere unit, and 10-ampere unit.

As illustrated in Figure 2, a contact to the base layer is also evaporated and alloyed into the crystal. The "impurity" in this case is a gold-antimony alloy which when melted into the semiconductor does not result in a rectifying junction, but instead establishes a low-resistance ohmic contact to the base layer. Next, a very small area, which includes only the two alloyed contacts, is protected while all the rest of the diffused layer is etched away chemically, thus isolating the active part of the transistor on a raised area or "mesa". The etching process greatly reduces the area of the collector junction and consequently lowers the value of the collector capacitance. Small collector capacitance is required for high-frequency operation.

These are merely two methods by which diffusion may be used in the fabrication of semiconductor devices. Actually, diffusion is a quite general technique having a wide range of applications. Besides the fine degree of control of impurities that diffusion makes possible, it has the additional advantage that it does not disturb the original crystal lattice, as do all processes that involve melting the semiconductor to change the conductivities of selected portions of the structure. In the growing list of semiconductor materials, many have properties that preclude the use of previously available impurity "doping" techniques, which means that diffusion will undoubtedly become more and more important to semiconductor technology.

At Bell Laboratories, diffusion is already an important technique in semiconductor research and development. Diffused-base germanium transistors have been fabricated, for example, which amplify up to about 500 megacycles, and the performance

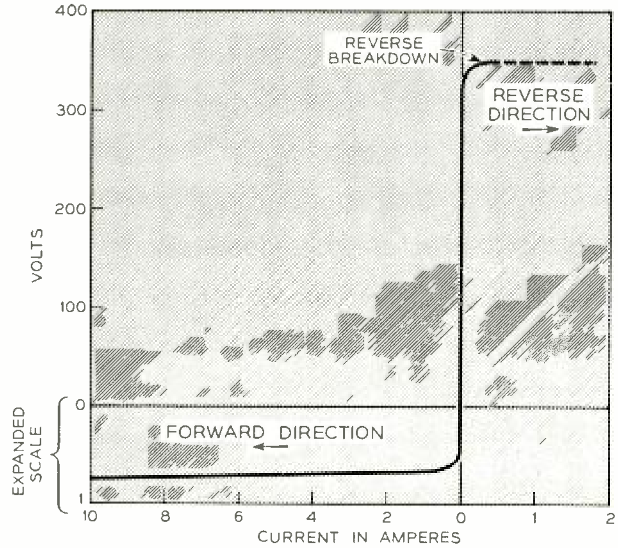

Fig. 6 — Voltage-current characteristic of laboratory model 10-ampere diffused silicon power rectifier, showing high current in the forward direction.

of selected units is even better. This is ten to fifty times higher than the amplifying frequencies previously obtainable with transistors. Furthermore, this newly accessible frequency range is a very important one. The germanium diffused-base transistor, for instance, could be used in television receivers for all currently assigned channels, including UHF. Figure 3 shows the internal structure of a germanium transistor fabricated by the single-diffusion method. In this illustration, the bent wires leading from the mounting posts on either side are joined to the alloyed emitter layer and base contact on the surface of the crystal. The "mesa" or region which remains after etching cannot be seen because it extends above the main portion of the germanium wafer only about one-tenth the diameter of a human hair. A typical gain-frequency characteristic for a unit of this type is shown as Figure 4.

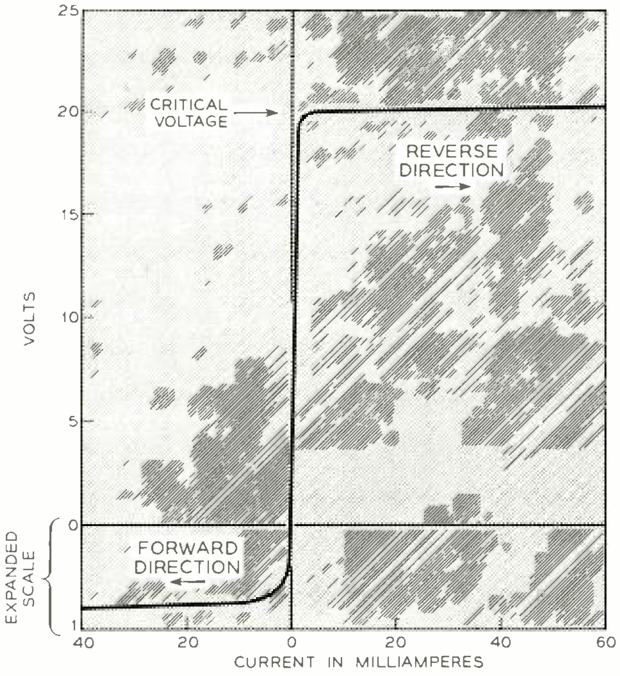

Fig. 7 — Characteristic of a laboratory model diffused silicon voltage limiter. Critical point at which current increases rapidly for small change in voltage can be tailored over a wide range of values.

Laboratory models of diffused-base transistors fabricated from silicon amplify up to about 120 megacycles. Although operating frequencies are thus seen to be lower than those of the germanium transistors, silicon units will nevertheless find a useful place in the Bell System. One reason is that silicon transistors can operate at higher ambient temperatures. Another and perhaps even more important reason is that silicon units when used as electronic switches have extremely high values of impedance in the nonconducting or "off" condition. This latter property will be particularly useful in new systems currently being designed.

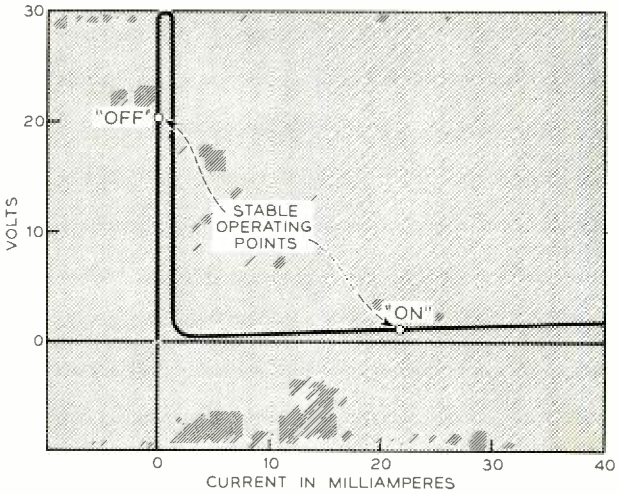

Fig. 8 — Characteristic voltage-current curve for the diffused silicon crosspoint switch, showing the high-impedance and low-impedance stable operating points of the device.

Such new and greatly improved performance features of transistors illustrate the importance of the diffusion techniques, but it should be emphasized that there are a number of other devices that employ diffusion to great advantage. It should also be pointed out that the development of diffusion, coincident with the availability of high-purity silicon material, has been a particularly important factor in the recent rapid progress in semiconductor technology. Besides the silicon transistor, another diffused silicon device has already been mentioned – the Bell Solar Battery. With this unit, about 11 per cent conversion of solar energy into electrical energy has been achieved, as compared to about 0.2 per cent for the best selenium photoelectric cells. In the silicon solar battery, diffusion produces a precisely controlled layer depth of about 0.0001 inch, which would be practically impossible with any other known method of introducing impurities into a crystal.

Diffusion into silicon has also proved to be a simple process by which high efficiency power rectifiers can be made.* Figure 5 shows the experimental design of three diffused silicon rectifiers with current-carrying capacities of 0.25, 1.0 and 10.0 amperes. In most circuits, these experimental units operate without special heat-removing arrangements, only the 10-ampere unit requiring a metal plate to serve as a "heat sink". Figure 6 is a typical voltage-current characteristic of a 10-ampere unit, and illustrates the ability of this device to deliver high currents at a low voltage drop in the forward or easy-current-flow direction. With this unit, power loss is only about 2 per cent of the dc output, and at the same time the unit can operate in ambient temperatures as high as 300°F. In the laboratory, potentials as high as 1,000 volts have been applied in the reverse or difficult-current-flow direction before breakdown of the rectifying junction occurs.

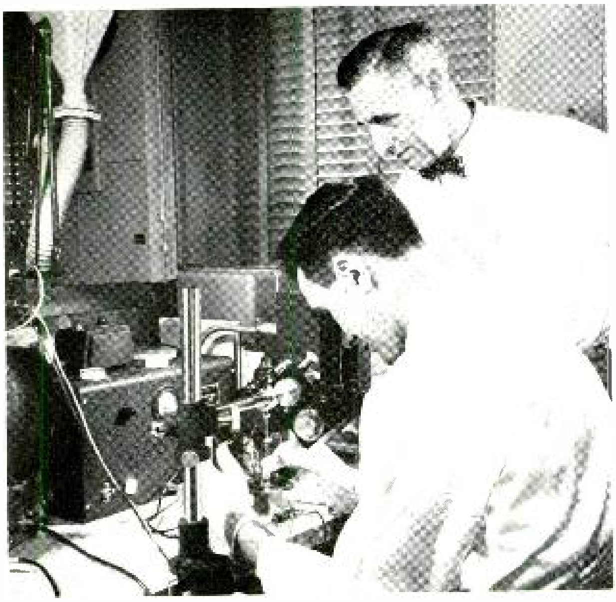

Fig. 9 — Assembly operation in which leads are attached to emitter layer and base of diffused transistors. L. P. Meloa is using the microscope, as J. F. Grandner looks on.

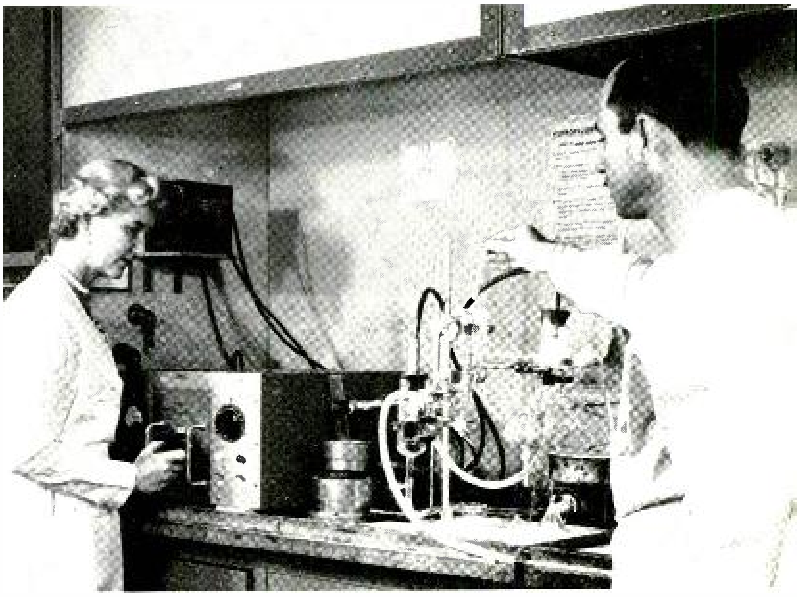

Fig. 10 — Washing operation in which foreign material is removed from transistor structure. Miss L. A. Leahy, left, and G. J. Sayko.

The diffusion technique applied to silicon has also given circuit designers a new tool in the form of diode limiters. In electronic equipment it is often necessary to regulate a voltage so that it does not increase above a certain maximum. The type of voltage-current characteristic in question is shown as Figure 7. The voltage to be limited is applied across the diffused diode in the reverse direction, and the current in this direction remains extremely small until the critical voltage is reached. Beyond this point the current rapidly increases with only a very small increase in voltage. The resistance along this high-current portion of the characteristic is approximately three to four ohms.

One advantage of using diffusion in the fabrication of silicon limiters is that this "reverse breakdown" voltage can be tailored to specific values within wide limits. Experience has shown that diffused silicon limiters can be designed to have reverse breakdown voltages from 6 to about 250 volts, accurate within plus or minus 5 per cent. Time and temperature of diffusion, and resistivity of the starting material, are the variables that determine the specific breakdown value within this range.

Another recently developed silicon device made possible by the diffusion breakthrough is the silicon "crosspoint switch". This is a two-terminal device, as distinct from a three-terminal device like a tran-

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* RECORD, *May*, 1956, *page* 161.

sistor. The crosspoint switch is somewhat analogous to a relay, in the sense that it has an "on" and an "off" condition. As shown by the voltage-current characteristic, Figure 8, it has two stable operating points, one at very high impedance and the other at very low impedance. Thus, the device is switched from "off" to "on" by a voltage pulse which forces the operating point into the low-impedance condition. This type of switching has been achieved previously with transistors, but the diffused silicon crosspoint switch simplifies circuitry associated with the switching action. When it is in the "off" condition the resistance of this crosspoint switch is in the region of 100 megohms, but in the "on" condition it drops to only five or six ohms.

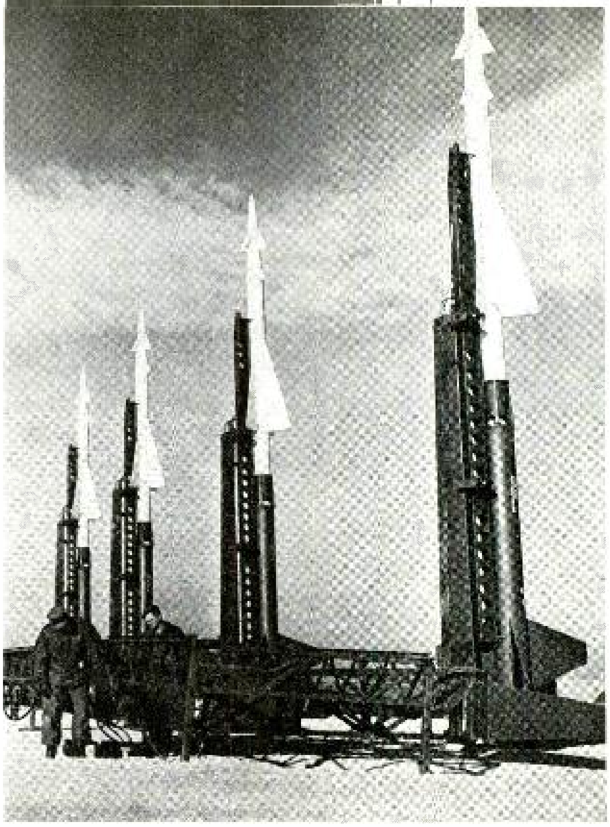
Diffusion as a method for fabricating solid-state devices is still in its infancy. It arose out of a desire to learn more about the fundamental way in which atoms move through a crystal, and it is now being applied to the practical problems of communications technology. Its significance is summarized by saying that it permits precise control of a crucial fabrication step, that it does not affect the crystal lattice of the original material, and that when used with high-purity silicon and other semiconductors, it has resulted in a series of important new devices.

THE AUTHORS

Morgan Sparks received the B.A., 1938, and M.A., 1940, degrees from Rice Institute and, studying under a Rockefeller Foundation Fellowship, received his Ph.D. degree from the University of Illinois in 1943. That year he joined the Laboratories and was assigned to an electrochemical group engaged in military projects. After World War II he conducted research on primary batteries and electrolytic rectifiers until 1948, when he turned his attention to transistor electronics. In this field he has been especially concerned with the development of p-n junction transistors and other p-n junction devices, and in 1955 he was appointed Director of Solid State Electronics Research. Dr. Sparks is a member of the American Chemical Society, the American Physical Society, Phi Beta Kappa, Sigma Xi and Phi Lambda Upsilon.

W. J. Pietenpol received the B.S. degree in Electrical Engineering from the University of Colorado in 1943, and after several years with the Radio Corporation of America, he continued his education at Ohio State University. At Ohio State he held Eastman Kodak, Westinghouse, and Research Foundation fellowships, and received his Ph.D. degree in 1949. He then joined the transistor design group at Bell Laboratories, where he has been primarily concerned with the development of junction diodes and transistors. In 1953 he was appointed Transistor Development Engineer at the Allentown Laboratory and in 1955 returned to the Murray Hill location as Director of Development – Solid State Devices. Dr. Pietenpol is a member of the American Physical Society, Sigma Xi, Tau Beta Pi, Phi Beta Kappa, and the Institute of Radio Engineers.

Maintenance Support of NIKE



J. H. HERSHEY *Military Design Engineering*

Effective protection of our vital areas by the NIKE guided missile requires the utmost in reliability for that system. To provide this high degree of dependability, a maintenance plan has been devised for NIKE, whereby plug-in units, on suspicion of malperformance, are replaced by units known to be good. The suspected units are later serviced in two trailer-mounted "electronic shops" by an elaborately conceived but simply executed maintenance procedure that can be used by Service personnel.

The great emphasis that the Bell System places on maintenance is reflected in the work Bell Telephone Laboratories does for the armed services. It was not enough for the Laboratories merely to design and develop the complex electronic equipment of the NIKE guided missile system, for this weapon is of such a nature that it absolutely must work when it is needed. New maintenance procedures and equipment were therefore prepared as insurance against failure at a crucial moment.

The maintenance of NIKE differs from the maintenance of a telephone system in one major respect. In the armed services, men must be trained quickly for the jobs they are to perform, and often their periods of service are short. This means that maintenance techniques had to be devised which could be performed by a limited number of personnel with little experience.

It is important to remember too that maintenance of NIKE, like maintenance in the Bell System and in many other areas, is divided into three broad categories. First, the people who actually use the equipment must be depended upon for a limited amount of maintenance; second, another level of personnel must exist to perform more extensive tests, adjustments and repairs within the limitations of a branch, district or field location. The third level of maintenance must have the capabilities of the first two plus the means for repairing units to the extent that it may be necessary to manufacture new parts. This third level could be considered as being military depots or suppliers' manufacturing plants.

In a system like NIKE, the ideal is to have all the equipment composed entirely of replaceable plug-in units, related in such a way that routine maintenance checks of the system will provide easily detected symptoms of malfunctioning. Operating personnel trained in the operation of the equipment and familiar with it on a functional basis may then quickly exchange good units for those suspected of malfunctioning. The units removed can later be sent to the second level of maintenance with no interruption in the readiness of the NIKE system. At the second level of maintenance, as much of the ator judgment in determining the suitability of a particular unit.

This method of maintenance is readily adaptable to any complicated electronic system. It should be kept in mind, however, that its success depends upon the design of the equipment to be tested. This equipment must take full advantage of the use of small plug-in units, and each of the units ideally should have only one measurable function. Such an idealized system can serve both for improvement of the preventive maintenance program in the operating system, and for second-level maintenance of the sort described here. Further, this method of maintenance more than any other type requires that the operating equipment be brought to a high state of development before production begins. The reason for this is modifications in units, if not closely integrated with the entire operation-testing program, can complicate the maintenance system.

In the NIKE test equipment, the problem has been alleviated by assigning testing responsibilities to the various consoles on a functional basis, as well as by the use of the patch card arrangement for establishing the individual test set-ups required. This method is entirely consistent with modern trends in electronics; as equipment gets more and more complex, maintenance must correspondingly become more and more specialized and simplified. The vast maintenance activity must be rigidly and logically broken down into a larger number of individual steps, each quite easily accomplished. This may well lead us toward the situation where, some day, even some forms of maintenance will be accomplished by automation.

THE AUTHOR

J. H. HERSHEY joined The Ohio Bell Telephone Company in 1928 on a work assignment of the Cooperative Engineering School of the University of Akron. During the next fourteen years he held a number of positions, including plant supervisor, transmission inspector, inductive-coordination engineer, and foreman in the Installation, Testing, and Repair Departments. He was licensed as a commercial radio operator first-class in 1936 and as a professional engineer in the State of Ohio in 1940. In 1942 he came to Bell Telephone Laboratories on loan and in 1945 he transferred to the Laboratories. In February of 1952 he transferred to Bell Telephone Laboratories, Burlington, N. C., in charge of a department in radar development. In October, 1955, he returned to the Whippany Laboratories as a subdepartment head to establish a reliability program for the Military Electronics Organization.

Members of the Laboratories Commended by the Department of State

A. G. Jensen, Laboratories Director of Visual and Acoustics Research, and F. H. Willis, Systems Engineering Department II, were commended by the Department of State recently for their part in the Eighth Plenary Assembly of the International Consultative Committee held in Warsaw, Poland.

A letter from the Department of State said in part "Mr. Jensen was United States Spokesman on Study Group XIV (Vocabulary) and also assisted with the work of Study Group XI (Television). He handled all of his assignments in such an excellent manner as to reflect credit upon the United States." In addition, Mr. Jensen was one of the six candidates for the position of Director.

"Dr. Willis was a very valuable member of the Delegation. His wide technical experience made him admirably fitted to assist with the work of a number of Study Groups, especially those dealing with propagation studies and telephone transmission questions. In addition Dr. Willis carried a great part of the Delegation's work on the Drafting Committee where he assisted with the drafting and editing of the English version of the final documents of the Assembly. He handled all of the assignments in such an excellent way as to reflect credit upon the United States."

E. B. Bemis of the A.T.&T. Operation and Engineering Department was similarly commended.

Corrosion— The Constant Enemy of Metals

A. MENDIZZA *Chemical Research*

One of the major concerns of the Chemical Research Department at Bell Laboratories is corrosion—the constant enemy of metals and a huge item of expense for the nation's industries. Besides the usual problems of atmospheric moisture and chemicals, telephone engineers must also be aware of corrosive environments in the earth and under water. A large fund of experience and of experimental data is available to aid in the design of equipment that will successfully resist attack by the natural elements.

Corrosion is the deterioration or destruction of metals by chemical action, and it encompasses a wide range of reactions between metals and their environments. In elementary terms, however, a corroding metal behaves chemically like the anode in a simple galvanic cell. That is, like the anode of a cell, a corroding metal goes into solution in an electrolyte, giving up electrons in the process. The "electrolyte" in a corrosive environment usually consists of water or moisture which contains some dissolved material that makes it electrically conductive.

Just as a galvanic cell requires both an anode and a cathode, so a corroding metal must have associated with it a cathodic element. This may be a second metal, in which case the system is termed a bimetallic couple, or the cathodic element may merely be another area of the same metal with somewhat different metallurgical or physical properties. By this chemical process, metals as a rule tend to revert to the more stable form in which they are generally found in nature. Iron, for instance, has a great affinity for oxygen and therefore will rust (oxidize) readily if exposed to the proper environment. The same can be said of most other metals, except perhaps the so-called noble metals like gold, platinum, and rhodium. Corrosion prevention and control, therefore, is largely a struggle against nature.

The annual national bill directly and indirectly attributable to corrosion has been estimated at more than five billion dollars. The Bell System, of course, pays its share of this huge corrosion bill. Were it not for the continuous effort and surveillance of corrosion scientists and engineers, the cost of corrosion would undoubtedly be many times greater.

At Bell Laboratories, the responsibility of providing development and design engineers with the right information regarding the use of metals and protective coatings rests with the Corrosion and Finishes Development Group of the Chemical Department. Even the most carefully engineered plant, equipment or apparatus may occasionally get into corrosion difficulties, usually as a result of some peculiar situation or some unforeseen circumstance. It is the job of this group to analyze these problems, suggest remedial actions, devise corrective measures and generally to assist in eliminating or at least in reducing these difficulties.

Telephone equipment, with its diversity of service environments, presents many interesting aspects of corrosion control and prevention. Every item must function well without causing interruption of service due to corrosion. In addition, there are corrosion problems which are peculiar to the requirements of the military services. Some of the environmental conditions under which military equipment must operate are exceptionally severe.

Laboratory studies provide basic information about the mechanism of corrosion and give indications of the suitability of various materials for particular uses. Exposure of materials to selected corrosive environments serves to complement the store of information gathered from field experiences as well as to obtain new data. Atmospheric exposure test sites are maintained at such diverse geographical and climatic locations as New York City; Perrine, Florida; Steubenville, Ohio; San Francisco and Point Reyes, California; and Kure Beach, North Carolina. These locations represent a broad cross section of typical atmospheric environments found within the continental United States. They range from the severe industrial atmosphere at Steubenville, Ohio, to the extreme marine location near the Pacific Ocean at San Francisco. The former is characterized principally by heavy gaseous sulfurous contaminations resulting from intense industrial activity as well as from prolonged periods of high humidity. The San Francisco site, on the other hand, is noted for its strongly saline atmosphere. Dense fogs, a fine salt mist carried ashore by an almost constant sea breeze, and a scarcity of rainfall to wash off the salt, combine to make this area one of the most corrosive of marine environments. The remaining test sites are representative of environments intermediate in corrosive intensity between these extremes.

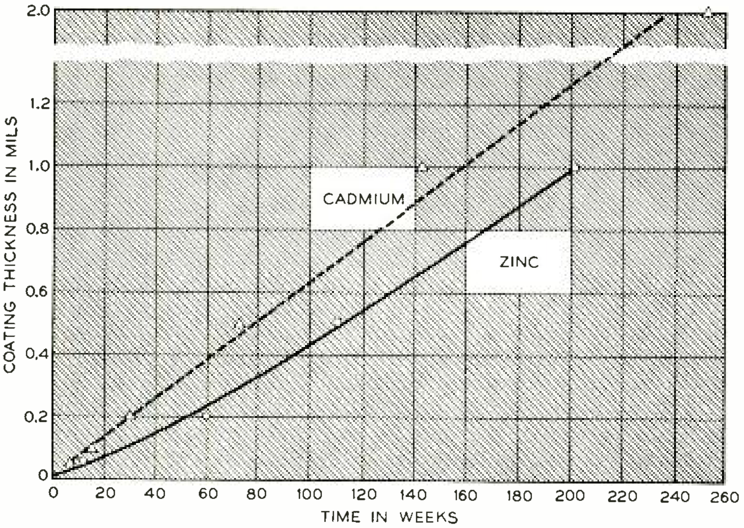


Fig. 1 — Cadmium- and zinc-coated steel; time taken for surfaces to acquire 50 per cent rust.

An example of the type of data obtained from such test locations is shown in Figure 1. Steel panels with two different types of electroplated coatings — cadmium and zinc — were exposed in a New York City test location. Different thicknesses of the cadmium and zinc were used, and the time taken for 50 per cent of the metal area to become covered with rust was observed. In this particular case, the superiority of the zinc coating is clearly evident from the graph.

Laboratory tests and experiments are also performed to add to this store of information. Valuable information is being obtained, for example, from studies of the electrode potentials of metals in various test environments. The electrode potential of a metal in a solution is the voltage measured between the metal and a reference electrode, both immersed in the same solution. It is also called the solution pressure of the metal, and is a measure of the tendency of the metal to go into solution, or, in other terms, to corrode.

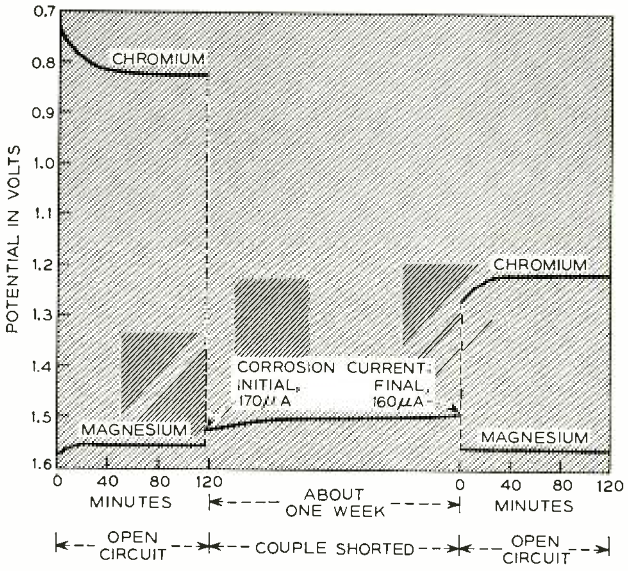


Fig. 2 — Results of electrode-potential and corrosion current tests of bimetallic couples as conducted in laboratory. Values of corrosion currents are indicated in this diagram at the points where the galvanic circuit was first closed and where the short circuit was finally removed.

Of particular interest is the study of the corrosive tendencies of a metal when in contact with another metal, for example, iron in contact with copper. In any bimetallic arrangement such as this, the single dominant factor which determines the amount of corrosion is the current that flows between the two metals. Laboratory measurements of such currents, together with electrode potential measurements, have given valuable indications of the expected behavior of dissimilar metal couples in various environments. Figure 2 shows the test results in an evaluation of the galvanic behavior of one such bimetallic couple – chromium-magnesium – in a dilute salt solution (0.01 normal, or about 0.58 grams of sodium chloride per liter). In this illustration, the open-circuit potentials of the individual electrodes were measured over a period of 120 minutes, both at the start and at the end of the experiment. The values for the initial and final galvanic currents and the potential of the short-circuited couple are also shown (central part of the graph).

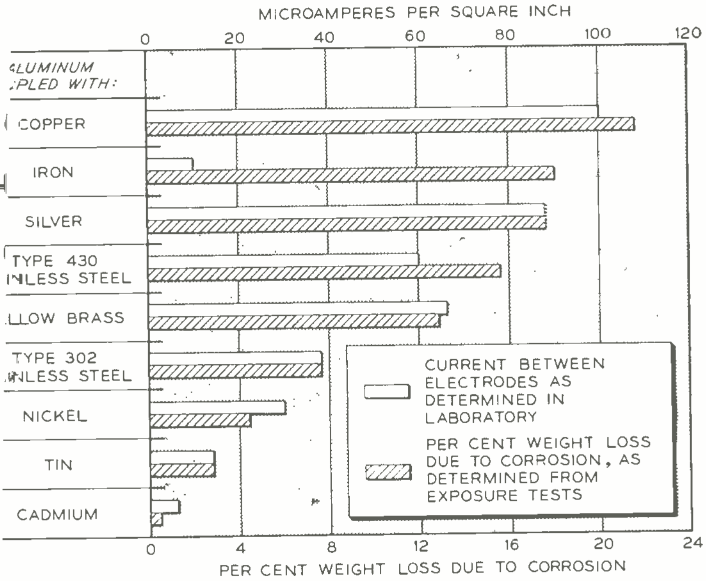


Fig. 3 — Comparison of field tests (shaded bars) and laboratory tests (white bars).

Such laboratory studies are frequently conducted in parallel with outdoor exposure tests. Figure 3 compares results obtained from such an exposure at Point Reyes, California, with those obtained by the potential-current method in a weak salt solution. The results shown are those for aluminum coupled with a variety of more noble metals. In this illustration, the cross-hatched bars show the corrosion weight loss of the aluminum, and the white bars show the equilibrium currents of the bimetallic couples per square inch of contact surface, as determined in the laboratory. With one possible exception, there is a remarkable agreement between the two sets of data. The apparent discrepancy in the case of the iron-aluminum couple indicates that the corrosion current did not reach equilibrium. It can thus be seen how preliminary laboratory tests will in many instances give a good first approximation to the results expected in the field.

In so far as possible, other accelerated tests are also used to predict the service life of metals and protective coatings. One of these is the standard salt-spray test. In this test, a finely atomized solution of common salt is allowed to deposit by gravity on the specimen.* The test has some deficiencies as a standard for evaluating the ability of electroplated coatings to resist attack by marine environment, but when judiciously applied as a limited research tool, it is useful in studying the performance of new finishes and materials.

Atmospheric humidity is another recognized enemy of metal surface stability. One test devised in the Laboratories simulates hot and humid tropical environments. In this test the atmosphere is kept

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* The photograph at the head of this article shows the author and Mrs. E. D. Anderson inspecting a specimen taken from a salt-spray chamber.

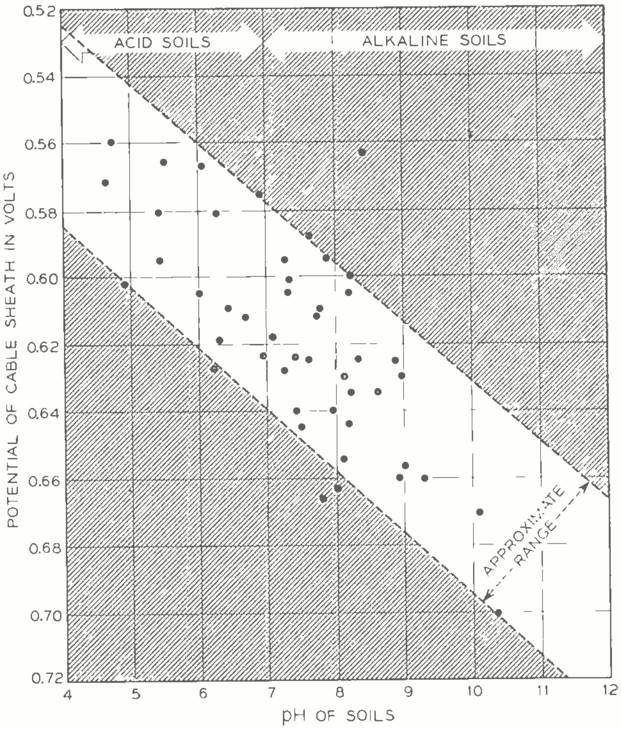


Fig. 4 — Electrode potentials of lead for a range of acid and alkaline soils.

Fig. 5 — R. G. Baker inspecting samples in Bell Laboratories outdoor exposure plot.

at a high relative humidity at all times, and the temperature is cycled twice daily between values which represent high and low readings for a typical jungle day. The condensation of atmospheric moisture appearing on the test specimen, together with the temperature changes, causes corrosion which quite often permits a fairly rapid evaluation of certain materials that may otherwise require many months of exposure under ordinary conditions. This test has proved very useful in the development of the familiar iridescent finish now applied to all zinc-plated items for telephone central office and a wide variety of other indoor applications.

A great deal of telephone equipment is placed underground. Although polyethylene jacketed cables are playing an increasingly larger part in this type of installation, the many thousand miles of existing lead-sheathed cable represent a huge investment which must be protected against the ravages of subterranean environment. Corrosion of underground cable installations may be due either to stray currents or to some other condition which renders the potential of the cable positive with respect to its surroundings. When lead is in this condition it will dissolve, or corrode anodically, in accordance with the fundamental precepts of the electrochemical theory of corrosion. This can be corrected, however, by applying a negative potential to the cable until it is slightly more negative than the surrounding environment. The negative potential can be achieved either through the use of an externally applied potential, such as by a rectifier or a battery, or by connecting the cable to a more anodic metal, such as magnesium or zinc. In the latter case, the magnesium or zinc is sacrificed to save the lead. This method of stopping corrosion is called cathodic protection and is quite widely used for the protection of metal structures buried in soils or submerged in water. The development of test methods for surveying electrolysis situations in the field and of new measures for controlling such electrolysis are the responsibilities of the protection group in the Outside Plant Department of the Laboratories.

While much has been done by way of systematically studying the electrochemical behavior of lead in soils, a great deal remains to be learned. Of particular importance in establishing a system of cathodic protection for lead-sheathed cables is the fact that lead is an amphoteric metal; that is, it will corrode in both acidic and alkaline environments. Thus, the alkaline condition created in cathodic protection may itself create a corrosive situation around the lead sheath. While this is not of serious consequence in the case of steel, over-protection or too high a negative potential on a lead cable can lead to disastrous alkaline corrosion, a clear case of out of the frying pan into the fire.

The complexity of the many soils in which cables

Fig. 6 — W. W. Bradley of the Chemical Research Department performing electrode potential experiment as part of laboratory study of corrosion.

are placed, involving such factors as composition, moisture content, acidity or alkalinity, and texture, greatly influences the electro-chemical behavior of lead. One of the several interesting results obtained from a recent laboratory study of the behavior of lead in various soils is shown in Figure 5. Here the pH values of many typical soils have been plotted against the electrode potential of lead. Although this information indicates that because of the scattered results, no definite conclusions can as yet be drawn with regard to a specific relationship between pH and electrode potential, it is of considerable help in understanding the behavior of lead in soils.

The advent of the submarine telephone cable has opened up new fields of endeavor for the corrosion engineer. Submarine cables contain galvanized-steel armor wire and copper, and information relative to the behavior of these materials in sea water is of great importance. The armor wire protects the cable against mechanical damage during laying and recovering operations, and copper is used as a shield against attack by marine borers, such as the teredo, and also as the return electrical conductor. From studies of submarine telegraph cables laid through the years, much has been learned about the behavior of armor wires, but relatively little is known concerning the action of sea water on copper at great depths. Of considerable interest in this respect is the activity of a microorganism generally called *desulfovibrio*. These bacteria have the power of reducing sulfates to sulfides during their metabolic process. If a cable should chance to lie in sediment where *desulfovibrio* is particularly active, the chance of copper being attacked by sulfides is a possibility that the corrosion engineer cannot overlook. This and other phases of submarine cable development involving consideration of corrosion protection are currently under active study by several groups at the Laboratories.

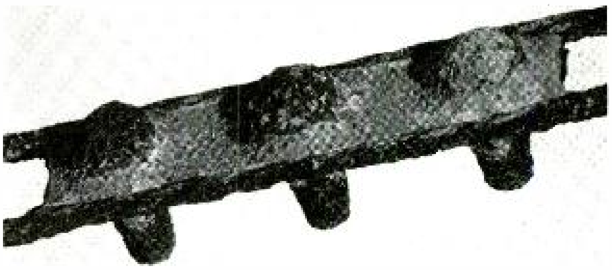


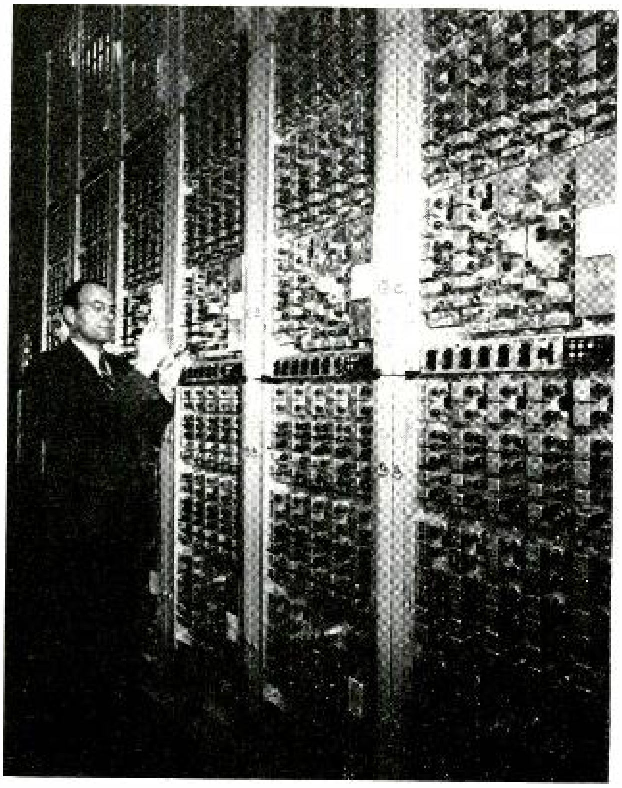
Fig. 7 — Cable clamp showing extreme corrosion from exposure to industrial atmosphere.

The help of other organizations in the Laboratories is very often enlisted in solving some particularly knotty corrosion problem. Thus, ample use is made of the facilities of the general analytical group. Corrosion products are often of an unusual nature, and when they also are available only in minute quantities, microchemical or spectrographic methods are employed to analyze them. The assistance of the microscopist is very often sought when his particular skill is needed in determining the effects of corrosive environments on the micro-structure of metals.

In a field of activity as broad and as varied as that in which the Bell System is engaged, the struggle against corrosion is never ending. With every new development, new corrosion problems are certain to arise. Thus, the corrosion engineer must be constantly on the alert to anticipate trouble, to recommend correction where it unavoidably occurs and to reduce the possibility of corrosion hazards by maintaining an up-to-date fund of information on corrosion protective practices.

THE AUTHOR

A. Mendizza received the B.S. degree in Chemical Engineering from Cooper Union in 1930 and the M.A. degree in Chemistry from Columbia University in 1938. After joining the Laboratories in 1928, he was first concerned with the development of metal surface-cleaning techniques for electron-tube parts, and since becoming a member of the Chemical Department in 1930, he has devoted most of his time to problems of protection and corrosion prevention. Included in these activities were the development and evaluation of color enamels for telephone sets, and, during World War II, work on the electrochemical phases of a military underwater project. After the war, Mr. Mendizza resumed his activities in the protection field, where he was placed in charge of a group chiefly concerned with general corrosion problems and with the engineering of metallic finishes for both Bell System and military developments.



Heat Dissipation from Electronic Equipment

Transistors-vs-Electron Tubes

E. K. VAN TASSEL
Military Communication Development

The heat given off by transistorized electronic equipment is usually much less than that emitted by equivalent electron-tube circuits. This, coupled with the fact that transistorized equipment is usually much smaller than electron-tube equipment, might at first indicate that transistors should be used whenever it is desirable to save space. Investigations at the Laboratories have indicated, however, that this is not always true. Under some conditions, the use of electron tubes may result in smaller equipment.

The impressive expansion of the Bell System not only means that communication facilities must be extended into new areas, but also that available facilities must be increased in existing locations. Many plant problems must be solved immediately to provide for this expansion. Planning for the future must also take into account the fact that communications art is moving toward the increased use of miniaturized transistor equipment. It is in order, therefore, to ask "How will the use of transistors affect the building and equipment engineers' plans for the future?"

Further miniaturization of transistorized electronic equipment is important because it increases the number of circuits that can be located within a given space. One result of packing more and more equipment into a given space is that it is necessary to remove more heat from that space. For example, in some of the older carrier equipment such as type-C carrier and the A-1 channel banks, about 0.5 watt must be removed per cubic foot of room volume. Newer carrier equipment, such as in the type-N system, requires the removal of about 6 watts per cubic foot of room volume.

An experimental transistor channel unit has been designed to perform the same functions as the type-N channel unit and it dissipates about 0.75 watt per channel. The type-N carrier channel unit in use in the field dissipates a total of about 22 watts. This indicates that the transistorized system might require only one-thirtieth of the power now used by a type-N system. If further miniaturization is assumed so that the size of a transistorized channel unit is limited only by heat dissipation, it has been calculated that this unit can be one-fifteenth the volume of an electron tube unit and still not have excessive temperatures. In a given bay of equipment, it would thus be possible to mount fifteen times as many transistorized channel units as electron tube units and the total dissipation per bay would be about one-half that required in the present type-N bay.

In general, it is less expensive to provide refrigeration to remove the heat from a given room than it is to make that room large enough to cool it by natural ventilation.* Architects agree that, for comfortable working conditions, natural ventilation can remove about 0.2 watt per cubic foot of room volume. Refrigeration is therefore required to dissipate the heat from electronic equipment concentrated in a room whether that equipment uses transistors or electron tubes. The use of transistors greatly reduces the load on the refrigeration equipment for a given number of carrier channels, but the problem for a room filled with transistorized equipment is substantially the same as for type-N equipment.

In many of the design details there are significant differences between the use of transistors and electron tubes, some of which can be illustrated by a more detailed discussion of the heat removal problem. This problem of removing heat from its source within an electron tube or transistor to the air outside a building may be divided into three steps: First, the transfer of heat energy from its source (electron tubes or transistors) to the surrounding materials; second, the transfer of heat energy from the surrounding materials (electronic equipment) to the surrounding air; and third, the transfer of heat energy from the surrounding air to the air outside the building.

The first step, transfer of heat from the source to the surrounding material, differs in equipment that uses electron tubes from equipment that uses transistors. In general, electron tubes operate at much higher temperatures than transistors. As a result, a considerable part of the heat is radiated from the tube, and this radiated heat can cause excessive temperatures in nearby components. These localized high temperatures are called "hot spots" and require special treatment for each situation. An intrinsic property of germanium transistors is that they become simple conductors at high temperatures and thereby lose their ability to amplify electrical signals. It is therefore necessary to design transistorized electronic equipment so that it can dissipate the unwanted heat without raising the temperature of the germanium bead above 175° F. With the resulting small temperature differences, very little heat is radiated; practically all of it must be removed by conduction. Thus, the problem in transistorized equipment is to obtain adequate conduction of heat away from the transistor without requiring a large temperature difference. Hence, the first step in the transfer of heat is to solve the localized problem of spreading heat through the electronic equipment without creating "hot spots" or, if transistors are used, without requiring a large temperature difference to cause the flow of heat.

The second step, transfer of heat from the surrounding materials to the surrounding air, which can be treated more generally than the localized problems associated with the first step, will be discussed in more detail later. The only influence that transistors have on the third step, transfer of heat from the surrounding air to the air outside of the building, is in the amount of heat to be removed; methods of transferring the heat are in general the same in both cases.

To compare heat dissipation in electron tubes and transistor circuits, there are three facts to be considered: Transistor circuits have less heat to be dissipated than electron tube circuits; transistor circuits are not able to dissipate as many watts per unit area as electron tube circuits (the rate at which heat is transferred is measured in watts per unit area); and more transistor circuits than electron-tube circuits can be compressed into a given space,

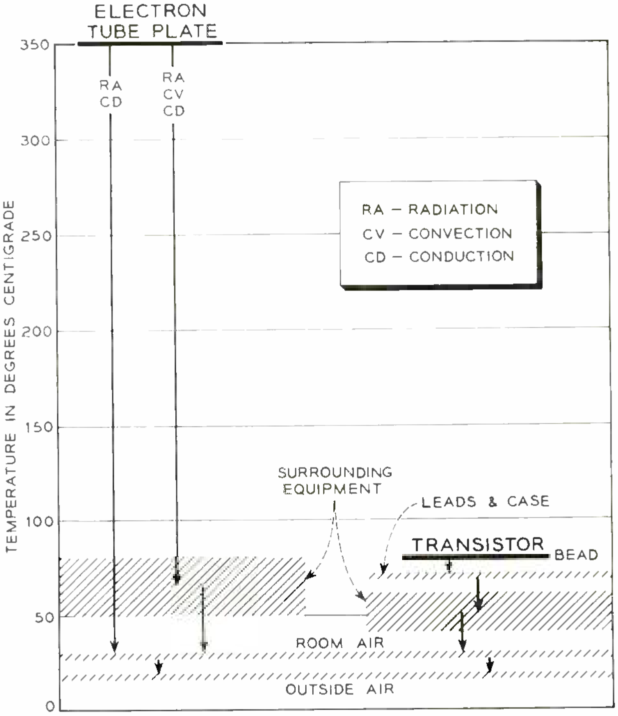


Fig. 1 — Flow chart illustrating the various paths by which heat is transferred to the outside air.

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* Record, *June*, 1953, *page* 225.

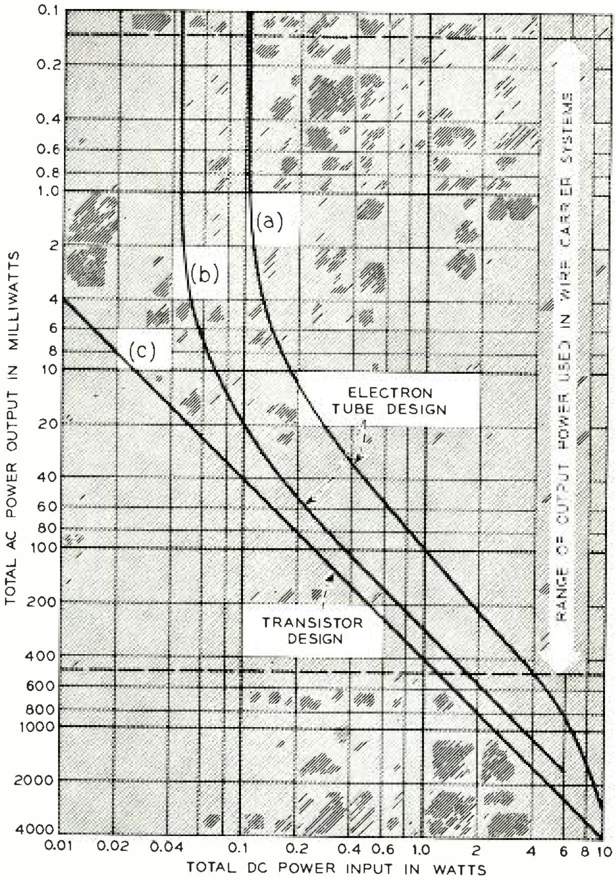

Fig. 2 — Signal output power versus applied power in a single stage.

and this, in turn, tends to increase the required dissipation per unit area.

Figure 1 is a flow chart illustrating the various paths by which heat is transferred from electron tubes and transistors to the outside air. With electron tubes, approximately 25 per cent of the heat goes directly into the room air and 75 per cent is transferred to the equipment immediately surrounding the tube. To transfer heat from the surrounding equipment to the room air, the equipment must be at a higher temperature than the room. The number of watts per unit area to be dissipated depends upon the total power put into the electron tube, the efficiency of the electron tube in converting the applied power to useful output signal and the portion of the total heat that is transferred to the surrounding equipment.

With transistors, essentially all of the heat is transferred to the surrounding equipment and must then be transferred to the room air. As in the case of the electron tube, the number of watts to be dissipated depends upon the total power put into the transistor, and the efficiency of the transistor in converting the applied power to useful output signals.

For a given difference in temperature between the room air and the equipment surrounding the transistor or electron tube, energy will be transferred from the equipment to the air in direct proportion to the effective area of the equipment. (If the exposed area is doubled, twice as much energy will be transferred.) Also, the larger the temperature difference between the air and the tube or transistor, the more watts per unit area will be dissipated.

Mathematical expressions have been worked out with which it is possible to compare equipment that uses electron tubes with equipment that uses transistors. If the effective cooling areas are the same for the two, the comparison is the ratio of the total power that can be applied to the electron tube equipment to the total power that can be applied to the transistorized equipment without producing excessive temperatures. The expressions show that a single output stage using electron tubes and having the same effective cooling area as an output stage using transistors can dissipate one and one-quarter to four times as many watts and still not have excessive temperatures. This conclusion is based on several differences between transistors and electron tubes. The temperature of the equipment associated with electron tubes, for example, may be 20 to 40 degrees Fahrenheit above the temperature of the room air. The temperature of the equipment associated with the transistors, however, is usually limited to about 15° F above room temperature. This difference is maintained to insure that the germanium transistor bead will not exceed a temperature of 175° F for any operating situation. Electron tubes, on the other hand, operate at temperatures measured in the hundreds of degrees. Efficiencies of electron tube and transistor equipment also vary markedly. Cathode-type electron tubes seldom attain more than 10 per cent efficiency, and usually less than 5 per cent. Transistors can attain more than 50 per cent efficiency, but a conservative estimate of 33 per cent is used in these calculations.

Instead of comparing two designs that have the same effective cooling area, it is usually desirable to compare two designs that can deliver the same output power. Figure 2 is a plot of the total output power versus the total power taken from the power supply for a single electron tube or transistor. Curve (a) represents the performance of cathode-type tubes for which the efficiency is usually less than 10 per cent. Curve (b) is for filament-type tubes with higher efficiency. Curve (c) is for transistors which are assumed to be 33 per cent efficient for all values of output power.

For the same ac power output, in the region of 20 milliwatts to 500 milliwatts, a cathode-type electron tube requires about four times as much input power from the battery as does a transistor. As previously stated, the equipment associated with electron tubes can dissipate between one and one-quarter to four times as many watts per unit area as the equipment associated with transistors. For the purposes of illustration, assume an arbitrary value of twice as many watts per unit area for the electron tube case as for the transistor case. For this assumption, the area required to dissipate the heat from a single transistor and associated equipment would be one-half that of the equipment associated with an electron tube.

Carrying on this restricted concept, which compares one transistor and one electron tube, to the case of a single filamentary electron tube, Figure 2 indicates that it is necessary to dissipate about one and one-half times more heat from the equipment associated with such a tube than it is from the transistor equipment. Hence, the area of the transistor equipment should be 1.333 or 33.3 per cent larger than the area of the equipment associated with the electron tube. Under these conditions, it is not desirable to mount as many transistors per square foot as filamentary tubes. When these same comparisons are made for single stages that are required to deliver more than 0.5-watt of output power, it is seen that an electron-tube stage again probably requires less area to dissipate the resultant heat than a transistor stage.

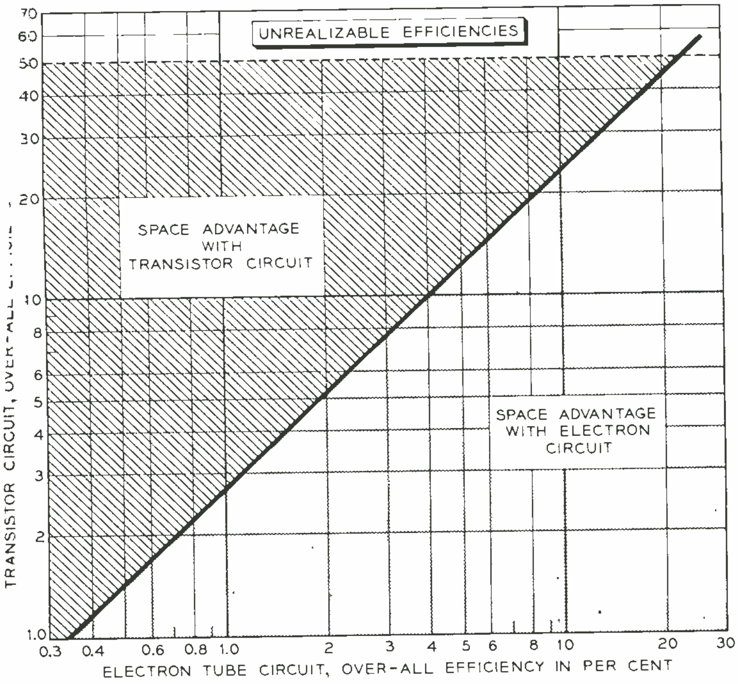

Fig. 3 — Comparison of typical electron tube and transistor over-all efficiencies.

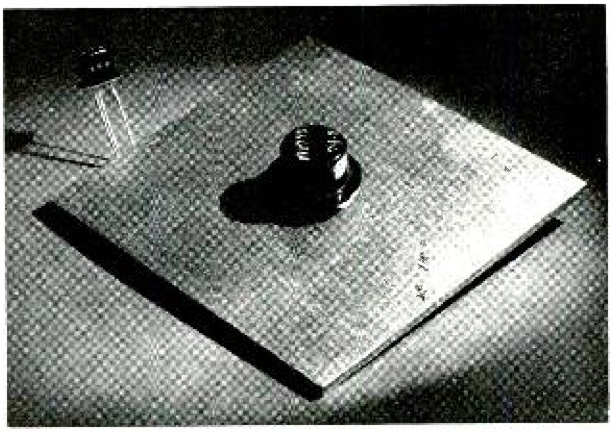

Fig. 4 — A junction transistor compared with a power transistor mounted on a cooling plate.

As shown in Figure 2, the region where transistorized equipment has an outstanding space advantage over electron-tube equipment is where the output power required is less than 10 milliwatts. The power that must be removed from the electron tube approaches a constant a little less than 100 milliwatts. The power required for the transistor, on the other hand, can be reduced almost without limit, and ideally this permits more and more miniaturizing.

The net efficiency of a complete equipment unit containing many active stages is different from that of the single output stage because only a few of the active stages are required to deliver large signal power. In this situation, transistors exhibit considerable advantages over electron tubes because low-level stages can be operated at significantly higher efficiencies than are possible in electron-tube circuits. Thus, transistor equipment will not be required to dissipate as many watts from these low-level stages.

The over-all efficiency of electronic equipment using electron tubes is represented on the abscissa of Figure 3, and the over-all efficiency of a similar equipment using transistors is represented on the ordinate. This efficiency is defined as the ratio of the power delivered to the output as desired signal, to the total power applied to the equipment. The curve is a plot of the two efficiencies that must be attained if the two types of equipment are to have the same area and the same output power. If, for example, equipment using electron tubes is one per cent efficient — that is, delivers one watt of power to the output for each 100 watts applied to the equipment from the battery — it would have the same area and output power as a transistorized equipment that is 2.9 per cent efficient. The transistor equipment would take about 35 watts from the battery for each watt of power delivered to the output. To the extent that the assumptions used in this illustration apply in other specific cases, it is possible to compare two designs to see which can be made the smaller and still have sufficient area to dissipate the necessary heat without excessive operating temperatures.

The curve in Figure 3, which represents two pieces of equipment having the same cooling area and same output power, divides that figure into two parts. When the over-all efficiency of equipment using transistors is compared with similar equipment using electron tubes, and the plotted point falls above the curve, the transistor equipment has the space advantage. Conversely, if the point falls below the curve, the electron-tube equipment has the advantage.

The former situation can be illustrated by again comparing a type-N carrier system and an experimental transistorized unit designed to perform the same functions. The type-N channel unit has an over-all efficiency of one per cent, and the corresponding transistor unit has an efficiency of about 30 per cent. The point on Figure 3 which corresponds to this comparison indicates that the transistor equipment can be appreciably smaller than the type-N equipment and still dissipate the heat without excessive temperature. Computations indicate that the area of the transistor equipment can be one-fifteenth of the area of the electron-tube equipment that does a comparable job.

As shown, there are significant differences in the problem of removing heat from transistorized equipment and electron tube equipment. Where the required signal level is small, less than 100 milliwatts, transistors permit considerable space saving. Where the required signal level is large, more than one watt, tubes possess the advantage in saving space. In any given space or room filled to capacity either with transistor or electron-tube equipment there is no significant difference in the over-all heat problem — cooling is required in both cases.

THE AUTHOR

E. K. Van Tassel received his B.S. and M.S. degrees in physics from Michigan State University in 1926 and 1928, respectively. He joined the staff of Bell Telephone Laboratories in 1928 where his first two years were spent as an instructor in the Technical Assistant's Training Course. Mr. Van Tassel transferred to the Systems Development Department in 1930 where he was concerned with applications of carrier transmission to cables. During World War II, he worked on a number of military projects and following the war he returned to carrier system development. Mr. Van Tassel supervised development work on type-N, type-O and the rural carrier transistorized type-P system. At present he is in the Military Communication Development Department at Whippany.

R. K. Honaman and W. G. Pfann Receive Alumni Citations

Two members of the Laboratories, R. Karl Honaman, Director of Publication, and William G. Pfann, Metallurgical Research Department, were cited recently by Franklin and Marshall College and Cooper Union, respectively.

Mr. Honaman received his citation at the Annual Founders Day Convocation of Franklin and Marshall College. The Convocation this year commemorated the 250th birthday of Benjamin Franklin. Mr. Honaman's citation, awarded annually to a graduate of the school who has made an outstanding contribution to the nation's welfare, honored Mr. Honaman for the "high honor he has brought to his Alma Mater" and declared that he "has fulfilled in great measure the best traditions of Franklin and Marshall in his service to his fellow citizens and to his country."

Mr. Pfann received his citation at an Alumni Banquet held at the Hotel Statler in New York as part of the Cooper Union Centennial Program. He was honored for "his invention of the zone-melting process for the extreme purification of crystalline materials and for his contributions in the fields of semiconductors and metallurgy."

Intertoll Trunk Transmission Measuring System

T. H. NEELY

Military Communication Development II

(formerly Switching Systems Development II)

When operators placed long-distance calls manually, they could judge that a trunk was not serviceable and report it to the maintenance force. With today's widespread application of automatic switching to long-distance circuits, some other means was needed for evaluating the serviceability of trunks. Bell Laboratories has therefore developed completely automatic equipment that can measure and record the transmission loss for each direction, check for excessive noise and then check its own circuits.

Prior to the development of the No. 4 toll crossbar switching system,* most telephone connections between exchange areas were established manually through long-distance, or toll, switchboards. Intertoll trunks linking exchange areas were each used some thirty to forty times a day, and when an operator established a connection she was able to judge whether or not it was serviceable. Any unsatisfactory circuit could be turned down by the operating force and reported to the maintenance people for appropriate remedial action.

Manual operation of the toll plant required relatively infrequent routine transmission-loss measurements. Depending on the type and length of intertoll facility, these routine tests were made monthly, quarterly, semi-annually and, in some cases, as infrequently as once a year. The introduction of automatic switching to the toll plant rendered operator observations less effective and created a need for frequent routine two-way transmission-loss measurements and noise checks.

This need was met through the development of a relatively fast automatic two-way intertoll trunk transmission measuring system. The originating office, or "near end," is the office in which a test is initiated, Figure 1. During a test the near end does the controlling. It is at the near end that a one-way or two-way intertoll trunk is seized for test, either automatically through the automatic outgoing intertoll trunk test circuit or manually at a toll test board.*

The "far end" or terminating office of the trunk under test has fully automatic transmission-measuring and noise-checking equipment. Although Figure 1 shows the transmission test lines associated with the transmission-measuring and noise-checking circuit connected to crossbar switches, this far end equipment works equally well in No. 4-type toll crossbar, No. 5 crossbar, crossbar tandem, and step-by-step transmission systems.

The transmission test line circuit is essentially a "parking" circuit. A testman or the automatic equip-

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* Record, *November*, 1943, *page* 101 and *April*, 1944, *page* 355.

* Record, *December*, 1954, *page* 457.

ment at the near end sends the code 104 over the trunk to be tested, causing the automatic toll switching equipment at the far end to connect to a 104 transmission test line circuit. When there are calls on other 104 circuits being served or waiting to be served, this incoming call must "park" and wait its turn as determined by a sequence circuit. The transmission test line circuit also serves as a termination for the trunk as long as the near end is connected.

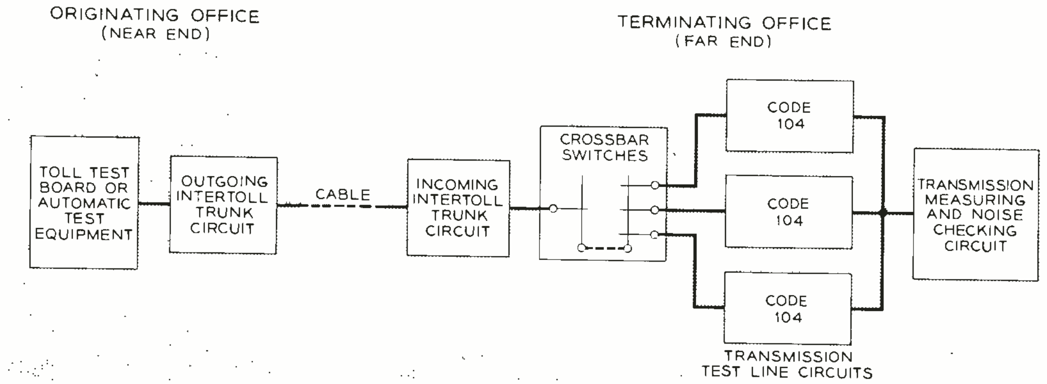

Fig. 1 — Elements of the transmission-measuring system.

Transmission loss is measured in this system by a loss compensation method, Figure 2. Basically, the far-end measuring equipment consists of an amplifier A, two adjustable attenuators, an amplifier-rectifier circuit that controls a sensitive relay P, and a relay control circuit. Amplifier A provides a fixed gain of 19.9 db. The amplifier-rectifier circuit is so adjusted that an input of 0 dbm will just cause relay P to operate. For transmission tests in the other direction, a 1,000-cycle tone supply is included.

Both attenuators, one in the receiving arm and one in the transmitting arm, are adjustable in steps of 0.1 db from 0 to 19.9 db, providing a reasonable margin above the loss that may be expected on an intertoll trunk between two offices. Each attenuator consists of nine transmission pads: 10, 5, 4, 2, 1, 0.5, 0.4, 0.2, and 0.1 db. There are nine pad adjusting relays, each controlling two equal-valued pads—one pad in each arm. Initially, the receiving-arm attenuator is set at 0 db while the transmitting-arm attenuator is set at its full 19.9 db. A 204-type stepping switch connects to each pad relay in turn, starting with the highest value; the duration of each step is controlled by a multivibrator timing circuit.* This multivibrator, in conjunction with a relay sequence circuit, controls all programming in the transmission-measuring and noise-checking circuit.

To begin a transmission test, a tone source at the near-end is connected to the trunk to be tested. This source supplies 1,000-cycle tone at a level of 1 milliwatt, or 0 dbm. Suppose, now, that the

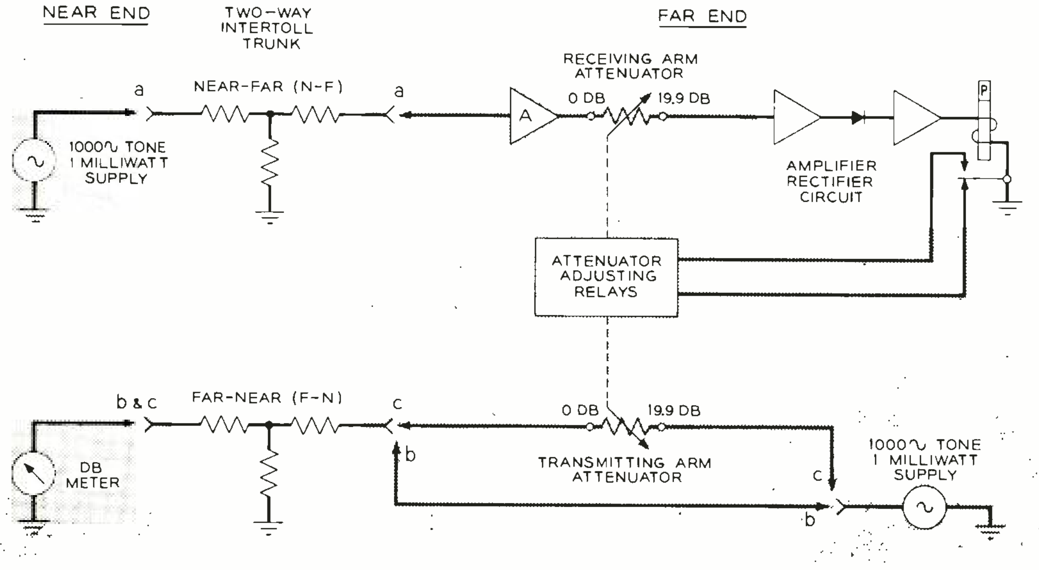

Fig. 2 — The system as used with manual operation at near end.

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* RECORD, *September*, 1943, *page* 17.

trunk has a transmission loss of 8 db in the near-far (N-F) direction. The tone will be received at the far-end terminal at −8 dbm; amplifier A raises this to +11.9 dbm at the input to the receiving-arm attenuator, which is set for 0 attenuation. Relay P operates, setting in motion the attenuator-adjusting circuit. This increases the receiving-arm attenuation until the input to the amplifier-rectifier is 0 dbm. Meanwhile, the control relays remove from the transmitting-arm attenuator the same amount of attenuation that they add to the receiving arm. Thus, in our example, the receiving-arm attenuation is increased by 11.9 db while the transmitting-arm attenuation is reduced by 11.9 db. The transmitting-arm now contains the same amount of attenuation as the trunk under test — that is, 8 db.

The test tone is applied for approximately three seconds, to allow time for the control circuit to adjust the attenuators. When the tone is disconnected at the near end, an automatic circuit-programmer at the far end connects a similar tone source directly to the far-end terminal of the trunk, using wiring (b), Figure 2. For simplicity, manual operation is shown at the near end. The testman there measures the far-near (F-N) loss. This time the test tone is applied for about 10 seconds, long enough for him to read and record the amount of the loss; let us assume a loss of 8.5 db. After a 2-second space period, the test tone is reconnected at the far-end terminal through the transmitting-arm attenuator, using wiring (c), Figure 2, for another 10 seconds. The testman now reads 16.5 db. Subtracting the previous F-N reading of 8.5 db, gives the N-F loss of 8 db.

Fully automatic operation is generally used at the near end. Figure 3 shows the steps involved. The trunk is seized automatically at the near end and the process of attenuator adjustment at the far end is identical with that for manual operation (step 1). Test tone is then applied directly at the far end as before, but only for three seconds, sufficient for the F-N attenuator at the near end to be automatically adjusted and checked (step 2). If a lamp-display key is operated, lamp relays light numbered lamps, indicating the value of the F-N loss. After a short space period, the tone is again received but at a lower level because the attenuator in the far-end transmitting arm is now in the circuit (step 3). The control circuit at the near end automatically adjusts the N-F attenuator there to give a 0-dbm output, and lamps are connected to indicate the N-F loss. To provide a printed record of the measured transmission loss and noise check result, teletypewriter "read-in" relays may be connected sequentially to the F-N and N-F groups of attenuator-adjusting relays.

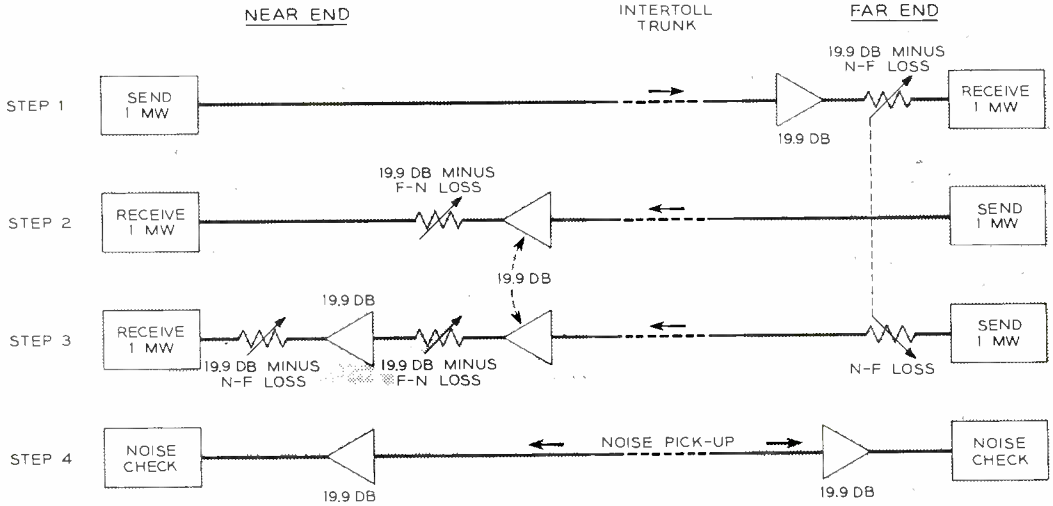


Fig. 3 — Steps in the measuring procedure. No signal is applied during noise checks.

When transmission measurements are completed, the trunk is checked to see that the noise level is below a preset limit. The programmer in the transmission-measuring and noise-checking circuit at the far end alters the feedback in the amplifier-rectifier circuit, increasing the gain, and rearranges the far end circuit for checking the noise level of the N-F channel of the trunk under test. A correct termination is placed on this channel at the near end at this time. For a period of approximately five seconds, the noise output of the N-F channel is amplified, rectified, and arranged to charge a capacitor. Since the time-constant of the circuit is about 20 seconds, any charging voltages due to noise on the channel must occur during the first, or nearly linear, portion of the capacitor charging curve. The net charge, at the far end, after 5 seconds is proportional to the F-N channel noise level, including cross-talk.

Following the observation period, the partly charged capacitor is connected to a dc amplifier through an opposing 13.5-volt battery. If the voltage across the charged capacitor is sufficiently high, it overcomes the battery voltage and relay P operates, indicating that the noise level is above the set limit. Where automatic transmission-testing equipment is used at the near end, it will be making a noise check on the F-N channel at about the same time the N-F channel is being checked.

After the noise check, the far-end equipment waits about two seconds to permit the near end to complete its noise check, and then tells the connected 104 test line circuit the results of the N-F noise check (satisfactory or unsatisfactory). This circuit immediately releases the transmission-measuring and noise-checking circuit, making it available for another test call, and signals the near end, indicating by an "on-hook" or a "reorder" signal whether the far-end noise check was satisfactory or unsatisfactory. After the near end releases the trunk under test, the far-end test line circuit also releases the trunk and is then ready for reseizure by another test call.

Attenuator adjustment by this equipment takes nearly two seconds, and during this time the overall loss of the trunk may vary. Furthermore, any measuring equipment is subject to many types of short- and long-term variations. The attenuator control mechanism works in only one direction – it is not reversible – and loss changes during the adjusting period can cause the final attenuator adjustment to be too high or too low by a small amount. Checks are automatically made to insure that the trunk loss has not changed more than 0.5 db during the measurement period. Satisfactory operation of relay P during these checks causes the programmer to connect the far-end tone supply directly to the trunk for step 2. Should these checks fail, the equipment releases the attenuator pad relays and requests a repetition of tone transmission from the near end.

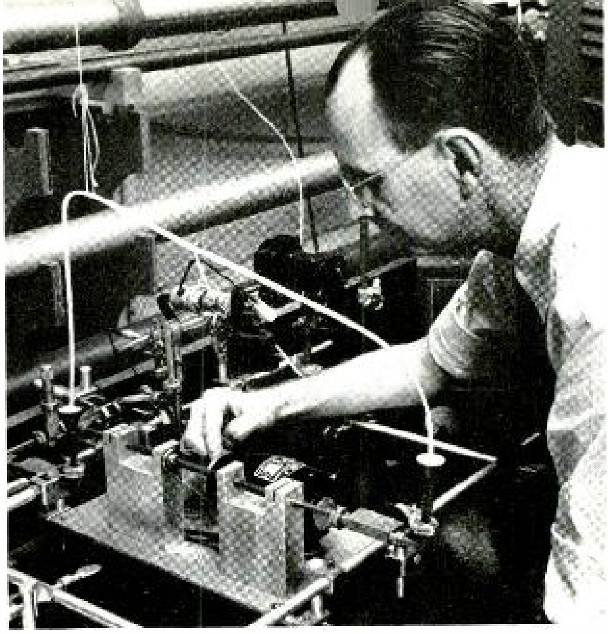
The far-end transmission-measuring and noise-checking circuit can test trunks at a rate of 120 per hour when operating with automatic equipment at the near end, and at about 30 per hour with manual near-end operation.

All of the far-end equipment mounts in a single bay, including the 104 transmission test line circuits. Although normally two to four test line circuits are used, provision has been made for mounting six circuits in the bay. Prototypes of this equipment have undergone field trials in toll offices in Atlanta, Boston, Garden City, N. Y., Oakland, Cal., and Richmond, Va., and a laboratory model for experimental testing has been in use in New York City for several years. This equipment has recently been standardized and is now available as a complete "package."

THE AUTHOR

T. H. Neely joined Western Electric Company in 1921, and later transferred to the Engineering Department of the New York Telephone Company. In 1929 he came to Bell Telephone Laboratories. In the Toll Systems Development Department he carried on community dial office and intertoll trunk developments, No. 4 toll office development, and initial development in toll cable composite signaling systems. In 1942 he was called to active duty in the United States Navy. Upon returning to the laboratories in 1945, he designed the "far end" automatic intertoll trunk transmission measuring and noise checking equipment. Since 1952 he has been engaged in military systems developments. Mr. Neely majored in electrical engineering in Cooper Union and in the Polytechnic Institute of Brooklyn and is a member of the A.I.E.E.

Single-Oscillator Microwave Measuring System



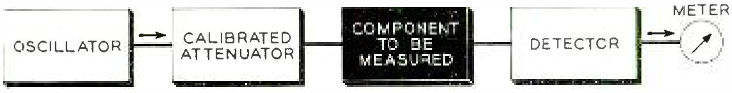
D. H. RING *Radio Research*

A superheterodyne two-oscillator system is often necessary for the accurate measurement of the transmission loss or gain of microwave components. For this purpose, however, a new single-oscillator circuit has been devised. With a simple arrangement of one oscillator and a rotating, motor-driven section of waveguide, loss and gain at millimeter wave lengths can be measured quickly and with great accuracy.

In the laboratory it is often necessary to measure the loss or gain of microwave circuits or components. For instance, we might wish to measure the gain of an amplifier or the loss of a section of waveguide. To do this, we first feed a signal directly into a detector circuit and get a meter reading. Next, we insert the unknown component into the measuring set between the signal source and the detector and get a new meter reading. The difference is a measure of the component's loss or gain.

The simplest arrangement for this kind of measurement is illustrated by the block diagram of Figure 1. A signal is connected via a calibrated attenuator to the input of the unknown component, and a detector is connected to the output. The purpose of the calibrated attenuator is to introduce a known loss which can then be compared with the loss or gain of the unknown component. (In practice, it is often more convenient to take readings from the attenuator rather than from the meter.) Because only one oscillator and one detector are used in this arrangement, it is termed a single-oscillator, single-detection measuring system.

This type of equipment is simple and easy to set up, and easy to operate, but it suffers from two major disadvantages. One is that the accuracy of measurement depends upon the calibration of the attenuator and upon the characteristics of the detector. These problems are not serious at the lower frequencies, but in the region of millimeter wavelengths (over 30,000 mc), it is often hard to establish and maintain the calibrations, particularly over a band of signal frequencies. The second disadvantage of the simple transmission measuring system is that the range of attenuation measurement is limited by the low available power that is delivered by microwave oscillators.



ig. 1 — Simple single-oscillator and single-detector system.

These disadvantages can be mitigated by using the superheterodyne detecting system illustrated in Figure 2. The superheterodyne principle involved is similar to that used in the common household radio receiver, in which a local oscillator generates a signal which mixes with the received signal to produce an intermediate frequency. In Figure 2, the local or beating oscillator signal mixes with the signal received through the unknown component being measured, and a relatively low intermediate frequency (IF) is produced. At this lower frequency, the attenuator can be more accurately calibrated. Because of the use of two oscillators, and because the mixer acts as another detector circuit, such equipment is termed a two-oscillator, double-detection measuring system.

In practice, the double-detection system of Figure 2 is relatively expensive and difficult to operate, especially when the frequency is changed. Also to be considered is the fact that the IF portion of the circuit must be designed to pass a certain range of frequencies. When the signal frequencies used in the measuring system are relatively low, the IF bandwidth can be kept quite narrow, but because oscillators always drift to a certain extent, we must use wider and wider bandwidths as we go to the higher frequencies. With frequencies in the mm wavelength region, the width of the necessary IF band becomes so great that we encounter a serious noise problem. Thermal noise (an unavoidable component of noise originating in the input circuit of the mixer) interferes with the measurement of weak signals, and the magnitude of this interference increases with the IF bandwidth. As a result, the sensitivity and measuring range are reduced as the IF bandwidth is increased.

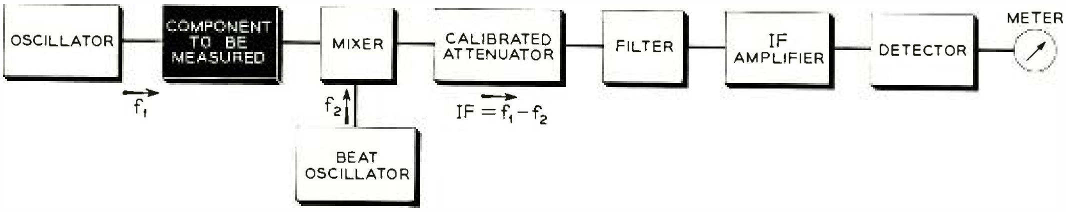


Fig. 2 — Superheterodyne measuring system with two oscillators.

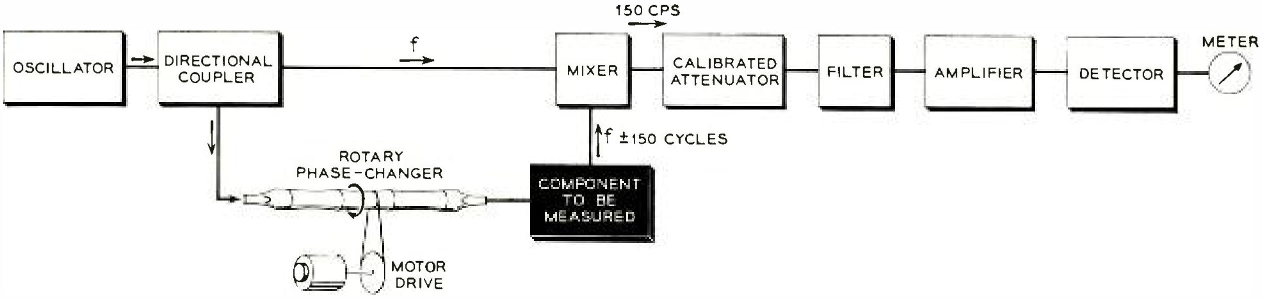


Fig. 3 — New single-oscillator system incorporating motor-driven section of rotating waveguide.

Both of the measuring circuits indicated in Figures 1 and 2 were used in the early mm-wave work at the Holmdel Laboratory, but their limitations inspired an attempt to devise an improved measuring system which would have the main advantages of both of the other systems. This result was achieved with the system shown in Figure 3. (Also see Figures 5 and 6.) The equipment indicated in this drawing comprises a double-detection system in which the RF output from a single oscillator is first fed into a directional coupler. A directional coupler as used here is simply a device for dividing the microwave output of the oscillator into two parts. One part is transmitted through the unknown component to the first detector or mixer stage, and the other part goes directly to the mixer. As in the conventional superheterodyne system, one part can be considered as the main signal, while the other part can be considered as the beating or local oscillator signal. For this purpose, however, the frequency of one part must be different from the other, so that when the two beat together in the mixer, their difference is the intermediate frequency. The difference is obtained in this system by passing the part representing the signal frequency through a mechanical frequency-changer which alters the frequency by exactly 150 cycles per second. The 150-cycle change is independent of signal frequency, and we therefore have a signal which always differs from the original frequency by 150 cycles per second. This low value permits the use of a very narrow IF band, about 30 cycles per second or less, which can easily be achieved in a simple IF amplifier.

The only unusual equipment component required to set up this system is the mechanical frequency-changer. This device is a simple version of the continuous waveguide phase-shifter described by A. G. Fox of the Laboratories.* It includes a section of round waveguide which is rotated by a motor drive. The rotating waveguide shifts the phase of the input frequency by 2° for each degree of rotation. Since

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* Proceedings of the Institute of Radio Engineers, December, 1947, page 1489.

frequency is, by definition, the rate of change of phase, the mechanical addition of 360° of phase change per second to a signal is equivalent to adding one cycle per second to the frequency. Thus, given a continuous phase-changer, it is only necessary to drive it fast enough to produce any frequency change desired. To produce a 150 cps change, we here drive the rotating section at 150/2 or 75 revolutions per second (4,500 revolutions per minute). The change may be plus or minus, depending on the direction of revolution of the rotating section of waveguide, and is achieved with practically no loss of signal power.

It may seem at first glance that a complex device would be required to add exactly 150 cycles per second to frequencies in the region of 50,000 mc without significant loss, but the waveguide structure is really quite simple. Figure 4 is a sketch which can be used to describe the essential electrical features of the continuous phase-shifter. Either end may be used for the input, but for convenience we will consider the signal as traveling from the lower left to the upper right in the illustration. First is a tapered matching section which gradually changes from the rectangular input waveguide to the round waveguide used in the phase-shifter. Next, it is necessary to convert from the vertically polarized input energy (lines of electromagnetic force oriented as indicated in the left part of Figure 4) to circularly polarized energy (rotating lines of force within round waveguide). This is done by using as a second section a piece of round waveguide that is somewhat elliptical in the center. The elliptical section is tuned to a particular frequency merely by squeezing a piece of round waveguide in a vise until electrical measurements indicate that the desired conversion to circularly polarized energy has been achieved. The third section is the rotating waveguide; this is another piece of round waveguide made somewhat elliptical in the center. Another elliptical section comprises the fourth part of the device, and this section reconverts from circular polarization to linear polarization. The fifth or final section transforms back again to rectangular waveguide. Ideally, the conversion back to linearly polarized energy would be perfect for a particular tuning frequency. However, due to slight imperfections or off-tune operation, the reconversion may not be absolutely complete, with the result that the output wave may have a component not oriented in the desired vertical direction. To avoid trouble from resonances that can occur under these conditions, small resistance elements (carbon-impregnated plastic strips) are mounted in polyfoam supports at the entrance to each taper section. One of these is indicated at the right end in Figure 4. The resistance elements do not attenuate output energy having the correct orientation, but they absorb any undesirable component that may appear.

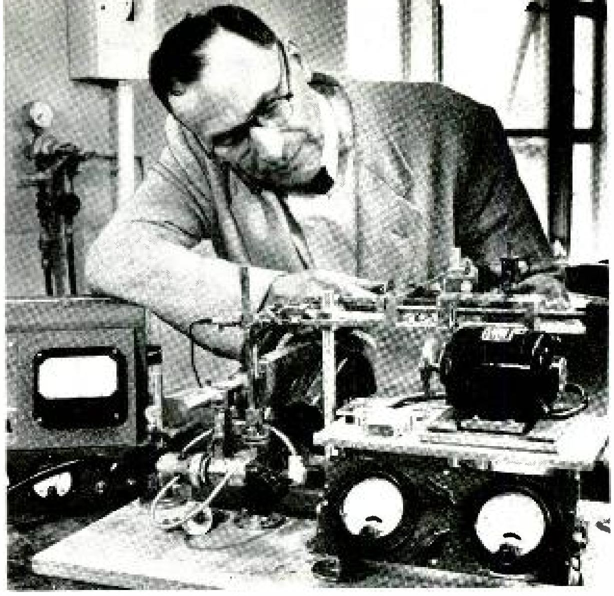

Fig. 5 — A. P. King adjusting a 5 mm single-oscillator, double-detection measuring set.

The useful bandwidth of the phase-shifter is enhanced by the use of moderately oversized round

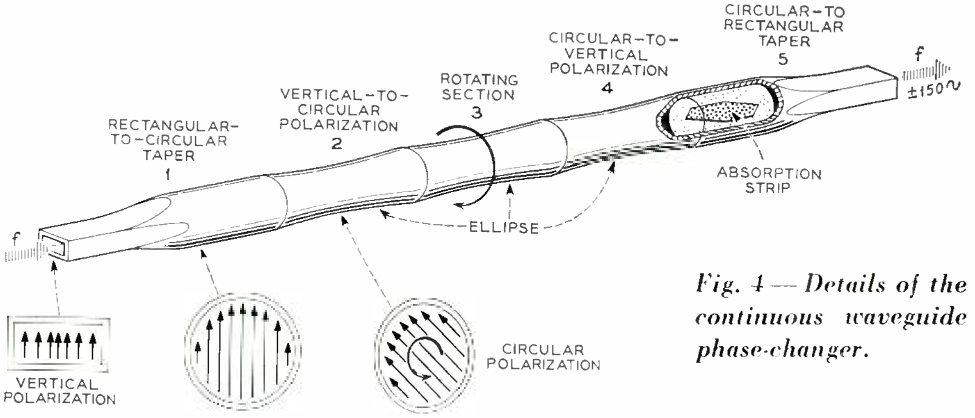

Fig. 4 — Details of the continuous waveguide phase-changer.

Fig. 6.—J. W. Bell assembling a 5 mm phase-shifter for use in a microwave measuring set.

waveguide and of gradual tapers in all transitions. Good performance in the measuring system may be expected over a band of 5 to 10 per cent of the operating frequency when the three elliptical sections are tuned to a single mid-band frequency. E. H. Turner of the Holmdel Laboratory has shown that this band can be extended to 10 to 20 per cent if the elliptical section on one side of the rotor is tuned to a frequency a little below midband, and the section on the other side to a frequency a little above midband.

Returning now to Figure 3, we see that the unknown component to be measured is inserted between the rotary phase-changer and the mixer. The 150-cycle IF from the mixer is then fed into the calibrated attenuator, and a filter, amplifier, detector and meter complete the circuit. In the models made at the Holmdel Laboratory, the attenuator is calibrated in 10 db steps and the meter is also calibrated in db to cover a 20 db range.

In considering the sensitivity of this single-oscillator system, it is convenient to compare its noise characteristics with those of the conventional two-oscillator system. As mentioned earlier, oscillator drift and the consequent increase in bandwidth mean that thermal noise will reduce sensitivity and measuring range. These detrimental effects of thermal noise can be decreased by narrowing the IF bandwidth, so we might expect that with the very narrow bandwidth of the single-oscillator system. extremely high sensitivity would be obtained. If the normal thermal noise were the only type of noise involved, the single-oscillator system would thus be very much more sensitive than the two-oscillator system. Crystals used in the mixer, however, generate additional noise which is inversely proportional to the IF frequency. This noise is negligible at the high IF frequencies normally used in microwave receivers, but at the low IF of 150 cycles, mixer crystal noise has increased sufficiently to cancel (approximately) the advantage expected from the narrow bandwidth. As a result, the sensitivity of this system is about the same as that of a two-oscillator system.

The measuring equipment described here has, therefore, both the sensitivity and the accurate calibration features of the conventional two-oscillator system. At the same time it also has the ease of operation and stability of the single-detection type of circuit. It incorporates the major advantages of both of the older types with only a modest increase in the equipment required for the simplest possible system. This circuit has proved to be so useful in millimeter work that it may well be worthwhile to consider its use at longer wavelengths.

THE AUTHOR

D. H. Ring received the A.B. degree in Engineering from Stanford University in 1929, and the Degree of Engineer from the same university in 1930. Joining Bell Telephone Laboratories in 1930, Mr. Ring was early concerned with research investigations on transatlantic short-wave radio telephone transmissions and with the MUSA radio-receiving system. During the war years, he was engaged in various research activities in connection with antennas and waveguide components for radar main-battery fire-control systems. In recent years, Mr. Ring has participated in the project that resulted in the long-distance radio-relay system, and has done additional work in military research and in the field of millimeter waveguides. He has also been concerned with long-distance waveguide transmission, and is currently engaged in this field of research.

Test Sets for No. 5 Crossbar

C. A. THROCKMORTON
Switching Development

Frame-mounted test equipment for the No. 5 crossbar system includes special circuits for testing registers and senders. Where this test equipment is furnished in a small central office, it represents a comparatively large part of the investment. Portable test sets, developed for use in small offices, require slightly more testing effort, but provide satisfactory maintenance with a substantial saving in first cost.

The use of dial switching systems in the Bell System is approaching the forty-year mark, yet those early installations that are still in use today continue to furnish satisfactory telephone service. As newer and better switching systems have been developed, apparatus requiring less maintenance attention has also been designed. Adequate maintenance facilities, however, are still essential to providing high-quality telephone service. Earlier common-control systems were arranged for periodic routine tests of the various circuits by automatic test equipment. New principles of testing were introduced in No. 5 crossbar, primarily the reduction of automatic testing and the almost complete dependence for trouble detection on a new trouble recorder machine.* Test equipment capable of making only a single test call at a time was substituted for the earlier type. Finally, as a recent development, portable test sets for registers and senders offer first cost advantages for small central offices using No. 5 crossbar equipment.

Test equipment for a No. 5 crossbar office is concentrated in one part of the office – the maintenance center – where a master test frame contains control circuits for all tests. Lamp displays indicate the principal points in the progress of test calls. The trouble recorder, an electro-mechanical device, automatically punches a trouble record card if trouble occurs in the system. It can also be controlled from the master test frame and a complete record of a test call that does not encounter trouble can be obtained when desired. The largest and most complex unit, requiring up to four equipment bays, is the automatic monitor, register, and sender test circuit. The monitor automatically gives the test portions of the circuit access to registers and senders to check their performance while handling regular service calls. Test calls, of course, can be used to check specific registers and senders when desired.

In smaller offices, this test equipment represents a sizable portion of the initial cost. Studies made to determine the feasibility of using less expensive test equipment resulted in the development of test sets and associated procedures as an alternate standard to the automatic monitor, register, and sender test circuit for those offices whose present capacity and anticipated future growth permit their use. The saving in first cost is accompanied by a saving in floor space. Slightly more testing effort may be required.

The test-set method of testing is based on the knowledge that improvements in circuit and apparatus design have built so much margin into the pulsing circuits of registers and senders that they will give long periods of satisfactory service without maintenance. Experience has also shown that many troubles in a central office can be detected by originating test calls and observing circuit operation.

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

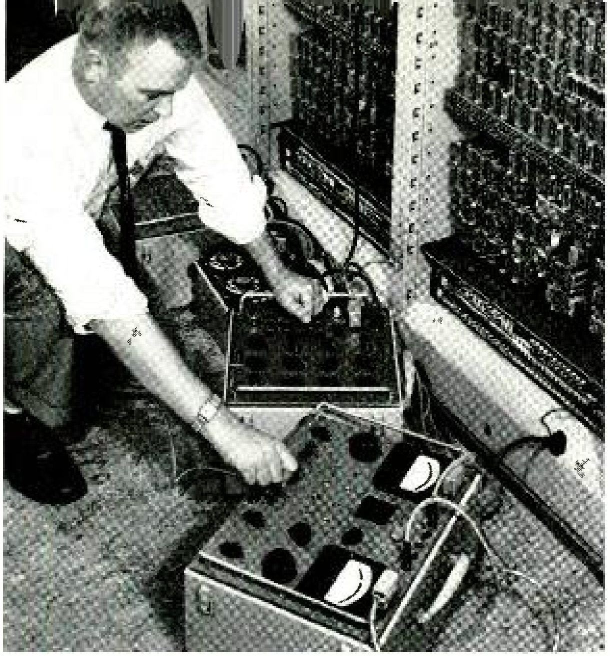


Fig. 1 — W. R. Rupp calibrates the 3A pulse generator. The 3A digit-control set is just back of the pulse generator. The power supply unit is located in the fourth box at the rear of the test-set group.

Analysis of the trouble record card supplies information for use when a circuit failure occurs. Because the pulsing circuits have been designed to operate for long periods of time with very little attention it is not necessary to make frequent tests of performance. Troubles that occur because of aging or gradual changes in adjustment can be anticipated by relatively infrequent marginal tests.

Test-set testing of No. 5 crossbar utilizes five items of portable equipment: a register test set, a sender test set, a 3A pulse generator, a 3A digit-control set, and a power supply unit. The first two are used whenever it is desired to check registers and senders for proper operation. The 3A pulse generator, with its associated digit-control set and power supply unit, is used to apply marginal tests of the pulsing features of registers and senders at infrequent intervals, to detect the weak circuits and recondition them before they give trouble.

The test sets have intentionally been kept small and light through the use of supplemental frame-mounted equipment occupying one-fifth of a bay. The test sets are associated with this supplemental equipment by plugging into specially-wired jacks at either the master test frame or the frames where registers and senders are mounted. In addition, a multifrequency (MF) receiver is required for testing MF senders. This may be one of the regular service MF receivers or an additional one mounted near the master test frame and used only for tests.

The register test set, shown in use in the laboratory, may be used to check both incoming and originating registers, and is the only means of checking tandem-type revertive-pulse incoming registers. Two telephone dials on the test set supply signals at either 10 or 20 pulses per second. For multifrequency, revertive, or tandem revertive incoming registers, the keyset is used instead of the dials.

Incoming registers can be checked with the test set without interfering with other tests being made with the master test frame, since it is not required for testing incoming registers. Keys associated with the supplemental register test equipment are pre-set to select an incoming register and also to control signals to the register and marker. Use of the proper speed dial sends pulses into the register and its operation can be checked by obtaining a trouble recorder card showing the register output. MF pulses are controlled by push-button keys on the test set. For revertive-pulse incoming registers, these keys control the number of revertive pulses returned from the register and this number of pulses should correspond to the desired test digit. Display lamps on the test set indicate the progress of the test. For revertive-pulse incoming registers associated with a central "B" switchboard, the digits are key-pulsed into the register by the operator after she obtains them verbally from the maintenance man. This particular test is actually the same as a service call. After the number has been received in the register, a trouble recorder card will be produced that may be used to verify the results of the test.

For checking originating registers, keys on the master test frame control panel are pre-set to select a register and to control the class-of-service and other signals sent to the register via the marker. Certain coin-telephone and party-line tests are controlled by keys associated with a trunk test circuit, also located at the maintenance center. Continuity and leakage tests of the line are controlled by the setting of a rotary switch on the test set. The presence of dial or busy tone supplied by the originating register may be verified by patching a telephone to the test set. A trouble recorder card must be punched to check the register output.

The sender test set can check all types of senders except intermarker group senders, which are checked using the master test control circuit. In offices having both the automatic monitor and the test-set units, simultaneous tests of originating registers and senders cannot be made using both arrangements. If the test sets are being used to check originating registers, the master test frame is unable to call in the automatic monitor for sender testing.

The sender test set is primarily a remote-control unit for the master test control circuit used to set up a test connection and furnish key-controlled information necessary for completion of the test call. The sender output is checked by the supplemental test equipment. After the test connection to a sender is set up, keys in the test set control the conditions and progress of the test, and numbered lamps indicate the digits outpulsed by the sender.

For dial pulses, the appropriate test-set lamp will light under control of the supplemental equipment. MF pulses are received and interpreted by the associated MF receiver before the result is passed to the test set to light the lamps. For revertive-pulse senders, the pulses are transmitted to the sender by the supplemental equipment and the lamps indicate the number of pulses required before the sender acknowledges completion of the digit. As a further check, the test set permits controlling the sender so that digits can be outpulsed one at a time under manual control.

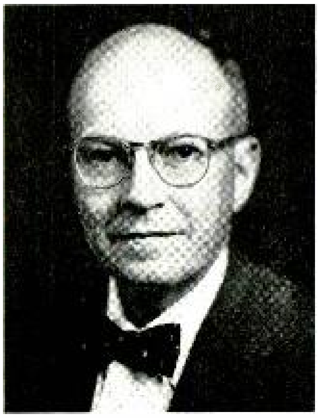
These are functional checks, to see that particular equipment units perform the functions for which they were designed. Routine functional checks aid the maintenance force in keeping the equipment in good condition, and register or sender troubles recorded during the progress of service calls may be located by using this test equipment. Of course, the fact that an equipment unit is working properly one day does not necessarily mean that it will work the next day; it could be just ready to fail. Additional tests must be made to determine the operating margins of the various circuits, and two other test sets are available for this purpose.

The 3A pulse generator, Figure 1, is a precision pulse-generating device, with certain features incorporated to adapt it for use with the register and sender test sets. Single, continuous, or trains of pulses can be chosen as desired. The time between trains of 1 to 10 pulses, representing a digit, can be adjusted from a few milliseconds to 2.5 seconds. Fast and slow dialing may be simulated by controlling the number of pulses per second. The percent break may be varied over a range of approximately 0 to 100 percent. Keys permit a choice of pulse output conditions, and also determine the digit to be outpulsed. Only one digit can be chosen at a time, however, and a series of digits must all be the same. This seriously limits the number of codes that can be outpulsed. For example, HIghland 4 could be tested because the complete seven-digit number would be 44-4-4444 and the generator can supply this series of 4's. HIghland 6 could not be tested because the code digits are 446.

Codes requiring a variety of digits can be tested by adding to the pulse generator a 3A digit-control set. This acts as an automatic switch advancing to the next digit to be outpulsed as soon as each digit is finished. Up to 11 digits can be pre-set on the control dials. When used with the register test set, the pulse generator takes the place of the telephone dials on the test set for pulsing the number into an originating register or dial-pulse incoming register. For MF incoming registers, it controls the interdigital time and duration of MF pulses transmitted to the MF receiver associated with the register under test. Revertive-pulse senders may be tested by using the pulse generator to supply the pulses returned to the sender. A switch in the sender test set permits building out the loop resistance to simulate a connection to a distant office.

These new test sets offer the possibility of immediate savings for new small offices. That test sets can be used instead of more elaborate and more expensive equipment attests to the excellence of modern telephone switching equipment.

THE AUTHOR



Charles A. Throckmorton joined the New Jersey Bell Telephone Company in 1922, and transferred to the Laboratories in 1954. Prior to 1954, he worked with A.T.&T. in 1943 on a temporary loan basis in a group responsible for the preparation of central office Bell System Practices. Mr. Throckmorton also transferred to the Laboratories for two years in 1946 to work on the No. 5 crossbar training program. During most of his Bell System career, Mr. Throckmorton has worked on machine switching central office maintenance problems.

Carbon Monoxide Indicator

One of the day-to-day problems faced by the telephone companies is the provision of safe conditions for craftsmen who must work in manholes performing such operations as splicing and maintaining underground cables. The predominant hazard associated with these underground installations is leakage of fuel gases from nearby gas mains into telephone manholes, despite all efforts to keep them out. Accumulations of fuel gases are extremely dangerous when they are present in sufficient concentrations to form explosive mixtures with air, and even in much lower concentrations. Carbon monoxide, for example, one of the main constituents of gases manufactured from coal and coke, and a minor constituent of gases made from petroleum, is highly toxic. A concentration of six or seven parts of carbon monoxide in 10,000 parts of air, if breathed for an hour, will cause headache and nausea. If the carbon monoxide concentration is increased to 10 parts in 10,000, and breathed for two hours, the result is usually lethal.

Although ampoule-type detectors have been in use for many years, the Bell System required an instrument that would more quickly indicate the presence of carbon monoxide in minute proportions, even at freezing temperatures, to provide personnel with better protection against carbon monoxide poisoning. Such a detector was developed by the National Bureau of Standards during World War II for use by the armed forces. Since then, it has been made commercially in a form suitable for field use by certain manufacturers of safety equipment. After trials by several telephone companies and thorough testing by the Laboratories, this indicator was adopted for general use in the Bell System.

The heart of the carbon monoxide indicator is shown in Figure 1. It consists of a hermetically sealed glass tube about five inches long and one-quarter inch in diameter. This tube contains a section of indicating gel sandwiched between guard gels that remove interfering gases and vapors. The indicator proper is a yellow silica gel impregnated with a complex silico-molybdate compound and catalyzed by means of palladium sulphate. It is so sensitive that as little as 0.005 per cent carbon monoxide in air (0.5 part in 10,000) will change the original yellow color of the gel to a light green in less than one minute. The operating apparatus, Figure 1, consists of an aspirator bulb with a special flow-control valve and a length of rubber tubing. This apparatus is designed to draw about 45 cubic centimeters of air through the indicating tube in about 30 seconds.

To make a test, the ends of an indicator tube are broken off and one end is inserted in the rubber tubing. After the tube is lowered into a manhole, the air is quickly squeezed from the aspirator bulb. As the bulb inflates, a sample of the atmosphere

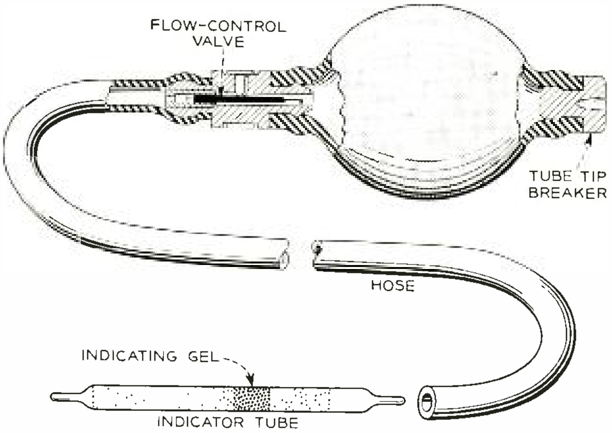


Fig. 1 — Diagram of carbon monoxide indicator.

is drawn through the indicating tube. If carbon monoxide is present, the yellow silica gel will turn a shade of green, the intensity of which is directly proportional to the concentration of carbon monoxide in the manhole atmosphere. Differences in intensity of green are quite sharp at 70°F and comparison with a color chart gives the concentration in the sample. This chart has colors ranging from the original yellow of the gel to various shades of green corresponding to concentrations of 0.005 to 0.1 per cent carbon monoxide in air by volume (0.5 to 10 parts in 10,000). In actual use, any color change is considered indicative of an unsafe manhole atmosphere.

Even though the indicator tubes lose part of their sensitivity below 50°F, they will detect low concentrates of carbon monoxide at freezing temperatures by a distinct color change from yellow to green. For more sensitive operation during periods of cold weather it is only necessary to carry the tubes in an inside coat pocket where they are warmed by body heat, or hold them in a bare hand for a short period before they are lowered into a manhole. The response of the indicating gel is further increased by operating the aspirator bulb two or more times.

The Bell System's use of this reliable means for detecting carbon monoxide is representative of its efforts to guard the safety of the people who make telephone service possible.

S. R. KING
Outside Plant Development

Drop Wire Cap

When service to a particular telephone is temporarily disconnected for any reason, the drop wire from a terminal box on a nearby pole to the telephone set on the customer's premises is disconnected at the terminal end. The stripped wires are then taped for protection and tagged to identify their destination, thus facilitating restoration of service. In the past, this labeling procedure has frequently proved fruitless because the white linen tags used did not withstand weathering and the markings were soon obliterated. An installer finding a tag illegible would have to climb down the pole, connect a test set to the customer's end of the drop wire and climb back up the pole. Then he would identify the particular drop wire by connecting his hand test set to the various wires in turn until he heard a buzzer tone.

To save time and avoid this inconvenience, a new method of protecting and identifying the ends of disconnected drop wires has been devised. This makes use of a B Drop Wire Cap consisting of a 3-inch length of clear cellulose acetate butyrate tubing that is sealed at one end. The installer places the cap, containing an identification tag form, on the end of the wire and seals the open end with tape. This eliminates the need for taping each bare wire and provides a quick and reliable means of identifying the drop wire.

R. J. SKRABAL
Outside Plant Development

T. W. Rolph places B Drop Wire Cap (arrow) on disconnected wire.

Lee de Forest Honored on Golden Anniversary of the "Audion" Tube

The year nineteen fifty-six is the fiftieth anniversary of the invention of the audion – a three element electron tube. Commemorating this occasion, a plaque was unveiled at the site of the laboratory where the audion was invented. This location, now 229 Fourth Avenue, is the site of the old Parker Building which was seriously damaged by fire in 1908, and subsequently rebuilt.

The ceremonies that accompanied the unveiling of the plaque were held at the site of the old laboratory on the morning of November 12. Rear Admiral Ellery W. Stone, President of the American Cable and Radio Corporation, and of the de Forest Pioneers, the sponsoring group, presided. The principal speaker was Brigadier General David Sarnoff, Chairman of the Board of the Radio Corporation of America. Fleet Admiral William F. Halsey, USN (Ret.), now Chairman of the Board of All America Cables and Radio, Inc., was scheduled to unveil the plaque. Since illness prevented Admiral Halsey from attending the ceremonies, Mrs. de Forest was called upon to take his place. Following the unveiling, Dr. de Forest gave a short response.

R. K. Honaman, Director of Publication, represented the Laboratories at the ceremony.

In addition to the officials mentioned, and other representatives of the electronics industry, the unveiling was attended by Clifford D. Babcock, de Forest's only assistant in 1906 when the audion was invented.

Several years after its invention, the amplifying ability of the audion was demonstrated to Bell System engineers. These early telephone engineers realized that such an amplifier of electric currents could overcome the distance limitation on the transmission of voice communications, and rights under de Forest's patents were, therefore, purchased by the Bell System. The original audion was modified and developed by H. A. Arnold of the Bell System, under whose direction the first high-vacuum tubes were produced. By 1913 electron tubes were being used as amplifiers in commercial telephone circuits between Baltimore and New York. In July, 1914, transcontinental telephone conversations were made possible by these amplifiers.

Born on August 26, 1873, at Council Bluffs, Iowa, Lee de Forest received his bachelor's degree from Yale University in 1896 and his Ph.D. degree from the same school in 1899. Early in his life, de Forest decided upon a career as an inventor, and after completing his university training, he began experiments in the new field of "wireless." Many of his early experiments, directed toward finding improved detectors for radio waves were conducted at the Western Electric Company's Chicago Laboratory, which was later to become the Armour Institute of Technology and is now the Illinois Institute of Technology.

After making a number of significant discoveries in both his own and industrial laboratories, de Forest invented the now famous three-element tube in 1906, and was awarded patent No. 841,387 for it on January 15, 1907. This patent has been called one of the most important to be issued by the U. S. Patent Office in its history. The audion itself has been described as "so outstanding in its consequences that it almost ranks with the greatest inventions of all time." Although it was originally designed as a detector of radio waves, the audion

R. K. Honaman, Laboratories Director of Publication, with Lee de Forest at the ceremonies.

was later modified to become a vacuum-tube amplifier as indicated by the title of the patent, a "Device for Amplifying Feeble Electric Currents." Another patent, No. 879,532, was granted to de Forest by the United States Patent Office in 1908 for a modification of the original audion.

Lee de Forest's contribution to electronics are by no means limited to the invention of the audion. In all, he has been awarded 285 patents that represent significant developments in such fields as wireless, radio telephony, talking motion pictures, radio therapy and television. He has, in fact, not only been called the "father of modern radio," but also the "grandfather of television."

Six Members of the Laboratories to Receive I.R.E. Fellow Awards in 1957

Six men from the Laboratories were among seventy-five leading radio engineers and scientists from the United States, Canada and Europe who were named Fellows of the Institute of Radio Engineers by the Board of Directors at its November 14 meeting. The grade of Fellow is the highest membership offered by the I.R.E. and is granted only by invitation to those who have made outstanding contributions to radio engineering or allied fields.

Presentation of the awards will be made by I.R.E. Sections where the newly elected Fellows reside.


W. J. ALBERSHEIM

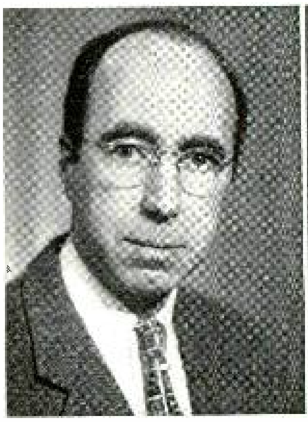

L. G. ABRAHAM

Recognition of the awards will be made by the President of the I.R.E. at the Annual Banquet on March 20, 1957, at the Waldorf-Astoria Hotel.

The six members of the Laboratories are:

LEONARD G. ABRAHAM, Director of Transmission Engineering – "for contributions to the engineering of broadband coaxial transmission systems." Mr. Abraham joined the A.T.& T. Co. in 1923 and transferred to the Laboratories in 1934. The University of Illinois awarded him the B.S. degree in Electrical Engineering in 1922 and an M.S. degree the following year. His work has been principally concerned with transmission engineering research and development on telephone, telephotograph and television, largely for long distances.

WALTER J. ALBERSHEIM, Military Systems Engineering – "for contributions in the fields of sound reproduction and military electronics." Mr. Albersheim came to the Laboratories in 1940 after some eleven years in the sound recording research field. Born in Germany, Mr. Albersheim holds the following degrees from the Aachen Institute of Technology: B.S., 1920; E.E. in 1922; EN.G.D., 1924. His work has concerned research on microwave techniques, radar systems, frequency modulation theory and delay distortion.


SIDNEY DARLINGTON


J. O. MCNALLY

SIDNEY DARLINGTON, Mathematical Research Department – "for contributions to the development and application of navigational radar." Since joining the Laboratories in 1929, Mr. Darlington has been engaged in research in applied mathematics with emphasis on network theory. He received the B.S. degree from Harvard University in 1928, a B.S. in E.E. from the Massachusetts Institute of

Talks by Members of the Laboratories

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

THE ELECTROCHEMICAL SOCIETY, SEMICONDUCTOR SYMPOSIUM, CLEVELAND, OHIO

Bemski, G., see Bridgers, H. E.

Benn, D. R., see Silverman, S. J.

Bridgers, H. E., and Bemski, G., *Copper Energy Levels in Silicon.*

Buck, T. M., and McKim, F. S., *Studies of the Surface Recombination Velocity of Silicon.*

Derick, L., see Frosch, C. J.

Frosch, C. J., and Derick, L., *Surface Passivation and Selective Masking During Diffusion in Silicon.*

Isenberg, C. R., see Trumbore, F. A.

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

Richards, W. H., see Trumbore, F. A.

Silverman, S.J., and Benn, D. R., *Identification of Junctions by Gold Chemi-Plating.*

Sullivan, M. V., *The Cleaning of Germanium Transistor Components.*

Trumbore, F. A., Isenberg, C. R., and Richards, W. H., *Solid Solubilities in Germanium and Silicon from Thermal Gradient Crystallization, Evaporation and Crystal Pulling Experiments.*

CONFERENCE ON MAGNETISM AND MAGNETIC MATERIALS, BOSTON, MASS.

Bozorth, R. M., *Review of Magnetic Annealing.*

Gould, H. L. B., and Wenny, D. H. Jr., *Supermendur, A New Rectangular Loop Magnetic Material with High Flux Density and Low Coercive Force.*

Gyorgy, E. M., and Rogers, J. L., *Some Switching Properties of Square Loop Ferrite* (presented by J. L. Rogers).

Looney, D. H., *The Ferrite Bead—A New Memory Device.*

Meinken, R. H., *Characteristics of a Memory Array in a Sheet of Ferrite.*

Nesbitt, E. A., and Williams, A. J., *Nucleation Experiments on Alnico 5.*

Rogers, J. L., see Gyorgy, E. M.

Sherwood, R. C., and Williams, H. J., *Magnetic Domain Patterns on Thin Films.*

Weiss, J. A., *A New Faraday Rotation Phenomenon and Its Application to Microwave Switching.*

Wenny, D. H., Jr., see Gould, H. L. B.

Williams, A. J., see Nesbitt, E. A.

Williams, H. J., see Sherwood, R. C.

I.R.E. PIEDMONT SUBSECTION, WINSTON-SALEM, NORTH CAROLINA

Brattain, W. H., *History of Semiconductor Research.*

Goldey, J. M., *Techniques and Applications of Diffusion in Device Fabrication.*

May, J. E., Jr., *Applications of Barium Titanate to Delay Lines and Ferroelectric Devices.*

Moll, J. L., *Transistor Theory.*

Owens, C. D., *A Review of the Properties and Uses of Magnetic Ferrites.*

SECOND ANNUAL TECHNICAL MEETING, I.R.E. PROFESSIONAL GROUP ON ELECTRON DEVICES, WASHINGTON, D. C.

Bodmer, M. G., *Results of a Traveling Wave Tube Life Test Program Including the Description of a New Technique for Measuring Cathode Activity.*

Early, J. M., Loman, G. T., and Warner, R. M., Jr., *Characteristics and Structure of a Diffuse-Base Germanium Oscillator Transistor,* (presented by R. M. Warner, Jr.).

Eigler, J. H., see Koontz, D. E.

Feder, D. O., *Methods of Detecting Contaminants on Electron Device Components.*

Feder, D. O., see Koontz, D. E.

Helmke, G. E., see Pondy, P. R.

Hittinger, W. C., see Kleimack, J. J.

Holonyak, N., see Kleimack, J. J.

Hughes, H. E., Robillard, T. R., and Westberg, R. W., *Medium-Power High-Speed pnp and npn Germanium Alloy Transistor.*

Kleimack, J. J., Holonyak, N., and Hittinger, W. C., *A High Frequency Diffused Base Silicon Transistor,* (presented by W. C. Hittinger).

Kompfner, R., *Selected Topics on Recent Microwave Tube Research and Development.*

Koontz, D. E., Feder, D. O., and Eigler, J. H., *Removal of Organic Contaminants from Electron Devices.*

Loman, G. T., see Early, J. M.

Michal, W. C., see Patterson, M. D.

Patterson, M. D., and Michal, W. C., *Some Ceramic Semiconductors Being Produced at High Volume.*

Pondy, P. R., and Helmke, G. E., *The Evaluation of Mica for Use in Electron Tubes.*

Prince, M. B., see Veloric, H. S.

Robillard, T. R., see Hughes, H. E.

Smith, K. D., *Economical Diffused Junction Silicon Varistors.*

Veloric, H. S., and Prince, M. B., *Design of High Voltage Conductivity Modulated Silicon Rectifiers.*

Warner, R. M., Jr., see Early, J. M.

Westberg, R. W., see Hughes, H. E.

INSTITUTION OF ELECTRICAL ENGINEERS, CONVENTION ON FERRITES, LONDON, ENGLAND

Fox, A. G., *Notes on Microwave Ferromagnetic Research.*

Galt, J. K., *Losses in Ferrites: Single Crystal Studies.*

Rowen, J. H., *An Integrated Program of Microwave Ferrite Device Development—A Novel Approach to the Analysis of Ferrite-Loaded Waveguide Structures.*

OTHER TALKS

Almquist, M. L., *The Systems Engineering Concept,* Research and Development Orientation Seminar on Organizing and Controlling Research and Development, American Management Association, Sheraton-Astor Hotel, New York City.

Anderson, P. W., *Applications of Paramagnetic Resonance to Semiconductor Physics,* Conference on Physics of Semiconductors, National Bureau of Standards, Washington, D. C.

Barnes, M. W. (Mrs.) see Basseches, H.

Barstow, J. M., *Color TV,* I.R.E. Student Branch, New York University, New York City.

Basseches, H., and Barnes, M. W. (Mrs.), *The Gassing of Liquid Dielectrics under Electrical Stress—Influence of Voltage and Pressure,* Conference on Electrical Insulation, National Research Council, General Electric Company, Schenectady, N. Y.

Bavelas, A., *Leadership in Management,* Personnel Group, Summit Area Chamber of Commerce, Summit, N. J.

Bavelas, A., *Communications,* Alcoa Research Laboratories, New Kensington, Pa.

Beck, A. C., *Waveguides for Long Distance Communication,* New York Section, Professional Group on Microwave Theory and Techniques Meeting, New York City.

Becker, F. K., *Video Transmission over Audio Bandwidth Telephone Circuits,* Student A.I.E.E.-I.R.E. Group, University of Colorado, Boulder, Colo.

Becker, J. A., *What We Can Learn About Surface Phenomena by Using New Physical Tools,* Physics, Dept., Marquette University, Milwaukee, Wis.

Becker, J. A., *Revelations by the Field Emission Microscope,* Milwaukee Physics Club, Milwaukee, Wis.

Benes, V. E., *A Continuous Time Treatment of the Waiting-Time in a Queueing System Having Poisson Arrivals, A General Distribution of Service-Time, and a Single Service Unit,* Mathematics Department, Dartmouth College, Hanover, N. H.

Bond, W. L., *Dislocations in Silicon,* Point Group and Colloquium, Polytechnic Institute of Brooklyn, New York.

Budlong, A. H., *Switching Logic,* Joint Student Branch A.I.E.E.-I.R.E., Rutgers University, New Brunswick, N. J.

Ciccolella, D. F., *The Bell Solar Battery,* A.I.E.E., Auditorium, Bell Telephone Laboratories, Murray Hill, N. J.

Cook, R. K., *Acoustics at the National Bureau of Standards,* Acoustics Laboratory, Columbia University, New York City.

Crawford, A. B., see Friis, H. T.

Dodge, H. F., *Continuous Sampling,* Albuquerque Section of the American Society for Quality Control, University of New Mexico, Albuquerque, New Mexico.

Dudley, H. W., *Speech Synthesis,* Chapters of A.I.E.E.-I.R.E., New York University, New York City.

Ferrell, E. B., *Attribute Control Charts for Experimental Work,* Metropolitan Section of A.S.Q.C., Newark, New Jersey.

Flaschen, S. S., Janssen, W. F., and Rigterink, M. D., *Microstructure of Ceramics for Communication Equipment,* Pacific Coast Regional Meeting, American Ceramic Society, Los Angeles, Cal.

Flaschen, S. S., see Sauer, H. A.

Friis, H. T., Crawford, A. B., and Hogg, D. C., *A Reflection Theory for Beyond-the-Horizon Propagation,* I.R.E. Convention, Toronto, Canada.

Galt, J. K., *Cyclotron Resonance Behavior in Bismuth and Graphite,* University of Amsterdam, Amsterdam, Netherlands.

Geils, J. W., *Research and Development in Industry Today,* Newark College of Engineering, Newark, N. J.

Herring, C., *Piezoresistance of Germanium and Silicon,* IBM Watson Scientific Computing Laboratory, New York City.

Herring, C., *Piezoresistance of Germanium and Silicon,* Physics Colloquium, U. S. Naval Ordnance Laboratory, Silver Spring, Md.

Hershey, J. H., *Test to Failure – The Yardstick of Reliability During Design, Manufacture, and Use of Military Electronic Equipment,* Joint Military-Industry Guided Missile Reliability Symposium (sponsored by the Department of Defense), Redstone Arsenal, Huntsville, Ala.

Hittinger, W. C., *Some Aspects of Alloying onto Germanium Surfaces,* American Institute of Mining, Metallurgical and Petroleum Engineers, Institute of Metals Division, Cleveland, Ohio.

Hogg, D. C., see Friis, H. T.

Ingram, S. B., *Industrially Sponsored Fellowships in Engineering Schools,* A.I.E.E. Fall Meeting, Chicago, Ill.

Ingram, S. B., *Encouragement of Formal Graduate Study by Industry,* Education Conference, American Society of Mechanical Engineers and Engineering Institute of Canada, University of Western Ontario, London, Ontario, Canada.

Janssen, W. F., see Flaschen, S. S.

Karp, A., *Electron Tubes at the Frequency Frontier,* Monmouth Subsection I.R.E., Little Silver, N. J.

Kelly, J. L., Jr., *Coding a Continuous Information Source,* National Electronics Conference, Chicago, Ill.

Matlack, R. C., *The Role of Communications in Integrated Data Processing,* A.I.E.E.-I.R.E. Student Seminar, Northwestern University, Evanston, Ill.

McSkimin, H. J., *Use of High Frequency Ultrasound for Determining the Elastic Moduli of Small Specimens,* National Electronics Conference, Chicago, Ill.

Meissner, C. R., *A High Vacuum Laboratory for Vapor Deposition of Conductors and Dielectrics,* Committee on Vacuum Techniques Annual Meeting, Hotel Sheraton, Chicago, Ill.

Mumford, W. W., *Microwave Noise Figures,* I.R.E. Professional Group on Microwave Theory and Techniques, Northern New Jersey Chapter, Federal Telecommunications Laboratory, Nutley, N. J.

Pearson, G. L., *Silicon in Modern Communications,* Thomas A. Edison Incorporated, West Orange, N. J.

Talks by Members of the Laboratories, Continued

Pedersen, L., *The Bell Telephone Laboratories – It's Place in the Bell System*, Men's Club, Chester, N. H.

Pfann, W. G., *Recent Developments in Zone Melting*, Sinclair Research Laboratories' Colloquium, Harvey, Ill.

Pfann, W. G., *Zone Melting*, Institute of Metals Colloquium, Chicago, Ill.

Pfann, W. G., *Zone Melting*, Northwestern University, Physics and Metallurgy Colloquium, Evanston, Ill.

Read., W. T., Jr., *Dislocations*, Symposium on Physics of Engineering Materials, American Society for Civil Engineers, Pittsburgh, Pa.

Rigterink, M. D., see Flaschen, S. S.

Rigterink, M. D., see Sauer, H. A.

Rosenthal, C. W., *Memory Systems and Input-Output Systems for Digital Computers*, I.R.E. Lecture Series on Computers, Northern New Jersey Section, Montclair, N. J.

Runyon, J. P., *Logic and the Design of Small Digital Circuits*, I.R.E. Lecture Series on Electronic Computers, Northern New Jersey Section, Hillside School, Montclair, N. J.

Runyon, J. P., *Arithmetic Operations in a Computer*, I.R.E. Lecture Series on Electronic Computers, Northern New Jersey Section, Hillside School, Montclair, N. J.

Sauer, H. A., Flaschen, S. S., and Rigterink, M. D., *Barium Titanate Semiconductors*, Pacific Coast Regional Meeting, American Ceramic Society, Los Angeles, Cal.

Scaff, J. H., *Impurities in Semiconductors* (presented by W. G. Pfann), National Metals Congress, American Society for Metals, Cleveland, Ohio.

Schawlow, A. L., *Superconducting Domains*, Physics Colloquium, Rensselaer Polytechnic Institute, Troy, N. Y.

Seidel, H., *The Character of Waveguide Modes in Gyromagnetic Media*, Physics Colloquium, Harvard University, Cambridge, Mass.

Singer, F. J., *Planning for New Communication Systems*, Bell of Pennsylvania, Long Lines and Western Electric Supervisory Groups, Engineering Club, Philadelphia, Pa.

Williams, H. J., *Magnetic Domains in Thin Films*, New York State Section Meeting, American Physical Society, Polytechnic Institute, Brooklyn, N. Y.

Williams, I. V., *The Selection of the Proper Materials for Design* (presented by W. Babington), Research and Development Flight of 9255th Air Reserve Squadron, Drew University, Madison, N. J.

Willis, F. H., *Some Results with Frequency Diversity in a Microwave Radio System*, A.I.E.E. Fall General Meeting, Chicago, Ill.

Patents Issued to Members of Bell Telephone Laboratories During September

Abbott, G. F., Jr. – *Trunk Circuit* – 2,762,865.

Barber, C. C. – *Damping Device for Lever Type Keys* – 2,763,737.

Blair, R. R. – *Protection Circuit* – 2,763,817.

Brooks, C. E., Lovell, C. A., McGuigan, J. H., Murphy, O. J. and Parkinson, D. B. – *Magnetic Recording Dial Pulse Storage Register* – 2,764,634.

Ciccolella, D. F. – *Crystal Unit Inductance Adjustment* – 2,763,050.

Collins, T. R. D. – *Field Synchronizing Pulse Selector* – 2,763,718.

Corenzwit, E., and Matthias, B. T. – *Titanium and Zirconium Alloys* – 2,763,548.

Follingstad, H. D. – *Electronic Square-Law Meter Circuit* – 2,763,837.

Goff, H. W. – *Tape Peforator* – 2,761,508.

Graham, R. E. – *Monostable Multivibrator* – 2,764,677.

Gray, P. R. – *Dial Telephone System Arranged for Operator on Machine Announcement on Intercepted Calls* – 2,764,636.

Joel, A. E., Jr. – *Telephone System of the Coin Controlled Type* – 2,761,900.

Keith, C. R., and Nickerson, C. A. – *Apparatus for Recording and Reproducing Telephone Messages* – 2,761,899.

Koerner, L. F. – *Thermistor Network* – 2,764,731.

Locke, G. A. – *Telegraph Switching System with Message Numbering* – 2,761,894.

Lovell, C. A., see Brooks, C. E.

Matthias, B. T., see Corenzwit, E.

McGuigan, J. H., see Brooks, C. E.

Meacham, L. A. – *Subscriber Telephone Circuit* – 2,762,867.

Morgan, S. P., Jr. – *Mode Conversion in Wave Guides* – 2,762,981.

Morgan, S. P., Jr. – *Mode Conversion in Wave Guides* – 2,762,982.

Murphy, O. J., see Brooks, C. E.

Nickerson, C. A., see Keith, C. R.

Parkinson, D. B., see Brooks, C. E.

Pfann, W. G. – *Semiconductor Signal Translating Devices* – 2,763,731.

Pfleger, K. W. – *Variable Bandwith Transmission System* – 2,763,840.

Pierce, J. R. – *Helix Couplers* – 2,761,915.

Robertson, S. D. – *Microwave Frequency-Selective Mode Absorber* – 2,764,743.

Shockley, W. – *Semiconductor Circuit Controlling Device* – 2,763,832.

Shockley, W. – *Semiconductor Signal Translating Devices* – 2,764,642.

Simkins, Q. W. – *Nonlinear Terminating Networks* – 2,763,-841.

Wallace, R. L., Jr. – *Multifrequency Oscillator* – 2,761,909.

Weller, D. C. – *Telephone Ringing-Signal Transmission System* – 2,763,726.