June 1961

Bell Laboratories RECORD

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Bell Laboratories **RECORD**

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Contents

Cover *R. J. Brennan of the New Jersey Bell Telephone Company uses caulking gun to inject epoxy resin into the end of a multiple cable joint* *(see page 205).*

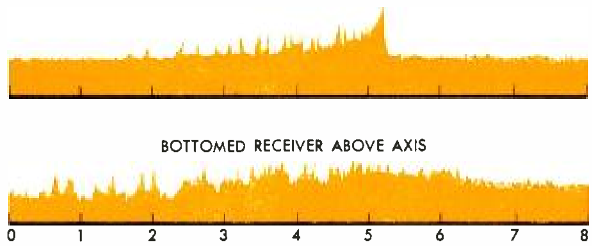
Atlantic Missile Range to be operational by November 1, 1956, with other links to be extended progressively after that.

The Underwater Systems Development Department at Bell Laboratories, with its knowledge of the properties of the ocean as a transmission medium, began to study the problem and to make recommendations for a system. A team was set up consisting of the North Carolina locations of the Laboratories for systems engineering, Western Electric's procurement, manufacturing, and field engineering forces for installation, and the Navy's supporting ships. These organizations hoped that the severe operational schedules could be met. They were!

The basic problem was to find a way to detect a burst of noise in a background of general noise, and to determine the position by "triangulation" methods. But what was the frequency spectrum of the noise created by the impact of a nose cone at the surface of the ocean? No nose cones existed then, and even their configurations were only in the planning stage. The development team thus decided to simulate impacts and measure the acoustic values. For this purpose, inert aerial bombs weighing 500, 1000, 2000, and 4000 pounds were dropped from aircraft at altitudes varying from 5000 to 25,000 feet. The developers adopted as design criterion the minimum signal produced by the impact of a 4000-pound bomb dropped from a height of 25,000 feet. They noted two important characteristics about this "splash" pulse. First, the signal was such that neither its character nor its level would permit long-range propagation. Second, the shape of the pulse was little affected by attenuating the higher frequency components.

Basic Equipment

These data, analyzed by L. G. Swart of the Underwater Systems Development Department, formed the basis for two important recommendations early in the program. First, for long-range detection and triangulation, a "Sofar" bomb should be included in the configuration of the nose cone or capsule to use for transmitting energy in the deep sound-channel in the ocean. The advantages of exploiting this so-called Sofar (Sound Fixing and Ranging) channel will be discussed a little later. The second recommendation was that high-accuracy locations of the impact itself should be limited to signals transmitted over the direct acoustic path, free of bottom or surface reflections. Additionally, these tests provided data necessary to determine the maximum



Comparison of signals from bomb explosion. Sofar signal, top, shows obvious peak, representing point to measure and convert. Bottomed receiver sends nearly unreadable signal.

length of submarine cable that could be used with a given hydrophone and still give the desired minimum signal-to-noise ratio.

The velocity of sound in water varies directly with the temperature and salinity of the water and inversely with its density. A velocity profile, typical of the Western Atlantic Basin (*see page 198*), shows a velocity of roughly 5000 feet per second at the surface. In an irregular "negative gradient," this velocity decreases to about 4900 feet per second at a depth of about 4000 feet, and then increases in a rather steady positive gradient. The depth at which underwater velocity equals the surface velocity is about 13,000 feet. The points of equal velocity at or near the surface and at a certain depth indicate the deep-channel boundaries, and the deep-channel, or Sofar, axis is, as shown in the figure, at the knee of the curve—minimum velocity. These channel boundaries and axis depths vary from area to area in the oceans.

Transmission of low-frequency signals along the axis suffers only spreading losses and the mean horizontal velocity is at a minimum. Other, longer paths have higher mean horizontal velocities but suffer larger spreading losses and are subject additionally to reflection losses. Transmission along the axis is reasonably stable and, if no interfering anomaly exists, permits reception over thousands of miles. The Sofar channel was used in the Pacific during the latter part of World War II for air-sea rescues of downed fliers.

As a sound source for air-sea rescue, the Navy developed the Mark 22/0 Sofar bomb. This bomb contains about four pounds of explosives and is arranged to arm and detonate at various depths by hydrostatic pressure. The depth of explosion can be selected by removing one of a choice of bottle caps appropriate to the desired depth and hence the more familiar name "bottle cap bomb." The signal from such a bomb has a much broader bandwidth than the impact signal of a 4000-pound inert bomb.

"Splash" signals created by the impact of an object at the surface of the ocean are transmitted by multiple reflected and/or refracted paths. One path, however, is free of reflection and is affected only slightly by refraction. This is the direct path from the "splash" signal to a receiver on the ocean floor *(see page 199)*. The length of this direct-transmission path is limited by the velocity profile and the depth of that area of the ocean. In the Western Atlantic, for example, in water three miles deep, the maximum range is about 18 nautical miles.

Thus, two methods of underwater acoustic transmission are applicable to the problem of locating missile impacts. The first is a short-range, very accurate method using the "splash" signal itself. The second method is a very-long range, less-accurate one using the Sofar channel and a Sofar bomb. Both methods use some configuration of hydrophones on the ocean floor or at the Sofar axis, connected by armored cable to shore.

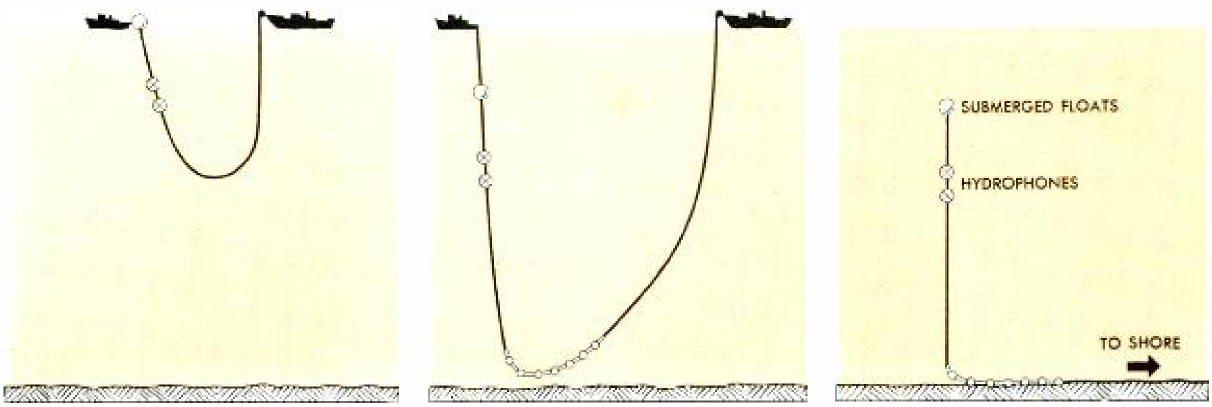
In a Sofar system, the hydrophones must be located approximately at the axis depth and in a clear acoustic environment. The importance of this is shown in the sketch on page 196, which compares the signal received under both good and poor environments. This figure also illustrates why a Sofar signal has such excellent characteristics for timing. The signal shown is rectified (full wave) and the recording instrument has an integration time of about 10 milliseconds. It is an excellent example of the classical Sofar signal, rising progressively in tempo and level until the minimum velocity rays arrive, whereupon the signal cuts off. This peak is the point to measure, and presents no difficulty in recognition or timing within an error of a few milliseconds.

The locations of the Sofar hydrophones with reference to the areas where an impact should occur are important in terms of the accuracy of the system. Unfortunately, however, the geographic distribution of the world's land masses and the equally important bathymetry of the oceans do not always lend themselves to proper locations. But careful planning and use of diversity has made it possible to meet requirements for accuracy.

Sofar Accuracy

As indicated earlier, use of the Sofar channel is not new. But the Laboratories design of a practical suspended hydrophone installation has made it possible to improve the accuracy of a Sofar system. In this installation, articulated anchors and subsurface buoys suspend the hydrophones from the ocean bottom at the depth of the Sofar axis, as shown below. The initial installation of this type was made off Bermuda in 1959, and since then Western Electric has installed several multiple hydrophone groups in the Atlantic and Pacific. Bell Laboratories engineers designed the articulated anchor to be integral with the cable, and thus it can be payed out over drums and bow sheaves of a cable ship with practically no interruptions.

In cases where fairly precise determination of the surface impact has been required, the military services have called for surveillance over a circular bull's-eye area of 10 miles radius. R. A. Walker and R. L. Tambling, of the Underwater Systems Development Department, found the



Articulated anchors and subsurface buoys suspend hydrophones above ocean bottom at depth of Sofar axis. Anchor is integral with cable, permitting reasonable continuity of laying operation.

"pentagon" configuration best as to quality in acoustic surveillance over such an area as well as for ease of installation. This consists of a center hydrophone surrounded by five other hydrophones located at the approximate vertices of a pentagon. All are connected by submarine cable and terminated on shore.

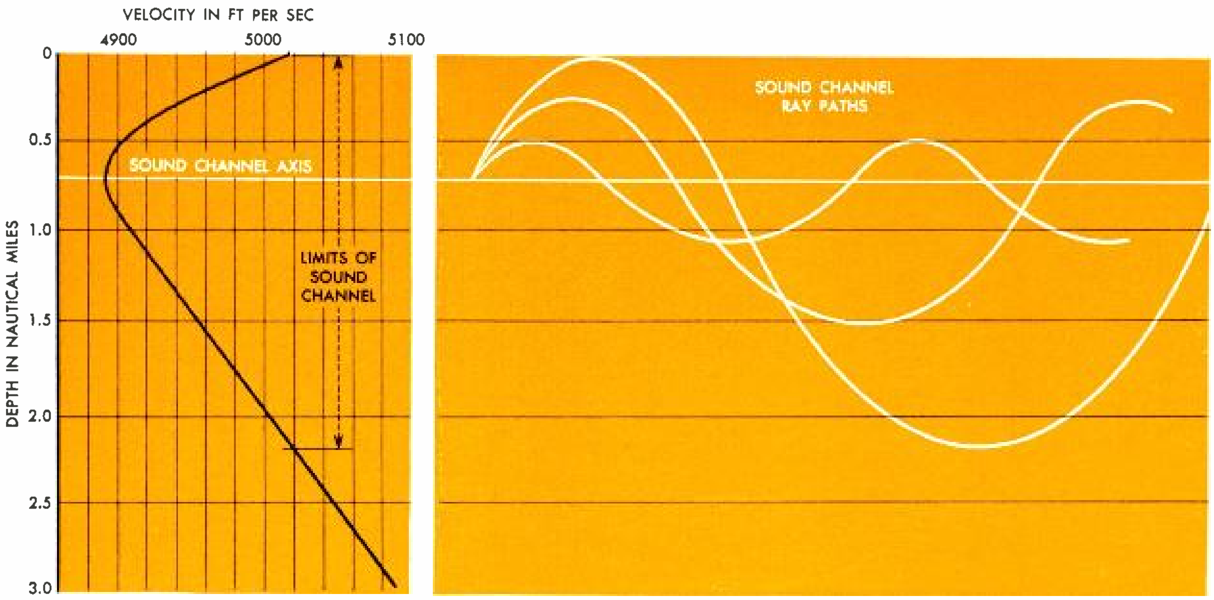
The "radius" of a pentagon depends on the depth of the area of the ocean and the sound-velocity profile. The center hydrophone, located at the nominal impact point, is most severely affected by attenuation because the pentagon is so arranged that this unit is connected to the cable first—it is the longest length of cable. But this is a deliberate selection because when a true bull's-eye is scored, the center hydrophone is least essential to the solution. In this case, the "splash" signals will be received on the five peripheral hydrophones.

An important attribute of the pentagon is that it permits rapid approximation of the area of the impact from no other information than the time sequence of the arrival of the signal at the individual hydrophones. The pentagon may be divided into cells and the order of arrival is unique in each cell. Precise location is then determined by detailed analysis of the incoming signals.

"Splash," or surface, signals must arrive and be recorded at a minimum of three hydrophones—the triangulation principle—to obtain the position of an impact. The solution in such a case is a unique point, but unfortunately, this can inspire an unwarranted degree of confidence and apparent precision. This optimism is not desirable since all terms in the equations that determine a fix are subject to errors. It is much more realistic to obtain an indication of the area of uncertainty around a position by the use of several preferably independent dipoles. A dipole consists of two hydrophones separated by a discrete distance—a few or hundreds of miles—depending on the type of system. At least four hydrophones are needed to establish two independent dipoles.

Error Evaluation

With two methods of transmission available, J. C. Beckerle and R. D. Jensvold, of the Underwater Systems Development Department, evaluated the various errors that combine to produce the over-all error in determining a position in the ocean by underwater acoustics. As with any geographical location system, there are uncertainties both in the actual position of the geodetic bench marks set up on shore, as well as in the positions of the underwater receivers relative to the bench marks. There are also errors in identifying and timing the desired signal, uncertainties in the calculated or measured velocity of sound in water, as well as the complexity of



Sofar axis is determined (left) by minimum velocity depth of sound in water. Sound channel boundary is determined by the points of equal velocity at surface. Right side of diagram depicts different paths acoustic rays, originating at the Sofar axis, can take through ocean environment.

multi-path transmission. Quality in a triangulation system also depends on the geometry or arrangement of the receivers with reference to the target point—the intersection angles of the lines of position.

Theoretical studies on these errors indicated the sensitivity of the system to the various uncertainties, and indicated the extent to which these uncertainties would have to be contained. Concurrent with these studies, the development team initiated an experimental program to determine empirically whether or not these limits could be met. Hydrophones were installed off Eleuthera, an island in the Bahamas, at the Sofar-axis depth and cables brought to shore at the Navy's experimental facility operated by Bell Laboratories. A ship under the navigational control of Lorac and Shoran, dropped Sofar bombs (4000 feet deep) and surface bombs (50 feet deep) at intervals of a few miles on various tracks out to about 200 miles. Position of the ship, time of detonation of bombs, and arrival times of acoustic signals were logged or recorded on magnetic tape and graphic recorders.

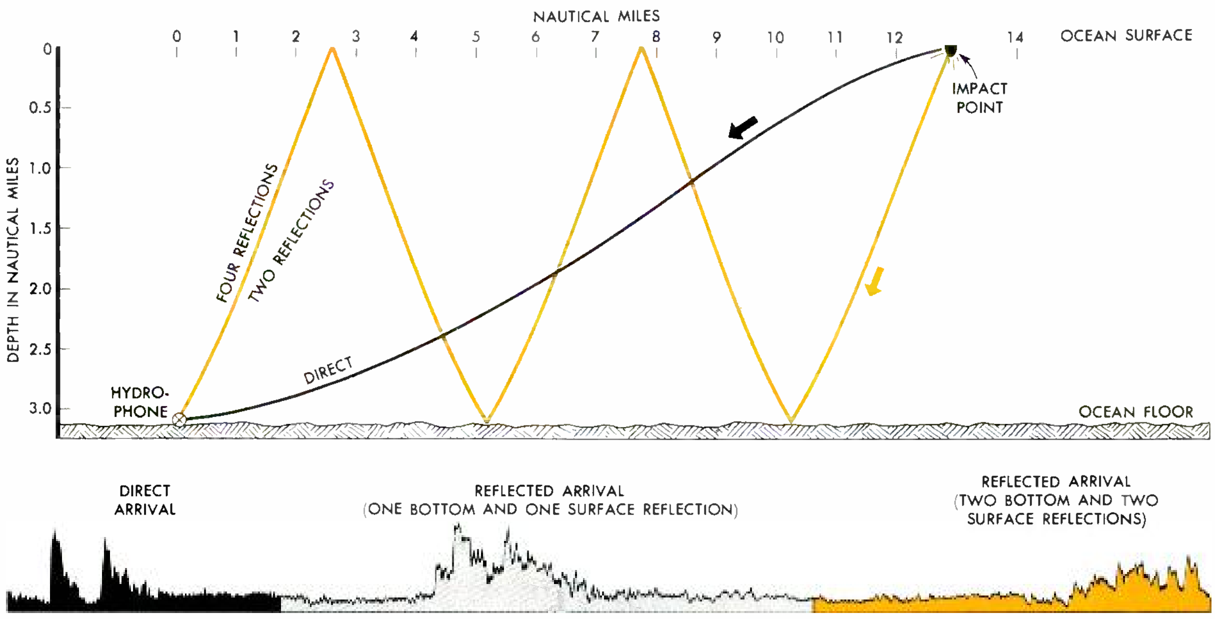
J. R. deGraaff and J. M. Busch, of the Underwater Systems Development Department, analyzed these data to confirm the system concepts for instrumentation. These analyses were valuable in establishing criteria for hydrographic and acoustic surveys. They also indicated the precision required of navigational aids for installing hydrophones and cable, and development of refined techniques for determining the position of hydrophones by acoustic methods.

At the North Carolina Laboratories in Winston-Salem, W. H. Garrison, J. L. Conklin, and S. A. Portaro began the systems engineering based on the system parameters. They then released specifications and drawings to Western Electric for procurement and manufacture. Western Electric's Field Engineering Forces accepted recommendations for various types of surveys and installations, and in liaison with the Navy, this group established the schedules for the various operations.

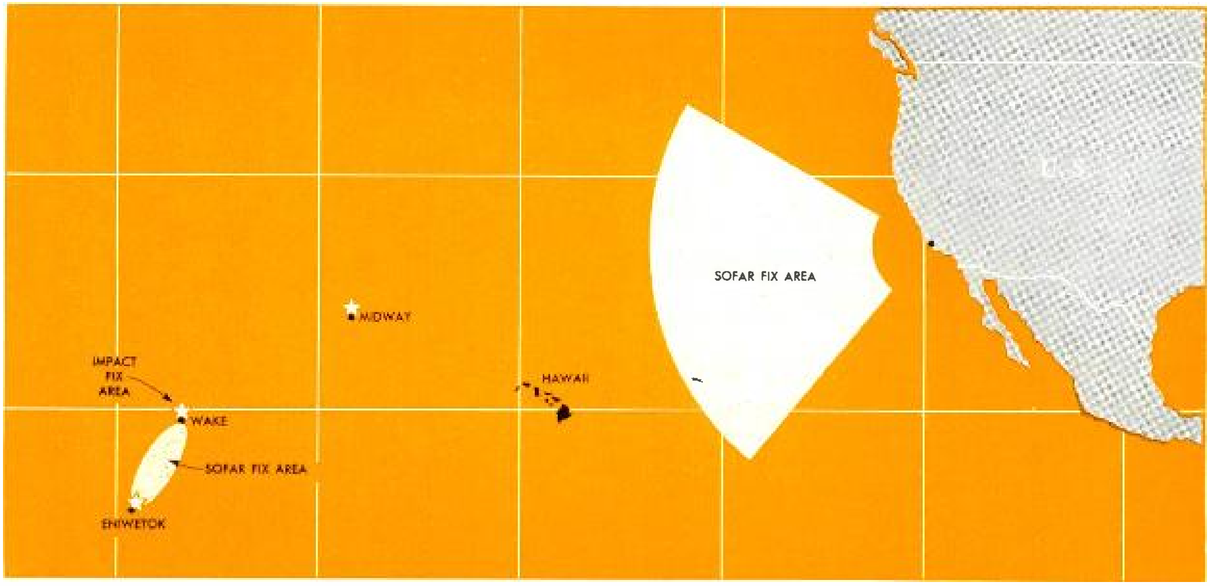
Fortunately, with one exception, the highly precise pentagons were laid within range of electronic navigation control systems whose accuracies are suitable for laying hydrophones relative to each other and to the bench marks on shore. These control systems are also suitable for acoustic calibration or demonstration of the network of receivers.

The one exception is interesting because with it, the underwater acoustic paths in the Sofar channel are used to locate and calibrate an off shore pentagon from Sofar axis hydrophones near an island. In other words, acoustics teamed up with radio to close the transmission loop, making it possible to use hydrophones to determine the location of other hydrophones.

Initially, the requirements for precise location



Signals from impact of object at ocean surface travel over multiple paths in the ocean environment. Bottom segment of the diagram shows appearance of different-path signals at receiver.



MILS has become part of the operational evaluation of U. S. missile research and development programs carried out in Pacific. Short and long range tests are carried out in this ocean area.

were such that so-called "hyperbolic distance-difference" charts were considered satisfactory for developing the position of a Sofar or "splash" event. The Laboratories recommended the mathematical formulas for both "splash" and Sofar systems. The Bureau of Ships, the David Taylor Model Basin, and the U. S. Navy's Hydrographic Office did the programming, computation, and construction of the charts.

At the same time, BuShips looked into the possibility of using small computers directly in the field. As time passed, and as the Atlantic Missile Range was extended to Ascension Island, the problem of the reduction of the data from some 1400 Sofar bombs and 1400 surface bombs in calibrating a large ocean area made essential more sophisticated computation methods.

Computer Application

Computation possibilities thus became of interest to Western Electric. Concurrent with a study for a mobile type of impact locating system, a study by the computer application group at the Whippany location of Bell Laboratories recommended using digital computers and suggested as suitable several types of relatively small ones.

Thus from several directions pressures developed for using automation in completing the MILS development. The computer group under R. T. Herbst at the North Carolina Laboratories proved to be both sympathetic as well as enthusiastic toward computer techniques. The result was about 36 computer programs, most of which are applied to installation and calibration phases of the work rather than to the operational solution. Routines and subroutines for correcting navigational controls, for scale factors, and for converting circular and hyperbolic coordinates to rectangular coordinates are only a few of the supporting types of computer programs. The computer technique has since been acknowledged as the primary method for the solution of MILS data. The distance-difference charts are now used only for quick field approximations and for checking purposes.

Obviously, MILS can be used to locate a seagoing vessel or a ditched aircraft equipped to release a Sofar bomb. But, it is associated with man's most recent and intensive scientific efforts—the ballistic missile and the exploration of space. It is more than slightly ironic, however, that this project has brought home some of the uncertainties of the geophysics of our own planet.

Perhaps the problems of accurate position location will be alleviated when a number of "navigator" satellites, such as the recently launched "Transits," are placed in orbit and the necessary instrumentation is available to prove the system against a known North American Datum grid. It is thus conceivable that astrophysics will provide the impetus required to increase our knowledge of geophysics.

With Touch-Tone Calling, the telephone line is open to hundreds of noises from the time a customer lifts the handset until "dialing" is completed. From this complex mixture of noise, the receiver at a central office must pick out the correct tone signals.

C. G. Morrison

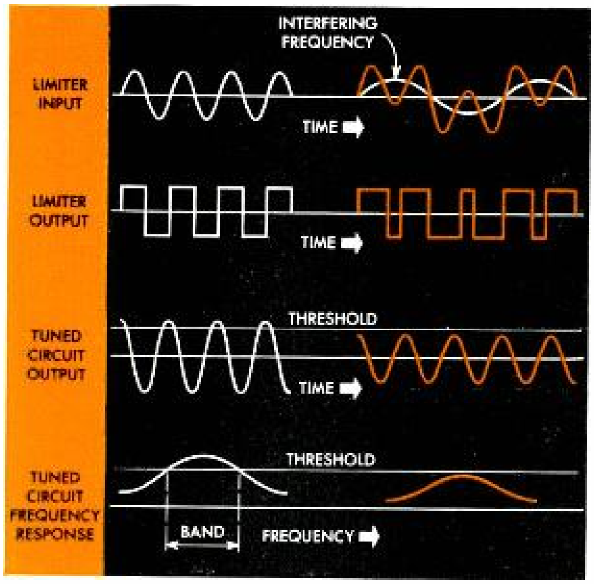
Central-Office Receiver for Touch-Tone Calling

Modern man has an affinity for pushbuttons, but Touch-Tone Calling is more than an outgrowth of the "pushbutton era." Replacing the rotary dial with pushbuttons has a practical benefit. The idea is rooted in the principle that Bell System service must be continuously improved—that communication must be made faster, more efficient, more convenient. Today, through the use of semiconductor devices and new electronic techniques, pushbutton "dialing," or Touch-Tone Calling, promises to become a popular Bell System service.

Once the feasibility of Touch-Tone Calling was established, Bell Laboratories engineers acted to design a practical system. To implement this service, a customer must have a telephone with a pushbutton dial that can transmit multifrequency tones over a line to a central office. At the central office, equipment must be provided to transform these tones into signals that can be used by the central-office switching equipment.

The additional equipment consists of two parts: (1) A multifrequency signal receiver, which receives ac signals from the pushbutton subset and delivers dc output signals in parallel form, and (2) a converter, which "translates" the receiver's dc output signals into a form which can be used by the central-office equipment. This combination serves both rotary dial and pushbutton calls. This article concerns the central-office receiver and tells how it distinguishes valid signals from a mixture of noise.

The receiver simply "receives" the voice-frequency pushbutton signals from the customer's set; it recognizes the frequencies of the signals and delivers dc output signals that indicate exactly what frequencies are present. If this were all that was required, a central office could use a receiver similar in design to the toll multifrequency receivers available in the telephone plant for many years. The important difference, however, between toll multifrequency signaling and customer pushbutton signaling is that the pushbutton receiver must be virtually unrespon-



This diagram shows how speech containing a signaling frequency component is prevented from operating a detector by action of the limiter.

sive to speech or noise picked up by the telephone transmitter. At the same time, the receiver must be able to respond to a wide range of signal amplitudes, must allow for variations in signaling frequencies and must not interfere with conventional dial pulsing. In addition, it must be able to work properly in the presence of normal levels of line noise.

When one realizes that all frequencies considered suitable for pushbutton signaling are certain to be present in speech, music, and room noise, the difficulty of making a receiver unresponsive to such sounds becomes apparent. This is not a problem with toll signaling since the toll receiver does not respond until a special signal is sent by the operator. Operators are also instructed to avoid exposing the line to speech. However, it is neither practical nor desirable to place such special restrictions on a customer.

When a customer presses a button on his pushbutton telephone, the transmitter becomes inoperative. In this way, each Touch-Tone signal is kept from having to compete with speech or room noise while it is being sent. But at all other times —from connection of the receiver to the customer's line until "dialing" is completed—the receiver is exposed to any sounds that may be picked up by the telephone transmitter.

In a further attempt to minimize speech simulation of digits (sometimes referred to as talk-off), Laboratories engineers selected a signaling code that is not easily imitated by speech. Pushbutton signaling employs what is known as the four-by-four code, based on the use of two groups of four frequencies each. A digit signal contains one frequency from each group. Special care was used in selecting the frequencies to avoid harmonically related combinations which could be simulated readily by speech. The following frequencies were chosen:

- low group — 697, 770, 852, 941 cps
- high group — 1209, 1336, 1477, 1633 cps

The four-by-four code yields a total of 16 frequency combinations. Since there is no immediate need for this number of combinations, the present design uses a four-by-three code in which the 1633-cps frequency is omitted.

As mentioned earlier, the basic job of the receiver is to recognize each pair of signaling frequencies and to determine whether they are valid tone signals or merely speech or noise. Frequency recognition requires a set of frequency-sensitive elements, such as band-pass filters or tuned circuits. In the receiver, each of these elements is followed by a detector, or threshold circuit, which detects the presence or absence of a particular frequency. Since the frequency-sensitive elements must have outputs dependent only on frequency and not amplitude, they are driven by a circuit that standardizes the signal amplitude. For pushbutton signaling, it is advantageous to use limiters for this purpose. These basic elements are combined in a way which not only provides frequency recognition but also protects against digit simulation.

Receiver Operation

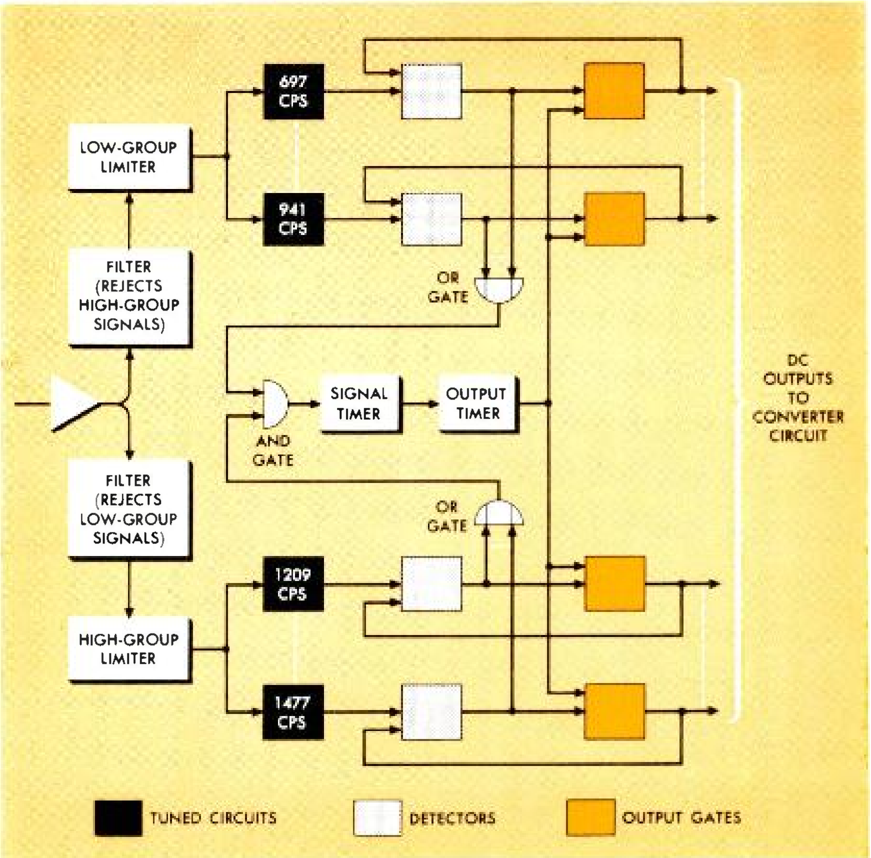
When a valid pushbutton signal is transmitted, the two frequencies pass through an input amplifier and then are separated into high and low groups by a pair of band-elimination filters. *(See block diagram of the receiver on page* 203.*)* The low-group filter attenuates only the portion of the voice spectrum containing the high-group frequencies. Similarly, the filter serving the high-group detectors attenuates only the low-group signaling frequencies. Each frequency then goes through a limiter which transforms it from a sinusoidal wave (whose amplitude varies with the length of the telephone line) to a square wave of fixed amplitude. Tuned circuits following the limiters recognize the two frequencies of each signal. The outputs of these tuned circuits energize detector circuits when a certain voltage threshold is exceeded.

Now let us consider how the limiters, in combination with the band-elimination filters, tuned circuits, and detectors protect against talk-off. As shown on page 202, the output of the limiter is a rectangular wave whose amplitude is fixed and whose transitions occur each time the input signal goes through zero. When a signaling frequency alone is applied to the limiter input, the output is a symmetrical square wave. This square wave contains the incoming frequency and its odd harmonics. The tuned circuit corresponding to the signaling frequency responds to the fundamental component of the square wave. If we plot the tuned-circuit output amplitude as a function of limiter-input frequency, we will have a curve similar to that shown at the bottom of the next page. The horizontal line drawn on this response curve marks the threshold level of the detector. The portion of the response curve above this line represents the frequency band over which the detector will operate.

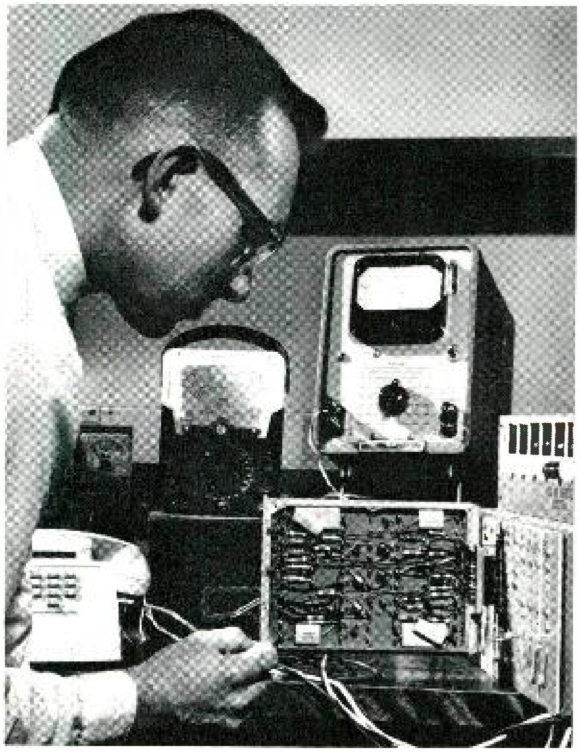
Since the limiter output amplitude is carefully controlled, the detector threshold may be set only 2 db below the peak of the response curve. Although speech tones may appear to be a valid combination of frequencies, they contain additional frequencies in the voice spectrum. Because the band-elimination filters reject a relatively small portion of the voice spectrum, most of these other voice frequencies will be present at the limiter inputs. Thus, speech may produce a waveform similar to that shown in the right half of the drawing at a limiter input.

When a limiter is driven by more than one frequency, its output will no longer be a symmetrical square wave but will have irregular transitions. Even though one valid signaling frequency is present, irregular transitions caused by other speech frequencies reduce the amplitude of the valid signal component to the point where it will usually not exceed the detector threshold. This considerably reduces the probability of speech operating a detector.

Another way to avoid digit simulation is to keep the detector bandwidths as narrow as possible. The bands must be wide enough to allow for variations in sending oscillator frequencies and receiver tuned-circuit resonance. These variations add up to about plus or minus 2 per cent of the nominal signaling frequencies. The bandwidths should exceed the plus or minus 2 percentage points only by an amount necessary to allow for differences in bandwidth due to various receiver parameters and band-narrowing caused by



Block diagram of push-button receiver. A channel circuit consisting of a tuned circuit, detector, and output gate is provided for each of the seven signaling frequencies. Only four such channel circuits are shown here.



C. G. Morrison checks the circuit voltage on one of the plug-in units of a pushbutton receiver.

the interfering effect of dial tone and noise. Laboratories engineers took great care in the receiver design to minimize bandwidth variations caused by changes in transistor and other component parameters.

We have discussed how digit simulation can be reduced by choice of a signaling code, by limiter guard action, and through the use of accurately controlled narrow-channel bandwidths. There are two checks the receiver employs to give additional protection against talk-off: (1) A check to determine the presence of one and only one tone in each of the two frequency groups, and (2) a signal-duration check to determine whether both frequency components of a signal are present continuously for a specified time.

Since speech frequencies change at a fairly rapid rate, it is unlikely that a simulated signaling frequency in each group will continue without interruption very long. The longer the signal duration test, the greater the protection against digit simulation. The time for this test, however, is limited by the fact that the receiver must respond to the fastest pushbutton operations likely to be attained by a customer. Present requirements indicate that 40 milliseconds is a reasonable receiver response time. Receiver response time is the sum of a small delay time caused by transients at the start of the signal, plus tuned-circuit buildup time, plus signal-duration test time. Since the first two of these may total as much as 15 milliseconds, the nominal time for the signal-duration test has been set at 22 milliseconds.

The block diagram of the receiver shows how the validity and signal-duration checks are made. To make certain that one and only one detector in a group operates, the output of each detector in a group is connected to a logic circuit called an "OR gate." The "only one" part of the test is provided by limiter action. The action of the limiter is such that if two frequencies are present in a group, neither of them will have sufficient amplitude to operate a detector. The outputs of the OR gates associated with each group of detectors connect to an "AND gate" whose output goes to the signal-duration timer. As long as the signal checks valid, the signal timer will run. If the validity check fails, the signal timer is reset immediately and will not run again until it receives a valid signal.

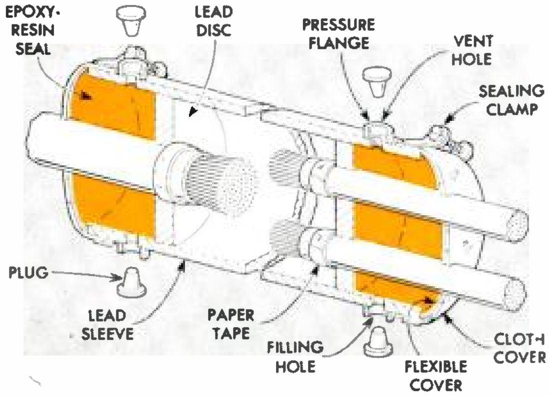
Once the signal duration test is completed, the receiver is ready to deliver dc output signals to the converter. These signals must be at least 40 milliseconds in duration. With short signals, only a few milliseconds may elapse from the end of the signal-duration test until the customer releases the button. Thus some sort of memory is required to prolong the output signals. Memory of fixed duration is achieved by an output timer, output gates, and detector circuits. At the end of the signal duration test, the output timer is turned on. This timer opens the output gates so that the output leads corresponding to operated detectors are energized. A portion of each output signal is fed back to its detector input. This holds the detector and gate in the operated condition. The detector-output gate combination remains locked so long as the output timer runs. During this period, the output timer increases the threshold level of all detectors so that no other detectors can operate. After about 45 milliseconds, the output timer shuts off and closes the output gates, terminating output signals to the converter and restoring detector threshold levels to normal.

Early model receivers have been performing successfully in field trials at Hagerstown, Maryland; Roanoke, Virginia; Findlay, Ohio; and Greensburg, Pennsylvania. The pushbutton program is gathering momentum, and assuming success of the present field trials, pushbutton service will be available to many Bell System customers within the next few years.

The use of molten solder to seal splices of lead-sheathed telephone cables sometimes presents problems. A new development from Bell Laboratories now makes it possible to seal these splices with epoxy resin.

New Way to Seal Cable Joints

When two lead-sheathed cables are connected, outside plant splicers usually cover the joint with a splice case or a lead sleeve. Each end of the lead sleeve is soldered to the cable sheaths. Although many central offices use splice cases, there are some applications where this technique is not desirable. Making a multiple joint (several cables branching out from a single cable) is a difficult and costly operation. The lead-sleeve method involves pouring and wiping molten solder at approximately 800°F over the ends of the sleeve to form sealed joints to the lead sheaths. Because plastic-insulated conductors are used in some of these cables, this high temperature can cause severe heat damage.



Section of a multiple cable joint showing how epoxy resin in splice chamber forms air-tight and permanent seal around the telephone cables.

To avert this problem and for applications where splice cases are not desirable, outside plant engineers developed a new method for making multiple joints. They substituted an epoxy-resin compound for the solder. In making a permanent seal over a joint, a splicer first constructs a chamber at each end of the lead sleeve covering the splice. To do this, he uses a lead disk and a flexible end cap consisting of sheets of rubber and fabric, as shown in the illustration below. A premixed putty-like resin filled with a metal powder is injected into these chambers with a caulking gun. The splicer simply fills the chambers from the bottom with the resin, forcing the air up through the top vents to minimize the formation of voids caused by air in the resin seal. To further reduce the possibility of voids in the filled chambers, the cap is kneaded with the fingers during filling. These flexible end caps expand as the chamber is filled with resin, and contract as the resin shrinks during curing.

As the resin cures, it hardens around the cable, and provides a secure mechanical grip to the sheath as well as an air-tight seal. The coefficients of thermal expansion of the cured resin and the lead of the sleeve and cable sheath are approximately the same. This makes it possible to retain a long-term seal despite moderate changes in temperature.

It is expected that this method will be used to advantage in solving many difficult splicing problems which are encountered in the field.

W. Sennett
OUTSIDE PLANT DEVELOPMENT

By combining the specific capacities and knowledge of Bell Laboratories with those of the Western Electric Company, the device-development engineer supervises the birth of a new type of transistor. The process is called "development for manufacture."

L. E. Miller

Transistor Development For Manufacture

The typical transistor manufactured by Western Electric goes through many stages at Bell Laboratories before it actually sees large-scale use in specific systems. Generally, the device is an outgrowth of some new principle, material or technique discovered through basic research. Based on this fundamental knowledge, device theoreticians can evaluate the possibility of designing a transistor that has certain desirable or greatly improved attributes.

If this initial evaluation looks promising, a limited number of experimental models are built in the laboratory. These models are then tested in various circuit applications and under various environmental conditions. During all of these stages, the research workers, device designers, and circuit engineers gather detailed data on the characteristics of the new device, and all of these groups contribute to its improvement. If the new device shows promise of fairly broad application in existing or planned communications systems, it reaches the "payoff" stage—development for manufacture.

In this next-to-last step in the creation of a practical device, the fabrication technology used in the manufacture of a component must be coordinated with the requirements of the men who will ultimately use it—the circuit designers. More specifically, this means coordinating the production facilities and know-how available at Western Electric plant with the knowledge and experience, plus the test and measurement facilities available at Bell Laboratories.

Chronologically, development for manufacture is usually carried out concurrently with advanced studies of circuit application, which involves exploring the entire electronic frontier opened by the new device. Geographically, development for manufacture is usually, and most efficiently, done at a branch location of the Laboratories.

Bell Laboratories at Laureldale, Pa., recently completed the development for manufacture of an important new diffused-silicon transistor, and the device is currently in quantity production at the Laureldale Plant of the Western Electric Co. This article will describe briefly this development-for-manufacture process.

Because the various early stages of a transistor's gestation are so important to the final stage, let us review some of them as they relate to the device at hand. In the beginning, a new device is conceived to fulfill certain basic, generalized objectives, such as: (1) high gain, or a large amplification ratio; (2) speed, the ability to switch rapidly from a high-current to a low-current state (or the converse), and (3) the ability to withstand severe environmental conditions, including operation at high temperatures.

Early experimental models of such a new device are made available to circuit designers, who evaluate the advantages and disadvantages of the design. Often, they discover limitations that can be "designed out" of the device, but sometimes these limitations must be accepted as inherent properties and allowed for in circuit design.

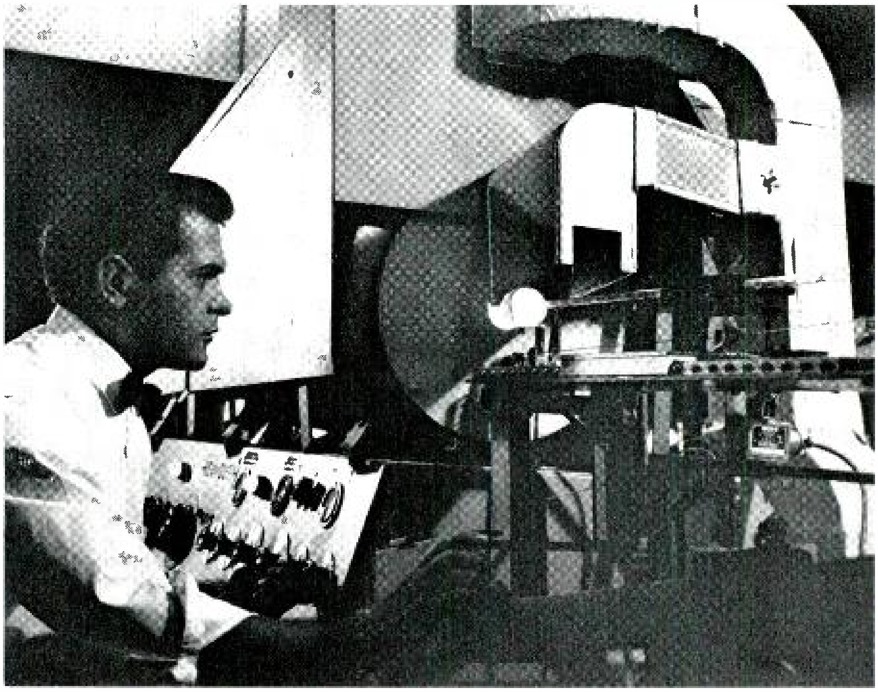
During this early period, the device-development engineer must modify the design to the extent that: (1) Its advantages are enhanced; (2) its disadvantages are designed out; (3) its characteristics are made compatible with the requirements of proposed systems in which it might be used; and finally, (4) it is readily manufacturable at low cost in a package that will provide high reliability.

As a specific example, the diffused-silicon transistor was designed basically to exploit the advantages of solid-state diffusion (RECORD, *December*, 1956). This technique makes possible a degree of control over the depth of the junction layer in semiconductors that is an order of magnitude more precise than that obtainable with previous junction-fabrication techniques, such as growing from the melt (RECORD, *June*, 1954; *October*, 1955; *February*, 1958) or alloying (RECORD, *January*, 1956).

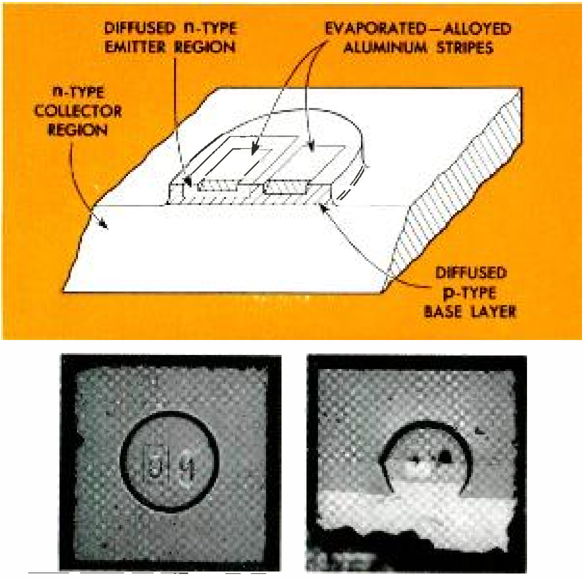
This improved control over junction formation expanded the frequency response attainable in a transistor by almost two orders of magnitude, providing the circuit designer with switching speeds and frequencies heretofore unattainable with semiconductor components. The large improvement in frequency response attainable in a diffused-junction device made possible extremely wide applications in several electronic systems. Specifically, the diffused-silicon transistor—designated the WE 2N560—is now being used in such military systems as Command Guidance for the Titan ICBM (RECORD, *June*, 1959). Nike Hercules (RECORD, *April*, 1960), the Nike Zeus anti-missile missile system, and the Ballistic Missile Early Warning System (BMEWS) (RECORD, *May*, 1960). A comparable device designed by Bell Laboratories at Allentown, Pa., is being used in developmental models of the Electronic Central Office (ECO) (RECORD, *October*, 1958; *December*, 1960) and the Electronic Private Branch Exchange (EPBX).

Even before the announcement of the diffused-germanium and silicon transistors in early 1956 (RECORD, *February*, 1956), a task force of members of several departments at the Laboratories was established to extend our basic knowledge of the mechanisms of solid-state diffusion, which play such an important role in the design of these transistors. The studies of this group provided knowledge that makes it possible to use the advantages of solid-state diffusion efficiently and routinely in the factory. The technique of oxide masking (RECORD, *November*, 1960)—also an important semiconductor-fabrication method — was the indirect result of a series of such studies.

We will not attempt to describe the total development program of the diffused-silicon transistor. Instead, several of the newer and more



Diffusion furnace used in fabrication of diffused-silicon transistor. "Boatload" of silicon slices on end of quartz rod is propelled into furnace, along track, by a wire and pulley.



Mesa transistor produced using double diffusion (lower left). N-type emitter region, in diagram and cutaway photo, was formed by oxide mask.

interesting processes that characterize semiconductor technology will be used to illustrate the type of technical problems that constitute "development for manufacture."

Most of these examples emphasize a central and continuing problem in such development: the property that makes a material or technique desirable for one process may limit the full and efficient use of a related fabrication technique. Often such limitations derive from a lack of complete understanding of the basic physical or chemical properties of materials and, more importantly, of the subtle interactions between these materials as their properties vary with time, temperature, and composition. This sometimes delicate interplay between materials can be well illustrated by an examination of the diffusion processes used in making the 2N560 transistor.

Knowledge of the diffusion coefficient of an impurity and its concentration at the surface of a semiconductor allows one to predict the impurity concentration in the body of a semiconductor at any given location. The laws governing this relationship are most conveniently expressed when the concentration of impurity atoms on the surface of the semiconductor and the coefficient of diffusion remain constant. Theoretically then, the diffusion problem simply requires that one establish an equilibrium concentration of the diffusant impurity in a carrier gas, and then control time and temperature accurately to achieve precise control of diffusion.

Practically, however, the diffusion process generally requires painstaking effort to insure reproducibility in manufacture. To illustrate this, let us compare the two important diffusion processes used in the fabrication of the 2N560 transistor. A photograph of the diffusion furnace used in this process is shown on page 207.

The first diffusion, which forms the base region of the transistor, establishes a surface concentration of gallium atoms (p-type) one hundred times that of the original n-type impurity over the entire area of this single-crystal "slice" of silicon. After the gallium diffusion, an n-type layer is formed by phosphorus diffusion. In this step, the phosphorus surface concentration should be approximately one hundred times that of the gallium surface concentration. When these conditions are achieved, theory predicts that an n-p-n layer will be formed in the semiconductor.

An n-p-n layer of this kind appears on the right in the photomicrographs on page 209. In this illustration, the vertical dimensions are enhanced by beveling, and the layers are made visible by "staining" them with a mixture of nitric acid and hydrofluoric acid. The series of parallel lines visible on this photomicrograph are "interference fringes" which are visible when the specimen is viewed in monochromatic light through an optical flat. They are helpful in determining the depth of the diffused layer. The layer thicknesses represented by the stained regions are approximately 0.0001 inch thick. And the tolerances required for a high yield of usable transistors from the diffused slices are plus or minus 0.00002 to 0.00004 inch, depending on the transistor type.

To achieve this precision, it is necessary to start diffusion from a surface that is polished optically flat and to maintain this uniformity of flatness throughout the several diffusions. Also, because silicon has been found to erode, or evaporate selectively, at the temperatures required, it is advantageous to diffuse in oxidizing atmospheres. Such an atmosphere forms a layer of silicon dioxide that prevents further erosion. This oxide protection results in several complex interactions, however, and these require skillful treatment in the manufacturing process to achieve reproducible diffusion.

In the case of gallium diffusion, the vapor pressure of the diffusant—gallium sesquioxide—is so low that the desired surface concentration of gallium atoms cannot be achieved in a strongly oxidizing atmosphere. Consequently, it is necessary to heat the gallium sesquioxide in a reducing atmosphere—hydrogen, for example. This converts the gallium sesquioxide to a form that has a higher vapor pressure, which, in turn, results in a higher concentration of gallium in the carrier gas and thus at the semiconductor surface.

Since the proportions of diffusant in the carrier gas is sharply dependent on the oxidizing characteristics of the furnace atmosphere, meticulous control of gas proportions is necessary to achieve an atmosphere which is slightly oxidizing. This inhibits erosion of the silicon surface, as well as controlling the diffusant concentration.

Phosphorus Diffusion

The same careful consideration of high-temperature chemistry is necessary in refining the phosphorus-diffusion process. But because the properties of the materials are different, processes that work well for gallium diffusion must be assiduously avoided when working with phosphorus. For example, phosphorus diffusion is inhibited by a surface layer of silicon dioxide. Thus, if oxide protection is desired, it must be provided in a way that will not inhibit diffusion of the phosphorus. Such inhibition is prevented by "growing" the oxide in the presence of phosphorus so that it is uniformly distributed in the oxide layer. This phosphorus-laden oxide layer then acts as a source from which phosphorus diffusion proceeds. As a consequence, phosphorus diffusion is carried out in a strongly oxidizing atmosphere.

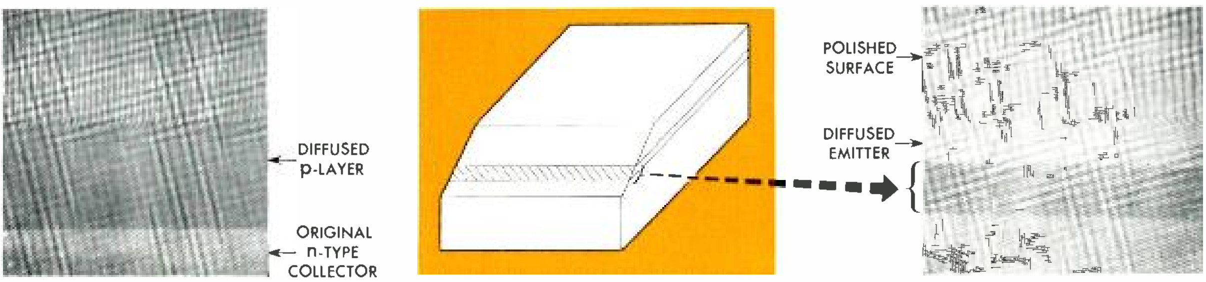
In contrast to the gallium diffusion, it is imperative that all traces of water vapor be removed from the phosphorus-diffusion atmosphere, since the source—phosphorus pentoxide—absorbs water readily. Traces of moisture in the system would cause a non-uniform concentration of phosphorus on the silicon surface and result in extremely non-uniform diffused junctions.

When development for manufacture of the diffused-silicon transistor was initiated, early production began with the type of double-diffused layers depicted in the photomicrograph shown below. However, the technique of controlling the area of the diffused emitters by oxide masking was conceived as a result of an improved understanding of the phosphorus-diffusion process. The oxide-masking technique was developed by exploratory development groups at Murray Hill, refined at the Allentown and Laureldale Branch Laboratories, and was first used in the production of the 2N560 transistor. A double-diffused layer, where the emitter has been formed by oxide masking, is shown in the photomicrographs on page 208. The advantages of this design have been discussed in a previous article in the RECORD (*November*, 1960). The photomicrograph shows a beveled and stained section of the transistor made by defining the area of the diffused emitter by oxide masking.

Exploitation of this improved technique of fabrication required a gradual changeover from the existing device to a modified design. This change had to be accomplished without a change in the electrical performance of the transistor and without a significant interruption in development and production schedules.

Another of the vital steps in fabricating the diffused-silicon transistor was the necessity of making contacts, which were both mechanically and electrically stable, to extremely small and precisely positioned areas on a semiconductor wafer. The photomicrograph on page 210 shows a small portion of a silicon slice 0.6-inch square containing a total of 400 transistor elements. The enlarged center inset illustration is a photomicrograph of a single transistor element, which shows two rectangular metal stripes centrally located within a slightly larger rectangular area. The area containing the short metal stripe is the diffused emitter depicted. The placement of the stripes relative to this diffused emitter controls the electrical performance of the transistor. This critical placement is achieved by evaporating the material that forms the stripe through carefully registered metal masks (RECORD, *October*, 1958).

If one examines the dimensions of the stripes shown in the photomicrograph of the slice, he



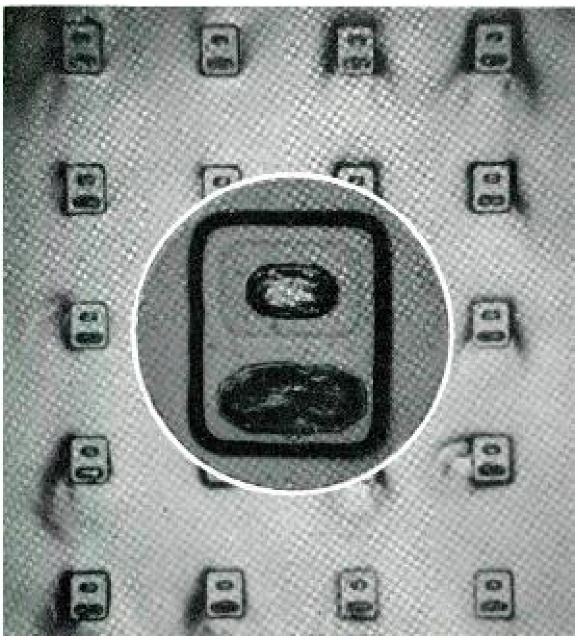
Typical n-p-n layer formed by double diffusion of gallium and phosphorus. P-type base region, shown on left, provides background in which later phosphorus diffusion forms n-type emitter (right).

gets a much fuller appreciation of how critical the problem of lead attachment is. Specifically, the emitter stripe is 0.002 by 0.004 inches, and the base stripe is 0.002 by 0.006 inches. There is a nominal separation of 0.002 inches between them.

During the early phases of the experimental development of the diffused-silicon transistor, electrical contacts were made to these stripes with spring-loaded point contacts or by soldering on wires. At about the same time, the concept of thermo-compression bonding was discovered and developed experimentally (RECORD, *November*, 1957; *April*, 1958). This technique for making a metallic bond between two metals at a temperature below the melting point of either has proven to be a highly satisfactory method of making delicate, critically-spaced contacts.

The major problems with thermo-compression bonding in final development involve the design of tooling that permits this process to be used quickly and efficiently in the factory. Although it does not show inner details, the photograph on page 211 gives some idea of the complexity of the thermo-compression-bonding tool used in the fabrication of the diffused-silicon transistor.

Any article describing the final development of an electronic device would not be complete without a discussion of its electrical parameters. We will look at only one of these, but its chronology will typify problems that often confront a designer during development for manufacture.



Portion from a silicon slice that contains a total of 400 diffused transistor elements. Detail of a single element is shown enlarged in center inset.

The potentially high speed of the diffused-silicon transistor was realized quickly in the early models fabricated by development groups at Murray Hill. These designers had to struggle, however, to achieve sufficient current gain to make the device useful in most circuits.

As their basic knowledge of the silicon material and the effects of heat treatment during diffusion became more complete, the early developers recognized that the low current-gain in the device was due to an extremely low "minority-carrier lifetime," i.e., the time it takes the concentration of electrons in p-type (or holes in n-type) material to decrease to a certain fraction of its "zero-time" value. By experimentation, they found that this lifetime could be maintained at a sufficiently high value by limiting the maximum temperature during diffusion and by annealing after diffusion. Further application of this basic understanding of process and materials made possible continued improvements in device performance until fabrication of high-gain transistors was shown to be feasible. At this point, final development began.

Final Development

One of the key characteristics of a semiconductor junction which limits the switching speed of a transistor is the "storage time"—the time that the collector remains on after the base, or control electrode, is turned off. This characteristic is also directly related to minority-carrier lifetime, which as pointed out, is critical in determining current gain. Thus, the development-for-manufacture engineer is faced with an ambiguity in the final development objectives. The circuit designer desires higher gain to make his circuits more efficient, and the device designer can provide this increased gain. But in this example, each improvement that produced higher gain also resulted in increased storage time and consequent degradation in the ultimate switching speed.

Fortunately, final development is in true partnership with the research, exploratory-development, and design-for-manufacture functions. During the period when this ambiguity was becoming apparent, basic studies of diffusion and semiconductor materials by all of these groups unearthed information that helped to identify and minimize the cause of low minority-carrier lifetime. Then, the solution of the problem of excessive storage time became straightforward. Processing was modified to yield the highest possible gain. An extra diffusion step was introduced. Here, controlled amounts of gold, which degrades minority-carrier lifetime, were diffused

Operators use complex tools for thermo-compression bonding leads to transistor element stripes. Element is exactly positioned by micrometers.

into the silicon at a temperature high enough to produce a uniform concentration of gold impurity in the silicon slice. Since the solid solubility of gold in silicon is temperature-dependent, the temperature at which the diffusion is carried out controls the concentration of gold in the silicon. The separation of variables that the basic understanding of the cause of low-minority-carrier lifetime allows now makes it possible to achieve the desired design compromise. The storage time can be decreased by increasing the temperature of the gold diffusion to the extent that current gain is not degraded below the value required for efficient circuit design.

The three problems detailed here—anomalies in diffusion, bonding leads to critically small areas, and resolving conflicts in the basic properties of a p-n junction—are typical of the multitude of problems that must be solved prior to or during development for manufacture. In each case, the final-development engineer must have a basic understanding of the underlying design theory, materials, and effects of various processes that enter into the fabrication of a device before he can release it for routine manufacture.

One of the most important reasons for solving such development-for-manufacture problems at a branch laboratory in a manufacturing location is the ease with which new concepts may be translated from the "drawing board" to "hardware." This metamorphosis is aided immeasurably by the presence of Western Electric process engineers. The experience and cooperation of these men are further important factors in successful development for manufacture.

Computer Indexes Scientific Documents

Scientific documents are being swiftly and automatically indexed according to important words in their titles by an electronic digital computer at Bell Telephone Laboratories. The titles are fed to an IBM 7090 computer on punched cards along with other cards containing the names of authors and identification numbers. The computer is programmed to scan these cards, reorganize the information, and print out a "Permuted Title" subject index.

The index is called "permuted" because each significant word of a title appears, in turn, as a "key" word in the index. The word is listed alphabetically at the index position in context with the other words of the title. The computer is instructed to ignore unimportant words such as prepositions, conjunctions, articles, verb forms, adjectives and some nouns which are considered to have little value as index words.

Each permuted title is stored in the computer memory. When all titles have been permuted, the computer reshuffles them and produces, on magnetic tape, an index in which all titles are listed alphabetically according to the key word. This tape is fed to a high-speed printer which prints out titles, in English, at 600 lines per minute.

One feature of this system is that the pages from the high-speed printer can be reproduced by photo-offset and bound into an index book; they do not have to be retyped or typeset.

Another advantage is that the output tape from any index can be saved and later "merged" with subsequent tapes to produce a cumulative index. The merging program permits up to eight tapes to be merged onto one tape; thus monthly indexes can be easily cumulated into semi-annual and annual indexes.

The computer can also be instructed to produce an alphabetical author index, a bibliographical list of all the indexed documents, and other indexes according to date, language, project or any other classification.

This method of indexing saves considerable time. It takes a clerk only about two minutes to punch the title, author and project number on standard punched cards. In one application the computer took only 12 minutes to index 1700 documents. Because the method can be applied so quickly and routinely, and because the information can be up-dated so easily, Bell Laboratories Library is using the technique to prepare a bulletin for publicizing new literature.

In all areas of science, there is an urgent need for better high-speed photographic techniques. At Bell Laboratories, scientists are developing new forms of cameras to reveal heretofore unknown physical and biological phenomena.

J. S. Courtney-Pratt

High-Speed Photography And Micrography

In a great many problems in research and industry today, it is necessary to take pictures with a very short exposure time to study what is happening, to see how certain kinds of faults occur, or to see whether equipment is behaving as it should. Many research studies at Bell Telephone Laboratories would be materially assisted by high-speed photographic analysis.

If we were photographing, for example, a fast-moving car, we might need an exposure time for any frame between a hundredth and a thousandth of a second. The exposure that is needed is dictated partly by the speed of the car and partly by the relative size of its image in the camera. Suppose a car travels at 100 miles per hour and that it is 75 yards away. If we have a camera that takes pictures of the same size as professional 35-mm cine cameras, each frame will measure 16 mm by 22 mm. With a lens of focal length 6 inches, the image of the car will be about half as long as the frame, and the speed of the image relative to the emulsion will be only 1/450 of the speed of movement of the car. If, to determine the detail we want, we decide that the image blur should never be more than one tenth of a millimeter, we obviously need an exposure time as short as one thousandth of a second.

If the car is farther away or moving toward the camera rather than across the line of sight, the exposure time need not be so short. On page 214 there are three successive frames of a racing car traveling at speed. These pictures are of high quality and are acceptably free from blur both with respect to the car and to the background. They were taken at the ordinary rate of 24 frames per second and with an exposure time for each frame not much shorter than one hundredth of a second. Because the car is a large and relatively distant object we do get sharp pictures at normal exposure times.

Suppose, however, that we wanted to study the deformation of the tread of the tire. One possible way would be to make a section of an elevated roadway out of glass and to photograph the car as it passed over the top. The tread pattern on tires may have details that are only a few tenths of an inch across. We would need to take pictures at something near natural size rather than reduced by a factor of 450, and the rate of movement of the image in the camera would then be

450 times faster. The exposure time that we would need would have to be 450 times briefer.

The extraordinary shortness of the exposure time needed to study fine detail is quite a general problem. It is greatly aggravated when we consider the problem of taking pictures through a microscope. In a typical example, an insect can walk at one or two feet per second. Suppose we wished to study the leg movement of a fly. We might well wish to magnify an image of its foot by, say, a thousand times; and so the image on our film would be moving intermittently at speeds higher than a thousand feet per second. In order to keep the blur on the film to the same figure as before (that is, 1/10 mm), we would need an exposure time shorter than a three-millionth of a second.

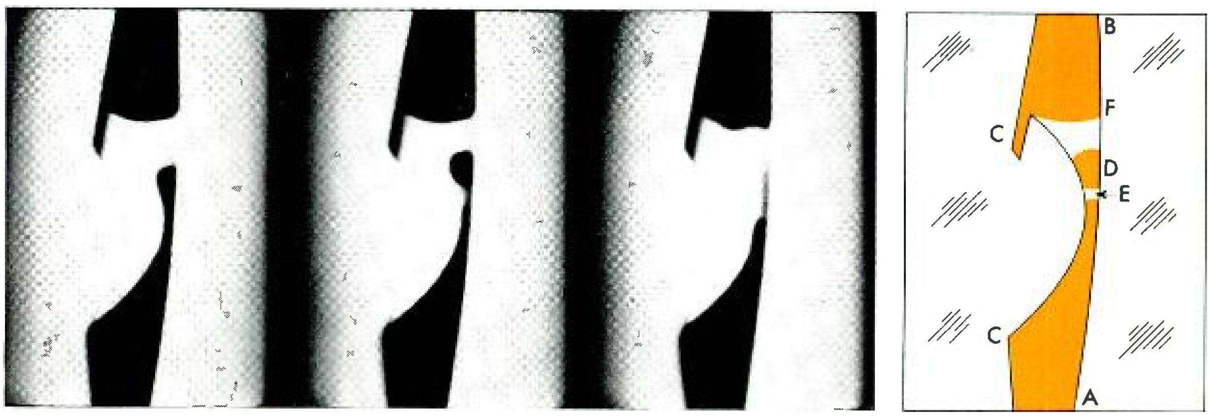
Again, we think of the movement of the column of mercury in a thermometer as a very slow process. In spite of this, we need high-speed cameras to find out how it moves. In a clinical thermometer there is a constriction just above the bulb, so that after a patient's temperature is taken the top of the column of mercury remains at the maximum height although the temperature of the bulb drops again, and the bulk of the mercury contracts within the bulb. A number of suggestions were put forward to explain the way that the mercury column breaks at the constriction. These explanations all seemed rather unsatisfactory in one respect or another.

Recently, the problem was studied in more detail. To overcome the awkward refraction due to the cylindrical curvature of the glass stem, flat surfaces were ground on the sides of the thermometer. This made it possible to examine the constriction with a microscope. Surprisingly, it was found that even when the mercury was expanding there was not a continuous thread of mercury through the constriction.

As the temperature in the bulb rose, the mercury was pushed into the convergent part of the constriction. The curvature of the mercury surface at the constriction became greater, and to overcome the surface tension effects, the pressure in the bulb increased. After the pressure reached a value sufficient to force some mercury past the narrowest part of the neck, a globule of mercury shot rapidly from the narrowest part of the constriction into the stem of the thermometer. The rate of movement of these globules was not tremendously high, but they traveled a distance as large as their own diameter in a very short time.

To follow these movements, it was necessary to use a cine camera working at about 3000 frames per second. Even so, one can rarely see the movement of the mercury globules; but one can follow the early stage of their formation and can form some estimate of their speed and frequency. The whole of this phenomenon is elucidated by a single series of high-speed pictures. Three successive frames from the record are reproduced below. One can see the stages in the formation of a globule, and the deformed surface of the column of mercury just after the globule crossed the gap.

When we are studying faster phenomena—such as the formation of electric sparks, the vibration and fatigue of metals, the formation of shock waves, the fracture of brittle materials, the ablation of hypersonic projectiles, or a host of other problems—the rates of movement are much higher, and the significant detail is often just as



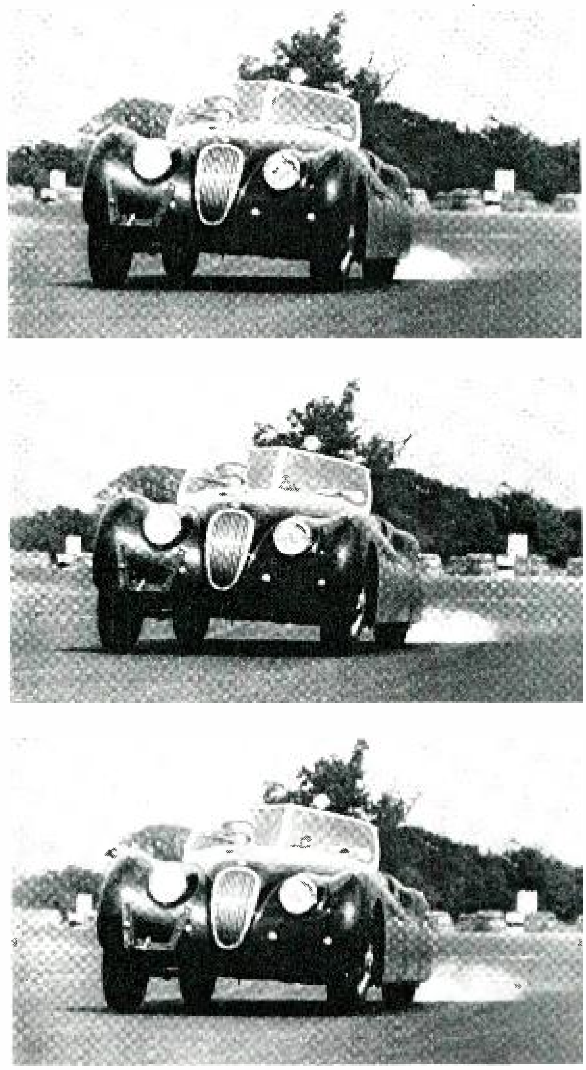
Courtesy R. McV. Weston and S.I.M.P.L.

Fastax Recording of movement of globule of mercury through constriction of clinical thermometer. Repetition rate: 300 fps; magnification: 70X. A. Mercury in bulb. B. Mercury in stem. C. Constriction. D. Globule forming (frame 1). E. Globule detaching from mercury (frame 2). F. Mercury surface at rest (frames 1, 2); mercury surface deformed by impact of globule (frame 3).

small. In such cases, it is more than ever necessary to use the most sophisticated and ingenious forms of camera.

It is also essential to apply research and development effort to the improvement of cameras, for it is not possible to go on increasing the speed of operation of a camera simply by increasing the speed of movement of the parts. Standard 35-mm cine cameras can be increased in speed to about 200 frames per second. If we try to go faster with these intermittent-movement cameras, the claw tears the film at the sprocket holes.

If we are prepared to put up with smaller pictures, we can increase the repetition rate. The resolution measured in line pairs per millimeter may then be no worse; but with the smaller format, the resolution in line pairs across the whole frame will probably be lower, and so the information content of each picture will be less. For example, we can achieve a speed of 400 frames per second with a relatively conventional 16-mm camera that stops the film while each frame is taken. However, the over-all resolution of each frame is less than half of that of the 35-mm camera mentioned above.



Courtesy of Shell-Mex and B. P. Ltd.

Racing car driven by Stirling Moss traveling at high speed. Repetition rate: 24 fps; linear magnification: 1/50; exposure time per frame: 1/100 sec.

The Fastax Camera

A big advance in speed is possible if, instead of stopping the film while we take each picture, we move the film continuously and introduce some form of image-movement compensation so that the image and the film move along together during the exposure. This is the basic principle of the Fastax camera, created by W. Herriott of Bell Laboratories about 25 years ago. Much of the subsequent development of this camera was done by John H. Waddell, formerly of the Laboratories.

In cameras like this, the film moves continuously through a film gate, and image compensation is achieved by rotating a small block of glass between the lens and the film. This general principle works as shown in the diagram on the opposite page. This type of camera can take regular pictures on 16-mm film (each 10.4 mm by 7.5 mm) at a rate of about 10,000 per second. It can take pictures half this height, twice as fast. If we try to drive a camera such as this faster still, we find that again there is a limit set to the speed by the mechanical strength and resistance to flexure of the parts.

If we wish to go even faster, one of the best general principles is to duplicate, or actually multiplicate, the equipment. We can easily take a set of four pictures at short intervals by arranging four cameras in a row and triggering their shutters one after the other with short phase delays between them. Some of the early studies of animal locomotion were made with a scheme not very different from this.

It is reasonably easy to set up such multiple equipment if we are trying to photograph a fairly distant object. However, if we wish to study something close by, it is difficult to pack all the lenses and cameras sufficiently close together to be able to get the pictures at all. In any case, these pictures would be taken from somewhat different viewpoints and we would have problems from parallax. We wouldn't be able to project such a sequence to give a steady picture.

A most valuable solution to this problem was proposed at about the same time by C. D. Miller and I. S. Bowen working independently. They arranged a row of cameras with their axes pointing toward one common point and formed a real image of the event on a mirror at this common point. As the mirror rotates, the beam of light points to the camera lenses one after the other. Since the mirror is small, it can be rotated at a very high speed. The camera lenses are fairly small and so an extraordinarily high repetition rate is achieved.

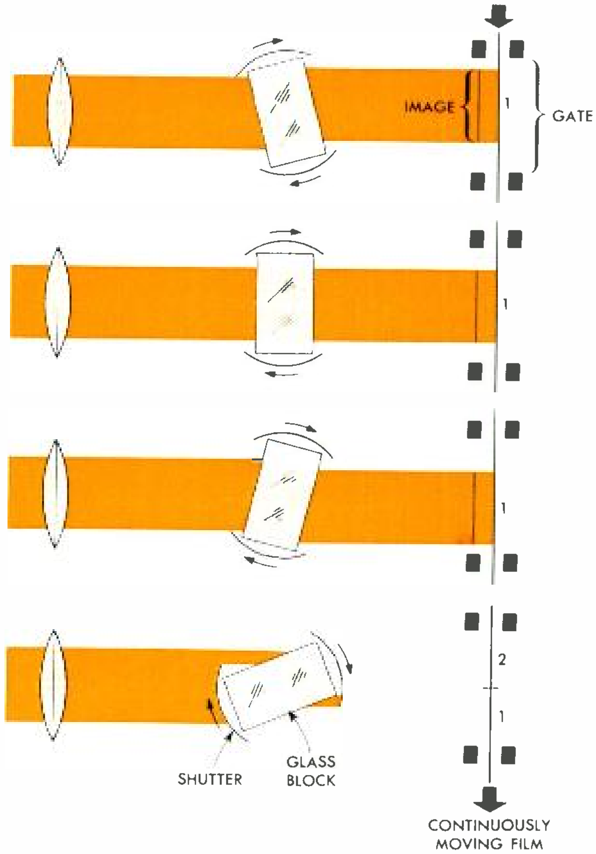
This kind of camera is now called a rotating-mirror framing camera. Some very elaborate cameras working on this principle have been built in a number of laboratories in several countries. One such American camera can take a sequence of 25 pictures at 1,200,000 per second. Another can take 80 pictures at 1,400,000 per second. A rotating-mirror framing camera built by the United Kingdom Atomic Energy Authority takes a sequence of 30 pictures at 10 million per second. The speed limit of a camera of this kind is again set by the strength of mechanical parts. Driving the rotor too fast causes it to burst because of centrifugal stresses.

If we use a wide aperture lens with a rotating-mirror framing camera, we need a large mirror. If the width of the mirror is large, we cannot rotate it at a high angular speed. If we use very narrow apertures, not only is it difficult to get enough light, but we find that the resolution of any picture is limited because of the diffraction of light. In 1956, Professor H. Schardin of the Institut Franco-Allemande de Recherche de St. Louis showed that it would not be possible to increase the product of the repetition rate and the number of lines resolved across each frame beyond a certain figure which would depend on the strength-to-weight ratio of the mirror material.

Today's cameras are still well below Schardin's fundamental limit. Even so, it is possible with rotating-mirror framing cameras to achieve a resolution of 280 line pairs across each frame at repetition rates in excess of 10^6 pictures per second. The cameras are excellent for photographing brilliantly illuminated events. Such image brilliance can be achieved when photographing objects at or near natural size. For example, M. Sultanoff of Aberdeen (Md.) Proving Ground has even recorded a sequence of pictures with a camera of this kind in color at sub-microsecond intervals—a really remarkable achievement.

The problem of light level becomes much more difficult when one tries to photograph at considerable magnification. There are some subjects which are bright enough. In several laboratories, series of pictures have been taken of the explosion of a wire or a foil when a large surge of current was passed through it. The magnification (from object to photographic emulsion) was about 25 times. However, for really high magnification, it would be almost impossible to get enough light through a rotating-mirror framing camera to be able to take such series of photographs.

At Bell Telephone Laboratories, we are trying to avoid the inherent limitations of conventional high-speed cameras, and are trying to find new and better methods for studying the changing detail of phenomena. One promising method follows an approach suggested some years ago. An ordinary photographic microscope was set up, but instead of putting a photographic plate at the image plane, it was decided to insert there two plates each embossed with a large number of cylindrical lenslets. The axes of the cylindrical lenslets were crossed at right angles and the effect was the same as if there were an array of spherical or



This diagram shows the principle of image compensation by means of a rotating block of glass. As the block turns, the image is displaced, and for the duration of the exposure, the image remains in register with the continuously moving film.

point-focus lenslets. Pitch spacing between the axes of the lenslets was 0.4 mm.

With plates five inches square, there are 300 lenslets each way across the image plane. Each of these lenslets focused the light that fell on it to a small point element. A photographic plate was placed at the focal plane of the pair of lenticular plates. A simplified diagram of the optical layout is shown on this page. The image on the photographic emulsion is made up of 90,000 dots, and is rather like a halftone illustration. The difference is that these dots are all about the same size but vary in density; whereas a halftone illustration in a magazine is made up of dots of varying size.

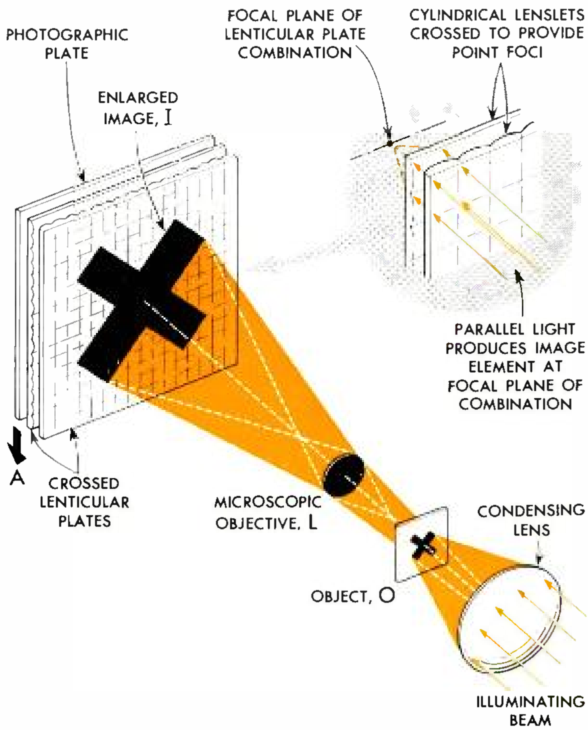
Because all the dots are small and are well spaced from one another, it is possible to record another picture, interlaced with the first, by moving the photographic plate sideways (in the direction shown by the arrow A) by the width of one dot. In a typical case, the image elements have a diameter that is only one thirtieth of their pitch spacing. Thus by moving the plate 1/750 of a centimeter, one can record a new picture. A simple traverse mechanism allowed one to move the plate at more than 100 cm/sec, and this meant that it was possible to record pictures at 100,000 per second with quite simple apparatus. Moreover, it proved possible to record sequences of about 300 pictures with a microscope of this kind without getting double exposure.

How does this microscope compare with the cameras previously described with respect to the amount of light that it will pass? We can use a wide numerical aperture microscope objective. All the light that passes through the objective falls on the lenticular plate. All the light that falls on any one lenslet is concentrated to a small dot. This dot is actually an image of the aperture of the microscope objective (or of the projection eye-piece, if one is used). The specific-brilliance of the image element is some 400 times greater than the average brilliance of the image in the plane of the lenticular plate. The microscope is then able to operate with a very low light level. In fact, it has been used to study events at magnifications up to 2000X at its full repetition rate.

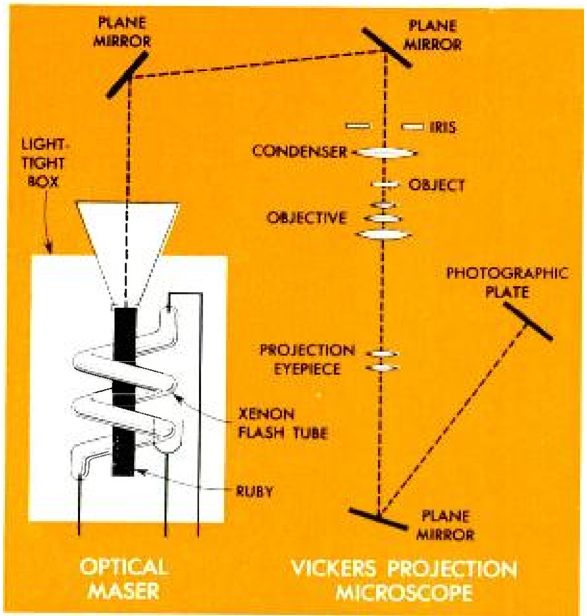
Work is in progress at Bell Laboratories on a microscope that operates on the same general principles. It will have a resolution a good deal higher than those previously constructed. A figure of 600 lines across the field each way is expected, and it is possible that repetition rates approaching one million per second may be achieved.

The first simple cine-microscope of this kind was built by the author at Cambridge University, and he built the second model at the General Electric Company. In typical cases, these microscopes have been used to study the combustion of small crystals of primary explosives, the first stages of the ignition of photoflash bulbs, and the failure of fine filament wires.

The factors to be considered in making a choice among these various types of equipment underline another general problem in high-speed photography. It is not possible to obtain a single camera that has wide aperture lenses, that runs at a great speed, that works at a high magnification, that gives extremely brief exposures, and that will give a high resolution. One has to make a compromise and a choice. Perhaps the maximum speed is required as, for example, in some ballistic studies. Perhaps the greatest possible light-gathering power is required, particularly when studying small objects in a laboratory. Perhaps two pictures of extreme resolution will show all the detail necessary, and we might use simple spark shadowgraphs. Suppose we were interested in the velocity in free flight of a small spherical



Design of an optical layout for a lenticular plate image-dissection cinemicrograph. The lens L forms the real image I of the object O on the plate. Each lenslet forms an image on the emulsion of the aperture of the microscope objective L. Sequential recording is effected by moving the photographic plate in the direction of the arrow A.



Arrangement for using beam from a ruby optical maser as a light source for photomicrography.

particle. We know that the velocity cannot change irregularly. Two sharp pictures would probably give us all the information we needed, namely, an accurate measurement of the change of position in a given interval of time.

On the other hand, we may not know anything about the details of the phenomenon that we are studying; for example, the way that a mechanical component vibrates and fractures. We may then need a long sequence of pictures so that we can look at it qualitatively; and high resolution might then have to be for the moment, a secondary requirement. There are many other ways in which we might approach special problems. For phenomena that are not self-luminous, we might concentrate on the production of extremely bright short flashes of light. In this connection, the recent advances in optical masers are of great prospective importance. As an example, a photograph, taken at a magnification of 1800 times by the flash of light from a ruby maser was published in the April 1961 issue of the RECORD. The optical arrangement for taking that photograph is shown above.

On some other occasion, perhaps a single picture is all that we need, but it might have to have an exposure time less than 10^{-8} sec. It might then be better to use a Kerr cell or an image-converter tube to take a single picture. There are a great variety of possible methods. Only a few of them have been mentioned in this article. There is much research and development still to be done. It is an exciting and interesting subject.

Card Dialer Telephone Will Be Marketed

A major innovation in business telephone service will take place this year as the Bell System begins to market the Card-Operated Dialer telephone set developed at the Laboratories. This development in automatic dialing will be offered as an aid to people who make many calls or who call the same numbers frequently.

Operating on the principle of automatic dialing of pre-recorded telephone numbers, the new telephone combines in one housing the regular components of a standard key telephone set with a punched-card operated dialing mechanism.

To call a number, the customer inserts a plastic punched card into the dialer, lifts the receiver, waits for dial tone and presses the START bar. The automatic equipment reads the card and dials the number. When the call is completed, the customer presses the RELEASE bar and the card is ejected from the slot.

The perforated cards—one for each frequently called number—are filed in twin receptacles at the rear of the telephone housing. Cards come with each new telephone and are punched out by the customer with any pointed instrument. Each card can accommodate a telephone number up to 14 digits in length and can thus be used for Direct Distance and Inward Dialing services.

The card dialer is now going into production at Western Electric's Indianapolis works. Beginning this spring, market tests will be made in selected telephone company areas. Later in the year limited quantities of the new telephones will be made available for customer use.

The Card-Operated Dialer telephone set is the first of a new family of automatic dialers.

Preventive maintenance, vitally important in reducing service interruptions in the Bell System, is made easier by improvements in equipment-monitoring devices.

T. J. Hofbauer

Metering Gas in Telephone Cables

To distribute its communications services throughout the nation, the Bell System relies heavily on underground, buried, and aerial transmission cables. These are subject, of course, to their environments, which beget a number of physical problems. One problem is sheath breaks caused by a wide variety of destructive agencies.

Such breaks permit moisture to enter the cable and be absorbed by the paper insulation of the conductors. This impairs or causes failure of telephone service. One way to prevent or minimize the entrance of moisture is to impose a positive internal gas pressure upon each transmission cable. For many years, in fact, a gas under pressure—usually dry nitrogen or dry air—has been an important part of the preventive maintenance for Bell System cables.

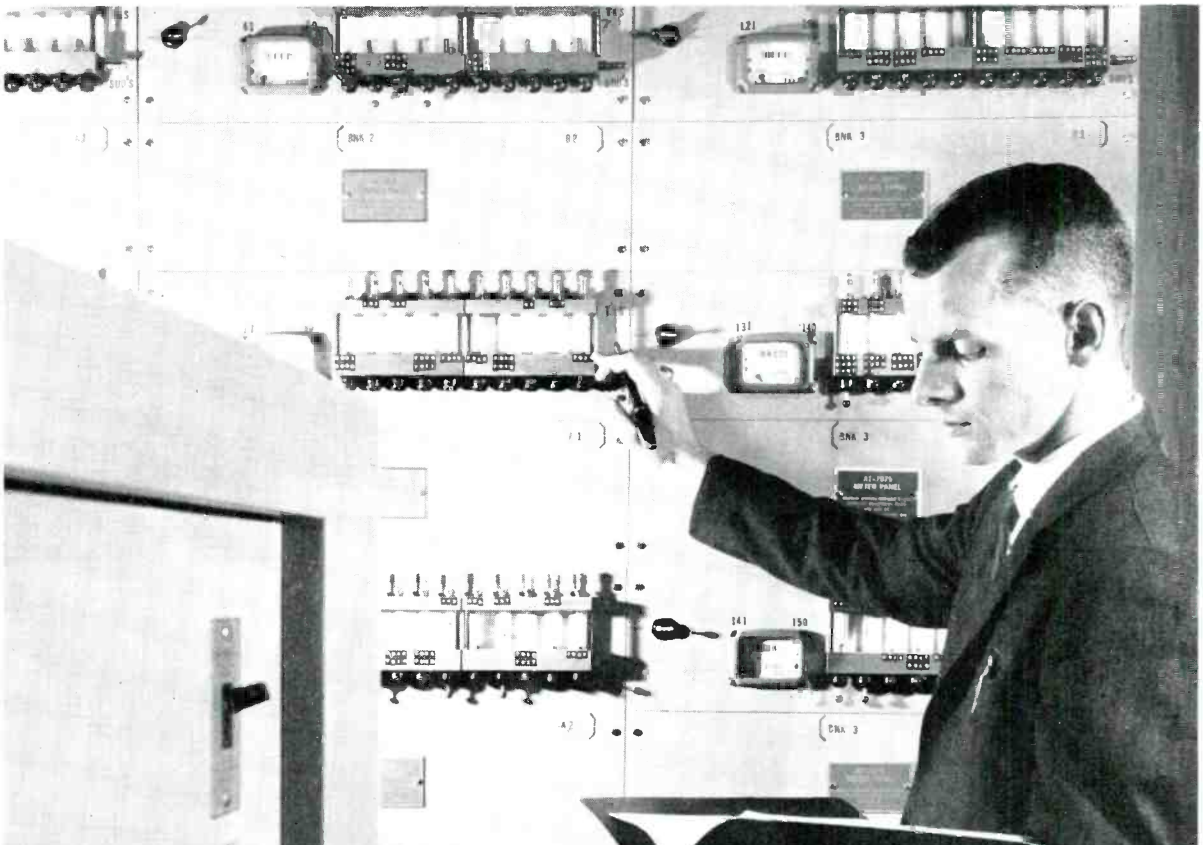
A typical cable network for telephone customers may contain as many as 50 feeder cables, originating in a metropolitan or suburban central office and branching out as a larger total of distribution cables until the amount of sheath in the network may measure as much as 500 miles. To prepare such a network for gas-pressure protection, Operating-Company personnel locate and repair the major existing sheath breaks, and seal or "plug" excessively leaky cable terminals. However, despite such preliminary sheath rehabilitation, a substantial distributed leakage may remain. After dry air is introduced, additional defects may be found and repaired. Local conditions will determine when it is expedient, economically as well as physically, to terminate sheath-repair operations. Then relatively large quantities of dry air must then be supplied continuously to sustain adequate protection. The system is pressurized, from the central office outward, as available money and manpower permit.

Dry air in the necessary quantities can be most practicably produced by air dryers located in central offices (RECORD, *October*, 1956; *January*, 1961). This equipment compresses, refrigerates, and expands air to cable pressure. Measurement of the volume of air flowing into each cable or more significantly, of changes in the rate of this air flow can be a useful indicator of the condition of the cable sheath. For example, a sudden increase in the gas consumption of an individual cable is often the first warning of a sheath break.

The quantity and distribution of dry air furnished to a cable network by a centrally located air dryer is monitored by a combination of gas meters and flow-rate indicators. Originally, this apparatus consisted of a gas meter for each cable being serviced and the necessary shut-off valves and piping to conduct the air from the source to the cables. The gas meter enabled central-office personnel to periodically check the total gas consumption of individual cables. Significant changes in demand indicated that a leak had probably developed in the cable associated with the meter, and leak-locating procedures could then be initiated.

This arrangement has a number of disadvantages. For example, in addition to requiring relatively large areas of wallspace, installation of the components requires custom-made mountings and plumbing to fit the particular location. The resulting installation is usually time consuming and costly. Also, many field-assembled pipe connections are susceptible themselves to gas leaks.

Both technically and economically, this situation has generated the need for a unitized piece of equipment capable of efficiently monitoring the gas system and simultaneously lending itself to easy installation. Consequently, the Laboratories



The author checks readings on new meter panel used to monitor gas in telephone cables. Arrangement replaces the need for meter for each cable, provides flowmeters to show changes in demand of dry air generated by equipment in foreground. Improvement saves space, speeds up reading time.

has developed a meter panel which, in addition to the desired features, is more compact and costs less than the original arrangement.

The new meter panel unit is comprised of a single gas meter (similar to those commonly used on utility service lines in private homes), five or ten dual-range float-type flowmeters, a main shut-off valve, and the necessary piping. Each cable has individual shut-off and pressure-testing valves as an integral part of the flowmeters, thus enabling isolation or pressure testing of any particular cable when necessary. Interconnection of the panels in a central office requires only two compression-type tube fittings to be assembled.

Each dual-range flowmeter contains two "floating balls." One operates in the range from 0 to 2.5 cubic feet per hour (cfh) and the other, heavier, ball in the range from 2.5 to 7.5 cfh. Sliding indicators on the tube of each flowmeter provide a way to mark the normal demand of each cable.

In operation, periodic readings of the meter indicate any general increase in over-all gas consumption of the ten associated cables. Also, location of the floating ball in relation to the sliding indicator on the individual flowmeters indicates which of the ten cables has developed a leak. Thus, ten relatively small and inexpensive float-type flowmeters have replaced all but one of the earlier gas meters without sacrificing the usefulness of the apparatus.

The new meter panel, neat and compact in appearance, saves several man hours of installation time. Also, since all connections are factory assembled and tested, the panel minimizes field maintenance and reduces the possibility of leaks.

Former arrangement for monitoring gas pressure in cables. In addition to requiring daily readings of each counter, these meters occupy considerably more space than do the new design meter panels.

Speed and convenience, two very important concepts of communications, are always part of the design goals for Bell System equipment. A recent development at Bell Laboratories incorporates these concepts in a new attendant's console for PBX's.

Speeding Call:

In recent years, Bell System Engineers have greatly improved the equipment used by attendants at PBX's (Private Branch Exchanges). The old-fashioned oak-paneled "plug and jack" switchboards have been replaced by modern-looking counterparts, equipped for pushbutton control and available in a variety of colors. Compact and colorful desktop cabinets with switching keys are also now being used for small manual PBX's.

Also now available are small dial PBX's with small, pushbutton-operated consoles similar in appearance to the popular Call Director. In place of a jack for each PBX station, these consoles use a dial to establish connections through the PBX switching equipment to the stations.

Dialing, however, requires several somewhat time-consuming actions on the part of the attendant when a call comes into the PBX from the nearby central office. On such a call, the attendant must determine the extension number desired, push a button, wait for dial tone, and dial the digits of the desired station. Then she may find that the station is busy.

To speed up this part of the call-handling process, Laboratories engineers proposed to equip the attendant's console on the 756A PBX (RECORD, *January*, 1959) with a group of illuminated pushbuttons—one button for each PBX station. In

D. J. Gagne

Through a PBX

Attendant's console for DSS with Busy Indication. Extension number dialing has been supplemented with pushbutton system for incoming calls.

this arrangement, by merely glancing at the pushbutton array on her console, the attendant would immediately know the busy or idle condition of each station. She would complete incoming calls to a station on the PBX merely by pushing one of the buttons, holding it down until the lamp in the button lights, and then releasing it. The lighted button would signify that the connection had been established from the central-office trunk to the desired PBX station, and that ringing had started. This button would stay lighted as long as the station remained busy. The button would of course also be lighted during calls originated by the station.

Since this arrangement offers a method of directly selecting PBX stations, it has been given the obvious name of "Direct Station Selection" or DSS. Also, the illuminated lamps in the DSS pushbuttons have been called the "Busy Lamp Indication." Hence, the Bell System refers to this service as "DSS with Busy Indication."

To investigate the feasibility of DSS with Busy Indication, the Laboratories built experimental equipment and connected it to a 756A PBX. The results of this experiment were so attractive that AT&T immediately decided to conduct a trial of DSS with Busy Indication in their market test program to ascertain customer acceptance and to determine whether any changes or additions might be needed. Through close cooperation among AT&T, the Western Electric Model Shop, and the Laboratories, 20 trial models of 756A PBX consoles equipped with DSS pushbuttons and busy lamps were installed early in 1960 in 756A PBX's already in service.

The PBX customers participating in the trial were delighted with this new equipment since their attendants could now handle incoming calls more rapidly. As a result, "DSS with Busy Indication" will soon become available as a standard feature in the 756A PBX.

The accompanying diagram shows the basic arrangement of a standard system. Control relays are connected to each of two dial-pulse registers —devices used to count and store dial pulses and to supply dial tone to lines requesting service. The control relays guide the station-selection signals to the digit-storing relays in the register. Each busy lamp is connected to a "make" contact on a "line hold" magnet. When a contact is closed, the corresponding lamp lights at the attendant's console.

Let us follow the operation of this system when the central office completes a call to the central-office trunk circuit. First, a supervisory lamp lights at the attendant's console. The attendant depresses a corresponding "trunk pick-up" key and asks the calling party the number of the station he wants. The attendant next observes whether the DSS pushbutton associated with this station is lit. If not, the station is idle and a call can be completed to the station by merely depressing the DSS pushbutton until it lights.

When the first American orbits the earth, his capsule will be tracked from a 59,800 route-mile communications network recently completed by Western Electric for NASA.

MERCURY COMMUNICATIONS NETWORK COMPLETED

News of Space Research

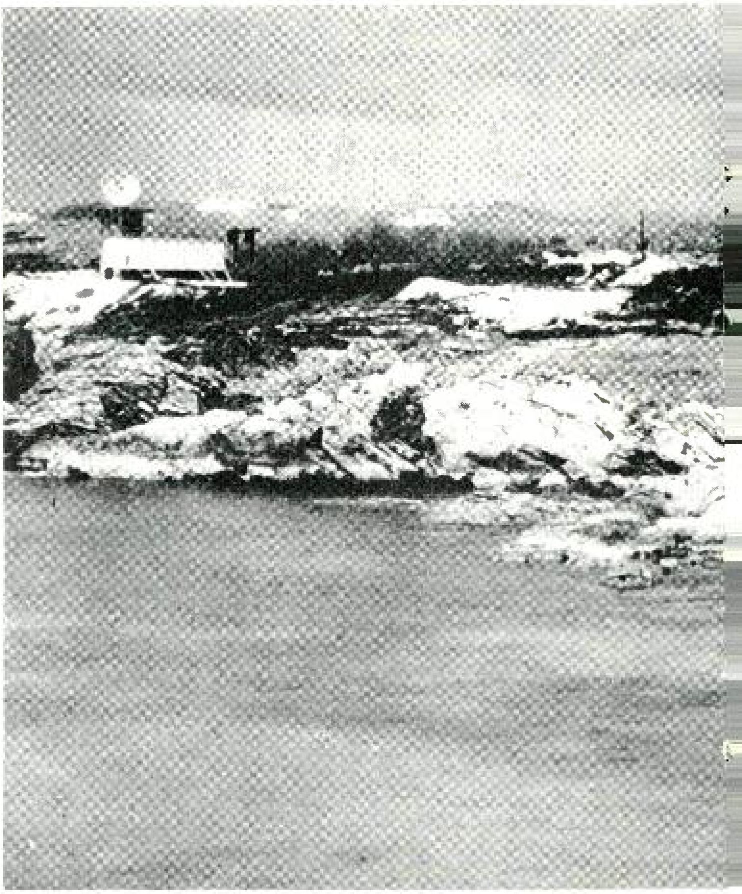
One of the most extensive communications projects ever undertaken—the globe-encircling ground tracking and ground instrumentation system for the National Aeronautics and Space Administration's manned space flight program—has been completed by Western Electric, the Bell System's manufacturing and supply unit. The 59,800 route-mile network was engineered and built for NASA which plans to orbit a manned spacecraft later this year.

The vast system for Project Mercury—code name for the NASA project—uses virtually all types of modern communications technology to track and monitor the capsule's flight, obtain data on the vehicle's performance in space, transmit command signals to the 120-mile high capsule, and talk to the astronaut by radio during portions of his 17,000 mile-an-hour journey.

Leased land lines and overseas radio and cable facilities from as many as 20 private and public communications services throughout the world are integral parts of Mercury's ground communications network, comprising more than 140,000 circuit miles of communications channels. Seven national governments are cooperating in the worldwide network, which spans the continents of North America, Africa and Australia and the Atlantic, Pacific and Indian oceans. Eighteen ground station sites—one of them the Mercury Control Center at Cape Canaveral—are linked into a single operating network through the Goddard Space Flight Center near Washington, D.C.

The responsibility for design, engineering and construction of this tracking and ground instrumentation system has been Western Electric's as leader of an industrial team brought together especially for the purpose. Other members of the group are Bell Telephone Laboratories, Bendix Corporation, International Business Machines Corporation, and Burns & Roe, Incorporated. Men from almost all of the associated Bell telephone companies were recruited by Western Electric to work on the project. As many as 630 first-line subcontractors also participated in developing the fully integrated system.

Among the highlights of Mercury communica-



This ground station in Bermuda may make "go no-go" decision if Cape Canaveral does not.

tions are new developments made at the Goddard Space Flight Center to assure rapid transmission of telephone and teletypewriter messages and high-speed electronic data. A new, specially designed switchboard called SCAMA (for "Switching Conference and Monitoring Arrangement") will permit Mercury's operating personnel at Cape Canaveral to talk simultaneously to all stations connected to the voice network. The Long Lines Department of A.T.&T. developed the SCAMA board expressly for this application in Mercury's ground communications network.

A global teletypewriter communications system will send and receive information from Mercury's ground stations on the progress of the spacecraft's flight. A transistorized IBM computer at Goddard will receive tracking data from field radar stations by teletypewriter. The computer uses. Among these will be the sending of tele-
will process this data and convert it for various typewriter messages from Goddard to the next site in line with the capsule's predicted position, thus enabling men on the ground to be prepared for the space vehicle's appearance overhead.

Incoming data will also be processed by the Goddard computer for high-speed electronic transmission to the Cape Canaveral control center. Making use of Bell System data transmission circuits, information essential to various phases of the orbital journey—launching, overhead passes, return into the earth's atmosphere—will flow back and forth between Goddard and Canaveral at near-instantaneous speeds. During the launch phase, for example, Canaveral's antennas will pick up impulses from the capsule to be relayed to the Goddard computer, processed there and transmitted back to the Canaveral control room at speeds approximating 100,000 miles per second, or more than half the speed of light.

Intercom systems, using Western Electric telephone and PBX equipment, have also been installed at Mercury's stations to provide communications among operating and maintenance personnel.

Every feasible principle of operational integrity and safety has been engineered into Project Mercury's tracking and ground instrumentation system, now ready to play its important role in the government's effort to put the first American safely into orbit.

TALKS

Following is a list of speakers, titles and places of presentation for recent talks presented by members of Bell Laboratories.

AMERICAN CHEMICAL SOCIETY MEETING, St. Louis, Missouri

DeBenedictis, T., see Hansen, R. H.

Fuller, C. S., *Reactions of O and Si in Ge.*

Hannay, N. B., *Semiconductor Chemistry.*

Hansen, R. H., Russell, C. A., DeBenedictis, T., Martin, W. M., and Pascale, J. V., *Inhibition of the Copper Catalyzed Oxidation of Polypropylene.*

Hawkins, W. L., see Winslow, F. H.

Huyett, M. J., see Lundberg, J. L.

Kolb, E. D., see Laudise, R. A.

Kuebler, N. A., see Nelson, L. S.

Laudise, R. A., and Kolb, E. D., *Hydrothermal Crystals Growth.*

Lundberg, J. L., Wilk, M. B., and Huyett, M. J., *Sorption Studies Using Automation and Computation.*

Luongo, J. P., *Chemical Structure by Absorption Spectroscopy.*

Martin, W. M., see Hansen, R. H.

Matreyek, W., see Winslow, F. H.

Moscowitz, A., see Snyder, L. C.

Murray, R. W., and Story, P. R., *A Proposed Mechanism of Antiozonant Action.*

Murray, R. W., and Trozzolo, A. M., *Dicarbenes. The Preparation and Some Reactions of 1,4-Bis(a-diazo-benzyl)-benzene.*

Nelson, L. S., and Kuebler, N. A., *Flash Spectra of Thermally Produced Free Radicals.*

Pascale, J. V., see Hansen, R. H.

Russell, C. A., see Hansen, R. H.

Snyder, L. C., and Moscowitz, A., *A Quantitative Treatment of the Octant Rule: Molecular Orbital Computations of Rotational Strengths for Saturated Ketones.*

Story, P. R., see Murray, R. W.

Trozzolo, A. M., see Murray, R. W.

Wilk, M. B., see Lundberg, J. L.

Winslow, F. H., Hawkins, W. L., and Matreyek, W., *Effect of Morphology on Polyethylene Oxidation.*

AMERICAN PHYSICAL SOCIETY MEETING, Monterey, California

Anderson, E. W., see McCall, D. W.

Augustyniak, W. M., see Logan, R. A.

Batterman, B. W., *Effect of Temperature on Diffraction of X Rays from Perfect Crystals.*

Blumberg, W. E., and Eisinger, J., *The Hyperfine Interaction of Europium.*

Blumberg, W. E., see Eisinger, J.

Blumberg, W. E., see Jaccarino, V.

Buehler, E., see Kunzler, J. E.

Dewald, J. F., *Corner Nucleation in the Oxidation of Germanium.*

Dietz, R. E., and Pappalardo, R., *Optical Absorption Spectra of Impurity Ions of the First Transition Series in ZnS.*

Douglass, D. C., see McCall, D. W.

Eisinger, J., Blumberg, W. E., and Geschwind, S., *Electron-Nuclear Interactions of Cu^{3+} in Sapphire.*

Eisinger, J., see Blumberg, W. E.

Fitzgerald, E. R., see King, J. C.

Flood, W. F., see Haynes, J. R.

Fraser, D. B., and King, J. C., *Electrolysis of Quartz; Effect Upon Acoustic Behavior.*

Geschwind, S., see Eisinger, J.

Gilbert, J. F., see Logan, R. A.

Happe, J., see Klein, M. P.

Hauser, J. J., *Effect of Plastic Deformation and Annealing Temperature on Superconducting Properties.*

Haynes, J. R., Lax, M., and Flood, W. F., *Efficiency of Production of Intrinsic Recombination Radiation.*

Hensel, J. C., *Quantum Effects in Cyclotron Resonance of Holes in Germanium.*

Hsu, F. S. L., see Kunzler, J. E.

Hutson, A. R., *Origin of Anomalous Photovoltaic Effect in ZnS and CdTe.*

Jaccarino, V., Blumberg, W. E., and Wernick, J. H., *NMR in the Intermetallic CaF_2 Structure: The Unusual Ga Knight Shift in $AuGa_2$.*

Jaccarino, V., see Walker, L. R.

Jaccarino, V., see Wertheim, G. K.

King, J. C., and Fitzgerald, E. R., *Effect of X Irradiation on Audio Frequency and Ultrasonic Dispersion in Synthetic Quartz Crystals.*

King, J. C., see Fraser, D. B.

Klauder, J. R., see Kunzler, J. E.

Klein, M. P., and Happe, J., *The Nuclear Moment and Knight Shift of W^{183}.*

Kunzler, J. E., Hsu, F. S. L., and Buehler, E., *Superconductivity of Nb_3Sn in a High Magnetic Field in Liquid Hydrogen.*

Kunzler, J. E., and Klauder, J. R., *The Observation of Four Types of Hall Constant Anisotropy in Copper and Their Role in the Determination of the Fermi Surface.*

Lax, M., see Haynes, J. R.

Logan, R. A., Augustyniak, W. M., and Gilbert, J. F., *Electron Bombardment Damage in Silicon Esaki Diodes.*

Matsuoka, S., *Hypothesis of Voids in Semicrystalline Polymers.*

Matthias, B. T., see Shulman, R. G.

McCall, D. W., Douglas, D. C., and Anderson, E. W., *Nuclear Magnetic Relaxation in Polymer Liquids and Solutions.*

Moore, R. L., see Wolfe, R.

Pappalardo, R., see Dietz, R. E.

Shulman, R. G., Wyluda, B. J., and Matthias, B. T., *Nuclear Magnetic Resonance in Intermetallic Compounds of Lanthanum.*

Slichter, W. P., *Molecular Motion in Disordered Regions of Solid Polyethylene.*

Smith, G. E., and Wolfe, R., *Thermoelectric Power of Bismuth-Antimony Alloys at Low Temperatures.*

Snyder, L. C., *Jahn-Teller Distortions of Large Aromatic Radical Anions: A Molecular Orbital Description.*

Turner, E. H., *Frequency Dependence of Yttrium Iron Garnet Line Width.*

Walker, L. R., Wertheim, G. K., and Jaccarino, V., *Interpretation of the Fe^{57} Isomer Shift.*

Walker, L. R., see Wertheim, G. K.

Wernick, J. H., see Jaccarino, V.

Wertheim, G. K., *Some Applications of the Fe^{57} Mossbauer Effect.*

Wertheim, G. K., *Systematics of the Fe^{57} Isomer Shift.*

Wertheim, G. K., see Walker, L. R.

Wolfe, R., and Moore, R. L., *Thermoelectric Properties of Heavily Doped N-Germanium.*

Wolfe, R., see Smith, G. E.

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

A.S.T.M. SYMPOSIUM ON MATERIALS AND ELECTRON DEVICE PROCESSING, Philadelphia, Pennsylvania

Biondi, F. J., *The Control of Impurities in Impurity Dominated Electronic Materials and Devices.*

Craft, W. H., see Feder, D. O.

Craft, W. H., see Thomas, C. O.

Feder, D. O., and Craft, W. H., *Detection of Trace Amounts of Oxygen Protective Gaseous Ambients.*

Feder, D. O., Howden, W. E., Huff, D. R., and Richards, J. W., *Electrode Potential: A Tool for the Control of Materials and Processes in Electron Device Fabrication. II: EMF Studies of the Behavior of Iron Nickel Alloys in Hydrogen-Peroxide-Formic Acid Etchants.*

Feder, D. O., and Jacobs, E. S., *Electrode Potential: A Tool for the Control of Materials and Processes in Electron Device Fabrication. I: EMF—Time Studies of Clean and Contaminated Platinum Electrodes.*

Frost, H. B., *Residual Gas Levels as a Function of Tube Processing.*

Helmke, G., *A Comparison of Electrostatic and Absolute Air Filters for Use in Device Development Laboratories.*

Howden, W. E., see Feder, D. O.

Huff, D. R., see Feder, D. O.

Jacob, E. S., see Feder, D. O.

Koontz, D. E., see Thomas, C. O.

Maurer, D. W., *Standard Leak Rates Measured by Different Techniques.*

Thomas, C. O., Craft, W. H., and Koontz, D. E., *Elimination of Contaminants from Electron Tube Components—Automation of Chemical Processing.*

OTHER TALKS

Benes, V. E., *A Non-Linear Integral Equation from the Theory of Servomechanisms*, Am. Math. Soc., N. Y. C.

Benes, V. E., *Ultimately Periodic Solutions to a Non-Linear Integrodifferential Equation*, Am. Math. Soc., N. Y. C.

Bennett, W. R., Jr., *CW Gaseous Lasers*, New York University, N. Y. C.

Bennett, W. R., *Gas Lasers*, IBM Res. Lab., Poughkeepsie, N. Y.

Bennett, W. R., Jr., *Gaseous Optical Masers*, Am. Phys. Soc., Louisville, Ky.

Bennett, W. R., Jr., *Properties of a CW Optical Maser*, Yale University, New Haven, Conn.

Bennett, W. R., Jr., *Properties of a Collision-Pumped Gas Laser*, RCA Res. Lab., Princeton, N. J.

Bennett, W. R., Sr., *Data Communication on Telephone Channels*, Advanced Systems Electrical Engineering Seminar, Cornell University, Ithaca, N. Y.

Benson, K. E., *Pure Materials by Zone Melting Techniques*, A.S.M., Indianapolis, Ind.

Berry, R. W., *Electron Beam Evaporation of Tantalum for Thin Film Components*, Third Annual Electron Beam Symposium, Boston, Mass.

Biskeborn, M. C., *Developments in Communication*, School of Mines and Technology, Rapid City, S. D.

Black, H. S., *Communication Satellites—Past, Present, and Future*, Union County Teachers Space Age Workshop, Union, N. J.

Black, H. S., *New and Exotic Communications*, A.I.E.E., N. Y. C.

Black, H. S., *Satellite Communication, One of Man's First Great Peaceful Uses of Outer Space*, Newark Science Fair, Newark College of Engineering, Newark, N. J.

Black, H. S., *Scientific Uses of Satellites*, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Blanchard, T. G., *New Uses for an Old Device*, University of Mich., Ann Arbor, Mich.

Bollman, J. H., *Reliability Prediction Procedures*, Vanderbilt University, Nashville, Tenn.

Boyle, W. S., *Discussion of Optical Masers*, International Solid State Circuits Conf., Philadelphia, Pa.

Bozorth, R. M., *Fundamentals of Magnetism*, I.R.E., New Haven, Conn.

Bozorth, R. M., *Magnetic Superconductors*, Brookhaven National Laboratory, Brookhaven, N. Y.

Bozorth, R. M., *Solutions of Iron Group Elements in Platinum Metals*, Brookhaven National Laboratory, Brookhaven, N. Y.

Brady, G. W., *Studies in the Critical State*, Duke University, Durham, N. C.; Rutgers University, New Brunswick, N. J.

Breed, R. N., *Description of Morris Electronic Central Office*, Joliet, Ill.

Buckelew, J. W., *A Report Concerning Thermal Shock Tests made on Various Types of Printed Circuit Thru Connections*, Fourth Annual Meeting Institute of Printed Circuits, N. Y. C.

Budlong, A. H., *Mechanized Intelligence*, Passaic High School, Passaic, N. J.

Bugnolo, D. S., *Information Theory and the Electromagnetic Field*, Cornell University Colloquium, Ithaca, N. Y.

Cave, J. H., *Introduction to "Echo"—the Bell Systems Space Communication Satellite*, Passaic Valley Chamber of Commerce, Warren Township, N. J.; Eleventh Masonic District, Masters and Wardens Meeting, Morristown, N. J.

Collins, R. J., *Experiments on a Pulsed Ruby Optical Maser*, University of Mich., Ann Arbor, Mich.

Collins, R. J., *Studies of the Emission from a Pulsed Ruby*

Optical Maser, Optical Soc. of Am., Pittsburgh, Pa.

Collins, R. J., *Optical Masers*, University of Rochester, Rochester, N. Y.; San Antonio Section I.R.E., San Antonio, Texas; University of Arizona, Tucson, Ariz.; A.I.E.E., Los Angeles, Calif.

Courtney-Pratt, J. S., *Optical Masers and High Speed Photography*, Soc. of Photographic Scientists and Engineers, Arnold Auditorium, Murray Hill, N. J.

Desmond, R. A., see Legg, W. E.

Deutsch, M., *Some Psychological Assumptions Relevant to National Policy*, Am. Orthopsychiatric Assoc., Thirty-Eighth Annual Meeting, N. Y. C.

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Barney, H. L.—*Hydrophone*— 2,978,672

Bibbins, G. S., see Bachelet, A. E.

Brown, E. F.—*Optimal Run Length Coding of Image Signals*—2,978,535

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Celentano, A. J., see Bachelet, A. E.

Crowson, F. B., Loche, G. A. and MacLaughlin, R. R.—*Printing Telegraph Automatic Switching System*—2,978,534

De Lange, O. E.—*Self-Timed Regenerative Repeaters for PCM* —2,981,796

Dickinson, F. R.—*Means for Continuously Passing Cable Including Rigid Housings Through a Caterpillar Cable Engine*— 2,981,454

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Turner, E. H.—*Non-Reciprocal Wave Transmission*—2,979,675

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Van Tassel, E. K.—*Multiple Output Diode Distributor and Amplification Circuits*—2,978,677

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Weiss, M. T.—*Solid State Microwave Device*—2,978,649

Wick, R. F.—*Signal Translating System*—2,979,006

Wier, J. M.—*Constant Output Impedance Network*—2,981,851

Wilder, L. N.—*Underwater Lowering Device*—2,981,074

Williams, R. D., see Abbott, H. H.

THE AUTHORS

H. H. Baker

'Hal' Baker was born in England and obtained most of his education there. After several years working with radio during the days of the magnetic detector, the balanced crystal detector, the "French" valve and the audion, he switched to heavy electrical construction. A few years later he came back to electronics, acoustics and special projects with the Electrical Research Products Incorporated, then a subsidiary of the Western Electric Company He was associated with the early BTL/ERPI stereo program. On leave of absence from 195 Broadway Corporation, he joined a group with Columbia University's Division of War Research in February 1942 and until February 1945 was engaged in ASW and Pro-Submarine underwater acoustic programs. He was consultant for BuShips from February to July 1945 in test and evaluation of sonar for submarines. Mr. Baker then returned to 195 Broadway but was again tapped by Bell Laboratories in February 1953 for the Underwater System Development Department. He is the author of the article on MILS appearing in this issue.

C. G. Morrison was raised in Berkeley, California, and Verona, New Jersey. He received a B.E.E. degree from Cornell University in 1943 and an M.S. degree from Stevens Institute of Technology in 1953. From 1943 to 1946 he served in the Signal Corps, working with voice-secrecy equipment. He started his Bell System career with the Western Electric Company during the summer of 1942 and continued there after World War II, working on the design of shop-test equipment. Mr. Morrison transferred to the Laboratories in 1948, and was initially engaged in the development of toll-crossbar common-control circuits. Since 1954, he has been concerned with signaling development work including the design of voice-communication circuits for the SAGE system and more recently both exploratory and final development work on pushbutton signaling. Author of "A Central-Office Receiver for Touch-Tone Calling" in this issue. Mr. Morrison is a member of the A.I.E.E. and Eta Kappa Nu.

C. G. Morrison

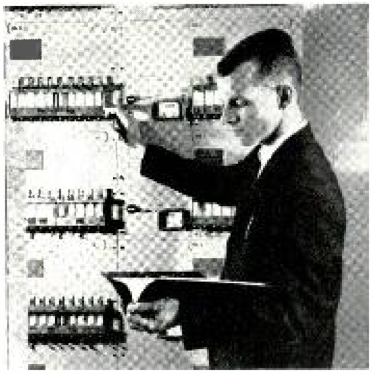
L. E. Miller, native of Pennsylvania, received his B.S. in Engineering Physics from Lafayette College. Easton, Pa., in 1949. Following graduation, he worked for General Aniline & Film Corp. for three years before joining the Laboratories at Allentown. Since that time, he has specialized in the development of a variety of transistors, ranging from germanium point contact and germanium alloy, to diffused silicon devices. These assignments have involved problems of device characterization, surface physics, physical metallurgy, and reliability. Some of Mr. Miller's contributions in these areas have appeared in a variety of technical publications including the *Bell System Technical Journal* and the Bell Laboratories Book Series on Transistor Technology. Mr. Miller, author of "Transistor Development for Manufacture" in this issue, is presently supervisor of a group responsible for final development of silicon transistors at the Laureldale location of the Laboratories. He is a member of the American Physical Society and a Senior member of the Institute of Radio Engineers.

L. E. Miller

J. S. Courtney-Pratt was born in Hobart, Tasmania, Australia and received the B.E. degree from the University of Tasmania in 1942. As a research student at the University of Cambridge he

J. S. Courtney-Pratt

did work on multiple-beam interferometry and high-speed photography, and received his Ph.D. from that University in 1949. From then until 1957, Mr. Courtney-Pratt was a Fellow of Gonville and Caius College and an Assistant Director of Research at the University of Cambridge. In 1954, he was awarded the Sir Charles Vernon Boys' Prize for experimental physics. In 1958, the University of Cambridge awarded him the degree of Sc.D. Since 1958 Mr. Courtney-Pratt has been at Bell Laboratories where he is responsible for research in mechanics and optics. Author of "High-Speed Photography and Micrography" in this issue, Mr. Courtney-Pratt has published many articles and holds several patents in this field of interest.

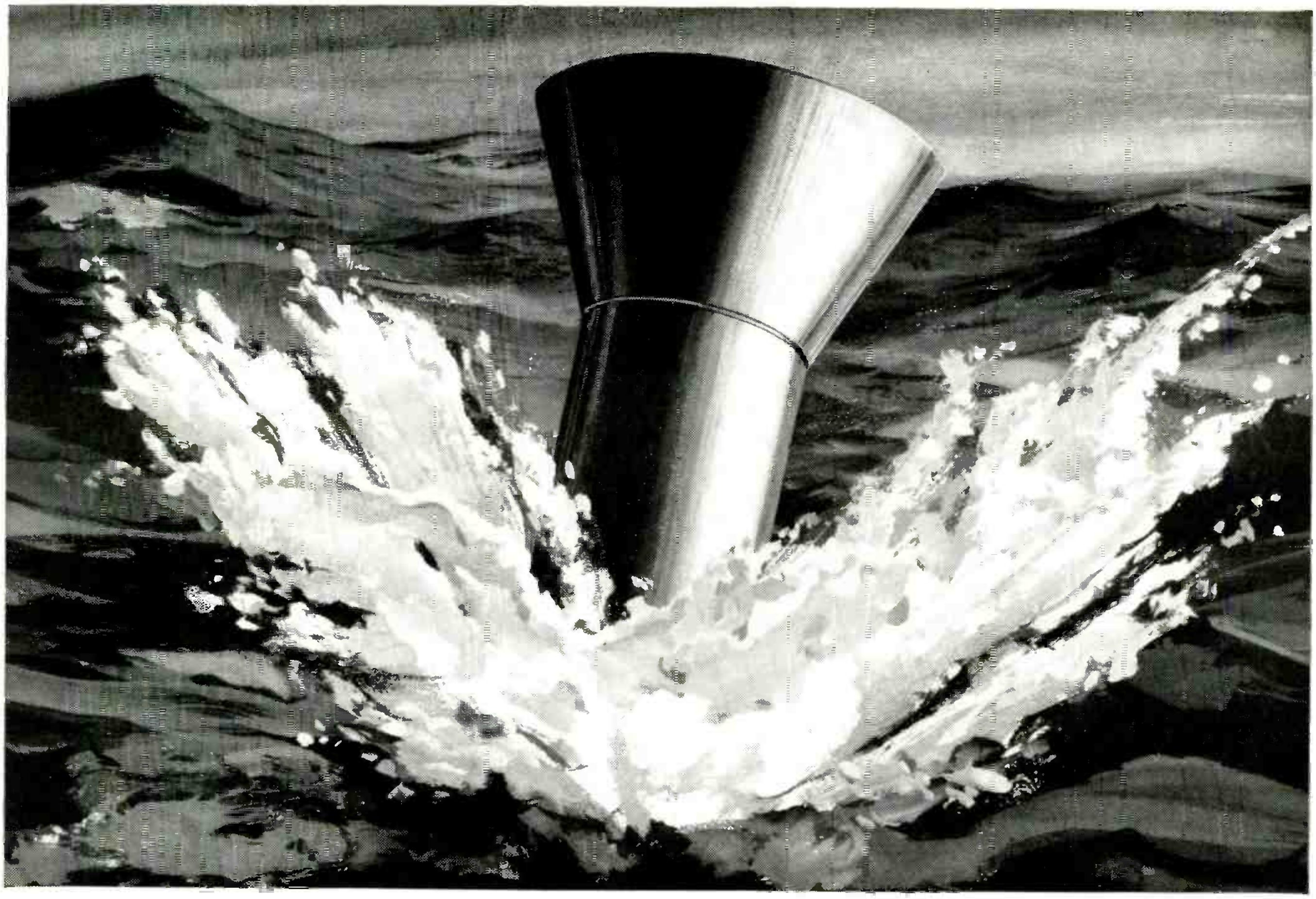


T. J. Hofbauer

Thomas J. Hofbauer, a native of Packanack Lake, New Jersey, was, until recently, a member of the Outside Plant Development Department. While at the Laboratories he was concerned with the development of air drying apparatus for pressurized systems, protection and alarm methods for wave guide antennas, and automatic equipment for securing cable pressure gradients. He recently received a degree in mechanical engineering from Newark College of Engineering. Mr. Hofbauer is the author of "Metering Gas in Telephone Cables," which appears in this issue.

D. J. Gagne

D. J. Gagne, author of "Speeding Calls Through A PBX", joined the Laboratories in 1945. During his first year, he was associated with the Apparatus Development Department on problems involving underwater sound apparatus. In 1946, he transferred to the Switching Development Department where he assisted in the development of intercommunicating facilities for television network systems, alarm circuits for carrier systems, and later, the development of local- and toll-trunk facilities for the No. 5 crossbar system. Mr. Gagne became associated with the Special Systems Engineering Department in 1954, on problems related to automatic telephone answering equipment and various recorded and announcement systems. More recently, he has also been associated with PBX Switching Systems utilizing crossbar switching techniques. A native of Long Island, Mr. Gagne received the B.E.E. degree from Pratt Institute in 1943.



HOW THE OCEAN GREW "EARS" TO PINPOINT MISSILE SHOTS

A quarter of the world away from its launching pad an experimental missile nose cone enters its ocean target area.

How close has it come to the desired impact point?

Where actually did the nose cone fall?

To answer these questions quickly and accurately, Bell Laboratories developed a special system of deep-sea hydrophones—the Missile Impact Locating System (MILS) manufactured by Western Electric and installed by the U. S. Navy with technical assistance from Western Electric in both the Atlantic and Pacific Missile ranges. MILS involves two types of networks.

- One is a long-distance network which utilizes the ocean's deep sound channel. It monitors millions of square miles of ocean. The impacting nose cone releases a small bomb which sinks and explodes at an optimum depth for the transmission of underwater sounds. Vibrations from the explosion are picked up by hydrophones stationed at the optimum depth and carried by cables to shore stations. Time differences in arrivals between these vibrations at different hydrophones are measured and used to compute location of the impact.
- The other is a "bull's-eye" network that monitors a restricted target area with extraordinary precision. This network is so sensitive it does not require the energetic explosion of a bomb but can detect the mere splash of a nose cone striking the ocean's surface—and precisely fix its location.

The universe of sound—above the earth, below the ocean—is one of the worlds of science constantly being explored by Bell Laboratories. The Missile Impact Locating System reflects the same kind of informed ingenuity which constantly reveals new ways to improve the range of Bell System services.

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