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Bell Laboratories RECORD

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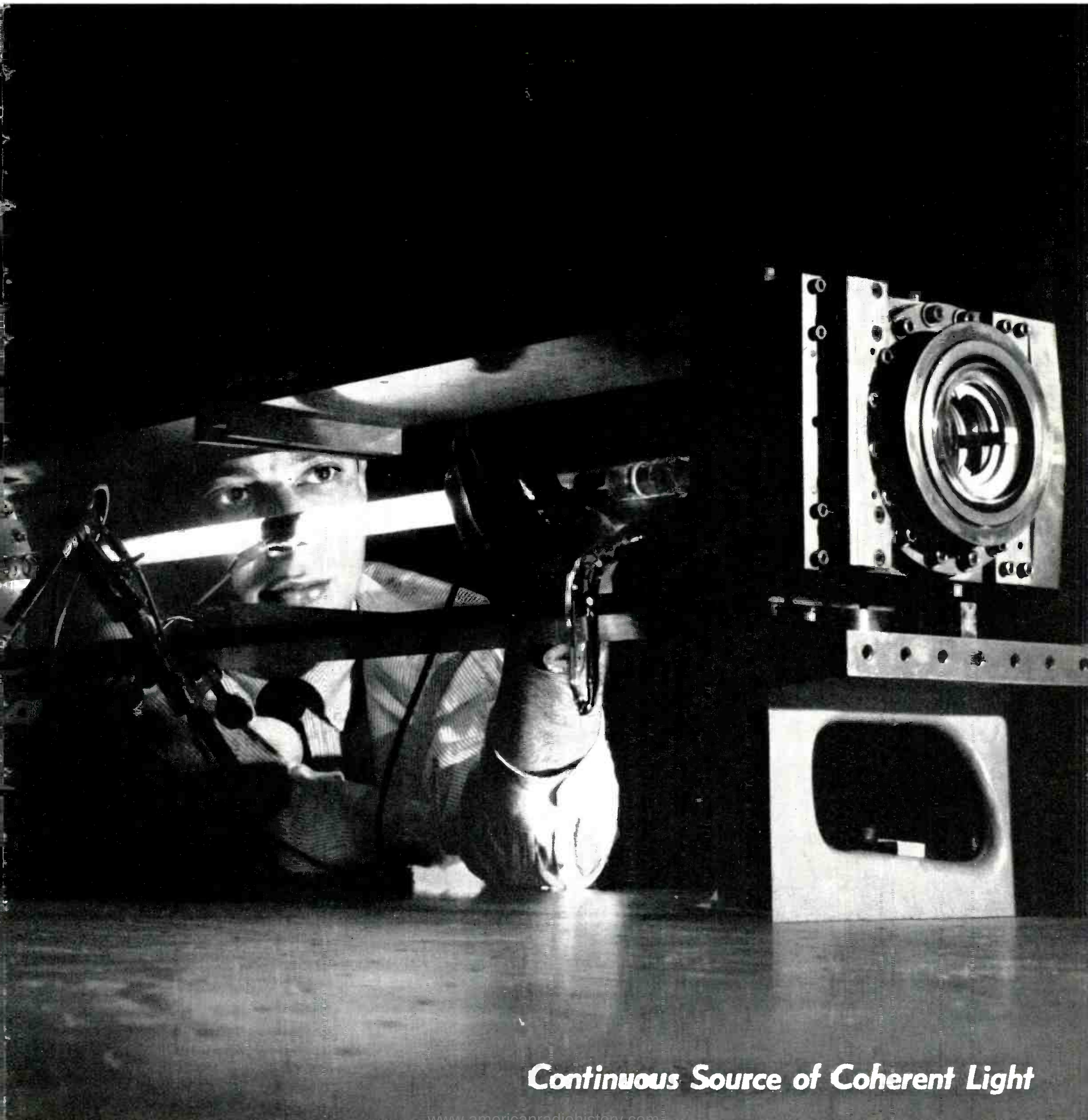

Continuous Source of Coherent Light

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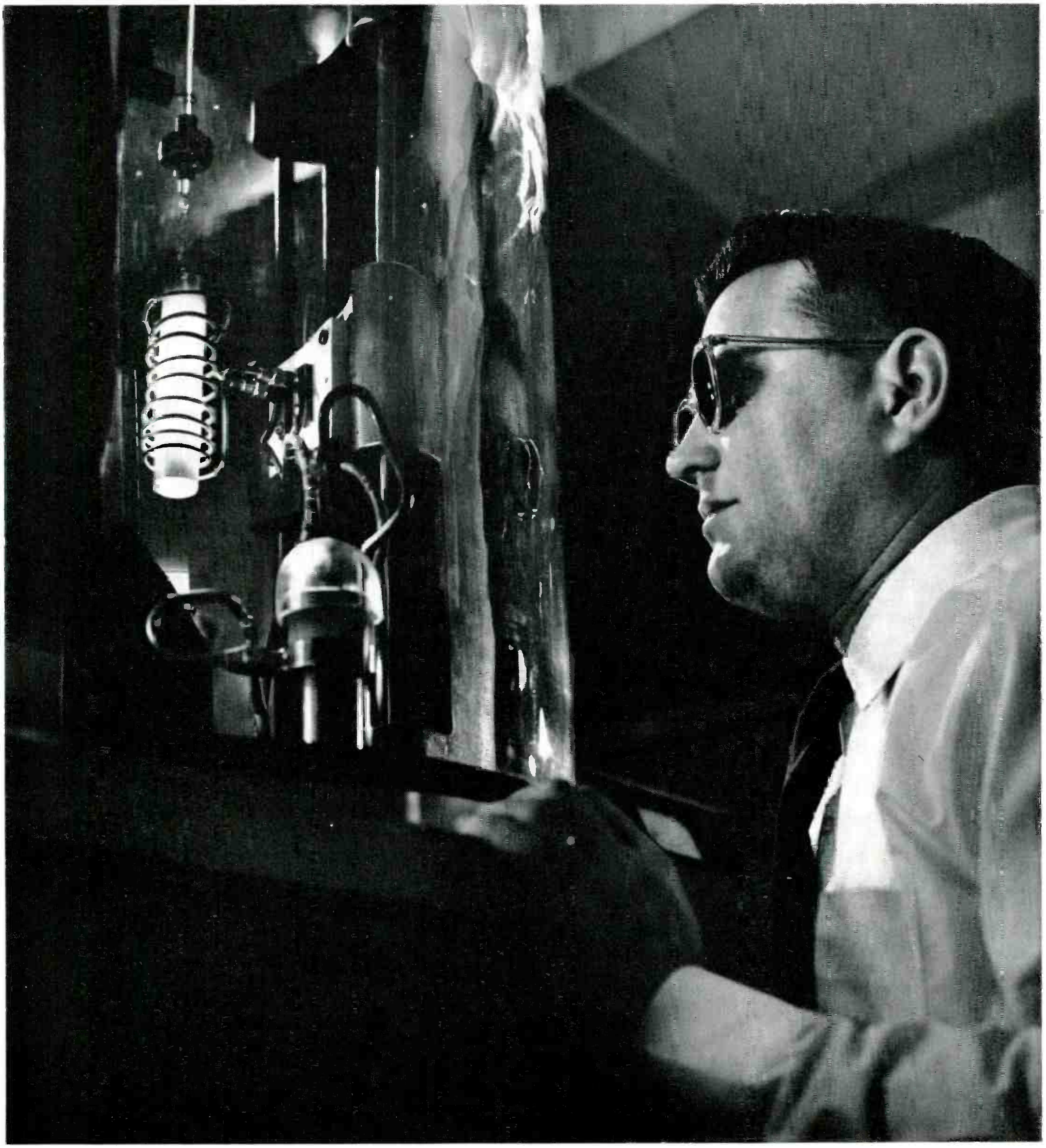
Cover

A. Javan adjusts gaseous optical maser, which glows brightly while emitting a continuous beam of coherent infrared light. New light source should prove valuable in many applications (See page 83).



Eugene Berry, of the Metallurgical Research Department, baking experimental sample of superconducting intermetallic compound, niobium-tin.

The practical use of optical masers and superconducting electromagnets has been held up for lack of suitable systems or materials. Important new developments at the Laboratories indicate that major problems in both area have been solved.

Research Breakthroughs in Optical Masers and Superconductors

Two events of major significance were announced by members of Bell Laboratories Research Department early last month. One was the achievement of a continuously operating optical maser; the other described the feasibility of constructing a superconducting electromagnet with ultra-high magnetic fields. Both developments were described in the February 1st issue of *Physical Review Letters*.

OPTICAL MASER

The continuously operating optical maser, a goal long sought by many industrial and academic research laboratories, was demonstrated to members of the general and technical press on January 31, by Messrs. A. Javan, and W. R. Bennett, Jr. of the Physical Research Department, and D. R. Herriott of Systems Research. In contrast to all the intermittent or "pulsed" optical masers announced heretofore, the new system takes a radically different approach, using a gaseous discharge to achieve continuous operation.

Also, instead of being excited by a high powered flash of light, the gaseous optical maser receives its energy from an electrical discharge of very low power. The coherent beam of radiation lies in the infrared portion of the spectrum, and is thus invisible except through a converter.

The spectral line width of the output beam is a hundred thousand times narrower than that from other coherent light sources, including that of the ruby optical maser (RECORD, *November*, 1960). This property has permitted the observation—for the first time—of difference-signals at radio frequencies between two optical lines. Also, the beam of coherent radiation is highly directional, having a spread less than one minute of arc. A gaseous optical maser on earth, operating with a suitable telescope, could send a beam to the moon that would be less than one mile in diameter.

Basic physical principles involved in the gaseous optical maser were described originally by Mr. Javan in the *Physical Review Letters* of July 1. 1959. These principles are considerably more sophisticated than those which apply to the solid state optical masers.

The ruby optical maser depends for operation on an external bright light to "pump" the chromium atoms in its crystal structure into an excited upper energy level. These excited atoms then emit their energy as coherent light. Work on optical maser action in ruby and various other crystalline materials is being conducted by a number of Laboratories scientists.

The gas maser uses a mixture of helium and neon gases through which an electrical discharge flows, in much the same way as in a conventional neon tube. The energy from the internal discharge excites the helium atoms to a very high upper "metastable" energy level, from which they normally would not radiate energy.

The neon atoms in the mixture collide with the excited helium atoms, and the energy is transferred to them through the collision process. The neon atoms themselves then can be stimulated to radiate their energy in a continuous stream. The beam of energy is reflected back and forth through the length of the gas-filled tube by semi-reflecting end plates, growing in intensity with each trip. Some of the energy is transmitted through the plates, and forms a very narrow output of coherent infrared light.

During this stimulated radiation, some of the neon atoms also drop into still lower energy levels, spontaneously emitting the reddish-yellow light typically associated with normal neon tubes.

Since the neon atoms can radiate energy from almost any one of four upper energy levels to one of ten intermediate levels, up to thirty discrete frequencies can be emitted by the maser, depending on the specific mode of operation. (The frequency of the output beam is proportional to the difference between specific upper and lower energy levels.) The range of possible wavelengths lies between 9000 and 17,000 A. Present laboratory models have operated at five different wavelengths between 11,000 A and 12,000 A.

The output-line width is far sharper than that of ruby masers. The light emitted by the ruby devices is about 60 times narrower than ruby's normal fluorescence. Normal fluorescence from the helium-neon mixture is already this narrow, and maser action narrows the beam more than one hundred thousand times more. Thus, the line is thousands of times sharper than the best spectroscopic lines available in the optical region.

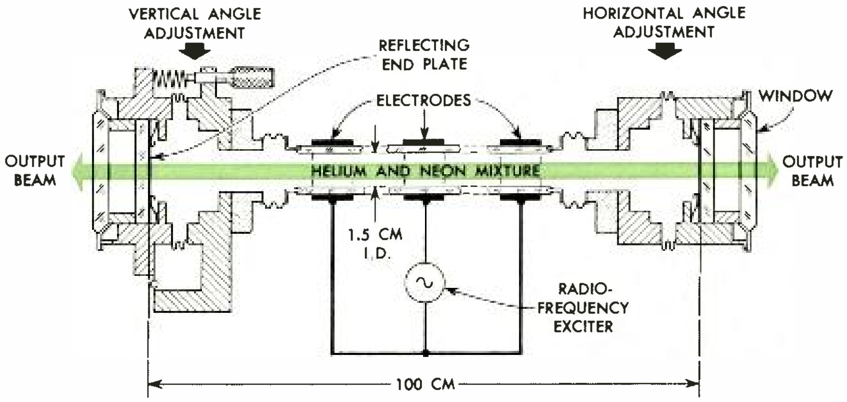
The power required to excite the maser action is in the tens-of-watts range, while the output power is in the 1/100th watt range. At this level of operation, the tube is so cool that it can be held in the hand without discomfort. The level of operation can be increased by using larger diameter tubes.

Other gas mixtures are being studied, and are expected to produce different output frequencies with comparable success to that of the helium-neon mixture. Optical gas masers and optical solid state masers are expected to complement each other in their applications. The latter maser, being essentially a high-power device, will have important uses even if limited to pulsed operation.

Communication Applications

Communication engineers have been actively seeking a continuously-operating generator of coherent optical frequencies. The wide bandwidths associated with carrier frequencies in this portion of the spectrum could provide a pathway for vast amounts of information.

Laboratories scientists have been experimenting with several methods of modulating a signal on such an optical carrier. As an initial experiment, they impressed a telephone conversation on a maser signal on December 14, 1960, by using an electro-optical device—the Kerr Cell. Broadband modulation has been accomplished at frequencies



Schematic drawing of gas optical maser. Device uses reflecting end plates, in similar fashion as ruby maser, but the active medium between the plates is a mixture of helium and neon gases.

Infrared beam is voice modulated by Kerr Cell (left foreground). A. Javan prepares to talk over beam, while W. R. Bennett, Jr., adjusts optics.

up to 60 kc. Other modulation schemes under investigation may lead to systems operating as high as several thousand mc.

The path of the optical carrier will be a straight line, except where it is reflected. Thus one application of the optical maser would be to transmit information to and between orbiting satellites. On earth, the beam could be contained in an enclosure such as a long pipe. This pipe could wind around the countryside carrying signals with very little loss, if turns were made at angles containing reflecting mirrors.

Another possible application of the device is the measurement of long distances with extreme accuracy. The gaseous optical maser should also provide physicists with an immensely useful tool, since the narrowness of the line will afford an accuracy hitherto unattainable in spectroscopic work at these frequencies. Investigation into optical maser action, moreover, is stimulating renewed interest in the whole field of gaseous-discharge physics.

SUPERCONDUCTING SOLENOID

While the second development can not yet be demonstrated with an actual device, its potentialities are equally important. The need for high magnetic fields is increasing, both in basic scientific work and in various technological applications. These magnetic fields are difficult to achieve with present magnets, and the few available high-field magnets require huge expenditures of electrical energy and cooling water.

Now, however, research scientists at Bell Laboratories have demonstrated the feasibility of producing extremely high magnetic fields with superconducting solenoids. The superconducting compound used is composed of niobium and tin (Nb_3Sn), which is fabricated and reacted by special metallurgical techniques.

Although it has been recognized for years that superconducting solenoids might be practical, the materials that have been tried in the past would not sustain fields of more than a few thousand gauss. At larger magnetic fields the superconducting properties of the material disappeared. Samples of niobium-tin have sustained fields of about 100,000 gauss, while carrying electrical current densities as high as 100,000 amps per square centimeter of cross-section.

This breakthrough in the field of cryogenics resulted from a combination of new metallurgical arts and experimental and theoretical knowledge of the physics of solids. J. E. Kunzler, E. Buehler, F. S. L. Hsu, and J. H. Wernick, of the Metallurgical Research Department, discussed the work in the February 1 issue of *Physical Review Letters.*

This new material development will have important applications wherever large volumes of magnetic fields are required, including several uses in communications. Many electronic devices require magnetic fields for their operation. Among these are traveling wave tubes and masers. The availability of large magnetic fields can extend the operation of these devices to higher frequencies, providing the possibility of broadband communications systems for use in earth based radio-relay systems and active satellite repeaters for space communications.

Another attractive application is the possible containment of thermonuclear fusion plasmas for the production of electric power. Most experiments attempting to control fusion have used extremely high magnetic fields to contain high-speed atomic particles in a magnetic "bottle". Some scientists have estimated that the input power needed to create a successful magnetic "bottle" with conventional electromagnets would exceed the expected power output of the fusion unless the machines were enormous.

The new material will permit the construction of a solenoid which has a volume large enough for fusion experiments and which can produce the high fields necessary.

Scientists caution that obtaining the large magnetic fields desired does not necessarily assure success in a controlled fusion experiment. It would, however, remove one large present-day obstacle.

A third important area of application lies in the research laboratory, where the present cost of producing high magnetic fields has greatly limited the experimenal physicist. This new discovery will make high fields available to a wider community of scientists throughout the world.

There is a striking contrast between the proposed superconducting electromagnet and a more conventional large magnet using copper as the conductor, installed at Murray Hill. While operating at its maximum field of 88,000 gauss, this magnet consumes 1.5 megawatts of electric power, 25 percent of the total power consumed at the Murray Hill Location. A superconducting solenoid magnet of Nb_3Sn producing a comparable field would not consume any electric energy once the flux is established.

The conventional solenoid also requires thousands of gallons of cooling water per hour, while the superconductor would not generate any heat during use. It would, of course, have to be cooled to superconducting condition with liquid helium. Estimated helium consumption for a magnet of this size would be in the order of one liter per day.

High Transition Temperature

Nb_3Sn becomes superconducting at 18 degrees K, a higher transition temperature than any other superconductor presently known. The compound was first discovered at Bell Laboratories in 1954 by B. T. Matthias, T. H. Geballe, S. Geller, and E. Corenzwit, while pursuing an empirical rule formulated by Mr. Matthias for predicting potential superconductors. Its critical field, or the magnetic field strength necessary to "quench" the superconductivity, had not been measured until recently, however.

It was not until late last year that measurements of its magnetic susceptibility were made by R. M. Bozorth, D. D. Davis, and A. J. Williams of the Physical Research Department. These measurements indicated that traces of superconductivity persisted in the compound even when exposed to magnetic fields up to 70,000 gauss.

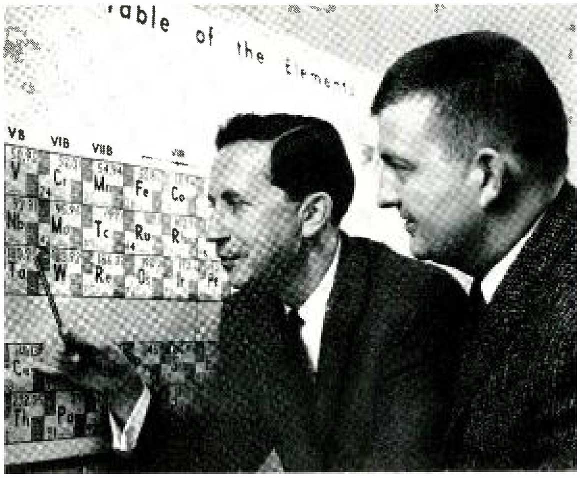
Although many uses for this unusual material seemed evident, its brittleness delayed practical application. There was no obvious way to produce a wire form of the material which could be used to build a superconducting solenoid. The latest work has shown that the critical field is much higher than originally anticipated, and has also resulted in the development of metallurgical processes which solve the fabrication problem.

Messrs. Kunzler, Buehler, Hsu, and Wernick first studied the properties of bars cut from an ingot of brittle niobium-tin which was formed by melting proper proportions of the metals niobium and tin together at about 2400 degrees. They found that the bars were superconductors in the magnetic fields up to 88,000 gauss. Furthermore, in these high fields the bars could carry electrical currents of up to 3,000 amperes per square centimeter at a temperature of 4.2 degrees K without heating or using up energy in any way.

With the help of C. V. Wahl of Metallurgical Processing, they then applied themselves to circumventing the brittleness of the compound, in order to use these unusual properties. They started with a niobium tube 1/4 inch in outside diameter and about 1/8 inch inside diameter. This tube was packed with a mixture of powdered niobium and powdered tin, both ductile metals, in the ratio of approximately 3 to 1. The ends of this tube were then sealed with niobium plugs and the tube was mechanically reduced to a diameter of 0.015 inches. This wire-fine tube was still very ductile, and had a powder core about 0.006 inches in diameter. It was then heated to about 1000 degrees C, at which point the powders react to form Nb_3Sn.

In the wire form, the Nb_3Sn is superconducting in fields of 88,000 gauss while carrying currents of over 150,000 amperes per square centimeter. These current densities are fifty times larger than the current densities the ingot material can carry. Since the mechanical forces produced by magnetic fields of this strength present numerous engineering problems, it will probably be about a year before a large solenoid is actually constructed from this unique material.

Present theories on the phenomenon of superconductivity do not provide a full explanation of these recent findings. The results are even now stimulating further growth of knowledge in this area of solid state physics.



B.T. Matthias discusses relative positions of niobium and tin on periodic table with J. E. Kunzler.

The time scale of transient effects in semiconductors reflects the presence of crystal defects. By measuring this "lifetime," scientists determine the properties of such impurities and imperfections introduced to give the semiconductor desired characteristics.

G. K. Wertheim

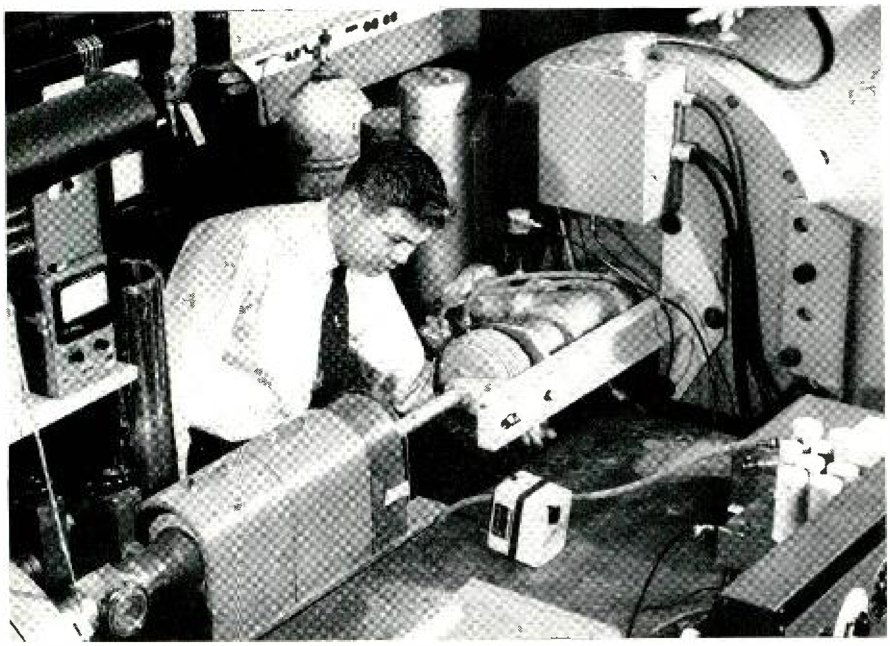
Measuring Semiconductor Lifetime

When semiconductor materials were first used in devices, such as photocells and detectors for radio and radar waves, manufacturers devoted a relatively small effort to careful construction of the crystals. However, when the transistor appeared on the electronic horizon, a new order of perfection, both chemical and crystallographic, became necessary.

Today, success in making a solid-state device lies both in the mechanical perfection of the crystal, and in the careful control of the concentration of its chemical impurities. The goal here is not only elimination of impurities, but the selective re-introduction of those few impurities that impart the crystal properties needed in the device. Some impurity elements introduce either holes (positive charges) or electrons (negative charges). These "carriers" make the semiconductor p-type or n-type, respectively, serving to modify the electrical conductivity of the crystal.

Other elements in a crystal have a dominant effect on the phenomenon of "lifetime"—a measure of the time required for an externally produced disturbance in the conductivity to disappear. Manufacturers can to a considerable degree remove the impurities controlling the lifetime or can deliberately introduce these elements to produce a device with desired characteristics.

The lifetime is a nonequilibrium property, and as such is of particular interest to the designer of a solid-state device. Operation of most semiconductor devices involves deviations from equilibrium conditions. For example, diodes and transistors are composed of n-type and p-type regions adjoining each other in a single crystal. In these devices, nonequilibrium concentrations of carriers are produced by the injection of one type of carrier across a junction into the region where carriers of the opposite type predominate. When these are used as switching devices, a short lifetime of the injected carriers is necessary for fast response. However, in photosensitive devices, such as the Bell Solar Battery (RECORD, *July*, 1955), or a photodiode, the nonequilibrium car-



W. L. Brown makes adjustments to Van de Graaff generator. An important use for this machine is the production of non-equilibrium carriers in a semiconductor, permitting study of carrier lifetime.

riers are produced by the absorption of light in the semiconductor. This application requires a long lifetime, enabling the nonequilibrium carriers to diffuse slowly to the junction, contributing to the output of the device.

Before we talk about the measurement of lifetime of the carriers, we must first understand the mechanism involved. The relaxation process that destroys nonequilibrium concentrations is called "recombination", because it involves the mutual annihilation of excess holes and electrons. In the inverse process, holes and electrons are simultaneously created. However, recombination usually involves more than a simple encounter between a hole and an electron, resulting in the disappearance of both. The most common way in which this takes place is through an impurity atom. A carrier, for example an electron, is first captured by this "defect" in the lattice, and later the same defect captures a hole. Two separate capture processes are involved here. In effect, the lattice defect catalyzes the recombination, since the final result consists of removal of one hole and one electron, leaving the impurity in its original state.

This recombination process was studied theoretically a number of years ago by R. N. Hall of the General Electric Research Laboratory, and by W. S. Shockley, formerly at Bell Laboratories, and W. T. Read, Jr., of the Laboratories Mathematical Research Department. These scientists considered the process statistically, without requiring a detailed knowledge of the nature of the defect. Other scientists have confirmed the results of this analysis experimentally. Today, experimental work is centered on the problem of relating probabilities of electron and hole capture to specific lattice defects or impurities in their structure. So far, however, very little is definitely known about this relationship.

Lattice imperfections are normally present in sufficient quantity to have a dominant effect on recombination, even in the purest semiconductor crystals. Among these "recombination centers" are certain chemical impurities, such as copper and nickel in germanium, and gold in silicon. Other centers, discussed later in this article, involve some structural imperfections, such as dislocations, and the more complicated configurations produced by bombardment with high-energy particles.

There are several experimental methods by which lifetime is measured. One of the simplest, and most generally used, was developed at Bell Laboratories by J. R. Haynes, of the Semiconductor Research Department, and J. A. Hornbeck, now Director of Electron Tube and Transistor Development. In this method, nonequilibrium carriers are produced by a flash of light. The process of excitation here is a photoelectric effect in which an incident photon gives up its energy to an electron forming part of the structure of the material. This frees the electron to travel through the crystal, and its original position in the lattice constitutes a free hole. In other words, the photoelectric effect inside the semiconductor produces an electron-hole pair. The recombination of these excess carriers is observed through their effect on the conductivity of the material.

Other methods use the diffusion of carriers along a "concentration gradient." The simplest of these, a direct measurement of the diffusion length, is frequently used in germanium. In this method, a well-defined line of light focused on the specimen generates the carriers in a small region. The carriers produced in the illuminated region diffuse into the dark region; the average distance they travel before they recombine is a measure of their lifetime.

Diffusion is used differently in the "photomagnetoelectric" effect. Here, carriers generated on the front surface of a specimen by strongly absorbed light diffuse into the body in a direction perpendicular to the surface. A magnetic field, perpendicular in turn to the direction of diffusion, deflects the carriers and causes a current at right angles to both the magnetic field and the direction of diffusion. The magnitude of this current, together with the rate of generation of carriers on the front surface, determines the lifetime of the carrier.

Junction Devices

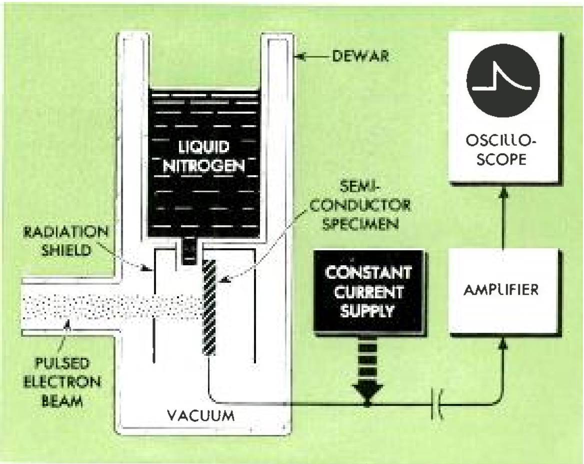
These methods are useful only in uniform semiconductor specimens. However, there are others that use the presence of a junction. For example, a p-n junction between a p-type region of low resistivity and an n-type region with moderate resistivity will inject holes into the n-type region when the p-type region is made positive. If the junction is then suddenly short-circuited, some of the injected holes will diffuse back to the junction and flow back into the p-type region. The magnitude of the resulting current is a measure of the number of minority carriers in the n-type region near the junction. Thus, both the magnitude and the time decay of the current can serve as a lifetime of the carrier.

The various methods for measuring lifetime have distinct advantages for particular applications. The pulsed-light and simple diffusion-length measurements are the easiest to apply and are used most generally in quality control and research. The photomagnetoelectric effect has been restricted almost entirely to research, while the junction method is most applicable to fast-acting switching devices.

Let us take a more detailed look at the Haynes-Hornbeck method and some of the variations that have been developed. In practice, we can obtain a short powerful flash of light with a duration of a few tenths of a microsecond by discharging a bank of condensers through a spark gap in air or in a gas-filled tube. However, this particular method of excitation has certain limitations. For example, the length of a pulse produced with a flash tube cannot be made much shorter than one microsecond without sacrificing the intensity of the light. Furthermore, the spectral distribution of the light produced is such that most of the excitation takes place on the front surface of the crystal. This can be remedied, again at the expense of light intensity, by using a filter made of the same material as the semiconductor to remove those wavelengths that are strongly absorbed. A final limitation is the one arising from the natural decay time of the excited gas atoms in the discharge.

An alternate method of excitation has been used during the past few years to overcome some of these difficulties. In this method, a beam of pulsed electrons, with an energy of about one million electron-volts (Mev), is substituted for the light source: This technique, of course, requires a high-energy accelerator like the Van de Graaff machine shown on page 88. Laboratories scientists have modified this particular accelerator to produce well-defined pulses 0.02 microsecond long. They are produced by "gating" the electron source with a transmission-line pulse generator using a coaxial mercury relay. The electrons in the pulse penetrate the specimen and produce ionization, resulting in a large number of electron-hole pairs along the paths of the incident high-energy electrons.

On the average, every three electron volts of energy lost by an incident electron produce one



Arrangement for observing recombination. Small bar of semiconductor is part of circuit. Transient changes in voltage of this bar, representing recombination, can be observed on the oscilloscope.

electron-hole pair. In silicon, for example, a one Mev electron produces 100,000 electron-hole pairs per millimeter of path. Among the advantages of this method are: the range of measurement can be extended down to 0.01 microsecond, a region of interest in many semiconductors; stronger and more uniform excitation can be obtained than is practical with light; and finally, the magnitude of the excitation can be readily kept independent of the temperature of the sample.

One practical way to observe the electron-hole pairs that have been created inside a semiconductor crystal is to measure the conductivity of the specimen. This reflects the contribution of both the holes and the electrons, but we must allow for the fact that one species may be more effective than the other. For example, an added electron may produce a greater change in conductivity than an added hole. For this reason, the effectiveness of a carrier is measured in terms of a quantity called the "mobility"—the velocity gained by the carrier in an accelerating field of unit strength. Since excitation produces equal numbers of both carriers we find that the change in conductivity is simply proportional to the product of the number of injected carrier pairs and the sum of their mobilities. As a result, we can observe the recombination of the electron-hole pairs by monitoring the voltage across a specimen.

Such observations are easily made with the equipment shown in diagrammatic form on page 89. The semiconductor sample, in the form of a small bar of rectangular cross section, is part of an electrical circuit supplying a constant current. Small transient changes in the voltages across the sample are capacitor-coupled into an amplifier and an oscilloscope, permitting observation of voltages as small as a fraction of a millivolt.

Sample of germanium that has been bent to predetermined radius. This "plastic" deformation produces a controlled density of the dislocations.

A sample excited with a pulse of electrons from the Van de Graaff machine produces a trace similar to that on page 91. In this graph, the vertical deflection is proportional to the number of excess carriers introduced; the horizontal deflection is given by a linear sweep triggered by the initial rise of the pulse. Under most circumstances this decay is quite accurately exponential, and represents the lifetime.

Applications

The usefulness of this method of excitation is indicated by the range of problems investigated within the last few years. It has been applied to studies of the intermetallic compounds indium antimonide and gallium arsenide, chemical impurities in germanium and silicon, dislocations, and radiation damage. Most recently, pulsed electron excitation has been used to study the decay of the light output of luminescent materials such as cadmium sulphide and ruby.

A more specific example of this method is the study of the chemical impurities of copper and nickel in germanium. Impetus for this work has come from recent developments in the theory of the recombination process which take into account the fact that many of the chemical impurities permit recombination to take place in more than one way. This happens because these atoms can capture more than one hole or electron when substituted into the semiconductor lattice; that is, they exist in a number of different states of charge.

Generalized theory here has called for not only reinterpretation of some of the earlier results, but also for new experiments, which have already yielded interesting information on systems such as nickel or copper in germanium. In both cases, at room temperature recombination proceeds through one particular "state" of the atom.

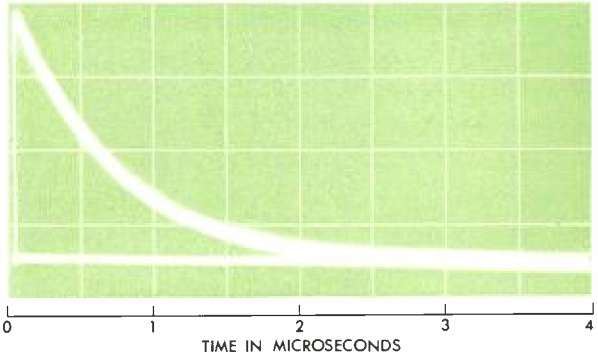
In the case of copper, for example, scientists carefully studied recombination at room temperature, through the "second state" of charge. It is now clear that the first level of excitation—the one close to the valence band—strongly contributes to recombination at low temperature, and even at room temperature in material of sufficiently low resistivity. Its "recombination cross section" is greater than that of the second level, but it is in a less favorable position to manifest itself at room temperature. The third level of the copper atom acts as a hole "trap" at low temperature and does not contribute strongly to recombination.

In nickel, the joint action of two levels of excitation results in a material whose lifetime decreases with increasing temperature. This unusual behavior is obtained quite directly from the two-level model; to explain it in terms of the single-level model requires artificial assumptions. The results therefore lend support to a new generalized theory of multilevel recombination.

Another type of crystalline imperfection, the dislocation, has also come under scrutiny. Dislocations exist to some extent in all crystals grown in nature or by man. (Only within the last few years has it been possible to grow small crystals without this defect.) They can also be deliberately produced by plastically deforming a crystal at a temperature somewhat below its melting point, to produce a permanent set. Controlled densities of dislocations in a crystal can be introduced by bending it to a predetermined radius (*see illustration on page 90*).

Scientists have studied the relationship between the density of dislocations and lifetime over a wide range. Lifetime in otherwise pure germanium is inversely proportional to the dislocation density from values of a few thousand per square centimeter (found in crystals as grown), up to values of thirty million per square centimeter (introduced by plastic deformation). Apparently, dislocations can catalyze the recombinations of electrons and holes just as do chemical impurities. The experiments also indicate that dislocations produced in the growth of crystals, rather than residual chemical impurities, may be the factors determining the lifetime normally found in germanium of highest purity.

As a final example, it is interesting to note that high-energy electrons, such as those used for the measurement of lifetime, can themselves produce permanent changes in the semiconductor. Such changes also have an effect on recombination. These are brought about by collisions of the electrons with the nuclei that make up the crystal. In such a collision, enough energy may be transferred to enable the atom to escape from its normal lattice site and to travel some distance through the crystal. The result of such an encounter is a vacancy where the atom was removed and an interstitial, or displaced atom, somewhere in the vicinity. These defects then undergo rearrangements by diffusion and eventually produce stable configurations, often involving impurities or other imperfections. The resulting complex defects, called radiation damage, have properties in many respects similar to those of chemical impurities. They may act as donors or acceptors, and can catalyze recombination.



Pulse of electrons through sample produces typical trace. Vertical deflection is proportional to number of excess carriers produced by the pulse.

Relatively small doses of electrons reduce the lifetime to values less than one microsecond. Despite this, however, we can use the pulsed electron beam to measure lifetime in silicon without producing a significant change in lifetime. The clue here lies in the small average current used in the pulsed experiments. Since the beam is turned on for only one millionth of the time, pulsed bombardment for 10 days is equivalent to a steady bombardment of only one second. In germanium the change of lifetime with bombardment is very much smaller than in silicon, permitting us to measure lifetime without producing measurable changes even in material of long lifetime. Some caution, however, must be exercised in silicon.

Studies of lifetime are of interest from two other points of view. First, the results may have direct application to device development, since scientists have both proposed and attempted the modification of the parameters of silicon-diode and p-n-p-n crosspoint-switches by electron bombardment. Here, the so-called radiation damage is actually beneficial to a device. Second, the experiment is of fundamental significance, since its results shed light on the nature of relatively simple lattice imperfections involving single vacancies and interstitials. In fact, the defects resulting from electron bombardment are likely to be the simplest that can be produced.

The study of the recombination properties of chemical impurities and crystal imperfections in semiconductors has led to a better understanding of their interaction with electrons and holes. This, in turn, represents a small step forward in the continuing effort toward a better understanding of the nature of crystalline defects.

Because undersea telephone cable is relatively inaccessible, Bell Laboratories must rely on a program in which it can evaluate the effects of undersea environments from samples of cables brought ashore from repair operations.

Peggy M. Hazard

How Environment Affects Ocean Cables

Almost a century has passed since the British steamship *Great Eastern* succeeded in laying the first commercially successful transatlantic telegraph cable to realize the dreams of Samuel Morse and Cyrus Field. Since that notable event in 1866, the oceans of the world have become laced with slender lines of telegraphic communication. The completion of the transatlantic telephone cables in 1956 and in 1959 created the two most recent milestones in the advance of communications by ocean cable.

From the earliest recorded experiments in 1838 to the present, ocean cables have progressed physically from a single conducting wire, insulated with tarred rope and yarn, to a repeatered system employing a coaxial cable insulated with polyethylene and armored with steel wires. This remarkable development has taken place despite the fact that little has been known of the environment in which ocean cables lie. Gathering such knowledge is an immense project since ocean waters cover 71 per cent of the earth's surface and their mean depth is 2075 fathoms. Oceanographic institutions and marine biological stations were established after 1900 to explore the seas, but it is only lately that these have collected more than fragmentary information.

The unknown aspects of the oceans became extremely important to the Bell System when plans were launched to lay, by the end of 1956, the first transatlantic telephone cable (TAT-1). To help determine the performance of materials in this and future telephone cables after long ocean-bottom service, Bell Laboratories arranged to obtain for examination sections of telegraph cable removed from service by the Western Union cable ship *Lord Kelvin.* This collection program, initiated in 1954, was expanded in 1959 to cover a wider range of environmental conditions and to provide a more complete history of each sample of undersea cable.

The broader collection program was arranged by the Transmission Systems Development Department with four companies operating cable ships in different areas around the world. In this arrangement, a section of every cable recovered by the ships during routine operations is forwarded to the Laboratories for examination. Cooperating in the program is a total of seventeen cable ships owned by the Western Union Telegraph Company, the American Cable and Radio Corporation, Cable and Wireless, Ltd., and the British Post Office. These ships operate out of ports in Nova Scotia, Florida, the Canal Zone, the British West Indies, Brazil, eastern Africa, Spain, the British Isles and the Malay Peninsula.

Each ship carries a number of Cable Sample Kits *(see page 94)* prepared by the Laboratories. Each kit consists of a mailing tube large enough to hold a 28-inch-long cable sample, a glass jar to be filled with ocean-bottom sediment and a Cable Sample Record booklet in which the ships officers record all pertinent data regarding the cable's history and description. The mailing tube, which is prelabeled for prompt shipment to the Laboratories by air freight, is designed to hold the cable sample, sediment jar and booklet.

Prior to the initiation of the world-wide collection program in 1959, approximately 80 cable samples had been received. Most of these were of telegraph cable from the North Atlantic. The larger collection program has increased the rate of sample accumulation and has given much broader geographical coverage. A total of 178 cable samples from both hemispheres has been received to date.

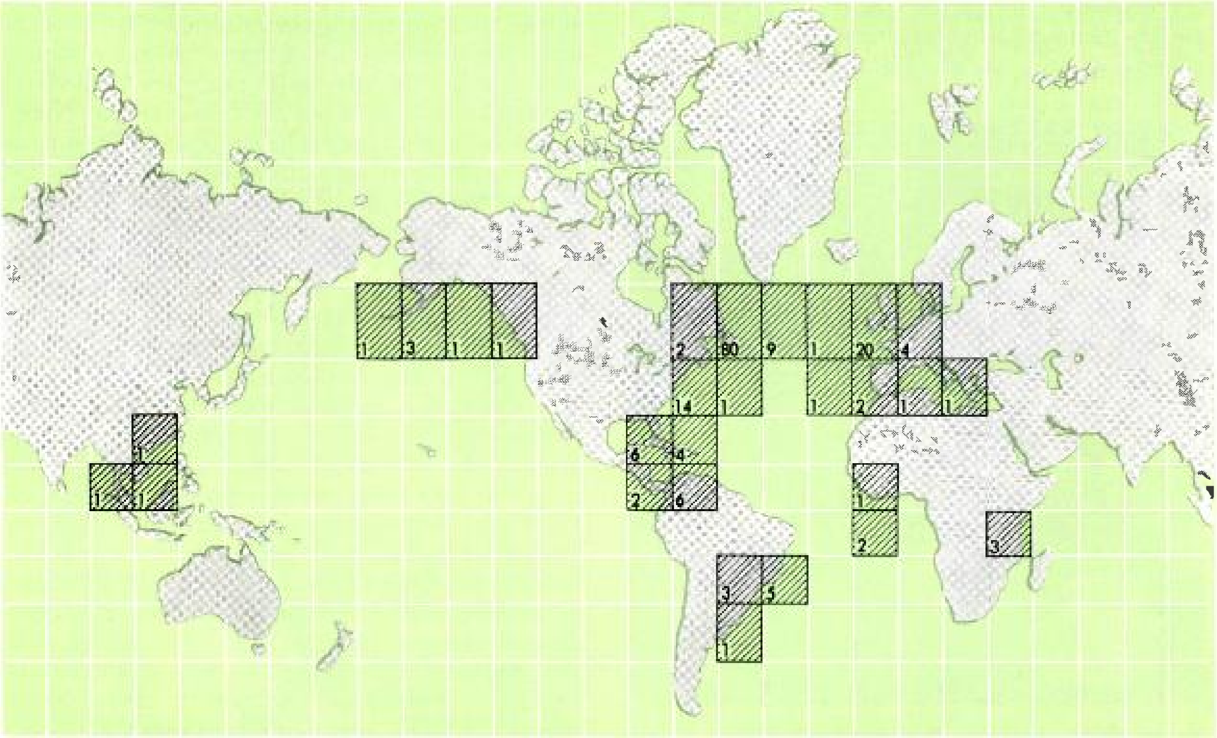
Examination of a cable sample entails its careful dissection and a thorough inspection of each component. The Laboratories determines the quality of each part by macroscopic examination and, where applicable, by microscopic, electrical, mechanical and chemical methods.

The forms of impairment observed in the ocean cables may be grouped into four categories—mechanical damage, corrosion, jute deterioration and insulation breakdown. The following discussions of these categories include methods of detecting the deterioration, descriptions of cables removed from service and the general nature of the deterioration as based on the samples examined so far. Most of the samples examined are telegraph cables, which have a structure similar to but less complex than that of a telephone cable.

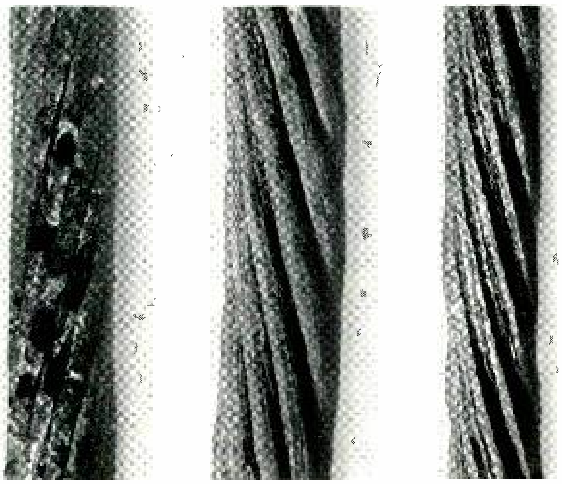
The first category of impairment—mechanical damage—is frequently caused by the heavy otter boards of fishing trawlers which may drag over or entangle a cable. This type of damage is generally evidenced by abraded or stripped outer jute, twisted, grooved or flattened armor wires, an exposed core and a tension break or shear cut. Although trawlers are the most common cause of mechanical damage, earthquakes, underwater landslides and icebergs have been responsible for several of the cable faults examined.

Corrosion, the second type of impairment, continues to be a major concern in ocean cable systems of conventional design. This is because all of the metal components, except the insulated central conductor, are exposed to sea water.

Corrosion of the galvanized steel armor wires is closely related to the condition of the outer jute, which shields the wires from the sea water environment and protects them from abrasion and the resultant removal of zinc. Additional protection of the armor wires comes from a "flooding" compound of asphalt, tar, or pitch. When the



Areas of world from which Laboratories has received cable samples. Number in each quadrangle represents number of samples collected and sent to the Laboratories by total of 17 cable ships.



Left, random cavity corrosion in sample having lain in North Atlantic at 40 fathoms for 90 years. Center, longitudinal striations in 91-year old cable from Mediterranean. Right, groove corrosion in cable in Caribbean at 250 fathoms for 35 years.

other five were from waters surrounding the British Isles, also subject to heavy fishing.

The 12 corroded samples were telegraph cables with varying backgrounds. The depths from which the samples were retrieved ranged from 19 to 2170 fathoms and their service ages were from 22 to 80 years. Five of the samples were from the North Atlantic near Newfoundland and Nova Scotia, two were from off Ireland, one from off the western coast of Spain, three from off Brazil and one from the Pacific Ocean off Panama. The character of the ocean bottom also varied for the samples. Some of the samples had lain on solid rock or on stones, others on mud. Many of them had lain on variable bottoms containing different proportions of mud, rock, coral, sand and clay.

Two of the four failures attributed to perished gutta-percha occurred in spliced sections. One was a thirty-year old telegraph cable splice buried in sand near Miami Beach, Florida. Nearby hotels were accustomed to draining their swimming pools over this area, and the chemicals they used in cleaning the pools or purifying the water might have been responsible for the deterioration. The affected insulation was cracked and very brittle. The other gutta-percha failure occurring in a splice was in a 62-year old cable near Jamaica. The insulation was cracked, eroded, and tended to flake off, and the overlying jute had also deteriorated. The insulation and jute on either side of the fault, however, were unaffected.

Two other gutta-percha failures were localized but were not at splices. They occurred in nine- and thirty-year old cables off the coast of Venezuela. The impaired insulation in the nine-year old cable was lighter in color than the surrounding gutta-percha, and the jute lying over it was bleached. The thirty-year old cable had small areas of cracked and eroded gutta-percha.

Closely allied with the Bell Laboratories cable-examination program is a study of ocean-bottom sediment. Results so far indicate a wide variation in cable conditions which is most likely associated with local environment. To explore this possible relationship, the Laboratories analyzes the sediment retrieved with each cable sample by special chemical techniques which help to define the environment and determine how it relates to cable conditions.

Examining cables removed from service is just one phase of a larger biological test program (RECORD, *August*, 1957) set up to gain information on the effects of marine environments on a variety of organic materials and cable components. The over-all program deals with the exposure of test materials and cables to artificial and natural marine conditions as well as the examination of cables from service. As a result, the Laboratories is obtaining correlative data useful in evaluating the suitability of new materials in submarine cables, as well as the performance of conventional cable components.

The vastness of the oceans and the wide variety of marine environments make a complete study of these conditions and their effects on cable materials a very broad subject. Thus a practical study must be limited to small samples from selected areas of the total service sites. The current program is a concentrated study of the areas of greatest interest, as it provides cable sections that have actually failed as a result of their immediate environment. This selective approach to the study of cable waters and their effects is reflecting a wide variety of cable failures and environmental conditions.

As this program progresses, the relationships between marine conditions and their effects on cables should become more apparent. Eventually, we will be able to answer more fully questions on the nature and causes of various cable deterioration processes, the existence and threat of organisms at different temperatures and depths, and the life expectancy of cables in various waters. Most important, we will be able to take protective measures to prolong the life of future ocean cables.

Attenuate a signal representing a telephone directory number to a minute level, and then try to identify it. This is one of the jobs of the Bell System's newest contribution to automatic telephone service the Automatic Number Identification System

C. H. Dagnall, Jr.

Automatic Number Identification: Outpulsers and Identifiers

The Bell System is continuously devising ways to bring all of its switching systems into the scheme of the entirely automatic completion of calls. One of the latest of these ways is the Automatic Number Identification System (RECORD, *June*, 1960). ANI was developed to identify the directory number of a calling customer and transmit this number to a tandem or toll point having Centralized Automatic Message Accounting (CAMA) equipment. A common-control type of system, it uses relays and electronic circuitry.

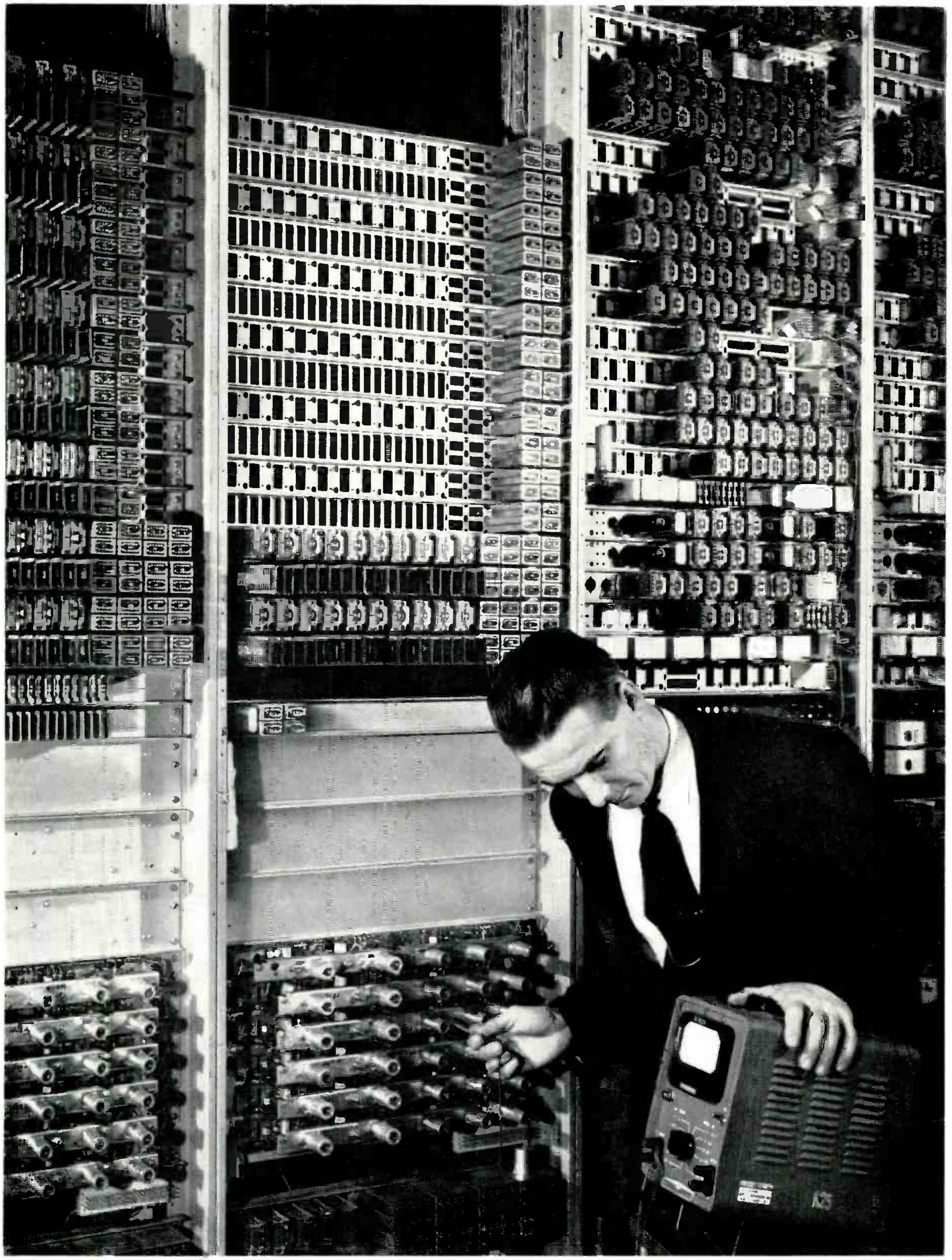
ANI will serve three types of central offices—panel, No. 1 crossbar, and step-by-step. For these three switching methods, the system will permit fully Automatic Message Accounting (AMA) for extended-area and direct-distance dialed calls without an operator.

When a telephone customer originates a toll call, ANI identifies his directory number and sends it to a tandem or toll office where CAMA equipment records the information needed to charge for the call. This fully automatic treatment takes the place of operator identification of customer dialed calls—a system in which an operator enters the connection to ask for the calling number. Automatic identification not only saves time for the customer, but also avoids the possibility of human error.

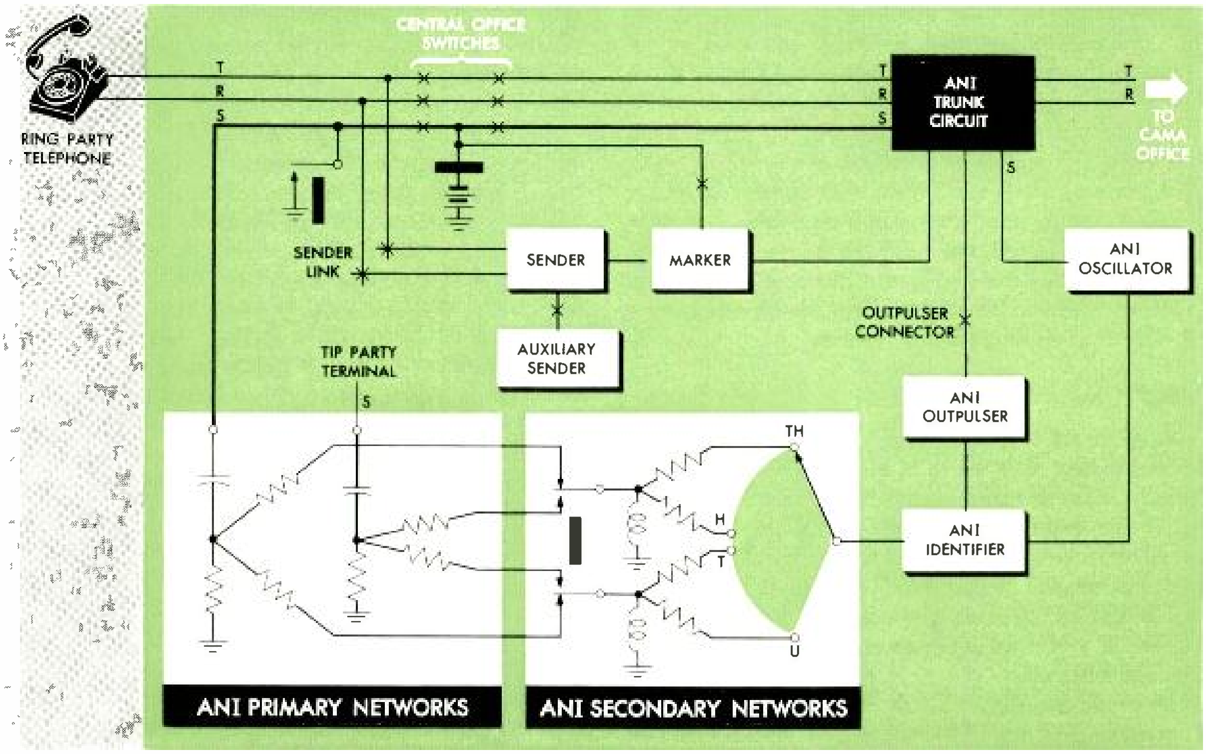
Panel, No. 1 crossbar, or step-by-step switching equipment is used in all of the local dial offices installed by the Bell System before 1948. The ANI system, plus direct-distance dialing switching features, added to these offices enable them to offer the same DDD service as newer No. 5 crossbar offices, permitting customer dialing all over the country with a minimum of equipment needed for charging purposes.

This article will deal specifically with two of the components in ANI—outpulsers and identifiers. To understand their features requires first a brief look at the operation of ANI. Perhaps the most logical way to look is to examine the circuits in the order in which they come into action. The first of these are the "trunk" circuits.

A trunk circuit (in this case, *not* the customary pair of wires) is inserted between the switches of the existing central office and a pair of wires to the tandem or toll CAMA office. One function of the trunk circuit is to determine when a called number has been transmitted to the CAMA office.



The author measures voltage on set of amplifier-detectors. These sensitive devices can operate on a signal of only 0.00009 volt to determine whether signal represents the digit of a dialed number.



Basic scheme of automatic number identification in a No. 1 crossbar switching office. Arrangement of the switching connection is augmented by passing party information into ANI trunk circuit. Outpulser passes information, modulated on signal, to identifier which locates number.

It then requests connection to one of several "outpulsers." When connected to a trunk, six leads are established between this outpulser and the trunk. After performing certain functions, the outpulser seizes one of two "identifiers," which immediately causes an oscillator to place a 5800 cps signal on a special lead to the trunk circuit.

This signal then goes back through the switches of the central office connection, through primary and secondary networks, and into the identifier circuit. The networks translate the directory number from the form of one-out-of-10,000 to a four-digit number having one-out-of-ten possible values for each of the thousands, hundreds, tens, and units digits of the directory number.

The identifier scans the output signal from the secondary network and passes the identified number to the outpulser. Then, the outpulser receives the four digits of the calling customer's number in the form of dc signals. These digits are stored in the outpulser until the complete number is identified. Multifrequency pulsing then sends the number to the distant office.

The block diagram on this page shows a No. 1 crossbar office with Automatic Number Identification. In this type of office, the customer dials into a device called the "sender" which secures a "marker." This marker then sets up the switching connection. One of the first things the marker does is to "seize" an idle trunk to which it passes party information. In the trunk, this information is registered for later use by the ANI system. Once the connection is set up, the called number proceeds from the sender through the trunk to the tandem or toll office. When the sender has completed its job, it releases, removing a ground signal that had been holding the connection. The trunk continues to hold the connection, detecting this removal of ground as an indication that the system is ready for automatic identification. If identification were attempted before this, the ground would short out the 5800-cps signal and identification would fail.

The trunk circuit responds to the removal of ground and a signal from the CAMA office by seizing an outpulser to which it then passes the stored party information (tip or ring party indication) previously received from the marker. When the outpulser has registered this information, it seizes the identifier and passes the information to it. The identifier then sets the secondary network to connect to the proper primary network for the calling party.

Meanwhile, the outpulser orders the trunk circuit to remove ground from the lead that is holding the connection and transfer the lead to an oscillator where a holding ground is applied. Then the identifier signals the oscillator to superimpose the 5800-cps signal atop the holding ground on the lead for identification. At the primary network the signal goes through a capacitor and a resistor to ground. Two other resistors are connected to the junction between that resistor and the capacitor. These resistors perform part of the required translation by carrying the signal, greatly attenuated, to primary buses.

Output Highways

A primary bus has many other primary networks attached to it. It is also extended to a secondary network. Here, two other resistors complete the translation by carrying the signal to leads commonly known as secondary buses. These are the output "highways" of the primary and secondary translating system—the leads that the identifier scans to find the calling customer's directory number.

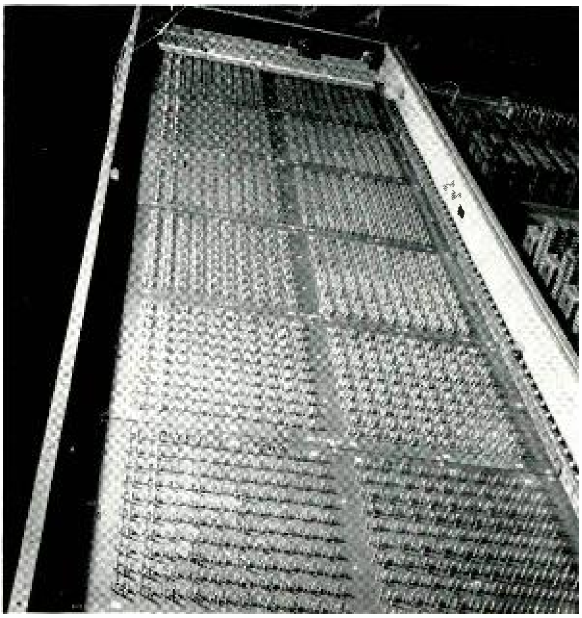
In many buildings, there is more than one central office. For example, one telephone building in New York City comprises the exchanges WA 5, CA 6, and WO 6. Such an arrangement requires more than one set of primary and secondary network output leads. In these cases, the identifier looks at output leads representing the thousands digit for the first office, then passes on to the second and the third, until it finds the signal on a set of "thousands" leads. This 5800-cycle signal is amplified, tested for frequency and duration, and is used to operate relays in the outpulser.

Once the proper office (and thousands digit) is found, the identifier similarly scans the buses associated with the same office to find the hundreds, tens and units digits. These digits also appear as 5800-cycle signals on corresponding secondary network leads. They too are amplified, detected, checked for frequency and magnitude, and registered in the outpulser. When it has completed registering the number in the outpulser, the identifier releases and is permitted to connect to other outpulsers to handle other calls. The total operating time of the identifier averages 0.27 second in the largest installations, somewhat less in smaller ones.

At the time the outpulser releases the identifier, it starts to transmit the identified number to the distant office by multifrequency pulsing. Completing this, the outpulser restores the trunk circuit to a condition for talking. After a total operating time of about 2 seconds, the outpulser drops off the connection leaving the switches in the central office controlled by the trunk circuit. At the end of the call, the trunk circuit receives a disconnection signal from the CAMA office. Meanwhile, all central-office switches have released.

Let us look a little more closely at some features in the outpulser and identifier circuits. On a two-party line in panel offices, for example, the outpulser must determine which party is making the call. But, the outpulser can't tell whether the call is from a two-party, a multiparty, an individual line, or a PBX. Thus, it must "party test" *all* CAMA calls in an office having two-party lines. In panel offices the party test is made by a district selector, and in No. 1 crossbar offices by the originating sender, where PBX lines can be segregated to skip the party test. If a party test arrangement similar to that used in these circuits were used, it would permit a connection in a PBX to release prematurely. A new party-test circuit in ANI permits the outpulser to test PBX lines, and other types, without releasing the connection.

Now let us examine the identifier. Here we find one of the features that enable the ANI system to take care of unusual or trouble conditions and still permit automatic handling of a call. In scanning the secondary network output leads, the identifier must find a very small signal. This signal, originating in the oscillator on the trunk circuit frame, is greatly attenuated by the primary and secondary networks in the course of its trans-



A number-network bay in an ANI laboratory. This is the cross-connection, or "strapping," side of the bay where pins are strapped according to which type of party-line arrangement is involved.

lation. Also, under certain conditions, the central-office switches can momentarily interfere with this signal and prevent its being found. Therefore, the identifier is arranged to look again for the signal if it misses identification the first time.

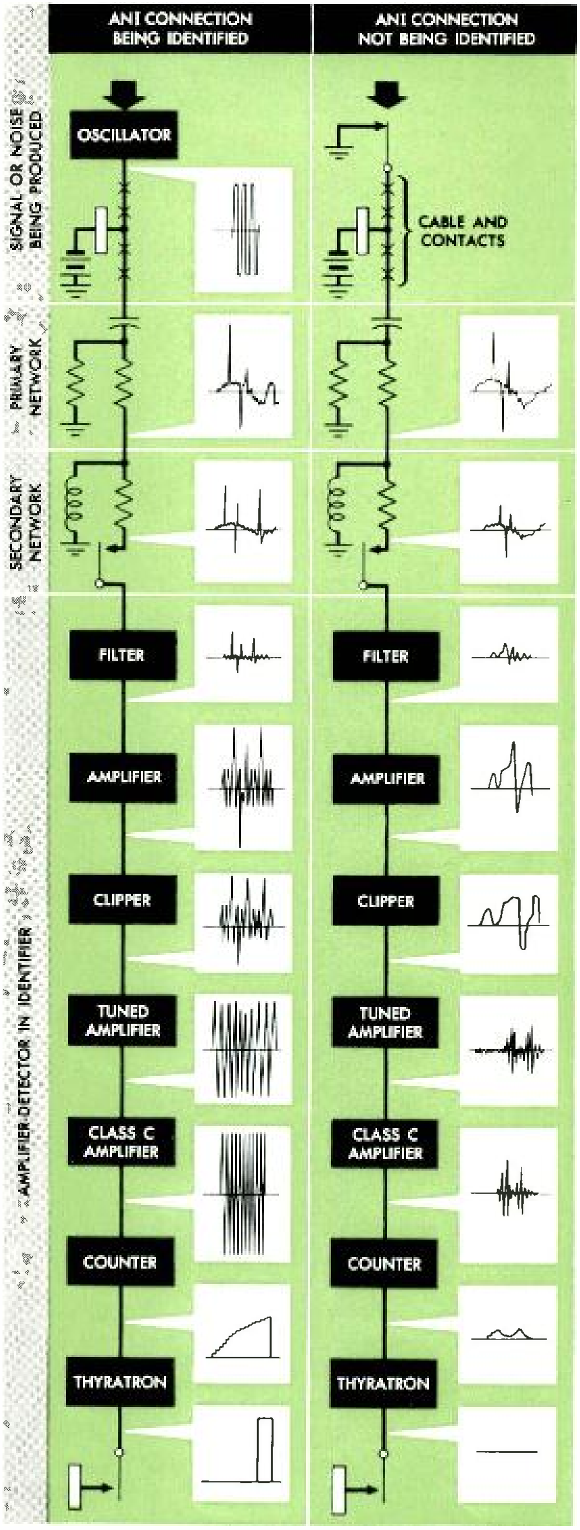
The procedure is briefly this. The identifier advances automatically in its scanning, whether or not it finds a signal. Therefore, if a momentary interruption of the identification signal occurs, the identifier may pass, without recognizing it, the set of leads that should have a signal. It will, however, go back for any digits it has missed. In this case, the digits already found are passed over to avoid undue lengthening of the identifier holding time. If no signal is found in the second attempt, the outpulser calls in another identifier and that one also can make as many as two attempts to find the signal.

In buildings with more than one central office, an identifier checks as many as six offices for first the thousands digit and then the hundreds digit. On the rare occasion when it fails to find either, it releases and the outpulser then connects to the other identifier for a second trial. If the identification is missed the second time, the outpulser sends a signal to the CAMA office to call in an operator who asks the customer for his number. As an aid to maintenance, a trouble record is made of identification failures.

Before we see exactly how an identifier detects a signal, let us consider what happens to the signal as it goes through the central office. The signal starts out with a pure 5800-cycle waveform at 2.2 volts. At the primary network the signal "branches" to a horizontal and vertical bus. On these buses the signal is about 0.0015 volt. (See diagram at right.) There may also be some miscellaneous electrical noise plus 60-cycle noise picked up from power cables. The noise illustrated will vary from office to office.

Passing through the secondary network, the signal is further attenuated to about 0.00009 volt, which is what the identifier sees. Here, too, is miscellaneous noise, and there may also be noise on leads to the identifier that have no signal. For example, the release of a connection in a No. 1 crossbar office may produce voltage surges with peaks up to 1100 volts. All this noise passes through the primary and secondary networks. It is also attenuated along the way, but is still large compared to the wanted signal.

ANI has a unique way to deal with this problem. In the identifier there are ten amplifier-detectors used to determine the calling number. These amplifier-detectors are electron-tube circuits with very high gain.



How the ANI arrangement distinguishes between a legitimate signal and incidental noise. Various devices in identifier operate in turn on signal to produce either an obvious pulse or none at all.

The diagram on page 101 shows in block form the components of two of these detectors with typical waveforms that appear at the input and output of each stage. The first amplifier-detector receives and detects an identification signal, and the second receives and rejects typical noise. In both cases, an input filter removes low frequency noise. A linear amplifier raises the voltage of the signal and the remaining noise so that a "clipper" can remove any large pulses of noise that may be present. A tuned linear amplifier then again raises the voltage of the wanted signal but rejects noise of frequencies other than 5800-cps. The circuit uses a "class C" amplifier, so biased that the input signal must exceed a threshold voltage before any output is produced. This rejects small voltages that might be present as a result of leakage or induction between adjacent leads in central-office cables.

To be sure that the signal received and detected is not a random burst of noise accidentally occurring at 5800-cps, the equipment counts the signal's cycles until the amplifier-detector knows that the signal is legitimate. Then a thyratron fires and the digit is registered in the outpulser.

Group Service

A single group of Automatic Number Identification equipment can serve up to six offices in a building. In buildings requiring two or more independent systems or groups, identifications are made one at a time in each ANI group with the usual 5800-cycle frequency.

When identification and outpulsing is complete, the CAMA "recorder" punches holes in a paper tape to record the charging information. For detailed records, this charging information includes the called number pulsed out by the sender in the originating offices, the calling number pulsed out by the outpulser, and the number of the trunk. Later, answer and disconnect entries are added to this tape at the CAMA office. When the tape is sent to an accounting center, the various entries for the call are assembled and computation is made to determine the charges for this call. The final result is the printed bill that is sent to the telephone customer.

Automatic number identification is one more step towards completely mechanizing the recording of billing information for telephone calls beyond local areas. Not only does ANI insure accuracy in identifying the calling customer for these cases, but it also increases the convenience to the customer who is making the call.

F. C. C. Approves "WATS" Plan

The Federal Communications Commission recently approved a proposal by the A.T.&T. Co. which will permit customers to pay a flat monthly rate for interstate long-distance service. Customers who choose to buy the new service will have a special telephone line giving access to the nationwide dialing network. Over this access line, the customer can dial as often and talk as long as he wishes to any telephone in a specified area outside his home state.

News of the Bell System

The new service is called Wide Area Telephone Service (WATS) and supplements present long-distance and private-line service.

The customer has a choice of six prescribed calling areas—the sixth or widest allowing him to call points outside his home state anywhere within the United States, except Alaska or Hawaii.

A first-area customer can reach telephones in all states adjoining his home state. If these border states do not represent about 10 per cent of the nation's total square miles and telephones, excluding his home state, other neighboring states will be added to his first area until this percentage figure is reached. A second-area customer would have unlimited calling to all first-area states and, in addition, other neighboring states up to a total of about 20 per cent of the nation's square miles and telephones. The remaining four areas each encompass an additional 20 per cent.

Depending upon his long-distance calling needs, the customer also has the option of buying WATS on a full-time or "measured-time" basis. In the measured-time option, the basic rate covers use of the service for 15 hours a month. If he exceeds this usage time, the customer pays a fixed charge for each additional hour.

For example, unlimited use of one access line to call all over the country would cost a San Francisco customer $2,275 monthly. To call anywhere in this same area on measured time, Wide Area Service would cost $600 for 15 hours plus $33.50 for each additional hour. Savings in telephone company expense resulting from the new service are passed along to WATS users in the form of lower cost long-distance calling.

Although the initial filing with the F.C.C. was for interstate calling, it is expected that filing will be made with state commissions at a later date for WATS within state boundaries.

At the horizons of the Bell System network—
outer space and the bottom of the sea—
transmission equipment is inaccessible.
Therefore two transatlantic cables were
assured by a meticulous reliability program.
of the longest possible trouble-free life.

A. H. Schafer

Repeaters for Transatlantic Cables: Passive Components

Six thousand electrical components in a transmission system present a formidable problem of ensuring reliability. When these components are part of a system that lies along the floor of the ocean, the problem is staggering. This is precisely the case in the deep-sea section of the first transatlantic cable, which embodies 102 repeaters each containing over 60 passive components.

The major objective in the design of circuit components for these repeaters was to achieve a degree of reliability that would result in a minimum rate of failure spanning twenty years of operation. At first glance this seems a usual task —Bell System equipment is always designed for a normal life of twenty to forty years. But in most areas of the Bell System, reliability is strongly supported by a competent technical staff that is always available to adjust and maintain equipment. Obviously, this cannot be done at the bottom of the sea. If the cable system fails, which can happen if a single component fails, it is returned to service only by raising it and replacing an entire repeater. The enormous cost of this operation is a further incentive to attaining almost unprecedented reliability in components.

Proof of the singular nature of these standards of reliability is furnished by a statement, in statistical terms, of what had to be attained. Stated in this way, the requisite degree of reliability presupposed an annual failure rate for components of less than one-in-a-million. This rate yields a 90 per cent probability of attaining a 20-year trouble-free life for the components.

The story of how this reliability was achieved is based on Bell Laboratories knowledge that many unique technological advances are not developed according to a completely original plan. It is a story which evolves, over a period of time, from the energy of people having the challenge of the moment as their spur and the experience of the past for their yardstick. Practically expressed, Laboratories engineers realized that the desired reliability could not be predetermined by any practical sampling procedure or test program; it could be achieved only by rigorous selection of materials, designs and manufacturing methods. Therefore. long and satisfactory field experience was the criteria for choosing any material or design; unless it had such a history it was not used in the repeaters.

A closely related problem was component stability; even a slight drift in performance, if it is in the same direction for all repeaters, can be magnified enormously and cause serious deterioration of transmission. All components were designed for stability and were reinforced with special stabilizing treatments. Generally, the treatments consisted of subjecting components to temperature cycling over a period of several weeks. In addition, capacitors were held under voltage for periods up to six months. These treatments served a two-fold purpose: they re-

Technician examines glass seal with a Geiger counter to test its effectiveness.

lieved strain and stress that manufacturing processes may have induced in materials and, additionally, provided a check against manufacturing or material defects.

A third exacting problem was related to the geometry of the repeater. The shape of the cable required that, instead of the usual chassis-mounted amplifier, all components be disposed within a long cylinder which, along with the cable, would be capable of withstanding all the handling, flexing and tensioning of the cable-laying operation. This precluded the usual geometric configuration, structures, mounting arrangements and terminations.

These geometrical restrictions thus necessitated a new and unusual scheme of network mounting arrangements which consist essentially of rods of methacrylate about an inch and a quarter in diameter and four inches long. They are riddled with holes and cavities in what may appear to be a disorderly array. These cavities, however, are not haphazard, but are arranged to support the various components in the best possible mechanical and electrical configuration.

Supporting structures for components are often of strange shapes and sizes—frequently interlocking to provide support for an adjacent component or a housing around it. To conserve space, many components are combined, such as two resistors in one, or two capacitors in one container or an inductor wound with resistance wire to form a combined inductor-resistor. Such measures introduced design and manufacturing problems but saved valuable space and reduced the number of soldered joints, which may in turn affect performance characteristics. Another design technique that saves space is the use of core tubes for paper capacitors as covers for resistors. Further, the ceramic casings of hermetically sealed capacitors are the cores and winding bobbins of resistors.

Typical examples of the ingenuity used in designing the repeaters are the inductors. Electrically, inductor designs range from 10 microhenries to 200 millihenries. Closed-core structures are used for all inductors, largely because of the proximity of the steel rings that protect the repeaters from pressures at the bottom of the sea. Rings of molybdenum Permalloy powder pressed to shape are used as cores for high inductance values, and nonmagnetic, methacrylate-core rings with windings applied in toroidal form for low values (usually below about 300 microhenries). In each case, a closed loop contains the magnetic field. In one instance, the inductance-resistance ratio desired was larger than could be obtained from a single toroidal core that would also fit into the network housing. To obtain the required inductance, two cores were arranged in a figure-eight pattern and wound by threading the wire through both cores.

Several examples of typical inductors are shown in the photograph on page 106. The inductors, at the left of the photograph, include an inductor-resistor combination, with one end of the winding applied to one of the fin separators as an essentially noninductive portion of the winding. Inductance is adjusted by removal of turns from the main toroidal body and resistance is adjusted by control of the turns on the noninductive fin. The fins serve as winding-section separators that keep the distributed capacitance at a minimum. Additionally, they support the inductor in the network assembly.

Other examples of proven design adapted to a new purpose are the input and output transformers, identical in appearance and quite similar electrically, which form an integral part of the two coupling networks in each repeater. In each case the core is wound of molybdenum Permalloy tape; the windings are supported by spools. A transformer is shown in the upper left part of the photograph on page 106 along with the methacrylate-winding separators, spool and channel insulator used. Windings were applied by rotating the spool on the core in a specially constructed winding machine.

A considerable part of the required gain vs. frequency characteristic of the repeater is obtained in the input and output networks, using the short-circuit inductance of the transformer and high distributed capacitance of the winding as part of a resonant circuit. Consequently, any change in these parasitic elements is extremely critical and must be kept to a minimum. Accordingly, the spool and winding separators were machined to precise dimensions and the windings were applied under fixed wire tension. This process fixes the relative position of the windings and results in a high order of uniformity.

Technician at Western Electric, Hillside, New Jersey, assembling the ocean cable repeaters.

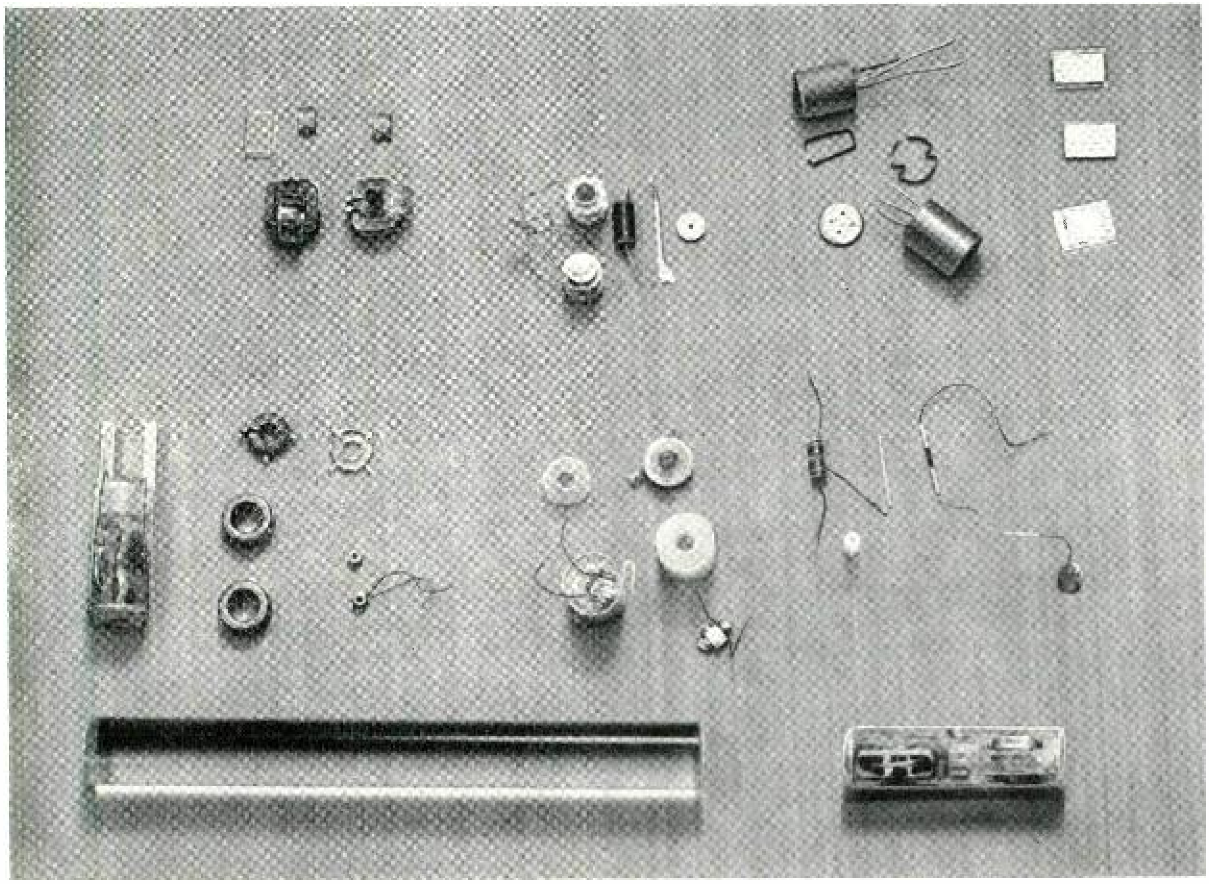
Capacitor designs range from about 10 micromicrofarads to 0.5 microfarads. Where high precision was required, silvered mica capacitors were used for capacitances up to a maximum of 10,000 micromicrofarads. These have several unusual features. One of these is the termination in which contact to the silvered surface is made by interleaving a fine silver foil between the laminations. The ends of the laminations and the foil are then clamped together, held by the terminals and, as an additional precaution, soldered. Another feature is the simple open construction made possible by the dry-nitrogen atmosphere of the repeater. Each capacitor is merely mounted by its terminals on a small slab of methacrylate. *(See the components in the upper right of the photograph on page 106.)*

High-Voltage Capacitors

For higher values, paper and foil capacitors were used. An extensive program of life tests, spanning a period of 15 years prior to the laying of the transatlantic cable, yielded precise data on the performance of these capacitors. These data are the basis for a statistical estimate (with 90 per cent assurance) that the first failure of a high-voltage capacitor should occur in not less than 16 nor more than 600 years. The tests also indicated the superiority of liquid impregnants at low temperatures and led ultimately to the use of castor-oil impregnated, kraft-paper aluminum-foil design. The photograph on page 106 shows one of the paper capacitors.

Another important group of components in the networks—resistors—were required to provide values from about 20 ohms to 300,000 ohms. Wire-wound construction was the basis of all designs. Resistors of low value (below 2000 ohms) were wound with straight wire, high values (above 10,000 ohms) with mandrelated wire—a helix of enameled resistance wire wound on a flexible silk core. Resistors of in-between values were wound as dictated by physical configuration and electrical requirements. Generally, high resistance values were wound with nickel-chrome wire and low values with copper-nickel wires.

The splice at the termination is the single most critical area of a resistor and the most likely spot for a failure to occur. Therefore, it was made with extreme care, usually under a microscope. Because nickel-chrome wire cannot be wetted by ordinary soft solder, all joints of this wire to terminals are silver-solder brazed. This type of brazing is common, but for this project the operation was performed in an inert atmosphere of nitrogen. In addition, the brazing was



Passive components for transatlantic cable repeater. Methacrylate rod and assembled repeater section are shown at bottom left. Above rod are: inductors and inductor-resistors at left, and resistors, right. Other components: transformers, top left, resistors, center, and capacitors.

done under conditions of meticulous cleanliness, using only fluxes and solders of greatest purity and under the most exacting control of temperature, dipping time and fluxing.

The photograph above also shows some of the resistor designs used in the cable repeater: a combined resistor-capacitor consisting of a sectionalized mandrelated wire winding, and with provisions in the end of the resistor spool to mount a mica-foil capacitor; a two-winding low-valued resistor (copper nickel wire winding), and two other resistor forms.

The care taken in design and selection of materials was supported by the manufacturing processes. Working sites were regulated like a hospital operating room. Employees and visitors wore sanitized clothing and were required to wash before entering any working area in the plant. All working surfaces, tools and exposed surface of equipment were kept impeccably clean. All materials were handled in a manner that excluded any contaminants.

A complete manufacturing history was kept on all components. Even though a component met all manufacturing specifications, it was not certified for use in the cable until it had been compared statistically with all others of its type. Finally, the component was used only if it was statistically within the bounds of all others.

The value of these apparently extreme measures is attested by the excellent service life and little "down-time" of the transatlantic cable. In effect, the methods of design and manufacture had to substitute for other measures, such as field trials, that are often keystones in the testing program for telephone equipment. The service-life record of the cable points out how effective a substitute these methods have been. Admittedly an expensive program, it is economically justified by the high cost of repairs and the even greater loss of revenue that can result from a failure in the deep-water cable. Finally—and of major importance—the reliability of the cable ensures that Bell System customers will not suffer the inconvenience that attends a sudden decrease in the number of message channels available to them.

New Electrochemical Technique For Polishing Semiconductor Wafers

News of Transistor Development

A new electrochemical technique for rapid, scratch-free polishing of germanium and silicon wafers for transistors was recently revealed by M. V. Sullivan of the Transistor Development Department. According to Mr. Sullivan, the new polishing method is much faster and more efficient than conventional polishing methods. In addition to the anticipated savings of more than 50 per cent of the polishing cost, there is a distinct improvement in the electrical characteristics of certain types of devices as well.

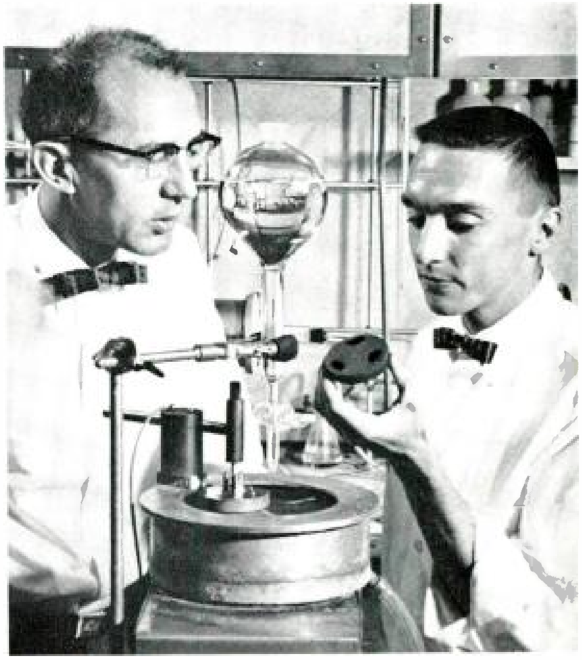
One of the major problems in the manufacture of transistors is maintaining an undamaged surface on the semiconductor slice used for the active element of the device. In conventional manufacturing practice, these slices are prepared in four steps. First they are sawed from a cylindrical crystal, then they are lapped with a coarse abrasive, and polished on optical lapping machines. These three operations produce a smooth, flat surface. In the final step, the slices are etched to remove all the residual mechanical damage to the crystal face caused by abrasive action.

When there are deep scratches from lapping and polishing, the etchant cannot remove all the damage, and poor-quality transistors result. In contrast, electrochemical polishing does not introduce new damage during processing.

In the technique Mr. Sullivan described, semiconductor slices are mounted on a nonconducting disk. After electrical contact is made to the slices, they are placed on a polishing wheel over which an electrolyte flows. When the polishing wheel rotates, a film of electrolyte· whose thickness is determined principally by the viscosity of the electrolyte, separates and automatically maintains the semiconductor at a relatively constant distance from the wheel.

A variety of etchants can be used satisfactorily. Dilute potassium hydroxide was chosen for most of the experimental work. This etchant is less alkaline than ordinary hand soap, and thus presents no safety hazard. Dilute acids, such as nitric, hydrochloric, and sulfuric work equally well.

The smoothness of the surface obtained by this method is apparent through study of photomicrographs of comparative surfaces. A mechanically polished surface shows distinct scratches when magnified 500 times. These scratches are caused by broken pieces of abrasive and semiconductor, which are ground into the face of the polished slice. On the other hand, semiconductor slices polished by this new technique show no texture that can be associated with surface roughness even under electron-microscope examination at 53,000 power.



M. V. Sullivan, left, and G. A. Kolb examine three germanium wafers which have been polished electrochemically. When the polishing device operates, the electrolyte (in glass container) drops on to the rotating wheel shown in foreground.

To track and monitor a space capsule,
Project Mercury's communications network
includes thousands of miles of teletypewriter,
telephone, and high-speed data circuits.
This vast system will soon be completed.

Project Mercury Communications Network Near Completion

News of Outer Space

The vast tracking and communications network for Project Mercury is nearing completion. Western Electric is the prime contractor to the National Aeronautics and Space Administration (NASA) for the engineering and construction of the project's world-wide tracking and communications system. This global network is being readied for a U.S. astronaut's first venture into space, scheduled to be launched from Cape Canaveral, Fla., this year.

The ground network connects 18 stations around the world with the Goddard Space Flight Center in Greenbelt, Md. The communications and computing center at Goddard will control and supervise the flow of information over telephone, teletypewriter and high-speed data circuits.

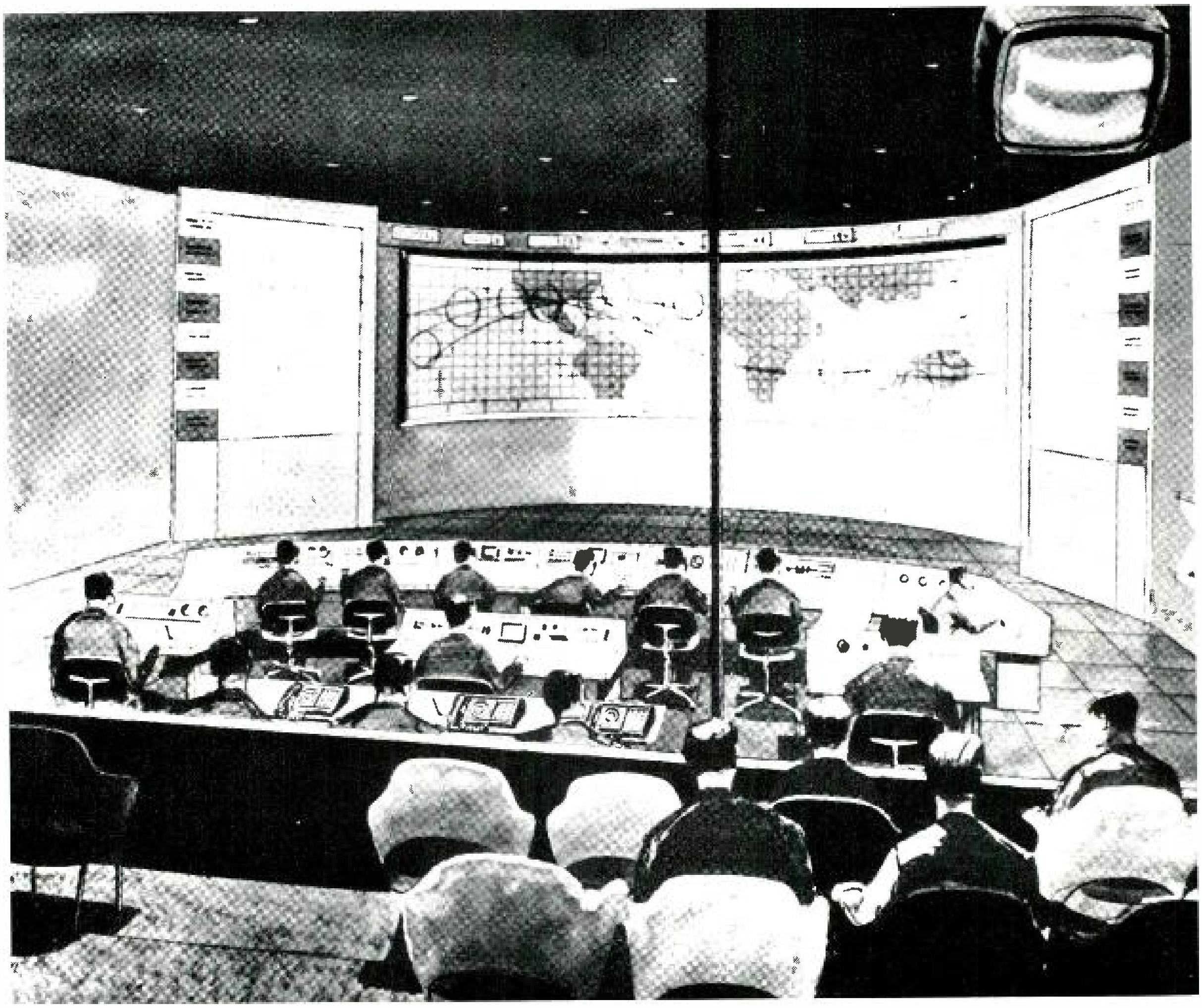
The basic means of communications with the stations is a teletypewriter network. To some sites, a voice circuit is also established for direct communications during the critical phases of the flight. The combined voice and teletypewriter communications network will enable NASA personnel in the U.S. to monitor the capsule's flight and transmit information to the range stations during the flight. The communications network will also enable NASA personnel at Cape Canaveral to transmit command signals to the range stations for relay to the capsule's instruments. At each site a specially designed intercom system will supply communications channels between all tracking-station personnel at the site. In addition, an air-to-ground radio system will furnish a direct-voice channel between the astronaut and the flight controllers at the Mercury sites. High-speed data circuits are provided to transmit radar tracking data from Cape Canaveral to computers at Goddard which send back information to NASA's control-center displays.

The vast network includes 58,000 route miles of communications facilities of which 22,700 are leased from the Bell System. In circuit miles, these figures equal 125,000 and 107,000 miles respectively. Range stations, being constructed in six other countries, on two ships and in six U.S. locations, are nearly finished. The network as a whole will be capable of monitoring the astronaut and the capsule as well as certain conditions affecting them during each phase of the capsule's flight—countdown, launching, insertion in orbit, orbit, and re-entry.

Thus the network must be able to transmit information rapidly and reliably to and from the range stations. Such facts as the capsule's condition and position plus the physical condition of the astronaut must be made available rapidly and accurately to the Cape Canaveral Control Center using an elaborate arrangement of data-processing machines at computer centers at the Goddard Space Flight Center and in Bermuda.

Design, construction and testing of Mercury's ground network is the responsibility of a five-member industrial team under Western Electric's leadership. Associated members are Bell Telephone Laboratories, International Business Machines Corporation, the Bendix Corporation and Burns and Roe, Inc. Bell Laboratories provided engineering consultation for the network. In addition, the Laboratories was responsible for the display, control and monitoring facilities in the Cape Canaveral and Bermuda operating rooms. The displays are designed for the wide variety of visual information necessary for NASA's command and control of the flight.

Plans call for sending a man on several circuits of the globe at 17,400 miles an hour before returning him safely to earth. Before this voyage is attempted, the astronauts will participate in a series of sub-orbital test flights. There will also be un-manned tests of the vehicle.



Artist's sketch of Project Mercury is Control Center at Cape Canaveral, Florida. This control and display equipment was designed and developed at Bell Laboratories in Whippany, N. J.

news in brief

Frequencies Authorized for Satellite Communications Experiment

The Federal Communications Commission recently authorized A.T.&T. to operate experimental radio stations for basic earth-satellite communications studies. A station at Bell Laboratories in Holmdel, N. J. will transmit and receive radio signals from as many as six satellites.

A.T.&T. plans to investigate space transmission of voice and television signals as well as various kinds of data and other communication. No commercial service is intended or will be permitted.

The F.C.C. stated that "Conditions to the A.T.&T. authorization require special tests to determine the feasibility of frequency sharing by space communication and common-carrier operation in the 4,000-6,000 megacycle region. The grant should not be construed as a finding by the Commission that the frequencies authorized for this test are best suited for space communication or that they will be made available for such communication on a regular basis.

In its statement A.T.&T. pointed out that satellites will supply the fast-growing need for international communications. "Our cable and radio network carried nearly 4 million telephone calls overseas last year and calling is increasing by nearly 20 per cent every year. By 1980, we expect there will be 100 million calls a year, 25 times what we have today. In addition, satellites will make possible the international transmission of TV and other forms of communication not feasible with today's cable and radio circuits.

"The United States now leads in the peaceful use of space technology. Project Echo—in which Bell Telephone Laboratories participated with the National Aeronautics and Space Administration—dramatically demonstrated this leadership.

The granting of these frequencies is a major step toward retaining this leadership."

T. H. Thompson Honored

Eta Kappa Nu, honorary fraternity for electrical engineers, has cited T. H. Thompson of the Military Electronics Department for honorable mention among the nation's outstanding young electrical engineers.

A certificate marking the award was presented to Mr. Thompson at a dinner in New York City by W. B. Groth, chairman of the Award Organization Committee.

The address of the evening was presented by H. S. Black of the Laboratories.

TELPAK: Versatile Broadband Service Offered For Large Volume Communications Users

Bell Laboratories engineers are helping to implement a new Bell System service which will create "electronic highways" between specified points for the transmission of almost all types of communications. Called TELPAK, the new interstate service is tailored for businesses and government agencies needing a large volume of point-to-point communication.

TELPAK will provide communications channels of various widths for handling existing services such as telephone calls, teletypewriter messages, and telephotographs. It will also handle new services such as control, signaling, facsimile, and data transmission.

In announcing this new service, which the Federal Communications Commission permitted to go into effect last month, A.T.&T. said that four classes of TELPAK channels would be offered. These range in capacity from the equivalent of 12 to the equivalent of 240 voice-grade circuits.

To a great extent, this new service is custom-made for each customer. The customer pays a monthly charge based on the size of the communications path selected at a fixed rate per mile, and on the type and number of circuit terminations which the telephone company provides. The customer has use of this communications path on a full-time basis. Furthermore, channels or terminals can be changed as the customer's needs change.

TELPAK offers wide frequency bands, available in the telephone plant, to provide the customer with the features of a private microwave system—but without compelling the customer to construct, finance and maintain his own system.

The customer selects the size of the TELPAK channel best suited to his particular needs. The telephone company will either terminate the broadband channel at the customer's premises or will subdivide the channel into lesser bandwidths to carry out the specific functions requested.

Compared with privately owned microwave systems, TELPAK offers customers many advantages. The cost is competitive; maintenance is part of the service; alternate circuits are available in emergencies; no capital investment is required; customers can readily change or add new locations; no losses from obsolescence. Furthermore, the Bell System will provide additional terminal arrangements as customers' new requirements develop.

TALKS

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

Ahearn, A. J., *Mass Spectroraphic Studies of Impurities on Surfaces*, Am. Vacuum Soc., Philadelphia, Pa.

Ballik, E. A., see Bennett, W. R., Jr.

Bennett, W. R., *Data Communication on Telephone Channels*, Electrical Engineering Department Grad. Seminar, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Bennett, W. R., Jr., Javan, A., and Ballik, E. A., *Measurement of Radiative Lifetimes*, A.P.S., Berkeley, Calif.

Black, H. S., *Global Communications Via Artificial Earth Satellites*, Midstate Section A.I.E.E., Winston Salem, N. C.; Armed Forces Communications and Electronics Assoc., Atlanta, Ga.; I.R.E., Cincinnati, Ohio.

Buchsbaum, S. J., *Experimental Studies of Ion Resonance in Multicomponent Plasmas*, M.I.T., Cambridge, Mass.

Buchsbaum, S. J., *Microwave Plasma Diagnostics*, Gas Dynamics Colloquium, Northwestern University, Evanston, Ill.

Bugnolo, D. S., *Information Theory and the Electromagnetic Field in Time Variable Media*, U.R.S.I.-I.R.E. Fall Meeting, Boulder, Colo.

Courtney-Pratt, J. S., *The Operation and Use of Optical Masers Particularly as Light Sources in Photography*, M.I.T., Cambridge, Mass.

Courtney-Pratt, J. S., and Fisher, M. G., *A Note on the Possibility of Photographing a Satellite Near the Moon*, The Ultimate Sensitivity in Photography Conf., London, England.

David, E. E., Jr., *Digital Simulation in Research on Human Communication*, Philadelphia, Pa.

Douglass, D. C., *A Study of Self-Diffusion in Liquids*, Cornell University, Ithaca, N. Y.

Drenick, R. F., *Adaptive Control Systems*, Westinghouse Research Laboratories, Pittsburgh, Pa.

Early, J. M., and Ross, I. M., *Epitaxial Semiconductor Devices*, Recent Advances in Physics Symposium, Bendix Research Laboratories, Detroit, Mich.

Eastwood, D. E., *Functions of an Assembly Program*, Programmer's Club, IBM Research Center, Yorktown Heights, N. Y.

Feldman, D., *Solar Energy Conversion*, A.I.E.E. Study Gp. on Direct Generation of Electricity, N. Y. C.

Fisher, M. G., see Courtney-Pratt, J. S.

Frisch, H. L., *Surface Structures of High Polymers*, Inst. for Study of Metals, University of Chicago, Chicago, Ill.

Frisch, H. L., *The Theory of One, Two and Three Dimensional Hard Sphere Fluids*, Inst. for Study of Metals, University of Chicago, Chicago, Ill.

Frisch, H. L., *Topological Isomerism in Closed Ring Systems*, Inst. for Study of Metals, University of Chicago, Chicago, Ill.

Fuller, C. S., *Chemistry of Semiconductors*, A.C.S., Midland, Mich.

Geller, S., *Magnetic Interactions and Distribution of Ions in the Garnets*, National Bureau of Standards, Wash., D. C.

Geusic, J. E., *The Solid State Maser*, New York University, N. Y. C.

Geyling, F. T., *Basic Considerations and Approaches to the Satellite Problem*, Fall Meeting of Soc. for Ind. & Appl. Math., Philadelphia, Pa.; Appl. Mechanics Seminar, University of California, Berkeley, Calif.

Gillette, D., *Application of Game Theory to Military Strategy and Tactics*. Biltmore Hotel, N. Y. C.

Glaser, J. L., *Radio Communication Via Satellites*, A.I.E.E., BTL, Murray Hill, N. J.; Chicago, Ill.; Washington, D. C.; New Haven, Conn.

Gupta, S. S., *Order Statistics from the Gamma Distribution*, Math. Statistics Department, University of Minnesota, Minneapolis, Minn.

Gupta, S. S., *A Single-Sample Decision Procedure for Selecting a Subset Containing the Best of Several Normal Populations and Some Extensions*, Math. Statistics Department, University of Minnesota, Minneapolis, Minn.

Guttman, N., *Recent Work on Pitch Perception*, Audiology Study Gp. of N. Y. Hunter College, N. Y. C.

Hagner, D. R., *Ballistic Missile Guidance*, A.I.E.E.-I.R.E. Meeting, Lafayette College, Easton, Pa.

Hagstrum, H. D., *Electron Ejection by Auger Neutralization of Ions at Solid Surfaces*, A.P.S., University of California, Berkeley, Calif.; Physics Colloquium, University of Washington, Washington, D. C.; Convair, San Diego, Calif.

Harr, J. A., and Smith, R. B., *Logical Design and Programming an Electronic Telephone System*, Morris, Ill.

Hensel, J. C., *Cyclotron Resonance of Holes and Acceptor Spin Resonance in Silicon Subjected to Uniaxial Stress*, IBM Watson Laboratory, Columbia University, N.Y.C.

Holden, A. N., *The Physics of Solids*, Lecture Series, Duggan Jr. High School, Springfield, Mass.

Howard, B. T., *A Method for the Rapid Evaluation of Semiconductor Device Reliability*, Prof. Gp. on Electron Devices Meeting, Wash., D. C.

Hughes, H. E., see Keene, F. R.

Jaccarino, V., *Correlations Between Superconductivity and NMR*, New York University, N.Y.C.

James, D. B., and Vaughan, H. E., *ESSEX — A Continuing Research Experiment in Time-Separation Communication*, Electronic Telephone Exchanges Conf., The Institution of Electrical Engineers, London, England.

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

Jenkins, H. M., *On the Development of Concepts Under Noncontingent Reinforcement*, AAAS, N. Y. C.

Kabak, I. W., *Simulation: The World of Make Believe*, Grad. Seminar Ind. Engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Kaenel, R. A., *The Bell Telephone Laboratories, Its History, Organization and Forward-Looking Activities*, Swiss Fed. Inst. of Tech., Zurich, Switz.

Kaenel, R. A., *Two Advantageous Tunnel Diode Applications*, Swiss Fed. Inst. of Tech., Zurich, Switz.

Keene, F. R., and Hughes, H. E., *Design for Reliability of a Parametric Amplifier Diode*, A.G.-E.T. Conf. on Reliability, Western Union Auditorium, N. Y. C.

Ketchledge, R. W., *The Morris Electronic Telephone Exchange*, Electronic Telephone Exchanges Conf., The Institution of Electrical Engineers, London, England.

Kirkwood, L. W., *High Temperature Insulation for Electronic Transformers*, Prof. Activities Gp. on Electrical Insulation of Soc. of Plastic Engineers, Newark College of Engineering, Newark, N. J.

Knox, K., *Preparation Structure and Properties of Some Fluorides*, Department of Chemistry, University of New Hampshire, Durham, N. H.

Kruskal, J. B., *The Number of Simplices in a Complex*, Symposium on Math. Optimization Techniques, Santa Monica, Calif.

Kunzler, J. E., *Anisotropies of the Hall Effect and the Magnetoresistance of Single Crystals of High Purity Copper and the Fermi Surface*, Solid State Seminar, Carnegie Inst. of Tech., Pittsburgh, Pa.

Laudise, R. A., *Crystal Growth*, Am. Inst. Chem. Engineers, City College of New York, N.Y.C.

Lax, M., *Phonon-Assisted Radiative Transitions in Si and Ge and Their Selection Rules*, Syracuse University, Syracuse, N. Y.

Lowry, W. K., *Some Functions, Interactions and Problems of Communication*, Fifty-First SLA Conv., Cleveland, Ohio.

Nicollian, E. H., *A Laboratory Leak Detector Using an Omegatron*, Am. Vacuum Soc. Symposium, Cleveland, Ohio.

Ohm, E. A., *Experimental Results of Project Echo*, Cape Canaveral, Fla.; University of Wisconsin, Madison, Wisc.

Mason, W. P., and O'Regan, R., *Recent Developments In Semiconductor Strain Gages*, Rochester, N. Y.; Appl. Mechanics Seminar, Stevens Institute.

McCall, D. W., *Characterization of Polymers*, Dayton Regional Symposium on Elastomeric Polymers, Dayton, Ohio.

Murphy, R. B., *Some Problems in Interpreting the Results of Life Tests*, Pittsburgh Sections of Am. Statistical Assoc., and A.S.Q.C., Pittsburgh, Pa.

O'Regan, R., *Semiconductor Strain Gages*, Instr. Soc. of Am., Winter Conf., St. Louis, Mo.

O'Regan, R., see Mason, W. P.

Power, M., *Generalized Calculation of Thermoelectric Efficiency*, Symposium on Thermoelectric Energy Conversion, Dallas, Tex.

Read, W. T., *Strategy for Active Defense*, Am. Economic Assoc., St. Louis, Mo.

Reed, E. D., and Scovil, H. E. D., *A Review of Solid-State Traveling-Wave Masers*, Electrical Eng.-Physics Seminar, University of Utah, Salt Lake City, Utah.

Riordan, J., *Delays for Last Come, First Served Service, and the Busy Period*, Operations Research Seminar, M.I.T., Cambridge, Mass.

Schawlow, A. L., *Sharp Line Spectra of Chromium in Crystals*, University of Indiana, Bloomington, Ind.

Schawlow, A. L., *Optical Masers*, National Research Council, Ottawa, Canada.

Scovil, H. E. D., see Reed, E. D.

Semplak, R. A., *Studies of the Effect of Rain and Water Vapor on Sky Noise Temperatures at 6 KMC*, U.R.S.I.-I.R.E., Boulder Lab., National Bureau of Standards, Boulder, Colo.

Slepian, D., *Random Processes in Communication Engineering*, Symposium on Engineering Application of Random Function Theory & Probability, Purdue University, Lafayette, Ind.

Slichter, W. P., *Nuclear Magnetic Resonance Studies of Disordered Regions in Solid Polymers*, Conf. on Polymer Phys., University of Bristol, England.

Smith, R. B. see Harr, J. A.

Snoke, L. R., *Careers with a Plus*, Fairleigh Dickinson University, Rutherford, N. J.

Sugano, S., *Zeeman and Strain Effects on the Degenerate Spectral Line of Chromium in MgO Crystals*, University of Illinois, Urbana, Ill.; University of Chicago, Chicago, Ill.

Taylor, R. H., *The Development of Research and Development Personnel for Management Responsibilities*, Chemist's Club, N.Y.C.

Tebo, J. D., *Satellite Communication and Project Echo*, Esso Remote Control Center, Morristown, N. J.; A.I.E.E., N.Y.C.

Tebo, J. D., *What We Have To Be Thankful For*, Combined Rotary & Kiwanis Clubs, Morristown, N. J.

Thomas, D. E., *Band Structure Resolution by Electronics Differentiation*, Ohio State University, Columbus, Ohio.

Thomas, D. E., *Fundamental Design Consideration for Linear Transistor Amplifiers*, I.R.E. Meeting, Columbus, Ohio.

Thomas, D. G., *Exitons and the Band Structure of CdS*, General Electric Research Lab., Schenectady, N. Y.

Varnerin, L. J., *Tantalum Film Circuitry*, I.R.E., Los Angeles, Calif.

Vaughan, H. E., see James D. B.

Wagner, R. S., *Dendritic Growth of Germanium*, Cornell University, College of Eng., Ithaca, N. Y.

Wasserman, E., *Chemical Topology: Interlocking Rings*, Michigan State University, East Lansing, Mich.; Columbia University, N.Y.C.

Weissmann, G. F., *Effect of Material Damping on Structural Vibrations*, Soc. Experimental Stress Analysis, N.Y.C.

Wertheim, G. K., *Some Applications of the Mossbauer Effect in Solid State Physics*, Pennsylvania State University, Philadelphia, Pa.

Wertheim, G. K., *The Mossbauer Effect of* Fe^{57} *in* Al_2O_3, A.P.S. Meeting, N.Y.C.

Williams, J. C., *Ceramic Printed Circuits—Some Materials and Applications*, Fall Meeting Southeastern Section, Am. Ceramic Soc., Chattanooga, Tenn.

Williams, W. H., *The Efficiency of Some Common Multistage Sampling Schemes*, A.S.Q.C., Princeton, N. J.

Yokelson, B. J., *Electronic Switching System, Morris, Illinois*, I.R.E. Prof. Gp. on Electronic Computers, Philadelphia, Pa.

PATENTS

Following is a list of the inventors, titles and patent numbers of patents recently issued to members of the Laboratories.

Bangert, J. T.—*Minimum-Phase Wave Transmission Network with Maximally Flat Delay*—2,969,509.

Bearer, P. J. and Llewellyn, F. B.—*Reduction of Cross-Modulation Between the Output Stages of Adjacent Transmitters*—2,968,716.

Bruce, E.—*Light Pulse Generator*—2,970,310.

Chase, A. J., Kalin, W. and Wise, P. L.—*Signaling System*—2,968,032.

DeLoach, B. C., Jr.—*Step-Twist Junction Waveguide Filter*—2,968,771.

Franz, E. E.—*Process for Making Printed Circuits*—2,969,300.

Hawkins, W. L., Lanza, V. L. and Winslow, F. H.—*Alpha-Olefin Hydrocarbons Stabilized with Carbon Black and a Carbocyclic Thioether*—2,967,845.

Hawkins, W. L., Lanza, V. L. and Winslow, F. H.—*Alpha-Olefin Hydrocarbons Stabilized with Carbon Black and a Compound Having* $R(SH)_x$ *Structure*—2,967,848.

Hawkins, W. L., Lanza, V. L. and Winslow, F. H.—*Alpha-Olefin Hydrocarbons Stabilized with Carbon Black and a Compound Having R-S-S-R Structure*—2,967,847.

Hawkins, W. L., Lanza, V. L. and Winslow, F. H.—*Alpha-Olefin Polymers Stabilized with Fused Ring Sulfide Compounds*—2,967,846.

Hawkins, W. L., Lanza, V. L. and Winslow, F. H.—*Composition of Stabilized Straight Chain Hydrocarbons Containing Carbon Black and a Compound Having R-S-S-R Structure*—2,967,850.

Hawkins, W. L., Lanza, V. L. and Winslow, F. H.—*Stabilized Straight Chain Hydrocarbons*—2,967,849.

Kalin, W. see Chase, A. J.

Lanza, V. L., see Hawkins, W. L.

Llewellyn, F. B., see Bearer, P. J.

McGuire, C. H. and Peek, R. L., Jr.—*Switching Device*—2,969,434.

Myers, O.—*Telephone Intercept System*—2,968,700.

Peek, R. L., Jr., see McGuire, C. H.

Poole, K. M. and Tien, P. K.—*Solid State Amplifier*—2,970,274.

Rose, C. F. P.—*Electromagnetic Wave Attenuator*—2,968,775.

Sandberg, I. W.—*Active One-Port Network*—2,968,773.

Schwender, G. E. and Vanderlippe, R. A.—*Code Signal Programmer*—2,968,694.

Thomas, G. B., Jr.—*Wave Filter* 2,986,772.

Tien, P. K., see Poole, K. M.

Vanderlippe, R. A., see Schwender, G. E.

Walsh, D. J.—*Thermal Expansion Fixture for Spacing Vaporized Contacts on Semiconductor Devices*—2,969,296.

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

Wise, P. L., see Chase, A. J.

PAPERS

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

Ahearn, A. J., *Mass Spectrographic Studies of Impurities on Surfaces*, Trans. Am. Vacuum Soc., pp. 1-5, 1960.

Aloisio, C. J., see Matsuoka, S.

Ballik, E. A., see Bennett, W. R., Jr.

Bemski, G., and Szymanski, B., *Spin Resonance of Electrons on Donors in p-Type Silicon*, The Phys. & Chem. of Solids, 17, pp. 173-175, Dec., 1960.

Bemski, B., and Szymanski, B., *Observation of Oscillatory Magneto-Resistance in InAs at Microwave Frequencies*, The Phys. & Chem. of Solids, 17, pp. 335-336, Jan., 1961.

Bennett, W. R., Jr., Javan, A., and Ballik, E. A., *Measurement of Radiative Lifetimes*, Bull. Am. Phys. Soc., 5, p. 496, 1960.

Birdsall, H. A., *Insulating Films and Fibrous Materials*, 1959 Digest of Literature on Dielectrics, 23, pp. 343-364, Nov., 1960.

Blumberg, W. E., and Eisinger, J., *Effective Mass in Gray Tin from Knight Shift Measurement*, Phys. Rev., 120, pp. 1965-1968, Dec. 15, 1960.

Bovery, F. A., see McCall, D. W.

Boyle, W. S., and Brailsford, A., *Far Infrared Studies of Bismuth*, Phys. Rev., 120, pp. 1943-1949, Dec. 15, 1960.

Bozorth, R. M., *New Varieties of Magnetic Materials*, Res., Appl. in Ind., 13, pp. 485-491, Dec., 1960.

Brady, G. W., and Petz, J. I., *Clustering in the Critical Region*, J. Chem. Phys., 34, p. 332, Jan., 1961.

Brailsford, A., see Boyle, W. S.

Brown, S. C., see Buchsbaum, S. J.

Brown, W. L., *Introduction to Semiconductor Particle Detectors*, Trans. I.R.E., Prof. Gp. on Nuclear Sci., pp. 1-7, Jan., 1961.

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