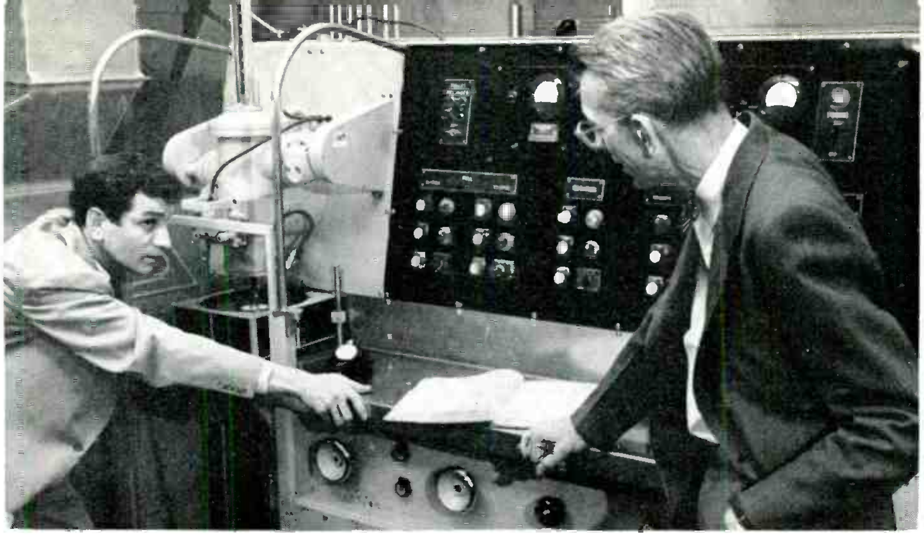


H. E. Bridgers (left) operating a machine used in the Research Laboratory for growing single-crystals of semiconductors for use in transistors. F. G. Buhrendorf, who designed the machine, is at the right.

A Foreword on Transistors

J. B. FISK *Vice President — Research*

The origins and early history of transistors have been told many times. Much of the story has reached receptive audiences in professional and lay circles. The unfolding scientific understanding is stimulating wide research interest in industry and the universities; in physics, metallurgy, and in chemistry. Transistors, with their unique properties, and other semiconductor devices likewise have stimulated users and exploiters – from extensive engineering developments to sometimes extravagant speculation on the "revolution in electronics." It is true there is substantial stirring in the electronics world, but "revolution" means total and rapid change. We are not involved in a total change; rather, in a rapid evolution.

The forecast for rapid evolution is well founded both in scientific understanding and in technological achievement. This does not mean that all phenomena are completely understood or that there is a ready explanation for every new observation. Nor does it mean that *a* transistor, of quick and universal application, is in large-scale mechanized production. The history of discovery and invention in a complex technology knows no examples of painless transition to mass production and use. Transistors are not exceptions in this respect. But their history is exceptional and in many ways unique – as will be their future.

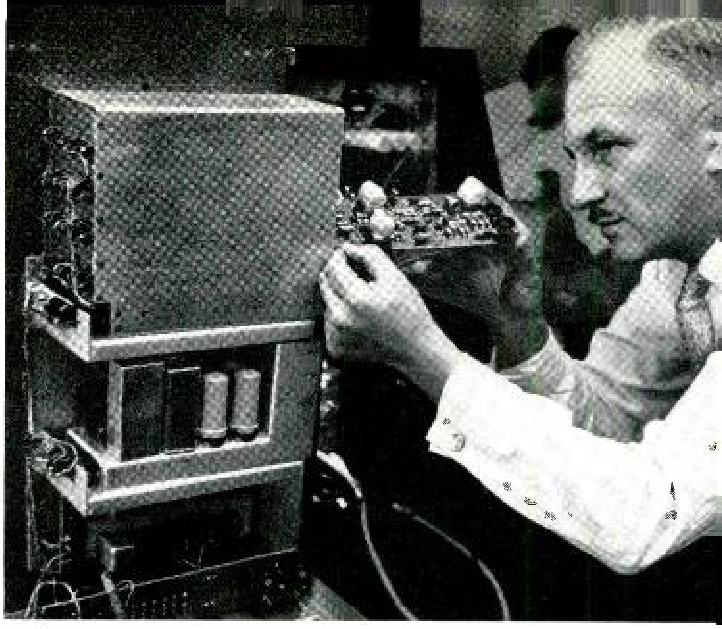
What is so exceptional and unique in the history of their development? One singular fact is the extent of detailed quantitative understanding of transistor action and of semiconductor materials generally. This understanding goes far beyond a description of external behavior. It tells *how* semiconductors work

A production line at the Allentown Plant of Western Electric. In the foreground pieces of germanium are being mounted for cutting into small dices for use in transistors. The machines in the background are converted grinders, now used for cutting the mounted germanium.

in terms of the atoms they are made of, how the atoms are arranged in crystals, how the electrons (and "holes") respond to electrical forces we apply to the crystal. It tells how to purify materials and make almost perfect crystals in simple ways, how to put the right number and kind of "extra" atoms where they are wanted. This is the basic science.

The rapid exploitation of basic knowledge to make new semiconductor devices is exceptional. The new devices are the response to needs and opportunities in communication systems and circuit design, to military needs, and sometimes to recognition of some inherent properties of the semiconductor, suggesting a very different use. Now, these needs and opportunities have coupled with the basic science in an unusual and seemingly unique way. That is, the *systems* are evolving right along with the new devices, instead of being fitted to them later on, or the new devices substituted awkwardly into present systems. Thus the evolution is an unusually comprehensive one. Transistors are appearing in a number of places; they will appear in *quantity* in Bell System use as the new systems appear.

There is now an abundance of transistor types for specific development – triodes, tetrodes, diodes, photocells and switches – and a number are in Western Electric manufacture. There is an even greater abundance of transistor uses and transistor users in our research and engineering development laboratories. Each new use demands careful design to give the user the operating characteristics he needs in his circuits and, usually, each new use requires new processes to obtain and control these characteristics. The user's appetite for transistors, in quantity and variety, is almost without limit. This appetite, of course, is not restricted to transistors alone. For proper use, transistors require capacitors, inductors, resistors, transformers and assemblies in correspondingly small size to match the transistor's modest requirements. The "rapid evolution" is indeed the evolution of a whole new, comprehensive technology.



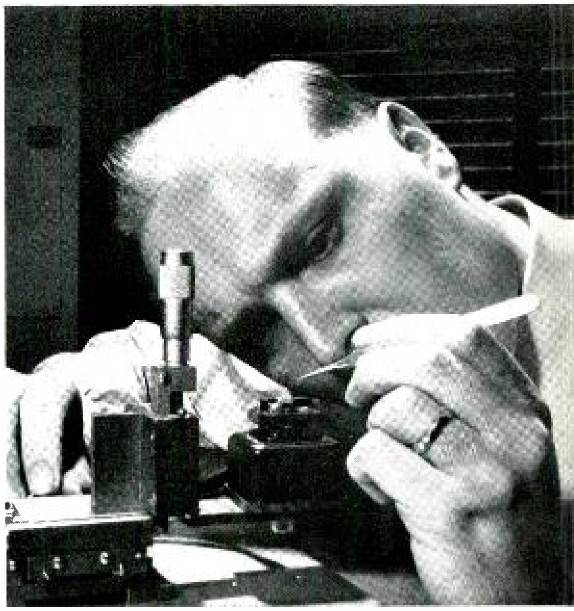
C. S. Yeutter assembling apparatus designed and built at the Laboratories for use in the Americus, Georgia transistorized rural carrier field trial. Transistors, hardly visible in the photograph, are mounted on the panel just above Mr. Yeutter's left hand.

The articles which follow in succeeding issues of the RECORD are a continuing story of this growing science and art, emphasizing transistors: research, development, and some of the present uses. Transistors are already at work in some telephone apparatus, and in circuit and systems trials. They are appearing in quantity as the technology, which these articles record, matures and confirms that the new art and new science will give the traditional efficiency and reliability of Bell System service.

THE AUTHOR

JAMES B. FISK, vice president in charge of research at the Laboratories, also serves on the General Advisory Committee of the Atomic Energy Commission as well as the Science Advisory Committee of the Office of Defense Mobilization. He was formerly Director of Research of the A.E.C. and simultaneously Gordon McKay Professor of Applied Physics at Harvard University. Dr. Fisk joined the Laboratories in 1939, heading the development group on the microwave magnetron for high-frequency radar during World War II. After the war, he was in charge of electronics and solid state research. He became director of research in physical sciences in 1949 and has been vice president since March 1 of this year. Dr. Fisk received his bachelor's and doctor's degrees from Massachusetts Institute of Technology in 1931 and 1935, respectively. He was a Proctor Travelling Fellow at Cambridge University and was later in the Society of Fellows at Harvard. Recently he was elected a member of the National Academy of Sciences.

P-N Junctions and the Junction Transistor



M. SPARKS *Chemical Physics*

One important development, following the invention of the basic transistor itself, has been the exploitation of semiconductor junctions. These junctions — simply boundaries between regions in a semiconducting crystal having different types of electrical conductivity — have not only increased the understanding and usefulness of transistors, but also widely extended the range of applications in which semiconducting devices may be used profitably. As the field of semiconductor research grows, these junctions, used singly or in various combinations, may well lead to additional applications and devices as yet unknown.

The first experimental junction transistors were described three years ago.* Structurally, they consisted of a simple sandwich arrangement of layers in a germanium crystal having two different types of electrical conductivity. The units were compact and rugged. Electrically, they showed tremendous improvements over previous transistor models in such important characteristics as efficiency, gain, and noise. Probably the most remarkable feature was their ability to operate at extremely low power levels. Scientifically, their behavior was predictable quantitatively in terms of the electrical properties of germanium. This material, in turn, was understood in terms of its atomic nature, crystal structure, and purity. This sequence is unusual for such a system even after years of study and development; to have it exist at the birth of the first assemblies is almost without parallel.

Subsequent articles in the RECORD will discuss the electrical conductivity of semiconductors in detail. We shall be concerned here primarily with the nature and properties of p-n junctions, and the extension of these concepts to explain the behavior of junction transistors. In fact, the versatile p-n junction has proved to be the basic workhorse of semiconductor devices.

There are two mechanisms for electronic conductivity in semiconductors. The distinguishing feature is that the current carriers in one case are negatively charged electrons (n-type conductivity), and in the other case are positively charged holes (p-type conductivity). Both of these mechanisms operate simultaneously, and which of the two types predominates depends on the balance between two kinds of impurities, called donors (producing electrons) and acceptors (producing holes).

Usually, there will be many more carriers of one kind than the other in any particular piece of a semiconducting crystal. An important experi-

Above, R. M. Mikulyak using a micro-manipulator in one stage of the assembly of a junction transistor.

* RECORD, *August*, 1951, *page* 379.

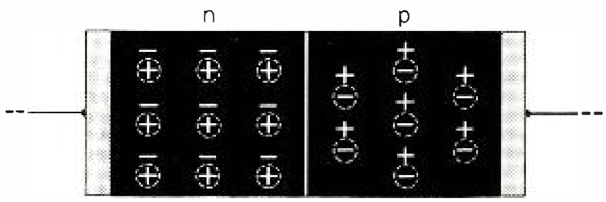


Fig. 1 — A p-n junction with charges provided by donor and acceptor impurities shown in circles.

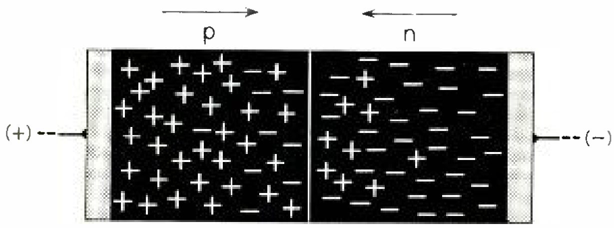


Fig. 2 — With a voltage of the indicated polarity, holes and electrons move across the p-n junction, and hence current will flow.

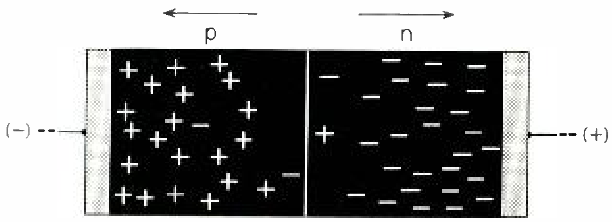


Fig. 3 — With a voltage of the indicated polarity, holes and electrons are drawn away from the p-n junction. This provides a high resistance to the flow of current.

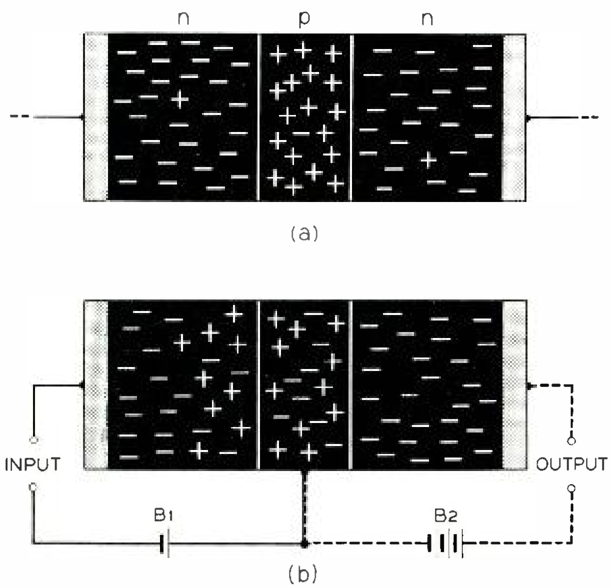


Fig. 4 — (a) An n-p-n junction transistor, and (b), such a unit wired in a circuit to operate as an amplifier. In actual scale, the middle p-type region is much narrower — perhaps only 5 per cent of the cross section of the transistor.

mental fact is that the relative numbers of the two types can be altered by several methods. This change will persist for a short time before it readjusts to the original equilibrium distribution that is determined by the impurity balance. The average time required for the distribution of holes and electrons to recover from such a disturbance is called the "lifetime" of the material. Successful operation of a transistor depends on having a material with a finite lifetime, although this interval may be only a few millionths of a second long.

A p-n junction is simply the boundary between two regions of opposite conductivity type in a semiconductor crystal, such as germanium or silicon. These boundaries are produced by any of several techniques for controlling the kind and location of impurities. Such a structure is illustrated in Figure 1. The circled charges represent donor and acceptor atoms which are electrically charged, but do not contribute to conductivity because they are tightly bound in the crystal. For this reason they can, for the most part, be ignored in the remainder of this article, although it is important to remember that they serve to neutralize the charges of the mobile holes and electrons which can move through the crystal and thereby carry current.

The big difference electrically between the two sides of a junction results from a very small chemical difference; typically, the donors and acceptors constitute about 0.001 per cent of the total number of atoms. The entire piece of semiconducting material is preferably a single crystal with no physical discontinuity at the boundary. Thus, the conductivity paths of the crystal are continuous across the junction. Another important fact is that there are always at least a few of each kind of carrier everywhere in the crystal. Those carriers present in smaller numbers, such as holes in n-type germanium, are called minority carriers.

Now, considering a p-n junction as a circuit element, if a voltage is impressed across a unit with the polarity as shown in Figure 2, current will flow readily. Both holes and electrons, from the p-type and n-type sides respectively, are pushed toward and across the junction. This provides one of the ways mentioned previously for disturbing the ratio of holes to electrons in a localized region of a semiconducting material. The polarity indicated in Figure 2 is called the "forward" direction of the junction. By pushing electrons into the p-type section, for example, their relative number is greatly increased. The distance of penetration into the p-type section that this "emission" of electrons influences depends on the lifetime of the crystal. As the emitted electrons diffuse into the p-type section they are lost by an annihilation reaction with the more numerous holes. An analogous situation exists in the case of holes emitted into the n-type section.

When the polarity of the voltage across the junction is reversed, the result is quite different. In this case, the holes on the p-type side and the electrons on the n-type side are pulled away from the junction as shown in Figure 3. The only carriers in a position to cross the junction are those few minority carriers that are inevitably present. The junction then represents a high resistance in a circuit since conductivity is proportional to the number of current carriers available. This polarity is called the "reverse" or blocking direction of the junction. Since a p-n junction effectively blocks the flow of current in one direction but passes it readily in the other direction, it is a rectifier. Such junctions, particularly those recently developed in silicon, are among the very best rectifiers obtainable.

The p-n junction properties that have been described are those needed to understand the operation of a junction transistor as an amplifier. Summarizing these properties — a p-n junction has a low electrical resistance in the forward direction, and a result of current flowing in this direction is to increase the minority carriers near the junction. In the reverse direction, the resistance is very high, perhaps 100,000 times as high, and the small current which does flow is due to the minority carriers near the junction.

An n-p-n transistor, which contains two p-n junctions located very close together is illustrated in Figures 4 and 5. As shown in Figure 4(b), leads are attached to each of the three sections. The solid line circuit includes one of the junctions (emitter) which is biased in the forward direction by the battery B1. The broken line circuit includes the other junction (collector) which is biased in the reverse direction by the battery B2. The thin p-type section, common to both circuits, is called the base.

A small alternating voltage, such as a weak voice signal in a telephone transmission line, may be introduced into the emitter circuit. This circuit contains no high resistances; it is a low power

Electron Tube — Junction Transistor Comparison

All amplifiers operate by using one kind of current to control another. In electron tube triodes, as in transistors, two mechanisms of conductivity are needed. Some electrons are confined to the metallic parts of the circuit: for example, those that flow in and out of the grid wire. Other electrons are released into the vacuum and are the source of the "space current" that is controlled by the charges in the grid wire. In the n-p-n transistor the flow of electrons across the p-type region is analogous to the space current. This flow is regulated by the potential difference across the emitter junction, and depends on the flow of holes in and out of the base contact.

Looking deeper into fundamental concepts, further similarities between the two amplifiers are found. What is the nature of the distinction between the two kinds of current we have said must be present in each instance? One distinction is the energy level of the charge carriers. In the electron tube triode, thermionic electrons are emitted from a hot filament to furnish carriers for the space current. Energy must be furnished to boil electrons out of the filament in much the same way that it takes energy to convert water to steam. The energy difference between electrons inside and outside of the metal is called the "work function." It is a potential energy difference, and is a measurable quantity which varies from metal to metal. There is also a difference in energy between electrons and holes in a semiconductor, and it is precisely this potential energy difference that permits two carriers of currents to be distinguished and separately controlled. In semiconductors this energy separation is called the "forbidden-energy gap," and its value, which can be measured by experiment, is an important characteristic of the semiconductor.

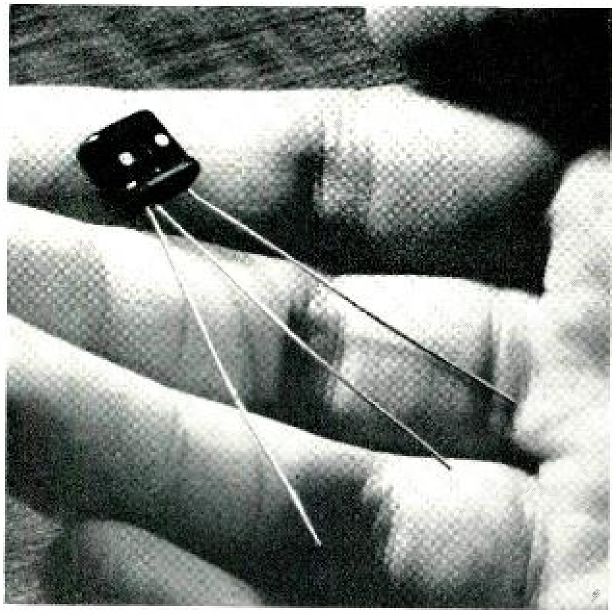


Fig. 5 — A typical n-p-n junction transistor of recent design.

circuit and even a weak signal produces a corresponding current across the emitter junction. As a result, minority carriers (electrons) are emitted into the thin p-type base layer. This base layer is also adjacent to the other junction which is biased so that any electron that reaches it from the p-type side will be pushed across (collected). The dimensions of the base layer are such that almost all emitted electrons will reach the collector junction before they find their way out to the contact at the surface, or are lost by reacting with holes. The efficiency of this *trans*fer of a signal across the collector junction is greater than 99 per cent in good models. Semiconductor rectifiers which function in the manner of the collector junction have in the past also been called var*istors*, and the name *transistors* was coined initially to indicate the function described above.

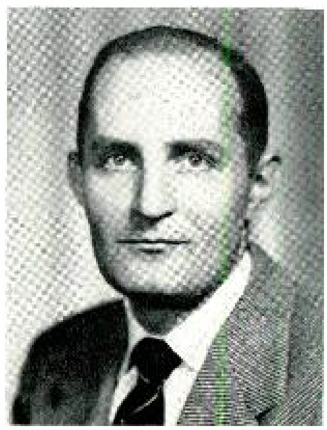
The collector circuit contains a reverse biased p-n junction that has a very high resistance; it is potentially a high power circuit. Transfer of the substantially unattenuated signal into this circuit represents power gain, and the energy for this amplification is furnished by the battery B2.

The junction transistor has lived up to its early promise. It has already appeared in a variety of models which maximize such properties as low power, high power, and high frequency response. Several quite different techniques have been developed for its construction, and both p-n-p and n-p-n versions are being manufactured. The operational difference between these two variations is simply that all polarities are reversed.

The essential function of the emitter is to change the number of minority carriers near the collector junction. This can also be done by absorbing light or by changing the temperature. Thus, a reverse biased p-n junction is a sensitive photocell or thermometer. If the voltage across such a junction is increased sufficiently, the breakdown point will be reached, and the current will suddenly increase rapidly. This breakdown, in contrast with that encountered in most materials, is non-destructive. As a result, p-n junctions also serve as excellent voltage limiters, and the critical voltage can be varied widely by controlling the impurity distribution across the junction.

Return now to Figure 3. Before the voltage was applied across the crystal, it was everywhere electrically neutral. When the mobile holes and electrons were drawn away from the junction as shown

THE AUTHOR



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

in the figure, however, the immobile donors and acceptors in this region were exposed as naked charges. A "space charge" is thus formed consisting of positive donor ions on the n-type side, and an equal charge of negative acceptor ions on the p-type side. This region has been swept of mobile charges, and represents a decrease in the conductivity of that part of the crystal. The width of the space charge increases as more mobile carriers are drawn away from the junction by increasing the voltage that is applied to it.

Since the space charge produces a non-conducting layer between two conducting regions, the p-n junction has an electrical capacitance. This capacitance is a nuisance in most cases; for example, its presence in the collector junction of a transistor adversely affects the high frequency behavior of the unit. It can be useful, however. The capacitance of the junction is changed as the width of the space charge is varied by the applied voltage. In this way, a p-n junction may be used as an active component for a frequency modulated circuit. Complete FM transmitters no bigger than a pack of cards have been made and demonstrated using this principle.

A single p-n junction is one of the least complicated structures possible in a semiconductor. It lends itself to complete mathematical analysis, and is not unduly difficult to make. It is a truly remarkable entity. It has served as a tool for research scientists and as a building block for design engineers. It is the basic concept in the rapidly evolving field of semiconductor devices.

Patents Issued to Members of Bell Telephone Laboratories During March

Barlow, D. S. – *Calling Station Identification Circuit* – 2,672,515.

Bostwick, L. G. – *Vibrating Reed Devices* – 2,673,482.

Davey, J. R. – *Telegraph Repeater* – 2,672,511.

Dickinson, F. R. – *Apparatus for Cooling Electron Discharge Devices* – 2,673,721.

Doblemaier A. H. – *Thermistor Measuring Apparatus* – 2,673,960.

Douvas, A. G. – *Square Wave Circuit* – 2,671,170.

Dunlap, K. S. and Malthaner, W. A. – *Telephone Subscriber* – 2,672,523.

Graham, R. E. and Harrison, C. W. – *Vertical Synchronizing Generator* – 2,671,133.

Grisdale, R. O., Pfister, A. C., and Teal, G. K. – *Electrical Resistors and Methods of Making Them* – 2,671,735.

Harris, J. R. – *Diode Gate* – 2,673,936.

Harrison, C. W., see Graham, R. E.

Holden, W. H. T. – *Channel Testing Circuit* – 2,672,521.

Holden, W. H. T. and Vibbard, E. L. – *Station Identifier* – 2,672,518.

Hoyt, F. A. – *Coin Collector* – 2,670,830.

Jones, T. A. – *Control of Transmission in Two-Way Telephotograph Systems* – 2,673,891.

Kock, W. E. – *Mode Suppression in Curved Wave-Guide Bends* – 2,673,962.

Lander, J. J. – *Plating with Oxides, Sulphides, Selenides, Tellurides of Chromium, Molybdenum, and Tungsten* – 2,671,739.

Lang, W. Y. – *Teletypewriter Line Feed Transmitting and Counting Apparatus* – 2,672,508.

Lewis, B. F. – *Recording System* – 2,672,395.

Malthaner, W. A., see Dunlap, K. S.

Mathes, R. C. – *System for Analyzing and Synthesizing Speech* – 2,672,512.

Mills, J. K. and Ross, W. S. – *Telephone Ringing Power Plant* – 2,672,604.

Miloche, H. A. and Obst, C. V. – *Terminal Strip* – 2,673,970.

Mumford, W. W. – *High Frequency Amplifying Devices* – 2,673,900.

McSkimin, H. J. – *Delay Line* – 2,672,590.

Obst, C. V., see Miloche, H. A.

Pfister, A. C., see Grisdale, R. O.

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

Shockley, W. – *Semiconductor Translating Devices* – 2,672,528.

Soffel, R. O. – *Signaling System* – 2,671,824.

Teal, G. K., see Grisdale, R. O.

Vibbard, E. L. – *Control Circuit* – 2,671,611.

Vibbard, E. L., see Holden, W. H. T.

Williams, S. B. – *Electronic Computer* – Re 23,807 (Reissue of 2,502,360).

Williamson, R. J. – *Inductance Coil* – 2,673,961.

Dr. Kelly Receives Industrial Research Institute Medal for 1954

Dr. Mervin J. Kelly, president of the Laboratories, recently received the Industrial Research Institute's 1954 Medal at a dinner climaxing the Institute's annual meeting in San Francisco. The medal, established in 1945, has been presented annually since then "to recognize and honor outstanding accomplishment in leadership in or management of industrial research which contributes broadly to the development of industry or the public welfare."

Dr. Fred Olsen, past president of the Institute, presented the medal to Dr. Kelly "for distinguished

Dr. Kelly accepts the Industrial Research Institute Medal from Dr. Fred Olsen, past president of the Institute. At the left is Dr. Allen Abrams, president of the Institute.

leadership in industrial research, joining the mind of the scientist and the hand of the technologist to serve the security and well being of mankind, and for outstanding personal contributions to national security." Dr. Allen Abrams, president of the Institute, presided at the award dinner.

"Industrial research is perhaps the most significant force in our society in determining the quality of our living, in conserving materials essential to industrial man's survival, and in insuring our freedoms," Dr. Kelly declared in his acceptance address.

In the last 15 years, he pointed out, the nation has spent $15 billion in research and development directly connected with our military strength, while we have invested only $11 billion in research and development for our civilian economy.

"The relative size of these figures is indicative of the importance we have attached to the application of science to creating new weapons and the strategy of their use," Dr. Kelly said. "While World War II was in progress, revolutionary weapons and methods of warfare were created and introduced that decreased the period of the war and brought victory with shorter casualty lists. In the postwar period, with atomic power as the destructive force, a military strength has been created that has deterred the Russians from all-out war. Recent developments have raised the destructiveness of an atomic explosion to a level where its very magnitude may well act as a deterrent even though both sides are capable of employing it."

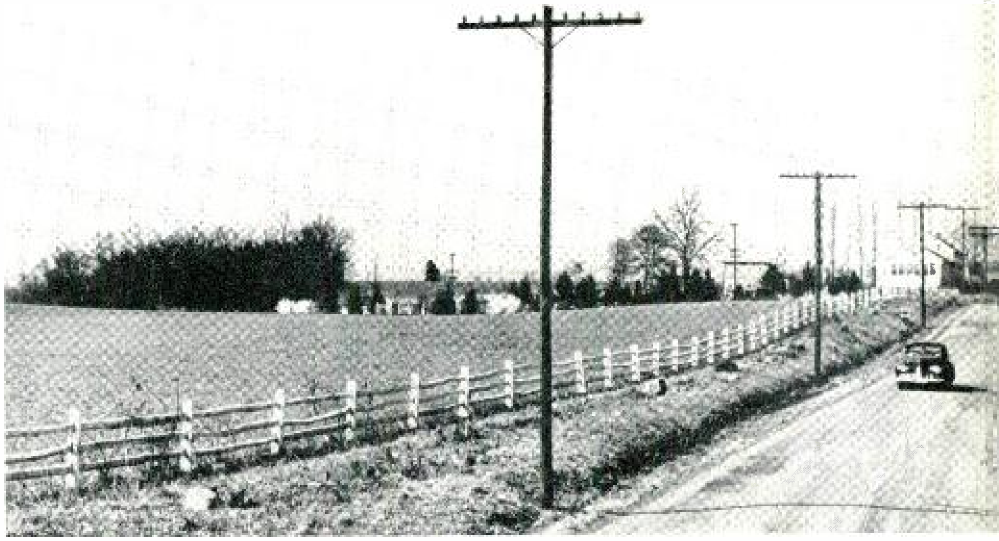
Industrial research has played the major role in producing these results, he declared, for some 60 per cent of this country's military research and development work has been carried out in the laboratories of industry. At the same time, industrial research has made equally important contributions to an abundant economy and a steadily rising standard of living for Americans.

He cited as a typical example of the fruits of industrial research the experience of the telephone industry. Thirty years ago the Bell System served about eight million subscribers; today it serves forty-one million, a five-fold increase. This has been accompanied by an expansion of the range of telephone communication and by the introduction of new services such as broadcasting and television networks and teletype facilities. Thus, through research, the expanded usefulness of the Bell System communications network has been achieved with only a three-fold increase in personnel.

Looking ahead, Dr. Kelly predicted that the trend toward increased productivity will continue at an accelerated rate with the introduction of electronic systems, generally of the "electronic brain" or computer type, in manufacturing, merchandising, business and banking operations.

"Automation through electronic systems has received large stimulation from the electronic components arising from industrial research in solid state physics," Dr. Kelly said. "The robot factory moves out of the Jules Verne area into one of reality. Electronic automation implemented with solid state devices will be one of the major economic and social forces during the next few decades."

Type-O Carrier: System Objectives



B. C. GRIFFITH AND H. KAHL *Transmission Engineering*

Increasing demand for more telephone circuits in areas served by short-haul open-wire lines posed the problem of how to make more effective use of the existing lines. Studies indicated that a suitable type of low-cost carrier system might be possible. As might be expected, this involved a comprehensive study of the problems common to various types of carrier systems, and objectives were established for an appropriate system, with particular emphasis on short-haul performance and minimum practicable cost.

Radio relay systems and coaxial cables are so commonplace today that it is easy to lose sight of an important transmission medium – open-wire lines. This mainstay of the Bell System provides toll and tributary telephone service over about 170,000 route-miles; many parts of the country are served almost exclusively by such lines. Since only a few circuits have been required on many of these routes, it has been economically advantageous to string additional wires in these areas rather than to install cables. Much of the service provided by open wire is comparatively short-haul, between small cities and towns separated by short distances.

In Iowa, for example, where open-wire constitutes a large part of the outside plant, 95 per cent of such toll circuits are less than 100 miles in length, and 98 per cent of the tributary circuits are less than 30 miles long. Groups of these circuits used either for "via" or terminated business between adjacent towns are generally small, averaging about four circuits per group for toll, and two circuits per group for tributary service – circuits between a toll center and a local office. The thousands of telephones in the Iowa area are thus interconnected by a spider-web of open-wire lines, as shown in Figure 1, and a few long cables.

Above — A typical rural scene showing five open-wire pairs in the foreground and another open-wire line in the distance. Many parts of the country are served almost exclusively by such lines.

Conversion of tributary offices to automatic operation has created a need for more circuits. Normal message service requires only a few trunks between a manual tributary office and a toll center. When, however, a tributary office uses automatic equipment, the operators are usually moved to the toll center. Since the trunks must still be used for message routing, items arising at the tributary office but handled from the toll center, such as directory information, complaints, and special services, require additional circuits. Expansion of telephone service and future conversion to dial operation are expected to further increase this demand for additional circuits.

The problem of providing new circuits in num-

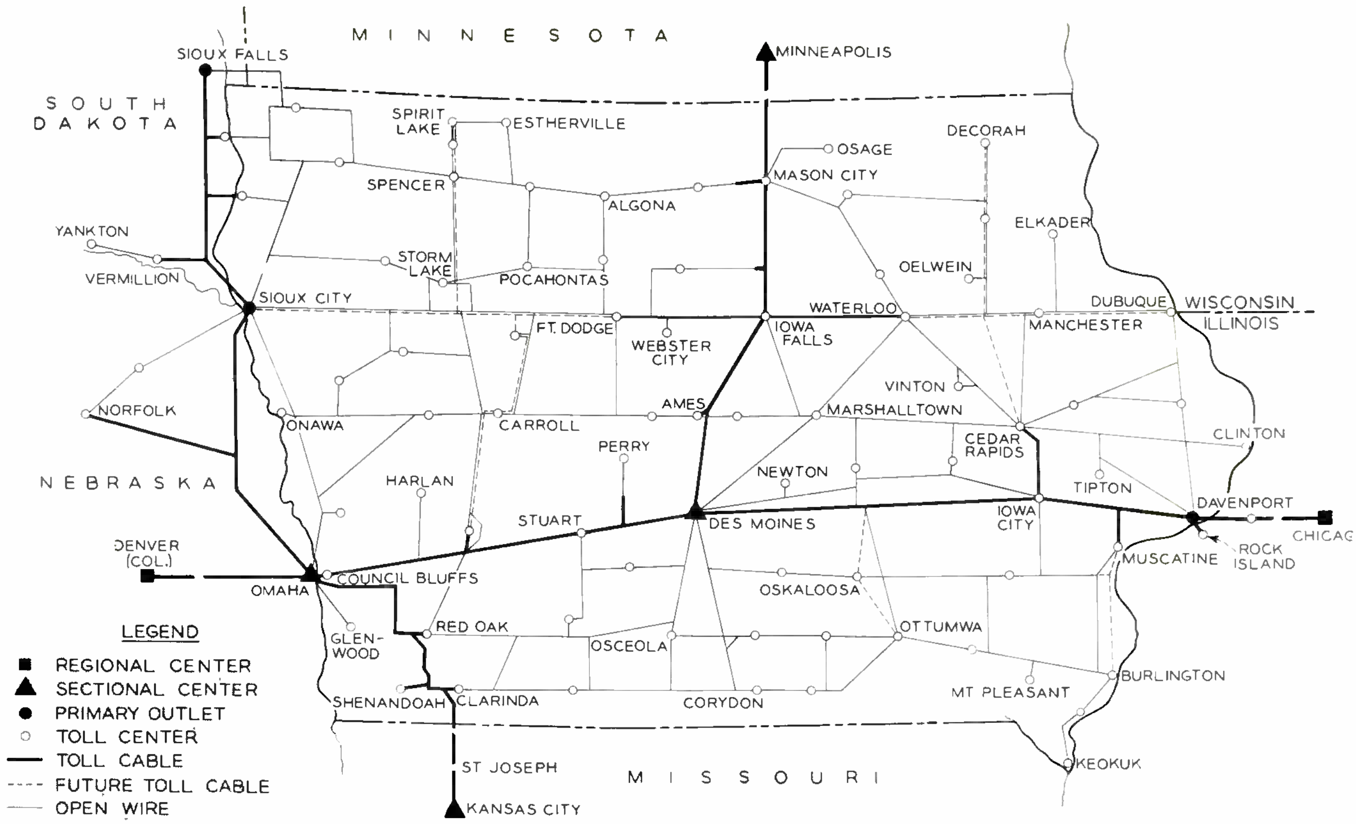


Fig. 1 — The spider-web of open-wire lines serving Iowa at the time of the studies.

bers sufficient to meet this demand presented the following alternatives: stringing additional open wire on pole lines already well loaded, replacing or paralleling such lines with cable, or applying suitable carrier systems to existing open wire. Of these alternatives, carrier seemed the most attractive since circuits could be made available as required without an initial large capital outlay.

None of the existing carrier systems designed for open-wire operation were considered suitable for this application. For instance, the present single channel systems do not provide enough extra circuits. Modified Type-M systems, originally developed for use on power lines in rural areas, have been used to some extent, but are restricted in application because of extreme attenuation at the high frequencies employed. Three-channel Type-C carrier is used on some of the longer routes, but is not economical for distances less than about seventy miles. Type-J carrier, providing twelve additional channels above Type-C, was not considered for such short-haul service for economic reasons. What was needed was a new carrier system for open wire, with a sufficient number of channels, designed specifically for economical application over distances between about twenty and two-hundred miles.

A primary consideration in an open-wire carrier system is the transmission properties of the lines on which it will be used. Figure 2 shows the loss-versus-frequency characteristics of a typical open-wire line transposed to transmit all frequencies up to about 150 kc. Curves are shown for three different weather conditions: dry weather, wet weather, and ¼″ radial thickness of sleet on the wires. A typical open-wire line under sleet conditions is shown in Figure 3. The resulting transmission losses must be overcome by amplification in the carrier equipment. For short systems, this amplification can be supplied by the terminal equipment, but longer systems need repeaters between terminals to compensate for line attenuation.

Since line attenuation is dependent on weather conditions, it is necessary for the carrier equipment to supply different amounts of gain as the line loss changes. Figure 2 also shows that the line loss increases with frequency, particularly under sleet conditions. Since attenuation of the higher carrier frequencies is greater, a carrier system using these frequencies needs repeaters spaced more closely than a system using lower frequencies. Consideration must also be given to equalizing, or compensating for, variations in line loss across the frequency band of the carrier system.

Another important item is noise on line pairs at carrier frequencies, primarily from atmospheric static. So that this noise will not interfere with transmission over the line, the transmitted speech and signaling energy must be appreciably greater than the noise. Since, in passing over a line, the transmitted energy is attenuated, or reduced in magnitude, it must be reamplified to keep it above the normal noise level.

Still another important property of the line is coupling between pairs, resulting in a small amount of the energy from one pair appearing as crosstalk on other pairs on the line. The amount of this coupling can be fairly well controlled by transposing the wires of the pairs, together with reasonable care in line construction and maintenance. In general, "crosstalk" coupling becomes greater as the frequency is raised, and more complex transposition arrangements are required for these higher frequencies. A practical device for reducing crosstalk is the compandor,* such as has been used with other systems in the past. For example, the compandor used in Type-N carrier reduces crosstalk by somewhat over 20 db. This advantage permits crosstalk coupling between pairs to be appreciably higher than for a system not using compandors.

A compandor, in addition to reducing crosstalk, effectively reduces noise introduced in the circuit and by about the same amount. Lines designed to meet relatively lenient crosstalk requirements are also found to be comparatively susceptible to noise and the compandor is expected to more than compensate for this increased noise susceptibility. Therefore, using a compandor permits lower transmitting levels, and reduces the effects of noise and cross-modulation produced in the carrier equipment. This in turn permits more lenient requirements for the carrier equipment components — the filters, as one example.

Since it was evident that one of the important uses for the new carrier system would be on pairs equipped with Type-C carrier, consideration was given to the requirements for such operation. There are many lines now using Type-C carrier, with frequencies up to about 30 kc, that are transposed to satisfactorily control crosstalk coupling over this range. Investigation of crosstalk on such lines showed that, although crosstalk coupling increases rapidly at higher frequencies, it does not increase by more than the expected compandor advantage for frequencies up to about 70 or 80 kc. Therefore, providing that compandors be used, the frequency range between 30 and 80 kc, adequate for at least four message channels, could be used for carrier transmission on these lines as they are now. Without compandors, extensive retransposing would be required, and this would by far exceed the cost of compandors.

A further important consideration for the new carrier system was the number of channels it should provide. In establishing this objective, the following facts were considered:

(1) It should be possible to apply the new carrier system in small groups of channels. Often only one or two channels at any one time will be needed to supply additional circuit requirements.

(2) Lines on which the new carrier system might be used may or may not already be using Type-C carrier. C carrier on some pairs of a line would necessitate a coordinating system—that is, one using approximately the same frequency ranges for equivalent directions of transmission. That portion of the new system operating in this range must therefore be limited to about four message channels. Since it was anticipated that compandors

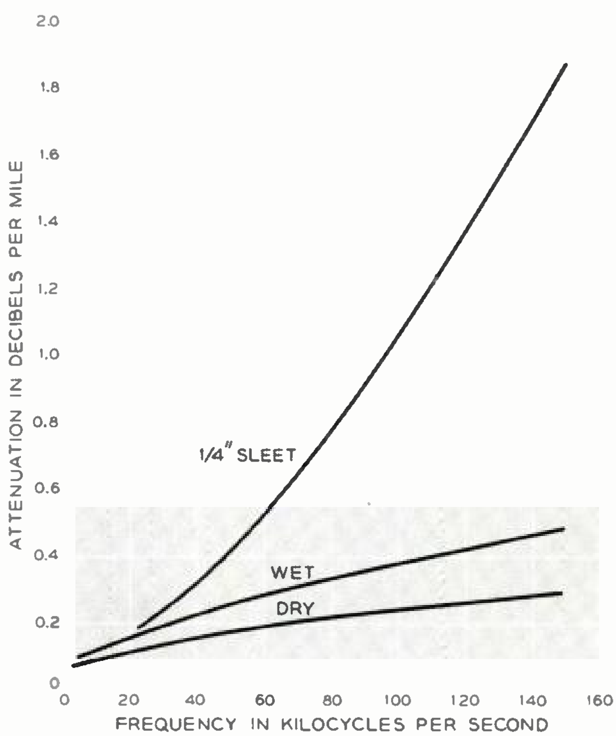


Fig. 2 — Attenuation versus frequency for an open-wire line transposed for frequencies up to 150 kc.

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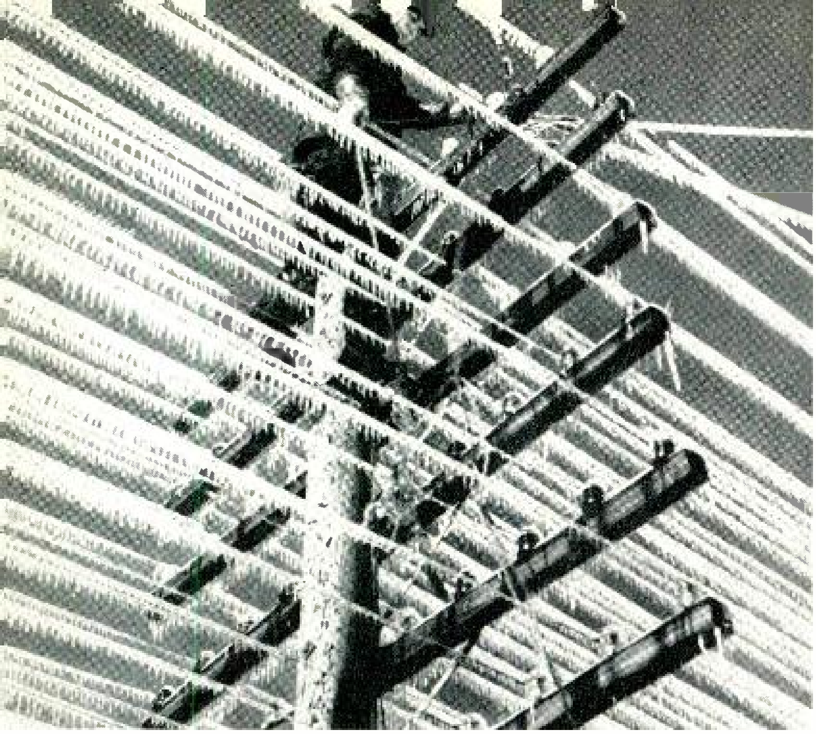

Fig. 3 — One of the problems to be considered in an open-wire carrier system is attenuation resulting from sleet on the wires. Here a lineman corrects a trouble arising from sleet conditions.

would be used, this part of the new system should be capable of operating on a line transposed for voice frequency only.

(3) Since the attenuation of a line increases with frequency, a system using the higher carrier frequencies would require more closely spaced repeaters than a lower frequency system. This factor is important for lines on which sleet may form.

(4) The availability of several similar systems, using progressively higher frequencies, would permit the initial use of only the lower frequency systems. These would require the least line modifications and the least number of repeaters between terminals. Later, if additional carrier circuits were required, they could be supplied by installing higher frequency systems on suitably retransposed pairs. These facts led to a decision to group four channels together to form a system, and to provide as many such systems as feasible to utilize the frequency space up to about 150 kc.

Another major problem, encountered at repeater points, is coupling from the repeater output of one system to the repeater input of another system. This particular crosstalk path is completed through other pairs of wires on the line that by-pass the repeater point. Figure 4 shows the manner in which these crosstalk currents flow; the crosstalk path may be blocked by placing filters or other suppression devices in the non-repeatered pairs as indicated. This practice is followed at all J-carrier repeater stations and requires a great deal of suppression equipment, especially if there are many pairs on the line involved.

A solution to this general problem involves the technique of "frequency frogging."* In existing types of open-wire systems, one group of frequencies is used for transmission in one direction and another group is used in the opposite direction. A frequency-frogging repeater, however, receives one group and translates it to the other group before retransmission. The result is that a transmitted signal that finds a crosstalk path to the input of a repeater on an adjacent pair can do no harm, since the frequencies received by this repeater are in another band. In effect, frequency frogging results in a repeater receiving only one frequency group from both directions and retransmitting another group in the other frequency range in both directions. This technique results in a considerable saving in the suppression equipment required on all non-carrier pairs.

Another advantage of frequency frogging is self-equalization. Figure 5 shows the successive attenuation and reamplification of a group of channels over two equal repeater sections. Channels at each end of the frequency group are shown by heavy lines so that their positions may be fol-

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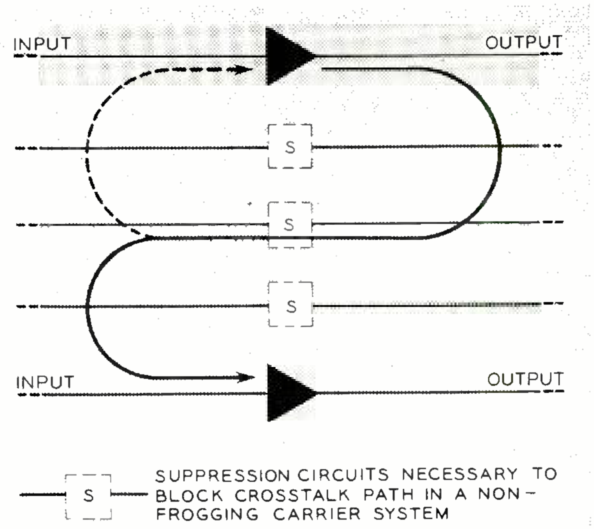


Fig. 4 — Crosstalk coupling from the output of a repeater may occur through non-repeatered pairs on the same line. Expensive suppression devices may be eliminated if frequency frogging is used.

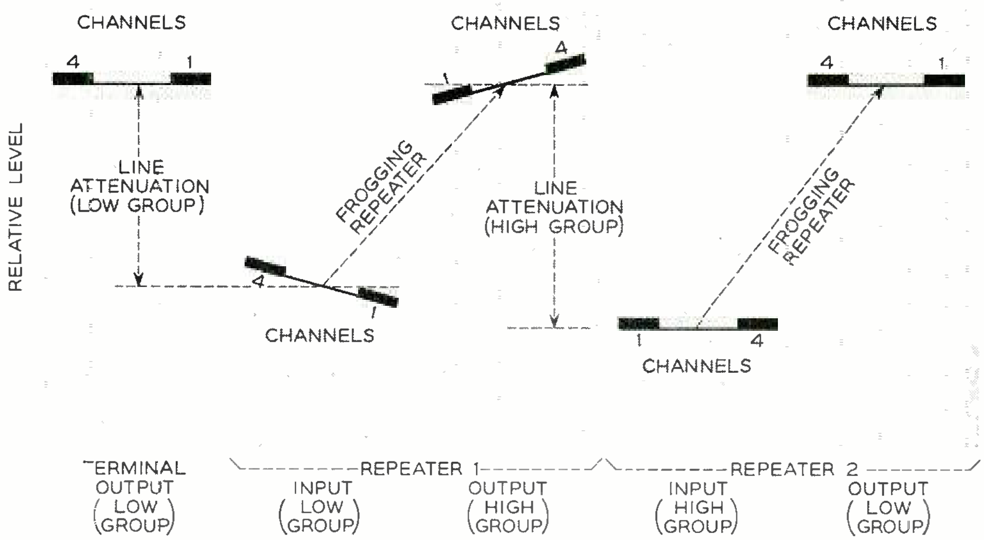


Fig. 5—Frequency frogging at repeaters provides self-equalization of line slope.

lowed. The levels across the group are equal at the output of the transmitting terminal. After transmission over a section of line, the sloping frequency characteristic results from the difference in attenuation with frequency in the line section. A frogging repeater shifts, inverts, and amplifies the group. At the end of the second line section, the relative attenuation of the different frequencies again gives the same level across the band. After passing through the next frogging repeater, the levels and frequencies would be restored to the initial condition. The inversion of the group in successive repeater sections minimizes the need for equalization, since the slope introduced by one repeater section will be effectively canceled by the reverse slope in the next repeater section.

Although the projected carrier system was intended primarily for open wire, transmission through short lengths of cable was also necessary. Open-wire lines usually terminate at the edge of town, and from this point to the office all circuits are in cable. Transmission characteristics of open-wire and cable pairs differ appreciably, and special treatment of the circuits is necessary at the open wire-to-cable junction.

Cable pairs at present used for the lower frequency range are usually loaded to simulate the impedance of open-wire pairs; it is practical to make this loading effective for transmission up to 30 kc. For the higher frequencies, cable pairs are nonloaded and a satisfactory impedance match with open wire in this range may be obtained by a fixed-ratio transformer. This requires the separation of high and low frequency ranges with a high pass-low pass filter arrangement, and the use of two cable pairs into the office. Since separation of the frequency groups is necessary before these various groups are repeatered or terminated, the filter set required for this purpose could be used at the open wire junction to perform this function there. Its special requirement was that it be capable of being used outdoors, probably mounted on the crossarm of a terminal pole.

The basic objective for any carrier system is its transmission performance; that is, its ability to satisfactorily transmit voice and signaling between terminals. Further requirements are that when it is used as a link in tandem with other facilities, its addition should not degrade the performance of the over-all circuit. Thus, the bandwidth of a carrier channel, as well as the frequency characteristic across the channel, should be similar to that of existing toll circuits. Also, the noise and crosstalk contribution must be held to such values that they will not add appreciably to other sources of noise and crosstalk on the over-all circuit. However, since this contemplated new carrier system was intended only for short-haul use, the transmission requirements were appreciably easier to meet than they would have been for a long-haul carrier system. In particular, this would permit greater magnitudes of noise and crosstalk per mile of line, and somewhat less precision in repeaters, since relatively few would be used.

Signaling information, as well as voice currents, must be transmitted over each carrier telephone channel, and is expected to be of increasing importance as the nationwide dialing plan grows. Particularly for small offices, a separate signaling channel associated with each message channel would provide maximum flexibility and eliminate the relatively large amount of equipment now required to transmit signals over the voice channel. A narrow signaling channel might be located adjacent to the message channel and the total energy, consisting of message and signaling information, could be transmitted over a single composite channel. If the signaling channel were at a frequency just above the normal voice frequency range, signaling and message information could be readily separated by filters. The addition of such a narrow-band signaling channel would use only a small amount of frequency space of the carrier channel.

To summarize, it was concluded that the objectives of this contemplated carrier system be as follows:

1. It should be designed to operate on open-wire lines not now using carrier, or using carrier to only a limited extent. A minimum of line rearrangement and a minimum of auxiliary equipment should be required. To do this, it was recommended that: (a) compandors be used on all channels to reduce the effects of noise and crosstalk, and to appreciably reduce the line rearrangement required; (b) frequency frogging be used at repeater points to eliminate crosstalk suppression devices on all noncarrier pairs; and (c) adequate regulation be provided to compensate for changes of line attenuation with weather conditions, including sleet.

2. The system should consist of groups of only a few channels, (a) a low frequency group to coordinate with Type-C carrier, using approximately the same frequency range; and (b) additional systems of four channels each using progressively higher frequencies up to about 150 kc.

3. Signaling incorporated in the system should be out-of-band; that is, should use frequencies outside the message channel. It should be capable of handling normal signaling and supervisory functions as well as transmitting dialing pulses.

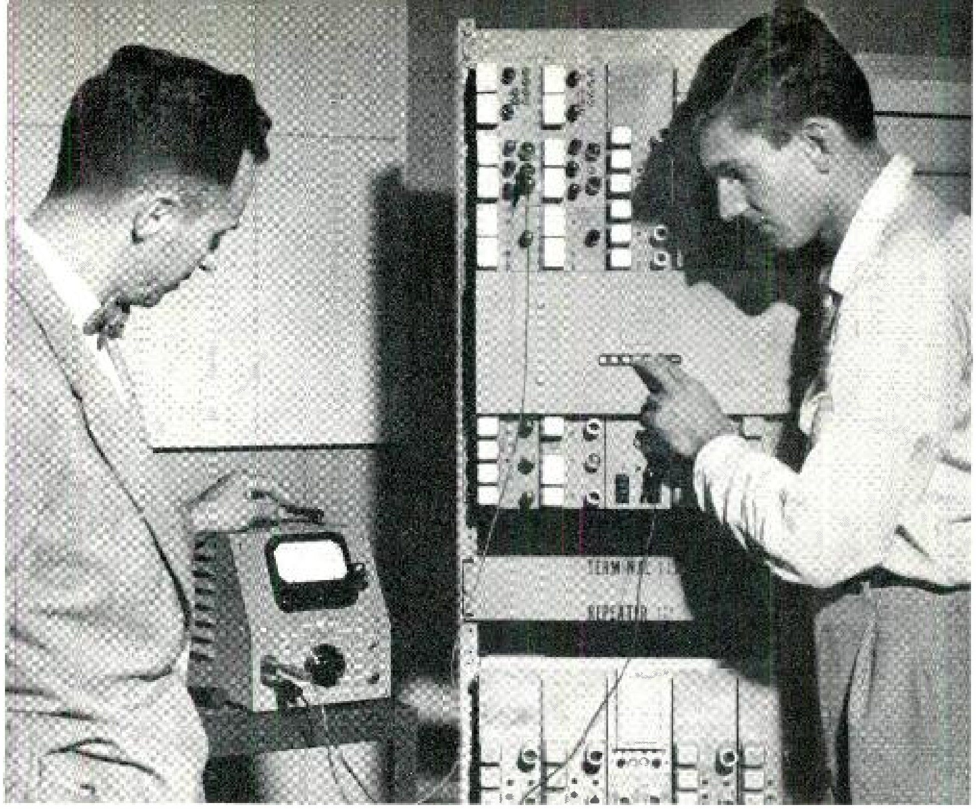
4. Cost of the system should be low enough to make it economical for application over short distances, in the order of twenty miles.

5. In the interest of economy, the carrier equipment should be kept physically small so that a minimum of office space will be required.

THE AUTHOR

Barrett C. Griffith received the Ba.Sc. degree from the University of Toronto in 1925, and the M.S. and D.Sc. degrees from Massachusetts Institute of Technology in 1926 and 1928, respectively. He joined the American Telephone and Telegraph Company in 1928, working on inductive coordination studies. In 1936, two years after his group transferred to the Laboratories, he was assigned to the development of the J carrier. Since 1939 he has been a member of transmission engineering, associated with noise and crosstalk studies and, more recently, with the development of carrier systems. He is currently devoting his time to the rural customer carrier system.

Henry Kahl joined the Laboratories in 1928 with a B.S. degree in E.E. from the State College of Washington. He was first engaged in fundamental studies of noise and its effects and the design of equipment for noise and transmission studies. In 1938 he transferred to a group concerned with problems relating to open-wire crosstalk, transferring again in World War II to work on military projects. Following the war he worked on negative impedance repeaters and recently turned his attention again to open-wire carrier systems.



The author (left) and A. G. Schuh operate the alarm circuit test on a Type-O terminal in the laboratory. An assembly of two repeaters fills the bay's lower part.

Type-O Carrier: System Description

R. D. FRACASSI *Transmission Systems Development I*

When it became evident that additional circuits would be needed for short-haul traffic in areas served by open-wire lines, careful studies were made of the existing situation and systems objectives were set forth. In meeting these objectives, a number of new features that are unique in carrier telephone service were incorporated in the design. Also, several design features of Type-N carrier were utilized. The result is an efficient, yet inexpensive, carrier system that meets the demand for more circuits without the need for stringing new wire.

Continually increasing demands for additional circuits on short-haul open-wire lines led to the development of Type-O carrier. The requirements for such a carrier system were studied and system objectives were set forth, together with certain recommendations as to how those objectives might be achieved.* The next step was to consider existing carrier systems as well as new ideas, to decide just how the objectives might best be met.

Some of the objectives were: the use of compandors to ease line crosstalk and filter requirements, the use of frequency-frogging at repeaters, wide-range regulation to compensate for large line loss changes caused by rain and sleet, repeaters small enough for pole mounting, and coordination with existing low-frequency systems. Several of these objectives were similar to those met in the design of the Type-N carrier system for cables, and it was decided to take advantage of the Type-N design features where possible. It was further decided that, while most of the design problems of Type-O were different from those of Type-N, the development approach of Type-O would be patterned after the Type-N design and thus make Type-O a companion system. This is most obvious in the equipment aspects of the two systems, where miniaturized components and plug-in units are used.

One of the first design problems to be settled was

* See page 209.

the type of transmission to be employed — double sideband or single sideband. Double sideband transmission, as employed in Type-N, offered the attractive advantages of simpler filter designs. However, double sideband transmission is wasteful of frequency spectrum. The top frequency limitation of open-wire lines is fixed by problems involving radiation, coupling between pairs, and large variations in loss caused by weather conditions. This sets the top frequency at 150-160 kc for Type-O, in contrast to about 260 kc used by Type-N on cables. It was therefore decided that Type-O should be a single sideband system, to provide a sufficiently large number of channels.

With the decision to use single sideband transmission, as in most other Bell carrier systems, the grouping of channels remained to be determined, to round out the development approach. It was finally decided that Type-O should consist of four separate systems of four channels each. A full complement of Type-O consists of sixteen two-way channels. Instead of being called the Type-O carrier system, it should more accurately be called the Type-O carrier *systems*. These four systems, then, were given designations OA, OB, OC, and OD, in ascending order of frequency. Figure 1 shows the line frequency allocations of the four systems. The high and low group arrangements employed are used for the two directions of each four-channel system.

A separation of 4 kc is provided between the groups to permit the use of selective group filters

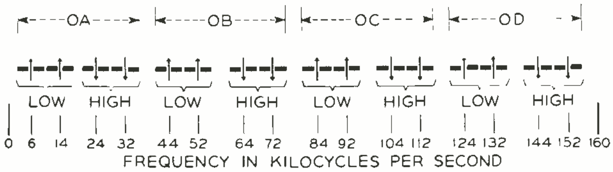


Fig. 1 — Frequency allocations of the four systems of Type-O carrier.

of practical design. For OA, it was possible to reduce this "cut-apart" region to 2 kc because of the lower frequencies involved. Line frequencies below 2 kc, not used by Type-O, are available for voice-frequency telegraph or similar services adaptable to such a limited frequency range.

This four-channel grouping of the Type-O equipment is of considerable advantage on routes where circuit growth is slow. Because the four systems may be "stacked" one above the other, frequency-wise, they may be added on a pair as the demand

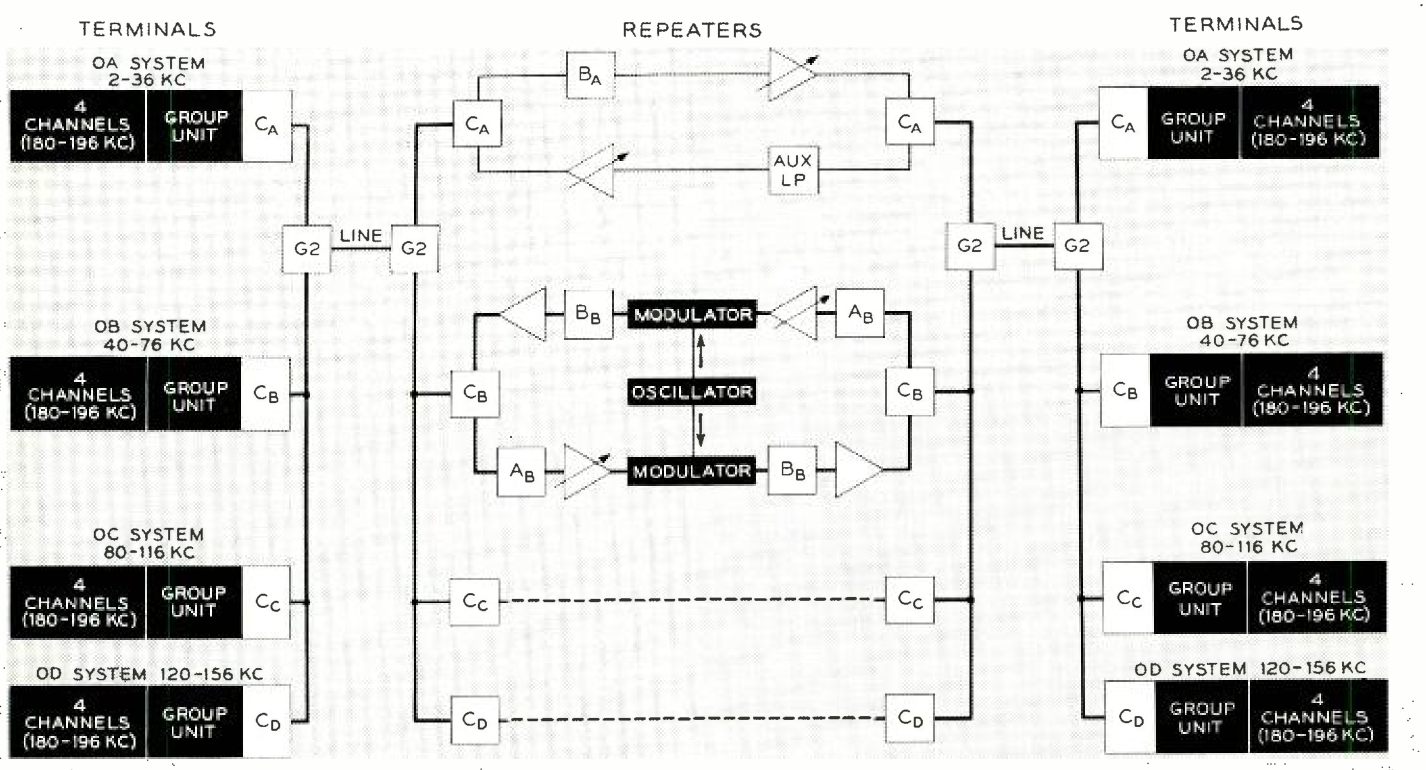


Fig. 2 — A complete Type-O carrier layout. Line filters G2 separate type OA from the other three systems.

increases. The four-channel grouping is also desirable where line facilities are not transposed for operation at the higher frequencies, and therefore can accommodate only a restricted number of channels.

Figure 2 shows a complete Type-O carrier layout, made up of the four systems OA, OB, OC, and OD. Transmission for both directions for all four systems is furnished by a single pair of wires. Directional filters labeled CA, CB, CC, and CD, provide the necessary frequency selection for two-wire operation according to the modulation plan that is shown in Figure 4.

The system features of Type-O carrier can best be discussed by starting at a terminal. Figure 5 is a block diagram of an OB terminal; this is identical with terminals of the OC and OD systems except for differences associated with line frequency allocations. An OA system terminal has additional differences in group circuits.

Since the use of compandors in the channel circuits was suggested in the system objectives, and since those used in Type-N* proved satisfactory, it was decided to use the same compandors in Type-O, virtually unchanged. This also permitted the use of the same 3,700-cycle signaling circuits, since they were included in the expandor unit, a part of the compandor. The original carrier frequency subassembly of Type-N was replaced by a similar one for Type-O, incorporating the necessary filters and other components.

The carrier frequency channel circuits of Type-O employ a "twin-channel" allocation similar to arrangements used in the past in overseas radio. In this arrangement, one carrier is made to serve two separate channels. A "twin-channel" unit, containing a transmitting oscillator and a receiving regulating amplifier, is common to *two* separate channels. Ordinarily, in single sideband transmission, each message channel has its own carrier associated with it and it alone. In Type-O carrier, one message channel is modulated onto a carrier supplied by the "twin-channel" unit, and one sideband is removed. At the same time, another message channel is modulated onto the same carrier frequency, supplied by the same "twin-channel" unit, and the opposite sideband removed. If the first channel has the lower sideband removed, the second channel has the upper sideband removed. The carrier frequency is completely removed from both channels during modulation, and is then reinserted in a

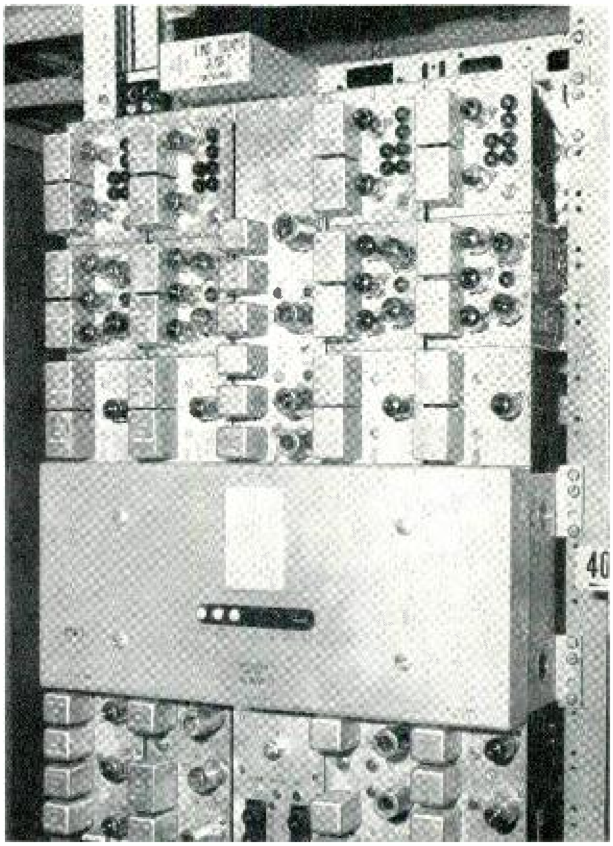


Fig. 3 — A completely assembled Type-O four-channel terminal.

combining multiple at a predetermined amplitude. From this point on, a single carrier is associated with two different message channels, as shown in Figures 1 and 4.

The "twin-channel" arrangement makes use of only two carrier frequencies for the four channels – 184 and 192 kc. The modulation plan provides that, if the transmitting side of channel 1 uses the lower sideband of 184 kc, or 180 to 184 kc, then the receiving side uses the upper sideband of 192 kc, or 192 to 196 kc. The two filter circuits providing these pass bands are contained in a single plug-in unit, called a channel band filter. The assignment for channel 4 makes use of the inverse arrangement – the transmitting side passes 192-196 kc and the receiving side 180-184 kc. It is obvious then, that the same code of channel band filter may be used in both channels by proper orientation in its plug-in socket. In a similar way, channels 2 and 3 make use of a filter code providing pass-bands of 184-188 kc and 188-192 kc. This feature of the modulation plan provides equipment economies in that four channel band filters involving only two codes are sufficient for four channels.

* RECORD, *November*, 1953, *page* 450.

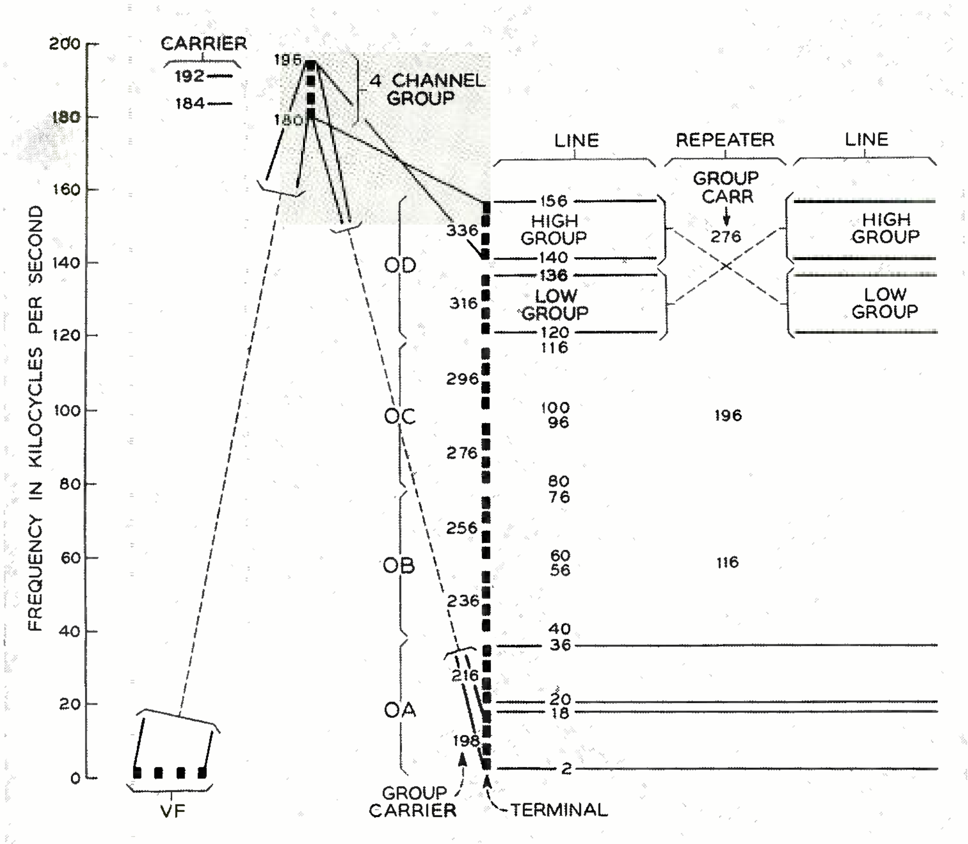


Fig. 4 — The modulation plan of Type-O uses only two carrier frequencies for four channels. The carriers with their sidebands are modulated to their proper line frequencies by group carriers.

Group transmitting circuits convert this four-channel band of frequencies (180-196 kc) to the proper frequency band for transmission over the line. For OB low-group transmission, a carrier frequency of 236 kc is used for modulation and the four-channel band is translated to 40-56 kc. In the case cited, the channel 1 band of 180-184 kc becomes 52-56 kc on the line. In the receiving direction, incoming frequencies cover the high-group band of 60-76 kc; a carrier frequency of 256 kc is used for demodulation in the group receiving circuit. Here, channel 1 line frequencies of 60-64 kc are converted to 192-196 kc, the proper allocation for selection by the receiving channel band filter. Channel carriers are adjusted to +6 dbm* at the transmitting group output where the message sideband levels are 0 db. The 3,700-cycle signaling tone of each channel, located 3,700 cycles away from the carrier, is 0 dbm at this point.

One of the system objectives was to provide wide-range regulation to compensate for variations in line loss caused by changing weather conditions. The group receiving circuit contains a regulating amplifier which maintains a nearly constant output with line loss changes of about 0 to 40 db. The "twin-channel" regulators are particularly effective as a supplement to group receiving regulators under sleet conditions. Over-all system performance is within tolerable limits for line losses up to 50 db, the engineering limit corresponding to conditions with one-quarter-inch radial thickness of ice on line wires.

In accordance with design objectives for Type-O, line-connecting circuits treat the OA system on a different basis from OB, OC, and OD. The line frequency allocation for an OA system is such as to require loaded entrance-cable pairs as are used in other low-frequency carrier systems. The other three Type-O systems are designed to work into non-loaded entrance cable and therefore must be separated from the OA system. The directional filters for OB, OC, and OD are arranged to work in parallel and are separated from the OA directional filter by a line filter. When entrance cable is involved in the circuit, the line filter, labeled G2 in Figure 2, is located at the junction of open wire and cable. The line filter contains a low-pass circuit for the OA entrance cable pair, and a high-pass circuit for the other systems.

Type-O line frequency allocations are such that

* Decibels above one milliwatt.

an OA system may in many cases be used on existing lines transposed for voice frequencies, without transposition alterations. OA system frequency allocations have been assigned to coordinate with Type-C carrier when Type-C is present on other pairs of the same line. The OB system, developed first because of its immediate usefulness, may be used above a Type-C system without change in line transposition. The higher frequency systems, OC and OD, may be used on a few existing lines transposed for Type-C but will, in general, require a new transposition design developed specifically for Type-O.

Frequency-frogging,* as was suggested in the system objectives, reduces interaction crosstalk and eliminates the need of equalization for "slope" in the line loss characteristic. Frequency-frogging is employed in the repeaters of the OB, OC, and OD systems. It is not used in OA because of coordination with Type-C. Conversion of a four-channel frequency band from high group to low group, or vice versa, in passing through a repeater is accomplished by the use of a modulator at a low level point ahead of the repeater amplifier. As illustrated in the modulation chart of Figure 4, this process produces a frequency inversion as well as an interchange between the two groups involved. For example, in the illustrated case of the OD system, the input frequency band of 140 to 156 kc is shifted to a band of 136 to 120 kc, respectively, by the use of a modulator carrier supply of 276 kc.

A completely assembled Type-O four-channel terminal is illustrated in Figure 3. It features a die-cast terminal framework and a number of plug-in units. Across the top there are four channel units and a group receiving unit. Hanging from the lower shelf of the terminal mounting are two "twin-channel" units, a group transmitting unit and a group oscillator unit. The central lower unit is a plug-in fuse panel containing the power circuits associated with the terminal. The central part of the terminal mounting beneath the cover contains components associated with the alarm circuit.

An assembly of two repeaters may be seen in Figure 6. This includes a frame-work which mounts four plug-in repeater amplifiers and a plug-in central unit containing the oscillator circuits, fuses, alarm lamps, and other components. The two oscillator circuits are small plug-in units, to supply the carriers required for frequency-frogging.

* Record, *July*, 1952, *page* 277.

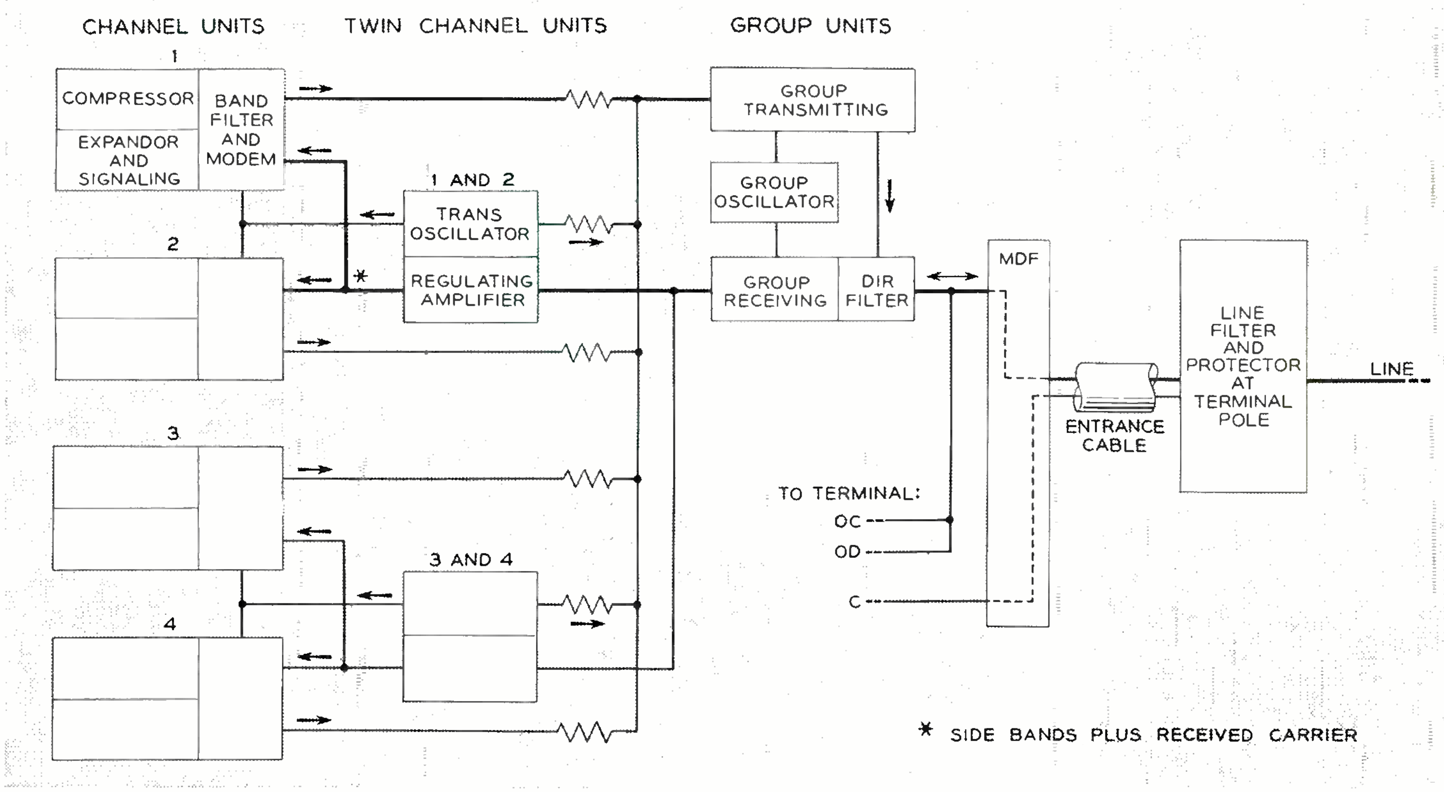


Fig. 5 — An OB terminal is illustrative of the general Type-O terminal arrangement.

Repeater assemblies may be installed in pole-mounted cabinets as in N1 carrier, with a power supply furnished by rectifiers operated on commercial ac supply. Separate cabinets are provided for the installation of batteries and charging equipment when a reserve supply is desired.

Each chassis of the Type-O plug-in units is die-cast, and a slide arrangement engages a guide section in the die-cast shelves of the frames. This aids in the proper alignment of jacks and plugs when inserting units in the frame and eliminates side-play when inserting and removing units, preventing interference between units. This feature made possible the elimination of protective covers on all units. The improved ventilation afforded by the lack of covers minimized the heat problem sufficiently to obviate the need of blowers for cooling at terminals.

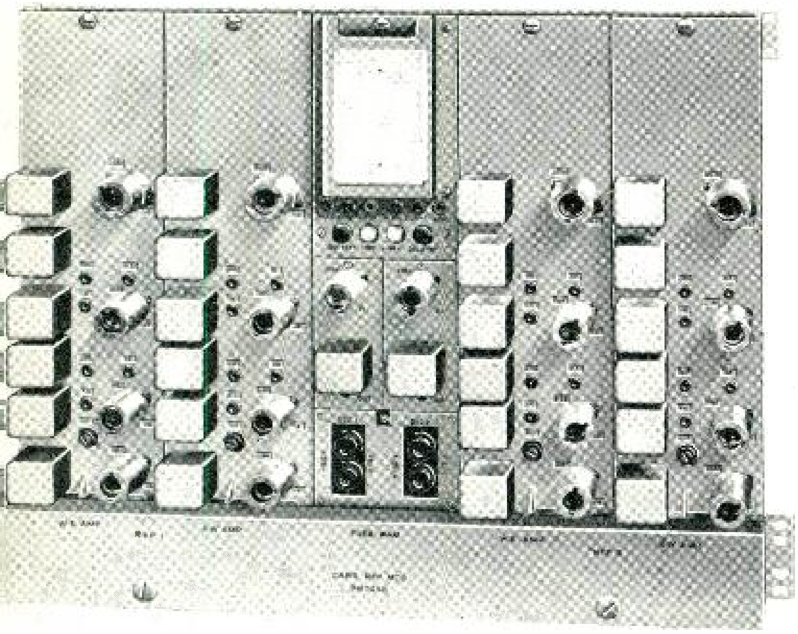


Fig. 6 — Two repeaters mount on one framework. The amplifier portions of OB, OC and OD repeaters are the same as used in group receiving units. Frequency-frogging carriers are furnished by the plug-in oscillators that are shown in the center.

Alarm circuits incorporated in terminals provide for visual and audible alarms in cases of line failure, 3,700-cycle oscillator failure, and blown fuses. The alarm for line failure ignores failures lasting less than 1.5 seconds, such as line shorts caused by swinging wires or swaying tree branches. When operated by a permanent failure, the alarm circuit completely disables the system at both terminals and makes the channels "busy" to avoid seizure of disabled circuits for placement of calls. Restoration of a terminal to normal is accomplished by depressing one of the control buttons on the front panel. When one of the terminals is located in an unattended office, a check may be made from the attended terminal to determine when transmission difficulties have cleared in both directions. This check and restoration of the system may be made at either terminal.

Line-up and maintenance operations of Type-O carrier are performed almost completely with a vacuum tube voltmeter and a small portable power meter used primarily at repeaters. Minor troubles, including tube failures, are corrected by operating personnel. Troubles of a more serious nature are handled by the use of spare plug-in units. The defective units may then be repaired at servicing centers where more test equipment is provided.

THE AUTHOR

R. D. Fracassi had been engaged in systems engineering in the American Telephone and Telegraph Company's Development and Research Department for four years when that department was transferred to the Laboratories in 1934. He became interested in thermistors and the stabilization of voice frequency cable pair losses as affected by temperature. He was also associated with the 15-kc program circuit. During World War II his assignments were related to radar development, covering tubes for radar use and allied apparatus. More recently he has been a member of Transmission Systems Development, concerned with Type N, Type O, and Type ON carrier systems. Mr. Fracassi received both his B.S. and M.S. degrees in E.E. from Massachusetts Institute of Technology in 1930.

A. H. Steunenberg aligning a multifrequency receiver.

A New Multifrequency Receiver

B. J. YOKELSON *Switching Systems Development*

With multifrequency equipment, operators can key a complete ten-digit number in about half the time required with a dial. To broaden the use of this improved method of sending telephone numbers, a new multifrequency receiver has been developed. This receiver is smaller, less expensive, and more efficient than an earlier version. It represents one more improvement that will aid in the development of nation-wide long-distance dialing.

Multifrequency pulsing is a form of voice-frequency alternating current signaling used to transmit digital information over telephone circuits. These signals are used to select appropriate switch paths in local, toll and tandem dial systems and thus set up telephone connections.

Customers calling numbers in some areas may have heard, after giving the number to the operator, a series of musical-sounding tones. These were the result of the operator keying multifrequency tones over the trunk to activate the automatic equipment at the other end and thus establish the connection to the called telephone.

Although the principles underlying multifrequency (MF) pulsing are now quite familiar in the telephone industry, it is well to review them briefly before describing the new receiver. The MF pulsing system employs six frequencies – 700, 900, 1100, 1300, 1500, and 1700 cycles – which, taken two at a time, provide fifteen combinations. Ten of these are used for the digits 0 to 9 inclusive, and two others for signals indicating the beginning of pulsing (KP) and the end of pulsing (ST). The remaining three possible combinations are available for future requirements. An operator in keying a number transmits two, and only two, simultaneous tones for each digit or control signal. These two tones, properly selected by the MF receiver, accurately identify the digit, which can then be used for further switching purposes.

This system of sending numbers over a line is particularly valuable in connection with the nation-wide dialing plan because of its relatively high speed and because the pulses, being in the voice range, can be passed readily over the same channel being set up to carry the subsequent telephone conversation. An operator keying multifrequency can send an average of two digits per second, which is about twice the speed obtainable with a dial.

The original multifrequency receiver was applied initially in the Bell System plant in 1942*, and is still quite serviceable. However, with the expansion of the toll plant and with the great emphasis on nation-wide toll dialing requiring large numbers of multifrequency receivers, the prime objective in the development of a new multifrequency-pulse receiver was low cost.

The new MF receiver has realized substantial savings in first cost, unit size, and operating power. The smaller size has also resulted in considerable

*Record, *December*, 1945, *page* 466.

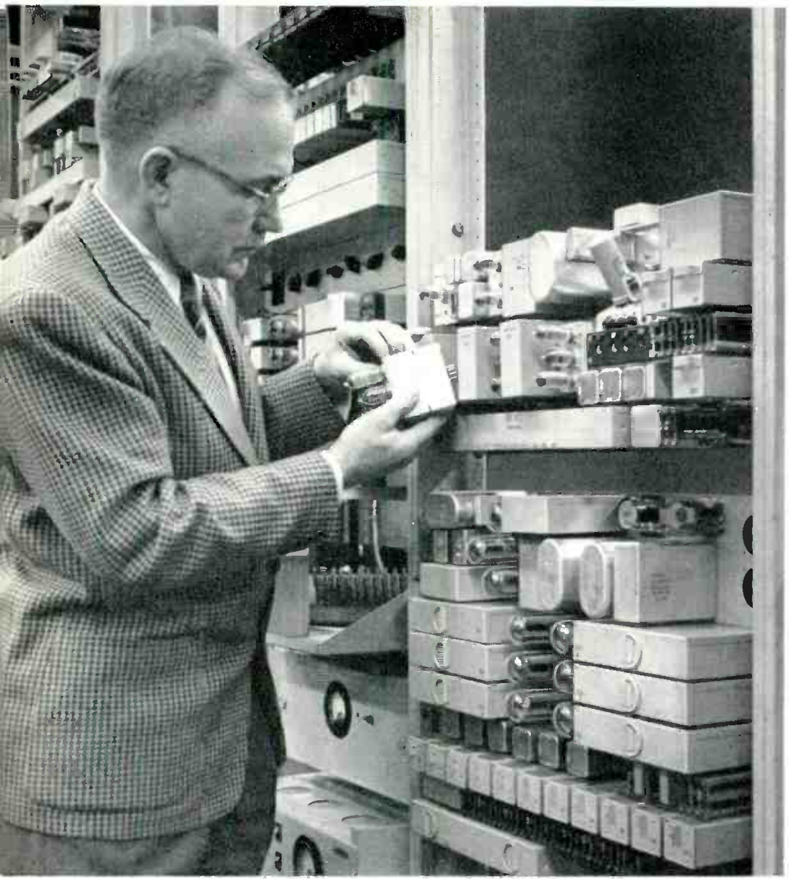


Fig. 1 — H. M. Pruden removing one of the twin-channel units, serving the 700-cycle and 900-cycle channels. The earlier multifrequency receiver is mounted below.

Fig. 2 — The author testing a new MF receiver with an experimental MF handset. The receiver is mounted in the Bell Laboratories wire spring No. 5 crossbar system.

conservation of space. In the No. 5 crossbar system, five receivers and registers can be mounted on a single frame, thus eliminating the additional frame and interbay wiring required for the registers when the older model receivers are used. In other systems, twelve of the new receivers can be mounted in the space used for six of the older type. Additional savings in power cost are effected by using alternating current as the normal supply for electron tube heaters. Arrangements are provided to transfer automatically to battery supply in case of ac power failure, without distortion of pulses that may be present at the time of transfer. The new receiver is equal or superior to the old one in all operating characteristics and is universally applicable to all uses of the present receiver without change in associated circuits. In Figure 1 a new receiver is mounted above the older model to show their physical differences.

The new receiver uses −48 volt signal battery and +130 volt plate battery and has thirteen miniature-sized electron tubes. Six of these, one in each receiving channel, are hot-cathode thyratrons. They are provided to operate flat-type relays in place of the more sensitive and expensive polar-type relays used in the earlier design. The polar-type relay, being a marginally operated device with critical mechanical and electrical adjustments, requires more frequent adjustment than the flat-type relay. Consequently, a saving in maintenance cost is effected in the new receiver.

In completing a connection in any dial telephone system, it must be kept in mind that at least two classes of signals are used – supervisory and pulsing. Supervisory signals include the connect and disconnect signals, and the "on" and "off" switchhook signals. The supervisory signals are used under certain circumstances for other purposes, such as controlling the start of pulsing and recalling an operator who may have been assisting in the establishment of the connection. The supervisory channel must be ready at once to transmit signals, and therefore the supervisory signaling equipment is provided individually to a trunk. On the other hand, pulsing signals are required only to set the switch paths and are sent toward the called end. Once the switch paths have been established, there is no longer any need for the pulsing equipment. Therefore, the pulsing means are detached from the connection at both ends of the circuit as soon as the connection is closed through the switching network. It is precisely for this reason that speed of signaling in the MF pulsing system is very important. As the time required for establishing a connection is reduced, the number of receivers required in a central office is also appreciably reduced.

In essence, the function of the MF receiver is merely to accept the voice-frequency alternating current signals pulsed over the trunk and to translate them into direct current signals suitable for operating an incoming register, which stores the information. This seemingly simple operation is complicated by imperfections in the transmission medium. Noise, always present in varying degrees, and echoes, which usually tend to lengthen the duration of the signal, may cause interference. The signaling frequencies may be attenuated by varying amounts in travelling from the sending to the receiving end of the system. Under extreme conditions, this difference in level between two frequencies representing a digit may be as much as 8.5 decibels. Similarly, transmission losses are different for different trunks and may range from 0 to 22 decibels. The multifrequency receiver has been designed to operate in a satisfactory manner under all of these varying conditions.

The MF receiver consists of a limiting amplifier, six channel filters terminated with rectifiers, gas tubes and channel relays, a signal-present bias control channel, and a few additional checking and control relays. The operation of this receiver can be divided into two main categories, a "pre-KP" and a "post-KP" condition. These terms derive from the fact that an operator preparing to pulse out a number first depresses a KP (Key Pulse) key to prepare the equipment to receive the digits. This KP signal consists of the 1100 cycle and 1700 cycle frequencies. Figure 3 is a simplified schematic of the pre-KP condition of the MF receiver.

In this pre-KP or idle condition, the input circuit is connected through the limiting amplifier to a group of six band-pass filters. These filters are tuned to the six frequencies used in the MF pulsing system. All filters are connected to rectifiers. The rectifiers associated with the 1100 cycle and 1700 cycle channels are terminated on the two grids of the

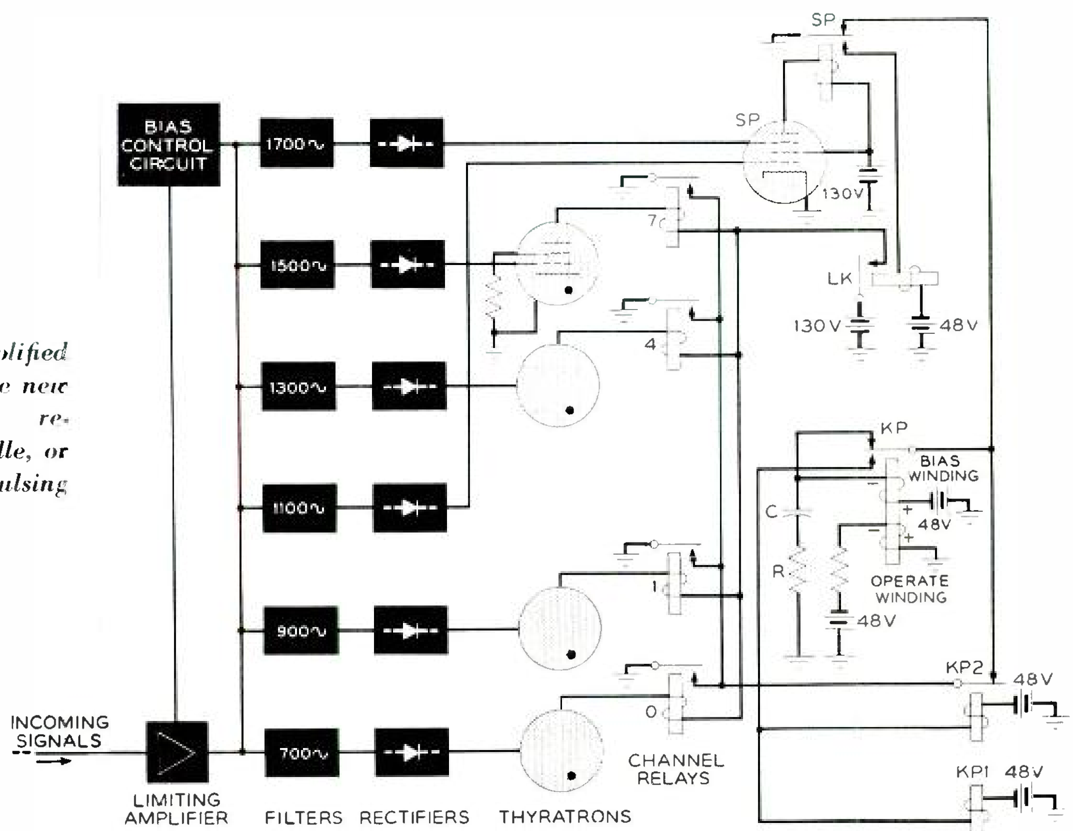


Fig. 3 — Simplified schematic of the new multifrequency receiver in the idle, or the pre-key pulsing condition.

SP (Signal Present) electron tube. This tube is arranged to operate the SP relay only when signals appear on both its grid and suppressor. The gas tubes terminating the 1100 and 1700 cycle channels through its back contact and the front contact of the KP relay to the windings of the KP1 and KP2 relays. These two relays operate and remain operated while the digits of the number are being registered.

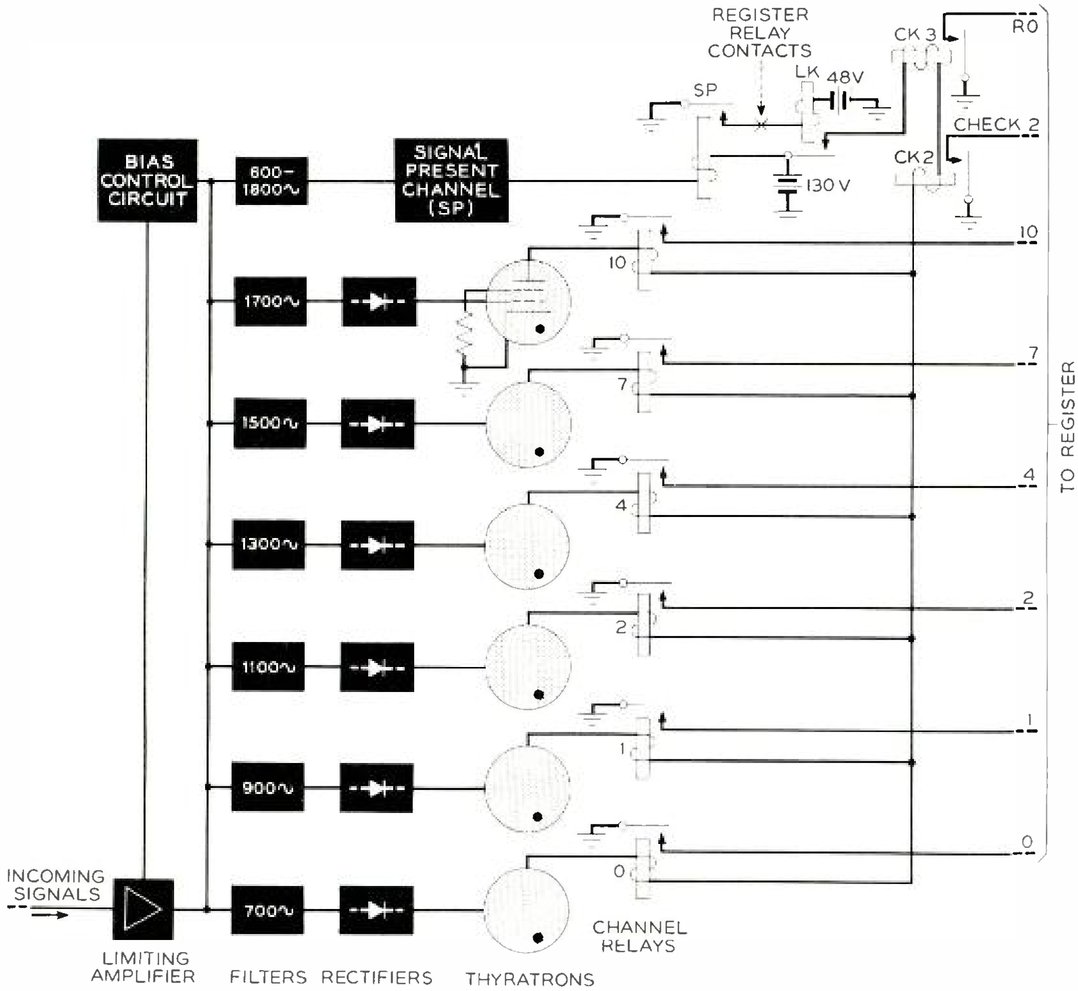


Fig. 4 — Simplified schematic of the new multifrequency receiver in the post-key pulsing condition, during which time MF digits are received.

are disabled, and the remaining channels are connected to their respective gas tubes.

When a key pulse signal is received, its two component signals appearing in the 1100 and 1700 cycle channels are rectified and applied to the grid and suppressor respectively of the SP tube to operate the SP relay. This relay in operating removes ground from the biasing winding of the KP relay, seen at the right in Figure 3. A resistance-capacitance timing circuit holds the KP relay non-operated for approximately 50 milliseconds. After this time interval, the current through the biasing winding is reduced sufficiently to permit the relay to operate on current through the operating winding. After the KP relay operates, removal of the incoming signal releases the SP relay to connect ground

During the reception of the key pulse signal, the circuit is arranged so that an interfering signal operating any of the other signaling channels will fire the corresponding gas tube and thereby operate the channel relay. Ground from the contact of an operated channel relay will disable the timing circuit and prevent relay KP from operating. Thus, no recognition takes place. This is done to prevent false operation of the KP relay on voice frequencies or noise that may be present on the trunk.

After the KP signal has been recognized, the KP1 and KP2 relays are left operated under control of battery from the associated sender or register. This is the post-KP or digit-receiving condition of the MF receiver, during which the operator keys the called number. A simplified schematic of this post key pulsing condition is shown in Figure 4.

In the post-KP condition all signaling channels are terminated with gas tubes, and the channel relays are arranged to signal the sender or register each time digits are received. At these times the signal appearing in the limiting amplifier is applied through a band-pass filter to the Signal-Present channel in the upper part of Figure 4. This SP channel introduces a delay to the signal and permits dissipation of transient voltages in the channel filters. Such transients normally occur at each application of signaling tones to the line before the SP relay operates, and would cause undesirable operation of channel relays. The SP relay in turn operates relay LK to supply plate battery to the gas tubes terminating the channels.

Since each signal normally consists of two tones, marginal relays in series with the channel relays are arranged so that the CK2 (Check 2) relay operates when two or more tones are received and does not operate when fewer tones are received. This relay in operating and releasing provides signals to advance the register after each digit. Relay CK3 (Check 3) in series with the battery supply to the gas tubes is arranged to operate if three or more gas tubes are fired. If relay CK3 operates because of an interfering signal, it connects ground to the RO (Reorder) lead to stop registration and causes a reorder signal to return to the operator. This signal indicates that the call has run into trouble and that it is necessary to start over again.

To provide greater margin of the signal over line noise, the 600-1800 cycles per second band-pass filter is provided in the Signal-Present channel. This filter limits the noise band and allows the new receiver to tolerate approximately 6 decibels more resistance noise than the older model.

The limiting amplifier does not function on the weaker signals and serves to provide an approximately constant output level when signals above a certain level are received. This prevents interference between adjacent channels. However, interfering third-order modulation products produced in this limiter circuit may cause false operation of the gas tubes. Therefore, to enable the channel gas tubes to function properly over a wide range of signal levels, the bias control circuit is provided. This circuit supplies a variable negative bias to the grids of the gas tubes so that these tubes become less sensitive in the presence of extremely strong signals.

An associated circuit provides the signals required for receiver adjustment. These signals are available at various convenient places in the receiver-bay line-ups. A receiver input jack is provided for introducing test signals, and other jacks are located at points where calibrating voltage readings are required.

The new MF receiver is in manufacture at the present time. It supersedes the older receiver in all new installations and additions to existing plant.

THE AUTHOR

BERNARD J. YOKELSON received the B.S. degree in E.E. from Columbia University in 1948 and immediately joined the Laboratories' Transmission Development Department. He was first concerned with the L1 coaxial cable system, later working with a group engaged in propagation studies on microwaves. In 1949 he was transferred to switching development and worked on a new multifrequency receiver. Two years later he was associated with military projects, including Nike, and since September, 1953, has been engaged in the design of electronic switching systems. Mr. Yokelson is an associate member of the A.I.E.E. and the I.R.E. and a member of Tau Beta Pi.

Contact Phenomena in Sealed Containers

R. H. GUMLEY *Switching Systems Development*

A typical 10,000 line dial telephone office uses about 60,000 telephone relays having a total of 300,000 contacts. Although the average relay will be required to operate only about ten million times in the life of the central office, many relays must operate up to a billion times or more. Electrical contact erosion seriously limits the life and reliability of such high usage relays. As a result of early probing tests of relays in sealed containers it was found that organic vapors could seriously shorten the life of an eroding contact. This discovery has led to a better understanding of contact erosion.

Although the contacts of a modern telephone relay are remarkably reliable, an attempt was made in the switching systems laboratory during World War II to achieve the ultimate in relay and contact reliability by operating relays in sealed containers. In this way it was hoped that the relays and contacts could be protected from the effects of dirt, humidity and other undesirable conditions that might otherwise contribute to deterioration of the relays in service. As sometimes happens in such experiments, the results were not as expected. The sealed environment reduced the failures traceable to atmospheric dust, but the electrical erosion of the contacts was found to be increased by as much as 100 times, resulting in an intolerable reduction in contact life. The enormous acceleration in the electrical erosion of contacts was a new phenomenon. The erosion of contacts has always been understood only in a very incomplete way, so that this experience opened up new fields for exploration that could lead to a better understanding of contact performance.

During the next few years, over fifty separate experiments were made to investigate the many factors that might influence the erosion of relay contacts in a sealed container. These tests included various contact metals, contact loads and contact protections under a number of different environments. Many of the tests were progressive in that

Above, the contacts of relays tested in sealed containers are here being adjusted by the author. The container with a glass front, used to seal the relays, is seen to the right removed from the unit.

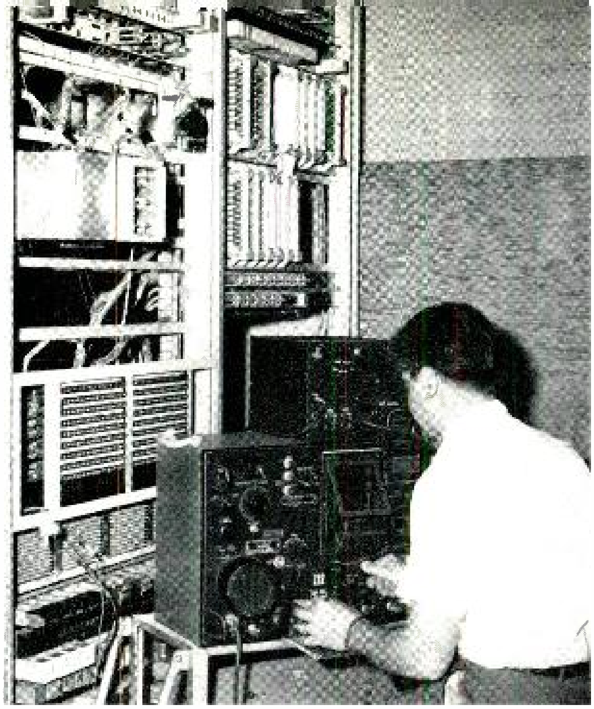


Fig. 1 — P. J. Cuffaro observing contact transient voltages by means of an oscilloscope. A camera is attached to this instrument to get photographs of the sort seen in Figure 7.

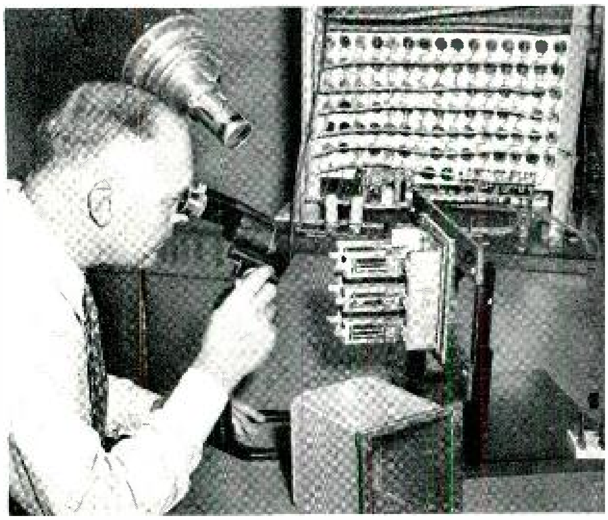


Fig. 2 — P. W. Swenson observing with a microscope the contact erosion of relays after being tested in a sealed container.

the results would raise new questions that could only be answered by further tests.

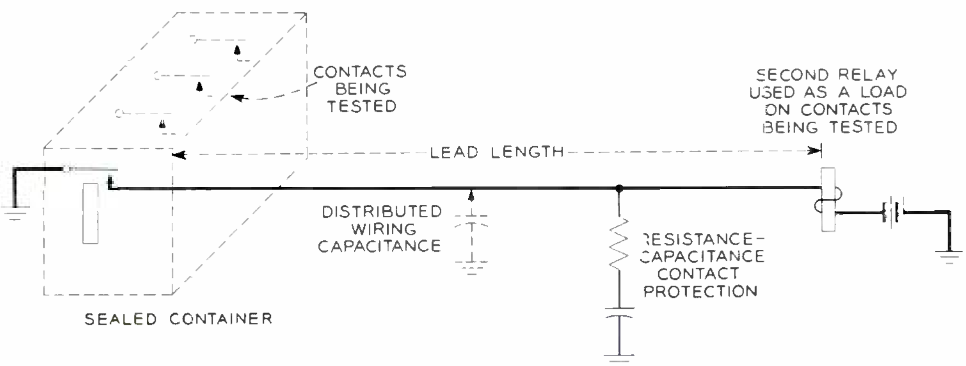
The sealed containers used in all these tests were large enough to mount six U-type relays. These containers were made from zinc-dipped steel except for the glass plate used on the front. The rear plate and the glass front were sealed to the cover with screws tightening a lead gasket. The seals of the containers were further insured by painting them with water-glass.

The six relays in the container were used to operate other relays mounted external to the container. The electrical circuit involved, with resistance-capacitance protection of the contacts, is indicated in Figure 3. All tests were made at relay operating rates of 7 per second continuously, 24 hours per day, in circuits arranged to stop if any contact failed to open or close electrically. The internal temperature of the containers assumed a stable operating temperature of about 100 degrees Fahrenheit during the tests. This temperature rise was the result of the power dissipated in the relays as they were pulsed.

It was believed from the beginning that the accelerated erosion was caused by vapors emitted from the organic materials used in the insulation of the U-type relay. Successive tests continually confirmed this belief. For example when activated charcoal was included in the container to absorb the organic vapors, the contact erosion was reduced toward the low figure expected for contacts performing in open air.

In another series of tests, certain of the organic materials were removed from the relays to determine which material was responsible for the high erosion. For one test, special relays were built without any organic insulation at all. These relays, shown in Figure 4, had glass spoolheads, glass insulators and glass insulated wire. The relays were baked to remove vapors and then carefully sealed in a container with clean air. These relays, with

Fig. 3 — Circuit arrangements for testing relay contacts in sealed containers.



half-ampere loads on the contacts, had a life of five billion operations. This is somewhat more than could be expected from relays operating in the open, but about 100 times as much as could be obtained from standard relays operating in sealed containers.

Other tests were made using non-inductive resistance loads to determine the effect on contact wear of the power dissipated in the load, of the voltage, and of length of leads to the load. The lead length is important in these tests, as indicated in Figure 3, because of the distributed capacitance to

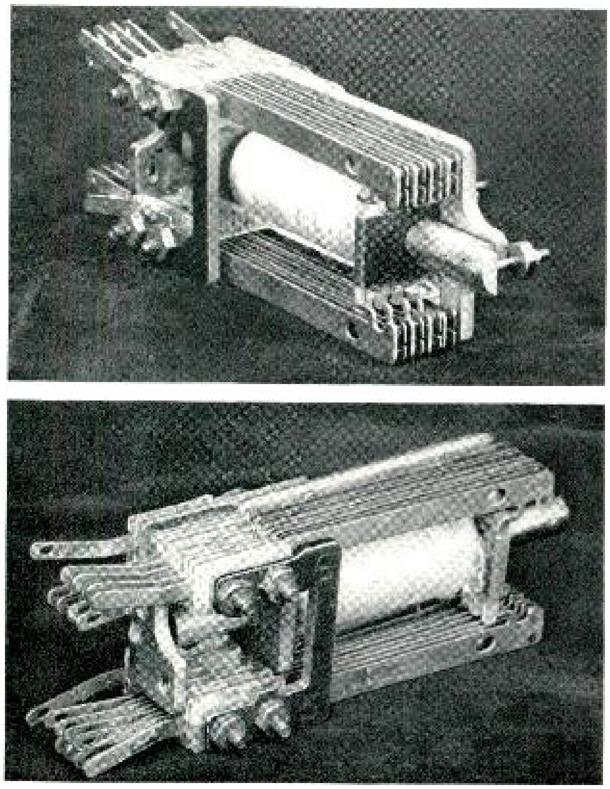


Fig. 4 — Two views of the special inorganic type of relay used to verify that organic vapors were the cause of much contact erosion.

ground. Figure 5 shows how the erosion was affected by circuit voltage and length of wire for a fixed contact current of 20 milliamperes. Figure 6 shows how the erosion was affected by circuit voltage and power for a fixed length of wire of 100 inches. The curves show that the voltage has a very marked effect, that the length of the line wire is significant, and that the power is the least important of the three parameters. These tests also showed that non-inductive contact loads result in the same rates of erosion as protected inductive loads under the same conditions.

During all these experiments the voltage transients occurring at the contacts were observed by means of an oscilloscope. Increased arcing of the contacts was always found to be associated with the sealed conditions that produced the high erosion. When the steady state contact current was high, in the order of 0.5 ampere or so, sustained arcs lasting up to 20 microseconds occurred on every make and break of a chattering closure of the contacts. In a chattering closure, the contacts close and bounce apart one or more times before final closure, and under certain conditions, as in Figure 7(a), arcs occur while the contacts are slightly separated. For comparison, the oscillogram of Figure 7(b) was taken prior to sealing the container and shows no sustained arcs.

It was found that the current had to be reduced below 0.1 ampere to eliminate the arcs. This was surprising because it was generally believed that palladium contacts would not arc if the contact current were maintained below about 0.7 ampere. Contacts that have had their arcing limits reduced in this way are termed activated contacts, since they have become good emitters of electrons and are therefore more easily subject to arcing.

However, even if the steady-state current in the contact is kept below 0.1 ampere to prevent these sustained 15-volt arcs, the erosion may not be greatly reduced. Although the sustained arcs disappear, the oscilloscope may show a phenomenon that has been dubbed "showering." This is illustrated in the oscillogram of Figure 7(c), where a 1,000-ohm resistance is being closed to a 50-volt battery. This effect is simply a train of transient arcs; each is initiated by the breakdown of the contact gap, sustained only by the discharge of the cable wire capacitance and extinguished by the failure of the load resistance and battery to supply a steady state current of the magnitude to sustain a 15-volt arc.

Of particular interest is the effect of the organic vapor in changing the type of contact erosion. For palladium contacts with protected loads and without vapor contamination, the erosion is small and takes the form of a crater in the positive contact and a buildup that fits the crater on the negative contact. However, with heavy vapor contamination as occurs in these sealed containers, the erosion is large and takes the form of a full area wear of the negative contact, leaving the positive contact virtually unaffected. In the latter case the erosion is always accompanied by a heavy deposit of black powder on both contacts, which on analysis proves to be carbon and finely divided palladium. Figures 8 and 9 show relay contact springs removed from

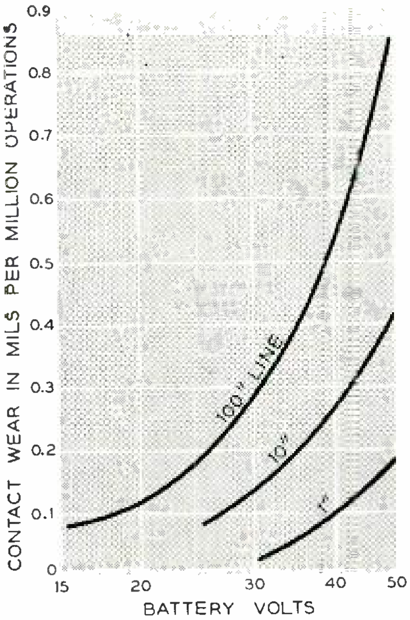
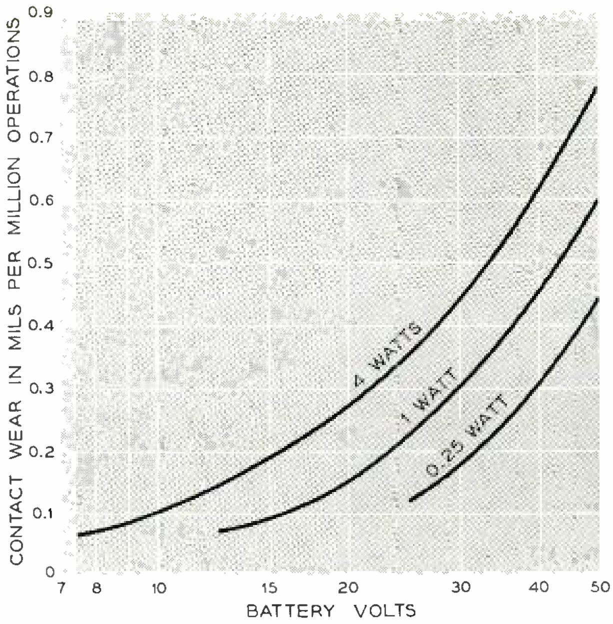


Fig. 5 — Left, curves illustrating the effect of circuit voltage and lead length on the erosion of relay contacts switching a constant current load of 20 milliamperes.

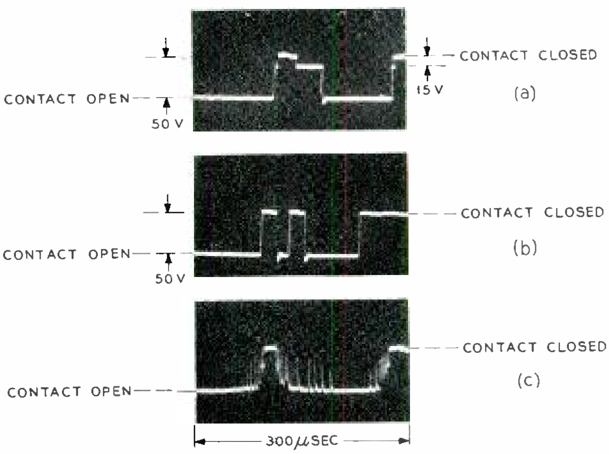
Fig. 6 — Right, curves illustrating the effect of circuit voltage and power on contact erosion for relays having a constant 100-inch lead length.



these sealed container tests. The black powder has been brushed away to show the contact erosion.

The effect of vapors on the erosion of silver contacts is less pronounced, being only two to three times greater than is experienced in open air. Silver also differs from palladium in that the erosion almost always takes the form of a large crater in the positive contact and a buildup on the negative contact.

Fig. 7 — (a) Activated palladium contact closing 0.5 ampere load, with chatter. Note arcs at 15 volts during the chatter interval before final closure, the second arc lasting about 30 microseconds. (b) The same palladium contact before becoming activated by organic vapors. Two chatter opens are seen, but no arcing occurs. (c) The activated contact of (a) with the load resistance increased to 1,000 ohms. Note the "showering."



Also, whereas the erosion of palladium in a sealed can results in a large net loss of contact metal, with silver the net loss appears to be very small. Just why silver acts differently from palladium is not completely understood. In fact, erosion of the positive contact, wherever it occurs, is as yet a poorly understood phenomenon.

For a while it appeared that the knowledge gained in these tests was mainly of academic interest. The contacts in central office installations had not indicated severe erosion except in scattered instances. However, in the postwar years, the faster No. 5 crossbar system taxed the contact capability of the relays by raising the current controlled by some contacts to as much as one-half ampere and by raising the required number of operations of some relays to as much as one billon in the life of the office.

Surveys made at the earliest No. 5 crossbar installations after several years of operation showed that the life of contacts switching one-half ampere loads would be less than the life of the office. A few further laboratory tests proved that the shortened life of contacts in the central offices was due to the same phenomena that shortened the life of contacts in sealed containers. This was the first substantial evidence that the phenomena of the sealed containers existed to a significant degree in field installations. This knowledge has played an important part in the design of new relays and enclosures for new relay switching systems.

About the time of the early work on sealed con-

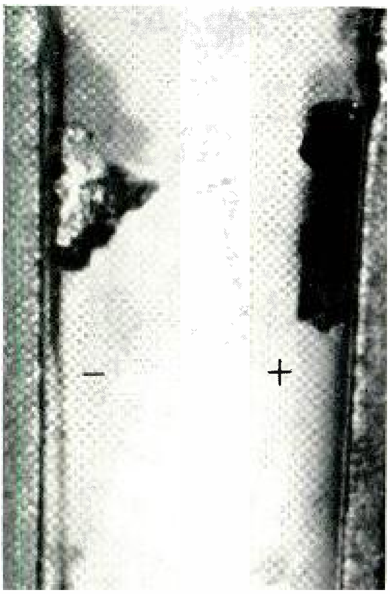


Fig. 8 — Left. A pair of contacts eroded after 286 million operations switching a one-half ampere load in a sealed container with inorganic relays.

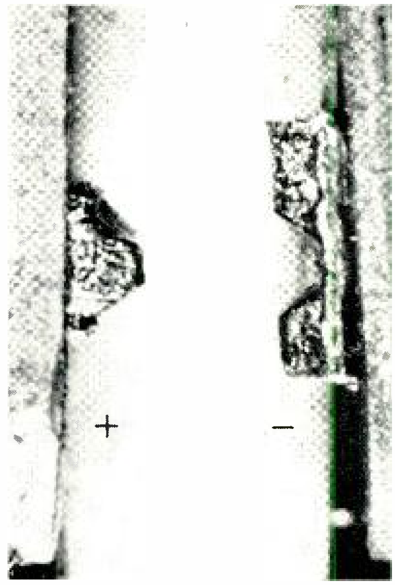


Fig. 9 — Right. A pair of contacts eroded after only 9 million operations switching a one-half ampere load in a sealed container with ordinary relays containing organic material.

tainers, an allied phenomenon appeared. It was noticed that contacts working in the open laboratory suddenly developed a greatly increased tendency to arc at the time the laboratory was painted — presumably from the vapors of the paint solvents. The investigations carried out by the Research Departments on organic vapor activation of precious metal contacts later showed that the minimum arc limit for a noble-metal contact was seriously reduced by the activating effect of organic vapors and that the increased arcing completely explained the greater erosion.

Since the early work on the sealed containers, much has been learned about relay contact performance in the presence of organic vapors. Relays and enclosures are now designed in the light of the new knowledge. But also important is the recognition of one more major variable which in the past has made contact performance somewhat difficult to predict.

THE AUTHOR

ROBERT H. GUMLEY, joined the Laboratories in 1930, and spent the next seven years on apparatus adjusting and wiring, including work on the No. 1 crossbar system. In 1937 he transferred to work on relay requirements and testing and the application of relays to circuits. During World War II he worked on the design and testing of operation flight trainers for the Navy. He has since been engaged in studies of relay performance and relay engineering. Currently he heads a group studying systems requirements and testing. Mr. Gumley received the B.E.E. degree from New York University in 1939.

Measuring Overhead Wire Clearances

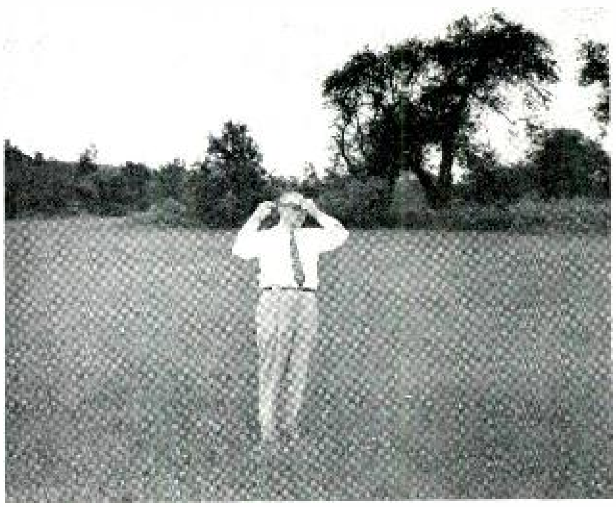


Fig. 1 — W. H. S. Youry sighting the wires overhead to determine vertical clearances.

"Stop, Look and Measure" might well be taken as a safety slogan by those in the outside telephone plant responsible for seeing that safe clearances are maintained between telephone wires and power lines. Normally, the telephone lines will be mounted below the power lines. Since increasingly higher transmission voltages are being encountered in power distribution systems, it is becoming more and more important that the Telephone Companies be provided with dependable facilities for quickly checking vertical clearances between these lines. In recognition of this need, a range finder has been standardized for use in the Bell System as an alternate to the clearance rod also used for this purpose.

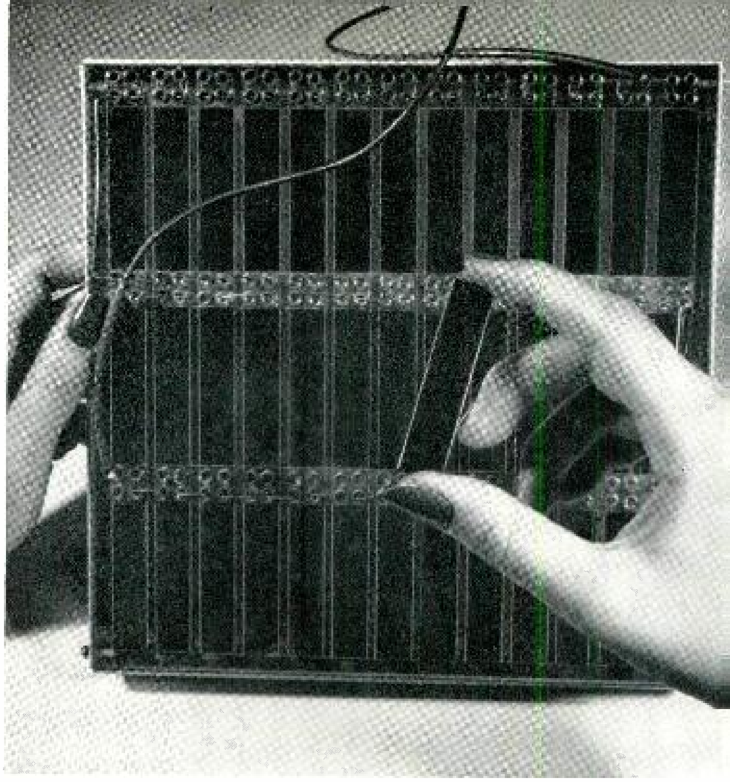
This finder, shown in Figure 2, is a modification of a commercial, metal-encased optical range finder, similar to those used on cameras, in which two contrasting images of the object sighted are employed to determine distance from the eye of the observer. The modification consists of the addition of a built-in erecting prism in front of the eye piece. This permits the observer to look horizontally while sighting overhead objects, and thus eliminates the uncomfortable procedure of tilting the head back and sighting in a vertical direction. The finder has a 6-inch base length between its sighting objectives for measuring distances from 8 feet to 100 feet. It is equipped with a neck cord at one end, and, with its leather carrying case, weighs approximately three-quarters of a pound.

When determining the vertical clearance between two overhead wires with this range finder, the observer stations himself directly beneath the wires, Figure 1, so that both may be seen at the point the clearance is desired. The range finder is held at eye level, and the small square field, seen when sighting the instrument, is centered on one of the wires. The dial is rotated until the two contrasting images of the wire in question are superimposed. The height of the wire above eye level is shown on the dial opposite the index mark. This distance plus the height of the observer's eye gives the height of the wire above ground level. Individual readings must be made for each wire, and their difference is the clearance between wires. Although an accuracy of 2 per cent at a distance of 30 to 40 feet is guaranteed by the manufacturer, it is desirable, in order to keep personal error to a minimum, to take the average of several readings.

W. H. S. Youry,
Outside Plant Development

Fig. 2 — Range finder used for measuring wire clearances.

The Bell Solar Battery



New silicon devices for use in communications, including the Bell Solar Battery—the first successful device to convert useful amounts of the sun's energy directly and efficiently into electricity—were demonstrated by Bell Telephone Laboratories late in April at the annual meeting of the National Academy of Sciences in Washington. A lightning protector was also demonstrated and a high-power rectifier, a silicon diode and a silicon transistor were exhibited.

All these devices resulted from a fundamental program at the Laboratories for studying silicon and its possible applications in modern electronics. Silicon is a semiconductor chemically related to germanium, the material used in most transistors, but it has a much greater electronic stability at higher temperatures than other semiconductors. The especially prepared silicon used in making the new devices is obtained originally from common sand, one of the world's most abundant materials.

In demonstrating the Bell Solar Battery, members of the Laboratories technical staff showed how the sun's rays could be used to power the transmission of voices over telephone wires. The battery—an amazingly simple looking apparatus made of strips of silicon—also used energy from the sun to power a transistor radio transmitter carrying both speech and music.

In its present experimental form, the Bell Solar Battery can achieve a six per cent efficiency in converting sunlight into electricity. This approaches the efficiency of steam and gasoline engines, in contrast with other photo-electric devices which have never achieved more than one per cent. With improved techniques, however, scientists and engineers who have been working on the project expect to increase this efficiency substantially—probably to ten per cent—and possibly even further. The theoretical limit of efficiency in conversion by this type of device is about twenty-two per cent. Nothing is consumed or destroyed in the energy conversion process and there are no moving parts, so theoretically, the device should last indefinitely. The fuel, of course, is free.

Work is still in the laboratory stage, but actual use of the Bell Solar Battery in the telephone business is a strong possibility. For example, these devices might be used as power supplies for low-power mobile equipment, or as sun-powered battery chargers which could be used at amplifier stations along a rural telephone system such as that now under trial at Americus, Georgia. This system, using Bell-invented transistors, points to greatly increased service on rural telephone lines without the addition of new wires.

Although the sun supplies over a thousand trillion (1,000,000,000,000,000) kilowatt hours of energy daily—comparable with all the reserves of coal, oil, natural gas and uranium found on earth—man has never been able to convert more than a small fraction of this energy directly to his use.

Developed by a three-member team of Bell Laboratories scientists—G. L. Pearson, C. S. Fuller and D. M. Chapin, physicist, chemist and electrical engineer, respectively—the experimental device uses strips of wafer-thin silicon about the size of common razor blades. Extremely sensitive to light, these strips can be electrically linked together to deliver power from the sun at the rate of fifty watts per square yard of surface.

Scientists have long sought a practical method of directly converting the energy of the sun to electricity. Until now the thermocouple and photoelectric cell have been limited by their low efficiency to the measurement of heat and light. For example, the thermocouple is used in industrial furnaces to measure temperature and in astronomy to measure the light from stars. A common use for the photoelectric cell is in photographers' exposure meters.

Among the other silicon devices being studied at Bell Laboratories is a lightning protector for telephone lines which would be more compact and easier to maintain than those now in use. Also under study is a power rectifier, which can convert very large amounts of alternating current to direct current. An important feature of these is that they can operate at much higher temperatures than other crystal rectifiers now in use. All these devices when applied in the Bell System, where ruggedness, long life and reduced maintenance costs are significant

The sun's rays falling on the Bell Solar Battery are the only source of power needed to operate this small mobile radio transmitter being demonstrated by D. E. Thomas. M. B. Prince is at a standard radio receiver across the lawn.

factors, would offer numerous advantages over equipment now used.

While the new silicon devices perform a variety of unique electrical functions, they all depend essentially on one feature known as the "p-n junction." P-N junctions built into germanium single crystals are the basis for the junction transistor, invented at the Laboratories. All of these silicon devices, however, perform in ways that are currently impossible for germanium; their unique electrical properties depend on the substitution of silicon as the crystalline material in which p-n junctions are made by the controlled introduction of traces of impurities.

The genesis of these devices can be traced back to at least the first decade of the century when semiconducting crystals provided one of several competing "wireless detectors," a competition in which the vacuum tube was decisively the victor. As radio frequencies moved persistently upward, the tube lost its advantage and the stage was set in the early 30's for R. S. Ohl of the Laboratories to show that the erratic "crystal detector" could in fact be made reliable and reasonably efficient, and that it was capable of taking a leading role in extending the useful frequency range to higher and higher limits. Thus began two decades of research and development at Bell Laboratories, providing an example of the benefits of a continuous and integrated attack in an area of science lying beyond the border of the communications technology of the time.

In this study of crystal detectors, the silicon to which the metal point was applied was found to be "spotty," indicating non-uniformity in material then available. Although these impurities could not be detected chemically, Ohl interested a colleague, J. H. Scaff, in setting out to remove them. They found that careful freezing of silicon, starting at the top of the melt and working slowly downward, segregated the impurities so that a considerable part of the ingot would be uniformly satisfactory for use in microwave detectors. This in itself proved to be the basis of a considerable industry. Ohl discovered, however, that this process automatically produced in such ingots the first known p-n junctions. They were imperfect and inefficient but were nevertheless the prototypes of all these devices. Scaff and H. C. Theuerer then identified the p-type impurity as boron and the n-type impurity as phosphorus, and went on to make the first synthetic p-n junctions by deliberately adding these impurities to molten silicon and by diffusing them into solid silicon. These junctions were of great scientific significance. The researchers went on to find that other elements whose electronic structures resembled boron and phosphorus behaved similarly when added to silicon as impurities.

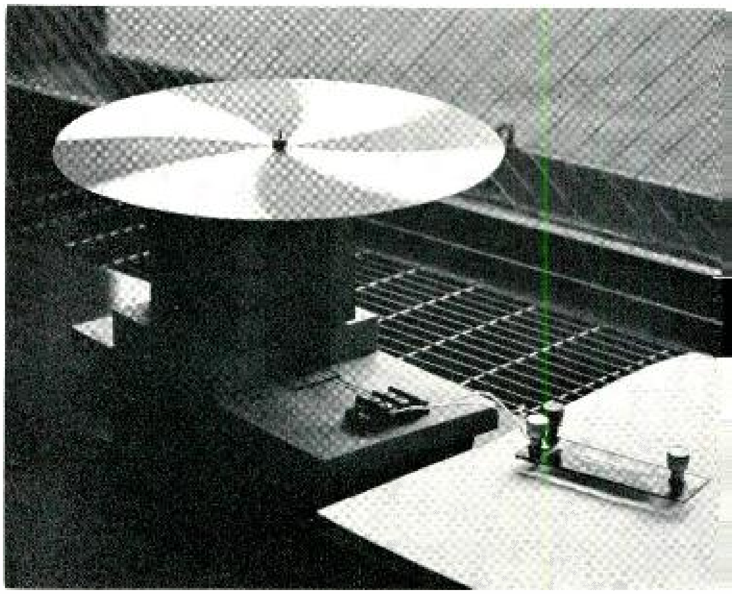
After World War II, William Shockley and his group attacked the many challenging problems in the physics of semiconductors that were posed by this work on silicon. In the course of this work, John Bardeen and W. H. Brattain discovered the point-contact transistor, in germanium rather than silicon because the former was more easily rendered extremely pure. Shockley constructed the complete theory of p-n junctions and junction transistors, and with his colleagues established the experimental conditions required to realize in germanium the tremendous potentialities of the theory. Meanwhile, Bardeen and Pearson attained a systematic understanding of the physics of both n-type and p-type silicon, thus providing an important part of the scientific foundation underlying silicon devices.

The science learned with germanium predicted that p-n junctions built into very pure silicon single crystals would perform many functions for which germanium was not well suited; i.e., ideally for computers and switching elements, for solar energy conversion, and for all kinds of transistor action at higher temperatures.

To apply this new knowledge to devices, the first successful step was taken by G. K. Teal and Ernest Buehler, who grew silicon single crystals. The second step of adequately purifying silicon proved very difficult, since it is chemically much more active than germanium. Careful fractionation, including distillation of silicon derivatives, finally led to unexcelled purity of the element. Co-operation of the Du Pont Company, already active in silicon chemistry, yielded a sufficient volume of silicon for the present experiments.

It was then found that further understanding of the physics of electrical processes in semiconductors was required before good devices could be made; this was supplied by J. R. Haynes and J. A. Hornbeck. The next step of building p-n junctions into the silicon crystal has been accomplished in a variety of ways. Pearson first made p-n junction rectifiers in silicon by welding aluminum wires on it. Baldwin Sawyer and D. K. Wilson went on to develop the finished device. The small-area junctions formed in this way are at present unsurpassed for a variety of low-current computer applications. More recently, N. B. Hannay and Buehler have employed special crystal-growing techniques for the successful production of p-n junctions for silicon transistors. These transistors have most of the desirable features of the earlier germanium devices and, in addition, can operate well at high temperatures.

The technique developed by Fuller, and which has been successfully used in a variety of silicon devices, consists of the preparation of p-n junctions by diffusing impurities into the surface of a silicon wafer. Using such "diffusion junctions," Pearson has made successful high-power rectifiers and lightning arrestors. Chapin has developed the techniques pioneered by Fuller and Pearson to make the large-area solar batteries.



Sunlight is providing the power to turn this motor-driven wheel. Bell Solar Battery in right foreground.

These diffusion techniques show great promise of being widely applicable to many kinds of semiconductor devices made from both germanium and silicon. The process developed by Fuller consists simply of heating the semiconductor wafer in the presence of a suitable impurity vapor. In this way, p- or n-type layers of controlled thickness are formed just below the semiconductor surface. The method may be used for either large-area, high-power devices or for devices with more complicated geometries where exceedingly small dimensions are required. The ultimate potentialities of this diffusion procedure are still being explored. The teamwork developments in crystal purity and perfection combined with a knowledge of ways to maintain extreme surface cleanliness have meanwhile removed many of the obstacles which formerly existed.

National Academy of Sciences Elects James B. Fisk

James B. Fisk, Vice President in charge of Research of the Laboratories, was elected a member of the National Academy of Sciences at the Academy's annual meeting held in Washington recently. It was at this meeting that the new silicon devices invented at Bell Telephone Laboratories were publicly demonstrated for the first time, including the Bell Solar Battery, the first device to convert the sun's energy directly and efficiently into useful amounts of electricity.

Under a Congressional charter signed by President Lincoln, the National Academy of Sciences was established in 1863 as a private, non-profit organization to act generally in the furtherance of science for the general welfare and to advise the Federal Government in scientific matters. The Academy now numbers about 500 of the most distinguished scientists of the United States, together with about 50 foreign associates. The membership is organized into thirteen sections, covering the major fields of physical and biological sciences.

Three members of the Laboratories are now members of the Academy. They are President M. J. Kelly, Dr. Fisk and Dr. W. Shockley.

W. Shockley Wins Comstock Prize

William Shockley has been awarded the Comstock Prize of the National Academy of Sciences "for his pioneering investigations and exposition of electric and magnetic properties of solid materials and for his researches in conduction of electricity by electrons and holes in semiconductors."

The Comstock Prize honors contributions to the advancement of knowledge in electricity, magnetism and radiant energy. It is awarded every five years from a fund established in 1907 by Cyrus B. Comstock, a member of the N.A.S.

During the past six years Dr. Shockley has made many contributions to solid state physics. He is also a visiting Professor of Physics at California Institute of Technology where he is teaching a graduate course in solid-state physics.

W. C. Tinus Receives Honorary Degree

W. C. Tinus, vice president of the Laboratories, was awarded the honorary degree of Doctor of Engineering from the Agricultural and Mechanical College of Texas during commencement exercises May 21. Mr. Tinus received his bachelor's degree in electrical engineering from the college in 1928 and immediately joined Bell Telephone Laboratories.

New Telephone with Illuminated Dial

Many times it would be convenient to be able to dial a telephone call without using the room lights: a mother guarding her sick child at night; a doctor trying to make a midnight call without waking his wife; a householder wishing to summon police because of unexplained noises; or a TV viewer who wants to dial a call without turning on a bright light. These and many other telephone users will be grateful for one of the latest 500-type telephones, the illuminated dial set.

Designed by Bell Laboratories and about to go into production at Western Electric's Indianapolis Works, this modification of the 500 set features a tiny electric light bulb that casts a glow over the dial whenever a customer lifts the handset. The lamp is a flashlight-type bulb powered by a small six-volt transformer which plugs into the standard household current. Except for the dial light and a transparent finger wheel that distributes light evenly over the dial number plate, the telephone is the same as the regular 500-type set.

Dialing your bedside telephone in a darkened room is easy with this new 500-type set. When the handset is lifted, a small electric light comes on to illuminate the dial.

Share owners in three additional rooms saw and heard the proceedings via closed-circuit TV facilities set up in the main auditorium.

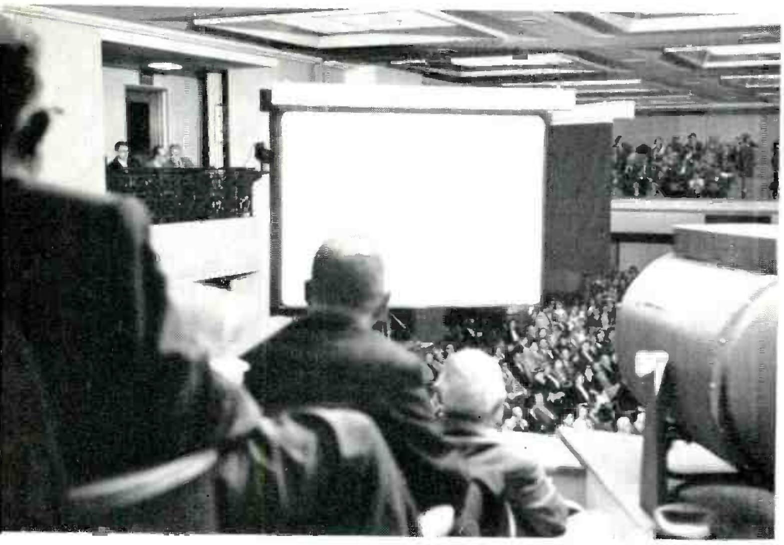
The 1954 Share Owners' Meeting

Cleo F. Craig, President of the American Telephone and Telegraph Company, told the share owners at the annual meeting that, "We are sound in wind and limb and well equipped to deal with whatever conditions may prevail. We have good momentum. People want our service. . . . Looking ahead, I am confident the public is going to buy freely of what we have to offer—because we will continue to make it so convenient, so satisfying and so reasonable in cost that people will just have to follow their natural impulse to pick up the telephone and make more and more use of it.

"Equally important, you may be sure of our utmost endeavors to produce financial results which will justify fully the splendid support you are giving us – yourselves in this room and your fellow investors. We were never more keenly aware of that welcome obligation."

This, the 69th annual meeting of A. T. & T. share owners, was more than a business meeting. Share

At the conclusion of Mr. Craig's talk, the telecast was projected onto large screens lowered from the ceiling.

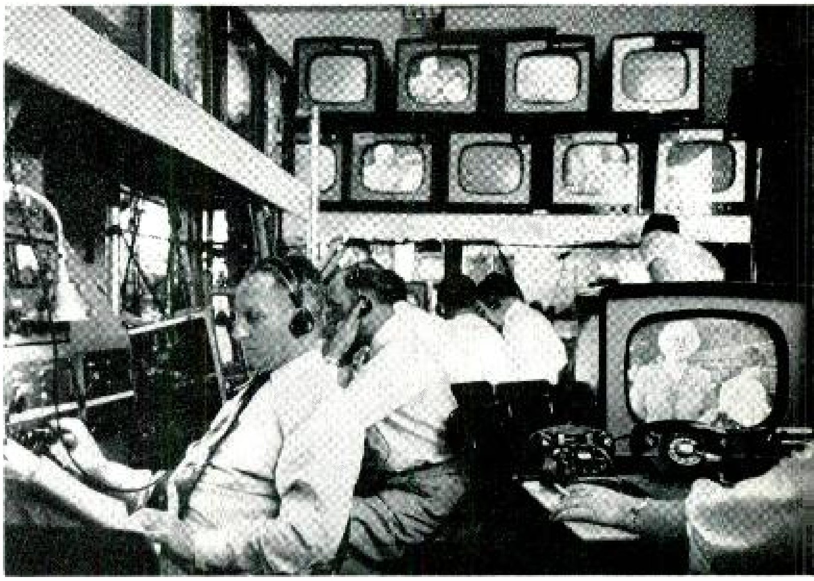


A share owner pauses after the meeting to introduce his young son to Mr. Craig.

owners were taken via closed circuit television on a tour of Long Lines operations, and were given a demonstration of customer long-distance dialing.

Immediately after Mr. Craig's talk, two large screens were lowered from the ceiling in the main auditorium and the "live" TV presentation began. Theatre-type TV projectors flashed the image on the screens. Those who could not see the screens conveniently watched the show on standard receivers.

The "camera's eye" view of Long Lines operations started with the handling of long-distance calls, briefly covered the work of traffic control, and then showed the crossbar equipment associated with the No. 4 switching system. Safety, a description of the techniques of cable splicing, maintenance, coaxial cable, carrier equipment and radio relay came next. After that, the viewers were given a glimpse of the TV control center in action, followed by a trip to the TWX operating room and the overseas operating room, including service on the high seas. Construction and planning for the future were then touched on. Immediately after the televised presentation of Long Lines operations, H. T. Killingsworth, A. T. & T. vice president in charge of Long Lines, demonstrated customer long distance dialing. Mr. Killingsworth dialed a call direct to the weather bureau in San Francisco.



Control room for the closed-circuit TV loop shows pickups from several cameras on the monitors.

Thirteen TV cameras were used to carry the Long Lines story to the share owners. This one provided an on-the-spot view of long distance operators on the job.

Mr. Craig had previously pointed out that, "we still have need of a very large construction program in order to meet all the public's telephone wants." Continuing on the subject of construction, he made two comments:

"First, our construction program has been averaging more than a billion dollars a year for the entire eight years since the war, and I would suppose it is about the largest carried on by any single business enterprise. This in itself is a factor of real importance in the country's general economic progress.

"In the second place, what we are doing today is putting us in an increasingly good position to make further gains in the future. This very process of construction and improvement today will widen tomorrow's opportunities for us. For we are expanding our service and making it better all the time and the possibilities keep growing."

Concluding his talk, Mr. Craig said that the Bell System is "well equipped. And it isn't just a matter of good technical equipment, though we certainly have that. It's infinitely more a matter of the kind of folks who live and work in this country and the freedom they have to better their lot. Progress grows out of the imagination and resolution of free men and women – and for seventy-five years or more the people of this country have increasingly used the telephone to help achieve their wants and aims. They aren't going to stop now. The telephone has grown in service and usefulness because telephone employees and telephone users and telephone share owners have all worked together to have it that way. In my judgment the human qualities that have brought us to here are going to take us farther – much farther."

Talks by Members of the Laboratories

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

Anderson, J. Reid, Ferroelectric Storage Devices, I.R.E. Professional Group on Electronic Computers, Murray Hill, N. J.

Anderson, O. L., Bommel, H. E., Fine, M. E., and McSkimin, H. J., Internal Friction in Fused Silica at Low Temperatures and High Frequencies, American Ceramic Society, Chicago.

Babington, W., The Development of Die-Casting Specifications Through A.S.T.M., Industrial Technical Assistance Division, U. S. Foreign Operations Administration, New York City.

Barstow, J. M., Television Transmission Factors, I.R.E. Cincinnati, and Intercity Transmission, A.I.E.E.-I.R.E. Series on Color Television, New York City.

Becker, J. A., Can We See Atoms and Molecules with the Field Emission Microscope, Technical Staff, Edison Laboratories, West Orange, N. J. and Chemistry Department, Notre Dame University, Notre Dame, Ind.

Beckerle, J. C., Ultrasonics, Manhattan College, New York City.

Berting, Miss F. M., Combined Use of X-Ray Diffraction and Electron Microscopy in the Study of Ceramic Materials, American Ceramic Society, Chicago.

Bommel, H. E., Ultrasonic Attenuation in Superconducting Lead, American Physical Society, Washington, D. C. See also Anderson, O. L.

Bown, R., Our Medalist, Introduction of Dr. M. J. Kelly, Industrial Research Institute, San Francisco (Presented by R. M. Burns).

Bozorth, R. M., see McSkimin, H. J.

Brattain, W. H., Transistor Physics, Lehigh University, Bethlehem, Penn.

Campbell, W. E. and Wadlow, H. V., Microchemical Techniques in the Diagnosis of Lubrication and Wear Problems, American Society of Lubrication Engineers, Cincinnati.

Clark, M. A., Transistor Physics, Hofstra College, Hempstead, N. Y.

Corenzwit E., see Matthias B. T.

Cruser, V. L., Equipment Features of a UHF Multi-Channel Military Radio Relay System, A.I.E.E.-I.R.E. Meeting, New York City.

Dudley, H. W., Speech Analysis and Synthesis, Annual Banquet of Tau Beta Pi, Newark College Chapter, Newark.

Elliott, S. J., Solderless Connections, Conference on Reliability of Electrical Connections, Radio-Electronics-Television Manufacturers Association, Chicago.

Finch, T. R., Circuit Applications of Transistors, A.I.E.E.-I.R.E. Student Group, Cooper Union Branch, New York City.

Fine, M. E., see Anderson, O. L.

Geller, S., The Rhodium-Germanium System, American Crystallographic Association, Harvard University, Cambridge, Mass.

Hagelbarger, D. W., An Out-Guessing Machine, I.R.E. Monmouth Section, Little Silver, N. J.

Hagstrum, H. D., Auger Electrons Ejected from Metals by Ions, Physics Department Colloquium, University of Maryland, Baltimore.

Hannay, N. B., The Mass Spectrographic Analysis of Solids, Physics Department Colloquium, Cornell University, Ithaca, N. Y.

Hearn, A. H., Creosote Retention as Determined by Toluene Extraction of Treated Wood, American Wood Preservers Association, Atlantic City, N. J.

Heidenreich, R. D., Emission Electron Microscopy, American Society for Metals, Buffalo, N. Y.

Hoffmann, J. P., Equipment Features of New Military Telephone Systems, A.I.E.E.-I.R.E. Meeting, New York City.

Huber, G. H., Miller, W. F., and Schramm, C. W., New Military Carrier Telephone Systems, A.I.E.E.-I.R.E. Meeting, New York City.

Jensen, A. G., Color Television, I.R.E. New York Section, Columbia University, New York City.

Karlin, J. E., Consideration of the User in Telephone Research, Ergonomics Research Society, Dortmund, Germany, and England.

Keister, W., Mechanized Intelligence, Georgia Engineering Society, Southern Bell Telephone Company Personnel, and Georgia Institute of Technology, Atlanta.

Kock, W. E., Polarized Airborne Sound Waves, Philco Corporation, Philadelphia.

Malthaner, W. A., An Automatic Telephone System Employing Magnetic Drum Memory, I.R.E. Professional Group on Electronic Computers, Murray Hill, N. J.

Mason, W. P., Ferroelectrics and the Dielectric Amplifier, Department of Insulation Research Seminar, Massachusetts Institute of Technology, Cambridge, Mass.

Matthias, B. T., and Corenzwit, E., Superconducting Alloys, American Physical Society, Washington, D. C.

McLean, D. A., and Wehe, H. G., Miniature Lacquer Film Capacitors, I.R.E. Meeting, Murray Hill, N. J.

McSkimin, H. J., Williams, A. J. and Bozorth, R. M., Measurement of the Elastic Constant of Cobalt and of Cobalt Zinc Ferrite Crystals, American Physical Society, Washington, D. C. See also Anderson, O. L.

Mertz, P., Transmission Line Characteristics and Effects on Pulse Transmission, Microwave Research Institute and I.R.E. Professional Group on Circuit Theory, New York City.

Miller, W. F., see Huber, G. H.

Nordahl, J. G., New UHF Multi-Channel Military Radio Relay System, A.I.E.E.-I.R.E. Meeting, New York City.

Ross, I. M., Transistors, Chemistry Teachers and Physics Clubs, New York City.

Schramm, C. W., see Huber, G. H.

Schumacher, E. E., Metallurgy in a Communications Industry, Rensselaer Polytechnic Institute, Troy, N. Y.

Simkins, Q. W., A Digital Transistor Multiplier, I.R.E. Professional Group on Electronic Computers, Murray Hill.

Sparks, M., The Chemistry of the Transistor, American Society of Lubrication Engineers, Cincinnati, and American Institute of Chemical Engineers New York Section, New York City.

Terry, M. E., Fundamental Differences in the Design of Experiments for Engineering Research, Columbia University, New York City.

Townsend, M. A., Glow Discharge Devices, Electrical Engineering Graduate Colloquium, Massachusetts Institute of Technology, Cambridge, Mass.

Wadlow, H. V., see Campbell, W. E.

Warner, A. W., Frequency Aging of Plated High Frequency Crystal Units, Frequency Control Symposium, Signal Corps Engineering Laboratory, Asbury Park, N. J.

Washburn, S. H., Relays, Columbia University, New York City.

Wehe, H. G., see McLean, D. A.

William, A. J., see McSkimin, H. J.

Williams, I. V., The Role of Testing in Metals Conservation, American Society for Metals Conference, Rochester, New York.

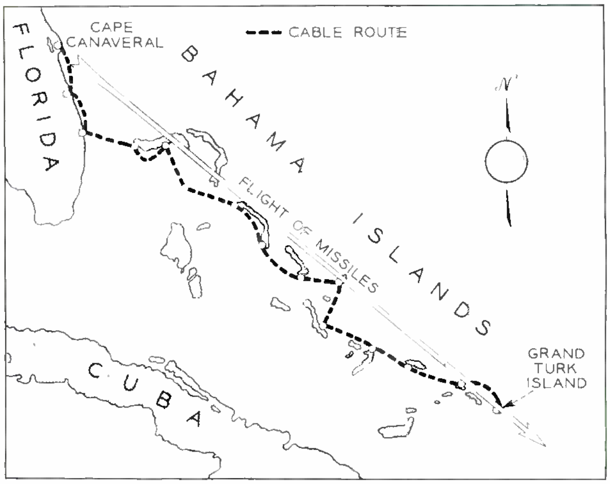
Submarine Cable for Air Force

Almost 1,000 miles of submarine cable, installed specially for the Air Research and Development Command of the Air Force, was put into operation last month between Cape Canaveral, Florida, and Grand Turk Island in the Bahamas. The new underwater communication system follows the path of the Air Force's guided missile test range southeast through the Bahama Islands, and will be used to facilitate the analysis of missile flight data.

This 1,000-mile portion of the communication system uses sixteen carrier telephone repeater stations along the coast of Florida and on various islands. Twelve channels are available in addition to other channels used for special purposes.

The system had its beginning in 1949 when the Signal Corps requested Bell Telephone Laboratories to study the problem of a communication system for a guided missile test range. This study led to the recommendation that a submarine cable system using land-based repeaters would provide the most reliable communication. In 1950, after responsibility for the missile test center was transferred to the Air Force, a survey of the route was requested. The survey was done by the U. S. Navy Hydrographic Office under the general direction of Bell Telephone Laboratories.

The Laboratories designed the cable and arranged for its laying, and also designed the special carrier transmission system. Western Electric procured the cable, arranged for its storage, and made the special carrier equipment at their Kearny Works. The installation and adjustment of the system was a joint effort of the Long Lines Department of A. T. & T., Western Electric, and the Laboratories, and there was close cooperation and coordination of effort of these organizations throughout the project.



300 TV Stations in Network

Three-hundred television stations throughout the nation are now receiving network service. The 300th station to be linked for network service, WKNY-TV, Kingston, N. Y., was connected to the Bell System's nationwide network of TV facilities on May 24, 1954. This brought the rollcall on network TV service to 191 cities in the United States. More than 54,000 channel miles of coaxial cable and radio relay facilities are being used to provide these cities with network television.

There is now a total of about 380 TV stations on the air in the United States. These stations, located in some 250 cities, broadcast to an estimated potential audience of 109,000,000.

Six years ago last month, when network television was inaugurated commercially, there were fewer than 1,000 miles of TV channels in operation, linking 12 stations in 5 cities – Boston, New York, Philadelphia, Baltimore and Washington. By the end of 1948, the embryo network facilities had been extended to 31 stations in 15 cities. During each of the succeeding four years, an average of 7,000 channel miles was added.

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:

Allis, W. P., see Rose, D. J.

Clogston, A. M., and Heffner, H., Focussing of an Electron Beam by Periodic Fields, J. Appl. Phys., **25**, pp. 436-447, April, 1954.

Conwell, E. M., see Debye, P. P.

Darrow, K. K., Solid State Electronics, Research, **7**, Jan., Feb., and March, 1954.

Debye, P. P., and Conwell, E. M., Electrical Properties of N-Type Germanium, Phys. Rev., **93**, pp. 693-706.

Dunn, H. K., Remarks on a Paper entitled "Multiple Helmholtz Resonators," Letter to the Editor, Acoustical Soc., Am., J., **26**, p. 103, Jan., 1954.

Ellis, W. C., and Fageant, J., Orientation Relationships in Cast Germanium, J. Metals, **6**, pp. 291, 294, Feb., 1954.

Ellis, W. S., and Greiner, E. S., Production of Acceptor Centers in Germanium and Silicon by Plastic Deformation, Letter to the Editor, Phys. Rev., **92**, Nov. 15, 1933.

Fageant, J., see Ellis, W. C.

Fine, M. E., Van Duyne, H., and Kenney, Nancy T., Low-Temperature Internal Friction and Elasticity Effects in Vitreous Silica, J. Appl. Phys., **25**, March, 1954.

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Germer, L. H., Arcing at Electrical Contacts on Closure Part IV—Activation of Contacts by Organic Vapor, J. Appl. Phys. **25**, pp. 332-335, March, 1954.

Gohn, G. R., Guerard, J. P., and Herbert, G. J., The Mechanical Properties of Some Nickel Silver Alloy Strips, Proc. A.S.T.M., **54**, Jan., 1954.

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Kenney, Nancy, see Fine, M. E.

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Kretzmer, E. R., An Amplitude Stabilized Transistor Oscillator, Proc. I.R.E., **42**, pp. 391-401, Feb., 1954.

Lewis, H. W., Search for the Hall Effect in a Superconductor, Experiment, Phys. Rev., **92**, Dec. 1, 1953.

Linvill, J. G., RC Active Filters, Proc. I.R.E., **42**, pp. 555-564, March, 1954.

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Machlup, S., Noise in Semiconductors: Spectrum of a Two-Parameter Random Signal, J. Appl. Phys., **25**, March, 1954.

Matthias, B. T., Transition Temperatures of Superconductors, Phys. Rev., **92**, pp. 874-876, Nov. 15, 1953.

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