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Bell Laboratories

RECORD

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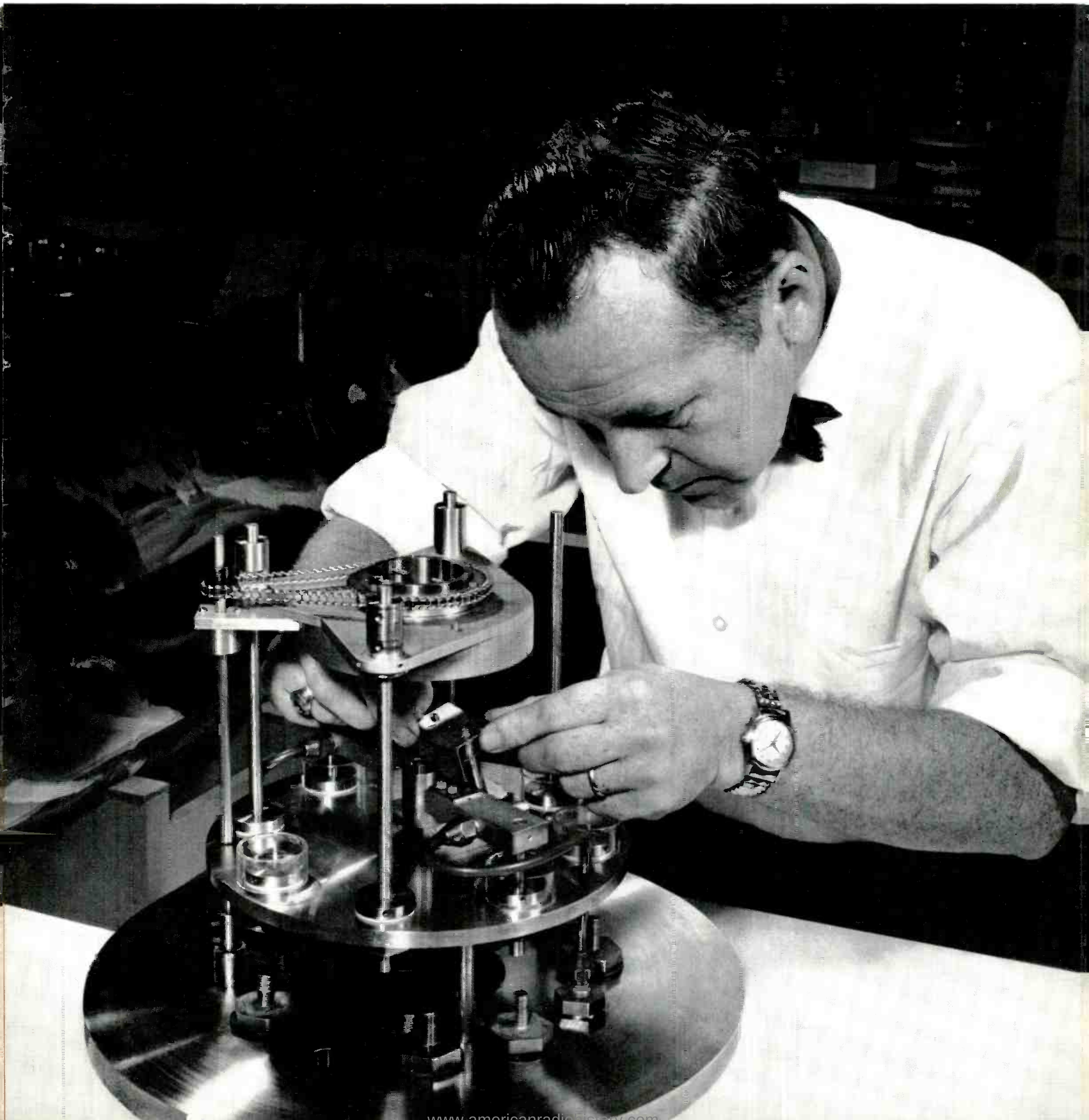
Cathode-Ray Displays in Weapon Systems

Multistation Operation in the 82B1 System



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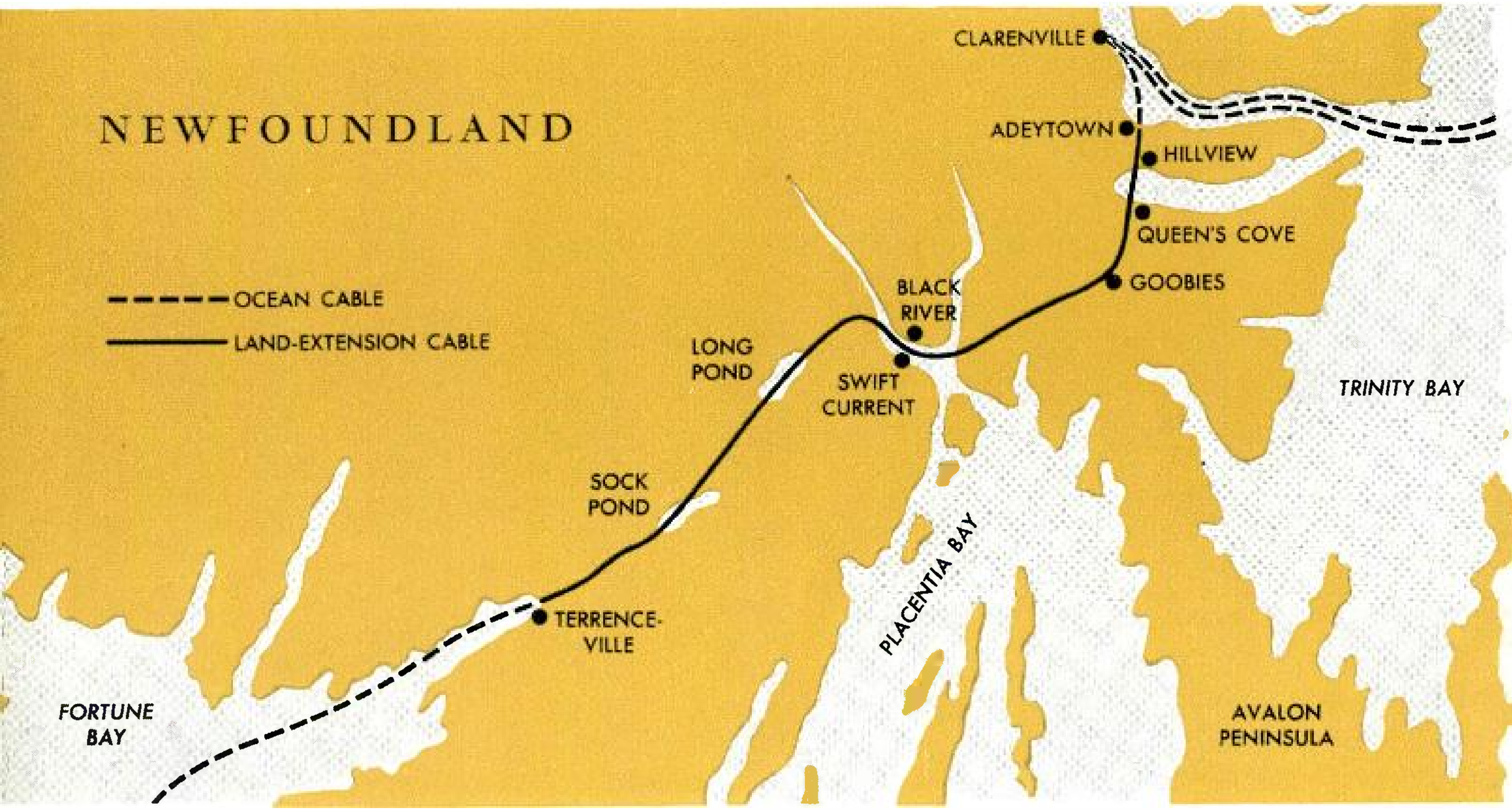
Contents

Cover *W. Wiegman adjusts evaporation equipment he designed to fabricate forty-nine Esaki diodes at one time (see article on page 122).*

Because land-extension cable is used in the ocean as well as on land, it may be logically called the amphibian of the Bell System. It functions equally well whether it crosses the coral reefs of the Caribbean, the cold inland ponds of Newfoundland, or Alaska's rocky shores.

Land Extensions fo



J. M. Eglin and W. K. Oser

Transoceanic Cables

The types of ocean telephone coaxial cable called land-extension cables received that name because they were first used as part of the transmission path between the shore station and an inland communication center. In addition, they are now frequently used as part of the transoceanic cable proper—usually the part connected directly to the shore station. They therefore serve not only for cross-country shortcuts to decrease the probability and cost of system repair and maintetance, but also as shallow-water ocean cables.

In most cases, depending on the particular application, these cables encounter some of the mechanical hazards that beset their exclusively aquatic relatives. These hazards include abrasion, cutting, crushing, and environmental corrosion. And, because the cables lack the shielding effect of the deep ocean, they must have "built-in" shielding against electromagnetic interference both from outside and from within the system.

External electromagnetic interference includes atmospheric or static noise and interference from radio stations and power lines. The internal interference is crosstalk; this is a problem chiefly when the transmitting and receiving circuits are brought from the ocean to the shore station in the same trench, a practice followed for economic reasons.

This article describes the modified protective elements on the outside of the cable which mitigate the mechanical and corrosion problems and the iron shielding layers inside the cable which reduce the electrical interference.

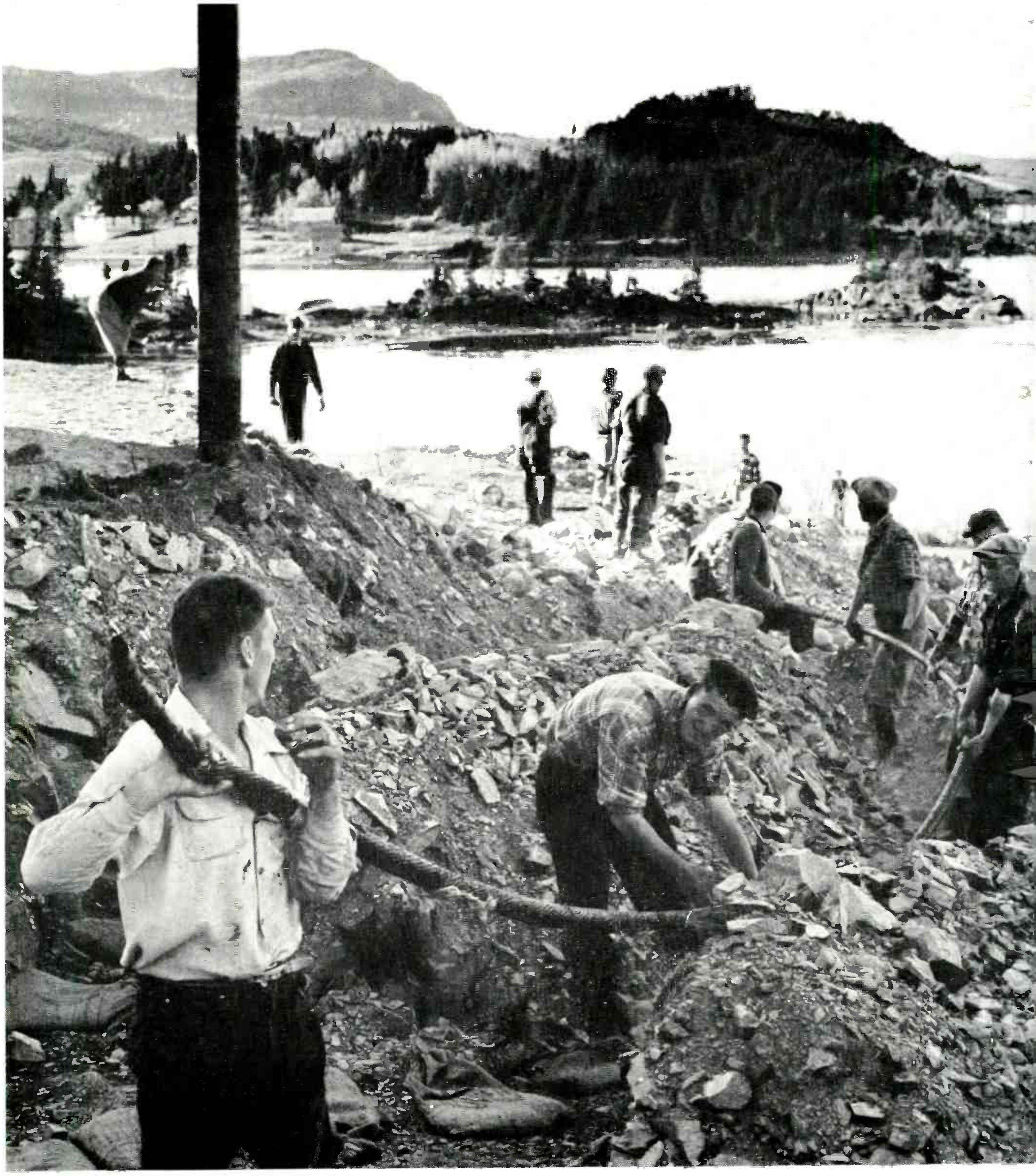
To determine the effectiveness of electromagnetic shielding, Laboratories engineers compared recent designs of shielded land-extension cable with unshielded ocean cable. One measure of susceptibility to electrical interference is known as transfer impedance. Transfer impedance is the reciprocal of the ratio of the current in one circuit to the voltage in another circuit caused by that current. A low transfer impedance implies good shielding and conversely, a high transfer impedance signifies poor shielding.

In the arrangement set up to determine the effect of the iron shielding, a 30-foot length of cable was inserted coaxially in a copper tube. At one end of the tube, all metallic elements of the cable were connected with a short-circuiting disk. A current generator was applied between this disk and the copper tubing. At the far end, the inner conductor was kept insulated and the rest of the metallic structure was connected to the copper tubing. The voltage between the inner conductor and the rest of the structure at this end was then measured. The transfer impedance for this length of cable was computed by dividing this voltage by the current fed in at the near end.

In comparing standard deep-sea armored ocean cable with heavily shielded land-extension cable, Laboratories engineers observed that the shielding reduced interference more than 60 db at frequencies down to 20 kc, which is nominally the lowest commercial frequency for these systems. Thus, such shielding reduces to tolerable levels both internal and external interference caused by any expected electromagnetic field.

The cable route for the first transatlantic system goes across some 50 miles of Newfoundland—from Clarenville, the landing point, to Terrenceville, on the shore of Cabot Strait. Regular ocean cable spans the 270 miles of Cabot strait between Terrenceville and Sydney Mines, Nova Scotia. For the Newfoundland run, a very heavily shielded design was chosen to insure against the effects of interference likely to result from future installation of any power lines or radio stations. This portion of the project was the responsibility of the British Post Office, and the cable for it was built according to their specification.

This Newfoundland cable employed the same coaxial conductor structure as the ocean cable (BSTJ, *January*, 1957). The special shielding consisted of five soft iron tapes, each 0.006-inch thick.



Shore-end cable being installed. The operation was conducted at Clarenville, Newfoundland, in 1956.

The innermost iron tape was applied longitudinally, and the remaining four were wound helically. Outside of these tapes, an extruded jacket of polyethylene compound kept the interior of the cable dry and prevented the shielding tapes from corroding. Over the polyethylene jacket, steel armor wires with the usual jute and bitumen coverings protected against mechanical damage.

For the second transatlantic system, engineers of the Long Lines Department of the A.T.&T.Co. selected cables similar to the Newfoundland cables for the Clarenville-Terranceville run. The same type of cable was used for terminating the ocean cables at Sydney Mines, Terranceville, Clarenville, and at Penmarch, France. Because of the difference in landing points, however, greater mechanical protection was necessary in some locations. Such added protection consisted of either one or two layers of heavy armor wires, the same size as those used on ocean cable near the shore.

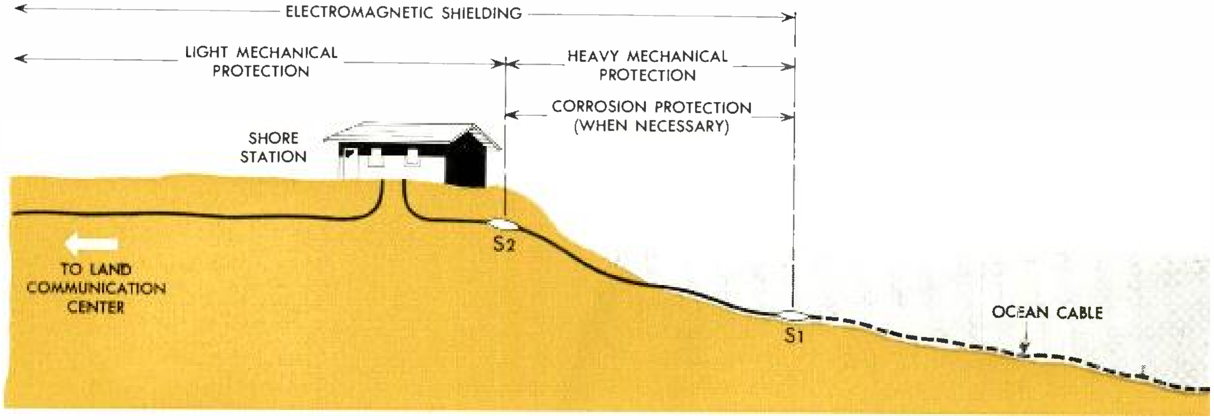
External Protection

The Florida-Puerto Rico cable employed the same internally shielded coaxial structure as that described above for the two transatlantic systems. Extensive precautions, however, were taken against environmental corrosion. At the Florida end, the cables are brought to shore at Palm Beach in the vicinity of the discharge pipe of the sewage disposal plant. Chemical analysis of the water and of the bottom sediments in this area showed the presence of corrosive gases, principally hydrogen sulphide. Because hydrogen sulphide diffuses through polyethylene very readily, an impermeable sheath was necessary for encasing the cable. Lead was the logical choice, since it is impermeable, resists corrosion, can be applied in long lengths, and provides additional electromagnetic shielding. Polyethylene was retained under the lead sheath as a further safeguard for the interior of the cable.

Near the Florida shore, the corrosion conditions also made it necessary to cover the armor wires with an extruded jacket of tough neoprene compound. Since this neoprene covering resists many kinds of abrasion better than steel, project engineers also specified neoprene-covered armor wires for the cables crossing the coral reefs and rough shallow waters off the coast of Puerto Rico.

At Palm Beach and San Juan, the cables travel in underground ducts from the shore to the terminal buildings. The cable specification called for the replacement of the usual outer covering of impregnated and bitumen-flooded jute yarns with a covering of dry yarns of mixed nylon and jute fibers. The dry yarns prevented clogging of the ducts, and the strong nylon fibers in the yarns lessened possible raveling of the covering as the cable was installed.

Future submarine cable systems will extend westward from Hawaii to Japan and other points in the Far East. Additional cables will be installed in the Caribbean area and possibly thence to South America; a third transatlantic cable will go directly from the United States to Great Britain. At each landing site engineers will assess the probable effects of electrical, chemical, and mechanical conditions and decide which type of amphibious cable to use.



This diagram shows typical uses of land-extension cables and the types of protection required at various sections. S1 and S2 are splice points. In some cases, the land-extension cable between the shore station and the ocean cable is laid in one piece, and the splice point S2 is omitted.

Usually a semiconductor device can do one thing well. Thus a device that can perform two important functions is something of a communications marvel. Such is the Esaki diode which may serve as a source of microwave power as well as a high-speed switch.

George C. Dacey

ESAKI DIODES

More than two years have passed since the Esaki diode broke into the news. Since the initial excitement surrounding its announcement, much additional work has been done on it both at Bell Laboratories and in other research organizations. Now that the diode has a "history" perhaps we can realistically assess its potentialities and the way it may influence technology.

The Esaki diode was discovered by Leo Esaki at the Sony Corporation in Japan. It consists of a p-n junction between a degenerate n-type semiconductor (one heavily doped with impurities) and a degenerate p-type semiconductor. Specifically, the communications industry is interested in this device because its forward characteristic—where positive voltage is applied—contains a negative-resistance portion. The figure on page 123, a typical voltage-current characteristic for an Esaki diode, shows that with forward polarity there are two regions of positive slope separated by a region of negative slope. The latter region is an area of operation where more voltage yields less current.

Two types of operation are thus possible. First, small-signal operation around a bias point in the negative resistance range leads to components such as oscillators and amplifiers. The second application is large-signal switching between the two branches representing stable positive resistance.

To understand the Esaki effect, we might first briefly study the operation of a conventional semiconductor diode and then compare the two. A conventional diode is composed of two sections of a semiconductor material, such as silicon, intimately affixed at a "junction". These sections differ chemically in the type of impurity intentionally incorporated in them. One impurity provides a surplus of free electrons, giving the semiconductor negative current carriers. It is called "n" type material. The other impurity causes a deficiency of free electrons, giving its section positive current carriers called "holes". This is "p" type material.

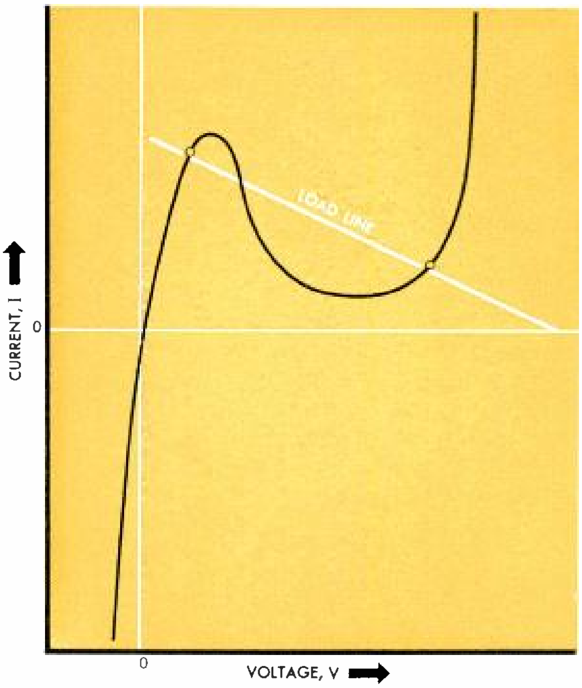
One might at first suppose that the electrons on the n-side of the junction and the holes on the p-side of the junction would diffuse across the junction until the entire crystal was uniformly filled with electrons and holes. And, indeed, this does begin to happen. However, as electrons leave the n-side, they leave behind, at the junction, ionized impurity atoms which are positively charged. Similarly, holes leave behind negatively charged impurity atoms. These charged impurity atoms at the junction generate an electric field which prevents the further diffusion of electrons or holes.

As a result, there are no carriers near the junction. This "depletion" area amounts to a "potential barrier", and to operate, the diode must be given an external voltage with the proper polarity to overcome this barrier. This voltage, or bias, gives the carriers enough energy to surmount the potential barrier and diffuse through the junction to the opposite side. Control of the traveling carriers amounts to control of the flow of current, permitting useful operation of this electronic device.

In any material, an electron must attain a certain level of energy, or be put in the higher "state" of energy, before it can break loose from its atom to become a current carrier. In a conducting material the slightest nudge in the form of external energy causes the flow of current. An insulating material, on the other hand, requires a huge amount of energy to dislodge electrons into a higher state. The amount of this energy is proportional to a "forbidden gap" in the spectrum of energy states where electrons cannot reside. Sufficient energy imparted to the electrons will release them from their atomic bonds, resulting in "breakdown" and, incidentally, destroying the insulating property of the material. A semiconductor is a compromise between a conductor and an insulator in that it has a forbidden gap narrower than that of an insulator.

The Esaki diode depends for its operation on a phenomenon of quantum mechanics known as tunneling—hence the alternate name "tunnel" diode. This process, which has no counterpart in classical theory, permits a carrier—an electron, for example—to "leak through" a potential barrier too high for it to surmount classically, provided that the barrier is not too thick.

Thus the Esaki effect is only observed in extremely narrow p-n junctions. Junctions are made narrow by virtue of their heavy doping. In other words, the relatively large number of impurities act to compress the forbidden region or narrow the potential barrier in the p-n diode. With sufficiently narrow junctions, tunneling can take place. But current can only flow if there are available electrons to do the tunneling and states into which they can go.

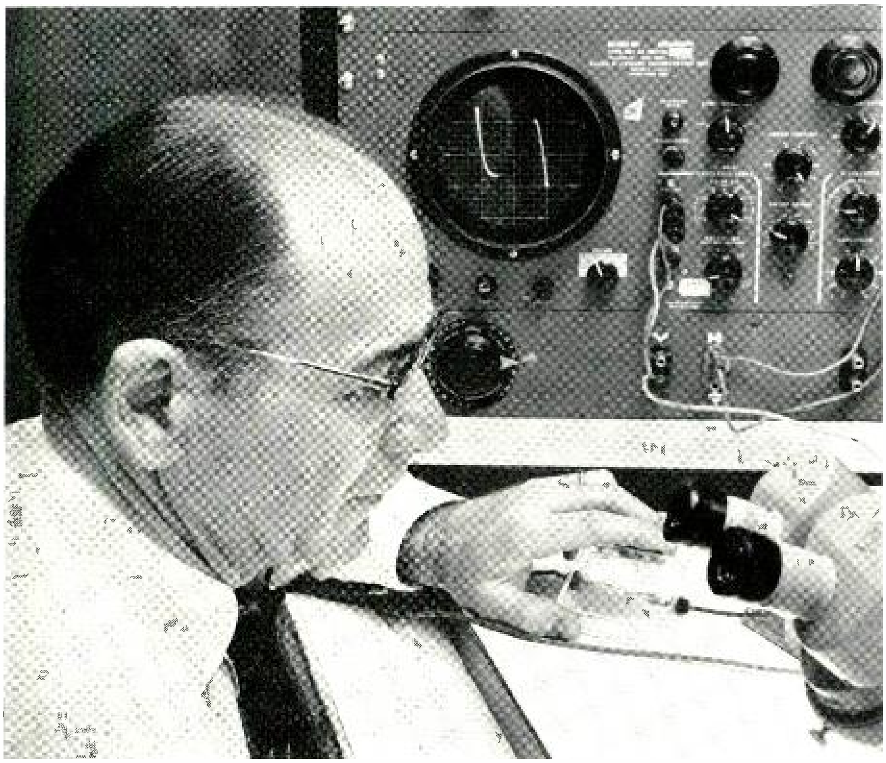


Typical voltage-current characteristic of Esaki Diode shows amplification and switching possibilities.

The significance of this can be seen in the diagram on page 125. The top portion of this figure represents an energy-band diagram of a degenerate p-n junction with no applied bias. The shaded areas are those energy states at which electrons exist, the cross-hatched area is the forbidden gap—no electrons can have this energy—and the white areas represent allowed, but empty, states of energy. To simplify matters, the diagram describes an Esaki diode operating at a low temperature where the energy level between filled and empty states is sharply defined.

The law of conservation of energy is expressed in this diagram by the requirement that any electron which tunnels through the barrier must arrive at an energy level on the other side of the junction represented by the same vertical coordinate it had on the side where it originated. In other words, electrons must tunnel into energy states that are horizontally opposite to those they came from. Note that for the zero bias condition, even though tunneling is possible, no current can flow because there are no filled electron energy states opposite empty states.

The middle portion of the diagram shows the



E. Dickten operates equipment that adjusts alloy of Esaki diode by current pulse through device. Oscilloscope picture of voltage-current characteristic indicates type of junction acquired.

situation when a small forward bias is applied. Now electrons from the n side are opposite empty states on the p-side and current can flow. As more and more forward voltage is applied, however, the energy states on the n side are raised relative to the p side. Then some of them lie opposite the forbidden gap which contains no states into which they can tunnel. Thus further increases in voltage begin to result in a decrease in current, representing the negative resistance of the device.

Finally, as shown in the bottom part of the diagram, sufficient forward voltage puts all of the filled energy states on the n side opposite the forbidden gap and the tunneling current ceases. As the forward voltage is raised still higher, however, the barrier becomes low enough so that thermal energy is sufficient to permit carriers to cross the junction thus giving rise to the familiar "forward injected" current of a p-n diode. When this current becomes appreciable, it dominates the tunnel current. This results in the characteristic, represented in the figure on page 123, of the high-voltage, positive-resistance portion of the voltage-current curve.

If the Esaki diode is biased to some operating point in the range of negative resistance it will operate like a small-signal equivalent circuit. One of the promising features of Esaki diodes is that the negative resistance remains constant up to extremely high frequencies. This is a result of the quantum nature of the tunneling process. The existence of capacitance, however, poses certain circuit problems in obtaining high-frequency operation. In many cases it is sufficiently large to create problems of stability in biasing and of impedance matching. Also, the series inductance associated with the leads to the diode must be minimized in high-frequency oscillators or amplifiers.

High Frequency Oscillators

The frequency response of an Esaki diode is related to the product of its capacitance and negative resistance. Recently, Laboratories engineer C. A. Burrus, Jr. made diodes oscillate above 100,000 megacycles. Of course, at these frequencies the power output is quite small. Nevertheless, these experiments demonstrate that the negative resistance persists, as predicted, to extremely high frequencies. R. L. Batdorf and W. Wiegmann have made Esaki diodes of gallium arsenide that have produced a power output of about one half milliwatt at 7400 megacycles. This oscillator, constructed by R. F. Tramburulo, is approximately 30 per cent efficient.

These results indicate that perhaps the most promising use for the Esaki diodes in the immediate future will be as a source of microwave power at frequencies of several kilomegacycles. Perhaps they may eventually replace electron-tube sources of microwave power.

In addition to their uses as amplifiers or oscillators, Esaki diodes can be applied to switching circuits. The load line shown in the figure on page 123 intersects the characteristic of the Esaki diode at two stable points, separated by a region of instability. If the diode is biased to the left point and triggered with a pulse of positive current, it can "switch" to the right point. The characteristic switching time is also related to the -RC product of the diode since part of the current must go into charging the capacity as it switches to the higher voltage state.

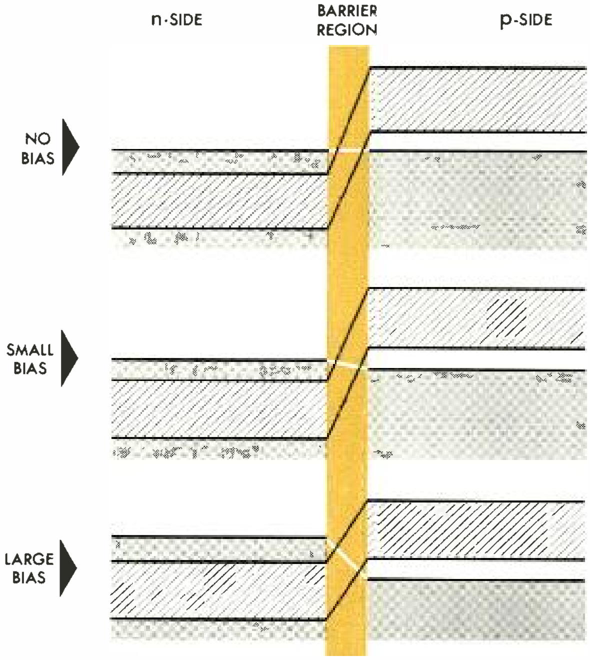
High Speed Switches

Using Esaki diodes made of indium antimonide, R. L. Batdorf, R. L. Wallace (Director of Special Communications Research) D. J. Walsh, and the author have succeeded in obtaining switching action in less than 10^{-10} second—one ten-thousandth of a microsecond. This is perhaps the fastest electronic switching yet observed. Thus, where switching at extremely fast rates of speed is necessary, the Esaki diode is a promising device. It does not appear at present, however, that the Esaki diode will replace transistors or other devices in switching circuits at lower frequencies. The reason is that for one diode to drive several others, it is necessary to put very close manufacturing limits on the values of current at the peak and valley of the characteristic. At present, this can only be done by hand tailoring each diode—a costly process.

Thus, future uses for Esaki diodes will probably be pre-dominantly in those areas where its properties are unique. Amplification and oscillation at frequencies above a few kilomegacycles have not yet been demonstrated with any other solid-state device. The same thing can be said for switching at rates above a few hundred megacycles. At lower frequencies, standard devices such as transistors and diodes will no doubt continue to be used. But even here, perhaps, Esaki diodes used with conventional components will enable designers to obtain new circuit functions.

Esaki diodes have now been made in a large variety of different materials: germanium, silicon, indium antimonide, gallium arsenide, indium arsenide, and other compounds in the III-V group combination of the Periodic Table. Each of these diodes has some special features to recommend it for operation under conditions of either low noise, high temperature, or high frequency. Many problems of manufacturing including reliability, have yet to be solved, but we can expect steady progress in their solution. There is no doubt that eventually the Esaki diode will assume an important place in the family of solid-state electronic components.

Whatever the eventual uses of Esaki diodes turn out to be, it is clear that their advent has already produced a considerable stimulation in the investigation of tunnelling physics and the application of tunnelling to the understanding of the properties of solids. The change in the distribution of energy levels in a semiconductor upon the application of large electric (Stark effect) and magnetic (Landau effect) fields has been observed. Recently, the use of tunnelling to probe the band structure of a superconductor has given experimental verification to theoretical ideas concerning the nature of superconductivity. These advances in pure science will in turn perhaps give rise to additional device possibilities.



Energy-band diagram of p-n junction. Shaded areas are energy states where electrons exist. Cross hatching depicts forbidden gap. White areas are allowed but empty states of energy.

The energy of radio waves reflected from Echo I was about one millionth of a billionth of a watt. To detect such faint signals Laboratories engineers had to design an extremely accurate system to steer the antennas at Holmdel, N. J.

R. Klahn

Antenna Steering for Echo I

On the morning of August 12, 1960, President Eisenhower's voice was reflected from a balloon satellite called Echo I. This moment marked the beginning of a new era in communications. For the first time, men could speak to each other via an artificial satellite. The success of Echo I, a project of the National Aeronautics and Space Administration, means that some day it will be possible to transmit telephone messages and television programs across the oceans of the world.

In the months preceding the launching of Echo I, a group of engineers at Bell Laboratories in Whippany, N. J. were working on two of the major problems posed by satellite communications: First, how to provide tracking information to the antenna site at Holmdel, N. J., and second, how to process this information so that the steering commands would point the antennas continuously at the satellite as it passed over the United States.

During the early planning of satellite communications experiment, it was hoped that the same methods devised by astronomers in predicting the positions of the planets in our Solar System could provide the tracking information needed for Echo I.

Satellite orbits are determined by the same laws of planetary motion that govern the course of the planets as they travel around the sun. If a scientist observes a satellite's position at several points as it moves around the earth, he can calculate the exact size, shape, and orientation in space of its elliptical orbit. From these orbital characteristics, he can predict the satellite's future position in the heavens.

Laboratories engineers decided to try these techniques to obtain steering information for the antennas in Project Echo. They considered it essential to determine whether a digital computer could satisfactorily calculate satellite orbits and generate accurate steering predictions for passes well in advance. The results of these tests would help indicate how well this method could provide steering data for sites in a future Bell System satellite-communication venture.

To experiment with these techniques, Bell Laboratories engineers worked closely with NASA's Goddard Space Flight Center at Greenbelt, Maryland. There, NASA personnel compiled observations of previous satellite positions from a number of Minitrack receiving stations scattered throughout the world. These radio-receiving stations, maintained by NASA, can tune in on a small, 108-megacycle radio beacon placed on a satellite and determine the path of the space vehicle as it passes overhead. These observations are sent to the Goddard Space Flight Center, where a large digital computer determines the orbital characteristics.

Predicting the Satellite's Position

The Goddard computer predicts future positions of the satellite and indicates the time and the place in the sky where the antennas at Holmdel should be pointed. To visualize the conversion of satellite orbital information into a set of sighting instructions, first consider an imaginary situation in which the earth does not turn on its axis. If this were the case, the satellite would pass over the same points on each circuit around the earth.

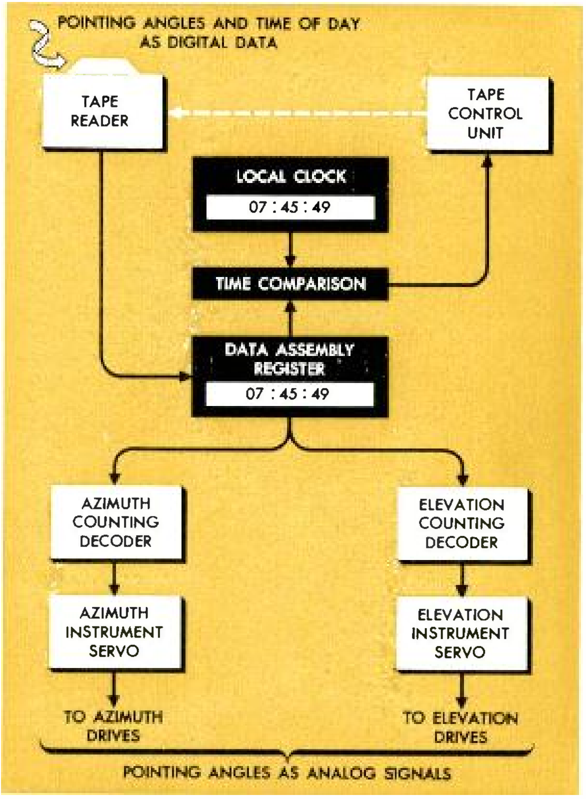
Because of the earth's rotation, however, this situation is more complicated. A satellite's path is fixed in space. It appears in different places in the sky on each of its passes because the earth rotates toward the east. This is why a new set of antenna-steering orders is needed for each satellite pass. To control the large antennas precisely, the satellite's position must be described in terms of the azimuth angle from north and the elevation above the horizon at the antenna site for every moment of its pass.

The construction of antenna-steering orders from information supplied by a digital computer several hundred miles away poses some interesting systems-engineering problems. The computer describes the steering angles as a series of numbers for specific times during the satellite's pass. These values are identified by specific times of the day, in much the same way that an almanac denotes the position of the moon and stars at certain times in the future. This information must be sent to the antenna site and kept ready for use as the satellite pass begins. At just the right time, it is taken from the storage, read by data-processing equipment, and reassembled into blocks denoting azimuth and elevation angles. Then the numerical data is converted into electrical signals that control the antenna-drive equipment.

In organizing a system to accomplish these functions, Laboratories engineers carefully considered several factors. If angular information were supplied for very short intervals of time, a simple conversion of each angle into equivalent electrical voltages would result in a reasonably good reconstruction of the pointing signal. However, angles for each small fraction of a second would have to be supplied. To describe a satellite passage lasting 20 to 25 minutes, this method would require the transmission and storage of reams of numerical data.

On the other hand, if information is furnished about the slope and curvature of the pointing signals, the data equipment needs fewer numbers to describe the signal. Although this eases the problems of transmission and storage, it means that the conversion equipment needed to reconstruct the signals must be more complex. The type of transmission circuit required and the method of storage used at the antenna site depends to a large extent on how the data equipment processes the signals. In general, the cost of transmission links and data storage facilities increases with their speed and capacity; and so economic factors play a major role in the overall design.

In the Project Echo system, a compromise was



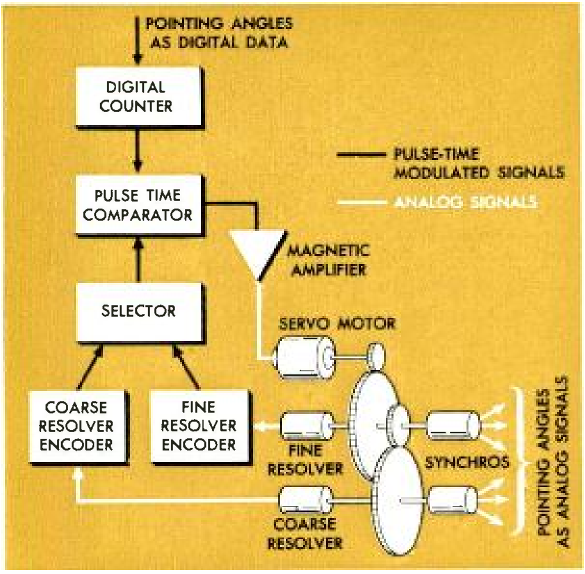
Flow diagram of digital-to-analog data converter for the Project Echo antenna-steering system.

reached by adapting a method that reconstructs the desired signals in short, straight line segments. This supplies sufficiently accurate pointing instructions with a moderate amount of data and reasonably simple conversion equipment.

The NASA computer provides pointing angles for every four-second interval as well as information indicating the rate of change of these angles during that interval. Each of these pointing angles is identified by the time of day that it is correct. This requires 26 decimal characters to describe the pointing instructions for each four-second interval. These data are sent from the Goddard computer over a Bell System teletypewriter circuit to Holmdel where they are stored on paper tape.

Just before Echo I begins a pass over the United States, an operator at the antenna site feeds the tape into a special digital-to-analog converter. Here, the functions of data assembly and conversion into continuous electrical signals are automatically performed. This machine includes a very accurate, 24-hour digital clock and tape-reading equipment. As the machine reads the tape, it synchronizes the "time of day" valid for each pointing angle with the actual time of day indicated by the digital clock.

The numerical equivalents for the antenna angles are loaded into high-speed electronic counting decoders where the first step in the conversion to smooth electrical signals takes place. The numerical data are changed to very precise time intervals by a process called "time-decoding." Each counter is activated by input pulses spaced 2-microseconds apart. With each pulse, the number registered in the counter is reduced by one. When the number is reduced to zero, the counter releases an output signal. By starting this process at precise reference times and counting at a constant rate, outputs are delayed an amount proportional to the number loaded in the counter. If an angle is represented by the number 104, the counter output occurs 208 microseconds after the reference signal.



A simplified schematic of an instrument servo.

Conversion of Digital to Analog Signals

After the counter reaches zero, it automatically recycles and produces a new output. This results in a steady stream of precisely timed output signals. Fifty times each second, the number in the counter is revised an amount determined by the rate of change of the angular data. In this way, the steering signals progress smoothly without requiring a great deal of input data. The counters thus provide temporary storage, revision, and decoding at the same time.

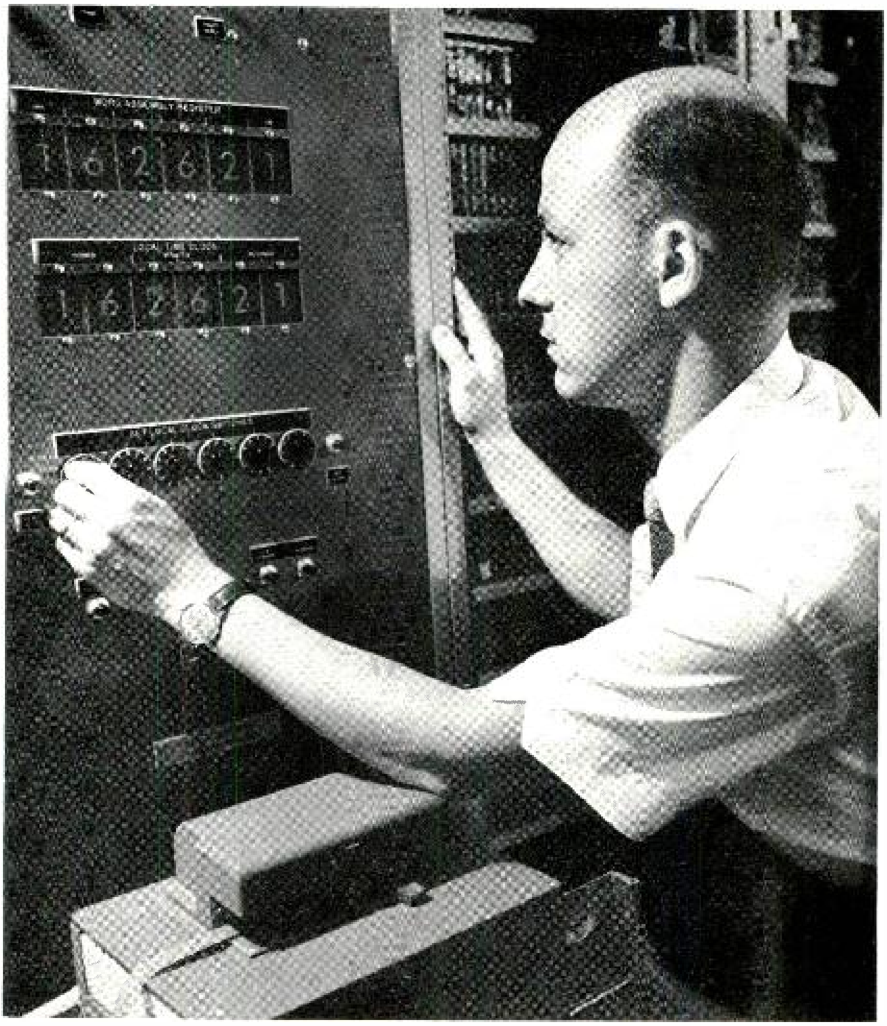
The output signals from the counter are in a form that can be used by small, instrument servos where the final step in the conversion to smooth steering orders takes place. These servos position synchro transmitters to correspond to the desired antenna-pointing angles by employing a feedback principle.

Electromechanical devices called resolvers are geared to the synchros and generate signals that indicate the synchro position. When the synchros are properly positioned, the resolver outputs indicate time intervals that are the same as those indicated by the decoding counters. Any differences result in signals which move the servos in a direction that reduces the difference between the predicted angles read from the paper tape and the position of the servo shafts.

Synchros transmit electrical voltages which convey the angular information to the antenna-drive system on both the receiving and transmitting antennas. As the data converter reads new angles from the paper tape, it feeds new numbers to the counters and the servos continue to reconstruct the steering orders. The antennas, in turn, follow the steering orders and point at the satellite as it moves across the sky.

The aspect of reliability is very important in this method of antenna steering. The adverse effects caused by errors which creep into the data in its passage from the computer to the conversion equipment at Holmdel must be minimized. In the Echo I experiment, a single-bit parity-check technique was used to help detect

At satellite communication center, Fred Young adjusts digital clock to synchronize the angular positions for the antennas with correct time values.



errors. There are four binary digits used to describe each number of an antenna angle. With the single parity check bit added, there must always be an odd number of binary 1's in each of these numbers (that is, either 1, 3, or 5 binary 1's). If there is an even number of 1's, the system detects the error and discards that data.

In observations made on a group of 30 of the Echo passes, the single-bit parity check was 90.3 per cent effective in rejecting bad data. For an experimental system, this was satisfactory. For operational systems, however, even better performance will be needed. Studies are presently underway to insure that these increased performance requirements will be met in future systems.

This concept of antenna-steering represents only one form that future systems may take. As orbiting radio-relay systems move out of the experimental field and join other types of communication facilities in the Bell System, the problems of antenna-steering will become more complex. In order to establish continuous telephonic transmission service over great distances, a number of satellites will be placed in orbit a few thousand miles above the earth. Each satellite's orbit will have to be precisely determined, and then periodically modified to allow for the effect of small irregularities in the earth's shape, gravitational effects of the moon and sun, and the effects of solar-radiation pressure. Information will have to be made available for steering antennas located at many points on the globe.

In whatever form future systems may take, the antennas must be controlled in an efficient, reliable manner. The experience gained on Project Echo has clearly established that digital computers can do this job.

To provide continuous visual displays of attacking aircraft, Bell Laboratories has developed for the Navy a symbol-generation system. This system represents each potential target as a letter or number on a cathode-ray tube.

C. W. Norwood

Cathode-Ray Displays in Weapon-Direction Systems

In naval warfare, one of the greatest threats to a fleet is an attack by high-speed enemy aircraft. Defense against such an assault requires rapid decisions: the relative threat of the various attacking planes must be quickly evaluated and defensive weapons assigned. Decisions of this type depend on a continuous visual display of the number, position and speed of the attacking aircraft. Such information is commonly obtained from radar displays that use cathode-ray tubes as the display medium.

However, in addition to raw radar information, supplementary information is required. This information is most useful when it is shown as coded marks or symbols, directly on the radar display. The Laboratories has pioneered in the design of equipment for the generation (RECORD, *February,* 1953), selective distribution and time sharing of such symbols. This article describes the use of such equipment in modern weapon-direction systems—specifically, a new naval air-defense concept developed at the Laboratories (RECORD, *July,* 1960).

When several blips—each one representing a different aircraft—are simultaneously displayed on a radar screen, it is desirable to tag each one with a distinctive identifying mark. As defense weapons are assigned, other marks conveying this information may be required. Various symbols, such as circles, squares and triangles, could be used for this purpose. However, for a complicated display showing many types of information there are not enough distinctly different geometrical patterns available. In addition, the association of these patterns with the various categories of information they represent presents a problem in operator training.

Therefore, letters and numerals were chosen as identifying marks because these symbols are familiar to everyone and are easy to arrange in groups to form a simple identification code associating them with the various kinds of information to be displayed. The characters are generated by applying waveforms to the horizontal and vertical (X and Y) deflection plates of the cathode-ray tube. A high-speed mechanical switch connects the output of many waveform generators to the tube in sequence. Because of the storage characteristic of the phosphor on the screen of the tube and because of the persistence of human vision, the characters appear to be displayed simultaneously. Radar information is combined with the symbols by means of a two gun cathode-ray tube. Separate electron beams trace each pattern independently; they are united on the face of the tube as one display.

Generating Display Characters

The simplest character to generate is the letter I. It is formed by applying a sine-wave voltage of proper amplitude to the vertical deflection plates only. To form the O, sine-wave voltages which are displaced 90 degrees in phase are applied simultaneously to both the vertical and horizontal plates of the tube. When the voltage applied to the horizontal deflection plates is passed through a half-wave rectifier the O is cut in half and becomes the letter D.

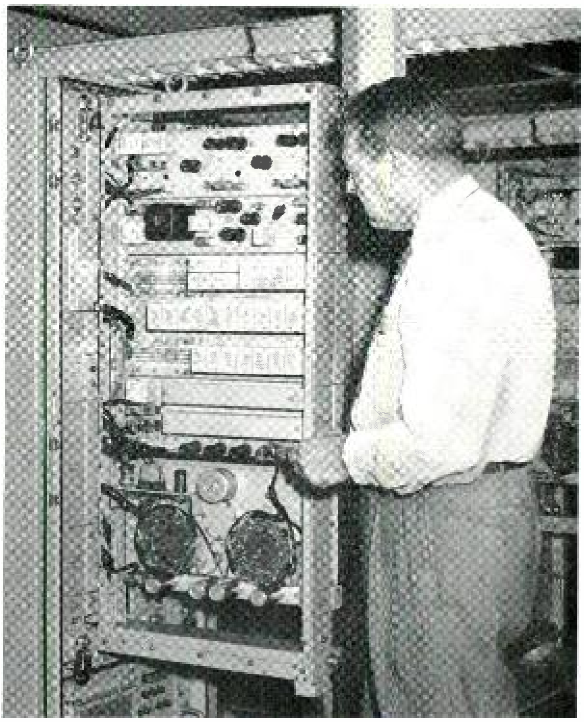
Another example: to generate the letter C, a full-wave rectifier circuit would be used to impose the second half of the trace on the first half. Further, the C can be displayed as a U through the interchange of voltages on the vertical and horizontal plates of the tube.

Other more complex letters are made in similar fashion by special shaping circuits that shift the phase of the sine wave, rectify it, and combine it with other parts of the wave to generate the desired symbol. The diagram on page 132 shows the waveforms used to generate some typical letter symbols and delineates the path followed by the electron beam as it traces each symbol on the tube.

The various input voltages for these waveform generating circuits are obtained from a sine-wave source by means of a small multi-secondary transformer. Phase shifting is accomplished by resistor-capacitor networks; and rectification, by germanium diodes. All components used in these circuits are passive. Each assembly of parts used to generate the waveforms for one character is packaged as a unit and encapsulated in epoxy resin to insure trouble-free operation and long life. These units are known as symbol networks.

In some cases, when complex waveforms are needed to produce a symbol, the circuitry may be simplified by forming the character with two traces, which are combined to display the complete symbol. For example, the letter Q can be generated in two parts—one an O, the other, a short diagonal line. The position of the two with respect to each other is accurately fixed by small dc bias voltages obtained by rectifying ac voltages from the transformer. Both parts of the letter are then shown on the display in rapid sequence. The components required for both the X and Y circuits of these two elements, together with the apparatus used to generate the dc voltages, are assembled in the same symbol—network package.

The waveform voltages used to generate the symbols are small compared to the voltage required to sweep the beam across the face of the tube. They are superimposed on externally supplied variable dc voltages which are used to position the symbol on the cathode-ray display as required. Where symbols are used in conjunction with radar information the positioning voltages are obtained from processed radar data so that the symbol will track the radar blip with which it is associated. The method of time shar-

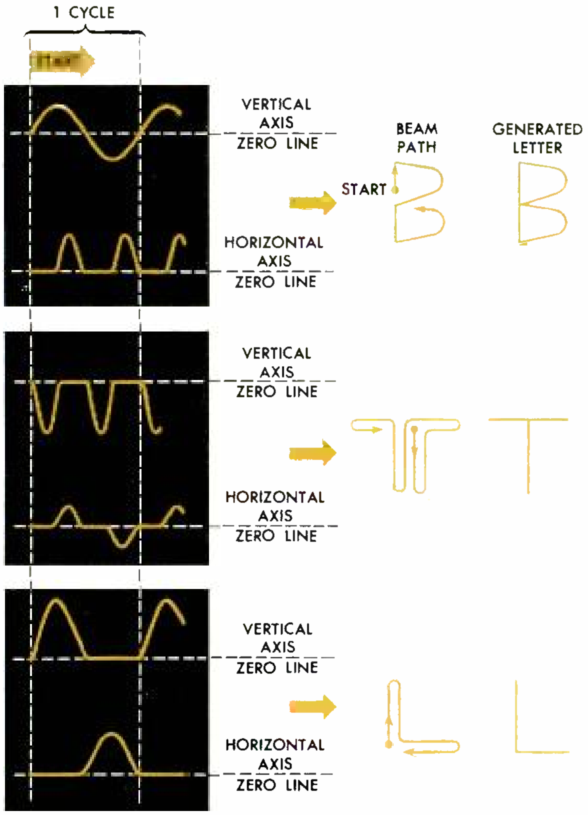


C. W. Norwood inspects symbol-generation apparatus. The encapsulated networks are located in center of vertical pull-out drawer and the time-sharing switch assembly is at the bottom.

ing the outputs of various symbol networks is shown on page 133. To furnish as many as 72 symbols on the display, an assembly of four 144-contact rotary switches is employed. Every second contact on each switch is unused; these dead contacts prevent bridging and consequent short circuits when the rotary wiper brush moves between successive live contacts.

Two of the rotary switches in the assembly are used to time share the X and Y output circuits of the symbol networks. A third is used to supply unblanking or brightening voltages to the grid of the cathode-ray tube. In normal operation the grid voltage is set at a point just below cutoff and the screen of the tube is not illuminated. After the X and Y circuits for each symbol are closed, a positive potential is applied to the grid so that brightening occurs and the symbol appears on the screen. This brightening voltage is removed just before the X and Y deflection plates are switched to the next symbol. By this means all switching transients and superfluous traces are masked and do not appear on the display.

The brightening or Z switch has a shorter duration of closure time than the others. The X and Y switches have a long duty cycle and these are adjusted to very close synchronization. The short-duty-cycle switch is adjusted so that its closure time is bracketed by the closure of the X and Y switches. The Z switch must always make last and break first.



The waveforms used to generate the letters BTL showing the path followed by the electron beam as the letters are traced on the cathode-ray tube.

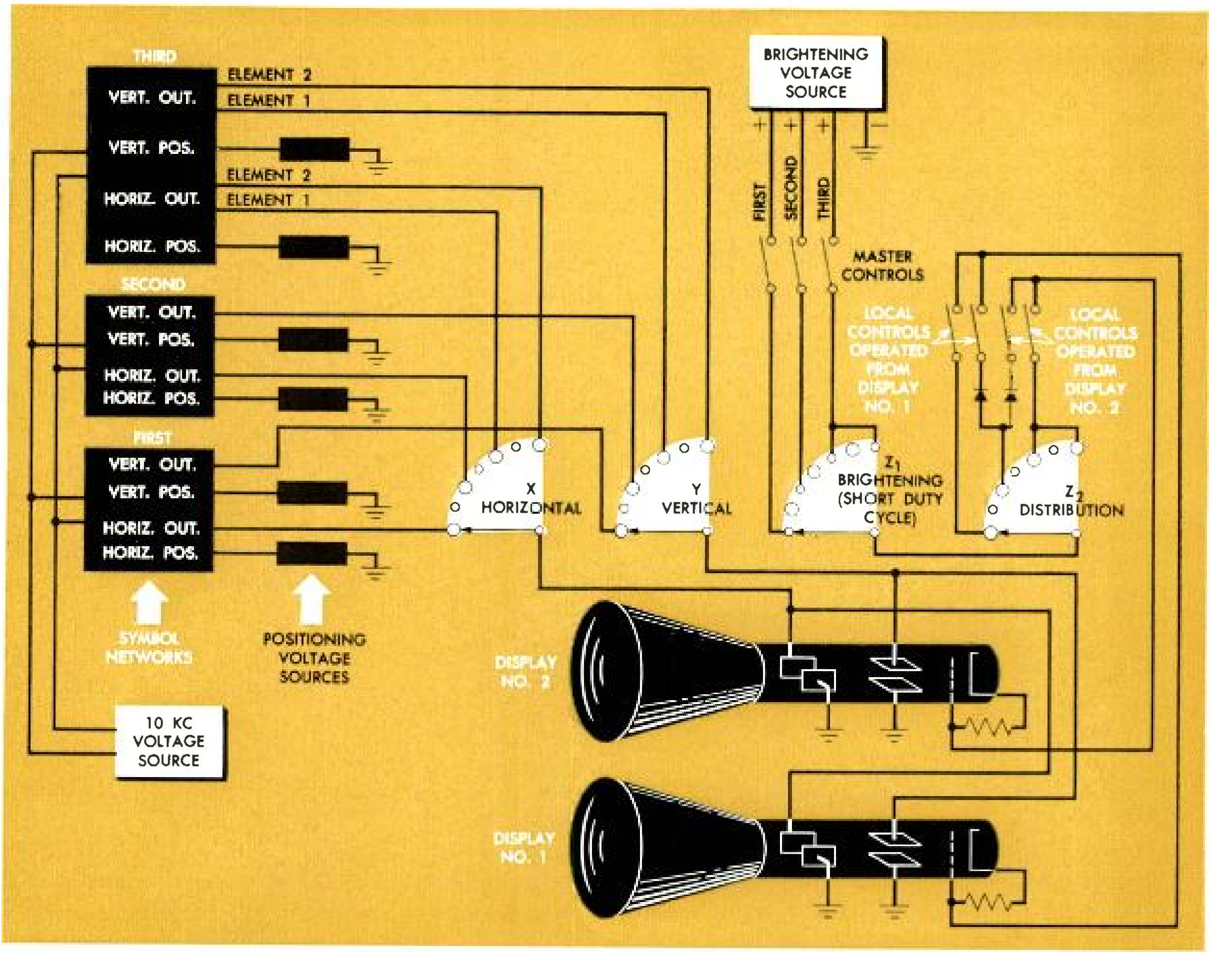
To assure equal brightness for all of the symbols on the display, various levels of brightening voltage are required. This is necessary because the length of the trace used to form some of the characters is greater than that required for others. The trace used to form the letter M, for example, has approximately four times the line length of the letter I.

Since the time-sharing switch has equal closure time for all contacts, each symbol must be traced in the same interval of time. This means that the electron beam travels faster to write the M and the phosphor on the cathode-ray tube screen does not receive the same degree of excitation. The M, therefore, will appear dimmer on the display than the I unless a higher brightening voltage is used. Approximately 15 levels of voltage are required to equalize the brightness of all the letters and numbers.

Control switches or relays are connected in series between the brightening voltage source and the Z time-sharing switch. These permit the various symbols on the display to be turned on or off as required. In small display systems which use only one cathode-ray tube, an assembly of three switches (X, Y and Z) will provide complete flexibility. In this case the rotary wiper brush of the brightening switch is connected directly to the Z input circuit of the tube.

In systems which use two or more identical displays, the Z circuits are all connected in parallel. In the application described here many displays are used. Because of the magnitude and complexity of the information shown, the problem of evaluation is shared by several operators each one of whom has his own area of responsibility. To avoid confusion it is necessary for each one to be able to turn off, at will, certain symbols on his display without disturbing the displays of the other operators. He does this with the last time-sharing switch in the assembly of four. This switch is the heart of a very flexible brightening voltage distribution circuit.

The distribution switch is connected back-to-back with the brightening switch; that is, the two wiper arms are connected together. Instead of one output circuit on which brightening-voltage pulses for 72 symbols appear in sequence, there are now 72 circuits each of which has



Simplified schematic of the symbol-generation system showing how the outputs from various symbol networks are time-shared in simultaneous displays. The brightening circuits that make possible the display of different symbols on each of several cathode-ray tubes are also illustrated.

properly timed brightening pulses for one symbol only.

The circuits for all symbols that appear on any one display are strapped together and are connected to the grid circuit of the associated cathode-ray tube. Local switches, or relays, between the distribution switch and the grid, permit any symbol to be turned off individually. The brightening circuits for all symbols that are to be used on additional displays are similarly strapped and local switches provided as required. When the same symbol is shown on more than one display, isolating diodes are provided to prevent interaction between the circuits. In multiple display systems of this kind, the switches in the circuits between the voltage source and brightening section of the time-sharing switch assembly are used as master controls to brighten the symbols that appear on all displays simultaneously.

The same techniques are used to show other types of information on cathode-ray tubes. Some displays have been developed to present data by thermometer-type, variable-length vertical lines, with or without supplementary designating letters and numbers. Each symbol or line is generated individually and then time shared with the others to form the complete display.

Because radar—the long-range "eyes" of naval air-defense systems—is only as effective as the information it displays, this method of generating, distributing and displaying symbols on cathode-ray tubes has been used on several weapon-direction systems designed by the Laboratories for the United States Navy. It has proven reliable in use and has been flexible enough to permit modification of the basic design to meet several specific applications. Such means of displaying information may lend itself to other military and commercial uses.

The 82B1 Teletypewriter Switching System achieves substantial economies by making extensive use of multistation operation. This type of system organization permits sharing of lines in a switching center.

G. Parker

Multistation Operation in the 82B1 Teletypewriter Switching System

A number of problems associated with sending teletypewriter messages to their proper destinations have been minimized in an automatic teletypewriter switching system designed by Bell Laboratories for the U. S. Navy. Called the 82B1 (RECORD, *May,* 1960; *August,* 1960), this switching system is fast and reliable, yet conforms to the requirements of economy and simplicity of design. One way it attains these requirements is by "multistation" arrangements that permit using a minimum of equipment.

Basically, the 82B1 system consists of switching centers and their associated stations. In comparison with a telephone switching system, the teletypewriter switching center performs a function similar to that of the telephone exchange, and the station equipment corresponds roughly to the customer's telephone set. There are, however, essential functional differences between the 82B1 and a typical telephone switching system.

In the first place, the 82B1 is a private line system. This means that all the various units and lines are arranged for the needs and special requirements of one organization, and furthermore, all the stations in the system are under that organization's control. Second, the input signals to a teletypewriter system come from a perforated tape obtained by typing a message on a teletypewriter keyboard, or from a tape obtained as the output of a "reperforator." All information transmitted over the system is in teletypewriter code. The final destination of the message is another station or stations of the system. There, the message appears in typed form on a teletypewriter receiving unit, and, when required, also as perforated tape for retransmission to other systems.

A third difference from a telephone system is that the 82B1 switches messages, not lines. The objective of a telephone system is to connect two customers directly by interconnecting their lines. In the 82B1 system, however, stations have no direct connection. Instead, each completed message is automatically transmitted to a switching center, which stores the message and then arranges to retransmit it to any number of other stations according to the addresses that form the beginning of the message. Finally, because the two directions of transmission are arranged to be independent of each other, messages can be sent to and from the station simultaneously.

The 82B1 teletypewriter system has two kinds of stations: those for single-station lines and those for multistation lines. These correspond roughly to individual telephones and party-line telephones, respectively. But in the 82B1, multistation lines are the most important and the most widely used. Although the locations of the various stations are distributed over the whole United States, the number of switching centers for this private network is very small. This makes it economically prohibitive to connect each station by an individual line to a switching center. Thus, distributing as many as five stations along one line between switching centers greatly reduces the cost of leasing lines. This is true even though the station equipment is much more complex.

Signal Channels

Multistations in the 82B1 system are connected to the switching center by two one-way channels to transmit messages to and from the switching center. In addition to message signals, various control signals also travel over these channels. The switching center automatically transmits instructions, directions and questions in a concise code, and the stations automatically originate responses and requests.

Each station has a "control circuit" whose task is to sort control signals from message signals, interpreting all coded instructions and carrying them out. It generates responses, decides which message signals should be printed on the teletypewriter, and regulates the sending of messages.

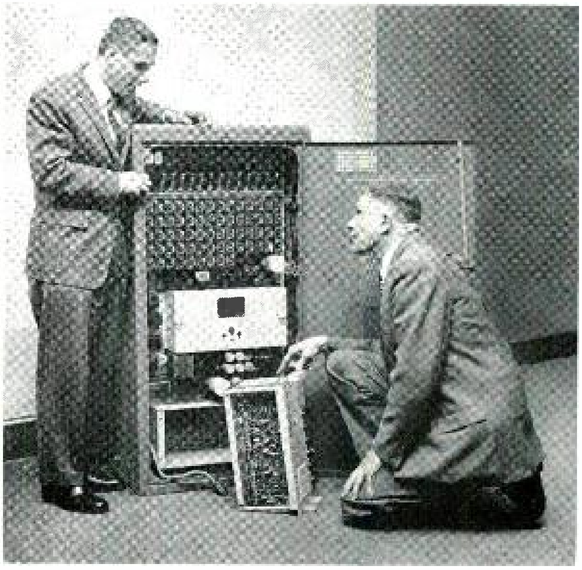
Messages used on the system have three major parts: (1) the address or addresses to which the message should automatically be directed, (2) the text, and (3) a special sequence of characters to indicate the end of the message. Before sending out a message to a multistation line, the switching center sends the codes of all those stations to which the message is addressed. The station-control circuit has to make sure the message is delivered only to those stations.

Since each multistation line has more than one transmitter, the switching center must regulate the sending functions of each station by issuing directions to all of them. Despite all the extra equipment required for the added control features for multistation line operation, this sharing of line and switching-center facilities achieves large economies.

All signals received at a station are monitored there by a transistorized reading device in an electronic "director." This director is equipped with transistor logic and memory circuits that can analyze the signals. For example, it can tell if the signals being received are a part of the address codes that precede each message, or whether they are a part of the message itself. It also can tell if the signals are a part of a message addressed to that particular station and should therefore be printed by the receiving teletypewriter. A selected station on the line, called the "master" station, checks all addresses in the address group to detect any errors or mutilations in codes that will make delivery to one of the stations impossible. In case of errors in the address codes, the master station will print the complete message and energize an alarm circuit.

The director also recognizes signals being received as instructions or questions from the switching center to control the transmitter circuit. These, of course, should not be recorded at the receiving teletypewriter (which might at the moment be in the middle of receiving a message). On the other hand, the director must correctly interpret these control-code signals so it can initiate action when necessary.

Before they reach the receiving teletypewriter, all signals are delayed one character in a "shift register" in the director. This is necessary because in some sequences it takes two special characters, uniquely spaced in time, to determine whether or not printing should be withheld. The decision to print is made by checking the line signals after transmission of the first character while it is still stored in the shift register and can be either fed to the teletypewriter, or suppressed. This delay introduces a difficulty, however. When the last character of a message is received, the teletypewriter will only print the next to last character. To handle this problem, the director is equipped to note the end-of message sequence



George Parker, left, and Eric Graber with station-control cabinet. Cabinet houses the relay-control circuit and the electronic director.

that terminates every message. When it sees this sequence, it immediately enables a circuit to "feed out" this last character. This, in effect, turns off the printing mechanism.

The director uses 52 transistors for its various functions. Several considerations influenced the decision to transistorize these circuits. Designers can obtain similar functions with relay circuits and a mechanical, motor-driven selecting device, probably at a lower "first" cost. Yet many advantages tip the scales in favor of the electronic device. For example, because the stations are widely dispersed geographically, and at least some of them hard to get at, maintenance is a more acute problem than it is for switching-center gear. Repairs of machinery on a customer's premises are always difficult, and transporting a spare selecting device, perhaps by truck over rough roads to an outlying station, might affect its adjustments. On the other hand, the electronic director itself is a plug-in unit and its adjustment is not affected by the rigors of transportation. In other words, in case of any service difficulties, a spare unit can simply be inserted, and repairs of the damaged unit can be made in a central repair shop.

Another reason for the choice of transistorizing lies is the great reliability required of the director circuits. Any one error in the printing device may merely result in one misprinted character. On the other hand, a single such error in the receiving selector of the director may result in a message being completely lost. Thus, because electronic circuitry is more reliable and requires less maintenance than mechanical machinery, this was another factor that favored its use. Finally, the absence of moving parts makes the electronic director quieter in operation than an equivalent mechanical device. In addition to the director, over one hundred relays and selectors are used in the control circuit.

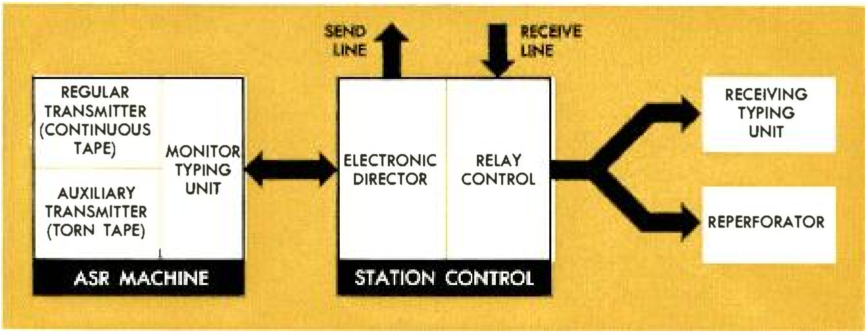
To send a message in the 82B1 system, an operator types on the keyboard of the teletypewriter the addresses to which the message is directed, the text, and finally the special end-of-message sequence. This typed copy is stored in the form of code perforations on a paper tape. The station takes no action until the message is complete—until a reading device detects the typing of the end-of-message sequence.

Transmission is withheld until the message is complete because in this way both lines and equipment at the switching center are tied up for shorter periods of time. The line, for example, is shared by five stations. Therefore, to reduce the time the line is held by any one station, transmission should be as fast as possible. Even the best typists are slower than the automatic transmitter, which sends at one of three set speeds—60, 75, or 100 words per minute. Only when a complete message is available, can it be sent without interruptions at these high speeds.

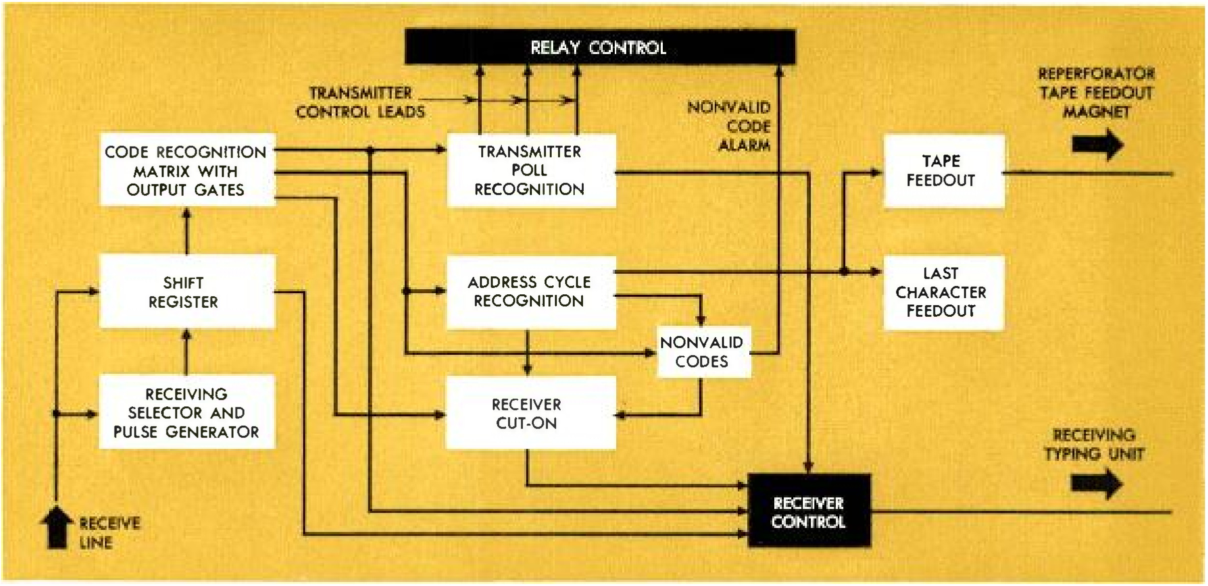
Procedure

In a typical example, when an operator completes preparing a message, the "reader" portion of the relay-control circuit detects the end-of-message sequence, and alerts the station that one or more messages are available for transmission. Let us assume the message has a priority rating, so the operator will push the "priority button."

Assume, also, that at this moment no traffic is being sent from any other station on the multistation line. A signal generator starts automatically at the station. It sends a signal to the switching center implying that one of the stations on the line has traffic ready for transmission. In response to this, the switching center sends a code sequence over the incoming line. If this line is receiving a message at the time, it must temporarily cease that in favor of receiving the control characters for the transmitter. The station printing the incoming message will "blind" its teletypewriter so that the control characters will not appear in the middle of the message. As soon as the station with traffic starts sending, the incoming message is resumed.



Typical arrangement of a station circuit. This connects incoming and outgoing lines of the switching center by two channels used for messages and control signals.



Director is reading device using transistor logic and memory circuits to analyze signals. Arrows show logical flow of information between white boxes which are the functional parts of director.

A code sequence sent by the switching center indicates that it will originate a "poll" for traffic. In this method, the stations on the line are asked, in turn, if they have any priority traffic. Stations asked this question, but having no priority traffic ready, send a code signal that implies the answer "no." A station having a priority message, however, immediately proceeds to transmit it to the switching center.

First, an automatic signal generator in this station will send the required "preamble," then the station identification, a consecutive message number, and finally the typed portion of the message. In the meantime, the switching center will have detected the successful poll, sent a signal to indicate the end of the polling cycle and resumed sending out any messages that might have been interrupted by the poll.

The end of the priority message is indicated to the switching center by its end-of-message sequence. The switching center then immediately proceeds to send a new poll. On the first round of this poll, it asks the stations for priority traffic. If it receives a "no" response from all of them, it starts on a second round to ask for regular traffic. If it again receives only "no" responses, it then sends a code signal indicating the idle condition of the sending line. After that, any station in that group that finishes preparing a message will automatically send the signal requesting a new poll.

In addition to its main function, the polling cycle provides a check of all lines and a great part of the station facilities. Sending the poll to a station requires a working receiving line to obtain a response. This requires recognition of the code that proves the director to be working, the relay equipment to be responding, the signal generator to be functioning, and finally, the sending line to be in working order. If the switching center fails to receive a response, an alarm indication alerts maintenance personnel to a trouble condition.

Messages may be prepared continuously at the station. For each end-of-message sequence being typed the "read" circuit causes a "count" circuit to increase the count by one. For each end-of-message sequence transmitted to the send line, the count decreases by one. In this way, the station keeps track of any complete messages still awaiting transmission.

The continuous perforated tape containing the messages moves automatically from the perforator to a storage bin, from there to the transmitter, and finally to a take-up reel. It need not be handled by the operator. An auxiliary transmitter is available to take care of re-runs, or of pieces of tape originating from a different system. By approporiate controls, operators can send messages for which the addresses are prepared in the regular transmitter and the text is contained on a tape inserted in the auxiliary transmitter. This makes it possible to re-send tapes to other addresses and to handle tapes from different systems.

The 82B1 has had over two years of satisfactory service as a military teletypewriter switching system. So far, it has shown a dependability that bears out the concepts used in its design.

Constructing the precision parts for microwave research equipment requires some rather special procedures. One of these, the art of electroforming, helps improve techniques in communications research.

N. J. Pierce

Electroforming Waveguide Parts

In the communications industry there has been a long-time trend toward higher and higher frequencies. For example, the TJ microwave relay system recently introduced operates with carrier frequencies near 11,000 mc. At this frequency, the wavelength in free space is only 1.1 inches. Intensive research is now in progress on waveguide microwave systems for the future that will use frequencies from 50,000 to 100,000 mc or more, where the waves are less than ¼-inch long. At these frequencies, ordinary electrical components become metallic cavities with dimensions that are fractions of the wavelength. These cavities and their connecting waveguides take on many shapes and combinations whose internal dimensions and finish must be produced to a high degree of precision.

One way to supply this precision is to use the old art of electroplating. In this method, a solid replica, or "mandrel," of a desired cavity is first made by standard techniques to the desired dimensions, tolerances, and finish. This mandrel is then electroplated with a thick coating of the material desired for the final product. The mandrel is removed from the plated structure by withdrawing, melting, or by chemically dissolving it. The remaining shell of electroplated material then encloses a cavity which reproduces the shape, size and finish of the original mandrel to a high degree of precision. This process is called "electroforming" and the product is said to have been "electroformed."

The parts required in waveguide research span a wide range of shapes and sizes, ranging from simple rectangular or circular waveguides, through tapered sections, to the multicurved device shown on page 141. Other complex structures consist of metal parts and mandrels cemented together and electroformed into a solid piece. In this case, the electroforming not only makes cavities but also electrical contacts and mechanical attachments of different parts of the composite structure. A simple example of this type of electroformed device is shown on page 140.

A variety of materials can be electroplated or electroformed on suitable mandrels with minor modifications in the techniques. For microwave circuits, copper is almost universally desired for its electrical properties. Fortunately it is a material that behaves well in the electroforming process. The procedures discussed below apply specifically to electroforming with copper.

Mandrels used for electroforming can be made from a wide variety of materials and the choice depends on the job at hand. For example, suitably shaped parts are made on permanent mandrels which can be withdrawn from the plated shell and reused. The best material in this case is polished stainless steel which will produce many parts without deterioration. The mandrel can be readily removed by heating the plated structure so that differential expansion frees the mandrel from the plated shell.

If only a few similar parts are desired, an aluminum mandrel may be used and removed by cooling in dry ice and acetone. Aluminum mandrels deteriorate with use, however, and are not suitable for more than a half dozen or so parts if they require high precision. Aluminum mandrels must be carefully polished before each use with powdered alumina and water. Alkaline polishes must be avoided because they cause the aluminum to absorb gases which are later given off during the electroforming and cause serious pitting of electroformed parts.

If the shape of the part to be made is such that the mandrel cannot be withdrawn, expendable mandrels must be used. Aluminum mandrels also fall into this category. They are removed by etching away the aluminum in a hot sodium or potassium-hydroxide solution. This leaves a black residue which can be removed with dilute sulphuric acid.

Non-metallic substances have a number of advantages for expendable mandrels. As an example, wax mandrels can readily be produced in quantity by several molding techniques, and can be easily removed by moderate heating. Mandrels made of a plastic, such as polystyrene, can be produced by molding, extrusion or machining and are advantageous where parts must be cemented together. This can be done by using jigs to hold the various plastic or metallic parts in the desired configuration and then carefully flowing a small amount of chloroform into the plastic-plastic or plastic-metal joints with a hypodermic needle. To insure a good joint, care must then be used in removing the plastic residue from the metallic parts. After electroforming, the polystyrene mandrel can be dissolved out with one of several solvents.

Before a mandrel of a non-conducting material such as wax or polystyrene can be electroformed, it must be made conductive in some way. One way to do this is to coat the part with graphite. This is most easily done by carefully brushing on a thin uniform coat of alcohol dag* — a suspension of colloidal graphite. However, metallic parts must not be coated with graphite or poor joints will result.

Plain graphite coatings have been used successfully, but initial formation of a thin coating of copper is very slow because of the high resistance of the graphite coating. This also apparently inhibits the penetration of the plating into deep recesses. The initial coating can be speeded up as much as ten times by carefully winding a spaced wire helix of fine copper wire over the graphite-coated mandrel and connecting the wire to the cathode connection of the electroplating bath. The structure to be electroformed may have recesses or an irregular shape so that the wires do not actually contact some areas of the mandrel. The wires shield these portions of the work from the electric field and pre-

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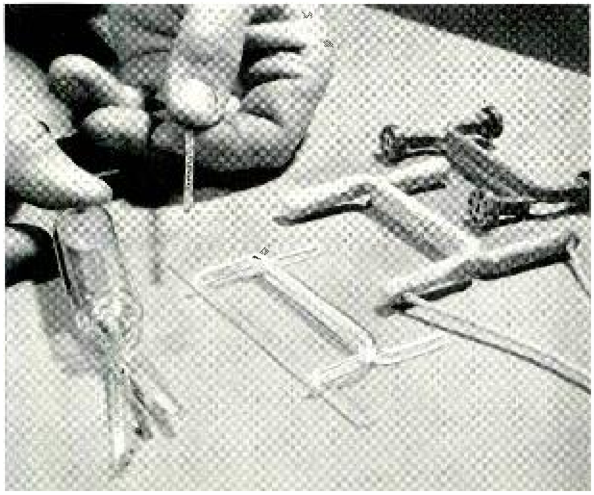
* Registered U.S. Trademark of the Acheson Colloids Co.

N. J. Pierce adjusts agitating equipment used in electroforming process. Mandrel is slowly rotated in plating bath, first in one direction, then in other. Polyethylene cylinder between tank and part acts as shield to lengthen path.



Metal foil is placed between polystyrene parts, structure is then cemented together. After plating bath, rough finish is machined and end pieces attached. Part then appears as in right background.

vent normal plating. In this case, the wires should be removed after the initial coating has been established over the bulk of the work.

A new and very effective method has been devised for producing a conducting coating on mandrels made of insulating materials. This method involves coating the mandrel with fine iron powder and then immersing it in copper sulphate solution. Copper replaces the iron powder chemically without the need for an external source of electric current, and this produces a good conducting coating upon which normal plating at standard rates can be started at once.

In practice, the insulating surface is first coated with the usual graphite dag solution and dried to form a uniform, highly resistant, coating that can bridge any possible gap between the iron particles. This is followed by a thinly brushed coating consisting of a suspension in alcohol of a half-and-half mixture by weight of the alcohol dag and finely divided carbonyl iron powder. When this coating has dried, the part is immersed in an acid solution of copper sulphate for a few minutes or until the iron is substantially all replaced by copper. The work is then removed, rinsed in pure water and is ready for normal electroforming. It is not entirely clear why the best results are obtained by mixing the iron powder with the graphite dag material to form the coating. But no one has so far been able to duplicate the excellent results obtained in this way by any other method.

A standard acid copper plating bath can be used for electroforming, but somewhat better results are obtained if the usual amount of sulphuric acid is reduced and the bath maintained at a Ph of about 3 to 5. This, combined with a suitable plating rate produces a finer grained, smoother surfaced, deposit. Copper can be plated from an alkaline bath at almost twice the rate attainable from the acid bath, but experience has indicated that this results in an inferior product both mechanically and electrically.

Minimizing the size of the copper crystals in the electroformed coating helps to produce a mechanically sound structure. The crystal is made smaller by reducing the plating rate, which depends on the current. Plating currents from 30 to 100 millamperes per square inch are satisfactory. Often the electroforming is started at a low rate and then increased after some thickness of plated copper has built up. Fifty milliamperes per square inch will plate at a rate of about 0.4 mils of copper per hour. Once a good coating has been established, accelerated plating by increasing the current can be achieved, but at the cost of a rougher outer surface.

Rotating Parts

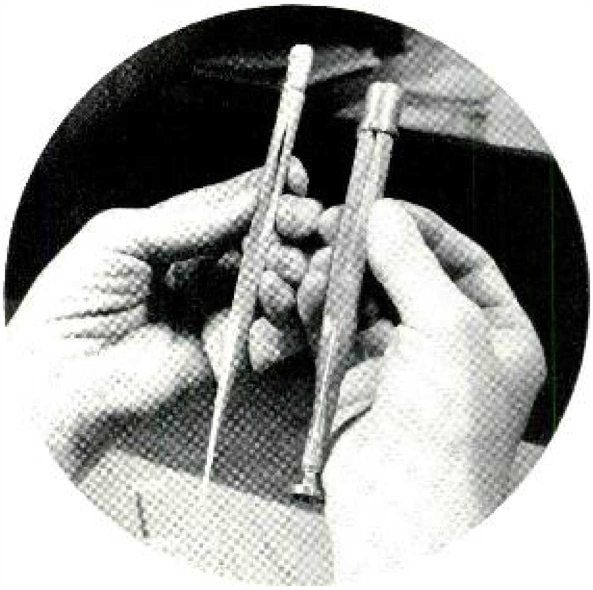
Some form of agitation of either the work or the electroplating bath is necessary to build up a really satisfactory coating at a reasonable rate. A simple way to do this is to mount the work so that it can be slowly rotated in the bath. Continuous rotation in one direction, however, tends to build up excessive thickness on the leading edges. Thus it is often desirable to reverse the direction of rotation automatically every few minutes with a simple relay-reversing device.

Ideally, in electroforming operations long tanks should be used so that every point on the cathode structure being plated would be equi-distant from any point on the anode. This condition is not normally met in small-scale laboratory operations, and it is worthwhile to try to equalize the path lengths reasonably well by shielding the anode. This can be done by placing a cylinder of insulating material, such as polyethylene, inside a cylindrical anode. This arrangement is illustrated on page 139. The copper ions from the anode are then forced to travel down through holes in the bottom edge of the shield on their way to the cathode structure. If the cathode structure is long, a further expedient to equalize the build-up is to sink a beaker in the bath and let the end of the structure extend down into the beaker. This will lengthen the path and reduce the buildup of the shielded end.

Good electroforming results call for a clean plating bath. A cover will prevent the accumulation of dust, and filtering at intervals removes any accumulation of solid contaminants which can cause large grain deposits and occasionally trigger the formation of streamers and whiskers which grow in wild profusion.

If certain areas of a waveguide part should not be plated, they can be masked by painting them with staging ink. More extensive areas call for vinyl electrical tape or a hot mixture of beeswax and paraffin.

The plating process depends on an active or receptive surface to receive the copper ions from the solution. When the work is temporarily removed from the solution for any purpose, exposure to air and greasy fingers tends to make the surface passive so that the renewed plating is not tightly bound to the previous work. This results in a poor structure of separate layers.



Wax mandrel, left, and the waveguide assembly that is electroformed over similar one. Internally, the waveguide is an exact replica of the mandrel.

Areas from which masking tape has been removed are also passive. Here, to avoid the layer problem, whenever plating has been stopped for any reason, the plating voltage should be reversed and "reverse plating" carried out for a few minutes. This activates the surface so that further plating will proceed without laminations.

These techniques have been worked out for use in a small laboratory environment on experimental waveguide parts. As microwave communications continues to grow, more electroforming may be required. Thus procedures for mass production will need further development.

Antiozonant Research Aims at Better Inhibitors for Elastomers

Increasingly greater amounts of smog hovering over major metropolitan areas give rise to higher concentrations of ozone—the gas generated in the earth's atmosphere by ultraviolet radiation from the sun. Means of protecting rubber from ozone-induced chemical decomposition therefore commands the attention of more and more research scientists throughout the world.

News of Chemical Research

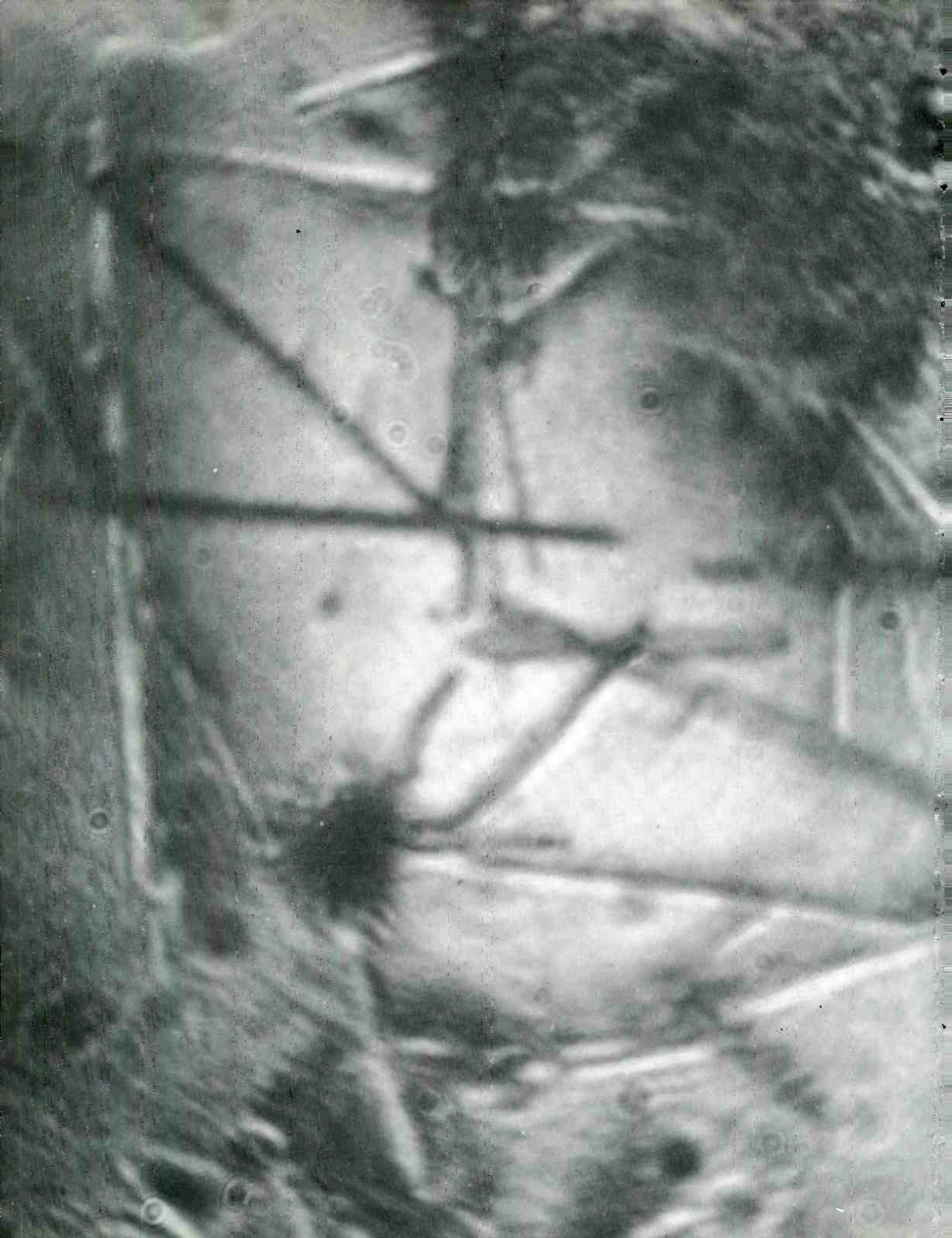
Now a new theory of the chemical actions involved may enable scientists to understand how some antiozonants prevent physical changes caused by ozone in certain elastomers and natural rubber.

According to the proposed mechanism, protection is obtained by a process which crosslinks the surface of the material, thus making it impervious to further ozone attack. It is believed that crosslinking occurs through radicals produced in a reaction between amine antiozonant and peroxides, or possibly hydroperoxides or ozonides, created in the rubber by ozone.

Though not yet experimentally verified, the new theory may explain why some radical-chain inhibitors commonly used to prevent oxidation do not inhibit the deteriorating effects of ozone. Many rubbers are now protected from ozone-caused stress cracking by waxes and antiozonants. In themselves, however, certain antiozonants may promote oxidation.

Robert W. Murray and Paul R. Story of the Chemical Research Department outlined these views in a recent paper presented at a meeting of the American Chemical Society. Based on a search of existing chemical literature, they find that present mechanisms for explaining antiozonant action are inadequate. An experimental program to determine the validity of their proposed new mechanism is underway at the Laboratories. Assisting in this program is George Bebbington, also of the Chemical Research Department.

Because the basic mechanisms of oxidation are fairly well understood, better and more efficient antioxidants have been developed. But there have been fewer investigations in antiozonant research. A number of antiozonants have been used with relative success for several years to prevent rubber degradation under field conditions. The new experimental program should reveal the reasons underlying the protective action of present antiozonants and may open the door to the development of more effective compounds.



Optical Masers and Micrography

Light given off from an optical maser is theoretically emitted as a nearly parallel monochromatic coherent beam. In actual ruby masers, these features of parallelism, monochromatism, and coherence do not obtain precisely. One can put a lens so that the maser beam can fall directly on it. This lens can then focus the beam to a very small spot. If the maser beam were exactly parallel and coherent, the spot of light could be as small as one wave-length in diameter. In practice, the spot of light is larger than this, but one can obtain a spot smaller than, say, 0.1 mm in diameter. The energy in a ruby maser beam is typically of the order of 1/5 of a joule during the half millisecond of emission. This means that the *specific brilliance* of the small spot image is very high indeed.

With the figures above, the mean power per unit area illuminating an object at the focus point is about 5 million watts per square centimeter. This may be compared with the mean power per unit area in the image we could form with a lens concentrating light from the Sun. Even if we consider all the light in the whole visible spectrum, and use an f/1 lens, the mean power per unit area in the image of the Sun is only about 500 watts per square centimeter. The specific brilliance of the focused maser beam is thus 10,000 times greater than this. Any of the usual continuously operable terrestrial light sources, and any images of such sources, no matter what condenser lens systems are used, are less bright than the image of the Sun.

If we wish to photograph a large object we need to illuminate it with a large total amount of light. If, on the other hand we wish to photograph an object through a microscope, we need a high specific brilliance, though the total amount of light is not necessarily large because of the smallness of the field of view. An optical maser is thus of great prospective importance as a brilliant light source for short-exposure pictures, particularly in micrography.

To test this, some simple experiments were conducted. A ruby optical maser was set up and its beam of light was focused using conventional microscope condenser optics. The spot of light at the condenser focus was 0.1 mm diameter. Even with this simple setup the beam turned out to be bright enough for photography at very high magnifications. The photograph (*left*) of some potassium titanate crystals is an illustration of this. The needle-shaped crystals are 1 to 2 microns in diameter. This photograph was taken on a fast red-sensitive plate at a magnification from object to emulsion of 1800 times by the flash of light from a ruby maser. The ruby rod was about 7 mm in diameter and 5 cm long. It was "pumped" by light from a flash tube supplied from a condenser bank of 500 μf charged initially to 4,500 volts. The burst of light from the maser lasted less than one two-thousandth of a second. The objective lens had a 4-mm focal length with a numerical aperture of 0.85. A 20-power compensating projection eyepiece was used.

It is also possible to use the light from a ruby maser in other aspects of micrography and photography. For example, the monochromatism of the beam may be of great use in interferometry.

It is to be expected that with further development, optical masers will be available which emit light more nearly monochromatic, parallel, and coherent than those used so far. It is also expected that the duration of the flash burst may be controlled at will, and that it may be more closely synchronized with any convenient trigger signal. All of these developments should make the optical maser an even more valuable light source for short exposure micrography and, in due course, for high-speed repetitive micrography.

◀ *First photomicrograph ever taken using beam from an optical maser as a light source shows potassium titanate crystals. Magnification in enlarged photo corresponds to 4250 times original.*

J. S. Courtney-Pratt
MATHEMATICS AND MECHANICAL RESEARCH

A.T.&T ANNUAL REPORT DESCRIBES TECHNOLOGICAL ADVANCES

News of the Bell System

The accomplishments of Bell Laboratories figured prominently in the A.T.&T. Annual Report released last month to 1,911,000 share owners. Last year was "one of the best years in Bell System history, not only in results but also in the foundations established for future progress," said Frederick R. Kappel, president of A.T.&T.

The Bell System completed its biggest construction program ever and began "working at top speed" toward a satellite network to provide world-wide telephone, data and TV communications and by next year hopes to test a satellite in orbit.

"We feel strongly that private enterprise can best maintain America's leadership in space communications," said Mr. Kappel. "We are ready to do the job, eager to move ahead, and confident the result will serve the public interest well."

"The impact of Bell Laboratories pioneering" said Mr. Kappel "is reflected in many topics: The vault of communications into space, the new ocean cables that will handle nearly three times as many calls as those built only a few years ago, the epitaxial transistor, the switching and transmission systems that enable people to talk across the nation in seconds, and operate distant computers with a few turns of a telephone dial."

1960 saw the world's first Electronic Central Office, forerunner of future switching systems, in operation at Morris, Illinois (RECORD, *December*, 1960). Mr. Kappel pointed out that "in February, 1961, Bell Laboratories' new 'heavy route' long distance microwave system, capable of handling nearly 11,000 conversations, was placed in service between Denver and Salt Lake City (RECORD, *February*, 1961). By the spring of 1962 we expect it to be working all the way from Utah to New Jersey. Meanwhile, the engineers are testing another new system designed to carry 24 conversations under city streets on two pairs of wires. This should make it possible to provide much more service over wires already in place underground."

Mr. Kappel illustrated the various aspects of Bell Laboratories. He stated that "within the laboratory and on pilot production lines, we are learning to build complete electrical structures for transistorized equipment by depositing films of metals and insulators on glass or ceramic materials. Other research has created new alloys that can be made into superconducting magnetic coils. This is a discovery of great potential usefulness in many fields of communication technology, including satellite communications. And, in 1960, Bell Laboratories demonstrated a new device, the optical maser (RECORD, *November*, 1960), that . . . may ultimately increase by 10,000 times the spectrum of waves that can be used for future communications through hollow 'wave guide' pipes.

"To strengthen the long distance network further, we are building a deep-buried transcontinental cable system. Amplifier stations along the route are all underground, as well as the cable itself. Like many other long distance routes, this one will by-pass critical defense areas.

"Telephone lines now link 14 SAGE air defense centers and Western Electric continues to provide coordinating management services on SAGE construction. Since September, a 6000-mile ultra-dependable communication system developed by Bell Laboratories, installed and tested by Western, and operated by telephone companies in Canada and the United States, has been carrying data from Ballistic Missile Early Warning System radars in Greenland to North American Air Defense Command headquarters at Colorado Springs. A defense communication system is also being installed in the Aleutians. Eastward from Baffin Island, work proceeds on extension of the DEW Line and related communications. For the Army Signal Corps, Bell Laboratories is heading an industrial team to develop an integrated communication system to meet all major military needs.

"Nike Hercules anti-aircraft missile systems now stand guard in the United States, Formosa, and NATO countries overseas. Western Electric is producing an improved version that has shown it can destroy not only aircraft but short-range missiles. Bell Laboratories is working intensively on development of the Nike Zeus system for defense against long-range missiles, and Western is developing methods to manufacture the system. At Kwajalein Island in the Pacific Ocean, preparations are being made for tests of Nike Zeus against ICBMs. (RECORD, *December*, 1960.)

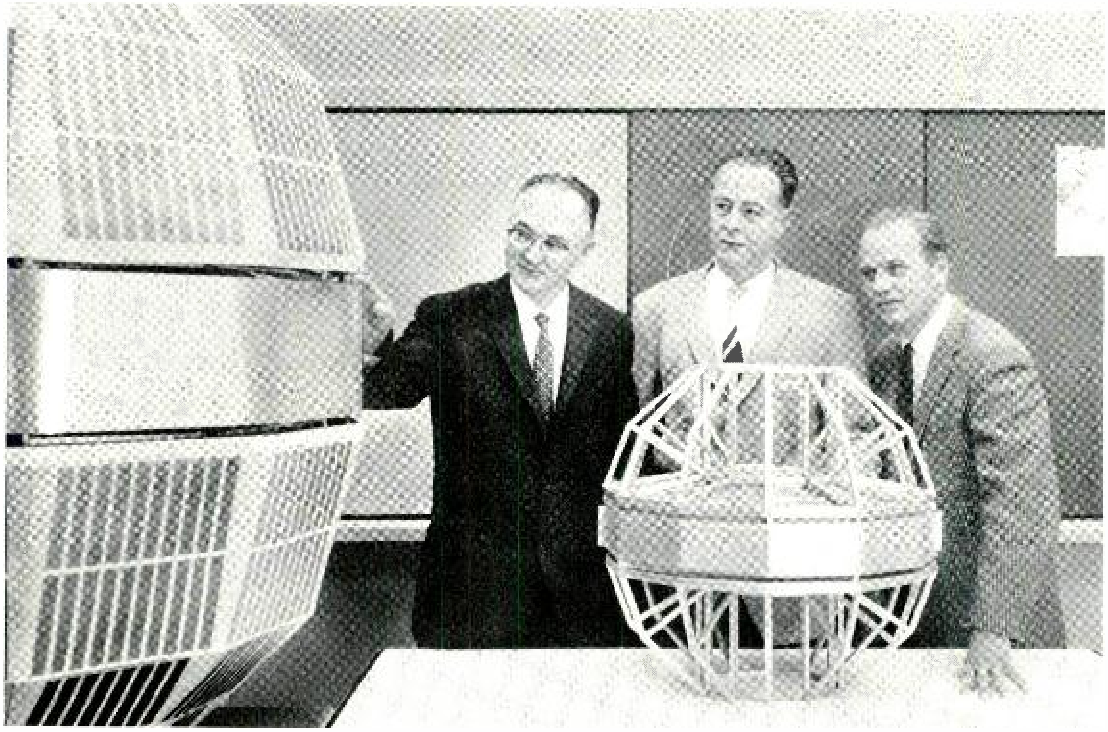
"Underwater sound systems developed by our Laboratories provide surveillance of ocean areas along missile ranges, and determine the point of impact of test missiles as they hit the water. The Laboratories' guidance system for the Titan missile and for space vehicles has been outstandingly successful. Last year it placed the Tiros weather satellites in near-perfect circular orbits and did the same for Echo I. We believe it will be used often in future satellite launchings.

"The importance of Bell Laboratories new 'epitaxial diffused transistor,' can hardly be overstated, for epitaxial transistors will operate several times faster than their predecessors (RECORD, *July*, 1960). Less than six months after the development, these new devices were coming off a pilot production line."

A recent Bell Laboratories development called TASI (Time Assignment Speech Interpolation) had doubled the capacity of the transatlantic cable. Mr. Kappel stated that, "similar equipment will be installed this year on the cables to Puerto Rico and Hawaii. A third transatlantic cable, directly connecting the United States and Great Britain, is planned for 1963, and in the same year the Florida-Jamaica cable will be extended to South America. In 1964 a cable will be built between Hawaii and Japan, and also a second cable between Hawaii and the U. S. mainland. In addition, agreement has been reached for the Bell System to share in the proposed British Commonwealth cables across the Atlantic and between Hawaii and Australia.

"The cables to Jamaica, South America, and Great Britain, and our new Pacific cables, will be of the new Bell Laboratories design, affording increased capacity and economy. With this large program, and a scarcity of adequate cable ships, a ship especially designed to meet these needs is now being built."

One of the highlights of Bell Laboratories achievements during 1960 was the successful launching of the Echo I satellite (RECORD, *September*, 1960). The A.T.&T. president noted that "Tests of the Echo I communications satellite last summer confirmed in all respects the studies made by Bell Laboratories scientists over a period of years. We are confident that man-made satellites can be used successfully and economically to provide high-quality, large-capacity microwave radio channels across the oceans. Such channels will be able to handle telephone conversations, data, and television programs."



Alton C. Dickieson, John W. West and Leif Rongved (l. to r.) with Laboratories' preliminary models (in full scale at left) of an active communications satellite.

New High-Frequency Ultrasonic Transducer

News of Device Research

A new, efficient device for converting electrical energy into ultrasonic energy and vice versa at microwave frequencies was described by D. L. White of the Development-Components and Solid-State Devices Department at a recent session of the Institute of Radio Engineers International Convention in New York City. The new device is a piezoelectric transducer that uses the depletion layer of a semiconductor. It should be useful primarily in ultrasonic delay lines where its operation at high frequencies and wide bandwidths may make possible the storage of large amounts of information.

Another possible use will be as a tool for studying the acoustical properties of materials at ultrasonic frequencies. Laboratories engineers expect that large-amplitude ultrasonic waves can be generated in materials at microwave frequencies; also, that extremely weak waves can be detected with greater efficiency than with existing devices.

The new Bell Laboratories transducer consists of a plate of piezoelectric semiconductor (such as gallium arsenide) on which a thin metal film is deposited. The film acts as a non-ohmic rectifying contact which produces a depletion layer in the semiconductor. (A depletion layer is a thin region of high resistivity that forms at the interface of two dissimilar materials, such as a p-n junction in a semiconductor, or on a rectifying metal-to-semiconductor contact. The difference in certain energy levels in the two adjacent materials produces an internal electric field which sweeps or "depletes" the thin interface region free of mobile charge carriers, thereby increasing its resistance.) The thickness of the depletion layer can be controlled with a bias voltage across the interface.

When an ac voltage is applied, most of the voltage drop occurs across the depletion layer and it behaves like a very thin piezoelectric crystal which is bonded to a solid. Since the layer is thin (10^{-3} to 10^{-5} cm) the electric field is very large and considerable piezoelectric stress can be produced in the layer. In other words, the ac voltage produces a large mechanical vibration in the crystal.

The depletion-layer transducer has several advantages over an ordinary transducer. First, because the layer is so thin, the transducer is expected to be most efficient at very high frequencies. Present models operate at about 1000 mc but the frequency range is expected to be extended to above 10,000 mc. In this high-frequency range, the device might be as much as one hundred times more efficient than any other known transducer.

A second advantage is that the thickness of the layer, hence the resonant frequency of the transducer, can be varied by changing the dc bias voltage. This adds great flexibility to its use. (Conventional piezoelectric transducers do not have this feature.)

Third, present models measured at 600 mc have a bandwidth of 30 mc, ten times larger than typical ceramic transducers at frequencies below 10 mc. This means that a comparable increase might be expected in the amount of information which can be transmitted. It is expected that even wider bandwidths can be achieved when operation at higher frequencies is possible. Finally, the transducer is relatively simple to make and easy to handle.

Up to now, the use of ultrasonic delay lines at high frequencies has been limited because ultrasonic waves could not be generated or detected efficiently at microwave frequencies, and furthermore, these waves were considerably attenuated in the delay material. Now, however, the higher efficiency of the depletion-layer transducer makes up for these losses and may make possible delay lines having longer delay times. This, with the large bandwidth characteristic, will enable large amounts of information to be stored.

In experiments at the Laboratories, the new depletion-layer transducers operated well at frequencies as high as 1200 mc. Improvements in circuit and fabrication techniques will greatly extend the frequency range.

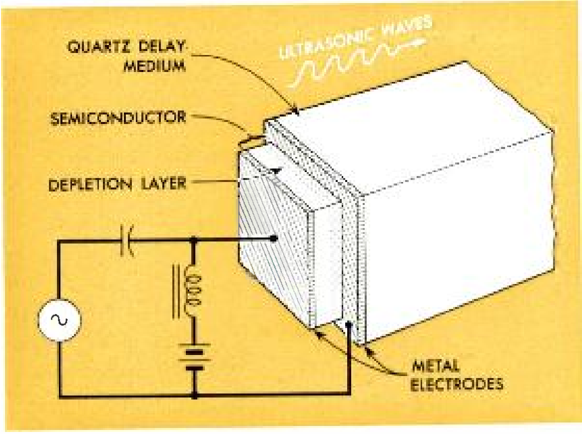


Diagram of new piezoelectric transducer. Device may find application in ultrasonic delay lines.

PAPERS

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

Anderson, E. W., see Douglass, D. C.

Apen, J. R., see Sikorski, M. E.

Bennett, W. R., Jr., see Javan, A.

Bott, M., see Garn, P. D.

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Wernick, J. H., see Kunzler, J. E.

TALKS

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

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, Winter General Meeting, New York City

Baker, W. E., and Froehlich, F. E., *A Buffer Store for Data Transmission.*

Baldwin, G. L., Crowley, T. H., and Rosenthal, C. W., *Design Automation—A Look at the Future.*

Bennett, W. R., and Froehlich, F. E., *Techniques for Comparing Modulation Methods for Data Transmission Over Telephone Channels.*

Burton, H. O., see Cowell, W. R.

Collins, C. A., see Williams, A. D.

Cowell, W. R., and Burton, H. O., *Computer Simulation of the Use of Group Codes with Retransmission on a Gilbert Burst Channel.*

Crowley, T. H., see Baldwin, G. L.

Feder, H. S., *Semiconductor Switches for Time Separation Telephone Switching.*

Froehlich, F. E., see Baker, W. E.

Froehlich, F. E., see Bennett, W. R.

Hays, J. B., *Grounding of Cord Connected Tools and Appliances.*

Herbst, R. T., Leagus, O. C., and Sellers, G. A., Jr., *Machine Processing of Manufacturing Information for Digital Systems.*

Leagus, O. C., see Herbst, R. T.

Malthaner, W. A., *Essex and Time-Division Communications.*

Morzenti, O. J., *Implications of Machine Aids to Design.*

Rosenthal, C. W., see Baldwin, G. L.

Sellers, G. A., Jr., see Herbst, R. T.

Washburn, S. H., *Programming Techniques for New Electronic Switching Systems.*

Williams, A. D., and Collins, C. A., *Noise and Intermodulation Problems in Multichannel Closed-Circuit Television Systems.*

OTHER TALKS

Abrahams, S. C., *Programmed Goniometer*, Stevens Institute of Technology, Hoboken, N. J.

Alger, E. A., *Ground Support and Test Equipment for the TITAN Radio Inertial Guidance System*, I.R.E. on Military Electronics, Los Angeles, Calif.

Batterman, B. W., *The Use of the Double Crystal Spectrometer in S-Ray Analysis*, Stevens Institute of Technology, Hoboken, N. J.

Benes, V. E., *An Application of Schauder's Theorem*, Dartmouth College, Hanover, N. H.

Benes, V. E., *A Fixed-Point Method for Studying the Stability of a Class of Integrodifferential Equations*, Am. Math. Soc., Wash., D.C.

Berger, U. S., *Communication Systems in the Bell System*, A.I.E.E., Manchester, N. H.

Black, H. S., *Global Communications via Artificial Earth Satellites*, A.I.E.E., Boston, Mass.

Black, H. S., *Latest Results on Project Echo*, Seventh Annual Meeting of Am. Astronautical Soc., Dallas, Tex.

Black, H. S., *World-Wide Communications via Artificial Earth Satellites*, Cornell Soc. of Engineers, N.Y.C.

Black, H. S., see Pierce, J. R.

Bond, W. L., see Garrett, C. G. B.

Buchsbaum, S. J., *Microwave Plasma Dynamics*, National Agency for Space Administration, Cleveland, Ohio.

Buchsbaum, S. J., *Ion Cyclotron Resonance in a Multicomponent Plasma*, National Agency for Space Administration, Cleveland, Ohio.

Buchsbaum, S. J., *Waves in Plasma*, Princeton University, Princeton, N. J.

Deutsch, M., *Studies of the Conditions Affecting Cooperation*, Pennsylvania State University, Philadelphia, Pa.

Dorris, H. N., *World-Wide Communication via Satellites*, Western Electric Co., Reynolda Road Building, Winston-Salem, N. C.

Eckler, A. R., *When to Stop Sampling*, Princeton University, Statistics Seminar, Princeton, N. J.

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

Feldman, D., *Solar Energy Conversion*, Cornell University Mechanical Engineering Department, Ithaca, N. Y.

Felch, E. P., *Electronic Guidance in Space*, Annual Meeting of N. J. Utilities Assoc., Atlantic City, N. J.

Foster, F. G., *The Microscope—Its History and Development*, Methodist Men's Club, South Orange, N. J.

Frisch, H. L., *Hard Sphere Fluids*, University of California, Berkeley, Calif.

Frisch, H. L., *Thermalization of a (Fast) Ion in a Plasma*, Radiation Laboratory, Livermore, Calif.; Institute of Math. Sci., New York University, N.Y.C.

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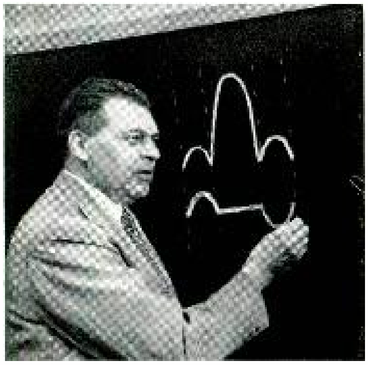

C. W. Norwood

tories in 1942 and until the end of World War II worked on the development of fire control radar equipment for the Navy. After the war he was active in the design of AM and FM radio broadcast transmitters until the Western Electric Company discontinued the manufacture of this apparatus in 1948. Since that time he has been associated with the Navy's Mark 65 program and in the development of symbol generating apparatus for use in the current series of weapon direction equipments for naval vessels.

George Parker is a member of the Data Systems Development Department of Bell Laboratories. Born in Vienna, Austria, he has always had two keen interests—engineering and far-distant places. Working on telephones seemed to be the ideal combination. He realized his ambition after volunteering for the British Army during World War II when he served as a Carrier Telephone Mechanic in the Royal Signal Corps.

After the war, Mr. Parker came to New York City where he received his B.E.E. degree from Brooklyn Polytechnic Institute, graduating Summa Cum Laude. Also a graduate of C.D.T., he is currently completing his Master's requirements at Columbia University. He is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi and Alpha Phi Omega.

G. Parker

N. J. Pierce, born in Stoneham, Mass. received his B.S. in E.E. and professional degree in E.E. from the University of New Hampshire. He joined the Research Department of the Laboratories in 1929 and participated in short-wave problems involving the Lawrenceville, Ocean Gate, Dixon, Cal., and Green Harbor transmitter installations. In 1938 he transferred to the television department and participated in various television projects. During World War II, he engaged in radar-transmitter design problems on the SCR523 and the Mark VII projects.

In 1944 Mr. Pierce transferred to Holmdel where he worked out the straight-through pulse circulating loop for testing microwave amplifiers in anticipation of the New York to Boston and cross country microwave links. From 1953 to date he has been involved in problems concerning the electroforming of microwave parts, the subject of his article in this issue.

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