November 1960

Bell Laboratories RECORD

THE OPTICAL MASER
A Million Times Brighter than the Sun

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Bell Laboratories **RECORD**

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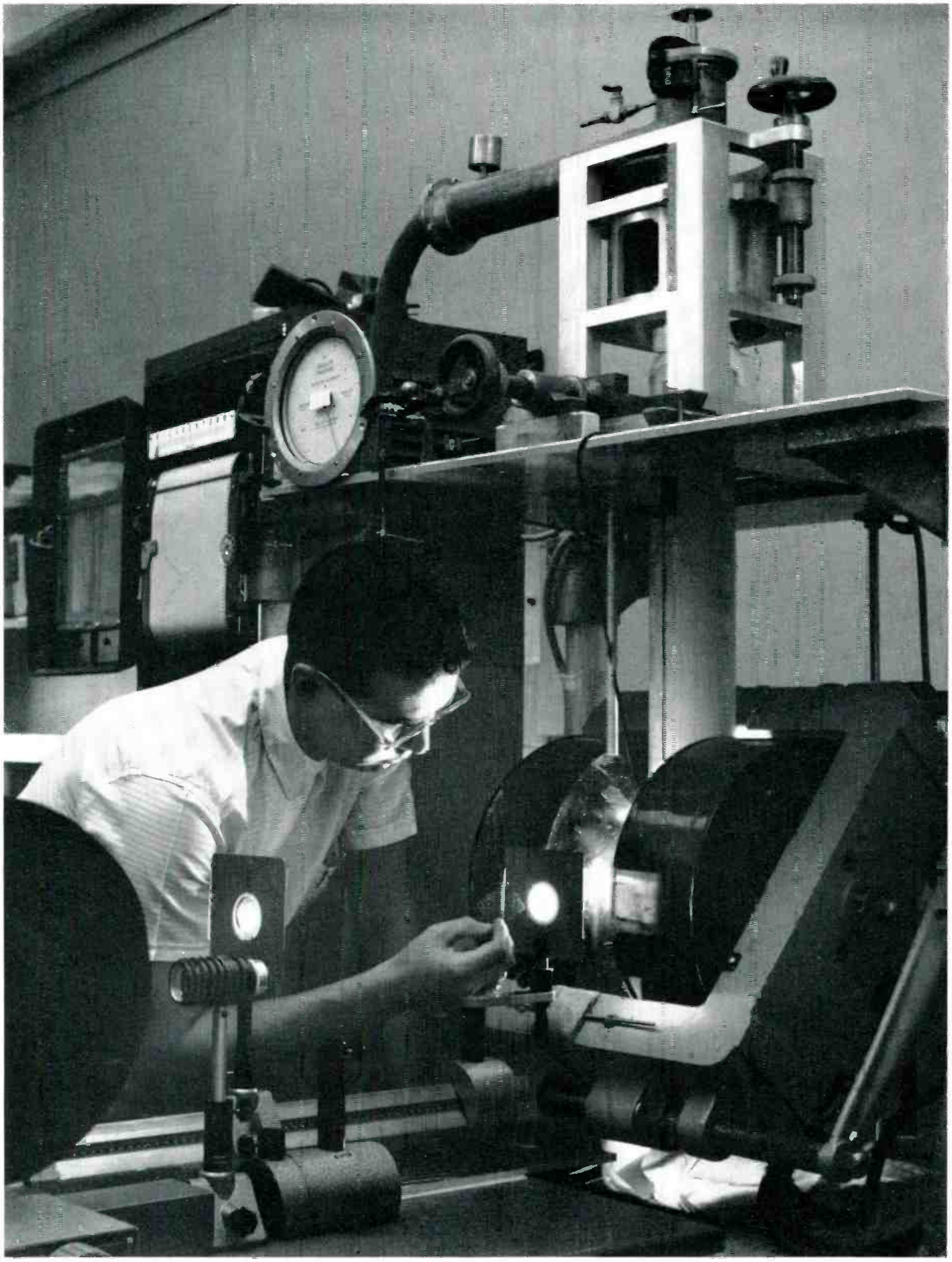
Contents

Cover *K. F. Rodgers, Jr. observes pulsed beam of coherent light emanating from an optical maser. Within its narrow cone and frequency band, this beam is more than a million times brighter than would be a comparable one of sunlight. (See article on page 403.)*



G. E. Devlin operates spectrometer and optical equipment used in study of materials for optical and infrared masers. These materials include metal vapors, inert gases, and crystalline solids.

By itself, an excited atom contributes little to the art of radio communications. But many such atoms, vibrating together, become a powerful source of high-frequency energy. The optical maser, now evolving at Bell Laboratories, produces this atomic teamwork, necessary to generate frequencies in the optical and infrared regions of the energy spectrum.

A. L. Schawlow

Infrared and Optical Masers

Ever since the earliest days of radio communication, there has been a steady drive toward the production and use of electromagnetic waves of higher frequencies and, correspondingly, shorter wavelengths. For this purpose, electron tubes have been refined through the years, and in the last decade they have been joined by transistors and other semiconductor devices. Today, with both tubes and semiconductor devices, we can produce wavelengths as short as about a millimeter, corresponding to a frequency of 300 kmc. However, continued progress in the construction of high-frequency devices has always been limited by some critical dimension which becomes inconveniently small as the wavelengths are reduced.

Recently, promise has come of break-through in this dimension-wavelength-frequency barrier. It now seems possible to apply electronic techniques to much higher frequencies using the "maser" principle (RECORD, *May*, 1960). Since the invention of the first molecular-beam maser by C. H. Townes, of Columbia University, these devices have been used as frequency standards and as microwave amplifiers having very low noise. The most recent application, invented jointly by C. H. Townes and the author, will produce "coherent" high frequencies by stimulating radiation from atomic systems in the frequency band encompassing the optical and infrared regions.

What are the advantages to using high frequencies? One important application is in carrier transmission. To transmit information, no matter what kind of modulation is used, we need a band of frequencies. To transmit more information, we need a wider band of frequencies. For example, a television program needs a channel several megacycles wide, while a telephone conversation requires one of only a few kilocycles.

As the volume of information to be transmitted increases, more and wider channels are needed. With large bandwidths, we can transmit many telephone conversations and several television programs with the same equipment. Now, as the carrier frequency is raised, a given percentage bandwidth, which might be dictated by practical considerations, is a proportionately larger absolute bandwidth. Thus, more information can be transmitted with high carrier frequencies and their accompanying large bandwidths.

A second major advantage of high frequencies has to do with directivity. Higher frequencies imply shorter wavelengths, and these waves can be beamed sharply by an antenna of given size. Now that we wish to communicate with small satellites and space vehicles at great distances, there are strong reasons for seeking the highest possible directivity in a very small package.

Electron-Tube Generators

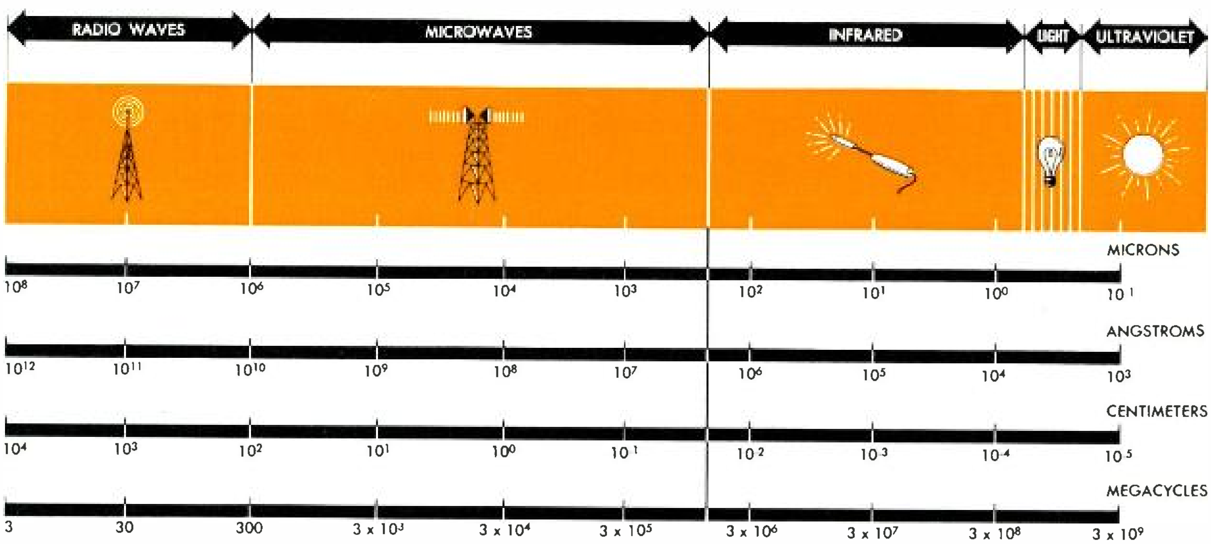
In their quest for higher frequencies and shorter wavelengths, engineers have built electron tube oscillators that produce frequencies as high as 100,000 megacycles. With harmonic generators, we can derive multiples of these frequencies as much as ten times higher. This corresponds to a wavelength of a few tenths of a millimeter —about one hundredth of an inch. The spectrum chart on this page shows this point. Below 1,000,000 mc in frequency (that is at longer wavelengths) lies the radio waves and above this point are the infrared and optical wavelengths.

All of these are electromagnetic waves; they differ primarily in wavelength or frequency. But because at this point there is an abrupt change in the way the waves are generated, there is one important difference in their nature. Radio waves generated by electron tubes have a single, definite frequency like a pure tone in sound. Light waves, on the other hand, always cover a fairly broad band of frequencies and so are more akin to noise than to a tone.

This comes about because light waves are generated by many individual atoms or molecules. Each of these emits radiation for a short interval, and is succeeded by others with a slightly different frequency. Since these individual oscillators are entirely independent, there is no connection between their phases. Thus the emitted wave has a phase that fluctuates randomly from moment to moment, and from point to point in the source. It is almost completely lacking in *coherence*. An electronic oscillator, with its phase progressing smoothly in time, *is* coherent.

Coherence in an electronic generator is an important advantage because it permits us to "beat" together waves of different frequencies, as in superheterodyne detection. Beating an incoming signal with a local oscillator in the "receiver-mixer" stage of a radio receiver permits us to convert the signal to a lower frequency band where, in some cases, it can be more easily tuned and amplified. Another advantage of a coherent source is that we can supply separate radiating elements with properly phased radiation for a directive antenna. Therefore, we can radiate waves coherent in space as well as in time.

Thus it would be most desirable to have powerful sources (amplifiers and oscillators) of coherent radiation in the infrared and optical regions of the frequency spectrum. As mentioned before,



Some of the major divisions of the electromagnetic frequency spectrum. Boundary near one million mc marks change in method of frequency generation. Below this point are easily generated single frequencies. Above it are broadband waves difficult to sort out for propagation purposes.

one approach to this is to continue scaling down electronic tubes to smaller dimensions. This approach has been very successful in the past and will continue, but becomes more and more difficult for signals at shorter wavelengths. Moreover, if man-made resonators of any kind are used, they become increasingly tiny and hard to make accurately because their dimensions must be comparable with a wavelength.

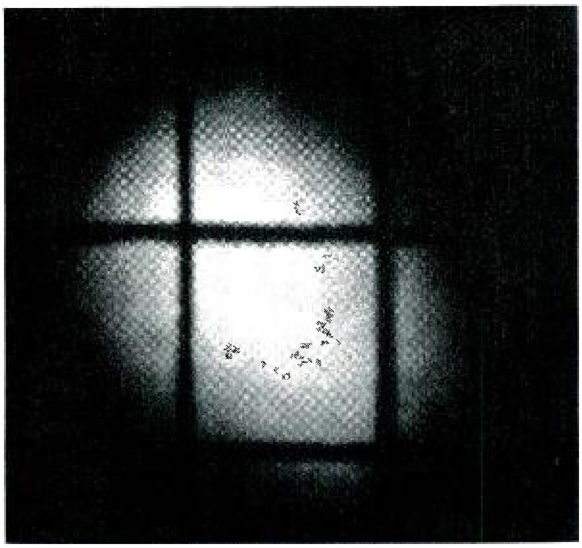
On the other hand, nature has endowed us with a copious supply of atomic, ionic and molecular resonators at almost all frequencies in this region. We need only find some way to excite them and then synchronize them so that they are made to radiate coherently. This much has been known for a long time, and indeed such light sources as gas-discharge lamps—the ordinary fluorescent light, for example—make use of radiation from excited atoms or molecules. But only since the invention of the maser has there been any indication of how the individual "radiators" might be synchronized.

The term maser is an acronym derived from "Microwave Amplification by Stimulated Emission of Radiation." Since there are now stimulated-emission devices in almost all frequency ranges, it seems best to change the "m" to stand for "molecular." Then we can retain the name for all the devices, whether microwave or not.

All atomic and molecular systems possess discrete energy levels, which are different for each kind of system. That is, they can store energy of certain fixed amounts only. An atom in its "ground" state can absorb energy from an electromagnetic wave of the right frequency, and make a transition to an excited state. Once in the excited state, the atom could lose the energy by spontaneously emitting a wave "quantum" of the same frequency as the one which originally excited it. Or, while the atom is excited, if another similar quantum comes along it can force the atom to emit its radiation and revert to the ground state.

A maser makes use of this stimulated emission. We can construct one so that in the material an excess of atoms is maintained in the upper energy state. Then an incoming wave of the proper frequency gains energy by stimulating emission from these atoms.

The lower sketch on page 406 illustrates the growth of a light wave by stimulated emission. Let us suppose that the wave travels from left to right through an active medium. Active mediums contain mostly atoms in the upper state indicated by the top "ball" in the sketch. When a light wave of the proper frequency strikes one of these excited atoms, the atom is forced to emit radiation of the same frequency, giving up its excitation energy in the process. Moreover, the stimulated emission is in phase with the original, and so augments it. Thus, as the wave progresses from left to right, it grows, or is amplified, by this process of stimulated emission. On the other hand, if the wave strikes an atom in the lower energy level (indicated by the bottom ball in the sketch) it may excite the atom, losing energy in the process. Thus for amplification, the number of atoms in the upper, or excited state must outnumber those in the lower state.



Generated light from optical maser. Spot focussed by device subtends less than one-quarter degree of arc. Thus the light spot covers only a single inch square on a screen 108 inches from the maser.

We can convert this maser amplifier into an oscillator by feeding back some of the amplified output. This is done simply by terminating the active medium with reflecting end walls (*see top sketch page 406*). A wave which travels along the axis of the system can now bounce back and forth, returning to its starting point. In fact, it can form a standing wave system between the plates. Such sustained oscillations are obtained if the amplification of a wave traveling from one end plate to the other exceeds the loss on reflection at the ends. Of course, the signal must be extracted somehow. Making one of the end walls partly transparent permits some light to be extracted through it.

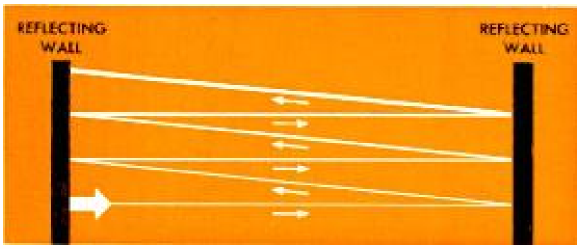
If the maser is producing light waves in or near the visible region, there will be many thousands of wavelengths between the end plates. These reflecting plates should be flat within a small fraction of a wavelength of light, but techniques for polishing plates to such flatness were developed long ago for other optical instruments. Thus, the whole system does not have to be comparable in size with a wavelength, but can be much larger.

For microwaves, the most commonly used "tuning" element is the cavity resonator. This is a hollow box inside which the radio waves bounce. When the length of an incoming wave has the right relation to some dimension of the box, there is a resonance. Ordinarily, microwave cavity resonators are comparable in dimension to one wavelength, usually about a centimeter.

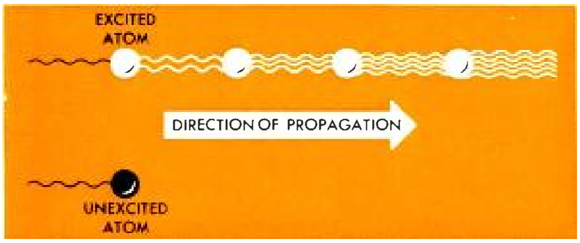
If we were to use a "large" cavity resonator for light waves, it would resonate in very many modes. However, the optical maser described here would have only the ends reflecting and, therefore would only be a good resonator for waves traveling along its axis. The other modes of the cavity resonator correspond to waves traveling in other directions. Most of these will miss the end plates entirely and will spend little time in the region of the active medium. Those only slightly off the axis will hit the end plates a few times and then pass the edge of the reflector and be lost. If the end plates are small enough in comparison with their separation, only waves traveling accurately along the axis will be amplified or generated. Then the light emerging from the partially transparent end plate will also be traveling along the axis of the system.

Thus the output of the optical maser is a wave which is inherently very directional. We expect that the radiation would initially have an accurately plane wave front, and would spread very little. The angular width of the beam of radiation should be approximately the ratio of the light wave length to the diameter of the end plates. Since the wavelength of the light is short, this is a small angle, and the light spread is very small.

So far we have not said much about the nature of the active medium. There are a great many



One arrangement of optical maser in which wave "grows" as it bounces back and forth between reflecting walls. (Vertical dimension of the diagram has been greatly exaggerated for clarity.)



Growth of a light wave by stimulated emission. Wave striking excited atom at same frequency forces it to "join" the original emission. Unexcited atom absorbs wave and ends emission.

possibilities here, and it seems likely that many different ones will ultimately be found suitable. The substance used must have a natural resonance, corresponding to a quantum transition between two energy levels at the desired operating frequency. This should preferably be a sharp resonance because broad resonances require more excitation energy in proportion to their width. Also, in the material it should be possible to keep empty the lower of the two quantum levels involved, while putting many atoms into the upper one. This excitation into the upper state can be obtained in some cases by using strong light of a suitable wavelength. In other cases, a suitably designed gas discharge may suffice. Each individual material is different, and requires its own technique. Possible materials exist in metal vapors, inert gases, and crystalline solids, and even some glasses or liquids might prove usable.

Maser Construction

A solid-state optical maser can be constructed very simply. Essentially, one consists of a rod whose flat ends are silvered and whose sides are left open to admit the exciting radiation. Recently at Bell Laboratories, solid optical masers using pulsed operation have been constructed by R. J. Collins, D. F. Nelson, W. L. Bond, C. G. B. Garrett, W. K. Kaiser, and the author. Based on an arrangement proposed by T. H. Maiman of the Hughes Research Laboratories, these scientists are conducting experiments with ruby rods about two inches long and one-quarter inch in diameter. The devices have verified many of their predicted properties. In particular, operation has shown the entire signal output to be contained in a very narrow beam. In fact, most recent operations have produced a beam with a total spread of less than one-tenth of a degree.

The possible uses of an optical maser will depend on the characteristics of the individual device, just as the uses of various kinds of electron tubes differ. Nevertheless, it is possible to see

Recent Optical Maser Experiments

Recent physical experiments at Bell Laboratories have confirmed several predictions of the behavior of an optical maser. The theory of this device is discussed in the accompanying article.

In the experiments, Laboratories scientists used a synthetic ruby rod, ½ inch long and 1/5 inch in diameter. The ends of this rod were polished until extremely flat and parallel, and were covered with a reflecting, yet slightly transparent, layer of silver. This rod was held in the center of a spiral photoflash lamp and illuminated with an intense flash of ordinary white light.

The investigators found that when the power applied to the flash lamp exceeded a certain value, a nearly parallel beam of light was emitted through the silvered ends. This light was red, like the ordinary fluorescent light from ruby, but differed from it in several important ways.

First, it was sixty times closer to being "monochromatic" (of a single frequency) than the ordinary ruby light. Second, the light is "coherent" as was demonstrated by arranging two fine, parallel slits in a thick silver coating on one end of a ruby rod. The pattern of emerging light showed the light from one slit to be interfering with the light from the other, indicating that the emitted light was in phase across the end of the rod. Third, almost all of this monochromatic light was emitted within a cone angle of only one-tenth degree. Within this cone, the intensity of the light was far higher than could be obtained by the ordinary fluorescent process.

As a communications experiment, a ruby optical maser was set up at the Holmdel, N. J., location of the Laboratories and aimed at the Murray Hill Laboratories, 25 miles away. Red flashes, clearly visible to the naked eye, registered on photo multiplier tubes. The circle illuminated by the beam at Murray Hill was only about 200 feet in diameter.

Another experiment involved transmitting pulses of light along a quarter mile of two-inch diameter circular waveguide, where the dust and fog of the atmosphere could not attenuate the beam. Photomultiplier tubes at one end of the waveguide recorded clear pulses of high-intensity light.

With further developments, a beam from an optical maser might be used for a variety of scientific applications, including communications. At present, messages can be sent only in a code based on repeated flashes. However, since the coherent light is emitted in short bursts rather than as a smooth pulse, it may eventually be possible to modulate the signal, permitting many telephone conversations or television signals to be transmitted simultaneously over such a link.

some general uses arising from the basic properties of the device. In communications applications, for example, it offers the possibility of extending radio techniques to much higher carrier frequencies. Undoubtedly, higher frequencies will have advantages and applications not yet envisaged. Some of these might turn out to be as important as the long-distance transmission properties of short-wave radio which were not predicted in advance.

Optical masers would also be particularly useful in communication from earth to satellites or space vehicles. For that purpose, their very directional beam would permit communication over large distances with small amounts of power.

Power Density

While the power output of the first continuously operating optical masers might be only a few milliwatts, nearly all the power would be beamed in a single direction. A lens or mirror could then focus the entire output to a spot of dimensions not much larger than the wavelength of light—about one-billionth of a square inch. The power density in the focal spot would then be some millions of watts per square inch. While this very high power density would exist in only a small volume, it should be enough to produce new nonlinear effects in atomic or molecular systems.

Optical masers can also provide us with sources of infrared radiation of specific frequencies with much more power than those now available. At present, if we want a single infrared wavelength, all we can do is to filter it out of a continuous spectrum of wavelengths and in so doing we throw away most of the power. If masers do give us strong sources of appropriate wavelengths, it may be possible to use them to excite particular molecular vibrations selectively. Vigorous enough excitation eventually may be possible to influence the course of chemical reactions.

Other scientific uses promise to be numerous and varied. Among the prospects are improved atomic standards of length. These would in turn extend to much larger distances the optical interferometry methods currently used for the most precise length measurements. Scientists have even suggested that sensitive detection of length changes might make possible new tests of the theory of relativity.

There remain many difficulties to overcome before the optical maser is a practical device. But now we know at least one way to extend radio techniques to the infrared and optical region. Thus, a whole new area is open for exploration.

Between the academic and industrial phases of an engineer's continuous learning experience lies a gulf of adjustment. Spanning this gulf at Bell Laboratories is a unique training program. It permits new employees to pursue advanced education while fulfilling the needs of the Laboratories for a staff of highly trained technical personnel.

J. N. Shive

The CDT-NYU Program

Few people would wish to question the value to Bell Laboratories of a technical staff well trained at all levels. This value has been attested to by the effort and concern invested in the evolution of the various educational programs offered by the Laboratories to its employees. Among the largest of these is the Communications Development Training Program. Through CDT, about 450 members of the Laboratories technical staff are now receiving graduate-level training in areas of communications science and technology.

The CDT program presents simultaneous solutions to two important sets of problems: (1) those seen by a young college graduate with a Bachelor's degree looking for placement; and (2) those seen by Bell Laboratories in fulfilling its needs for new employees of high caliber and advanced training.

The problems seen by the graduating college man are mostly personal. Many young men, as they approach graduation, are beset on the one hand by the practical need for going to work and justifying the time, money, and effort already invested by themselves and their families. On the other hand, they realize that without still further training it will be difficult to fulfill their present hopes for careers of real contribution and leadership in the technical life of their generation. The recent college graduate, or the college senior nearing graduation, may well wonder how to reconcile these conflicting realities. The choice of employment with the Laboratories and participation in the CDT program offers a way to resolve his problem.

As seen by the Laboratories, the problem is one of maintaining the company's strength and vigor through the continued and continuing addition to the staff of strong personnel with advanced training. Communications technology has progressed to the point where graduate training is needed to prepare for productive careers, and the need of the Laboratories to develop a technical staff having such advanced training has become increasingly compelling.

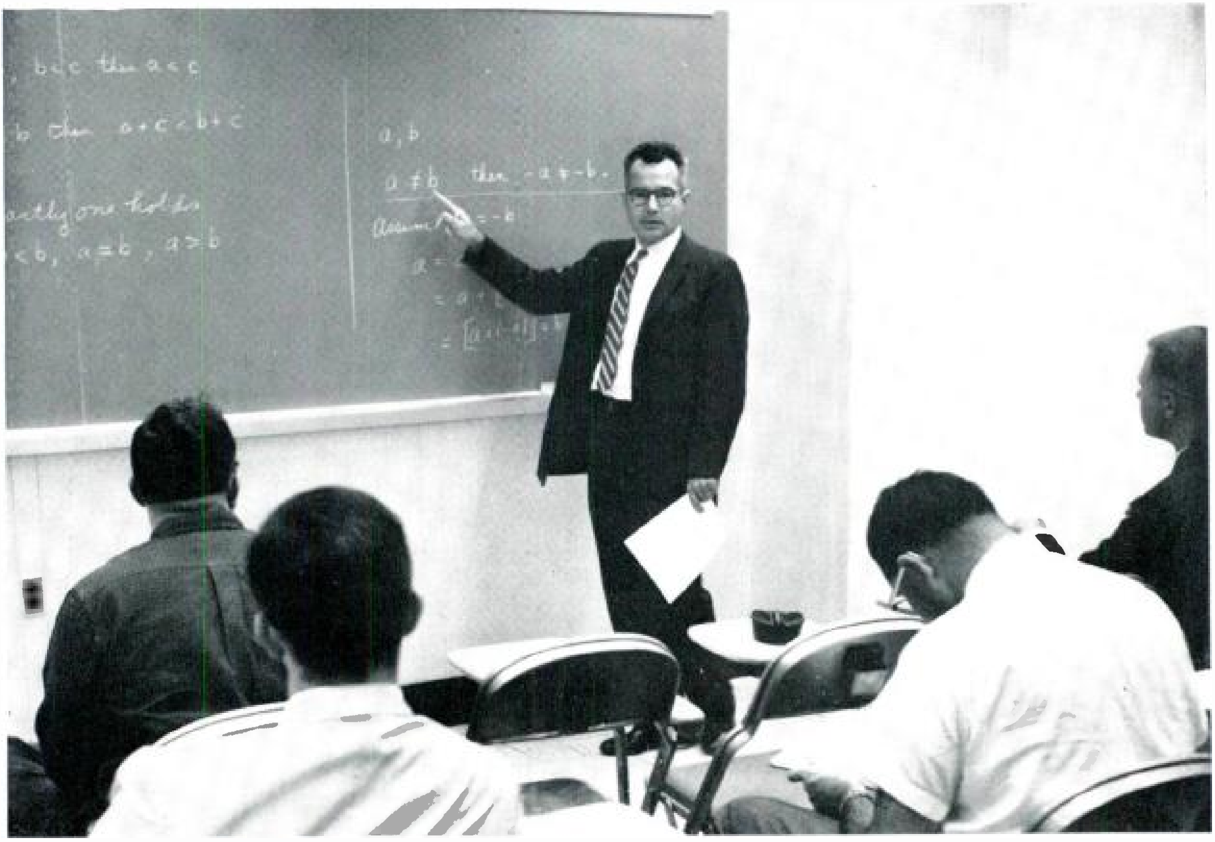
Unfortunately, men with Master's and Doctoral training are not graduating in sufficient numbers from the universities to fill these needs, even though the Laboratories may be securing its full share of such men in competition with the rest of industry. The most promising alternative is to employ the best candidates who can be found at the Bachelor's level and to undertake their further training as a company-supported enterprise. For this reason, then, in 1948 the CDT program was inaugurated.

Completion of CDT ordinarily requires three years for a man starting with a Bachelor's degree. It includes between 55 and 60 semester hours of course work and three 3-month laboratory assignments in different technical departments. During his entire stay in the program, a trainee reports to the technical department that originally employed him. He thus has a departmental "home" and can develop an identification with this department while still a student. He can also benefit from the friendship and counsel of the people who hired him and who have a continuing interest in his progress.

Today's CDT program is the result of a sustained process of evolution and is still evolving. The most significant single change in the program came in 1957. Up to that time, all courses in CDT were organized and taught by instructors selected from the various technical departments of the Laboratories. Much of the material in these courses paralleled rather closely the engineering, physics, and mathematics material available in the engineering graduate schools, and it appeared worth while to contract with a university to come in and teach these subjects for us. Accordingly, in 1957 a five-year renewable contract was negotiated with New York University to establish a branch of the NYU Engineering Graduate Division at the Murray Hill location of the Laboratories.

This graduate center offers a two-year curriculum of courses leading to the degrees of Master of Science in Electrical Engineering, Mechanical Engineering, and Engineering Mechanics. NYU furnishes the administration, faculty, and staff to operate the graduate center, while the Laboratories provides classroom and office space and contributes certain personnel functions.

This NYU program constitutes the academic portion of the first two years of CDT. During his first year a trainee attends classes three days per week; during his second year he attends classes two days per week. The rest of the time he spends with his own department, working on a current project. The first-year E. E. courses are listed in the table on page 411. Inclusion of these courses in the curriculum is determined



New York University instructor conducts class in non Bell System subject. CDT-NYU program was designed to shift to the professional educators the teaching of general graduate subjects.

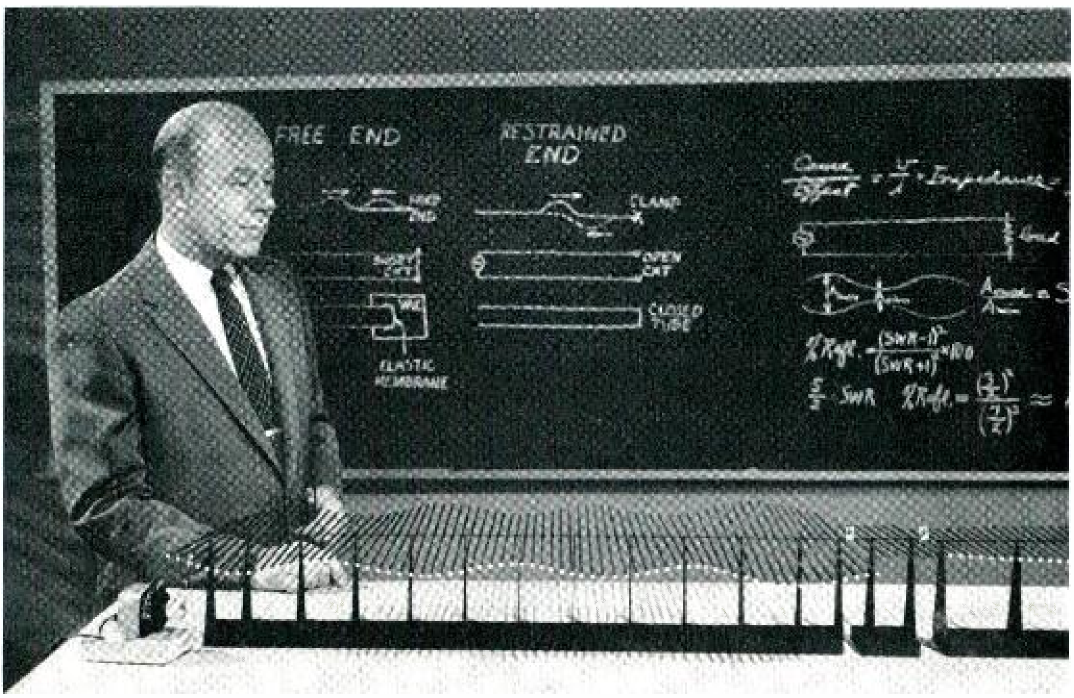
"Similarities in Wave Behavior": A Laboratories Film

The contributions of members of Bell Laboratories Education and Training Department to the field of scientific education often go beyond their responsibilities for training Laboratories personnel. A recent example is John Shive's participation, as writer and narrator, in a Laboratories science film, "Similarities in Wave Behavior." This is one of a series of films produced by the Educational Film Production Group of the Publication Department. It is designed for classroom use in college science and engineering courses.

In "Similarities in Wave Behavior" Mr. Shive describes the fundamental physics of wave motion and compares the behavior of waves in various mechanical, electrical, acoustical, and optical wave systems. Using a mechanical wave-demonstration machine which he designed, the narrator generates waves and shows how they are reflected or absorbed when the machine is terminated in different ways. Film viewers can see how transmitted and reflected waves travel through a medium and how independent waves in the same medium affect each other.

Specifically, the film shows the reflection of waves from a free and from a clamped end, then, in slow motion, demonstrates the essential ideas of superposition, standing waves and resonance. Also demonstrated is impedance matching and mismatching.

"Similarities in Wave Behavior" is being distributed to interested educational institutions by the Operating Telephone Companies. A booklet, available with the film, contains the spoken commentary, additional explanatory notes, information on machine construction, and suggestions for further demonstrations.



partly by the requirements for the NYU Master's degree and partly by the Laboratories best judgment of the body of knowledge needed by young men entering professional careers in electrical communication. The first year's studies are completely prescribed by these two sets of requirements, and are the same for all the trainees taking the curriculum leading to the Master's degree in Electrical Engineering.

During the second year, however, a trainee has considerable elective freedom and can choose most of his second-year courses from a list of several offered at the graduate center (*see table on this page*). The second-year courses, while still basic and general in their application, have a more specialized bearing on the work of various development and systems engineering departments in the Laboratories. A trainee normally chooses his electives after consulting with his department head to assure representation of the interests of the department, as well as those of the trainee himself.

Bell System Courses

During his first two years, each trainee also takes a sequence of courses called Bell System I, Bell System II, and Bell System III. These courses, taught by Bell Laboratories instructors, are intended to acquaint new technical employees with the nature of the telephone business. Bell System I treats the corporate structure of the Bell System, the role played by the Laboratories, and some of the financial, economic, public-utility, and patent features of Bell System operations. Bell System II and III describe some of the technological aspects of telephone communications systems—both those existing and those planned for the future. Among the topics covered here are the nature of telephone signals and what happens to them in local loops, central offices, exchange trunks, and toll circuits. Here also are described various switching, transmission, and signalling systems. Additionally, these courses cover associated problems such as automatic message accounting, alternate routing, and direct distance dialing.

During this period a trainee also undertakes two 3-month laboratory assignments in departments other than the one that originally employed him and to which he will later return as a CDT graduate. These rotational tours of duty broaden his knowledge of the diversity of Laboratories operations and give him practical insight into the nature of the work currently under way in these departments. The rotational assign-

FIRST-YEAR COURSES

Courses	Semester Hours
Functions of a Real Variable	3
Functions of a Complex Variable	3
Theoretical Physics	3
Fundamentals of Network Theory	3
Fundamentals of Electromagnetic Fields	3
Logic and Switching	3
Vacuum Tube and Transistor Circuits	6
Bell System I	1

SECOND-YEAR COURSES

Courses	Semester Hours
Probability and Statistics (required)	3
Time Series	3
Fundamentals of Solid State Electronics	6
Physical Electronics	3
Introduction to Microwave Networks	3
Solid-State Electronic Devices and Circuit Applications	6
Electrical Transients	6
Feedback Amplifiers and Control Systems	6
Network Theory	6
Sampled Data Systems	3
Bell System II, III	4

THIRD-YEAR COURSES

Courses	Semester Hours
Acoustics	1
Statistical Methods	2
Probability Applied to Traffic Engineering	2
Communication Theory	2
Signal Theory	1
Design of Electroacoustic Apparatus	2
Transmission Devices	2
Switching Devices	2
Large-Signal Semiconductor Device Circuitry	2
Switching Circuits	2
Systems Engineering	2
Transmission Systems Design I, II	4
Switching Systems	2
Data Processing Systems	2
Digital Computer Programming	1
Design for Production and Service	2
Human Engineering	1
Technical Writing	1
Advanced Topics in Mechanics	2

ment is intended also to give the trainee an opportunity to learn by doing. CDT trainees on rotational assignments frequently make important technical contributions to the work of their department; occasionally such work results in a patent application.

After completion of the NYU portion of the CDT program, the trainee has one more year of course work in various areas of Bell Laboratories technology. These third-year courses are organized and taught by Bell Laboratories instructors. They deal with material that falls into one of the following three categories: (1) material that is so new that it has not yet found its way into regular university courses (examples: signal theory, switching devices, large-signal semiconductor circuitry); (2) material that is available in college courses, but the Laboratories prefers to offer it under such circumstances that a strong Bell System flavor can be incorporated (examples: communication theory, systems engineering, transmission systems design, switching systems); (3) material that is so specific to Bell System operations that it is not generally found in college courses (examples: probability and traffic engineering, design for production and service).

During his third year a trainee attends courses one day per week and works with his department the remaining four days per week. The third-year courses he selects from the list of those

G. K. Helder is a member of the Transmission Engineering department. He received his Master's degree last spring, and is now completing his third and final year under the CDT program.

available (*see table on page 411*) depend partly on his personal interests and partly on the particular needs of his department. Normally a third-year load consists of 5 class hours per week for two semesters.

An employee coming to the Laboratories with a Bachelor's degree in Mechanical Engineering or Engineering Mechanics and wishing to pursue his advanced studies in one or another of these fields enters one of the CDT mechanical curricula. At the end of his second year he receives a New York University Master's degree in Mechanical Engineering or Engineering Mechanics, and then goes on with the third-year courses.

In 1960 new curricular options in mathematics and physics are being offered for the first time. Options in equipment design, electromechanical switching and others are in prospect. Each of these alternate options will be comparable in intellectual content with the programs already established.

Advanced Standing

Bell Laboratories frequently employs men who have graduate credit or Master's degrees already earned at other universities. These new employees are admitted to the CDT program with advanced standing. They can then complete the CDT graduation requirements in less time than can a man starting with a Bachelor's degree and undertaking the entire program.

For employees at the branch laboratories there is a program similar to CDT. This program, called the Branch Laboratories Educational Plan (BLEP), includes a Master's degree complement of graduate courses taken at a university conveniently located to the branch laboratory site. The employee may also take additional university work beyond the Master's requirements. The BLEP program requires a laboratory assignment at a New Jersey location for one summer during which the trainees take the Bell System I, II, III sequence. Graduates of CDT and BLEP who wish to do so may continue graduate study for the Doctorate under the terms of the Graduate Study Plan.

Evolutionary growth and development are needed to keep the CDT and BLEP Programs abreast of the changing environment of which they are a part. These programs have proven to be satisfactory media for providing the Laboratories with a continuing supply of well-trained engineers in sufficient numbers to meet its current employment needs.

Engineers realize that nature seldom gives us something for nothing. Still, the new "ON-over-K" carrier system comes close to providing a free transmission medium for telephone circuits up to 200 miles in length.

J. B. Evans, Jr. and E. Homan

The "ON-over-K" Carrier System

The type-K carrier system, standard Bell System equipment for many years, furnishes long-distance telephone circuits using 19-gauge wire pairs in a cable. Each pair carries 12 channels, "stacked" between 12 and 60 kc by the conventional single-sideband frequency-multiplex techniques. Pairs in separate cables are used for the two directions of transmission. Thus two pairs provide 12 two-way talking circuits. All of us have spoken over these facilities at one time or another, sharing a cable pair with 11 other customers (RECORD, *April*, 1949).

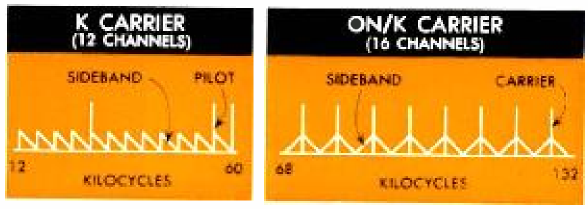
Many miles of K cable are now in the field. On some of these routes there is need for short-haul circuits too; that is, telephone trunks at intervals along the cable route, each trunk connecting cities or towns up to two hundred miles apart (RECORD, *February*, 1959).

A transmission system known as "ON-over-K" (abbreviated "ON/K") permits use of certain existing K-carrier cable pairs to carry these short-haul circuits as well as the usual long-haul channels, thus obviating or at least deferring the installation of new cables. This is accomplished by straightforward frequency-multiplex techniques; specifically, by stacking up to sixteen short-haul channels in the frequency space above the K signals. This means that the ON channels are all above 60 kc. (*See drawing on page 414.*)

The multiplex equipment that effects the stacking consists mainly of ON-type terminal equipment in four-channel blocks, standardized earlier for other short-haul applications (RECORD, *November*, 1956). Thus, the development of new equipment for the system was limited essentially to the line filters and the ON/K repeater. These components function to separate the high ON/K frequencies from the low K frequencies, amplify them and recombine them with the amplified K signals at each K repeater station. The same ON/K repeater design is used at terminal stations to connect the ON terminals to the cable.

In spite of the conventional nature of the frequency-multiplex scheme, many interesting problems arose in the design of the system. For example, one of the basic requirements prohibits cutting into the cable and adding repeater stations between the already existing K buildings (up to 18 miles apart). This requirement comes from the more basic objective of least disturbance and minimum addition to existing plant. However, it results in extreme signal-level differences between the two carrier-frequency bands. These level differences occur because the cable loss is very high (over 100 db) between K repeater stations at the higher frequencies used for ON/K. A tenth of a watt of carrier power must be delivered to the cable at the output of each repeater. This power level is rather high for telephone work. But even so, its magnitude is attenuated by the cable to one hundred-thousandth of a microwatt at the next station.

This brings even loud-talker energy so close to the ever-present, electron thermal-agitation noise that even a perfectly "quiet" (zero decibel noise figure) receiving amplifier would not permit the system to meet Bell System standards. In fact, it would be impractical to meet well-established noise objectives without a device called a "compandor," which is an integral part of the ON terminal (RECORD, *November*, 1953). The compandor effectively improves signal-to-noise ratio about 20 decibels by boosting weak-talker energy before transmission and restoring it to normal at the receiving terminal. (Strong talkers

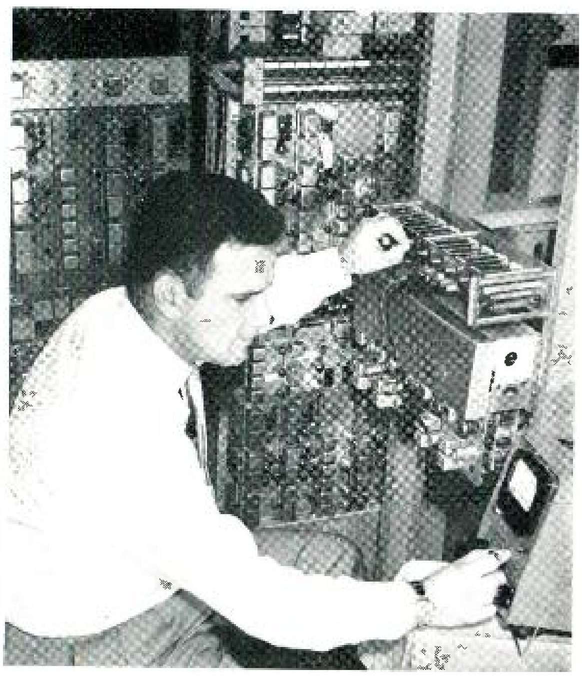


Line frequency spectra for the K and ON/K signals—all are transmitted on the same cable pair.

are unaffected or perhaps reduced in energy slightly for transmission.)

The more obvious approach—increasing transmitted power—would have defeated the basic objectives by requiring so much additional battery power that the K buildings would have to have been expanded.

Even with the compandor, thermal noise alone is amplified to within a few decibels of the objective for 200-mile ON/K systems, so care must be taken in installation to avoid the introduction of more noise energy by induction from foreign sources. This means observing special requirements for installation of office-cable, installing longitudinal noise suppressors, and even removing certain signals (for example, local loop dialing) from the K cable. The savings in situations where ON/K has been applied have easily justified the extra effort and special precautions.



E. Homan with experimental laboratory ON/K installation. An adjustable deviation equalizer is mounted on the rack. The ON/K repeater or terminal amplifiers are mounted below the equalizer.

To make up for the 100-decibel cable loss between repeater stations, the ON/K repeater amplification is also 100 decibels. This is a power ratio of ten-billion to one, which required very careful circuit and equipment design to avoid oscillation and crosstalk. For example, a stray hundred-thousandth of a microwatt picked up at the repeater input would drive the output stage to full power.

To control crosstalk and prevent self-oscillation, high-level signals must be kept physically remote from low-level ones. In the line facilities, the normal K-carrier feature of separate cables for the two directions of transmission eliminates serious problems of crosstalk. In the ON/K repeater, separation is achieved by dividing amplification into two pieces, a receiving amplifier feeding a transmitting amplifier (*See next page*). In a two-way repeater, two receiving amplifiers (low-level signals) are separated from two transmitting amplifiers (high-level signals) by an interposed fuse-panel. In addition, low-level signals are cabled down one side of the mounting bay and high-level cabling goes up the other so that the bay itself assures separation. Also, special shields are used between adjacent bays. Besides controlling crosstalk, separation of the amplification function into two pieces permits the use of the same amplifier designs at terminals, where the transmitting amplifier alone amplifies the intermediate ON terminal levels for transmission to the cable and the receiving amplifier alone amplifies signals received from the cable.

The separation of amplifiers also permits branching off of the ON/K to type-N or type-O carrier systems for extension over a branch cable or open-wire for ultimate termination at a point remote from the K cable. This requires the use of additional equipment not discussed here.

The circuitry of the ON/K amplifiers closely resembles a type-N carrier repeater (RECORD, *September*, 1953). The main difference is the 418A output tube in the ON/K transmitting amplifier. In the equipment design, die-castings of the kind used in type-O carrier are used for both amplifiers.

Amplifier Circuitry

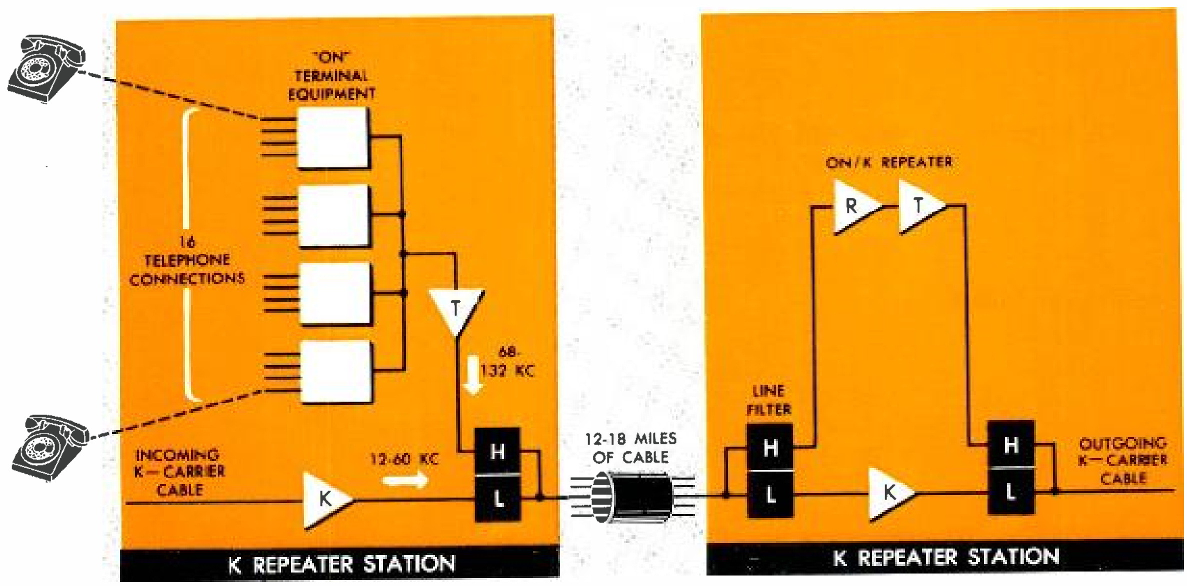
In the transmitting amplifier, (*see drawing page 416*) which provides 43 db of gain at 132 kc, a two-stage amplifier with a 418A power output tube to handle the high power output (22 dbm) is required for adequate signal-to-noise ratio. A thermistor regulator in the feedback network assures an output that is stable within plus or minus 0.5 db for variations in input power of up to plus or minus 10 db. Because the thermistor is sensitive to ambient temperature a compensating network is furnished. The feedback circuit is connected as series feedback at the input, and high-side hybrid feedback at the output. Also, a network is employed in the feedback circuit to equalize the deviations from the desired characteristics in the basic slope equalizer and the line filters. The basic slope equalizer—mounted on the amplifier chassis—is used to pre-equalize for the cable frequency characteristic of the following line section. Thus, all channels are equal in level at the input to the next repeater.

The receiving amplifier, giving approximately 57 db of gain across the frequency band, is a two-stage feedback amplifier (two 408A tubes) with slope adjustment, plus a low-pass filter. Operation of the amplifier is similar to that of the transmitting amplifier, the main difference being in the feedback network and the output tube. The receiving amplifier has no basic slope equalizer.

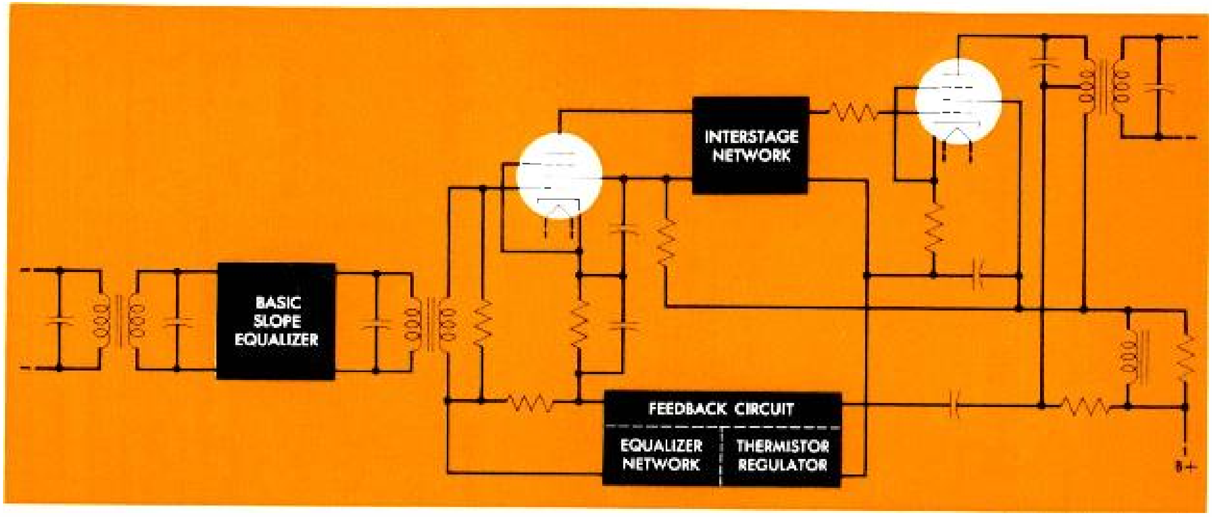
The feedback circuit includes the manufacturer's flat gain adjustment and a field slope adjustment. The slope steps, which do not affect the total output power, have slope variations of 0 db, minus 1 db, and minus 2.8 db. Slope adjustment compensates for unit replacement, component aging, and cable build-out deficiencies. The power output level of the receiving amplifier is only –25 dbm per carrier, hence the use of a 408A output tube.

When K carrier cable sections are less than 18.2 miles in length, artificial lines are used to compensate for integral miles, and span pads (in 2 db steps) for fractional miles. However, span pads compensate only for the flat level difference of fractional miles, leaving a small slope error.

The ON and K carrier frequencies are com-



Block diagram of part of an ON/K system. ON-type terminal equipment at a K repeater station translates 16 voice channels to the frequency spectrum 68-132 kc. The line filters, which have low-pass and high-pass sections, separate and recombine the ON and K signals at the repeater stations.



Simplified schematic of ON/K transmitting amplifier in tandem which, with a receiving amplifier, makes up an ON/K repeater providing 100 db of gain at 132 kc. The output is stable within ± 0.5 db.

bined or separated by a line filter. This filter is a balanced network with a low-pass section which passes K carrier frequencies (12 to 60 kc) and a high-pass section which passes ON carrier frequencies (68 to 132 kc). The impedance level at the low-pass, high-pass, and line sides of the filter is 135 ohms.

There are several sources of systematic transmission level deviations in the ON/K system, depending on individual system layouts. The major equalization problem is an impedance mismatch—caused by inserting the input line filter between complex impedances (the cable and the input side of the ON/K receiving amplifier). This mismatch is greatly increased when artificial lines, originally designed for type-N carrier, are inserted between the filter and the amplifier. Therefore, a new 2-mile artificial line was designed which minimizes the deviations; two of the new 2-mile artificial lines can be used in tandem where a 4-mile artificial line is required.

Eliminating "Sing"

The accumulation of many of these small deviations throughout an ON/K system could surpass the limits set for nationwide distance dialing. Such limits are established to reduce the probability of "sing" on a built-up connection. Sing can result when any part of a channel frequency band is higher than its 1-kc level. For satisfactory protection against probability of sing and for good voice reproduction on a 200-mile ON/K system, the requirement is that the variation in any 2-kc band shall not exceed 1 db. Because the deviations discussed above vary from system to system, an adjustable deviation equalizer was developed to equalize system deviations to within required limits.

The equalizer comprises eight series resonant circuits, four of which are effectively parallel resonant circuits because of their location in the feedback network of the amplifier stage. It was found that the use of the amplifier stage is the most practical method of obtaining series and parallel resonant circuits with minimum interaction, and with a 7-db pad it produces unity flat gain for the entire network. Because a low gain is desired, the feedback circuit is unusual in that only a shunt network is used (a resistor shunted by the four resonant circuits), and the signal is fed back from the tap of the output transformer to the control grid of the tube.

Besides transmission-frequency characteristics and noise, crosstalk must be kept under control. This is achieved by shielding the physical layout to minimize coupling, and by the use of about 30-db negative feedback around the transmitting amplifier to suppress crosstalk caused by amplifier nonlinearity. In installation, careful attention must be paid to bay cabling.

With these special measures applied to control noise and crosstalk, ON/K telephone circuits meet all Bell System objectives and give good commercial service up to the design limit of 200 miles. Moreover, a total length of individual ON/K systems up to 400 miles may be installed along any one K carrier route. The system is now providing message-circuit relief along several K cable routes and in one installation it is being used for program transmission.

The trend towards miniature devices has brought forth some new, critical techniques for their manufacture. A typical technique is oxide masking—used to make possible mass production of a widely used silicon transistor.

K. E. Daburlos and H. J. Patterson

OXIDE MASKING

Electronics systems under development at Bell Laboratories will require large numbers of new solid-state devices. These include high-speed diodes and transistors, rectifiers, three-junction devices, and many more. Along with the development of the appropriate devices must come new techniques of fabrication that lend themselves to large-quantity manufacture. These techniques must be perfected to such a degree that manufacturers can guarantee an easily made, inexpensive device for the new systems. It also, of course, must be reliable.

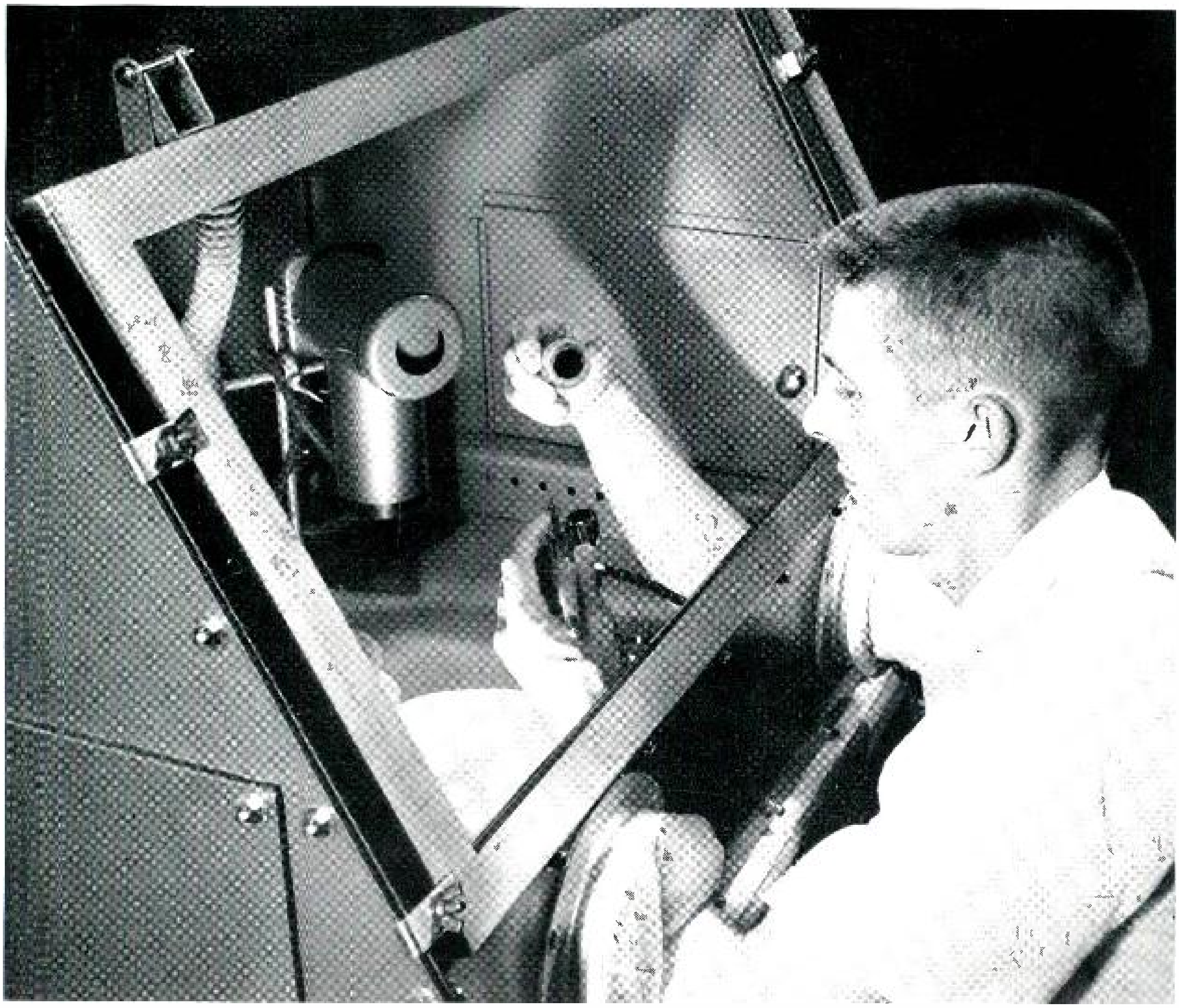
One such technique is oxide masking, used in making silicon transistors. Oxide masking is a proven process step for a new silicon transistor currently in production at the Western Electric Company at Allentown, Pennsylvania. This transistor is being used in the preliminary development stages of the experimental Electronic Switching System (RECORD, *October*, 1958), the Electronic Private Branch Exchange, Pulse Modulation Carrier, and in other systems now being investigated. The Bell System has estimated that by 1967, it will need eight to ten million of these transistors every year.

In the oxide masking technique, silicon dioxide is used to "mask" silicon from certain impurity diffusants, while permitting others to pass through it. This is done during the formation of the transistor junction (p-n or n-p) by the method of diffusion (RECORD, *December*, 1956). To understand more easily and to appreciate the advantages of oxide masking, we will use this silicon transistor as an explicit example.

Transistor Construction

The basic configuration of a diffused transistor made without oxide masking can be visualized as a piece of silicon that has been converted into a "n-p-n" structure by diffusion techniques. To achieve this conversion, a slice of n-type silicon—a material in which the dominant electrical carriers are electrons—is highly polished mechanically. The polished surface is necessary to ensure the flat and parallel junctions indispensable to proper performance in transistors. This surface, therefore, is the reference surface for all subsequent diffusions.

In the next step, the element gallium is diffused into the silicon to a depth of 0.00015 inches to form the collector junction. This is a p-type impurity, acting as an "acceptor" of electrons. It is in the same family of elements as aluminum and boron. Phosphorous, an n-type impurity, acting



M. A. Peters operates apparatus with which photo-resist solution is sprayed on silicon slice. *This work is done in the absence of ultra-violet light and in as clean as possible an atmosphere.*

as a "donor" of electrons is then diffused in on top of the gallium layer to a depth of 0.0001 inch. This forms the emitter region. The resulting structure is an n-p-n device—emitter (the phosphorous layer), base (the gallium region between the emitter and collector) and collector (the original silicon material).

To complete the transistor, an assembler must bond electrodes to each of the three regions. He can easily make electrical contact to the emitter and collector, because they are exposed to the outside surfaces of the transistor element. However, the base region is sandwiched between the emitter and collector and, furthermore, is only 0.00005 inch thick (approximately 1/70 the thickness of a sheet of paper). So it is easy to imagine the difficulty an assembler would have in attaching a wire contact to this base. Moreover, eventually this step must be performed for millions of transistors per year.

This difficulty can be circumvented, however, by containing the emitter region in a "column" of n-type material projected into the gallium layer from the polished surface. This forms the desired width of base region, and leaves the rest of the surface area for base contact. Such an arrangement is achieved by oxide masking.

As we mentioned earlier, certain impurity diffusants are selectively masked by silicon dioxide. Phosphorous is one of these; gallium is not. The procedure takes advantage of these chemical phenomena and exposes the base layer to the top surface of the slice as follows.

In the procedure, silicon dioxide is thermally grown to a thickness of 0.00004 inch on the polished surface of the silicon slice at a temperature of 1250 degrees C in a wet-oxygen atmosphere. The gallium is then diffused through the oxide into the silicon slice. Since the oxide will mask the subsequent phosphorous diffusion, the assembler must now remove the oxide from selected areas on the slice to allow the phosphorous to diffuse into the silicon.

Chemical Treatment

To accomplish this, he sprays the surface of the oxidized slice with a "photo-resist" solution that is sensitive to ultra-violet light. Upon receiving this solution, the slice becomes, in effect, a photographic plate. A master mask containing opaque areas of the same shape and size of the desired emitters is placed in contact with the coated slice. This mask consists of an array of over 1000 blackened emitter patterns, 0.004 inch by 0.006 inch, and spaced in an array of 0.030 inch by 0.030 inch center lines. Each pattern will ultimately result in a transistor.

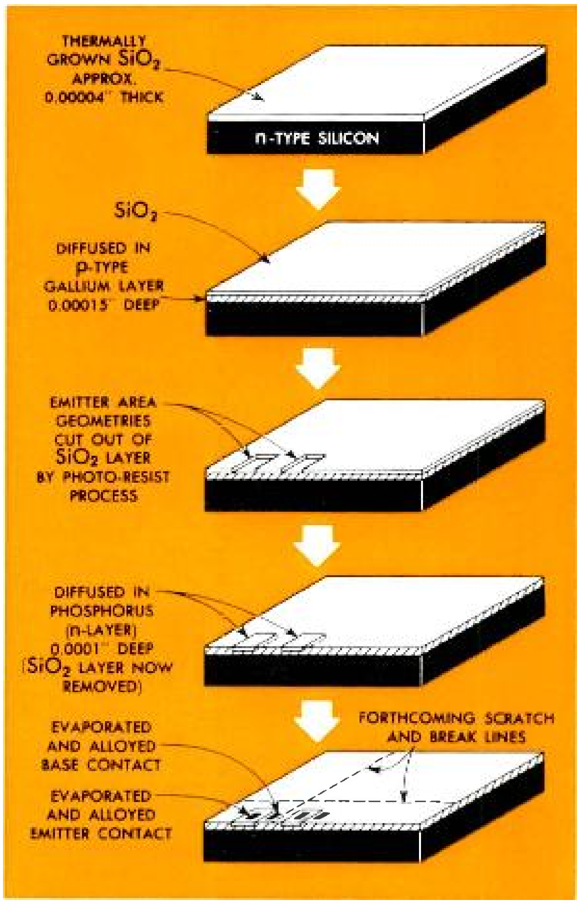
The assembler then exposes the slice and its mask to ultra-violet light from a mercury vapor lamp. Since the photo-resist film under the blackened areas is not exposed to the light, it remains unchanged. However, the exposed portion of the film is polymerized by the ultra-violet light—it undergoes a chemical and physical change that renders it insoluble during subsequent operations. The assembler then develops the photo-resist film, just as he would a photographic plate, and washes away the soluble photo-resist at the unexposed emitter areas, leaving the insoluble (exposed) photo-resist in place.

During the next step, he washes the slice in deionized water and dries it at an elevated temperature. This hardens the remaining photo-resist film, protecting the underlying oxide. After drying the silicon slice, the assembler immerses it in a solution of ammonium fluoride and hydrofluoric acid to dissolve only the exposed oxide at the emitter areas. After this step, he removes the remaining photo-resist with trichlorethylene. He then diffuses phosphorous into the silicon through the exposed emitter regions, the oxide acting as a barrier to phosphorous diffusion elsewhere. A hydrofluoric acid rinse now removes all oxide to prepare the slice for electrical contacts.

Metallic stripes that will facilitate connecting wire leads to the silicon surface are now made on the emitter and base areas by metallic vaporization and alloying techniques (RECORD, *October*, 1958). A one-inch square of silicon yields approximately 900 potential transistors. The assembler can separate these into individual elements by "scribing" with a diamond point and then breaking along the scribe mark. The method is similar to cutting window glass.

Before the slice is scribed, however, the collector junctions of all the transistors are "etched in" as a group. This step is necessary since scribing or breaking *through* a junction will electrically damage it, impairing its rectification characteristic.

Before etching takes place, wax is sprayed through a mask that exposes only the area immediately surrounding the emitter junction and metal contacts. With this protecting layer of wax over each transistor, the assembler immerses the slice, in an etching acid that dissolves the exposed silicon to a depth deeper than the collector junction. This etching action on the junction is a very mild treatment compared to mechanically breaking through it, and permits a good rectification characteristic. Finally, the assembler washes off the protecting wax with a suitable organic solvent. The slice



Major steps in making a diffused n-p-n silicon transistor using mass-production technique of oxide masking. One-inch square piece of this material yields approximately 900 transistors.

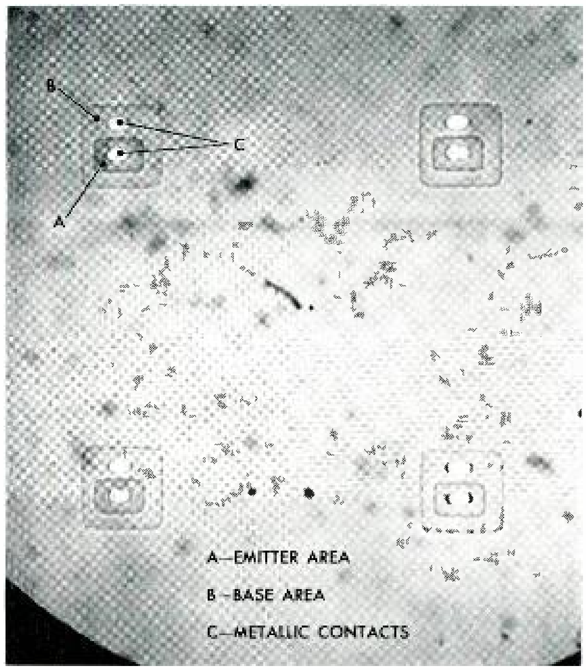
then consists of 900 small mounds called "mesas" —each a potential transistor.

The assembler can now scratch and break the slice into separate transistors without damaging either the collector or emitter junction. He can attach electrical leads to the emitter, base and collector regions, and then give the unit a final but very light etch to clean the emitter junction. The latter has not been damaged during scratching and breaking since no fracture lines pass through it. Each unit is then mounted on a metal-glass platform and enclosed in a suitable envelope, or can.

The above example shows the advantage of using oxide masking to expose the base area to the surface of the silicon. However, even further advantages can be had by also using the oxide to contain, or selectively diffuse, the base region as has been described for the emitter region. One of the advantages here is that the electrical capacitance of the collector junction can be held to the smallest possible value and to within very tight tolerances. One should hold constant all process parameters, such as the starting resistivity of the silicon and the depth of the junction. Then the capacitance of the collector junction at a given bias will be determined solely by the area of the collector junction—the larger the area, the greater the capacitance.

Most circuit applications require a low capacitance for collectors. The area of the collector junction, and hence the capacitance, is determined by the area of the wax dot used during the etching of the collector junction. This dot is only 10 mils square. Device designers have found it much easier to hold close tolerances for a given pattern using photography than by spraying wax. Since the tolerance can be held to very small values, it is economical to decrease the area of the collector junction, thereby decreasing the capacitance. Of course, the added advantage of guaranteeing a customer a uniform product is also desirable.

Another advantage in oxide-masking the base region is the probability of increased reliability. Since the collector junction would now be contained in a small area, such that the scratching and breaking fractures would not pass through it, a prolonged etch to restrict the collector area would no longer be necessary. Therefore, the wax spraying would no longer be needed, and hence a cleaner transistor could result. The final, very mild, etch used to etch-in the emitter junction in "single" oxide masking will now etch-in the collector and emitter junction at the same time.



Microphotograph (magnification 42 times) of transistor elements made with boron as the impurity.

To make the transistors this way, an impurity masked by silicon dioxide must be used for diffusing the base. Boron is such an impurity. The same process used to form the emitter areas are used to form the emitter and base areas. In this case, it is imperative for silicon dioxide to be regrown over the base area during the boron diffusion. Thus it can provide a sufficient layer of oxide for masking during the emitter diffusion. The microphotograph on this page shows a design of a transistor element fabricated in this way at the Allentown Location of the Laboratories.

As advantageous as oxide masking appears to be, it is still quite a specialized technique. One prerequisite for its use is the need for polished silicon slices. These are necessary since a continuous oxide layer with very good masking properties will grow only on a polished surface. On the other hand, a discontinuous and spotty layer with very poor masking properties will grow on a rough silicon surface.

We have seen that the technique of oxide masking provides a valuable tool in making diffused silicon transistors. It is basically a simple process, economical and compatible with mass production. Therefore, it can take its place with those techniques required to meet industry's very large demands for transistors.

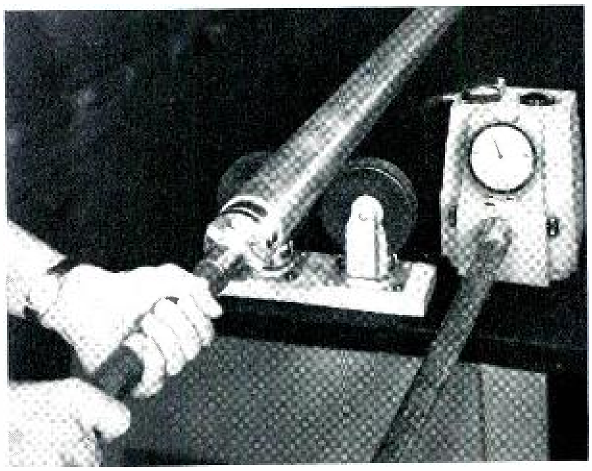
Microwave "plumbing"—the vital arteries of waveguide used in radio-relay transmission—requires very precisely dimensioned "pipes." To check the inside dimensions of waveguides to accuracies of 10-millionths of an inch, Laboratories engineers use air gages.

L. E. Abbott and A. F. Pomeroy

AIR GAGES FOR CHECKING WAVEGUIDE DIMENSIONS

Modern microwave transmission systems, though designed primarily as radio media, nevertheless require many thousands of feet of waveguide for the "direct" transmission of microwave signals. Waveguides conduct these signals between repeaters on the ground and antennas atop towers in point-to-point, radio-relay systems. Someday, circular waveguides may conduct hundreds of thousands of multiplexed telephone signals directly from one repeater to another, underground.

The inside dimensions of the waveguide determine its electrical characteristics. For this reason, transmission engineers and research scientists at Bell Laboratories are vitally interested in methods for accurately measuring these important dimensions. In current research work, for example, it is important to know accurately the dimensions of experimental waveguides. Also, the tube mills that manufacture waveguides require explicit infor-



Measuring inside dimensions of a length of circular waveguide. Fluorescent tape on rear of gage head indicates the direction of measurement.

mation on inside dimensions to be certain their product will meet the very strict requirements for satisfactory performance.

To measure the inside dimensions of both circular and rectangular waveguides, Laboratories engineers have recently standardized several types of suitably designed air gages. This article describes briefly some of the important types of air gages currently in use in the measurement of waveguides for the Bell System.

Earlier Measurement Methods

For many years, the inside dimensions of a tube were usually measured by calipers. But for waveguides, calipers have several limitations. For example, the depth to which calipers can be inserted in a tube is quite limited. If measurements are not made at a sufficient depth, accuracy is questionable because of "belling," or local expansion, at the mouth of the waveguide.

Another popular method for checking inside diameter is to measure outside diameter and wall thickness with a micrometer and then determine the inside diameter by subtraction. The final result is then only half as accurate as any one micrometer reading. To check the diameters at different orientations, this technique requires many micrometer measurements.

Still another method, commonly used in tube mills, is to insert plug gages of graduated sizes in the openings. This technique also has drawbacks. A gage that is easily inserted is always smaller than the true opening, since the gage must "ride" on high spots. Conversely, a gage that is forcibly inserted distorts the guide and hence does not lead to a true indication of size.

Since we have mentioned the strictness of tolerance and accuracy, it might be well to indicate the requirements that a suitable waveguide-measurement method must meet. Specifically, these are: (1) accuracy to plus-or-minus 0.0001 inch (2) for rectangular waveguide, simultaneous measurement of three or four dimensions in one plane perpendicular to the length of the tube; (3) for circular waveguide, measurement of true diameter in any cross-sectional plane through the tube; (4) measurement at any perpendicular plane within a ten-foot length of either circular or rectangular waveguide.

The air gages designed to meet these requirements were, in general, adapted from existing commercial designs. Operationally, air gages are based on some elementary principles of air flow through a tube. To a first approximation, the pressure in a pipe through which air is flowing is proportional to the flow. If an obstruction (in this case a gage) terminates the pipe, flow becomes inversely proportional to the back pressure developed at the end of the pipe, either at the point where the gage terminates the pipe or at the point of exhaust to the atmosphere. In other words, if the gaging orifices are close to the wave-

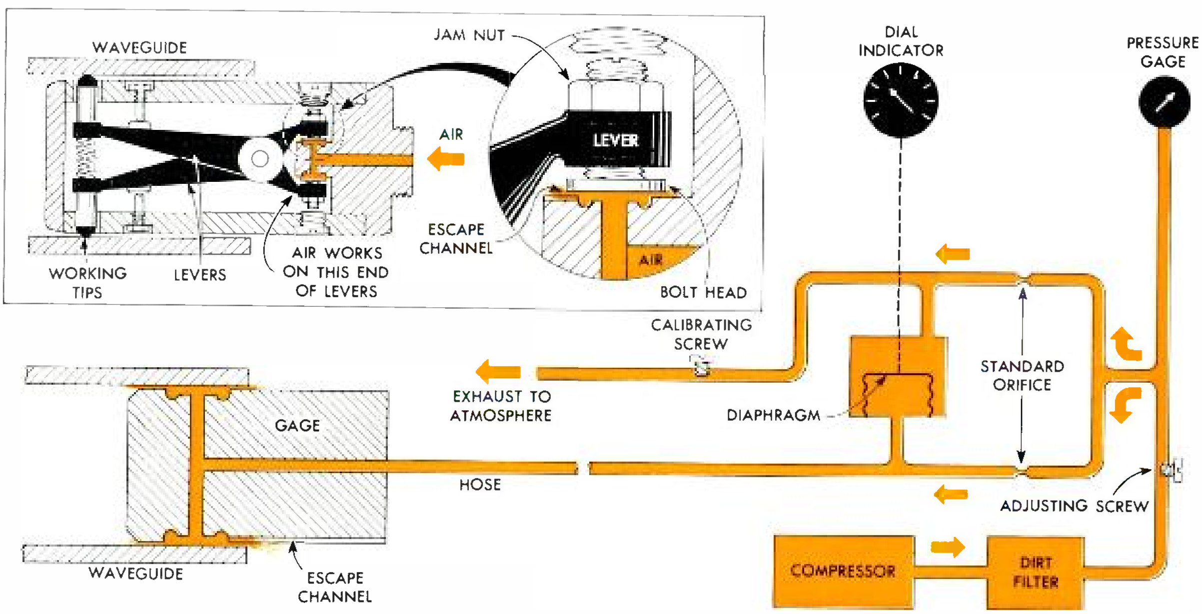


Diagram showing the air-gaging principle. Arrows show flow of air, starting at compressor, lower right. Readings from the dial indicator can be translated into a linear measurement. Details of the lever-type gaging head and its air-flow pattern are shown inset at the upper left-hand corner.

guide walls, air flow is reduced; if they are far from the waveguide walls, air flow increases. If the pressure in a pipe exhausting to the atmosphere is compared to the pressure in a pipe terminating in a gage, one has an air-gaging system.

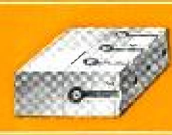
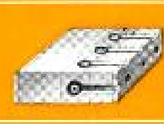
If these two pressures are connected to the opposite sides of a diaphragm, the movement of the diaphragm will indicate the difference between the two pressures. A very sensitive dial indicator can be used to read the movement of the diaphragm, thus translating comparative pressure into a linear measurement of dimension. This arrangement is shown in the diagram on page 422. Accuracies of 40 millionths (0.000040) of an inch are easily obtainable by this method, even in measuring dimensions that vary as much as plus and minus three thousandths (0.003) of an inch.

The adjacent table shows the range, dimensions and general appearance of the gages developed for use in the Bell System. The actual "gaging" points, where air pressure is introduced into the waveguide, are the small orifices on the side of the gage plugs shown in the left-hand column of the table.

For the largest circular head, a unique lever-action arrangement was developed to extend its linear range of sensitivity from 0.003 inch to 0.010 inch. A sketch of this lever arrangement is in the inset in the first diagram. The other gages measure the pressure of air that is in direct contact with the surface being checked. By contrast, the lever arrangement works with the tips of the X-shaped lever in contact with the surface and the gage measures the air pressures on the opposite ends of the levers. Their linkage is arranged to allow a fairly wide motion of the gaging tips with a limited effect on the pressure of the measuring air.

Before the circular gage is inserted in the tube, the indicator dial is calibrated by inserting the gage head in a "master ring." One ring gives maximum tolerance and the other gives the minimum. Variations between the maximum and the minimum can then be read directly from the indicator dial. A similar procedure is used to calibrate the dial for measurements on rectangular waveguide.

The gages for checking rectangular waveguides all work on the direct air-pressure principle. They are significantly different from the round heads, however, in that they measure several dimensions simultaneously. This means that within each rectangular head there are actually three or four independent measuring systems. For this reason, the very small, 0.900- by 0.400-inch gage was the most difficult to design. Providing space for six

GAGE	DIMENSIONS
	2.812D ± 0.005
	2.000D ± 0.002
	(NOT SHOWN) 0.875D ± 0.0015; 0.750D ± 0.0015
	0.4375D ± 0.0015
	A = 2.290 ± 0.003 B = 1.145 ± 0.003
	A = 1.590 ± 0.002 B = 0.795 ± 0.002
	A = 0.900 ± 0.0015 B = 0.400 ± 0.0015

Left-hand portion of table shows general appearance of round and rectangular heads. Column on right shows direction of measurement, indicated by arrows, with dimensions and tolerances below.

airports in the limited volume available is a tribute to the design effort and workmanship of the Federal Products Corp., who supplied these gages.

The rectangular gages require three or four separate hoses with a dial attached to each. The round head, shown in the photograph on page 421, can be rotated at any point in its passage through the ten-foot pipe to check diameter in several directions. A strip of fluorescent tape on the rear of the round gage indicates the direction of the gaging ports.

The air-gage method is currently in use at the Laboratories, at the Western Electric Shops in Merrimack Valley, Mass., and at suppliers' manufacturing plants. Air-gaging has proved a most satisfactory technique for checking waveguide dimensions and has overcome a significant problem in both microwave research and the development of microwave transmission systems.

In a continuing effort to provide the best possible telephone service, maintenance personnel now utilize 30 automatic or manual test devices of various kinds. These devices quickly indicate possible areas where trouble may arise, so that remedial measures can be taken promptly.

R. C. Nance

Test Circuits for Toll Crossbar

When the average telephone customer, on his first visit to a toll crossbar switching office, views the vast array of pulsating and seemingly alive switching equipment, he may be left in a state of bewilderment and wonder. How can this maze of wiring and equipment possibly work in response to spinning the dial of his home telephone? Further, how can the maintenance personnel possibly keep this equipment working properly?

The complexity of the problem has increased with the expansion of direct distance dialing (DDD) throughout the present telephone network. The greater automation made possible by the new technique does result in more efficient service. However, the fewer customer-operator contacts required by direct distance dialing, make it imperative that switching or circuit component failures be kept to the absolute minimum. For this reason, circuit units include as many self-checking features as is economically feasible. In addition, adequate testing facilities are provided to perform rapid and thorough routine checks to detect circuit malfunctions promptly.

It is well to remember, however, that self-checking features and routine testing serve merely as a convenient and timely means of trouble detection and reporting, and do not remedy the malfunctions encountered. Prompt and aggressive maintenance action is required to analyze reported trouble conditions, to seek the source of malfunction and to apply remedial measures.

Many factors are considered in developing test philosophy. Among them are economics, service requirements, number of circuits requiring tests, reporting or recording means, test access, desired frequency of test cycles, automatic or manual test progression, relative importance of the circuits in the system and the simplicity of operation, interpretation of results, and maintenance of the test gear.

We are faced with a rather complex problem. However, some answers to the questions it poses become clear when one examines the equipment quantities shown in the table on page 426. This table lists the principal circuits in a large toll crossbar office arranged to perform centralized automatic message accounting functions. Associated with each group of circuits are the test circuits used for their maintenance. Common control systems such as toll crossbar are designed to employ a relatively small group of high-usage common-control circuits for switching calls over large numbers of trunk circuits. The table illustrates the relationship of the quantities of common control circuits—that is, markers, senders, transverters, decoders, and the like—to the quantities of trunks. Many of the test circuits listed in the table are discussed in this article.

Since dialed calls may originate or terminate at panel, step-by-step, or the crossbar offices, many variations of toll-connecting trunks are required to perform the switching functions. Additional variations of trunk circuits are brought about by the type of signaling employed to transmit the called telephone number from one switching center to another; such signaling includes multifrequency (MF) pulsing, revertive pulsing, panel call indicator (PCI) pulsing, call announcer (recorded), and step-by-step dial pulsing. One test unit, capable of testing all varieties of trunk circuits in any toll crossbar office would be unnecessarily complicated and expensive. Accordingly, several test units have been developed to perform efficient routine checks on specific types of trunk circuits.

Toll tandem trunk circuits, for example, are incoming. They are maintained from the originating end and do not require routine tests at the toll crossbar office. However, when troubles are reported by operators or switchmen at the originating office, maintenance of the toll crossbar portion of the circuit is expedited by use of a portable "tea-wagon" type test set. This device can connect into the line side of the selected incoming trunk-circuit relay equipment and can thereby route test calls through the toll crossbar switches to a test line which is looped back to the test set. By controlling the inputs to the trunk circuit under test and observing the resultant outputs via the test line, all of the trunk-circuit operational features can be verified and the detected troubles can be isolated for remedial action.

Calls over incoming intertoll trunk circuits originate in crossbar tandem, another toll crossbar, No. 5 crossbar, step-by-step intertoll offices, or manual switchboards. The outgoing intertoll trunk circuits from these offices appear as incoming intertoll trunk circuits at the toll crossbar office. At each originating switching office a testing device is provided to complete test calls via selected trunk circuits through the toll crossbar switches to an operational test line. If more detailed tests of the toll crossbar end are necessary, the portable tea-wagon test set is used as on the incoming toll trunk circuits. Troubles on switchboard trunk circuits are reported by the operators.

Test calls are routed via toll switching trunks by the automatic-outgoing-toll-completing trunk test circuit to test lines in the panel, No. 1 crossbar, No. 5 crossbar and step-by-step terminating offices. These test lines simulate customer lines in respect to ringing and supervisory conditions. Also, a manual outgoing trunk-test-frame tests the toll switching trunk-circuit conductors and local terminating-office incoming-trunk-circuit relay equipments.

The principle facilities furnished to maintain outgoing or two-way intertoll trunks are incorporated into the automatic outgoing intertoll trunk test circuit (RECORD, *December*, 1954) with the associated automatic transmission measuring circuit (RECORD, *December*, 1957), the 17C toll testboard and the portable tea-wagon test set. The toll testboard and the portable test set can be used to manually verify the results indicated by the automatic test circuit.

In a toll crossbar office, senders also require extensive routine tests. Incoming and outgoing senders perform differently and are tested by separate test circuits. All varieties of incoming

T. P. McGuiness checks a relay that failed in the sender circuit during a service call. Trouble-recorder card records progress of call and indicates trouble items detected by self-checking features.

F. R. KAPPEL TALKS ABOUT NEW SERVICES

News from the Bell System

Plans for a whole new array of telephone services and products for the present and future were described by Frederick R. Kappel, President of the American Telephone and Telegraph Company in Boston recently. Speaking before the Conference on Distribution, Mr. Kappel cited: Pocket radiotelephones from which you can talk with anyone, anywhere; satellite communications, including worldwide television; and high-speed machine-to-machine "talk" over the regular telephone network.

"We have a strong feeling that in a few years' time, data communications will actually exceed, in sheer volume, the communication of speech," Mr. Kappel said. "In the future, it is quite possible that trade publications, news bulletins, and even newspapers will be widely circulated over electrical circuits."

He noted that the era of machine-to-machine communications over the regular telephone network is already at hand through the use of Bell System Data-Phones, which "make it possible and practical for many types of business machines to 'talk' over telephone lines."

Mr. Kappel pointed out that use of the regular telephone network for machine-to-machine communication "makes possible a wonderful flexibility—a company's communication system can be expanded or modified almost at will."

He envisioned the development of a network "over which we shall be able to switch pictures, whole rivers of data, or what have you, between any two customers who have compatible equipment."

He cited as evidence of growing telephone versatility the fact that whereas Direct Distance Dialing, by which telephone users can dial their own long distance calls, is now enjoyed by about 20 million customers, it will be almost universal in a few years.

"Further," he said, "it appears to me that step by step, the distinction between 'local' and 'long distance' in communications will gradually disappear. We have already seen the broadening of local telephone calling areas, so that calls between many adjoining communities are not treated as toll calls. Not visionary, but extremely practical, is the concept that many of our customers will want forms of service enabling them to call over wide areas, and even across the continent, at a flat monthly rate."

On the future of mobile telephone services, Mr. Kappel said that "Eventually, it is altogether possible that you could carry a pocket radiotelephone enabling you to talk with anyone else, anywhere, any time."

"Let us say for example that a Boston wool merchant, on his way to visit a customer, might pause a moment to call Australia and check a few facts with an agent there who happened to be off on a camping trip."

In the field of faster calling, Mr. Kappel noted that next month an experimental electronic central office will go into operation. It will enable calls to be switched in millionths of a second, instead of thousandths as in present equipment.

Mr. Kappel predicted overseas calls of the future would go not only via space satellites but through additional overseas cables as well.

Pointing out the necessity for both systems, he said, "Whereas this year we shall be handling something less than 4 million overseas calls, twenty years hence we think the number may be around 100 million—more than 25 times as many."

He cited the Bell System's plan for 50 satellites providing channels between various points all over the globe and said "We have increasing confidence that such a system will not only provide high-quality talking channels, but will also make worldwide television a practical reality."

He pointed out that these developments emphasize the importance of communication research.

"Since 1920," he said, "the Bell System has spent more than a billion dollars for research and technical development. At the present going rate we would spend more than that in the next ten years.

"Looking at the public we serve, at industry, at communities across the land, we are keenly aware that communications needs are growing and changing," he said.

"And we are determined to meet them."

Laboratories Scientists Honored for Outstanding Achievement

Four Bell Laboratories scientists recently received awards for their outstanding contributions to communications technology and physical science. The Franklin Institute awarded Stuart Ballantine Medals to John R. Pierce, Rudolf Kompfner and Harry Nyquist, and the American Institute of Physics honored Karl K. Darrow with the Karl Taylor Compton Gold Medal.

News of Professional Honors

Mr. Pierce, Director of Research — Communications Principles, Mr. Kompfner, Director of Electronics and Radio Research, and Mr. Nyquist, formerly Assistant Director of System Studies, received the Ballantine Medals at formal ceremonies at the Franklin Institute in Philadelphia. Mr. Darrow, formerly a research scientist at Bell Laboratories, was presented the Compton Gold Medal at Columbia University's Arden House, in Harriman, New York.

The medal citation to Mr. Pierce and Mr. Kompfner reads: "For the conception and invention of the traveling-wave tube amplifier, a device based on a new principle of continuous interaction between an electromagnetic wave and an electron beam, that removes the frequency bandwidth limitation of electronic tubes; for the formulation of the fundamental theory of its operation and for its development as an important instrumentality in commercial and military communications."

Mr. Nyquist is cited "for his theoretical analyses and practical inventions in the field of communications systems during the past forty years including, particularly, his original work in the theories of telegraph transmission, thermal noise in electric conductors, and in the theory of feedback systems."

The Karl Taylor Compton Gold Medal, the highest honor which the American Institute of Physics can bestow, was presented to Mr. Darrow for his devotion to physics "in ways without precedent or parallel." The citation for the Gold Medal stated, in part: "With the farseeing cooperation of the Bell Telephone Laboratories, he was able to make a notable career of his great power for exposition, shedding light on newly appearing facets of physics for the benefit of generations of his colleagues."

The Stuart Ballantine Medal was founded in 1946 by the Boonton Foundation. It is awarded by The Franklin Institute, a 136-year-old educational organization, for outstanding achievement in fields of communications which employ electromagnetic radiation.

John R. Pierce earned his B.S., M.S., and Ph.D. degrees from California Institute of Technology. He joined Bell Laboratories in 1936, specializing in the development of electron tubes and in microwave research. During World War II, he concentrated on the development of electronic devices for military applications. Mr. Pierce became Director of Electronics Research in 1952, Director of Research in Electrical Communications in 1955, and Director of Research —Communications Principles in 1958.

In 1954, Mr. Pierce analyzed the possibilities of radio relay by way of artificial satellites, and in 1955, two years before the first satellite was launched, he offered concrete proposals for satellite communications in the journal, *Jet Propulsion.*

For his research leading to the development of the beam traveling-wave tube, Mr. Pierce was awarded the 1947 Morris Liebmann Memorial Prize of the Institute of Radio Engineers. Earlier, he was voted the "Outstanding Young Electrical Engineer of 1942" by Eta Kappa Nu, national engineering honor society.

Holder of 55 patents, Mr. Pierce is author of three books: *Theory and Design of Electron Beams* (1949), *Traveling-Wave Tubes* (1950), and *Electrons, Waves and Messages* (1956). With E. E. David, Director of Visual and Acoustics Research, he is co-author of *Man's World of Sound* (1958).

Mr. Kompfner was graduated from the Technische Hochschule, Vienna. For eight years, he practiced architecture in London, England, while pursuing physics and radio engineering as a hobby. In 1941, the British Admiralty offered him a position in physics and radio engineering under Professor M. L. Oliphant at Birmingham University. It was there that Mr. Kompfner invented the traveling-wave tube. From 1944 to 1951 he did further work for the British Government at various institutions, including the University of Oxford where he worked under Professor Lord Cherwell. He received his Ph.D. degree from Oxford in 1951.

In 1951, Mr. Kompfner joined Bell Laboratories. He was named Director of Electronics Research in 1955 and Director of Electronics and

Radio Research in 1957. The Physical Society of England awarded its 1955 Duddell Medal to Mr. Kompfner for his work on the traveling-wave tube.

The third Ballantine Medalist, Mr. Harry Nyquist, received his B.S. in electrical engineering and his M.S. from the University of North Dakota, and his Ph.D. from Yale University.

From 1917 to 1934, Mr. Nyquist worked for American Telephone and Telegraph Company in the Department of Development and Research, where he was concerned with studies on telegraph, picture and voice transmission. He continued this work at the Laboratories from 1934 until his retirement in 1954.

During his 37 years of service with the Bell System, Mr. Nyquist received 138 U.S. patents and published 12 technical articles, several of which attained classical distinction. His many important contributions to the radio art include the well-known "Nyquist Diagram" for determining the stability of feedback systems and the invention of the vestigial-sideband transmission system, now widely used in television broadcasting.

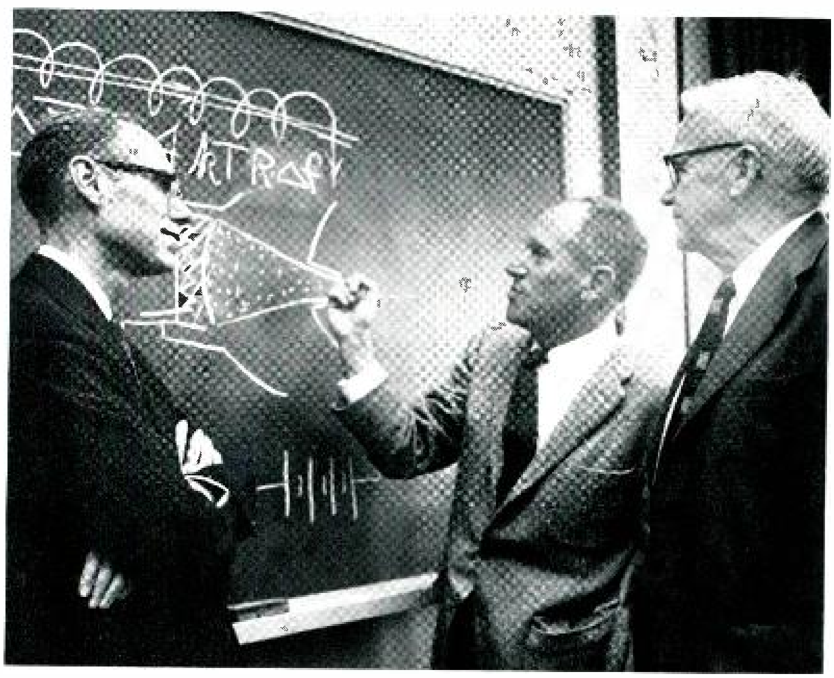
Mr. Nyquist presently is an engineering consultant associated with the Stavid Division of the Lockheed Electronics Company and is working as a consultant on military communication problems at the Laboratories.

In March of this year, Mr. Nyquist was awarded the Institute of Radio Engineers 1960 Medal of Honor for his "fundamental contributions to a quantitative understanding of thermal noise, data transmission and negative feedback." (RECORD, *January*, 1960.)

Mr. Darrow, recipient of the Compton Gold Medal, devoted a major portion of his time to the study and interpretation of current and historical scientific information for his colleagues, to keep them informed of developments in fields of science related to their research activities.

As a result of his extensive writing and lecturing, the influence of Mr. Darrow's work in interpreting science has extended outside the Bell System to include almost the entire body of workers in the physical sciences throughout the world. Among his eight published books are *Introduction to Contemporary Physics*, *The Renaissance of Physics*, *Electrical Phenomena in Gases*, and *Atomic Energy*. He has also written more than 200 scientific articles for professional and technical journals. Mr. Darrow has been a member of the French Physical Society for many years and served for a term on its council. He is also a member of the Physical Society of London and of the International Union of Pure and Applied Physics, which he served as vice president from 1947 to 1951.

In recognition of Mr. Darrow's contributions to science, the University of Lyons in 1949 granted him the honorary degree of Doctor of Science. In 1951 the French Legion of Honor awarded him its decoration, with the rank of Chevalier, for "services rendered to the international relations of science and to the cultural relations between France and the United States."



Stuart Ballantine medallists, left to right, J. R. Pierce, R. Kompfner and Harry Nyquist, discuss Mr. Nyquist's important contributions to the theory of the traveling-wave tube.

news in brief

New Nike-Zeus Contract To be Directed by Laboratories

Bell Laboratories will direct the work for a $199,125,000 contract recently awarded to the Western Electric Company by the Army for continued development of the Nike-Zeus anti-missile missile system.

Included in the contract are funds for continued engineering, installation, and operation of equipment required in the development and test program. The Nike-Zeus system, now in the advanced development stage, is being tested at the White Sands Missile Range and at the Whippany Laboratory. Additional future tests are planned at Point Mugu, California, Ascension Island in the Atlantic, and Kwajalein Island in the Pacific.

A major portion of the work will be performed at the Western Electric plant in Burlington, N. C. Many subcontractors and suppliers will share in the work specified by this contract.

The Nike-Zeus system uses advanced radars and electronic computers to detect and track incoming ballistic-missile warheads, and to discriminate between real warheads and decoy devices. It can launch and control Nike-Zeus missiles to intercept the attacking warheads and render them ineffective without causing damage to defended areas.

New Dimensions in Spring Cords

A new development in station apparatus, the "slim-line" spring cord, is a result of joint efforts by the Western Electric Co. and Bell Laboratories engineers at Western's Baltimore Works. Smaller in diameter than previous spring cords, it also weighs less, is more attractive, and will have a longer service life.

To manufacture the slim-line cord, a single nylon thread "core" is first spirally-wrapped with four flat ribbons of bronze "tinsel." Each bronze ribbon is about as wide as the thread itself and only one-third the thickness of a human hair. For strength, a nylon jacket is knitted over the tinseled plastic. A complete cord has four of these insulated conductors combined into one unit and jacketed with thermo-plastic.

A great saving in production costs is made by using nylon instead of cotton in just two steps of manufacture. Although the new slim-line cord is only about three-hundreds of an inch thinner than the older model, the saving in raw materials will be extensive since more than 17 million spring cords will be made by Western Electric this year.

TASI Aids in Doubling Capacity of Ocean Cable

The TASI system, developed at Bell Laboratories, has helped to more than double the traffic capacity of the undersea cable between Newfoundland and France.

TASI, an acronym for "Time Assignment Speech Interpolation," was first put to use earlier this year on the telephone cable to Great Britain.

The Long Lines Department of the A.T.&T. Co. announced recently that the call-carrying capacity of the deep-sea circuits was boosted by the installation of 3-kc channel banks (RECORD, *July*, 1960) and by the addition of TASI (RECORD, *March*, 1959).

TASI's principle of operation is based on the fact that most telephone circuits consist of two completely separate talking paths —one for each direction of speech. One of these paths is idle while the other is in use, because one party normally listens while the other talks. During pauses in conversation both paths are idle. TASI equipment takes advantage of this idle time by sampling the line several thousand times a second. In this way, it determines which line is momentarily idle and connects that line to someone who at that very instant is starting to talk.

When that party stops talking or pauses, TASI switches the line to someone else. When the first person starts to talk again, TASI instantly has a line for him. This switching is not done until the number of talkers exceeds the number of full-time circuits.

TASI sorts out the fragments of conversations and sends each fragment in proper sequence to the person for whom it is intended. The two persons holding a conversation remain unaware of the whole process.

Laboratories Scores Success in Nike Mobility Program

Bell Laboratories, which is directing a new Nike-Hercules mobility project, has developed a method for making the Hercules missile available to fast-moving ground armies.

According to a recent announcement from the Department of the Army, Nike Hercules can now be transported and launched from mobile carriers. This is one of the most powerful additions to the Army's arsenal of mobile nuclear weapons.

Formerly tied to relatively fixed positions for protection of industrial cities, population centers and defense installations, Nike Hercules can now be made more mobile with the addition of newly developed field equipment that allows the missile to be fired without the use of a concrete launching pad.

Nike Hercules, for which Western Electric is prime contractor, is a supersonic missile with a range over 75 miles and an altitude ceiling in excess of 150,000 ft. Designed to carry either a conventional or nuclear warhead, Hercules will give field armies a high-altitude defense capability and will supplement the Hawk missile, a low level surface-to-air killer.

W.E. Awarded "Project Press" Contract

The Department of the Army recently awarded Western Electric a $1 million contract for installation of facilities for Project Press, an experimental program in the detection and identification of ballistic-missile warheads.

The new contract calls for installation of submarine cable systems linking the islands of Kwajalein and Roi-namur in the Marshall Islands, southwest Pacific. Project Press (Pacific Range Electro-magnetic Signature Study) involves experiments with radar systems of advanced design and other sensing devices that will be installed on Roinamur.

These experiments are part of "Project Defender," administered by the Advance Research Projects Agency, Department of Defense. They are concerned with the physics of ballistic missile flights and the investigation of missile discrimination and identification. The cable system to be installed between the islands, approximately 55 miles long, will be used for voice communications and data transmission.

Support for the Project Press installation on Roi-namur will be furnished from Kwajalein. The Army is presently constructing facilities in and around Kwajalein with which to test its Nike Zeus anti-missile missile system against Atlas ICBM's fired from California. Project Press will use these missiles and other targets available on the Pacific Missile Range.

New Nomenclature Proposed to Aid the Scientist and Engineer

A general method that engineers and scientists can use to differentiate the "natural" from the "artificial" was proposed by Willem van Bergeijk of the Visual and Acoustics Research Department in the October 28 issue of *Science*, a publication of the American Association for the Advancement of Science.

Artificial lung, heart, and kidney machines have become fairly common in hospitals, and electronic laboratories are building synthetic nerves, and sensory elements.

The language a researcher must use to describe such devices has become extremely confusing, even to an inventor who must either make up a name for each new system, or be sure he uses the words "artificial" or "synthetic" every time he wishes to distinguish the replacement from the real thing.

Mr. van Bergeijk proposes to add the suffix "-mime" (from the Greek stem meaning "to imitate") to the accepted medical adjective or root for a given bodily function or organ. Thus, an artificial heart would be called a "cardiomime," while an artificial kidney would be called a "nephromime." The generic term would simplify reporting, and would not require a specific knowledge of the actual device being discussed.

Within this system of general names, Mr. van Bergeijk feels that there would still be room for those who want to name their own devices distinctively. For instance, a specific device might be named ARKID, for ARtificial KIDney.

In Mr. van Bergeijk's own field, artificial nerves would become "neuromimes," hearing machines would be "auromimes" or "otomimes," and seeing machines would be "oculomimes."

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Fox, A. G.—*Phase Shifter*—2,952,821.

Fritts, M.—*Antenna Mechanism*—2,952,018.

Gerkensmeier, O. F.—*Balanced Impulser Circuit*—2,953,646.

Goodale, W. D., Jr., see Boysen, A. P., Jr.

Grubbs, W. J., Jr., see Doucette, E. I.

Hamilton, J. O.—*Reflex Klystron*—2,954,498.

Herckmans, A., see Boysen, A. P., Jr.

Johanson, A. E.—*Magnetic Drum Repertory Dialer*—2,953,647.

Koenig, W., Jr.—*Inverted Speech Privacy Using Irregular Inverting Wave Form*—2,953,643.

Krecek, J. A., and Locke, G. A.—*Teletypewriter Switching System*—2,951,893.

Lane, R. F., see Carpenter, K. R.

Lewis, W. D.—*Error Detection and Correction Circuitry*—2,954,432.

Lewis, W. D., and Rose, A. C.—*Multiple Error Correction Circuitry*—2,954,433.

Locke, G. A., see Krecek, J. A.

Louisell, W. H., see Cook, J. S.

Malthaner, W. A., and Vaughan, H. E.—*Telephone System for Repertory Dialing*—2,951,908.

Miller, R. L.—*Wave Transmission System*—2,953,644.

Myers, G. H.—*Cyclic Digital Decoder*—2,954,165.

Newhouse, R. C., see Carpenter, K. R.

Ostendorf, B., Jr.—*Character Timing Impulse Circuit for Telegraph Receiver*—2,954,487.

Ostendorf, B., Jr.—*Station Selector and Control Apparatus*—2,953,631.

Pearson, G. L.—*Silicon Alloy Diode*—2,952,824.

Pfeiffer, S. B.—*Jitter Suppression in High-Frequency Strodoscopic Oscilloscope*—2,954,501.

Pferd, W., see Boysen, A. P., Jr.

Porter, R. M., Jr.—*Non-Reciprocal Wave Transmission*—2,954,535.

Quate, C. F.—*Electron Beam Systems*—2,951,964.

Rose, A. C., see Lewis, W. D.

Ruggels, D. M.—*Piezoelectric Crystal Unit*—2,953,696.

Ruppel, A. E., see Benewicz, T. F.

Sears, R. W., see Danielson, W. E.

Schroeder, M. R.—*Generation of Interpolation Waves*—2,953,645.

Stone, H. A., Jr., see Doucette, E. I.

Ulrich, W.—*Gate Circuits*—2,954,483.

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

Warner, A. W., Jr.—*Crystal Unit Mounting*—2,954,490.

Warner, R. M., Jr., see Doucette, E. I.

White, P. R., see Bouton, G. M.

Williams, R. D.—*Coordinate Switching Arrangement*—2,954,440.

Wilson, R. L.—*Pulse Distributing Arrangements*—2,953,694.

Wintringham, W. T.—*Multiple Beam Scanning System*—2,953,638.

Yocom, W. H., see Cook, J. S.

CONGRESS OF INTERNATIONAL UNION OF CRYSTALLOGRAPHY, CAMBRIDGE, ENGLAND

Abrahams, S. C., *The Crystal and Magnetic Structures of Lithium Cupric Chloride Dihydrate and of Ludlamite at the Temperature of Liquid Helium.*

Abrahams, S. C. *Thermal Motions in Cupric Fluoride Dihydrate at 298° K and at 4.2° K.*

Compton, V. B., see Wood, E. A.

Geller, S., *The Crystal Structure of B-Ga_2O_3.*

Geller, S., *The Crystal Structure Exchange Interaction and Ionic Distribution in Substituted Ferrimagnetic Rare Earth Iron Garnets.*

Wood, E. A. and Compton, V. B., *Structure and Stacking Faults of $HfFe_2$.*

INTERNATIONAL CONFERENCE ON SEMICONDUCTOR PHYSICS PRAGUE, CZECHOSLOVAKIA

Geballe, T. H., see Pollak, M.

Herring, C., *The Current State of Transport Theory.*

Hopfield, J. J., and Thomas, D. G., *Magneto-Optic Absorption Spectrum of CdS.*

Lax, M., *The Present Status of Semiconductor Physics.*

Pollak, M., and Geballe, T. H., *Incipient Impurity Conduction in Silicon.*

Thomas, D. G., see Hopfield, J. J.

OTHER TALKS

Anderson, P. W., and Morel, P., *Aligned Orbital Angular Momentum in the Proposed Low-Temperature Phase of Liquid He_3*, VII International Conf. on Low-Temperature Physics, Toronto, Canada.

Baker, R. A., *The Anodic Oxidation Rate of Pure Lead in Sulfuric Acid*, Electrochem. Soc., Houston, Tex.

Benes, V. E., *The Covariance Function of a Simple Trunk Group with Applications to Traffic Measurement*, Institute of Mathematical Statistics Summer Meeting, Stanford, Calif.

Bennett, W. R., *Effect of Random Noise on Sinusoidal Systems*, 1960 Special Summer Prog. on Modulation Theory and Systems, M.I.T., Cambridge, Mass.

Bennett, W. R. *Effect of Random Noise on Pulsed Systems*, 1960 Special Summer Prog. on Modulation Theory and Systems, M.I.T., Cambridge, Mass.

Bobeck, A. H., *Twistor Memories —Past, Present, and Future*, Seventh Annual Symp. on Computers and Data Processing, Estes Park, Colo.

Bradburd, E. M., *Digital Transmission in the UNICOM System*, Statler-Hilton Hotel, Washington, D. C.

Brown, W. L., *Introduction to Solid-State Detectors*, Seventh Annual Meeting of Professional Gp. on Nuclear Science, Gatlinburg, Tenn.

Buchsbaum, S. J., *Ion Resonance in a Multicomponent Plasma*, Los Alamos Scientific Laboratory, Los Alamos, New Mex., Gaseous Electronics Conf., Monterey, Calif.

Chynoweth, A. G., *The Esaki Effect*, Congr. of Canadian Physicists, Kingston, Ontario, Canada.

Chynoweth, A. G., *Tunnelling in InSb. I. Phonon-Assisted Transitions II. Magnetic Field Effects*, Am. Phys. Soc. Meeting, Montreal, Canada.

Courtney-Pratt, J. S., *Image Dissection Cameras*, M.I.T., Cambridge, Mass.

Courtney-Pratt, J. S., *Reflection of Light at the Boundary of a Dense Optical Medium Coated with a Less Dense Absorbing Medium*, S.P.I.E. Symp., Los Angeles, Calif.

Chapin, D. M., *Making Solar Cells in the High School Laboratory*, Traveling Science Teacher Prog., Oklahoma State Univ. Stillwater, Okla.

Dacey, G. C., *Materials Requirements for Esaki Tunnel Diodes*, A.I.M.E. Technical Conf., Boston, Mass.

DeGrasse, R. W., *Traveling-Wave Masers*, Eighteenth Annual Conf. on Electron Tube Research, Univ. of Washington, Seattle, Wash.

Dietmeyer, D. L., Gordon, G., Runyon, J. P., and Tague, B. A., *An Interpretive Simulation Program for Estimating Occupancy and Delay in Traffic-Handling Systems Which Are Incompletely Detailed*, 1960 Pacific General Meeting of A.I.E.E., San Diego, Calif.

Engelbrecht, R. S., see Mumford, W. W.

Evan, W. M., *Due Process of Law in Military and Industrial Organizations*, Am. Sociological Assoc. Annual Meeting, N.Y.C.

Franks, L. E., and Sandberg, I. W., *A Sampled-Data Technique for Realizing Network Transfer Functions*, I.R.E. Wescon, Los Angeles, Calif.

Frosch, C. J., *The Preparation and Properties of Gallium Phosphide*, Electrochemical Soc. Meeting, Chicago, Ill.

Galt, J. K., and Merritt, F. R., *Cyclotron Resonance Observations in Zinc*, Conf. on Fermi Surfaces, Cooperstown, N. Y.

Geller, S., *Magnetic Interactions and Distribution of Ions in the Garnets*, Mineralogical Institute, Zurich, Switz.

Gershenzon, M., *Preparation and Characteristics of p-n Junctions in Gallium Phosphide*, Electrochemical Soc. Semiconductor Symposium, Chicago, Ill.

Gershenzon, M., *The Vapor Phase Preparation of Gallium Phosphide Whiskers*, Am. Chem. Soc. Meeting, Cleveland, Ohio.

Geyling, F. T., *Drag Displacements and Decay of Near-Circular Satellite Orbits*, International Astronautical Cong., Stockholm, Sweden.

Gnanadesikan, R., *One Degree of Freedom Plots in Multiresponse Factorial Experiments*, I.M.S., A.S.A. and Biometric Soc., Stanford University, Calif.

Gnanadesikan, R., *Some Remarks on Plotting Procedures in the Analysis of Experiments*, I.M.S., A.S.A., and Biometric Soc., Stanford, Calif.

Gordon, G., see Dietmeyer, D. L.

Hamming, R. W., *Computer Appreciation Courses*, Computer Comm., Ford Foundation Computer Proj., Univ. of Michigan, Ann Arbor, Mich.

Hamming, R. W., *Presidential Address to A.C.M.*, A.C.M. Meeting, Milwaukee, Wisc.

Hammock, J., *Criterion Measures; Instruction vs. Selection Research*, Am. Psychological Assoc. Meeting, Chicago, Ill.

Javan, A., *Topics on Beam-type Masers and Problems in the Inversion of Population Within Excited Atomic Levels*, Radio Spectroscopy Section Summer School, Varenna, Italy.

Kaenel, R. A., *Novel Adder-Subtractor Circuits Utilizing Tunnel Diodes*, Wescon, San Diego, Calif.

Leutritz, J., Jr., *Relationship of Evaporation Pattern and Distillation Characteristics of Coal Tar Creosote*, 1959 Annual Meeting Amer. Wood-Preservers Assoc., Dallas, Tex.

Logan, B. F., and Schroeder, M. R., *A Solution to the Problem of Compatible Single-Sideband Transmission*, M.I.T., Cambridge, Mass.

Lumsden, G. Q., *Creosote-Pentachlorophenol Solution—A New Fortified Wood Preservation for Southern Pine Poles*, Fourteenth Annual Meeting of Forest Products Research Soc., Montreal, Canada.

Lundberg, C. V., *Potting Containers for Casting Resin Compounds*, Western Electric/Bell Telephone Laboratories Casting Resin Conf., Merrimack Valley, North Andover, Mass.

Mallery, P., *Counter-Wrapped Twistor*, 1960 Electronics Components Conf., Washington, D. C.

Masson, W. P., *Recent Developments in Semiconductor Strain Transducers*, Instrument Soc., N.Y.C.

Mathews, M. V., *Spoken Digit Recognition Using Time-Frequency Pattern Matching*, A.S.A. Meeting, Providence, R. I.

McSkimin, H. J., *Method for Measuring Ultrasonic Wave Velocities in Solids*, Fifty-ninth Meeting, Acous. Soc. Am., Providence, R. I.

Merritt, F. R., see Galt, J. K.

Mina, K. V., see Newhall, E. E.

Morel, P., see Anderson, P. W.

Mottel, S., *Structural Design of the TH Radio Power Supply Utilizing Glass Reinforced Molded Chassis*, Electronic Circuit Packaging Symposium, University of Colorado, Boulder, Colo.

Mottram, E. T., *Design of a New Bell System Submarine Cable System*, National Symposium on Global Communications, Washington, D. C.

Mumford, W. W., and Engelbrecht, R. S., *Some Engineering Aspects of Microwave Radiation Hazards*, Fourth Annual Tri-Service Microwave Conf., New York University Medical Center, N.Y.C.

Nesbitt, E. A., *Magnetic Annealing of Permalloy and Perminvar*, Gordon Research Conf., Meriden, N. H.

Newhall, E. E., and Mina, K. V., *A Straightforward Way of Generating All Boolean Functions of N Variables Using a Single Magnetic Circuit*, Denver Research Institute, University of Denver, Estes Park, Colo.

Nylund, H. W., *Comparison of Wideband and Narrowband Mobile Circuits*, Wescon Meeting, Los Angeles, Calif.

Rosenthal, C. W., *A Computer Program for Preparing Wiring Diagrams*, A.I.E.E. Pacific General Meeting, Computer Design Automation Session, San Diego, Calif.

Rothkopf, E. Z., *Habits Strength and Intralist Interference in Identification Learning*, Amer. Psychological Association, Chicago, Ill.

Runyon, J. P., see Dietmeyer, D. L.

Sandberg, I. W., see Franks, L. E.

Schroeder, M. R., see Logan, B. F.

Smith, W. L., *Miniature Transistorized Crystal Controlled Precision Oscillators*, 1960 Conf. on Standards and Electronic Measurements, National Bureau of Standards, Boulder, Colo.

Tague, B. A., see Dietmeyer, D. L.

van Bergeijk, W. A., *Nerve Trees and Loudness Functions*, First Annual Meeting of Psychonomic Soc., University of Chicago, Chicago, Ill.

van Roosbroeck, W., *Transport with Space Charge of a Pulse of Current Carriers Injected in a Semiconductor*, A.P.S., Detroit, Mich.

Waltz, M. C., *Semiconductors and the New World of Electronics*, Navy Officers, Mechanicsburg Air Depot, Pa.

Wasserman, E., *Chemical Topology: Interlocking Ring*, University of Michigan, Ann Arbor, Mich.

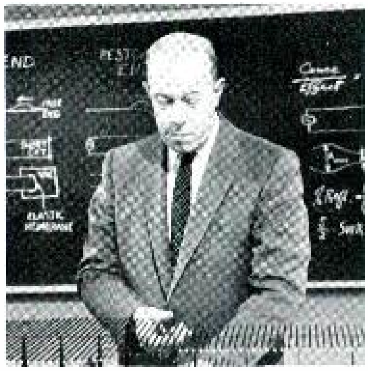
THE AUTHORS

Arthur L. Schawlow was born in Mount Vernon, New York. He was educated at the University of Toronto, receiving the Ph.D degree in 1949. From 1949 to 1951, he did research on microwave spectroscopy at Columbia University, where he began his association with Professor C. H. Townes. Since 1951 he has been in the Physical Research Department at Bell Laboratories, and has conducted investigations on nuclear quadruple resonance, superconductivity, and optical spectra of solids. For two years, he lectured on Solid-State Physics in the CDT program. In 1960 he was Visiting Associate Professor at Columbia University. With C. H. Townes, he is co-author of a book,

A. L. Schawlow

Microwave Spectroscopy, and co-inventor of the optical maser. He is a Fellow of the American Physical Society, and a member of the Optical Society of America.

John N. Shive. A Baltimorean by birth and a New Jerseyite by upbringing and family ties, John N. Shive holds degrees of B.S. from Rutgers and Ph.D. from Johns Hopkins. Since coming to the Bell Labs in 1939, Mr. Shive has worked in Physical Research. Device Development, and Education and Training. He developed the phototransistor whose modern embodiment is employed in the 4A Card Translator and made contributions to the development and design of transistors and rec-



J. N. Shive

tifiers. In his present role as Director of the Department of Education and Training, Mr. Shive is responsible for the administration of the various educational programs of the Laboratories including CDT, BLEP, OETP, and others. A year ago he joined the ranks of Bell Labs authors with his book, *The Properties, Physics and Design of Semiconductor Devices*. A one-time Fellow of the American Physical Society, he is a member of the American Society for Engineering Education and a senior member of the Institute of Radio Engineers.

J. B. Evans, Jr., a native of Washington, D. C., received the B.S. degree from Brown University in 1947 and the M.S. degree from Worcester Polytechnic Institute in 1949. He joined the Laboratories in that year and was assigned to the Communications Development Training Program.

J. B. Evans, Jr.

During that time he worked on development of L3 Carrier terminal filters, thermistors for military carrier systems and short-haul carrier signaling equipment. At present, Mr. Evans is concerned with broadband carrier terminal development. He is the co-author of "The 'ON-over-K' Carrier System" in this issue.

E. Homan, who was born in Sayreville, New Jersey, is co-author of "The 'ON-over-K' Carrier System" in this issue. After four years of service as a radar technician with the United States Air Force, Mr. Homan studied design technology at DeVry Technical Institute in Chicago, Illinois. In 1955 he joined Bell Labora-

E. Homan

tories and was assigned to a group working on short-haul carrier systems. He has worked on final development and equalization of the ON/K Carrier System and on development of the Wide-band Digital Data System. At present he is concerned with N and ON/K carrier development and with N and ON carrier equalization.

Harold Patterson attended the University of Michigan from which he received the BS degree in 1952 and the MS in Physics in 1953. He continued post-graduate studies in physics until 1956. During this time he engaged in work in the application of infrared spectroscopy to various medical problems and worked in the in-

H. J. Patterson

vestigation of the magnetoresistive properties of bismuth crystals. He joined Bell Laboratories at the Allentown, Pennsylvania Location and was assigned to a group designing diffused silicon crosspoint diodes. The group responsibility was then changed to designing diffused silicon transistors in which work he has continued until the present. Mr. Patterson is co-author of the article on oxide masking.

K. E. Daburlos was born and reared in Reading, Pennsylvania. After serving as an Electronic Technician in the United States Navy, he joined the Allentown Location of Bell Laboratories in 1954. He has worked on mechanical problems associated with alloy junction germanium transistors, "Snow White" transistors, and the diffused silicon transistor. More recently, he has been engaged in metallic contact evaporation techniques in connection with the diffused silicon device. Mr. Daburlos transferred to the Laureldale Location of the Laboratories in 1958 and is currently working on the electrical characterization of diffused silicon devices. He is also currently attending evening courses at Lafayette College. Mr. Daburlos is co-author of "Oxide Masking."

K. E. Daburlos

L. E. Abbott, co-author of "Air Gages for Checking Waveguide Dimensions," graduated from the Brooklyn Polytechnic Institute with the degree of M.E. in 1928, and obtained his M.S. there in 1931. As a member of the materials group, he worked on various problems connected with the physical properties of metals, the use of welding in telephone-apparatus fabrication, and the application of industrial x-ray techniques. He is presently a member of the metals engineering group in the Metallurgical Research Department. A native of Brooklyn, N.Y., Mr. Abbott is a member of the American Welding Society.

L. E. Abbott

A. F. Pomeroy was born at Buffalo, N. Y. He graduated from Brown University in 1929 with a B.S. degree in Engineering and joined Bell Laboratories that year. His early work was devoted to developing test and measurement equipment and the study of transmission lines. His work with manufacturers has resulted in the development of waveguides with improved transmission qualities. Since 1956 he has been concerned with the development of ferrite devices such as microwave attenuators, isolaters and switches. Earlier this year, Mr. Pomeroy transferred to Western Electric at the Merrimac Valley Works. A member of the IRE, he is the co-author of "Air Gages for Checking Waveguide Dimensions."

A. F. Pomeroy

R. C. Nance, a resident of Wood-Ridge, New Jersey, joined the Laboratories in 1936. He received the A.E. degree from Newark College of Engineering in 1940. After graduation, he was called to active duty with his National Guard regiment and, during five years of service with the U.S. Army, he participated in several amphibious assaults in the Pacific Theatre of Operations. Mr. Nance returned to the Laboratories as a member of the Switching Development Department and worked on the design of automatic test circuits for No. 4 toll crossbar and crossbar tandem systems. Recently he has been concerned with the design of circuits for crossbar tandem CAMA to permit customer dialing of special toll calls. Mr. Nance is the author of "Test Circuits for Toll Crossbar" in this issue.

R. C. Nance