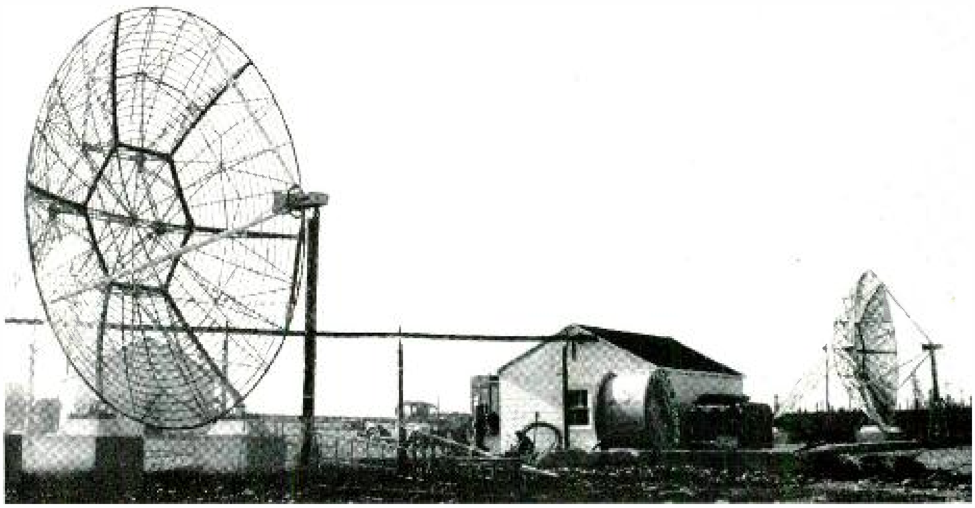


"Over-the-Horizon" Radio Tests

H. N. MISENHEIMER *Transmission Engineering I*

Until recently, reliable radio transmission in the ultra-high-frequency range and higher was generally assumed possible only on line-of-sight paths. The few instances of good reception at distances beyond the horizon were considered to be "freaks." As transmitting powers were increased and larger antennas came into use, such hitherto unreliable reception occurred more frequently and interest was aroused in the possibility of reliable over-the-horizon transmission. Scientists at the Laboratories have investigated the field for some years and have proved that reliable transmission is possible. To provide information on long-term performance, continuous tests of over-the-horizon transmission were made in Newfoundland for a full year.

Radio transmission at the frequencies employed for FM and television broadcasting was, until recently, generally considered reliable only where a line-of-sight path existed between transmitter and receiver. This restriction was thought to apply even more strongly to the higher frequencies (UHF and SHF) used in radio-relay systems. It is true that strong signals are occasionally received at these frequencies over paths extending well beyond the horizon. However, with the testing techniques employed earlier, these transmissions were not found to be suitable for providing dependable communications.

During the past few years, higher transmitting powers and larger antennas have become available and the increased reliability that has resulted from their use on over-the-horizon paths has aroused considerable interest. Long-term measurements of UHF and SHF over-the-horizon transmissions have shown that for distances of 100 to 300 miles, the median (middle value) received signal levels are only 50 to 90 db below the intensity expected at such distances in free space;* this is hundreds of decibels higher than the spherical-earth diffraction theory would predict.

In the autumn of 1952, a need arose for a radio-relay communication system in an area where the

* RECORD, *June*, 1952, *page* 245.

terrain presented serious operating difficulties. It was realized that if the requirements for this communication system could be met through the use of over-the-horizon methods there would be very substantial cost advantages over a line-of-sight relay system, and that more reliable communications might result. A comprehensive test program was undertaken to confirm the reliability of over-the-horizon transmission. The purpose was broader than simply answering the immediate question – it was to determine a basis for engineering radio-relay systems involving over-the-horizon links, with particular reference to systems that are installed in the northern latitudes.

Newfoundland was chosen as the test area, and testing equipment was installed at St. Anthony, Gander, and Harbour Main, Figure 1. The two receiving antennas used at Gander are shown in the headpiece. Tests were conducted from October, 1953, to October, 1954, providing wide variations in both weather and transmission conditions. This extensive program was carried out by the Laboratories and the Bell Telephone Company of Canada, in collaboration with the U. S. Air Force.

At the time the tests were begun, available information on over-the-horizon propagation consisted of little more than a few dozen short-term measurements collected from various sources. These measurements indicated that at distances of 100 and 200 miles the median path losses were greater by about 55 and 73 db, respectively, than the losses expected in free space. This provided a rough basis for estimating median values of path loss as it varies with path length. However, there was no adequate basis for estimating the variation in path loss with frequency or with the season of the year. Also, very little was known about how propagation would be affected by periods of fog, rain, or snow.

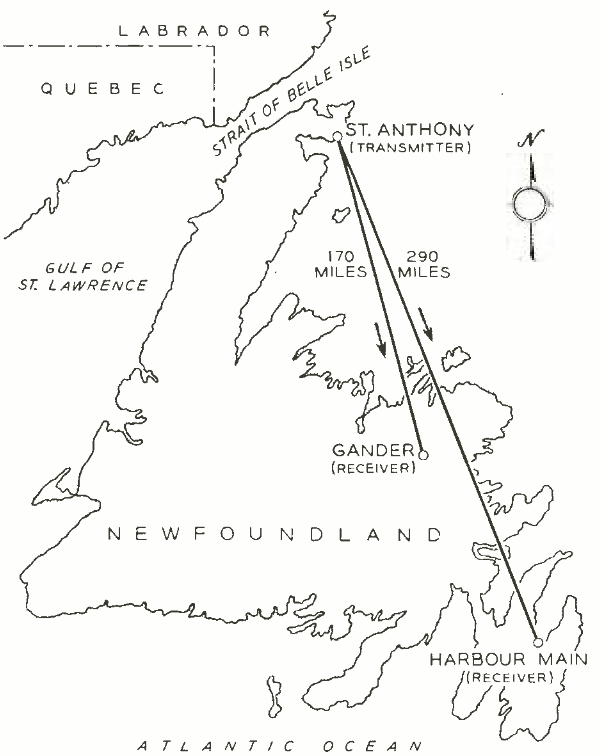


Fig. 1 — Map showing paths of over-the-horizon tests that were conducted in Newfoundland.

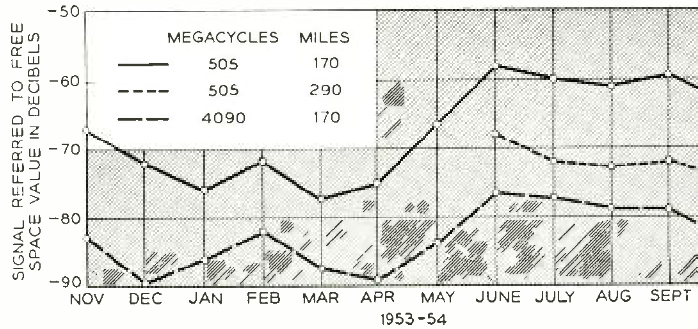


Fig. 2 — Comparison of the received signal levels.

The two test paths in Newfoundland were about 170 and 290 miles long. Frequencies of 505 and 4,090 mc were used. Unmodulated carriers were transmitted and continuous graphical records were made of the received signals. Good results were obtained at both frequencies over the 170-mile path, and at the 505-mc frequency over both paths. At 4,090 mc, the transmitter power and antenna gains were insufficient to provide a continuously useful received signal over the 290-mile path. On both test paths, the long-term median signal levels at 505 mc were very close to the values that had been expected. The ranges of signal variation, with regard to both long-term and rapid fading, were also in good agreement with expected values.

The principal information obtained from the tests has to do with long-term variations in the received signal level, Figure 2. The monthly medians of the hourly medians are plotted in terms of received signal referred to the signal that would be received if the paths were located in free space. The 505-mc observations over the longer path did not begin until June, but it appears very likely that the full year performance would have paralleled that observed for the 170-mile path.

A second and closely-related group of information obtained from the tests is illustrated by the curves of Figure 3. These curves are cumulative distributions of the hourly median signals received at 505 mc over the 170-mile path. They show the percentages of the time that the hourly median signal was greater than particular values. In such a distribution, the value that is exceeded exactly 50 per cent of the time is the median value. Similar information was obtained for 505-mc transmission over the 290-mile path and for 4,090-mc transmission over the 170-mile path.

Comparison of the 505-mc results with the earlier data shows that the results of the Newfoundland tests conform to expectations in the following respects: (1) for transmission over the 170-mile path, the average level of received signal was 65 to 70 db below that for free space; (2) transmission over the 290-mile path was about 12 db poorer relative to free space than transmission over the 170-mile path; and (3) the range of hourly median values for the full year was such that 95 per cent of them were within about plus or minus 18 db and were equally distributed about the median value.

Figure 2 also supplies new information concerning the long-term variation of average signal levels with the season and with the frequency. In particular, it shows the 505-mc signal to be about 15 db stronger in the summer and fall, when temperature and humidity are high, than in the winter and spring (the minor rise in February accompanied minor increases in temperature and humidity). It also shows that the 4,090-mc signal varied in the same general manner, although the signal was 10 to 18 db weaker and did not vary as much between seasons. Part of this reduction in the 4,090-mc median signal level is due to reduced antenna effectiveness on over-the-horizon paths in comparison with that realized from the same antennas on line-of-sight paths.

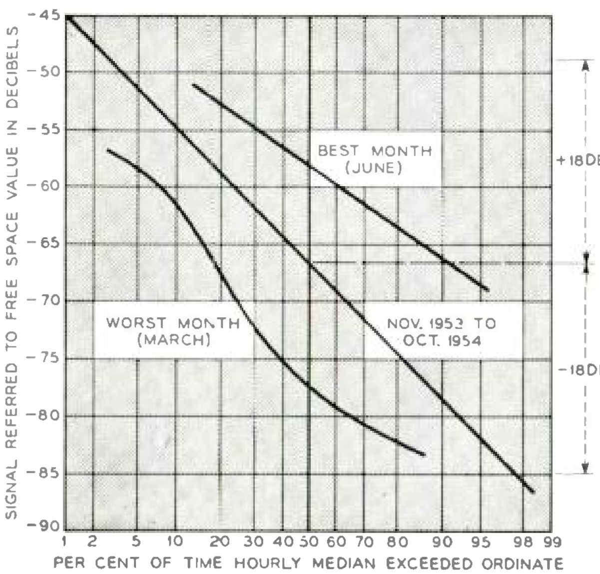


Fig. 3 — Comparison of 505-mc transmission carried on in Newfoundland during the best and worst months with that for the entire year.

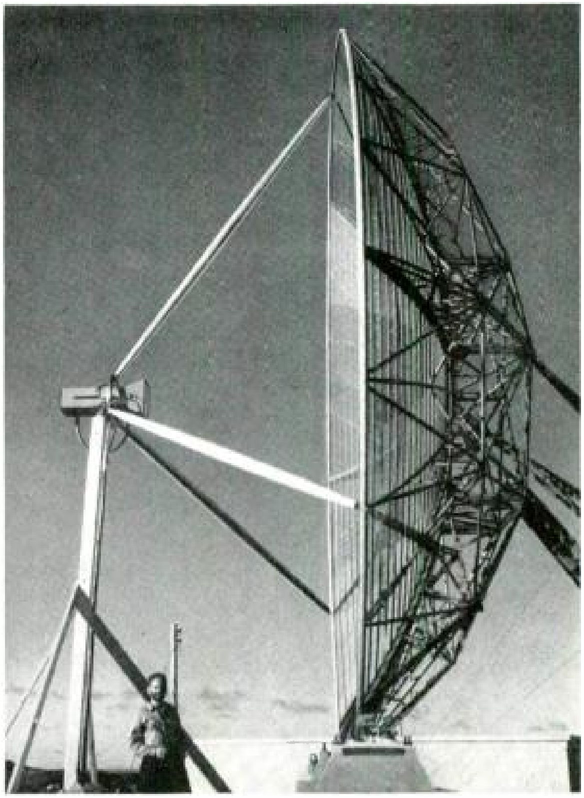


Fig. 4 — Transmitting antenna, 28 feet in diameter, at St. Anthony, Newfoundland.

Figure 3 shows the amplitude distribution of the comparatively slow variations in the received signal. The NOV. 1953 TO OCT. 1954 curve exhibits a normal distribution, in which losses more than x db greater than the median value and losses more than x db less than the median value are equally likely.

It is characteristic of over-the-horizon propagation that practically continuous rapid fading is superimposed on the slow variations. Over short intervals of time, the distribution of instantaneous signal amplitudes in this rapid fading is not symmetrical but approximates a "Rayleigh" distribution; this means that signal levels differing from the median by more than a given amount are downward fades more often than upward swings. It was found in the tests that the depth or magnitude of rapid fading showed no significant variation with the time of day and very little with the season of the year.

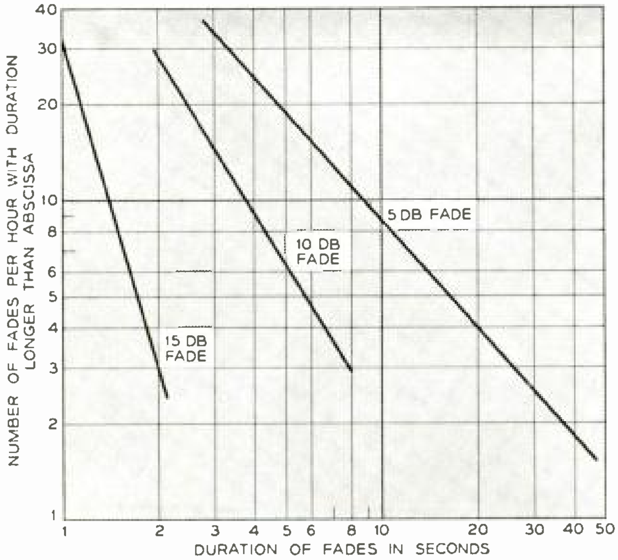


Fig. 5 — Characteristics of the rapid fading observed in the 505-mc tests.

Typical data on rapid fading were obtained from high-speed graphic records of the 505-mc signal received over the 170-mile path, Figure 5. The curves give the number of fades per hour that were more than 5, 10, and 15 db below the hourly median level and lasted longer than the time intervals shown on the abscissa scale. They indicate, for example, that in a typical hour about 32 fades exceeded 15 db in depth and lasted longer than one second. Of these, only three lasted longer than two seconds. At 4,090 mc, fast fading was about 8 times faster than it was at 505 mc.

The numerical data on long-term medians, slow variations, and fast fading are needed so that adequate transmission margins can be engineered into a communications system. When the seasonal variation of monthly medians and the comparatively slow variation of hourly medians combine to produce a low signal, the superimposed rapid fading can cause momentary fades down into the noise level unless the transmission margin is found to be ample. However, the required margin can be reduced considerably by the use of space diversity in reception.

Space diversity can be achieved by receiving a signal simultaneously on two or more antennas spaced many wavelengths apart, using a separate receiver for each antenna, and combining the outputs to obtain the strongest instantaneous received signal. Use of this technique in over-the-horizon systems does not materially affect long-term signal variations, but is useful in reducing the effective range of the rapid fading.

Results of the space-diversity tests, which were a part of the test program, showed that substantially the full theoretical diversity improvement was realized at both test frequencies with a 200-foot antenna separation. In these tests, the better signal received through two antennas and associated receivers was chosen from instant to instant by automatic switching equipment. The percentile signal strength (the value exceeded for all except 1 per cent of the time) with the diversity arrangement was approximately 10 db higher than the corresponding signal strength from a single receiver. This is the improvement expected when two uncorrelated Rayleigh distributions are combined by switching-type diversity equipment.

Some effects of snow and fog for November through April are shown in Figure 7. The collection and segregation of data for this purpose was undertaken because early in the tests it was observed that the signal levels seemed to be lower than usual during snowstorms yet higher than usual during conditions of fog. The curves distinguish between the hourly periods of the 505-mc tests during

Fig. 6 — Some of the receiving and recording equipm used in the year-long over-the-horizon tests.

which snowfall occurred and those when fog was present. Curve A is a cumulative distribution that includes all the hourly median signal levels for the six-month period. Curve B includes only those hours when snowfall was reported at the receiver site, and curve C includes only the hours when fog was reported. From the 50 per cent points on these curves it may be seen that the median signal was reduced about 4 db during hours of snowfall and increased about 6 db during hours of fog.

These effects are even more striking when weather observations at the transmitter site are included. The cumulative distributions of curves D and E include only the hours when snow and fog, respectively, were reported at both ends of the path. Compared with the median signal for all hours, that for snowfall at both terminals shows a reduction in signal strength of about 6.5 db and that for fog at both terminals shows an increase of about 12 db. There was some evidence of signal reduction during rainfall, but the effect was less pronounced than for snowfall.

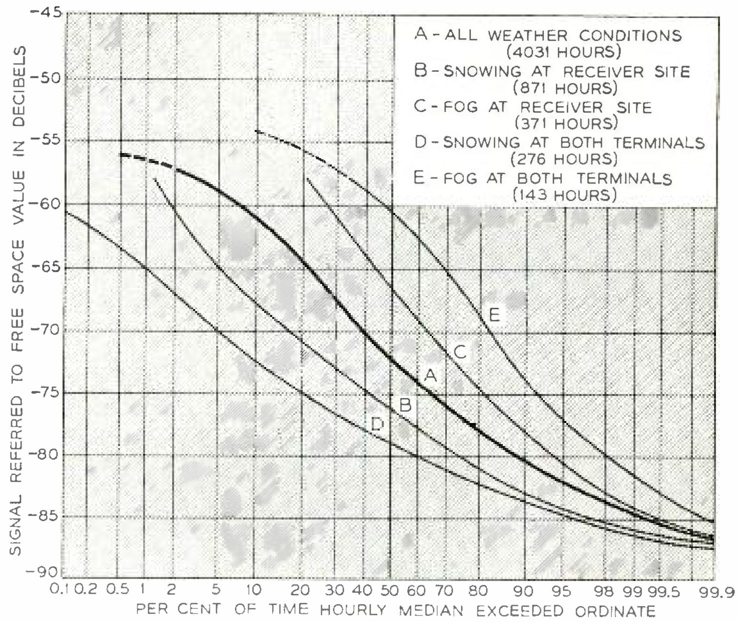


Fig. 7 — How weather conditions, particularly snow and fog, affected transmission.

The utility of these results lies in their providing a basis for engineering new communication systems using over-the-horizon radio links. Specifying the transmission requirements and margins for such systems is essentially a matter of first determining the path loss to be expected over a particular route under the worst conditions and then determining a combination of transmitter powers, receiver bandwidths, receiver noise figures, and antenna gains that will lead to acceptable performance.

THE AUTHOR

Harvey N. Misenheimer received his B.S. degree from Coe College in 1925, after service in the Navy in World War I and two years in the Merchant Marine as a radio operator. His M.S. degree was received from New York University in 1935. He joined the Department of Development and Research of the A.T.&T. Co. in 1925, where he took part in the early development of overseas radio transmitters and systems. This work continued after his transfer to the Laboratories in 1934. Mr. Misenheimer was on military leave with the Army from 1941 through 1945 and is now a Colonel in the Signal Corps reserve. Upon returning to the Laboratories, he resumed work on overseas radio problems for a time. More recently he has been engaged in cost and performance studies of radio relay systems.

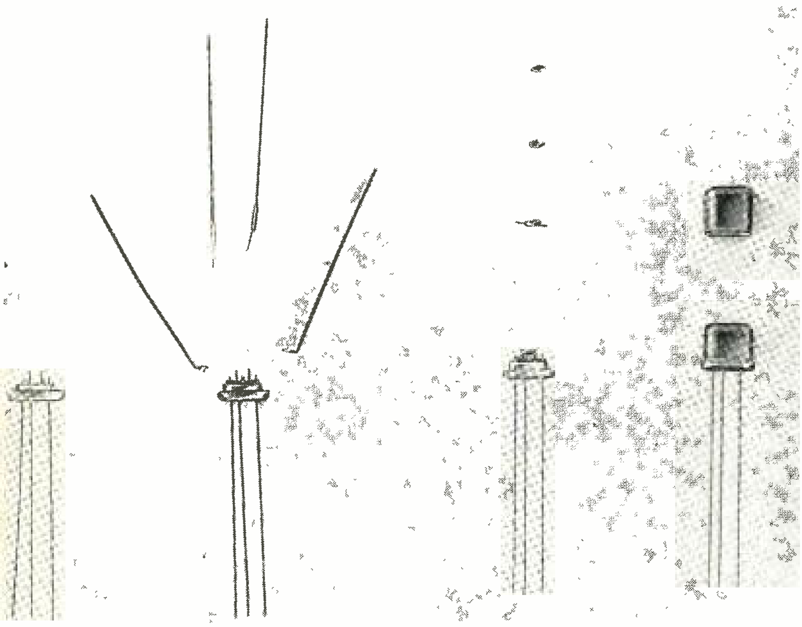


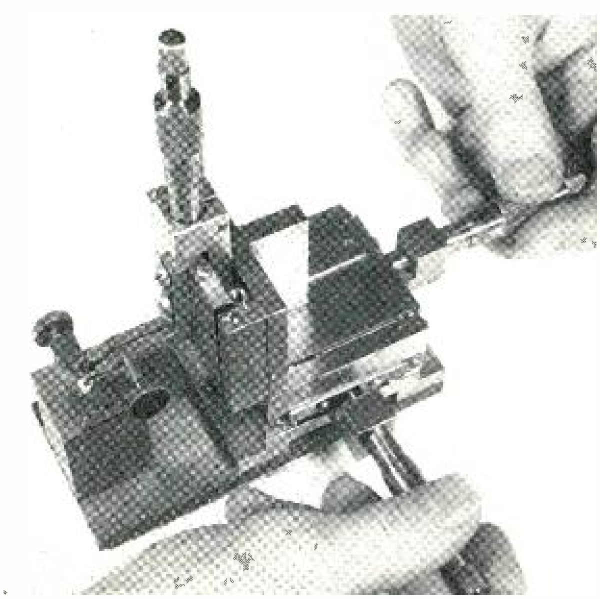
Fig. 3 — The 2N21 hermetically sealed point contact transistor with parts and partial assemblies.

of an inch high. This roughness of the etched surface tends to anchor the contact points, thus resulting in good mechanical stability.

Other design variables, such as germanium conductivity type and emitter and collector point materials, can be determined from experimental results recorded in the earliest days of transistor development. For example, n-type material is more suitable than p-type for optimum current gain. The reverse is true with regard to bandwidth — the electrical frequency at which the current gain begins to diminish. The product of the gain and the bandwith, a useful figure-of-merit for amplifying devices, is frequently more important than either current gain or bandwidth alone, and depends upon both. The decision to use n-type material for the 2N21 was based on the optimization of a combination of device properties such as stability, low collector leakage current (collector current at zero emitter current), ease of fabrication, and of course, gain-bandwidth product.

Point materials which have proved most suitable for nearly all point contact transistor emitters and collectors are beryllium copper and phosphor bronze, respectively. The latter plays an active part in the electrical forming of the device by supplying additional n-type impurities in the form of phosphorus atoms, and must be carefully controlled with regard to phosphorus content. In addition, the spring properties of both point materials must be properly chosen so that mechanically stable contacts are attained.

Since it was an objective that the 2N21 be an extremely rugged transistor, a major portion of the design and development effort on it was devoted to mechanical considerations. Resistance to shock, vibration, and centrifuge acceleration, and to the mechanical motions which result from temperature cycling, was achieved by making all of the pieceparts and their assemblies rigid except for the point wires themselves. These are shaped as "C" springs. The pressures at the metal-germanium contacts are probably greater than 50,000 pounds per square



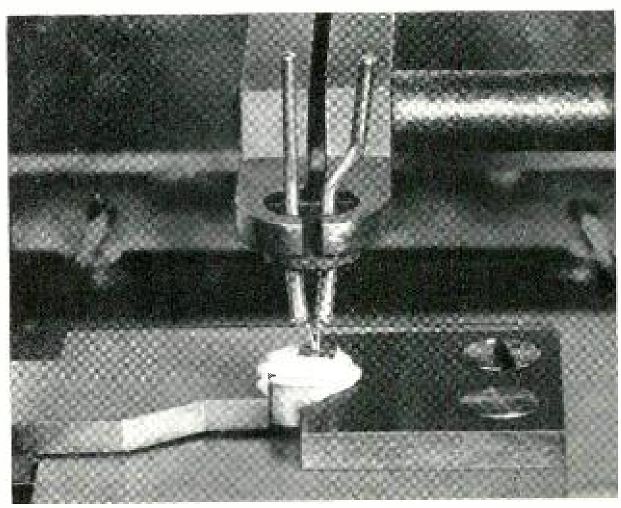


Fig. 4 — Left, a micromanipulator; above, closeup of points pressing on germanium wafer.

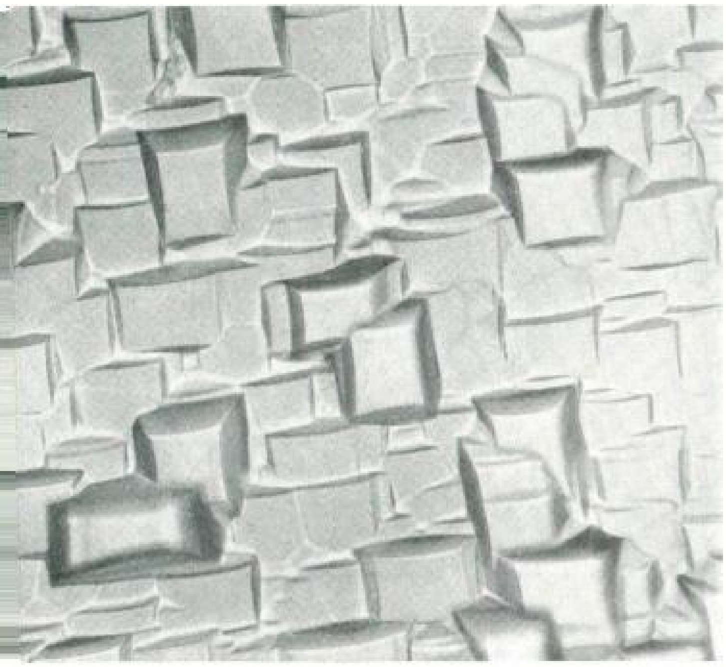


Fig. 5 — Microscopic view of germanium surface properly etched for point contact transistors. Width of area shown about 0.01 inch.

inch, so that the springs hold the point contacts securely at their original positions on the germanium surface, even though the other parts of the structure may move slightly with forces resulting from thermal changes or mechanical accelerations. Glass-to-metal seals where the lead wires enter the transistor subassembly and a solder seal between the can and the subassembly provide the hermetically sealed jacket that keeps atmospheric effects out and the transistor impregnant in. The lead-wires are fabricated of molybdenum to provide maximum thermal dissipation and mechanical strength. A special gold plate, which adheres tenaciously even though the leads are sharply bent, was developed for the molybdenum leads. This plating permits the use of rosin-alcohol solder for wired-in applications and protects the leads from atmospheric corrosion.

All of the design variables mentioned heretofore, including the important structural dimensions of the device, require the specification of manufacturing tolerances. Many of the decisions as to tolerance are as important as the choice of the nominal values. The ranges over which the electrical, mechanical and thermal properties of the device may vary in manufacture are, of course, composites of the permitted tolerances. Fortunately, the final major processing step, that of electrical forming of the collector point, is one which compensates to a large degree for some of the other variations which affect the final electrical properties.

In this forming treatment a pulse of controlled voltage, current, and duration is applied between the collector and base terminals in the reverse direction (opposite to the direction of easier current flow). Before forming, the electrical characteristics of the emitter and collector contacts are very much alike, and there is little interaction between them. That is, the collector current is affected very little by changes in emitter current. Moreover, in such a unit the electrical noise is usually excessive and the other electrical characteristics are unstable and of little use.

In a properly formed unit, on the other hand, the collector characteristic is highly dependent upon emitter current. In Figure 6 the collector characteristic is plotted for several different values of emitter current. Note that, at a given collector voltage, the separation between two adjacent members of this family of curves corresponds to a change in

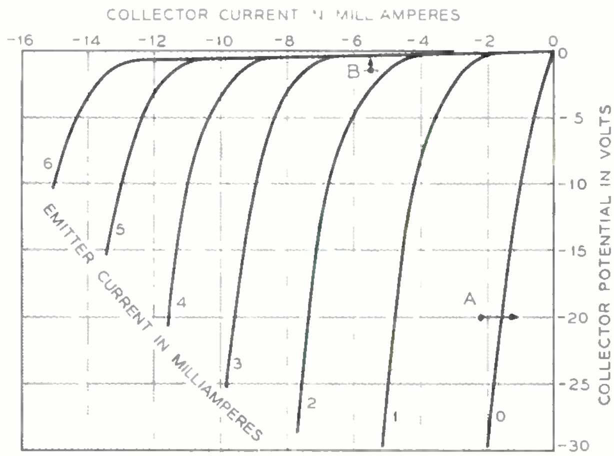


Fig. 5 — Microscopic view of germanium surface of emitter current, illustrating current gain in properly formed 2N21 point contact transistor.

collector current which is greater than the change of emitter current producing it. This current gain in a properly formed 2N21 has a value of about 2.5, which is to be compared with values usually less than 1.0 for junction transistors. Since the current gain of a point contact transistor does not begin to diminish appreciably until the operating frequency has reached several megacycles, the device can be used as an amplifier for radio frequencies and as a switch capable of being turned off and on several hundred thousand times per second.

Electrical forming decreases the noise inherent in the device, though not enough to make it useful

Fig. 7 — Mrs. Betty Haas placing wire attachments on point contact transistor under microscope.

for operation with very weak signals. For this reason, present-day uses are mainly restricted to applications in pulse amplifiers, multivibrators, and oscillators where the signal amplitude is many times greater than the transistor noise. The 2N21 finds its greatest employment in switching-type circuits where transistor noise is of little consequence. Additional effects of electrical forming are to increase the collector leakage current and to reduce the output resistance. Both of these changes are in the "undesirable" direction, and forming must therefore be a compromise between what one is willing to lose and what one wishes to gain in improved current gain and decreased noise. A still further effect of forming is that the stability of all electrical characteristics with time has been radically improved.

Two of the electrical tests used to establish the degree of electrical forming are shown at points "A" and "B" in Figure 6. Collector leakage current must be less than that corresponding to the bias conditions at point "A"; the collector saturation voltage must be less than that corresponding to the bias conditions at point "B." Other tests, such as average current gain and maximum frequency of useful operation, may also be used as criteria for the forming operation.

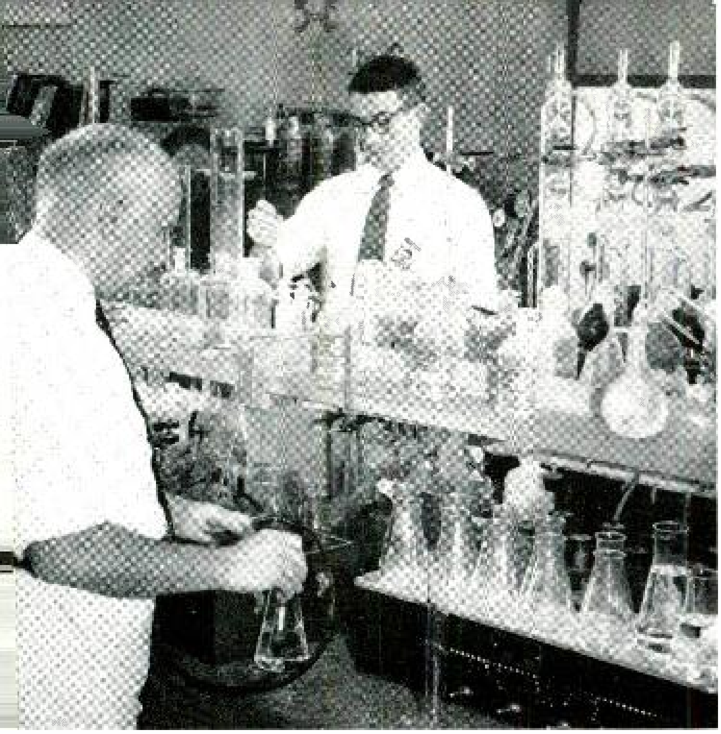
The internal mechanical structure developed for the 2N21 is now being used in several other transistors for specific Bell System applications. For example, the 5A transistor, which is now being manufactured by Western Electric for use in multi-frequency generators of the No. 5 crossbar system* and for direct distance customer dialing, embodies all of the same rugged internal structural features found successful for the 2N21.

Point contact transistors are rugged and reliable. Their development to date has required a combination of known point contact transistor physics and extensive empirical studies. As the physics become better understood and more quantitative, further improvements will surely accrue. Electronic circuit engineers need not wait, however, to add this reliable circuit device to their growing list of useful components. The point contact transistor has come of age.

* Record, *June*, 1954, *page* 221.

THE AUTHOR

N. J. Herbert joined Bell Telephone Laboratories in 1948 following his graduation from Purdue University with a B.S.E.E. degree. After completing the Laboratories' Communications Development Training Program, he began work on carrier frequency transformers. In 1951, he transferred to the transistor group of the Laboratories at Allentown. From 1953 to mid 1955, he was in charge of a group responsible for the final development for manufacture of transistors for Bell System and military use. Mr. Herbert is now Transistor Development Engineer at Allentown. His group is responsible for transmission semi-conductor devices, and for the exploratory and final development of semiconductor materials. Mr. Herbert is a member of the I.R.E., Eta Kappa Nu, and Tau Beta Pi, and represents the Laboratories on several committees of the Joint Electron Tube Engineering Council.



The General Analytical Laboratory

H. E. JOHNSON and J. P. WRIGHT
Chemical Research

In the course of the research and development that leads to improved telephone service, Laboratories scientists and engineers must frequently have a complete analysis of some material that may be new to a particular application. They must know not only what elements constitute the material, but also how much of each is present. To help provide this vital information, the general analytical laboratory maintains a staff that is expert in the techniques and processes of quantitative chemical analysis.

One section of the analytical chemistry group* at Bell Laboratories is the general analytical laboratory. It is in this laboratory that one finds the flasks, beakers, and omni-present odors usually associated with a chemical laboratory. Here, Laboratories chemists are applying so-called classical, or "wet", methods of analysis to the myriad problems of the Bell System.

The function of the general analytical laboratory is primarily one of service; service to, and cooperation with, the many research and development groups within Bell Laboratories comprises about 85 per cent of the work load. Materials checking for the Western Electric Company Supplies Inspection, and preliminary analysis leading to the establishment, or alteration, of specification limits accounts for another 10 per cent. The remaining 5 per cent is divided among short-term research projects, methods development, and cooperative analysis for standardizing bodies such as the American Society for Testing Materials and the National Bureau of Standards.

* RECORD, *November*, 1953, *page* 427; *December*, 1953, *page* 470; *March*, 1954, *page* 88; and *December*, 1955, *page* 451.

Perhaps the outstanding feature of the work in the general laboratory is the wide variety of samples received for analysis. During 1954, samples requiring analysis for 60 of the 98 elements passed through the laboratory. Analyses were made for amounts of these elements comprising from 0.001 to 99 per cent of the sample.

The samples themselves are of every conceivable size, shape, and type. Pike pole points, seepage from a manhole in Kokomo, a new type of semiconductor, corroded contacts from a central office in Iowa — these, and many others might constitute samples received on a given day.

The demand for speed, accuracy, and precision in the analysis of a highly diversified list of materials requires a broad array of specialized apparatus. The apparatus in the general laboratory is of the latest design, and every effort is made to derive from it the highest possible precision.

The most important single instrument found in the general laboratory is the analytical balance shown in Figure 1. Capable of weighing samples accurately to one part in one hundred thousand, it is used at the beginning of every analysis, and as the final measuring device for many. Balances

Fig. 1 — H. E. Johnson using a balance in a special temperature-humidity controlled room.

in the general laboratory are arranged in a temperature-humidity controlled room. Items to be weighed are kept in this room for a period prior to weighing in order to establish temperature-humidity equilibrium.

Most of the analytical methods used by general laboratory chemists may be grouped under three broad headings; titrimetric, gravimetric and photometric. In titrimetric analysis, a solution of the substance being analyzed is treated with a solution of a suitable reagent of exactly known concentration. The addition of this reagent solution is continued until the amount of reagent added is equivalent to the amount of substance being determined. An indicator is sometimes added which changes color when this equivalence or end point is reached. This same end point, in some cases, can be determined electrically. From the amount of reagent added and the weight of sample taken, the per cent of the substance being determined is calculated.

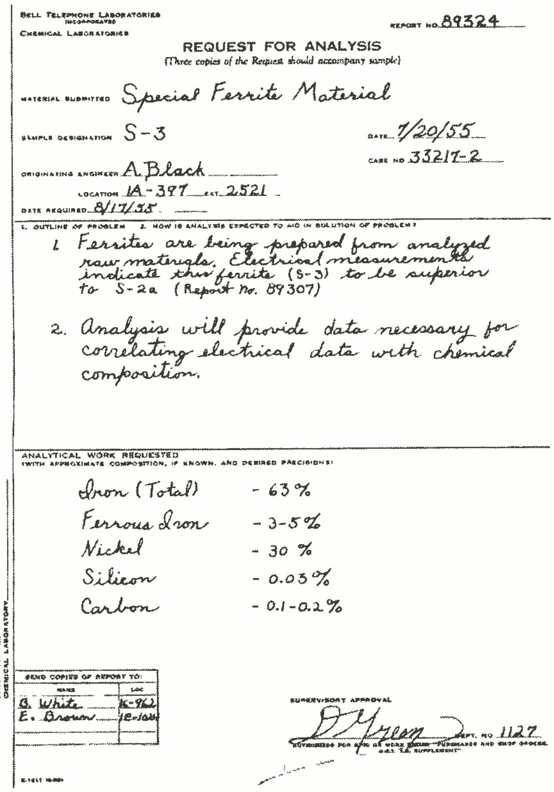
In gravimetric analysis, the substance being determined is separated from all other constituents of the sample in some suitable weighing form. This may be the substance itself, or a compound of it with a known and definite composition. In the latter case, the weight of the substance can be calculated from the weight of this compound.

In photometric analysis, a solution of the constituent to be determined is treated with a color-forming reagent. The desired constituent reacts with this reagent to form a new compound which imparts a characteristic color to the solution. Since the intensity of this color is logarithmically proportional to the concentration of the substance which gave rise to it, comparison with suitable standards completes the analysis.

The over-all operation of the general laboratory can best be illustrated by a typical problem from the time it is received until the completed analytical report is in the proper hands.

A physicist, let us say, is concerned with fundamental studies of ferrites, the ceramic-like magnetic materials now being investigated for use in electronic circuits, particularly in microwave transmission.* Having obtained a special ferrite material, and having completed the desired electrical measurements, he wishes to correlate these results with the actual chemical composition of his sample. As may be seen in Fig. 2, five separate analyses are requested in this particular case: total iron, ferrous iron, nickel, carbon and silicon.

In requesting an analysis of this sample from the general laboratory he gives the analyst a brief, but



BELL TELEPHONE LABORATORIES
INCORPORATED
CHEMICAL LABORATORIES

REPORT NO. 89324

REQUEST FOR ANALYSIS
(Three copies of the Request should accompany sample)

MATERIAL SUBMITTED Special Ferrite Material

SAMPLE DESIGNATION S-3

DATE 7/20/55

CASE NO 33217-2

ORIGINATING ENGINEER A. Black

LOCATION 1A-397 EXT. 2521

DATE REQUIRED 8/17/55

1. OUTLINE OF PROBLEM 2. HOW IS ANALYSIS EXPECTED TO AID IN SOLUTION OF PROBLEM?

1. Ferrites are being prepared from analyzed raw materials. Electrical measurements indicate this ferrite (S-3) to be superior to S-2a (Report No. 89307)

2. Analysis will provide data necessary for correlating electrical data with chemical composition.

ANALYTICAL WORK REQUESTED
(WITH APPROXIMATE COMPOSITION, IF KNOWN, AND DESIRED PRECISIONS)

Iron (Total)	- 63%
Ferrous Iron	- 3-5%
Nickel	- 30%
Silicon	- 0.03%
Carbon	- 0.1-0.2%

DATE RECEIVED IN CHEMICAL LABORATORY

SEND COPIES OF REPORT TO:

NAME	LOC
B. White	K-962
E. Brown	1E-1044

SUPERVISORY APPROVAL

DEPT. NO 1127

Fig. 2 — A typical Request for Analysis form as it is received in the general analytical laboratory.

invaluable glimpse of the problem as a whole. This knowledge frequently enables the analyst to sidestep time-consuming trial and error methods, and in some cases, to supply additional, helpful information as the analysis is performed.

The actual measurement of the desired constituent is the easiest part of the analyst's job. His first task is to select a homogeneous sample from the

* RECORD, *April*, 1955, *page* 131 and *October* 1955, *page* 385.

material submitted, assuming that the original sample is truly representative of the lot being tested. In many cases, he must mill, file, drill, grind, or otherwise reduce the particle size to facilitate handling and dissolving the sample. Powdered samples must be thoroughly mixed to minimize the possibility of segregation.

Few reagents used in chemical analysis are specific for any desired constituent, although such specificity would be highly desirable. Consequently, all interferences must be eliminated prior to the actual measurement of the desired constituent. By interference, as distinguished from other sources of error, one usually means the action of some constituent, other than the one desired, to produce erroneous results. The analyst must anticipate these interferences and know how to deal with them. Thus, the separations or special treatments necessary to obtain the desired constituent in a measurable form pose the analyst's foremost problems.

The analyst to whom the ferrite job is assigned studies the request and selects methods capable of producing accurate results for the concentration levels indicated. In this case, he elects to use a titrimetric method for total iron and ferrous iron. Ferrous iron has a positive valence or charge of 2, but since another form of iron, *ferric* iron, has a valence of plus 3, the analyst must distinguish between the two. He knows the other components of the sample will not interfere with the iron titration.

For total iron determinations, a sample of the ferrite weighing about 0.1 gram (about 0.003 oz.)

'ig. 3 — J. F. Jensen maintains an atmosphere of carbon ·ioxide while dissolving a sample for ferrous iron deter-.iination. In the background, E. Bloom, Jr. is filtering off 'ickel dimethylglyoxime precipitate.

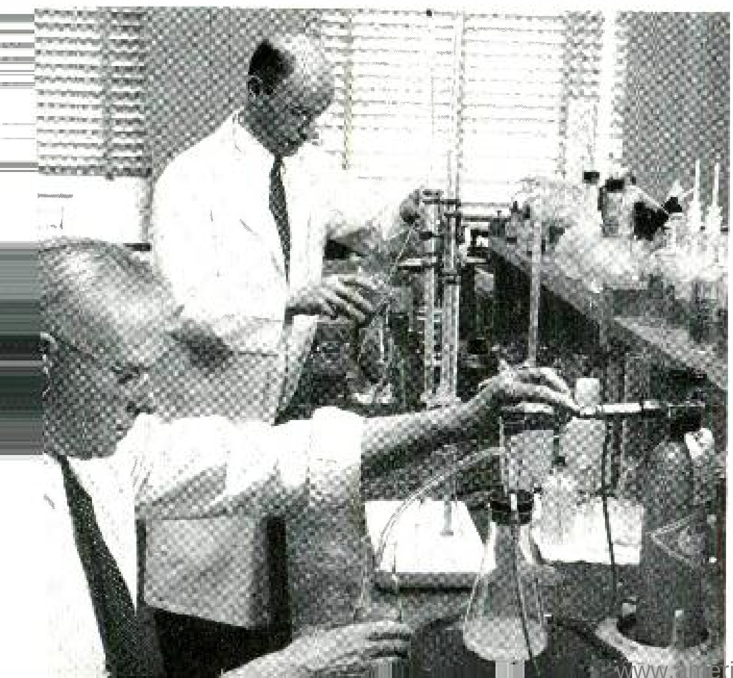


Fig. 4 — F. W. Ryan operating the high-temperature induction furnace for carbon determination. The carbon dioxide evolved is collected in the absorption bulb shown in the upper-left corner.

is dissolved in hydrochloric acid. This solution is then passed through a silver reductor, a glass column containing finely divided silver. In this reductor, all of the iron present in the sample is converted to ferrous iron. An indicator is added and the solution is titrated by adding a reagent (ceric sulfate) which converts all of the ferrous iron into ferric iron. When all of the iron has been so converted, the indicator changes color, thus marking the end point of the titration. A unit volume of the titrating solution has a known capacity for effecting this conversion. From the amount of titrant used, and the weight of sample taken, the analyst can calculate the total amount of iron present in the ferrite.

The determination of ferrous iron presents a special problem since it may easily be converted to the ferric type by accident. Grinding the sample, or heating it in acid *in the presence of air* will produce this change. The sample is, therefore, ground under alcohol and dissolved in dilute hydrochloric acid in an atmosphere of carbon dioxide (Figure 3). The solution is then titrated, still in an atmosphere of carbon dioxide, using the same titrant and indicator as for total iron. In this case, however, the amount of titrant used represents only the ferrous iron originally present.

The analyst now turns his attention to the determination of nickel. As always, the nature of the matrix material dictates the method to be used. He knows that iron will interfere with the gravimetric determination of nickel, since the nickel precipitant, dimethylglyoxime, is effective only in an ammonia solution. Iron will precipitate in the presence of ammonia and so it must be removed or rendered inactive if the gravimetric procedure is to be used. To do this, carefully weighed samples

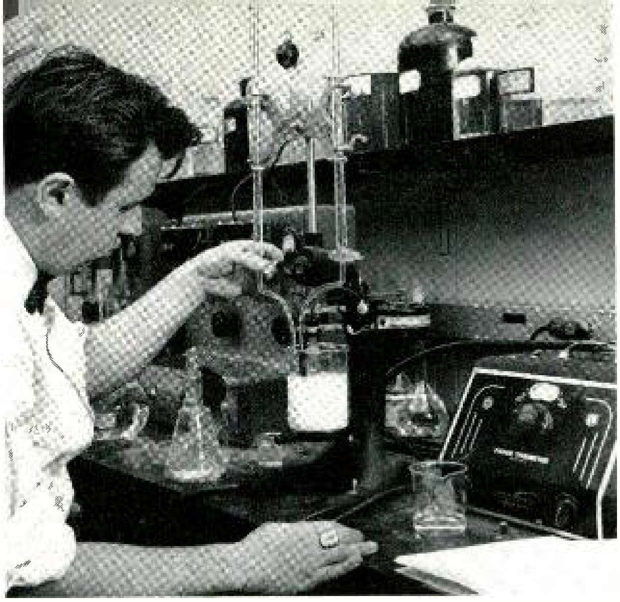


Fig. 5 — J. E. Kessler titrates a sample using the automatic titrimeter to determine the amount of chloride in a wood boring.

are dissolved in acid and the solution is diluted to a convenient volume. Then a few grams of tartaric acid are added. The iron present reacts to form a complex tartrate which will *not* precipitate in the presence of ammonia. Ammonia is now added until the solution is slightly basic because the nickel precipitate will not form in an acid solution.

Dimethylglyoxime solution is added to the sample and the nickel reacts to form a bright red precipitate. After a few hours settling, the precipitate is filtered off, washed, dried, and weighed (Figure 3). The composition of this precipitate is constant and well known; for every gram of precipitate there were 0.2031 grams of nickel in the sample. Knowing the weight of sample, the analyst can easily calculate the nickel percentage.

The carbon determination requested by our inquisitive physicist presents no special separation problems since carbon can be removed from the matrix material and measured without interference from other elements. A weighed sample of the ferrite is burned in a stream of pure oxygen at a temperature of 1000°C or above (Figure 4). Under these conditions, the carbon present reacts to form carbon dioxide which is caught in a previously weighed bulb containing an absorbant such as ascarite (asbestos impregnated with sodium hydroxide). From the gain in weight of the absorbant, the amount of carbon present is calculated.

The determination of silicon completes the ferrite request. However, the silicon content of this sample is too low for ordinary gravimetric techniques. One gram of sample would yield only about 0.0006 grams of material for final weighing. Photometric analysis is particularly well suited to the determination of such relatively small amounts of silicon.* A color-forming reagent, in this case amonium molybdate, is added to the sample, and since the intensity of the color formed is logarithmically proportional to the silicon concentration, a comparison with suitable standards completes the analysis.

The preceding description is only one example

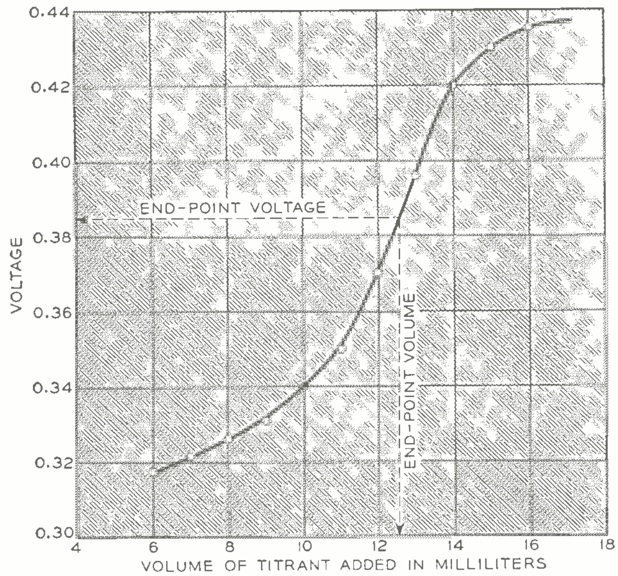


Fig. 6 — Typical titration curve showing voltage versus volume of titrant added.

of the work of the general laboratory. In many cases, two or perhaps three analysts would have combined their efforts and know-how to complete this one request. Frequently the general laboratory completes one section of a request while the spectrographic, or X-ray laboratory completes another. One analyst may also be working on parts of several requests at one time.

One of the special instruments used in the general laboratory is an automatic titrimeter. With this instrument, one can follow the course of a titration and detect the end point electrically, (Figure 5). In recent months, the automatic feature of this instrument has become increasingly important.

One request that illustrates the use of this titrimeter was received early in 1955. It covers wood samples taken from poles exposed in various Bell System test plots, and will require more than 1,500 determinations. Chloride concentrations in the wood must be determined so that the pentachloro-

* RECORD, *March*, 1954, *page* 88.

phenol preservative retentions may be calculated.

The chloride is extracted from the wood by fusion with lime. The fusion products are dissolved in acid and the chloride is titrated with silver nitrate usng the automatic titrimeter. The analyst adds the titrant in small increments, adjusts the instrument to a null position after each addition, and records the voltage reading. The null is indicated by a "magic-eye tube" identical to the one used in several radio receivers to indicate accurate tuning. A plot of voltage versus volume of titrant added shows the end point for the titration as well as the voltage at the end point, (Figure 6).

After titrating the first sample, the analyst can set the instrument for the end point voltage indicated by the curve. Subsequent samples of the same type are then titrated without reference to the voltage scale. At the end point, the eye blinks open, and the analyst needs only record the volume of titrant used.

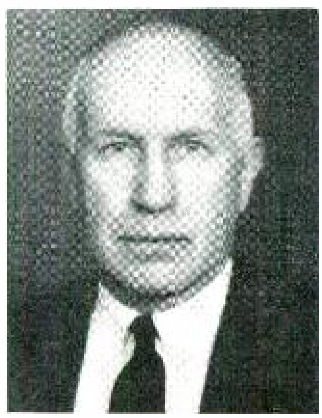
In addition to the strictly chemical methods already discussed, there are many physical testing methods for which the general laboratory is responsible: viscosities for polymer degradation studies; conductivities for purity studies; softening point, melting point, flash point and many other tests on pitch, asphalt, creosote and cable impregnants; and distillation ranges and toxicity studies for degreasing solvents. These tests, together with straight physical-constant determinations such as boiling point, refractive index and density make the average day anything but routine. Some of the apparatus used in these tests is shown in Figure 7.

Fig. 7 — W. C. Jordan uses oil bath to determine the viscosity of a polymer solution.

During 1954, approximately 512 requests were received and completed either wholly or in part by the general laboratory. Each request requires an average of five or six separate determinations, and each must be run in duplicate. Thus, some 6,000 determinations were made last year. Virtually everything used in the Bell System is found once, or perhaps many times, as a notation in the records of the general analytical laboratory.

THE AUTHORS

J. P. Wright received a B.A. degree from Wabash College in 1950, and an M.S. degree in Analytical Chemistry from Purdue University in 1952. He joined the analytical chemistry group at the Laboratories in September of 1952. Since that time, he has been associated with H. E. Johnson in the general analytical laboratory where he has been engaged in various programs in the field of analytical chemistry. Mr. Wright is a member of the American Chemical Society and Sigma Xi.



H. E. Johnson received a degree from the New Bedford Technical Institute in 1914. After working for several years in the chemical industry, he joined the chemical analytical group of the Western Electric's Engineering Department in 1924, and transferred with that group to the Laboratories in 1925. Since then Mr. Johnson has supervised the general analytical laboratory, a group responsible for the chemical analysis of materials submitted by various research groups. He is a member of the American Chemical Society and the A.S.T.M. Committee on the chemical analysis of ferrous and non-ferrous metals.

Miniature FM Transistor Transmitter

D. E. THOMAS *Physical Research*
Formerly Transistor Development

A miniature FM transmitter has been built to illustrate the very high frequency performance of transistors and to show that a transistor oscillator can be frequency modulated in a simple manner. In addition, this transmitter demonstrates how the transistor can greatly reduce the size of broadcast equipment for remote points.

The small size and low power requirements of transistors have already brought the "Dick Tracy" radio out of the world of fiction into the world of reality. The miniature transmitter seen in Figure 1 demonstrates what the transistor can do when incorporated into electronic circuits. This particular transmitter, however, has been used principally for Laboratory purposes and has not been optimized electrically nor engineered mechanically. Actually it could be made appreciably smaller if a special container were designed for the most efficient arrangement of components.

The transmitter owes its existence to a more fundamental objective than that of merely demonstrating the possibilities of miniaturization with transistors. The real reason for building it grew out of a study of transistor oscillator circuits. In the early stages of the development of very high frequency point-contact transistors, performance in an oscillator circuit was the principal means of characterizing their properties. The method of frequency modulation on which this transmitter is based originated from behavior studies of such a VHF oscillator.

The transmitter in Figure 1 is enclosed in a volume of 3½ cubic inches, and has a total of ten elements, including the transistor and a single battery used as the power supply. The one transistor performs all the functions required of a complete FM radio transmitter.

Any FM transmitter must include first an RF oscillator, second an arrangement for varying the frequency of oscillation – that is, a method of frequency modulating the oscillator – and third a means of introducing the audio signal in such a way that the frequency shift of the oscillator will be proportional to the instantaneous amplitude of the audio signal. In describing the operation of this transmitter it is therefore convenient to divide the circuit into two parts – the radio frequency portion and the audio portion – and to show how interaction between them modulates the transistor. Fig-

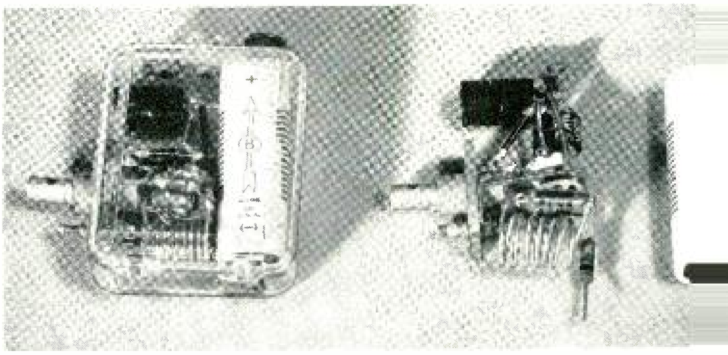
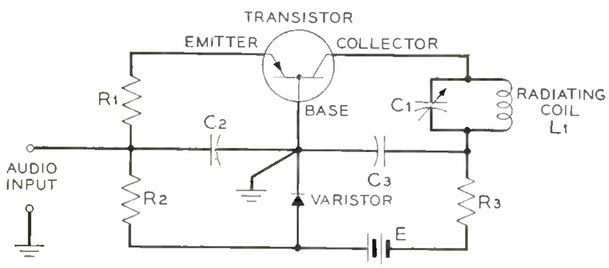


Fig. 1 — Complete transmitter (left), with internal components (center) and power source.

ure 2 is a circuit diagram of the complete transmitter, and Figure 3(a) is a diagram of the effective RF section. It will be noticed that the RF section consists of only the upper part of the circuitry in Figure 2, since capacitors C_2 and C_3 effectively short circuit the bottom part of the circuit at radio frequencies. Figure 3(b) is the effective audio portion, in which the resonant circuit L_1-C_1 becomes a short circuit and C_2 and C_3 become open circuits at the relatively low-frequency voice signals.

Considering first the RF circuit in Figure 3(a), we notice the additional capacitances indicated by the dotted lines. These are the inter-element capacitances of the transistor and socket that become significant at very high frequencies. Capacitance Cec (capacitance between the emitter and collector of the transistor) will be seen as particularly important to the operation of the transmitter.

Any device having power gain can be made to oscillate by feeding a portion of its output energy back to its input, providing the fed-back energy is in phase with and is at least equal in magnitude to the original input. The path for feeding back energy in this oscillator is through the collector-to-emitter capacitance of the transistor, Cec. At first



SPECIFICATIONS:

TRANSISTOR------M1832	R3-------2000 OHMS
VARISTOR------W.E.400A	C1-------ABOUT 9 $\mu\mu$F
E---------22.5V	C2-------0.001 MF
R1--------3000 OHMS	C3--------0.001 MF
R2-------2000 OHMS	L1------ABOUT 0.25 μH

Fig. 2 — Schematic of transistor transmitter.

glance, it might appear that this arrangement would be unsatisfactory, since a capacitor shifts the phase of the signal about 90°. The key to the RF oscillation of the circuit is that the characteristics of the transistor itself provide the major portion of the compensating phase shift in the opposite direction, so that the fed-back energy can be brought in phase with the original input.

Figure 4 can be used to illustrate how this compensating phase shift comes about. Using the current gain at low frequencies as the reference or zero point, the solid-line curve in the upper part of Figure 4 shows how the magnitude of the current gain or "alpha" drops off with increasing frequency. The frequency at which the current gain is down 3 decibels from its low frequency value is defined as the "alpha cutoff" frequency, which for this particular transistor is seen to be at 40 mc. A decrease of 3 decibels corresponds to a loss of half the output power, and has become a convenient reference point in characterizing many circuits used in electronics.

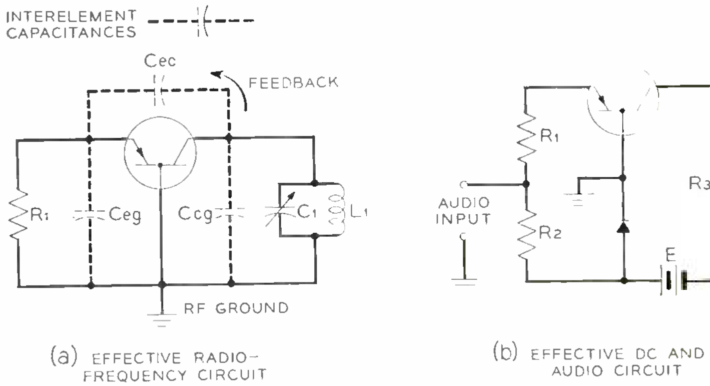


Fig. 3 — (a) Effective radio-frequency portion of circuit; (b) effective direct-current and audio portion.

Accompanying the decrease in the magnitude of the current gain there is a corresponding phase shift of the output current as compared to the input current, as shown by the solid-line curve in the lower part of Figure 4. This phase shift is due to the fact that carriers of electrical charges take different amounts of time to traverse the distance between the emitter and collector within the body of the semiconductor crystal. At 100 megacycles, in the operating range of the transmitter, this phase shift is seen to be about −70°. Thus the +90° shift of Cec is largely cancelled, but there is still an additional −20° of phase shift required if the fed-back energy is to be exactly in phase with the input. This is automatically taken care of because the circuit will oscillate just enough off the resonant frequency of the L_1-C_1 tank circuit to supply the additional shift. Appreciable additional phase shift can be obtained with only a small decrease in efficiency.

The phase condition for sustained oscillation is thus fulfilled. Since oscillation requires a circuit gain only slightly in excess of unity, a circuit having high gain at low frequency can be made to oscillate at frequencies much higher than the alpha cutoff frequency. The 100-mc region was chosen because of the convenience of receiving the RF signal on ordinary FM equipment by operating on a frequency not occupied by a commercial FM station.

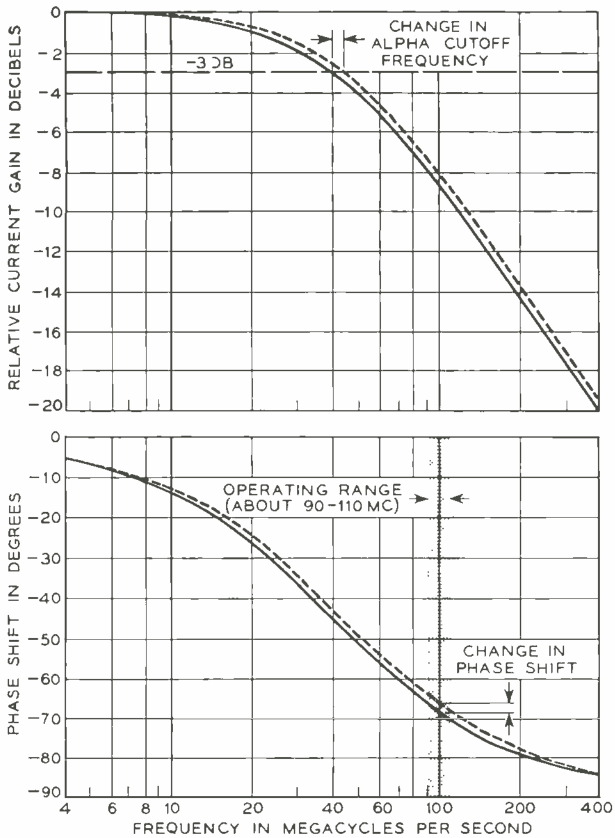


Fig. 4 — Current-gain and phase-shift curves illustrating transistor's dual functions as VHF oscillator and as a frequency-modulated device.

We now see how the transistor can be made to oscillate, and there remains to describe how it can be frequency modulated. For this purpose we refer to the audio portion of the network, Figure 3 (b), and to the dashed curves of Figure 4.

The key to the frequency-modulation mechanism is also found in the characteristic current-gain and phase-shift behavior shown in Figure 4. The solid-line curves show the amplitude and phase of the current gain for a particular direct-current operating point of the transistor. The operating point is defined by the dc emitter current and dc collector voltage when no audio signal is applied. If this dc operating point is changed, the positions of the current gain curve and of the phase shift curve also change, as shown by the dashed curves in Figure 4. (The displacements of the curves are in reality too small to be seen on a graph of this scale, so the distances have here been considerably exaggerated.) The change in the phase shift means that the fed-back energy will now no longer have the in-phase relationship required for sustained oscillations. Like all oscillators, however, it automatically "seeks" the correct oscillating frequency. It alters the frequency of oscillation by just the right amount to restore the necessary phase relationship. When the operating point is varied at an audio rate, the oscillator is therefore frequency modulated.

The audio signal is introduced by the effective circuit shown as Figure 3(b). The operating point is varied by the voice signal applied to the emitter of the transistor to produce frequency modulation. The diode (W.E. Varistor 400A) in the base circuit permits efficient and stable operation using only one battery to supply power to both the emitter and collector circuits. Resistor R1 prevents undesirable transistor oscillations, and R2 provides a path for emitter current, yet has a sufficiently high value of resistance to avoid shorting out the audio signal. Resistor R3 adjusts the dc voltage on the collector of the transistor and acts as a load resistance in the audio circuit.

The maximum frequency deviation used for standard broadcast type FM transmission is ±75 kc in 100 mc, or less than 0.1 per cent. For such small percentage shifts, the frequency variation of the transmitter is sufficiently close to being linearly proportional to the instantaneous value of the audio

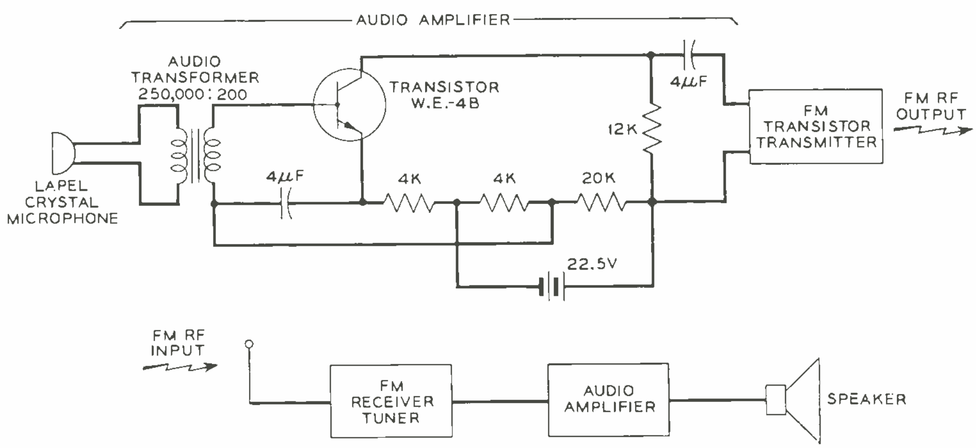


Fig. 5 — Diagram of public address system using transistor transmitter and lapel microphone.

signal to provide high-fidelity FM transmission of speech and music.

This transmitter has been demonstrated in a number of ways, but perhaps the most dramatic has been its use with a lapel microphone as a part of a public address system. As shown in Figure 5, some additional audio amplification is necessary in this application, since the output of a crystal microphone is too low to drive the transmitter directly. A single-stage n-p-n transistor amplifier is therefore added to the circuit, and is mounted along with a matching transformer in a plastic case similar to that used for the transmitter. The transmitter and amplifier may both be carried in pockets of the speaker's clothing, leaving the lapel micophone as the only visible element of the system. The FM signal is picked up by an off-stage receiver, and the audio output of the receiver is fed into conventional public address equipment. The speaker is thus free to move about the stage unencumbered by a microphone cable. The particular system illustrated in Figure 5 has been used to deliver lectures without the audience being aware that any equipment other than that of a conventional public address system was in use.

Alternatively, the transmitter has been demonstrated by modulating it directly with the audio signal from a crystal phonograph pickup matched to the input of the transmitter with a suitable transformer. The FM signal is then received by a nearby standard commercial FM radio for presentation to an audience. In another arrangement, the transmitter has been powered by a Bell Solar Battery.* By this procedure, the radio frequency energy is derived entirely from sunlight.

Since this transmitter operates in the vicinity of 100 mc, 2½ times the alpha cutoff frequency, the power gain is much below the potential maximum. Transmitting distances therefore are limited to a few hundred feet using the radiation from the L_1 coil of the oscillator circuit. This range could be considerably extended by using a simple antenna.

The design shown in the headpiece of this article has a somewhat different and more compact arrangement of microphone, audio amplifier, and transmitter. The microphone is attached directly to the case, and a single battery housed within the handle supplies all the necessary power. The unit is thus a complete roving FM radio station. The assembly was built by the Sapan Engineering Company under the direction of H. J. Kostkos of the Laboratories' Publication Department.

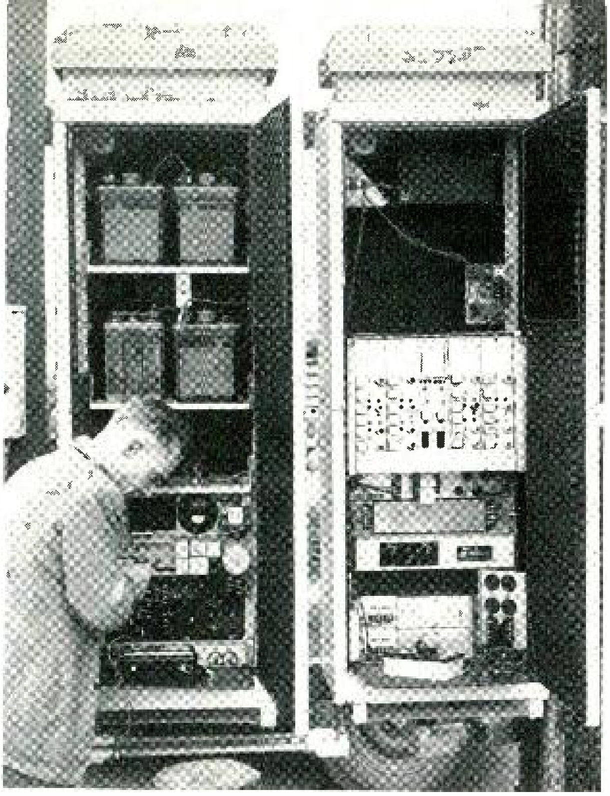
The circuit element values of the transmitter are not critical. A number of these transmitters have been constructed, and all have worked with no other adjustment than that of the L_1-C_1 tank circuit frequency and of the value of resistance R_3. In one of the transmitters, twenty different transistors functioned properly with no circuit adjustments required to compensate for the varying characteristics of the transistors. The circuit thus needs only a transistor with sufficient gain and with an alpha cutoff frequency which is close to half the frequency of oscillation. An FM transmitter using a tetrode transistor had been demonstrated earlier by R. L. Wallace of the Laboratories.

These laboratory units have demonstrated the VHF possibilities of point-contact transistors and the principle of frequency modulation by alpha cutoff frequency shift. Similar transmitters operating at frequencies many times higher than the one discussed are now possible with current developmental models of other types of transistors.

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

THE AUTHOR

Donald E. Thomas received a B.S. degree in E.E. from Pennsylvania State University in 1929, and an M.A. degree from Columbia University in 1932. He joined the Laboratories in 1929 where his first assignment was in submarine cable development. Later, he was engaged in the development of sea and airborne radar. In 1942 he entered military service where he was engaged in electronic countermeasure research and development activities. Mr. Thomas rejoined the Laboratories in 1946. Following the war, he was active in the development and installation of the Key West-Havana repeatered submarine telephone cable, and in the development of transistor devices for special applications. At present, he is a member of the Solid State Electronics Research Department where he is engaged in characterization and feasibility evaluation of research models of semiconducting devices. Mr. Thomas is a senior member of the I.R.E. and a member of Tau Beta Pi and Phi Kappa Phi.



Pole-Mounted Repeaters and Reserve Power Supplies

W. A. MacMASTER
Underwater Systems Development
Formerly Transmission Systems Development

Carrier telephone systems are always dependent on the joint problems of where and how to mount repeaters and the power supplies for those repeaters. In the type-O carrier system for open-wire lines, repeaters are mounted directly on the poles, and use commercial power. To protect the carrier system against possible failure of the commercial power, reserve power supplies have been developed that mount in companion cabinets on the same poles as the repeaters.

One problem in the design of type-O carrier* was the need for repeaters at fairly short intervals. Sometimes these repeater locations are convenient, coinciding with a telephone office or a repeater hut for other systems. Quite often, however, repeater locations fall somewhere along a stretch of open-wire line, away from such enclosures.

Studies indicated that such isolated repeaters might be conveniently mounted directly on the poles, in weatherproof cabinets. In type-N carrier for cables,† power is fed to pole-mounted repeaters over the cable, eliminating separate power supplies and permitting the use of relatively small cabinets. This method, however, is not very satisfactory for open-wire lines; it was therefore decided to use separate power supplies for the type-O repeaters. Metallic rectifiers operating from commercial ac sources were chosen as most suitable, and they were small enough that the same cabinets could be used as for type-N carrier.

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

Once the choice of cabinet and power source was settled, the necessary mounting details were worked out and a rectifier power supply was developed. In addition to the power supply, each cabinet provides for four repeaters. When the cabinet is open, a shelf may be dropped into position to support test equipment and facilitate maintenance, and power outlets are available for the repairman's convenience. A single, all-purpose alarm circuit provides an indication at the nearest attended terminal or repeater, so that a repairman may be rapidly dispatched should a repeater develop any trouble.

The higher-frequency type-O systems – OC and OD – require repeaters spaced half as far apart as those for OA and OB. Sometimes it is necessary to branch off a given system while repeatering or bypassing others. The many possible combinations of repeater types, filters, and simulating networks at each cabinet make it very desirable to be able to rearrange units and wiring without using a soldering iron. This has been made possible by the method of mounting the various units in the cabinet. The repeater and oscillator units plug into a mounting, and the mounting and all other units are bolted to the cabinet. Plug and jack connectors are used for the repeater, oscillator, and power units, and all incoming leads are connected to screw-type terminals. Should the ac power be off, units may still be replaced and connections changed without using a soldering iron.

Coincident with the development of a pole-mounted repeater was that of a reserve power supply for the repeater. The voltage of commercial ac lines sometimes varies widely, and occasional failures occur. To insure that telephone service would not be degraded or interrupted by such conditions, a reserve supply was developed. It is contained in a cabinet similar to that of the repeater, to provide a companion pole-mounted unit.

The reserve power supply uses a 12-cell storage battery, charged and controlled by a 24-volt metallic rectifier. To provide the needed 130 volts, the battery operates a 24- to 130-volt dynamotor. When only one or two repeaters are used, the power supply will operate for about ten hours. For the full complement of four repeaters, an additional dynamotor is added, reducing the reserve time to about four hours. An optional arrangement requires another cabinet, in which is mounted a second battery and dynamotor. This provides ten hours of reserve time, and can be used when four hours is not sufficient.

A control circuit automatically switches the reserve supply into operation when the regular supply fails. Figure 1 shows how this circuit works. Although controlled by the reserve supply, the actual transfer relays are part of the repeater equipment and are in the repeater cabinet; they connect between repeater and rectifier, thus also preventing interruption of service should the rectifier fail. The heart of the control circuit is a 267A high-speed marginal relay. By adjusting the potentiometer, relay VR can be made to release when the ac line voltage falls below any predetermined value, so that service is protected against low voltage as well as complete failure. When VR releases, it removes ground from relay L; release of relay L supplies ground to both the heavy-duty dynamotor-starting relay and the transfer relay, and the reserve power supply takes up the load.

Unless preventive measures were taken, such a control system could cause rapid recycling between the regular and reserve power supplies. This could happen, for example, if the ac line voltage were to fluctuate slightly above and below the predetermined minimum value. Rapid recycling is prevented by an additional relay H and a resistance-capacitance timing circuit. Although the transfer to the reserve supply is immediate, there is about a one-minute delay in transferring back to the regular supply after the line voltage becomes normal. As in the repeater, an alarm circuit is provided, to indicate at the nearest attended office that a power failure has occurred.

Polystyrene-cased batteries permit the water level to be seen through their transparent sides, and an offset hydrometer is used to fill the batteries and measure specific gravities without moving them. A drop-shelf is provided for use by the repairman, and the leads to the dynamotor are long enough so that it may be moved out and placed on this dropshelf for maintenance. The rectifier and all controls and fuses are mounted on hinged panels for easy maintenance.

Since the repeater and reserve power supply are pole-mounted, they are exposed to all types of weather, and several provisions have been made to keep temperatures inside the cabinets within normal operating limits. The outside is finished in gloss white enamel and the inside is lined with an inch-thick layer of insulating material to minimize absorption of heat from the sun. To control the flow of convection air currents within the cabinets, thermostatically-controlled dampers are installed in the cabinet bonnets.

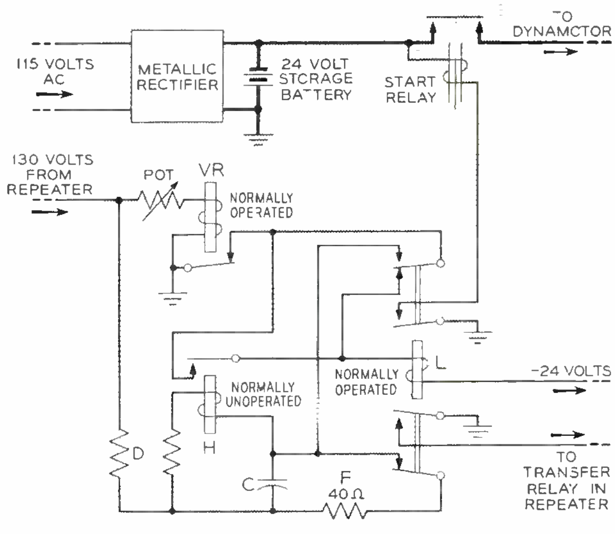


Fig. 1 — Diagram of the reserve power supply control unit in the normal condition.

Certain components of the repeaters are temperature-sensitive, and the heated air that results from the use of electronic equipment must be removed from the repeater cabinets. Thermostatically-controlled twin blowers provide forced-air cooling when the damper-controlled flow of convection currents is not sufficient to keep the temperature below a predetermined limit. The bottom vent is normally left open to give free flow to the convection currents, but during the winter months in certain areas it might be possible for wind-driven snow to enter the cabinet in sufficient quantity to cause failure of the equipment. For such locations, a removable insert is available. All vents are screened to exclude insects.

The situation in the power supply cabinet is just the reverse. One problem with storage batteries is that their efficiency drops as the temperature goes down; furthermore, should the electrolyte freeze, the batteries would be ruined. To maintain proper cabinet temperature, the thermostatically-controlled damper is used but, instead of blowers, a regulated heater is provided.

Although the cabinets are designed for "pole" mounting, they are usually mounted as in the headpiece, on two wooden crossarms. Sometimes only one pole is used, with the cabinets on either side, yet mounted on crossarms and facing in the same direction. In all cases, they must be accessible for maintenance. Where it is not practicable to mount them close to the ground, a wooden platform is provided at a suitable height.

Trial installations have proved the feasibility of pole-mounting both the reserve power supply and the repeaters. When repeaters of the OB system used in the tests were operated on the reserve supply, the noise level increased slightly but not enough to be discerned by ear. The transfer from regular to reserve supply produced only a single small click, not disturbing to the customer.

THE AUTHOR

W. A. MacMaster received a B.S. degree in physics from Union College in 1927, and joined the Laboratories that same year. After short periods with the Personnel and Research Departments, his entire Bell System career has been devoted to equipment development, primarily of control facilities between radio links and land lines. During the war he was involved in the development of military equipment, and then became engaged in the system coordination and development of the New York State Police radio system. Mr. MacMaster subsequently spent some time on message-circuit radio control terminals and the pole-mounted repeater for type-O carrier, and then transferred to military equipment development where he has since remained.

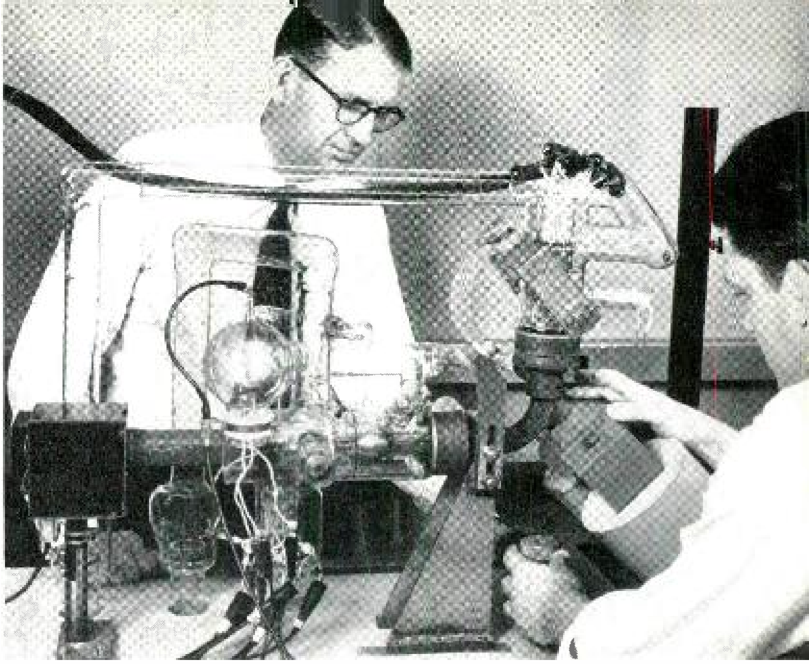
A. I. E. E. Cites Laboratories Authors

The technical paper, "A Transatlantic Telephone Cable," co-authored by Dr. Mervin J. Kelly and George W. Gilman on the part of the Laboratories, and Sir W. Gordon Radley and R. J. Halsey of the British Post Office, has been awarded First Prize in the Communication Division of the American Institute of Electrical Engineers.

Dr. Kelly attended the General Session of the five-day Winter General Meeting of the Institute on Jan. 30 at New York's Hotel Statler to accept the award for the authors. At the same meeting, G. H. Huber, W. F. Miller and C. W. Schramm were awarded Second Prize for their paper, "New Military Carrier Telephone Systems."

Institute Paper Prizes were awarded in all five technical divisions of the A.I.E.E. Winners were selected by the Institute's Committee on Prize Awards, of which W. R. Brownlee, of Birmingham, Ala., is chairman. The awards are for papers submitted between Aug. 1, 1954 and July 31, 1955.

Electron Ejection from Metals by Ions



H. D. HAGSTRUM *Physical Research*

The operation of a gas-filled electron tube depends upon the release of electrons from the cold cathode by the action of gaseous ions — a process of much technical interest since these tubes find many applications in the Bell System. Study of this phenomenon has contributed to our picture of the mechanisms involved and is providing another means of probing the surface properties of solids and energy levels of electrons in them.

The release of electrons from metals is a matter of considerable scientific interest and technical importance. If you were to ask most any physicist how it can be done, he would probably specify four ways: you may heat the metal, shine light upon it, bombard it with fast electrons, or subject the surface of the metal to a strong electric field. A fifth and less well known method involves the ejection of electrons by slowly moving gaseous ions.

This last method is the predominant mechanism by which electrons are released from the cold cathode of a gas-filled tube. Such tubes are now being used extensively in the Bell System, and they seem destined to play a fundamental role in projected all-electronic switching systems. Investigation of this type of electron ejection gives promise of providing a new tool for study of solid surfaces and of the energy levels of electrons in solids.

These investigations concern the release of electrons from the surfaces of metals like tungsten and molybdenum by slowly moving ions of the so-called noble gases (helium, neon, argon, krypton, and xenon, in ascending order of atomic weight). We recall that an ion is an atom from which an electron in the outer-most shell has been removed and which, for this reason, is positively charged. To remove this electron one must expend an amount of energy called the ionization energy, which is characteristic of the parent atom. In these experiments, an ion that has been accelerated from rest through a potential difference of less than 100 volts is considered to be "slowly moving."

The mechanism by which an ion releases an electron from a metal is illustrated in Figure 1. At the left in the figure a helium ion is approaching a metal surface. As the ion approaches the metal surface a transformation takes place as indicated in the right part of Figure 1. Two electrons from the metal are involved – one is captured by the ion, which is thus neutralized and returned to its normal or atomic "ground" energy state. A second electron is accelerated and, if properly directed, may leave the metal as a free electron. As will be seen later in connection with the quantitative data obtained in the experiments, our evidence indicates that the source of energy is the recovered ionization energy. Although the ion has kinetic energy of motion as it strikes the metal surface, this energy is not used directly in the electron ejection process.

The physical picture of this type of electron ejection has of course been highly simplified in Figure 1. To take a closer look, we must consider the energies of electrons in various situations. For this purpose Figure 2 has been drawn illustrating the relative amounts of energy that electrons involved in the ejection process may have.

We may understand the implications of this diagram if we first imagine electrons as they occur in a gaseous atom, in metals, and finally as they occur at rest in space, free of influence from either metal or atom. Merely for reference, we arbitrarily assume that the electron at rest in space has zero energy, and for this electron-energy state we draw the zero line in Figure 2. All electron energies greater than this will therefore be placed above zero, and all lesser energies will be put below. The fact that we deal here with negative energies is simply the result of our arbitrary choice of zero

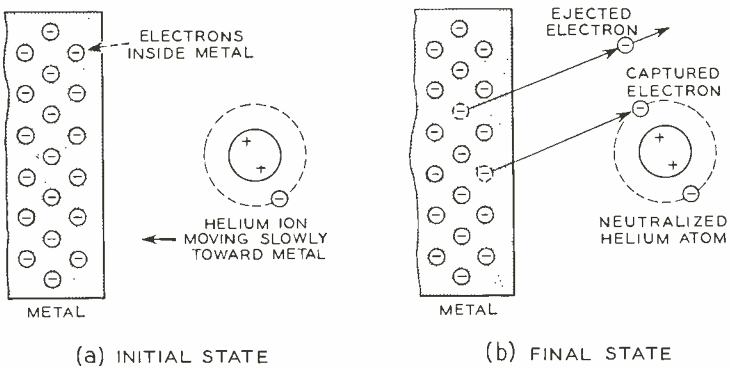


Fig. 1 — Simplified representation of electron transitions which occur when a slowly moving helium ion is neutralized at a metal surface.

energy, and should be no more troublesome than is our everyday use of negative temperatures, that is, temperatures below zero on the Centigrade or Fahrenheit scales. On the right-hand side of Figure 2 are placed convenient symbols for the different levels of electron energy.

The shaded region in Figure 2 represents the range or allowed band of energies which electrons may have inside the metal. Since this range falls below our zero line, we see that an electron escaping from the metal into space must gain energy — it passes from a lower energy state to a higher. The easiest electron to remove is one whose energy is $-\varphi$ at the top of the allowed band and which ends up at rest in space with zero final energy. Clearly more energy is required if the electron is removed from an energy lower in the band, at C in Figure 2 perhaps, and appears outside the metal with kinetic energy greater than zero, let us say of amount E_k at D in Figure 2. We also see that an electron captured from the metal by the ion will lose energy, its energy state drops to the line at the very bottom of the diagram. This level at energy $-E_i$ represents the energy of the electron in the atomic ground state of the neutralized atom outside the metal. E_i is the ionization energy of the atom since it is the amount of energy required to remove the electron from the atom to a state of rest outside.

Enough information is now available to show graphically what happens when a gaseous ion approaches the metal surface. The ion captures a first electron which may have an energy indicated by A in Figure 2. The energy of this electron thus drops to level B, the length of the line AB being a measure of the energy liberated. Another electron, perhaps one with energy C on the diagram, will pick up this energy, and its energy state will rise to point D, the length CD being equal to AB. Having energy at D, the electron *may* escape from the metal, or it may not.

The type of process we have just described is known as an Auger process, named after the French physicist Pierre Auger, who first recognized and studied a similar process of electron ejection from atoms irradiated by X-rays. The hallmark of an Auger process is that two electrons interact: one loses energy when captured into a "bound" state, and the other gains the energy thus released and escapes from the system. The particular process described here may thus be termed "Auger neutralization," since the captured electron nullifies the postiive charge of the ion.

The electron at energy level D is called an "ex-

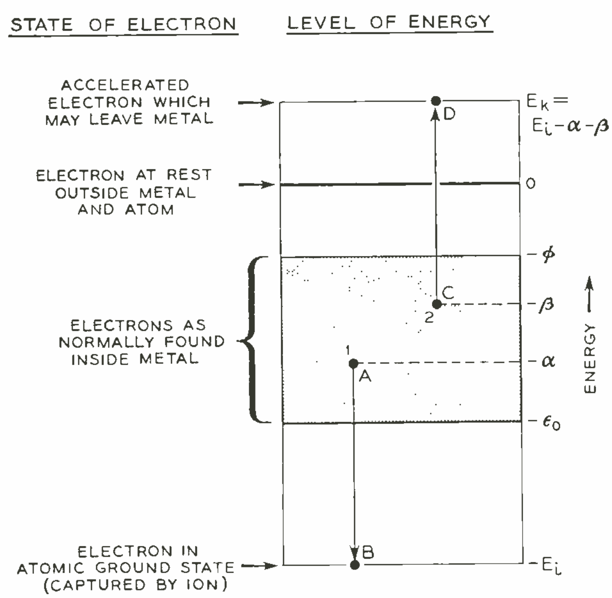


Fig. 2 — Energy-level diagram of electron-ejection process. Energies are specified relative to energy of electron at rest outside metal.

cited" electron because it has considerably more energy than electrons normally have in a metal. We may now calculate its final energy E_k above our arbitrary zero. E_k is the length of line CD minus the quantity β. But CD is equal in length to AB which in turn is equal to $E_i - \alpha$ from Figure 2. Thus $E_k = E_i - \alpha - \beta$. This equation indicates directly what E_k is. E_i is the ionization energy of the atom and is thus the *total* energy released when the ion is neutralized. α and β are the energies required to remove the participating electrons from the metal and place them at rest outside. Thus E_k is the energy we recover from neutralization of the ion minus the energies required to remove the electrons from the metal. It is thus the kinetic energy which the excited electron would have outside the metal if it escaped from the metal.

We have now come upon the fact that not all electrons excited in the Auger neutralization process will leave the metal. In the first place it is essential that the electron have enough energy to do so; thus E_k must be a positive number, that is, point D in Figure 2 must lie above our zero energy level. We recognize that electrons 1 and 2 at A and C in Figure 2 are only two of many electrons which might participate in an Auger process. In particular, should both electrons lie near the lower limit of energies of electrons inside the metal, that is, if α and β have values near ε_0, it is possible for lines AB and CD to be so short that point D will fall below zero. Obviously, this depends upon where the level at $-E_i$ lies, which in turn is determined by the type of ion involved in the process. But even though E_k is positive and the excited electron has sufficient energy to leave the metal it may not do so because it is not properly directed. If it is to leave it must approach the metal surface from the inside with sufficient energy normal to the surface to escape. If this is not the case, the electron will move around inside the metal, and in collisions with other electrons will soon lose its extra energy and fall back into the band of normally allowed energies. Thus only a fraction of the excited electrons do actually leave the metal.

We have said that electrons 1 and 2 may have any energies between $-\varphi$ and $-\varepsilon_0$ in the allowed band of electron energies inside the metal. It is for this reason that the energy, E_k, of an ejected electron may lie in a range of energies. It has its maximum value when electrons 1 and 2 lie at the top of the allowed band, that is, when $\alpha = \beta = \varphi$. The maximum value of E_k then turns out to be $E_i - 2\varphi$ from our general expression $E_k = E_i - \alpha - \beta$. The agreement of experiment with this theoretical upper limit of the ejected electron's energy is one of the most convincing proofs of the correctness of our picture of the ejection process.

The instrument with which the experimental study has been carried out is shown schematically in Figure 3. One of the actual tubes can be seen in the headpiece. In the source end of the apparatus, ions are formed in an electron beam by ionization of the noble gas admitted to this part of the tube. A beam of ions is formed and accelerated in an electrostatic lens which focuses the beam on the entrance slit of the magnetic analyzer situated in the 90° bend in the tube. In a magnetic field an ion moves in a circular path whose radius depends upon the speed of the ion, its mass, and the strength of the field. By suitable adjustment of the magnetic field strength relative to the accelerating potential applied to the ions, we may cause ions of only one mass to pass through the exit slit of the analyzer.

The selected or filtered beam then passes through

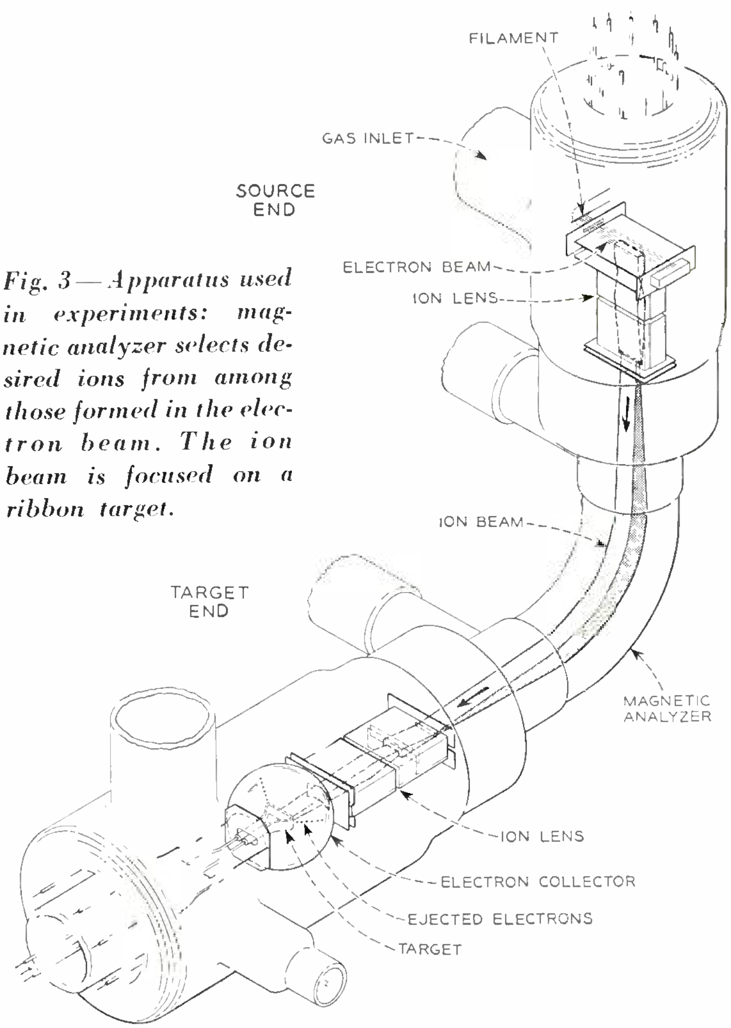


Fig. 3—Apparatus used in experiments: magnetic analyzer selects desired ions from among those formed in the electron beam. The ion beam is focused on a ribbon target.

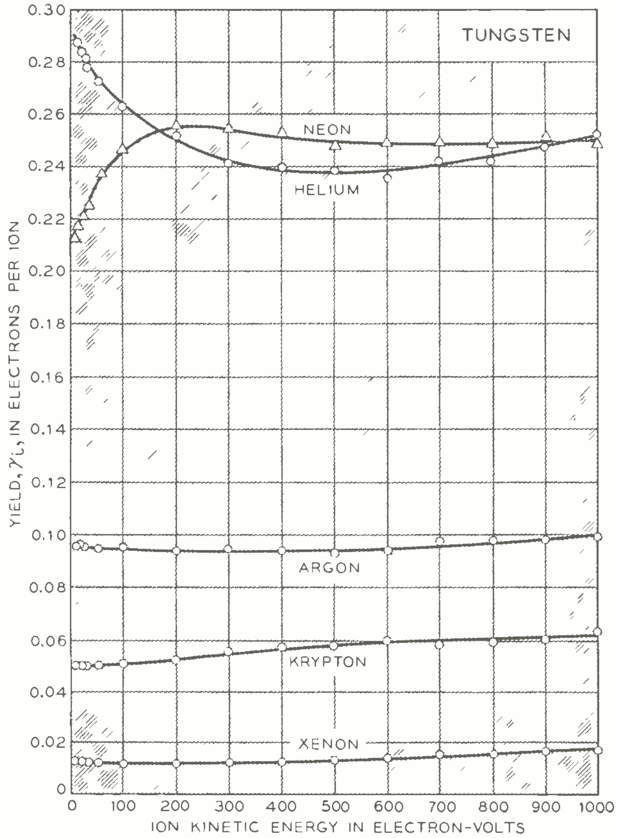


Fig. 4 — Yield of electrons ejected by singly-charged noble gas ions of various kinetic energies.

another lens which focuses it upon the target. Around the target, which is in the form of a metal ribbon, is a metal sphere which collects the electrons ejected from the target by the incident ions. The numbers of electrons ejected and of incoming ions can then be determined by electrical measurement. The number of ejected electrons per incident ion (called the yield, γ_i) will always be less than unity because, as we have already explained, many electrons fail to escape from the metal. The energies of the electrons that do escape can be measured by a procedure of varying the voltage on the spherical collector.

The experiment is complicated by two factors. The first of these is the problem of focusing the beams of ions at low energy. In the apparatus used this is possible for ion energies as low as ten electron volts. This is in the range from which an extrapolation can be made to the lower ion energies observed in actual gas-filled electron tubes. The second complication has to do with the "cleanliness" of the metal target. Even with a relatively high vacuum, layers of gas quickly accumulate on the surface of the metal. At a pressure of 10^{-6} mm of mercury, for example, a single layer of atoms of gas will form in one second.* However, with careful processing, the pressure can be made to drop below 10^{-10} mm of mercury. Then the time to form a monolayer is greater than 10 hours. When the metal ribbon is "flashed", or rapidly heated to a high temperature and allowed to cool, most of the adsorbed gas is driven off. If we take our measurements within the next few minutes, we are assured that we are dealing with a metal surface having on it less than 1/100th of a layer of foreign atoms. Thus, we are able to study either atomically clean surfaces or surfaces specifically contaminated with known atoms.

Figures 4 and 5 show examples of the basic data obtained in these electron ejection studies. In Figure 4 are plotted the yields in electrons ejected per incident ion, γ_i, for the five noble gases and for accelerating potentials from 10 to 1000 volts. Perhaps the most striking feature of these curves is the fact that they are essentially flat. As noted earlier, the incoming ion has both kinetic and potential energy, and here we see that the kinetic energy resulting from the accelerating potential has relatively little effect on the electron yield —

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

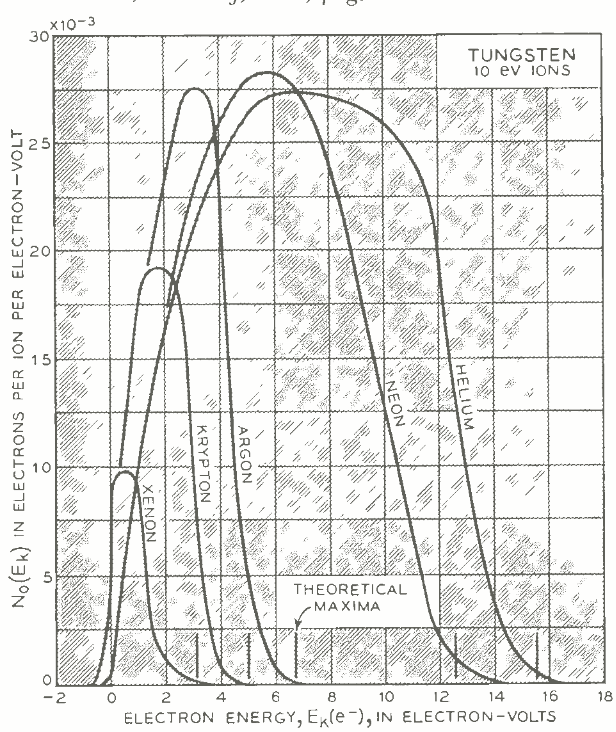


Fig. 5 — Energy distributions of electrons ejected by ions of 10 electron volts energy. The values indicated along the horizontal scale are theoretical maxima for the Auger neutralization process.

the energy transferred to the ejected electron comes mainly from the recovered ionization energy.

In Figure 4 we should also notice the trend in yields in going from the relatively light helium and neon ions toward the heavier ions at the bottom of the graph. The heavier noble gases have smaller ionization energies and therefore can give less energy to electrons inside the metal when their ions are neutralized. This results in smaller yields.

We have seen earlier that the energy of the ejected electron may lie anywhere within a range of energies having a maximum at the value $E_i-2\varphi$. How the electrons are distributed in number over this range is shown by a so-called energy distribution function. In Figure 5 are plotted such functions for electrons ejected by the noble gas ions of 10 electron volts kinetic energy. These plots give the number of electrons which have energies in a given range as a function of the electron energy. Thus the total area under each curve is the yield of all electrons, irrespective of their energy, at the incident ion energy in question.

Of particular interest in Figure 5 are the maximum kinetic energies indicated. These are the electron energies at which the distribution functions fall to zero. It is seen that this occurs for each gas very close to the theoretical value $E_i-2\varphi$ we have already calculated and which are indicated by the vertical lines along the horizontal axis in Figure 5. This good agreement is another strong indication that for these slow ions our picture of the Auger neutralization process is the correct one. It is of interest that at higher ion energies in the case of neon a deviation from the theoretical maximum is found. This indicates the presence of electrons which arise in a two-stage process, which is more complicated than the direct process discussed.

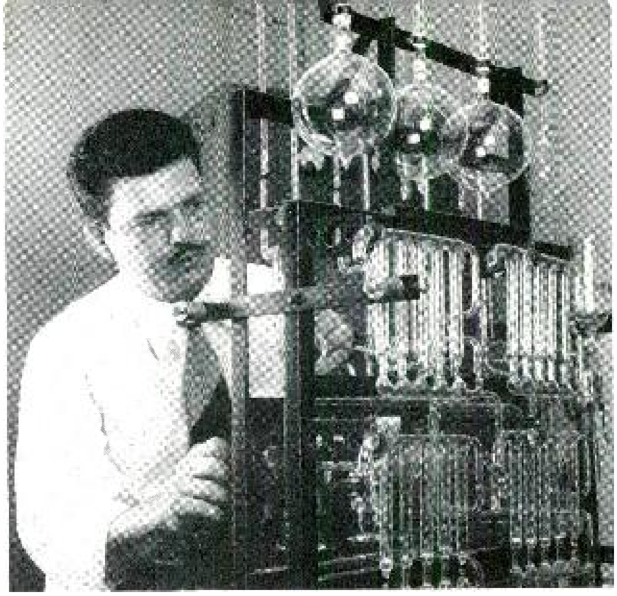


Fig. 6 — C. D'Amico adjusting apparatus that is used for the admission of gases.

The data of Figures 4 and 5 are typical of the basic information obtained from these experiments. They provide a quantitative measure of the most important electron liberation mechanism operating at the cold cathode of a gas filled tube, and have led to our understanding of the physics of the ejection process. In addition, the phenomenon is of interest in the study of solids because it is so strongly dependent upon surface properties and energy structure of the solid which the ion strikes.

THE AUTHOR

H. D. Hagstrum joined Bell Telephone Laboratories in 1940 and was engaged in the development of microwave magnetrons during World War II. Since then he has been in the physical electronics group, which he now heads. His work has been concerned with electron impact in gases and ion impact on solid surfaces. Dr. Hagstrum received a B.E.E. degree from the University of Minnesota in 1935. In 1936 to 1940 he received the B.A., M.S., and Ph.D. degrees in physics from the same institution. He has been secretary-treasurer and is now vice chairman of the Division of Electron Physics of the American Physical Society.

A Capacitor Scanner for Signal Generation

G. A. Backman measuring the transmission characteristics of a capacitor scanner.

In a telephone system, information dialed by customers is often stored in the local office to be transmitted to a distant office after a connection has been made. This information is stored in a register, and the equipment that transfers the information must usually send it, digit by digit, in the same order in which it was received. The transmitting equipment must also convert the information to a type of signal that can be sent over the lines that connect one office with another.

A simple device called a "capacitor scanner" has been designed to fulfill the requirements for such a signal transmitter. A laboratory model of this scanner has been tested by using it for transmitting digital information experimentally over K and L carrier and other long distance lines.

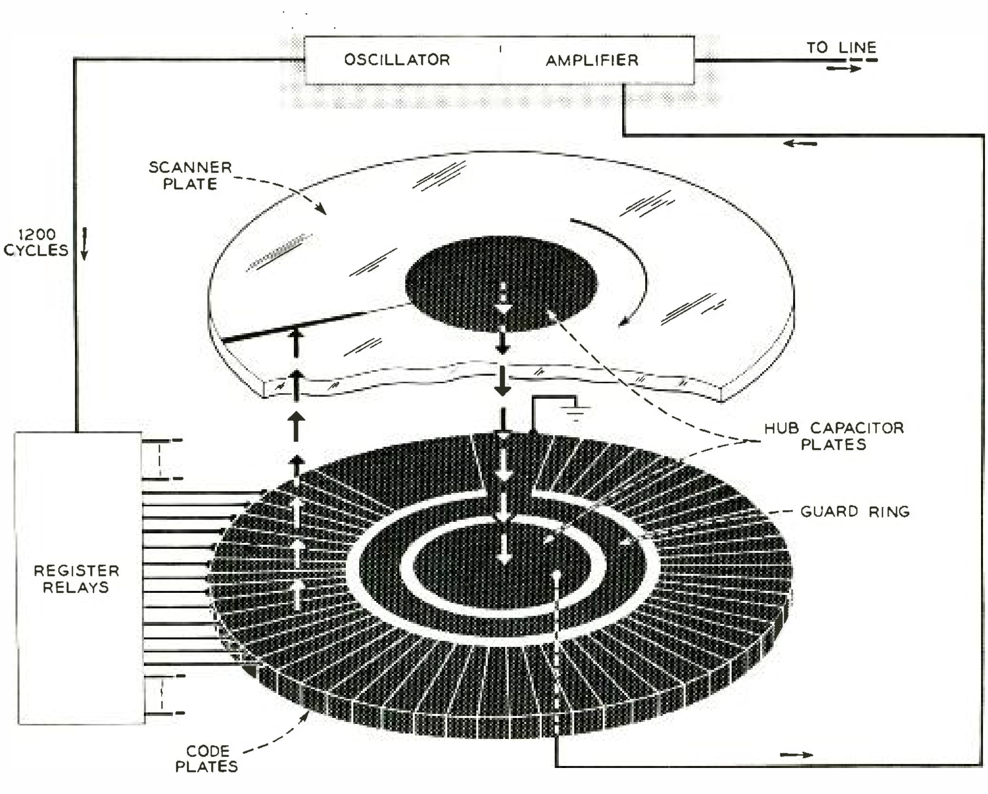


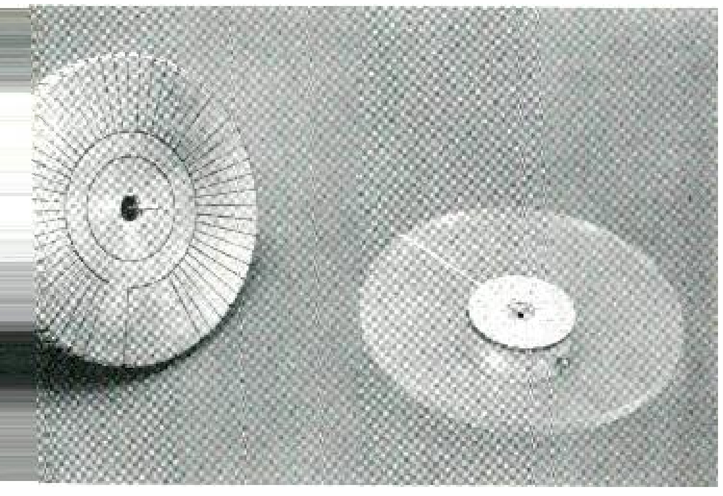
Fig. 1 — In capacitor scanner, rotating disk picks up signals, which are applied through a hub capacitor to the amplifier.

The simplified diagram, Figure 1, shows that the capacitor scanner uses two disks – a stationary disk on which a group of code plates is arranged radially, and a rotating disk on which is placed a single scanning plate. Certain of the fixed code plates are supplied with a voice-band carrier frequency (1,200 cycles) by the contacts of the relays that store the dialed information. A voltage is thus produced in the rotating scanner plate as it passes over each of these energized code plates. This voltage is then amplified and applied to the line as the signal.

As seen in the photograph, Figure 2, the rotating disk on the right carries the scanning capacitor plate and a hub capacitor plate. These two plates are connected together electrically. The stationary disk on the left contains the code element plates, separated from another hub capacitor plate by a guard ring. The guard ring prevents leakage of the carrier frequency to the hub plate. The stationary and rotating hub plates act together to form a capacitive slip-ring which carries the signal from the scanning plate to an amplifier. Since the signal is taken off the stationary capacitor plate, no electrical connections have to be made to the rotating structure.

The scanner is divided into twelve positions. Two of these (the wider elements seen on the stationary disk in Figure 2) are used for a start signal and for a synchronizing pulse. Each of the remaining ten positions is used to derive a digit and consists of five code element plates. Energizing two

Fig. 2 — The two halves of the scanner: left, the stationary disk with its code element plates; and right, the rotating disk with its scanning plate.



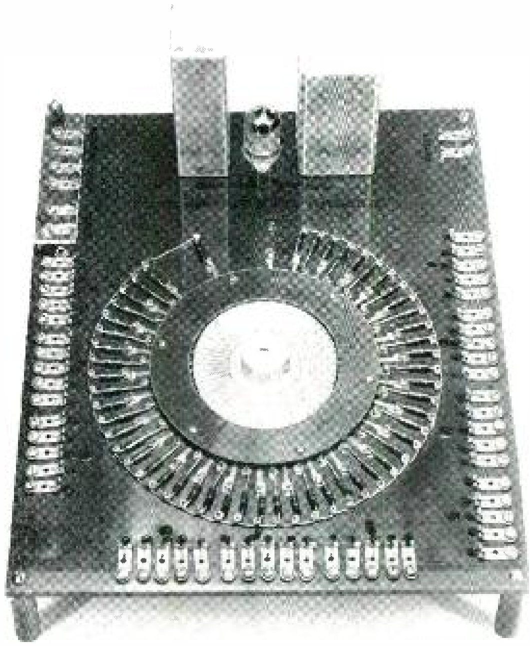


Fig. 3 — The complete capacitor scanner with associated oscillator and amplifier.

of these five plates determines a digit 0 to 9. A small 3.6 watt motor drives the rotating disk at 500 rpm. Since the disk completes one revolution to 120 milliseconds, each digit is generated and transmitted in 10 milliseconds, or at a rate of 100 digits per second with 20 milliseconds required for the start and synchronizing pulses.

The associated amplifier and oscillator are very simply constructed using a dual triode tube. One-half of this tube is used in the oscillator circuit to produce the 1,200-cycle carrier, and the other half is used in the amplifier circuit. The amplifier delivers one milliwatt into a 600-ohm load. The complete scanner is seen in Figure 3.

Printed circuit techniques may be employed in the construction of this device. Also, by properly designing the scanning and code element plates a signal of the desired shape may be formed without the use of filters. This shaping tailors the signal to fit the characteristics of the line and tends to minimize the amount of distortion. In actual tests over Bell System transmission lines, the scanner operated without error over some of the longest toll circuits.

G. A. Backman,
Switching Research

To provide the Signal Corps with multiple telephone message channels over a wide range of frequencies, a very low distortion radio receiver has been developed at Bell Telephone Laboratories. As part of the "Antrac-24" (Army-Navy Transportable Radio Communications Model 24), it is being used with associated transmitters, antennas, and cable systems in setting up 800 to 1,000-mile military communications networks.

U. S. BERGER and A. J. MUNN
Military Communications Development

AN/TRC-24 Radio Set: Receiver

The radio receiver for the AN/TRC-24 radio-relay equipment is unique in performance characteristics and in its coverage of a wide frequency band. It was designed as an integral part of a combined cable-carrier and radio network for military communications. As described in a previous article* covering the over-all arrangements of this communication system, the radio equipment operates in conjunction with either or both of the associated four- and twelve-channel cable-carrier systems.

Radio receivers for multi-channel military service must meet requirements that are more stringent than those governing the design of the most exacting high-quality broadcast or FM sets. In addition, the equipment must have the stability required of unattended gear, so that military personnel are not required to "ride" the controls continuously to keep the set in tune or to readjust input and output levels. Finally, multi-channel radio equipment of the type described must be tunable over a very wide range of frequencies to satisfy the military needs for a very large number of operating radio channels and to provide the flexibility required in the selection of these frequencies.

Two plug-in units or "heads" are provided for this receiver: a "B"-band tuner for the range 100 to 225 mc and a "C"-band tuner for the range 225-400 mc. The position of the tuner heads in the circuit is indicated by the shaded area in the block diagram, Figure 1. By inserting the proper tuning unit into the frame, the receiver is at once ready to operate in the particular band chosen, since the other components are universal for both bands.

The tuners use the familiar superheterodyne principle to translate the incoming radio frequency signal to an intermediate frequency. A high-frequency oscillator in the tuner is so tuned that when its output is mixed with the incoming RF signal, a difference frequency of 30 mc is obtained. The "B"-band tuner uses a single stage of RF amplification ahead of the oscillator and mixer circuits, and the "C"-band tuner uses two stages of RF amplification. The "C"-band tuner also includes a buffer amplifier to improve the frequency stability of the oscillator by isolating it from interaction with the RF circuits. Conventional types of tubes – that is, those that can be plugged into standard miniature sockets – are used in both tuners. The dials are calibrated in terms of the various channels, which are channels B1, B200, C26, C250 and so forth.

The modulated 30 mc signal is amplified by the intermediate frequency (IF) amplifier shown as the next block in Figure 1. The IF band-pass characteristic of this circuit is wide enough to transmit all of the significant sidebands of the FM signals, yet restricted enough to prevent interference from unwanted signals. The phase and amplitude characteristics of the networks used in this amplifier are very carefully controlled by factory adjustments.

Following the IF amplifier, the receiver uses two stages of limiting to reduce undesirable amplitude modulation. These stages have been designed to have very fast recovery characteristics in order to

* Record, *August*, 1955, *page* 290.

provide the optimum protection against the interfering effects of strong impulse noise, such as that from a nearby spark or other electrical discharge. This combination of frequency modulation and good limiting greatly aids in keeping constant audio output from the receiver under varying RF input conditions, and allows the circuit to be set up and operated with a lower net loss than would be permitted by the use of amplitude modulation.

The discriminator, grouped with the limiter circuits, demodulates the intermediate frequency and thus provides the composite message signal. It is carefully adjusted for linearity to obtain a low distortion. The discriminator also supplies a dc error signal used in the automatic frequency-control circuit. This dc error signal determines the phase and amplitude of an ac voltage, which is used to actuate an AFC motor. The motor turns the plate of a small capacitor connected to the oscillator in the RF tuner and thus performs the minor corrections necessary to keep the receiver tuned to the correct frequency. The IF, limiter, and discriminator circuits will be described in a forthcoming issue of the RECORD.

A three-stage audio amplifier completes the main flow of the through-transmission path represented in Figure 1. The amplifier output transformer is carefully balanced to ground to reduce the effects of induced voltages on the line. Other components of the audio system are carefully designed to obtain a flat transmission characteristic with low distortion. Output impedance is accurately controlled by means of feedback, at either 135 or 600 ohms as required for operation with 12- or 4-channel carrier systems. The receiver can be connected to an adjacent cable-carrier terminal, or the receiver output signal can be transmitted over a cable network. Finally, the output can be delivered to another radio transmitter and retransmitted. As many as eight radio links may thus be connected in tandem. For this service, two receivers and two transmitters are interconnected "back-to-back" to provide separate paths for the two directions of transmission.

In addition to the telephone message channels, order-wire (monitoring) facilities have been provided. The order wire signal is transmitted in the normal voice-frequency range — that is, without translation to carrier frequencies — and is used by operating personnel for system maintenance. The lower band-pass frequency limit of 250 cycles per second is therefore determined by this monitoring channel. Since the message channels of the 12-channel carrier system occupy the region 12-60 kc with a pilot tone at 68 kc, the radio system has a passband of 250 cycles to 68 kc. Figure 2 shows the gain-frequency characteristic of one complete radio link, including a receiver and transmitter. A modest amount of pre-emphasis (increased level of modulation of high frequencies) in the transmitter and a corresponding de-emphasis (equalization) in the

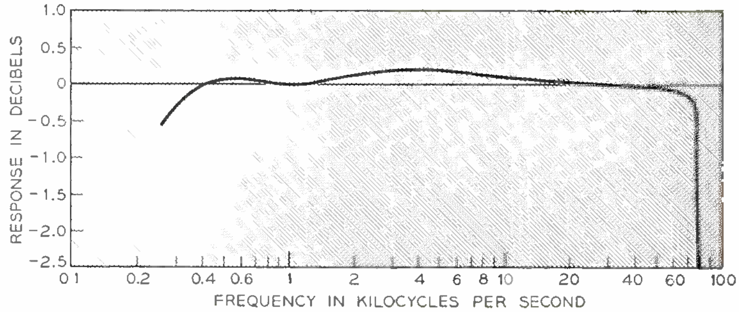


Fig. 2 — Gain-frequency characteristic of one complete link, including a receiver and transmitter.

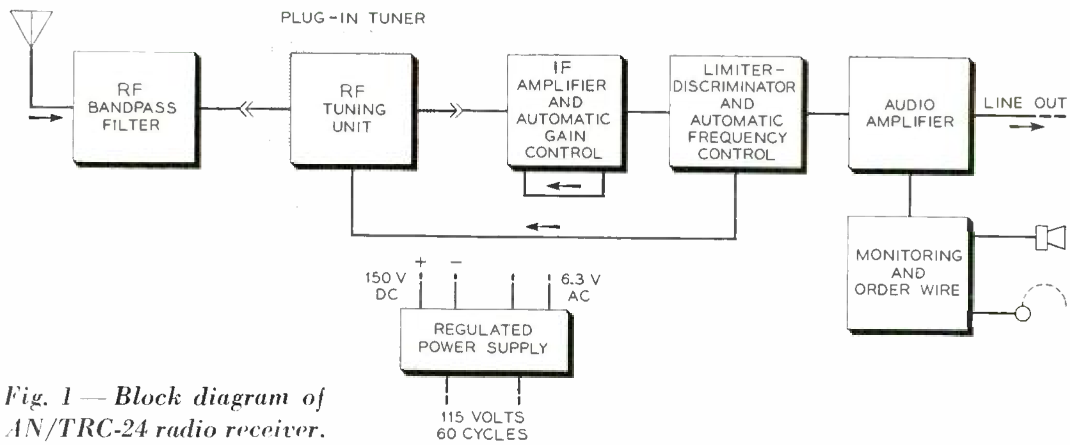


Fig. 1 — Block diagram of AN/TRC-24 radio receiver.

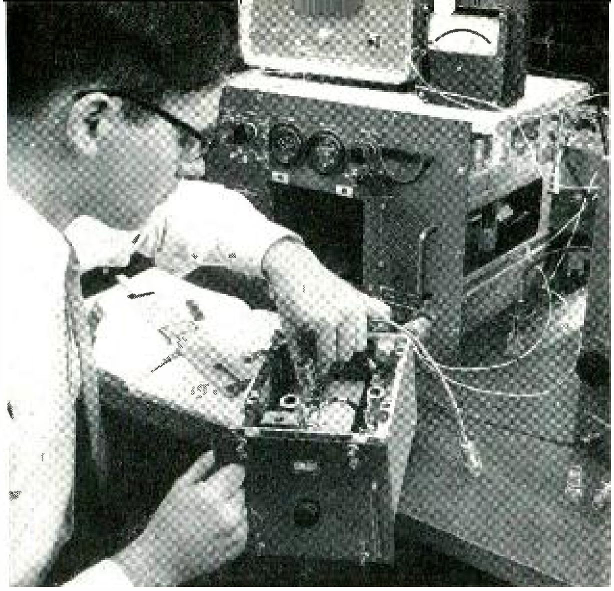


Fig. 3 — H. R. Beurrier engaged in noise-figure measurements on the 100-225 mc "B"-band tuner.

receiver have been provided to improve the signal-to-noise ratio in the upper carrier channels. The amount of pre-emphasis used effects a compromise between random noise disturbances in the upper carrier channels and intermodulation disturbances in the lower carrier channels.

The 68-kc pilot tone and a 1-kc line-up tone may be used by operating personnel for system maintenance and circuit adjustment. The levels of these two tones are indicated by a metering circuit built into the receiver. In each receiver, a 1,600-cycle ringing oscillator is also provided; with this tone an operator can call any radio station in the network and either of the two cable-carrier terminals.

A crystal calibrator is also included in the receiver. An 11-mc crystal oscillator and harmonic generator unit produces a series of harmonics from 55 to over 600 mc, which are used in setting the RF circuits to the correct frequency. No portable test equipment is required to install, line up, or operate the AN/TRC-24 receiver.

The receiver operates from a single 150-volt regulated power supply included in the set, and it requires 180 watts of 115-volt, 60-cycle, single-phase power. All of the subassembly units are of the "plug-in" type and are completely interchangeable in all receivers. All hardware and cable connections are designed for maximum ease and rapidity of maintenance.

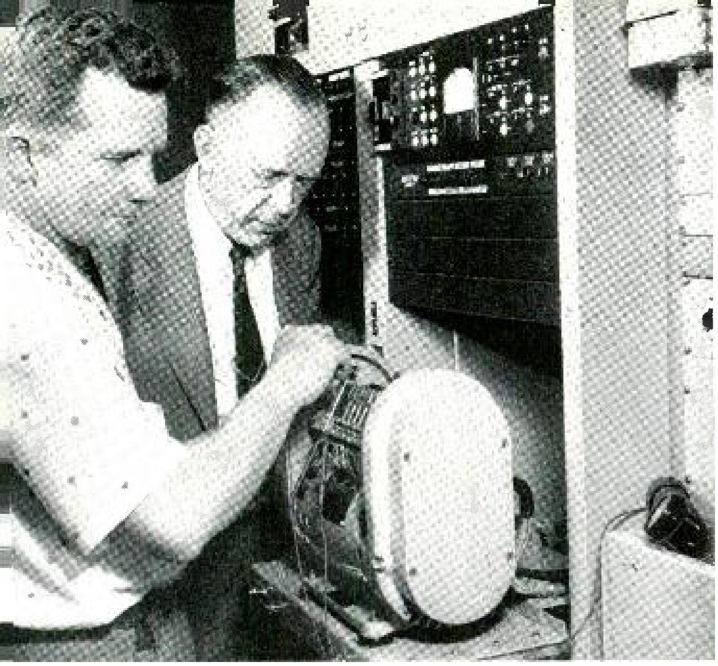
This description has dealt mainly with the 0.25-68 kc system designed for twelve message channels, but the receiver can also be used with the four-channel cable system which uses the range from 4 to 20-kc.* In addition, the receiver can be used for any service requiring a 68 kc bandwidth with very low distortion.

* The four- and twelve-channel cable-carrier units developed along with the radio components will be the subject of other RECORD articles.

THE AUTHORS

U. S. BERGER received a degree of B.S.C. in E.E. from Ohio State University in 1937, and then joined the Research Department at the Laboratories where he was concerned with voice-operated devices. Early in World War II he transferred to a group doing radio development for the armed services where he was engaged in HF, VHF and UHF receiver design. After the war, Mr. Berger was concerned with mobile telephone receivers and short-haul microwave systems. In 1953, he again transferred to the Military Communications Department and was given responsibility for circuit design of communication equipment and systems. Mr. Berger has recently assumed responsibility for TD-2 microwave relay system development.

A. J. MUNN joined the Laboratories in 1923, and subsequently received the degree of B.S. in Electrical Engineering from Cooper Union in 1936 and B.E.E. from New York University in 1941. He was engaged in electro-mechanical design on the Musa system and overseas radio transmitters and receivers. During World War II, Mr. Munn worked on radar test equipment and frequency-shift telegraph. Later, he participated in design of LD-R1 and LD-T2 radio equipment. He was responsible for the mechanical design on the AN/TRC-24 radio receiver. Mr. Munn is a Senior Member of the I.R.E. and a member of Eta Kappa Nu.



New Universal Ringing Power Plant

W. S. ROSS *Power Development Department*

Every common-battery telephone office must have a power supply to provide all the necessary ringing and signaling currents. Obviously, the size of an office determines the size of ringing power plant needed, so both small and large plants have been available in the past. Recognizing the fact that an intermediate size was needed, the Laboratories has developed a new universal ringing power plant that can be used economically in small offices while two or more plants can handle larger offices.

Ringing a telephone bell doesn't seem like much of an operation, nor should it require much electrical power. After all, a pair of dry cells or a small transformer will operate a doorbell. However, a central office may be required to ring many telephones at once, and this adds up to a considerable amount of ringing current. In recent years, the trend has been toward high-impedance ringers,* permitting ringing power plants to handle more "busy hour" calls per ampere than with the older low-impedance ringers.

It was recognized that a new ringing power plant was needed to bridge the gap between those such as the 805- and 806-types, with a capacity of only ½ ampere, and the more expensive 803C plant† with a capacity of 2 to 6 amperes. Design objectives were a 1-ampere plant capable of handling a multi-unit office, that would be adaptable to any type of office, and that would be of modern and pleasing design yet not occupy much floor space. Electrically, the new 804C plant fulfills the first two requirements and, as can be seen in Figure 1, physically it fulfills the last two.

First consideration was given to the ringing machine itself. This machine must supply not only the 20-cycle current for ringing telephone bells and several tones for signaling purposes, but also a variety of interruptions of both ringing current and tones as required by particular offices. As finally evolved, the machine consists of a driving motor operated from 120 volts, 60 cycles ac – 48 volts dc for the emergency machine – and a 1-ampere 20-cycle generator on the same shaft. On the left end of the shaft, Figure 2, is a tone alternator that provides three outputs – one of "high tone" and two of "low tone." "High tone" is a 500-cycle tone used primarily for operator signaling, but it is also used for other purposes when interrupted at various rates. "Low tone" is actually a 600-cycle tone but it is modulated by 120 cycles so that what is heard is the standard dial tone; it sounds like 120 cycles with a lot of overtones. At a higher level, and interrupted, it becomes the standard busy tone.

To obtain the various interruptions required, a slow-speed shaft, mounted at the top of the machine and driven by gears at the right end, carries up to 26 nylon interrupter cams. Spring pile-ups placed on each side of the cam shaft are equipped with nylon-tipped cam followers, and their contacts are continuously opened and closed by the cam ac-

* RECORD, *October*, 1954, *page* 366. † RECORD, *December*, 1938, *page* 111.

Fig. 1 — Two bays are all that is required for the new ringing power plant.

tion. Each spring pile-up has several adjusting screws, permitting the various springs to be set as desired. This, coupled with close tolerances in machining the nylon cams, results in interrupter timing that is much more accurate than has been obtained before. Different combinations of cam shapes and spring pile-ups are available for different office requirements.

Since the 20-cycle ringing current is inaudible, an audible ringing tone is derived by modulating the high tone with a 40-cycle tone and superimposing the combination on the 20-cycle ringing signal by means of a network known as a 106A frequency generator. Whenever ringing current is applied to the line, the calling customer hears a 40-cycle tone, indicating that the distant telephone is being rung.

The complete ringing power plant, Figure 1, consists of two bays of equipment, with everything under removable covers except keys, fuses and lamps. The left-hand bay mounts the ac-driven machine while the right-hand bay mounts the battery-driven machine used during ac failures. The machines themselves have easily removable top covers for simplicity in adjusting the spring pile-ups and other maintenance, and are mounted on smoothly sliding shelves so that they may be pulled out of the bay where it is more convenient to make spring adjustments or do brush maintenance. The fuses are the new 70-type in enclosed mountings so that no voltages appear at the front of the bays. As a result, the generally "clean" appearance and modern styling harmonize very well with the decor of modern telephone offices.

Some offices also require "howler" equipment, used to produce the loud, distinctive sound that attracts a customer's attention to the fact that his receiver is off the hook. Howler equipment can be mounted in the top part of the left-hand bay, where space has been left for it. When a 120-volt coin-control power supply is required, it can be mounted in the top and bottom parts of the right-hand bay. Four-party selective ringing uses two batteries of dry cells poled in opposite directions and connected in series with the 20-cycle ringing current. Space for these batteries and the positive tripping battery has been provided on hinged gates at the rear of the bays, Figure 3. Equipment for testing the batteries is mounted at the top of the gates.

One of the "universal" features of the new ringing power plant is a single local cable that may be used for several different types of offices. The requirements of the different offices are met by simple cross-connections on terminal strips, plus the selection of the proper ringing machine. Each ringing machine comes equipped with its own local cable, with all outputs brought to standardized positions on fanning strips. The proper tone levels for various outputs, and any interruptions required, are selected by simple cross-connections between terminal strips. Installing a machine involves only

* Record, *January*, 1955, *page* 1.

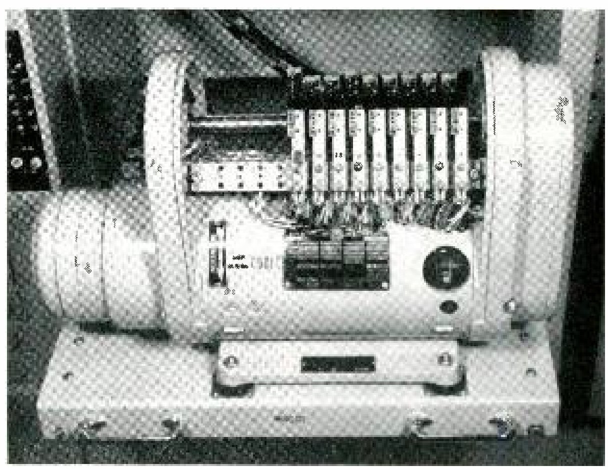


Fig. 2 — Cams on a slow-speed shaft provide the various interruptions. The tone generator is at the left end of the ringing machine.

a mounting operation – 4 bolts – and connecting the fanning strips to the terminal strips.

Operation of the plant is completely automatic. Normally, the ac machine carries the load; should the ac service fail, the load is automatically transferred to the dc machine. Transfer will also occur automatically in the event of dial-tone failure or low or high 20-cycle ringing voltage. After an ac service failure, the load is returned to the ac machine when service is restored, but a slight delay is provided to permit the tubes in the electronic voltage regulator to warm up. Transfer because of dial-tone failure or high or low ringing voltage means trouble in the ringing power plant itself, and the circuit cannot transfer back to the ac machine until the trouble has been cleared and the restore key operated. Automatic transfer may occur during a ringing cycle, but the plant cannot be returned to the ac machine, either automatically or manually, until the end of a ringing cycle. This prevents the possibility of garbling any code ringing that may be provided. A special interrupter keeps the operating machine running until the end of the cycle, and then another interrupter short-circuits its 20-cycle generator output to provide a quick stop and at the same time opens the generator field circuit.

The 20-cycle output of the ac machine is held to 84-88 volts by an electronic voltage regulator that controls, through a metallic rectifier, the field current of the 20-cycle generator. The dc machine is controlled by a combined speed and voltage regulator of the contact type. One element of this regulator keeps the motor speed within limits, to control the frequency, and another element controls the generator field current to keep the voltage within the limits of 84-88 volts. Self-contained alarms are provided for possible failures of the machines or outputs.

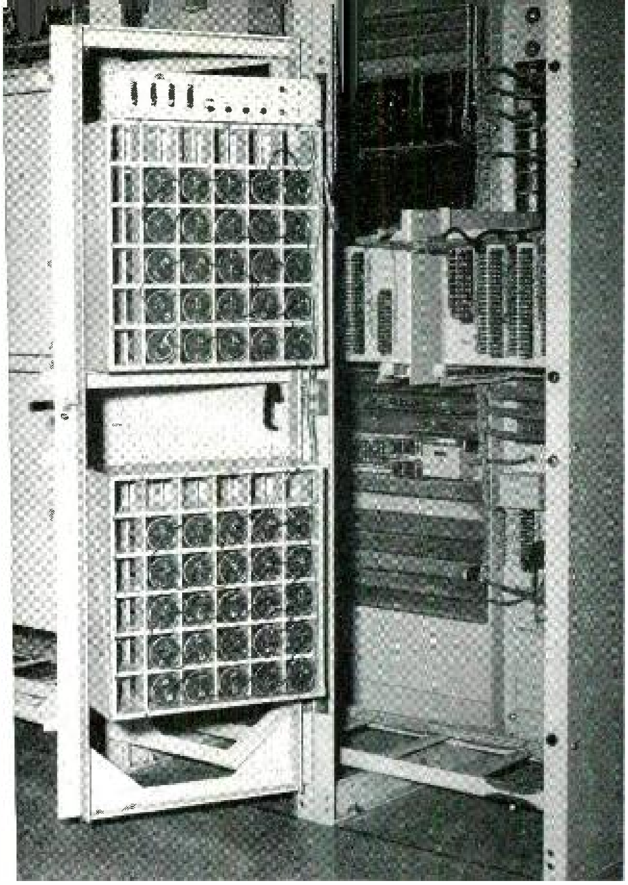


Fig. 3 — The protective cover has been removed to show how the batteries used for four-party selective ringing are mounted at the rear of the plant.

This new ringing power plant occupies only half the floor space of the larger 803C, and is about half as expensive. One plant may be installed initially and a second added when needed, without exceeding the floor-space requirements or cost of the larger plant. Depending on the type of ringing needed, the plant can handle up to 50,000 busy-hour calls under some conditions. Since it is shop wired, the principal installation work is that of mounting the ringing machines on their sliding shelves and attaching the fanning strips to the terminal strips.

THE AUTHOR

W. S. Ross left Dartmouth College in the spring of 1917 to join the Signal Corps and served two years, spending a year in France. In the meantime, he received the B.S. degree from Dartmouth. After leaving the Signal Corps, he entered M.I.T., and received the B.S. degree in 1921 and the M.S. degree in 1922. He joined the Technical Staff of the Laboratories in 1925, where, except for a year and a half spent elsewhere, he has been engaged in power development work for the Systems Department. He has been largely concerned with the design of automatic power and ringing plants, and since 1930 has specialized on ringing power plants exclusively. Mr. Ross is a member of A.I.E.E. and Phi Beta Kappa.

New Transistor Technology Announced by Laboratories

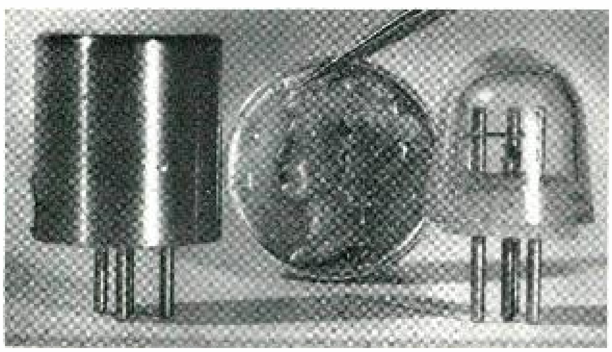
C. A. Lee adjusts optical pyrometer to determine temperature in diffusion chamber where germanium diffused base transistor is made.

A major advance in transistor technology – new fabricating techniques for an entirely new kind of transistor, technically known as the diffused base transistor – was recently announced by the Laboratories. The announcement was made simultaneously with the publication of the January issue of the *Bell System Technical Journal* which contains two articles by C. A. Lee, and M. Tanenbaum and D. E. Thomas describing the new techniques. The articles are titled respectively "High-Frequency Diffused Base Germanium Transistor" and "Diffused Emitter and Base Silicon Transistors."

These techniques may have far-reaching effects on the use and manufacture of miniature amplifiers, especially for electronic applications in the telephone industry, but also in other fields. The way is now believed open for the transistor to replace the electron tube in many telephone and television applications.

The new device's performance at very high frequencies surpasses that of any other transistor. Experimental units made at the Murray Hill Laboratories have amplified currents by 100 to 1 across a band 20 megacycles wide. Either the amplification or the number of communication channels can be made three times that of any other transistor. The new transistor could amplify 2,500 telephone conversations simultaneously on a telephone line.

Because of its very high frequency characteristics, the new transistor appears to be ideally suited for application in guided missiles and electronic "brains" for military and computer uses. Tradic, an electronic computer designed by the Laboratories for military applications, now uses a transistor of a different type, and transistors are being used in other military equipment. Although these transistors are well suited for the jobs they do, they cannot be used for a large number of other applications. The new transistor opens up many new possibilities for military technology.



Laboratory models of diffused base silicon and germanium transistors shown in comparison with U. S. dime. Silicon transistor model, with brass cap, is shown at left and germanium transistor, with glass cap is at right.

The diffused base transistor is also expected to be extremely useful in television transmission, which requires a much wider communication channel than a telephone conversation. Color television sets also offer a possibility for the new transistor. Although electron tubes are now doing this job, the new transistor is much smaller, requires less power, and does not heat up like a tube. In addition, it is expected to have a longer life than an electron tube. The new device has been made of both germanium and silicon, with striking improvements in both.

Key to the new fabricating techniques is the development of controls over microscopic chemical layers. The heart of the new transistor is a base layer 50 millionths of an inch thick. The narrower the base layer can be made, the higher the frequency at which it will operate.

The new techniques involve the adaptation of the chemical process of diffusion used in treating silicon for the Bell Solar Battery, first device to convert sunlight directly into substantial amounts of electricity. Diffusion is a process by which controlled minute amounts of impurities are introduced into a material. It is more precise than the older "double-doping" and alloy processes.

In making the new transistor, an impurity must be introduced only once into the growing crystal. The fully grown crystal receives two other doses of impurity in the easily controlled diffusion process. Previously developed processes require control, at very high temperatures, of the boundary between liquid and solid germanium or silicon, to determine the dimensions of the base layer. This is very difficult compared with controlling diffusion, in which the desired foreign atoms move through the solid crystal to the required depths.

Currently available transistors have a frequency cutoff of 1-10 megacycles, and several recently announced transistors have had a frequency cutoff between 100 and 200 megacycles. Thus far, the new transistors have been found to reach a cut off between 500 and 600 megacycles. Even though the effective operation of many military electronic devices is in a much lower frequency range, the higher cutoff would provide a greater number of communication channels or more amplification than was previously possible.

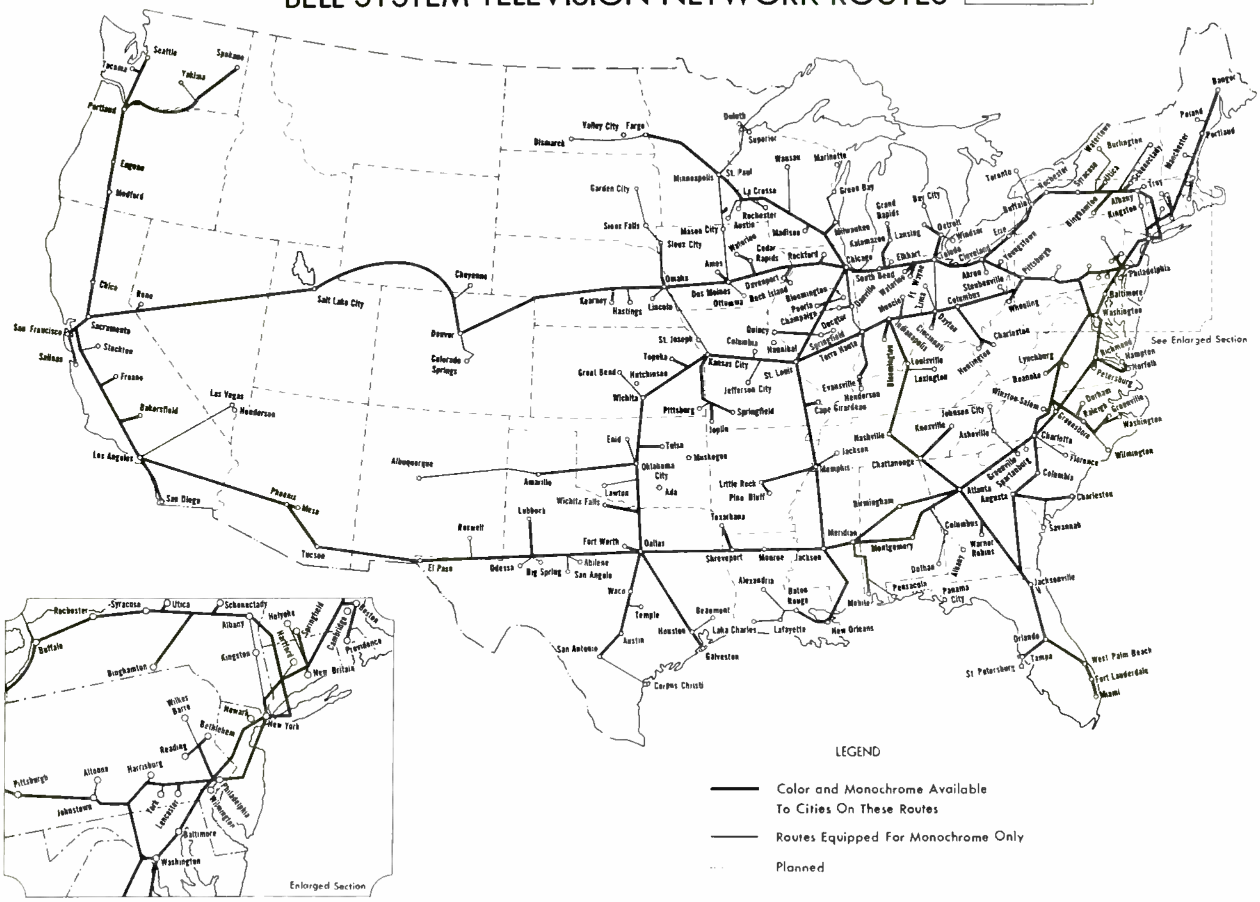
C. A. Lee, of the Laboratories, is chiefly responsible for perfecting the techniques with germanium. C. S. Fuller and M. Tanenbaum have applied the diffusion technique in making the new transistor from silicon. W. Shockley and G. C. Dacey were instrumental in directing work that led to the development.

Bell System Television Networks Extended

Over 70,000 channel miles of Bell System facilities now link 391 television stations in 262 cities in the United States, A.T.&T.'s Long Lines Department reported at year's end. During 1955, network service was extended to 34 additional stations and 29 cities.

Color network television reflected even a greater expansion last year. With 51 stations and 33 cities having been equipped for color transmission during the year, there are now 51,000 channel miles linking 190 stations in 134 cities to the color network. In 1955, the World Series, as well as a number of football games, were broadcast in color for the first time. During the year there was an increase in the use of closed-circuit television. One of these occasions, the largest inter-city hookup — for the Marciano-Moore fight — was provided by Long Lines.

BELL SYSTEM TELEVISION NETWORK ROUTES JANUARY 1956



J. M. Goldey lectures on "Evaporation Alloying and Electrode Attachment" to Western Electric Company Licensees.

Semiconductor Symposium Held for Licensees By Laboratories

At the request of the Western Electric Company, Bell Telephone Laboratories held a symposium on new semi-conductor technology in mid-January. Among the principal subjects covered were diffusion as a new technique, and the large-scale introduction of silicon into the semiconductor field. This symposium, held at the Murray Hill Laboratory, was attended by about 130 representatives from some 65 corporations licensed by the Western Electric Company to produce transistors. Forty-eight of these scientists came from seven different foreign countries. Guests at the symposium were welcomed by Dr. J. B. Fisk, Executive Vice President of the Laboratories, and E. F. Kane, Western Electric Patent License Manager.

The two-day program consisted of lectures in the Arnold Auditorium, and demonstrations in various transistor laboratories. Subjects ranged from the preparation of semiconducting crystals to the fabrication and testing of completed transistors, rectifiers, and solar cells. Programs were conducted by members of the Laboratories Semiconductor Research, Solid State Electronics Research, Metallurgical Research and Solid State Device Development Departments.

The symposium was designed to provide licensees with basic details to reduce duplicated technical effort and thus aid the national defense and generally advance the state of the semiconductor art.

Shannon M.I.T. Visiting Professor

Claude E. Shannon of the Laboratories Mathematical Research Department has been appointed visiting professor of electrical communications at the Massachusetts Institute of Technology for the spring term. He will continue as an active member of the Laboratories during this period.

"Dr. Shannon will teach an advanced course on information theory based on his recent Laboratories research which has opened up new, important avenues in this field," the M.I.T. announcement said.

Brattain Delivers Memorial Lecture

W. H. Brattain of the Laboratories Physical Research Department delivered the fourteenth annual Richtmyer Memorial Lecture at the American Institute of Physics meeting in New York City on Feb. 2. Dr. Brattain's subject was "The Development of Concepts in Semiconductor Research."

The Richtmyer lecture is part of the Joint Ceremonial Meeting of the American Association of Physics Teachers and the American Physical Society. Each year, a scientist who has made an outstanding contribution in the field of physics is invited to deliver this address. Dr. Brattain is one of the co-inventors of the transistor.

Papers Published by Members of the Laboratories

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

Alsberg, D. A., 6-KMC Sweep Oscillator, I.R.E. Trans., **PGI-4,** pp. 32-39, Oct., 1955.

Anderson, O. L., and Andreatch, P., Stress Relaxation in Gold Wire, J. Appl. Phys., **26,** pp. 1518-1519, Dec., 1955.

Andreatch, P., see Anderson, O. L.

Augustine, C. F., see Slocum, A.

Becker, J. A., Adsorption on Metal Surfaces and Its Bearing on Catalysis, Advances in Catalysis, 1955, Nov., 1955.

Bradley, W. W., see Compton, K. G.

Brattain, W. H., see Pearson, G. L.

Charnes, A., see Jacobson, M. J.

Compton, K. G., Mendizza, A., and Bradley, W. W., Atmospheric Galvanic Couple Corrosion, **2,**p. 35, Sept., 1955.

Dodge, H. F., Chain Sampling Inspection Plan, Ind. Quality Control, **11,** pp. 10-13, Jan., 1955.

Dodge, H. F., Skip-Lot Sampling Plan, Ind. Quality Control, **11,** pp. 3-5, Feb., 1955.

Flaschen, S. S., A Barium Titanate Synthesis from Titanium Esters, J. Am. Chem. Soc., **77,** p. 6194, Dec., 1955.

Franke, H. C., Noise Measurement on Telephone Circuits, Tele-Tech, **14,** pp. 85-87, Mar., 1955.

Harker, K. J., Periodic Focusing of Beams from Partially Shielded Cathodes, I.R.E. Trans., **ED-2,** p. 13, Oct., 1955.

Israel, J. O., Mechling, E. B., and Merrill, F. G., A Portable Frequency Standard for Navigation, I.R.E. Trans., **PGI-4,** pp. 116-127, Oct., 1955.

Jacobson, M. J., Charnes, A., and Saibel, E., The Complete Journal Bearing With Circumferential Oil Inlet, Trans. A.S.M.E., **77**, pp. 1179-1183, Nov., 1955.

Mechling, E. B., see Israel, J. O.

Mendizza, A., see Compton, K. G.

Merrill, F. G., see Israel, J. O.

Moll, J. L., Junction Transistor Electronics, Proc. I.R.E., **43**, pp. 1807-1818, Dec., 1955.

Mumford, W. W., and Schafersman, R. L., Data on Temperature Dependence of X-Band Fluorescent Lamp Noise Sources, I.R.E. Trans., **PGI-4**, pp. 40-46, Oct., 1955.

Owens, C. D., Stability of Molybdenum Permalloy Powder Cores, Proc. Conf. on Magnetism and Magnetic Materials, **T-78**, pp. 334-339, Oct., 1955.

Pearson, G. L., and Brattain, W. H., History of Semiconductor Research, Proc. I.R.E., **43**, p. 1794, Dec., 1955.

Pedersen, L., Aluminum Die Castings in Carrier Telephone Systems, Modern Metals, **11**, pp. 65, 68, 70, Sept., 1955.

Prince, M. B., High-Frequency Silicon Aluminum Alloy Junction Diode, Trans. I.R.E., **ED-2**, pp. 8-9, Oct., 1955.

Saibel, E., see Jacobson, M. J.

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

Slocum A., and Augustine, C. F., 6-KMC Phase Measurement System For Traveling Wave Tube, Trans. I.R.E., **PGI-4**, pp. 145-149, Oct., 1955.

Wannier, G. H., Threshold Law for Multiple Ionization, Phys. Rev., **100**, pp. 1180, Nov. 15, 1955.

Wannier, G. H., Possibility of a Zener Effect, Letter to the Editor, Phys Rev., **100**, p. 1227, Nov. 15, 1955.

Talks by Members of the Laboratories

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

Acoustical Society of America, Providence, R. I.

Bommel, H. E., see Mason, W. P.

David, E. E., and McDonald, H. S., A Note on Pitch-Synchronous Processing of Speech.

Mason, W. P., and Bommel, H. E., Ultrasonic Attenuation and Velocities in Normal and Superconducting Metals.

McDonald, H. S., see David, E. E.

Miller, R. L., The Nature of the Vocal Cord Wave.

Schroeder, M. R., On the Separation and Measurement of Formant Frequencies.

American Physical Society, Los Angeles, Calif.

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

Hrostowski, H. J., see Shulman, R. G.

Lax, M., Generalized Theory of Mobility.

Moore, G. E., The Dissociation of Solid Compounds by Electron Bombardment.

Morin, F. J., see Reiss, H.

Reiss, H., Morin, F. J., and Fuller, C. S., Ion Pairing Involving Lithium in Germanium and Silicon.

Shulman, R. G., Wyluda, B. J., and Hrostowski, H. J., Quadrupole Broadening of NMR Lines by Reversible Axial Stress.

Wyluda, B. J., see Shulman, R. G.

Other Talks

Baird, J. A., Transistors and Their Application to Digital Computers, Texas A&M College, College Station.

Blecher, F. H., Design Principles for Transistor Feedback Amplifiers, Polytechnic Institute of Brooklyn, N. Y.

Bond, W. L., Infrared Studies of Dislocations in Silicon. Conference on Defects in Crystalline Solids, Rutgers University, New Brunswick, N. J.

Budlong, A. H., Control Circuits, I.R.E., Newark College of Engineering, N. J.

Clark, M. A., Measurement of Small Signal Parameters of Transistors and Transistor Noise, A.I.E.E. New York Section, Power and Industrial Division, Westinghouse Auditorium, New York City.

Diamond, A. H., Certain Classes of Finite Sequential Machines with Distinguished States, American Mathematical Society, Winter Meeting, Houston, Texas.

Ellis, G. O., Assembly of Alloyed Junction Transistors, U.S. Army Reserves, New Brunswick, N. J.

Ferrell, E. B., Electronic Switching, A.I.E.E., Buffalo.

Hagstrum, H. D., Auger Ejection of Electrons from Metals by Ions, Physics Colloquium, Yale University, New Haven.

Hammann, P. L., NIKE I, A Guided Missile System for AA Defense, Northern New Jersey Alumni Association, Union College, Belleville.

Hart, H. C., The Art of Communicating Complex Patent Matters, Rochester Patent Law Association, N. Y.

Hayward, W. S., Traffic Engineering and Administration Problems in the Line Concentrator, Informal Seminar, M.I.T., Cambridge, Mass.

Holbrook, B. D., Dial Telephony: An Example of Automation, Stevens Institute of Technology, Hoboken, N. J.

Jahn, A. P., Rural Wire and Urban Wire for Telephone Distribution Systems, Annual Signal Corps Wire and Cable Symposium, Asbury Park, N. J.

Keister, W., Mechanized Intelligence, A.I.E.E./I.R.E. Joint Student Branch, Cornell University, Ithaca, N. Y.

Talks by Members of the Laboratories, Continued

Lax, M., Trapping and Recombination in Semiconductors, Physics Colloquium, Boston University.

Levenbach, G. J., Accelerated Life Testing of Capacitors, American Society of Quality Control, Princeton Conference, Metropolitan Section; and American Statistical Association, Annual Meeting, New York City.

Lewis, H. W., Superconductivity and Electronic Specific Heat, National Low Temperature Conference, Baton Rouge, Louisiana.

McKay, K. G., Gaseous Electronics in Silicon, University of Toronto, Ontario, Canada.

Merz, W. J., Domains in Ferroelectrics, Watson Laboratory of I.B.M., New York City.

Monro, S., Basic Aspects of Tolerance Limits, American Society for Quality Control, Metropolitan Section, Princeton University, N. J.

Pearson, G. L., The Silicon Solar Battery, American Association for the Advancement of Science, Atlanta, Georgia; and Silicon in Modern Communications, Southern Bell Telephone Company, Atlanta.

Phelps, J. W., Protection Problems on Telephone Distribution Systems, Annual Signal Corps Wire and Cable Symposium, Asbury Park, N. J.

Remeika, J. P., High Temperature Crystal Growth from Solvents, City College, New York City.

Schawlow, A. L., Structure of the Intermediate State in Superconductors, Physics Colloquium, New York University.

Slepian, D., Information Theory, Esso Research and Engineering Company, Linden, N. J.

Sobel, M., On the Number of Units Needed for Certain Selection and Ranking Problems, American Statistical Association, Biltmore Hotel, New York City.

Struthers, J. D., Radioactive Isotope Techniques, American Ceramic Society, Metropolitan Section, Newark, N. J.

Weisbaum, S., Microwave Ferrite Devices, Physics Colloquium, New York University.

Windeler, A. S., Polyethylene Insulated Telephone Cable, Annual Signal Corps Wire and Cable Symposium, Asbury Park, N. J.

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

Anderson, F. W. – *Line Voltage Regulator* – 2,722,655.

Ashenhurst, R. L. – *Electrical Circuits Employing Magnetic Core Memory Elements* – 2,724,103.

Bond, W. L. – *Plural Metal Vapor Coating* – 2,724,663.

Brewer, S. T., Reenstra, W. A., and Ritchie, W. J. – *Remote Line Concentrator* – 2,724,744.

Brewer, S. T. – *Signal Amplitude Detector and Indicator* – 2,724,745.

Bruce, E., and Reenstra, W. A. – *Communication System* – 2,724,746.

Chesnut, R. W. – *Suppressed-Carrier Amplitude Modulation* – 2,724,742.

Cisne, L. E. – *Method of Fabricating Electrode Spacers* – 2,724,216.

Cisne, L. E. – *High Tolerance Impedance Elements and Methods of Making Them* – 2,724,761.

Cutler, C. C. – *Quantized Transmission with Variable Quanta* – 2,724,740.

Dimond, T. L. – *Peak Voltage Limiter* – 2,722,603.

Duncan, R. S., and Stone, H. A., Jr. – *Adjustable Inductance Device* – 2,722,664.

Field, L. M. – *High Frequency Amplifying Device* – 2,725,-499.

Fisher, E. L. – *Protector* – 2,724,793.

Fuller, C. S. – *Method of Fabricating Semiconductive Bodies* – 2,725,315.

Fuller, C. S. – *Method of Preparing PN Junctions in Semiconductors* – 2,725,316.

Graham, R. E. – *Diode Gate Circuit* – 2,723,355.

Harris, J. R. – *Inhibited Trigger Circuits* – 2,724,780.

Haynes, J. R., and Heidenreich, R. D. – *Germanium Elements and Methods of Preparing Same* – 2,722,490.

Heidenreich, R. D., see Haynes, J. R.

Hopper, A. L. – *Automatic Frequency Control* – 2,725,555.

Kleimack, J. J. – *Method of Fabricating and Heat Treating Semiconductors* – 2,725,317.

Malthaner, W. A., and Vaughan, H. E. – *Common Control Telephone Systems* – 2,723,311.

McGuigan, J. H., and Murphy, O. J. – *Magnetic Drum Dial Pulse Recording and Storage Registers* – 2,723,312.

McKay, K. G. – *Pulse Generator Utilizing Bombardment Induced Conductivity* – 2,724,771.

Michal, J., and Staehler, R. E. – *Pulse Counting System* – 2,722,675.

Murphy, O. J., see McGuigan, J. H.

Oliver, B. M. – *Error-Voltage-Sensitive Differential Amplifier* – 2,725,424.

Reck, F. – *Hand-Operated Wiring Tool* – 2,725,198.

Reenstra, W. A., see Brewer, S. T.

Reenstra, W. A., see Bruce, E.

Ritchie, W. J., see Brewer, S. T.

Staehler, R. E., see Michal, J.

Stone, H. A., Jr., see Duncan, R. S.

Tillotson, L. C. – *Electromagnetic Wave Hybrid Junction Coaxial Transmission Line Structures* – 2,724,806.

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

Vroom, E. – *Automatic Transcribing System* – 2,723,308.

Willard, G. W. – *Ultrasonic Velocity Measuring Device* – 2,723,556.