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Cover   *Ed Hughes tests printed circuit boards in new 101 Electronic Switching System, soon to be given field trial in New Jersey (See page 43).*
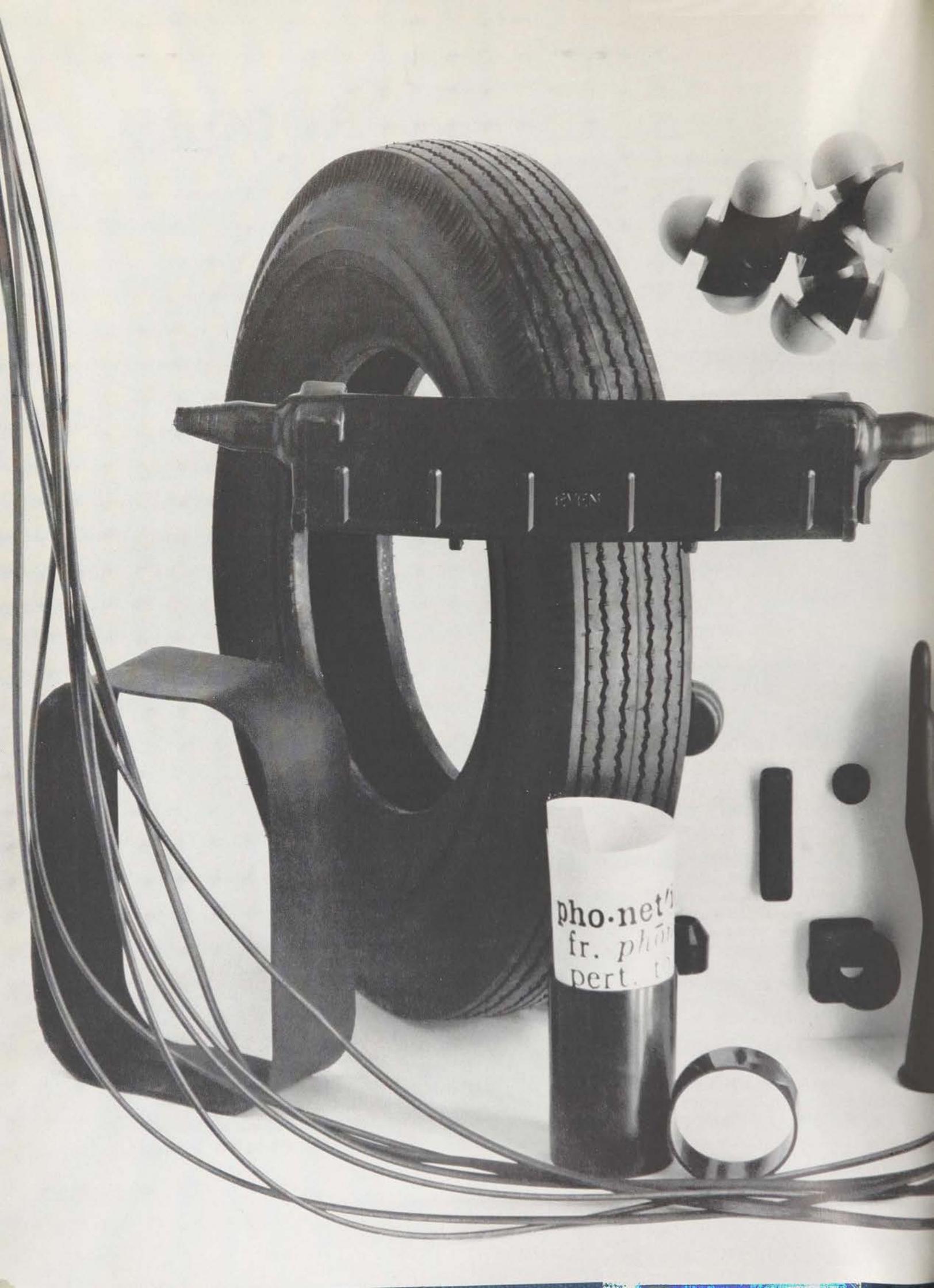
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Rubber products used in the Bell System shown with a model of the natural rubber monomer, range from tires and splice cases to sleeves for concrete conduit and recorded announcement machines.

G. N. Vacca

Rubber and Its Use In the Bell System

GENERALLY, the word "rubber" connotes a natural product and brings to mind textbook pictures of tropical natives collecting latex from rubber trees. Actually, today, instead of being the name of just one product, it describes a class of materials which includes not only natural but synthetic products.

Natural rubber was the only rubber available until the early 1930's, and up until World War II it was the most extensively used rubber. It can be obtained from many plants, shrubs and trees, including members of the dandelion family and goldenrod. However, the principal source of natural rubber is the *Hevea brasiliensis* tree, a native of the Amazon jungle. Early explorers found the natives wearing shoes fashioned from rubber and playing with rubber balls. The shoes did keep their feet dry and the balls did bounce, but neither lasted very long—the rubber became soft and sticky and it had a tendency to flow. The U. S. War Department, however, was extremely interested in rubber for weatherproof gear. Until 1839, all efforts to produce such gear were unsuc-

cessful. In that year, Charles Goodyear discovered that when rubber was heated with sulfur, it became much stronger and lost all tendency to flow and its sensitivity to temperature. It remained dry and free from tack and retained its strength and elasticity in summer or winter. This process, named vulcanization or curing, was the breakthrough that permitted the production of useful rubber products, although by modern standards such articles still had rather poor keeping qualities.

For a time, improvements in rubber resulted only from changes in mixing equipment, and from determination of the effects of the addition of varying amounts of an array of filler materials such as clay, limestone and talc. Then in the early 1900's, chemists discovered that certain organic materials would vastly accelerate the vulcanization of rubber. Benefits were twofold: A substantial reduction in the time needed for vulcanization and a marked improvement in durability of rubber products, because less sulfur was needed to achieve the desired properties.
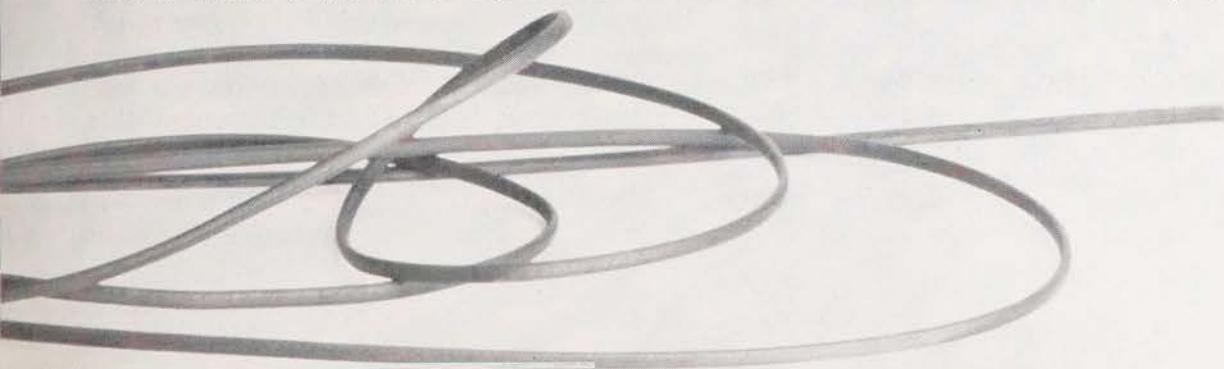
Much of the impetus for improved rubber compounds came from the rapidly expanding automotive industry and its urgent need for satisfactory tires. Between 1920 and 1930, for example, there were two outstanding developments. First was the discovery that carbon black—basically, soot from a gas flame—would remarkably increase the toughness and abrasion resistance of rubber. Second, materials were found which when added in small quantities substantially increased the resistance of rubber to the degrading effects of oxidation. The tire tread formulations shown in the table below reflect the progress in technology. Although progress in technology went forward, natural rubber remained the sole source of rubber until the early 1930's. Pressure created by the increasing demand for rubber for automobiles and widely fluctuating price of the rubber, as well as by some attempts by rubber planters to control prices, however, resulted in intensive efforts to produce a synthetic rubber between 1910 and 1912. (In 1910 the price of natural rubber was $2.88 per pound.) However, as the price of rubber became more realistic, these efforts to produce synthetic rubber were dropped.

Meanwhile, possibilities of producing a useful rubber appeared in results of studies not originally undertaken for this purpose. Thus, J. C. Patrick was investigating means for using waste refinery gases with the hope of producing glycols which could be used as antifreeze. This work resulted in the development of Thiokol rubber in 1930. Thiokol, though deficient in mechanical properties, has important advantages, including resistance to oil and solvents. While it has not approached other synthetics in tonnage, it still finds use in critical specialty applications.

Similarly, reports of Fr. J. Niewland's study of the reactions of acetylene led du Pont chemists to the development of Neoprene rubber, which was announced in 1931. Neoprene is a polymer of chloroprene, similar to isoprene, the monomer of natural rubber, but it contains a chlorine atom in place of a methyl group (CH_3). Compared to natural rubber, neoprene products have much greater resistance to oils, fats and waxes, outstanding resistance to ozone and weathering as well as resistance to flame propagation. From an initial 250 tons in 1932, production of neoprene has grown to 118,000 tons in 1961.

The most intensive development efforts on synthetic rubber were being made by German chemists, who had settled on butadiene as the most suitable monomer. They used sodium as a catalyst to develop a class of "Buna rubbers" during the 1930's.

The major rubber companies in the U. S. had been following developments in Germany, and by 1939 several of them had pilot plants in operation producing Buna and similar rubbers. As the possibility of a rubber shortage in the U. S. became more likely, plans to produce Buna S, or GR-S for "Government Rubber-Styrene," were put into effect. (This rubber is now called SB-R.) Production rose from 1750 tons in 1939 to 820,000 tons in 1945. This fantastic performance kept the Armed Forces and essential civilian services on wheels. Another Buna rubber, based on acrylonitrile, was also produced in this country during the war. It was designated GR-A then, now NB-R. Natural rubber imports meanwhile rose to a high of 989,000 tons in 1941 and then fell to 50,000 tons in 1943.

Also in the United States, a new synthetic rubber called Butyl rubber was announced in 1940. This rubber was prepared from isobutylene, which cannot be vulcanized, plus a small amount of isoprene which can, producing a polymer which was more stable than natural rubber in many respects. In addition, permeability to air was much lower than that of natural rubber; this property naturally lead to the use of Butyl rub-

	1905	1912	1918	Current
Rubber	50	50	90.3	100
Reclaimed Rubber	100	100	19.4	—
Zinc Oxide	30	89	40	5
Sulfur	20	3.75	6.3	3
Whiting	20	—	—	—
Magnesium Carbonate	—	3.5	—	—
Lamp Black	—	0.3	—	—
Carbon Black	—	—	12.4	50
Litharge	30	—	—	—
White Lead	29	—	—	—
Blue Lead	—	—	10	—
Lime	6	1.25	—	—
Aniline	—	2.5	—	—
Hexamethylenetetramine	—	—	1	—
2 Mercaptobenzothiazole	—	—	—	1.25
Pine Tar	—	—	—	4
Asphalt	—	—	15.5	—
Fatty Acid	—	—	—	3
Phenyl β Naphthylamine	—	—	—	1

Formulations for tire tread compositions reflect the changes in rubber compounding technology.

RUBBER	CHEMICAL FORMULA	OUTSTANDING PROPERTIES	COST COMPARED TO NATURAL RUBBER
Silicone (Silastic)	$-O-\underset{\underset{R}{\mid}}{\overset{\overset{R}{\mid}}{Si}}-O-\underset{\underset{R}{\mid}}{\overset{\overset{R}{\mid}}{Si}}-$	Stability at high temperatures, Resistance to weather, Low temperature flexibility	15×
Chloro-sulfonated Polyethylene (Hypalon)	$-\underset{\underset{Cl}{\mid}}{\overset{\overset{H}{\mid}}{C}}-(CH_2-CH_2)x-\underset{\underset{\underset{Cl}{\mid}}{SO_2}}{\overset{\overset{H}{\mid}}{C}}-$	Excellent resistance to: Weathering Oxidation Heat Abrasion	1.5-2.5×
Fluorocarbon Rubber (Kel-F, Viton)	Copolymers of: $CH_2=CF_2$ and $CF_3-CF=CF_2$	Resistance to: Heat Corrosive Chemicals Fuels Lubricants	40×
Polyurethanes	$-\underset{\underset{\underset{O}{\mid}}{CO}}{\overset{\overset{R}{\mid}}{N}}-\overset{\overset{H}{\mid}}{N}-\overset{\overset{O}{\parallel}}{C}-R-\overset{\overset{H}{\mid}}{N}-\overset{\overset{O}{\parallel}}{C}-\underset{\underset{\underset{O}{\mid}}{CO}}{\overset{\overset{R}{\mid}}{N}}-$	High Strength, Excellent resistance to: Abrasion Oxygen Ozone	4 to 6×
Synthetic Natural Rubber: Cis polyisoprene	$-CH_2-\underset{\underset{CH_3}{\mid}}{C}=CH-CH_2-$	Same as Natural	Same
Ethylene Propylene Terpolymer	Copolymer of: 60% $CH_2=CH_2$ 40% $CH_3-CH=CH_2$ Small amount of diene.	Excellent resistance to: Oxygen Ozone Heat	Same

The major rubber-like materials developed since the end of World War II show broad promise for general and special-purpose application. Table lists outstanding properties and relative cost.

ber in automobile inner tubes.

Since the war, synthetic rubber production has gradually increased to 1,400,000 tons in 1960; world production of natural rubber in the same year was about 2,000,000 tons.

Post-War Synthetic Rubbers

In the years since World War II, increased research activity has resulted in a large number of new, rubber-like materials, some of which show great promise. The most important are listed in the table above. Of all the postwar developments in synthetic rubber, probably the most important is that of the stereospecific polymers. Under normal polymerization conditions, the molecules of isoprene can combine in several different ways, since the two "ends" of the molecule are different.

Thus, they can join head-to-head, tail-to-tail, head-to-tail, or head-to-center. In most variations, two spatial arrangements are also possible. Only one of these matches natural rubber. With new catalysts, the polymerization of isoprene can be directed to produce a highly ordered structure— truly a remarkable achievement. Tests have shown that the new cis-polyisoprene rubber gives results practically identical to those obtained with natural rubber.

The national importance of this development is great. For example, it can replace natural rubber in the production of bus, truck, and airplane tires, where no other presently-available synthetic rubber can be used.

Rubber is seldom, if ever, used by itself as an end product. As evidence of this, we speak of

rubber heels, rubber soles, rubber tires and rubber mats, and while a rubber serves as the basic ingredient in such products, it is often not the major ingredient. Rubber content ranges from more than 90 per cent in some specialty items to 60-65 per cent in tires. It may actually go as low as 5 per cent in some floor tiles. The rubber content is dictated primarily by design intent but economics also plays a part.

Although the vulcanization reaction is irreversible, a usable product can be reclaimed from rubber scrap through mechanical working, heat and addition of plasticizers. Reclaimed rubber has respectable properties of its own and helps in processing rubber compositions.

Though perhaps technically somewhat incorrect, a mixture of rubber with other materials is called a rubber compound. Typical factors which influence the design of a rubber compound for Bell System applications, as for others, are listed in the table below. Obviously, not all of these properties are considered in every rubber compound, but in all cases the compound must comprise the best possible combination of properties for the intended service. Economics must of course not be neglected.

The compounder has at his disposal the twelve or so available varieties of rubber, plus a variety of other materials which produce necessary effects or properties. These are listed and shown on the opposite page. Though there has been great progress in establishing a scientific basis, rubber compounding is still something of an art. The complexity and the infinite number of combinations possible can be gleaned from the table. Adding to the complexity is the fact that some ingredients do not perform the same function in different varieties of rubber.

While rubber compounds are listed and prepared on a parts-by-weight basis, weight of the finished compound is seldom significant. Density, however, is important. Whether it is molded or extruded on wire, the volume used, not the weight, governs the cost. Therefore the cost-per-pound of a rubber compound will only give a rough idea of cost. By the expedient of multiplying the cost per pound by the density, the compounder arrives at a pound-volume cost which can be used in comparisons and in estimating costs.

Bell System Applications

Probably the first use of rubber in the telephone system was as insulation on wire and as hard-rubber piece parts. Hard-rubber parts were made at the Hawthorne Works of Western Electric in the early 1900's, and included plug and jack mounts, key shelves, switchboard lamp mounts, and mouthpieces and receiver shells for the desk stand telephone. Gradually, soft-rubber piece parts were added to the manufacture, and in the early 1920's development work on continuous vulcanization of rubber-covered wire began. In 1930, a plant built in Baltimore for the production of rubber-covered wire using the continuous vulcanization process began operation.

Prewar drop wire consisted of two rubber-insulated conductors, each circular in cross section and joined together by a thin fin of rubber. The pair was covered with a cotton braid which was then saturated with asphalts and steam pitches for weatherproofing. This structure had poor resistance to abrasion and weathering. Rubbing on trees and other obstructions soon removed the weatherproofing and insulation, leaving the conductors bare. Sun and rain would deteriorate and remove the weatherproofing, leaving the insulation exposed to air and ozone. Since the rubber was under stresses imposed during the braiding and weatherproofing operations, it was susceptible to attack by ozone. Corrosion of the conductors, loss of adhesion between insulation and conductor and loss of insulation resistance soon followed and the drop wire was in trouble. There were too many of these troubles.

A. Mechanical Properties
  1. Hardness
  2. Tensile strength and elongation
  3. Stress at a specified elongation
    (Modulus)
  4. Compression Characteristics
  5. Abrasion Resistance
  6. Tear Resistance
  7. Flame Resistance
  8. Miscellaneous special requirements, such as "feel" in rubber gloves

B. Electrical Properties
  1. Dielectric strength
  2. Dielectric constant
  3. Volume resistivity
  4. Dissipation factor

C. Service Environments (Expected useful life)
  1. Weathering
    a. Resistance to light and heat-induced oxidation
    b. Resistance to ozone.
  2. Resistance to oils and solvents
  3. Resistance to heat
  4. Low temperature
  5. Humidity and water immersion

Typical considerations in rubber compounding.

Constituents of Rubber Compounds

| MATERIAL	FUNCTION	EXAMPLE	ADVANTAGES
Rubber		Natural and Synthetic	
Vulcanizing Agents (Curing Agents)	To promote cross-linking (vulcanization)	Sulfur, peroxides	Reduce plasticity Increase elasticity Increase strength
Accelerators	Speed up vulcanization	Organic sulfur and nitrogen compounds	Reduce amount of sulfur and time required. Can also permit low temperature cure
Activators	React with accelerators	Zinc Oxide, Stearic Acid	Enhance effects of accelerators
Retarders	Delay action of accelerators	Salicyclic Acid, Phthallic Anhydride	Prevent premature curing during processing
Protective Systems: Antioxidants Antiozonants Light Absorbers Waxes	Protect integrity of compounds	Substituted phenols and aromatic amines	Generally restrict aging process. Increase service life
Fillers	Reinforcing	Carbon Black	Improve mechanical properties
	Non-reinforcing	Clay, whiting	Dilute compound, reduce cost
	Extenders	Vulcanized vegetable oils	Permit greater loading
Peptizers	Chemical softening of rubber	Thiols	Decrease mixing time
Softeners	Aid to dispersion of fillers	Petroleum oils, Pine tar Cumar resins	Reduce mixing time Improves processing
Special Effects Ingredients	Colorants	Dyes and Pigments	
	Flame proofers	Antimony Trioxide, Chlorine-containing Waxes & Chemicals	Decrease flammability
	Odor maskers	Perfumes	Conceal or change odor
	Blowing agents	Sodium bicarbonate Organic Nitrogen Compds.	Production of sponge & foam rubber
	Low temperature plasticizers	Alkyl & aryl Esters	Improve flexibility at low temperature
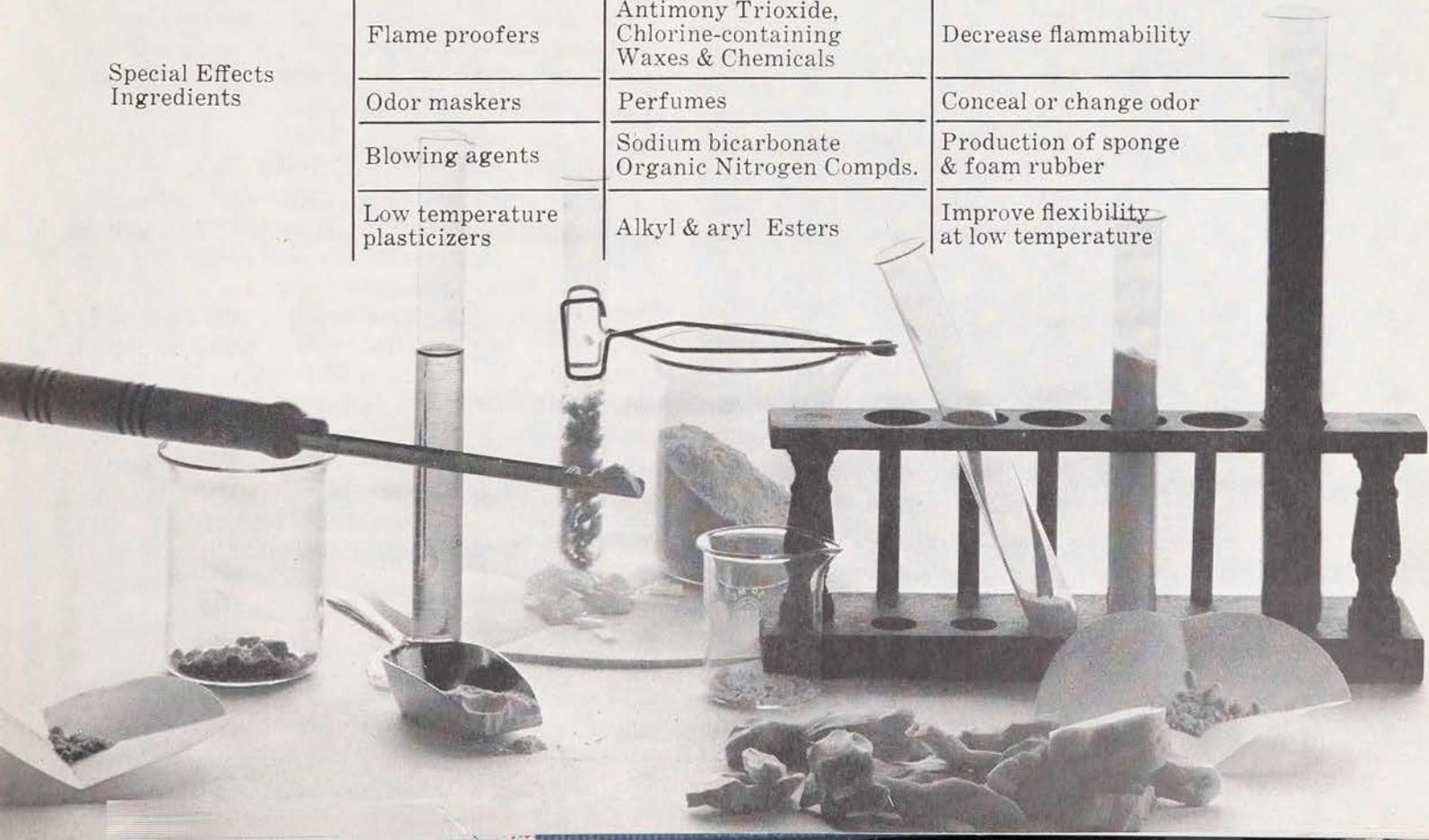
Intensive consideration was given to changes in design which would drastically reduce the trouble rate. The design developed for post-war production emphasized toughness in the insulation at the expense of some electrical qualities which were not very significant in the short lengths in which drop wire is used. The tough ozone-resisting insulation was applied in a "D", shape over each conductor, with the flat sides of the "D's" joined together by a fin. The fin was of such size as to permit separation of the insulated conductors without tearing insulation. A cotton braid or serving was applied over the twin insulated conductors. This added reinforcement to the structure and at the same time facilitated removal of the jacket at terminations.

Synthetic Rubber Insulation and Jacket

The new insulation was based on SB-R instead of natural rubber. The use of SB-R has been continued because its aging characteristics indicate that its service life will be considerably longer than that obtainable with natural rubber.

For the jacket a tough neoprene compound was selected. Evidence gathered from trial lots of neoprene-jacketed wire installed early in 1942 in hard service areas in the Atlantic City, N. J.

Radome over horn antenna at Andover is made of Dacron coated with Hypalon synthetic rubber.
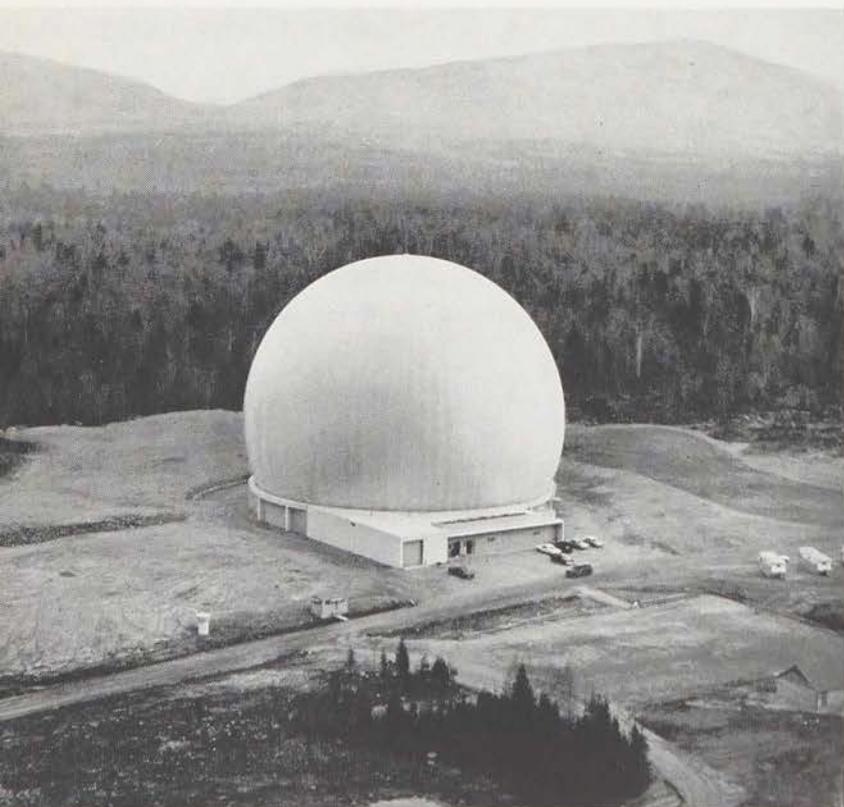
area, in Florida and in California indicated that the neoprene jacket would have the wear resistance and weatherability desired.

The wedge-action clamps used for supporting drop wire depend on adhesion of the insulation to the conductor for successful operation. Adhesion must be good originally and it must endure. While this quality of adhesion may be achieved by various means, brass plating of the conductor is used and adhesion is no longer a problem.

Production of drop wire of the new design was started in 1945. Today practically all of the old wire has been replaced. Over nine billion linear feet of the new wire have been installed, enough to encircle the earth almost seventy times. Tests indicated that the new wire would have a useful service life of about 20 years. The limiting factor would be a gradual hardening of the jacket with consequent loss of elongation. Samples which have been in service in the Los Angeles area for over 16 years look as good as new wire. The jacket has hardened, but elongation is still far above that at which the jacket would crack if the wire were bent back upon itself. It appears that the original estimate of useful service life may have been quite conservative.

Drop wire troubles have dropped from 8 to 4 per hundred due to the elimination of failures due to weathering and abrasion. In the latter case plastic guards and a program of tree trimming have also been helpful. Practically all of the troubles presently encountered are due to wire breaks caused by storms and construction or other accidents.

In keeping with advancing technology changes have been made in both the insulation and jacket to improve processing or reduce costs. However, in all cases rigorous maintenance of quality has been the prime consideration.

Sleeves for Concrete Conduit

Another interesting application of rubber in the Bell System lies in concrete conduit which is attracting attention as a replacement for clay conduit for underground telephone cables. In both concrete and clay conduit, the conduit is laid in sections and the sections must be joined together so as to exclude silt. With clay conduit, mortar "bandages" are used; these require 10 to 15 minutes of a skilled operator's time for each application. With concrete conduit, the design provided shoulders and tapering ends, so that sections could be forced into a rectangular sleeve for joining. Assembly time could thus be cut considerably.

40

Roy Werner, Western Electric Co., checks a batch of newly-formed rubber "loaves," fresh from the mixer.

The success of this method depended on the choice of a material for the sleeves. The sleeves would have to be rigid, and for this reason several plastics were tried. However, the stress imposed by the tapering ends caused plastics to relax and the joint was no longer tight. Various rubber materials were tried but all proved too flexible; they would buckle when attempts were made to push two conduit sections together. At this point, it was decided to try the recently announced chemically cross-linked polyethylene. Sleeves made from this material possessed the dimensional stability, low relaxation, rigidity for successful installation and resistance to microbiological organisms present in the soil. In addition they resisted swelling by oils commonly found in soils in the Southwest and were not subject to the stress cracking which could be induced by these oils.

Several trial installations of concrete conduit with cross-linked polyethylene sleeves have been made and results indicate a bright future for the new product.

Rubber in Telstar Radome

Perhaps one of the most dramatic recent applications of synthetic rubber in the Bell System was its use in the radomes which shelter the Telstar horn antenna at Andover, Me., from wind, snow, and differential temperature changes.

The structure was fabricated and erected by Bird Air Structures, and is the largest inflated shelter ever built—210 feet in diameter and 161 feet high. It was constructed of two plies of Dacron coated with Hypalon synthetic rubber, and is 1/16th inch thick. The radome is large enough to cover three acres if laid out flat, and weighs thirty tons. In spite of its great weight and size, it is supported by less than one-tenth pound of air pressure over atmospheric, not even noticeable to workmen and operators inside the radome.

"Talking" Rubber

One final example represents a successful use of a rubber derived from a plastic to gain desirable properties of each. Telephone answering sets, weather and stock quotation reporting machines, as well as some machines used in telephone traffic require storage and reproduction of speech and the facility for changing the stored speech rapidly and easily. Magnetic recording and reproduction was chosen as most feasible for these uses, but materials were needed which would survive millions of operations under conditions where coated tapes would wear out in a few thousand operations. (Metal tapes were not suitable because record and playback heads would tend to bounce with consequent noise, loss of speech and wear of the heads or scanners.)

Design considerations led to the conclusion that the magnetic recording media should be in the form of sleeves or bands which could be slipped over metal cylinders or wheels, and that the material should be $\frac{1}{8}$-inch vulcanized soft rubber —rubber which could store speech and talk back whenever needed. Duration of storage time could range from a few minutes to several years.

The development of this talking rubber presented an intriguing challenge. The sound properties demanded incorporation of a fairly large volume of magnetic iron oxide. Special physical requirements also existed, including resilience, hardness, permanent set, ozone and abrasion resistance, low coefficient of friction and a surface which would not cause undue wear of the heads (scanners) nor show any bloom (migration of substances to the surface) for at least ten years. Proper resilience permits the scanning head to make the required contact at low head pressures. Hardness can influence friction of the scanning head over the sleeve as well as noise as the head glides over the rubber. Permanent set must be low since the success of the system depends on the sleeve or band clinging tightly to the steel cylinder or wheel. Sleeves and bands are of such dimensions that a 6 per cent stretch is needed to put them in place. This stress immediately makes ozone resistance important, because rubber under stress is rapidly attacked by ozone. Resistance to abrasion is important because of the long service desired, and a low coefficient of friction reduces frictional noise.

Natural rubber, neoprene and Butyl were unsuited for use as the base rubber because of poor abrasion and frictional noise. Addition of waxes and oils of limited solubility helped matters, but since the rate of migration was not controllable,

Armored Wire for Submarine Cable	Neoprene
Ready-access Terminals	Neoprene
Core Wrap Tape	SB-R
Telephone Feet	Neoprene
Recording Bands	Polyurethane
Insulating Gloves	Natural Rubber
Insulating Blankets	Hypalon, Polyurethane
Floor Mats for Booths	NB-R
Sleeves for Concrete Conduit	Cross-linked polyethylene
B Cups	Neoprene
Hard-Rubber Piece Parts	Natural Rubber
Automobile Tires (about ½ million tires)	SB-R and Natural Rubber

Several typical Bell System products and the basic rubber from which each is compounded.

wax piled up under the head and contact was lost.

Hypalon proved to be much more suitable and was chosen as the base rubber and a satisfactory composition was achieved. A very acceptable low level of noise from various sources has been attained and in all respects it has provided trouble-free performance. This talking rubber has proved truly garrulous. In a five-year period over automatic machines, the same announcement has been repeated over 3,000,000 times without failure! New requirements now call for service life of twenty years; moldable polyurethanes are being considered for this application.

In 1941, aside from purchased items such as tires, the Bell System was consuming 3,000,000 pounds of natural rubber annually. 2,700,000 pounds were used in rubber-covered wire, while the rest went into hard and soft-rubber piece parts. Currently drop, block and HD wire require 3,000,000 pounds of SB-R and 6,000,000 pounds of neoprene annually.

Rubber is also used in a variety of other Bell System items. Some of the big runners are listed in the table above, together with the type of rubber used for making them.

While other materials have come along which can serve some purposes better, there still exists a wide area of application for a material with the unique properties of rubber. New developments, such as the exciting stereospecific polymers and new chemicals for rubber, offer a continuing challenge to the rubber chemist to improve existing compounds, and to fashion rubber compounds which may advantageously replace other materials.

A fast new electronic switching system, which combines flexibility with electromechanical compatibility has now been designed, primarily for use as a business PBX.

101 ESS: A More Flexible Telephone Service for Business

A new electronic telephone switching system that operates in microseconds, provides new kinds of telephone service, and is compatible with existing electromechanical switching systems was described at the annual meeting of the Institute of Electrical and Electronic Engineers in New York.

Designed by Bell Laboratories, the No. 101 Electronic Switching System (ESS) was developed primarily for use by businesses as a private branch exchange (PBX). It will soon be given a field trial in the plant of a New Brunswick, N. J., company.

Flexibility is a keynote of the new system, C. Breen and O. Williford, of the Switching Systems Engineering Division, told the meeting. It is designed so that services can be easily changed and expanded to accommodate future growth and a company's changing requirements. Also, unlike conventional PBX equipment, switching and special features in the new system are controlled by electronic equipment located in the telephone company's central office. Therefore, only a small amount of switching equipment is installed on the business premises and floor space can be saved for other uses.

W. A. Depp and M. A. Townsend of the Electronic Switching Division told the meeting that these innovations are brought about chiefly by the use of small high-speed electronic devices, by data-processing-system-like arrangements to control switching, and by the use of time-divided electronic switching.

The No. 101 ESS does not simply substitute high-speed electronic devices for slower-operating electromechanical ones. The Laboratories engineers pointed out that the new system takes advantage of the high speed of electronic circuits to process a great many calls quickly—so quickly, in fact, that the system can have many circuits which are used in common by a large number of lines. Connections for calls are made so rapidly that the equipment can be released to make connections for other calls without keeping anyone waiting for service. To get the greatest utility from this ability of electronic devices, the 101 ESS has been designed as a common control, stored program system.

Two groups of equipment make up the system —a switch unit in a PBX customer's office, and a central control unit in a central office. A switch unit can handle 200 telephone lines. However, as many as 32 switch units can be connected to and controlled in common by one central control unit. Actual switching actions take place in the switch unit, but they are directed by the central control which contains a series of stored programs that

F. Tendick (l) and R. Wiese of Bell Laboratories discuss switching unit circuit module of 101 ESS.

detail each step needed to set up a call or direct a special service feature.

Each switch unit contains the time-division switching network, the line circuits, and the trunk terminal equipment for one customer business office. One cabinet, about the size of three ordinary 5-drawer filing cabinets standing side-by-side, contains all the equipment. It needs only about one-quarter the floor space of a conventional PBX and it can be plugged into a 110-volt wall outlet. Its operating power is only about 600 watts, less than that of a home toaster.

Time-Division Switching

J. A. Herndon and F. H. Tendick, Electronic PBX Laboratory, described how time-division switching works in the unit. The essence of this technique is that periodic samples of an information signal will completely define that signal. In this way samples from a number of conversations can be transmitted over a common path. In the No. 101 ESS, the common path is a single lead called the "common bus." A cycle of time for the

bus is divided into discrete intervals. The same interval, prepared in each successive cycle, is called a "time slot." A call connection can be assigned to each time slot. In this system, there are 50 time slots and thus 50 connections can exist simultaneously.

The switch unit keeps a continuous check on all the telephone lines associated with it; at any moment it knows which lines are busy with a call, and it informs the control unit of any change. The control unit sends data messages to the switch unit that tell it what actions it must take in setting up a call and when to take down the connections.

Two Memories

The control unit acts according to information in both its semipermanent (program) and variable ("scratchpad") memory systems. E. A. Irland and J. H. Vogelsong, also of the Electronic PBX Laboratory, said that the permanent magnet twistor used for the program memory is an economical device to store information that the system will use over and over again to process calls. The scratchpad memory, a ferrite sheet device, stores more volatile information concerning the prograss of a call through the system.

E. L. Seley and F. S. Vigliante of the same Laboratory discussed the common control unit and its programming.

Instructions on how the control unit should process calls are embodied in magnetized spots on metallic cards in the twistor memory. Any program card can be replaced, and simple changes in its magnetic pattern change switching actions. The scratchpad memory governs the selection of the particular card program that is required at any stage of a call. To do this, it inserts a "progress mark" in each time slot which indicates when a telephone is not being used, when it goes off hook to begin a call, when it is being dialed, when it is connected, and when it is hung up.

These programming techniques are the road to some new service features. For example, a conference call may be set up after two parties are talking if one of them "flashes" the switch hook to get dial tone and then dials the number of a third party. Any one of the three may bring a fourth party into the "conference" and any party may hang up without disturbing the others. Another feature permits a customer to hold one call while making a second, after which he can return to the first. The system will also permit customers to dial three digits to reach frequently-

called seven or ten digit numbers, and to use pushbutton as well as standard rotary dial telephones. Any of these or other features available now or in the future can be added to the system merely by changing or adding program cards.

Reliability, as the Bell Laboratories engineers pointed out, is a rather difficult quality to achieve in any switching system made of a large number of new types of components. First these components must be highly reliable. Components for the No. 101 ESS were carefully selected and rigorously tested to insure a high degree of reliability. Then, with a foundation of long-lived components, other techniques can be used to insure a trouble-free system. Redundancy is one technique that was used to give No. 101 ESS a high degree of reliability. For example, the switch unit has two 25 time-slot buses rather than one 50 time-slot bus. The two buses each have separate switches to every line in the PBX, and each bus has its own memory and control circuits.

The control unit is divided into three major units and several minor units, and each is designed with an effective amount of redundancy.

To back up this plan, the new system was designed to detect trouble quickly and to switch defective units out of service and duplicate units in. The control unit is programmed to send test calls continually—about one a minute—through the system. If a test fails, redundant units are immediately switched in to restore service. Information on the part of the system that has failed is printed-out on a teletypewriter at the control unit. Tests are also made on the control unit, and any defective units are switched out of service until repairs by maintenance personnel are made.

It is expected that the field trial of No. 101 ESS will continue for about a year and that commercial systems, manufactured by the Western Electric Company, will be available toward the end of 1963.

Pushbutton console is used with 101 ESS; cabinets at rear contain switching network and circuits.
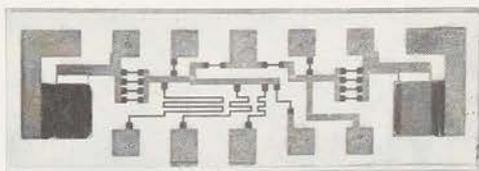
Tantalum Thin-Film Circuitry and Components

R. W. Berry

THE scientific impetus towards miniaturization began during the second world war in order to cope with the complexity of electronic systems. This trend has proceeded with increasing vigor into the 1960s. Small components have become, in turn, miniature, subminiature, and microminiature. One of the latest technological approaches to the development of small electronic elements is thin-film "two-dimensional" circuitry. In this area of research, Bell Laboratories scientists have investigated the properties of the transition metal, tantalum, and its compounds.

The major uses of tantalum in the past have been for the fabrication of hardware for the chemical industry, in incandescent lamps and vacuum tubes, and for electrolytic capacitors. Each of these uses has usually taken advantage of just one of the properties exhibited by the metal. For example, the chemical hardware industry took advantage of tantalum's extreme inertness to chemical attack; its high melting point was advantageous in manufacturing electron tubes and lamps, and its capability of having a controlled thickness of oxide grown on its surface by anodization made the metal ideal for fabricating electrolytic capacitors. It is the combination of all these properties in a single material which makes tantalum interesting from the point of view of the component development engineer.

There are several reasons for this. First of all, the refractory nature of the metal implies a high recrystallization temperature. This means that tantalum's structural features (on a near atomic scale) are not annealed out at normal operating temperatures. This is an important factor in fabricating resistors, because resistivity is strongly influenced by the amount of disorder in a crystal structure. Tantalum's inertness to chemical attack makes it possible to manufacture a stable unit without using an hermetic seal. Thirdly, anodic oxide films may be grown on a tantalum surface; this technique has been used successfully in the fabrication of capacitors, and this leads to the possibility of being able to manufacture capacitors based upon the same technology as that used for resistors. The anodizing process is basic to the formation of the dielectric of tantalum electrolytic capacitors and tantalum thin-film capacitors.

If certain metals, such as tantalum, are used as the anode in an electrolytic cell, oxygen is not given off; rather, a thin oxide film grows on the surface of the anode until the thickness of this film blocks the flow of current and the reaction halts. To obtain more current flow, the voltage must be increased; the oxide will continue to grow until its thickness is sufficient to block the current and the reaction again stops. At room temperature, fields of the order of 7 million volts per centimeter are required to cause current flow. The thickness of the oxide film grown in this way is proportional to the "anodizing" potential. This

*Mrs. J. A. Frohboese examines a tantalum thin-film circuit. In fabricating circuits, tantalum is deposited molecule by molecule on substrate by bombarding tantalum cathode with ionized gases.*

voltage dependence precisely controls the thickness of the film which is almost perfectly uniform. During this process, metallic tantalum is converted to the oxide; and, as will be explained later, it is this conversion phenomenon that makes possible the precise adjustment of resistors.

The tantalum films used as the starting material for the production of either individual components or integrated circuits are prepared by the technique of "cathodic sputtering." This involves creating a low-pressure glow discharge in an inert gas atmosphere using a tantalum cathode. Ionized gas molecules bombard the tantalum cathode and dislodge its atoms which redeposit on a substrate. The process is shown schematically on page 48. Despite the exceptionally low vapor pressure and high melting point of tantalum, deposition is

achieved with the cathode remaining essentially at room temperature. The properties of the film may be altered by introducing active gases into the gas stream. For example to produce superior resistive films, small amounts of nitrogen are introduced into the chamber.

The anodically grown tantalum oxide is the dielectric used for capacitors. The voltage used during anodization controls precisely the thickness of the dielectric. The tantalum substrate forms one electrode, and the second electrode is formed by depositing gold on the oxide, thus completing the capacitor. This structure is shown on page 49. The properties achieved in capacitors of this type include low leakage current, low dissipation factor, high dielectric strength, and high capacitance per unit area of substrate.
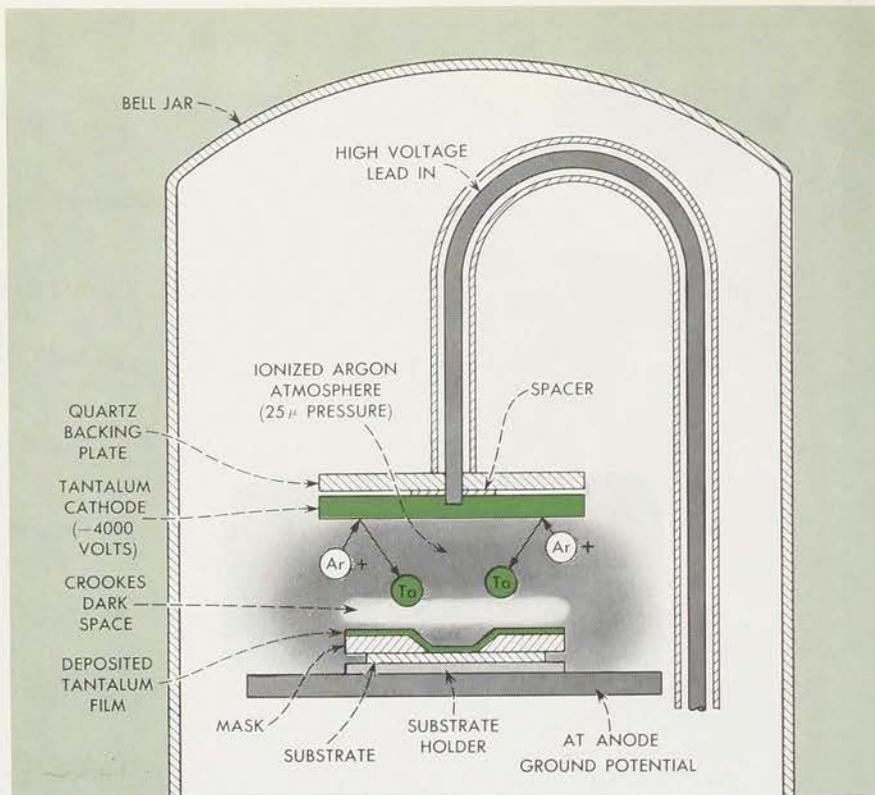
Schematic diagram of bell-jar apparatus used for "cathodic sputtering." The photograph (right) shows R. D'Angelo removing a sheet of tantalum-coated slides from bell jar at the Laboratories.

To illustrate these statements quantitatively, let us consider a unit made with a dielectric thickness of 2000 Å (0.000008 inch) and an area of 0.3 sq. cm. (0.05 sq. inch). Such a capacitor has the following approximate properties:

- leakage current—(75 volts)—1×10^{-9} ampere
- dissipation factor—0.01
- breakdown strength—100 volts
- capacitance—0.03 microfarads

The capacitance value is proportional to area and inversely proportional to thickness. With the exception of the smallest sizes, area may be controlled to better than one per cent, and for all sizes, thickness control to one per cent is easily achieved.

Although satisfactory resistors may be made from films of the same quality as those used to fabricate capacitors, considerable improvement in the stability and reproducibility of resistor properties is achieved by adding one to five percent nitrogen to the argon used as the sputtering atmosphere. Although nitrogen is present in the atmosphere in these relatively small quantities, the films produced in this fashion are principally a mixture of two different tantalum nitrides. The properties of these films are quite superior to those of normal sputtered tantalum. The temperature coefficient of resistance is lower (i.e., 25 to 125 parts per million negative) and more reproducible than the normal tantalum films. The specific resistivity is also more reproducible than in normal films, and lies at a level of about 250 microhm-centimeters.

These films permit the manufacture of resistors with reasonably high values without resorting to extremely thin films and exceptionally fine lines. The most significant effect of the added nitrogen, however, has to do with the stability of resistors. In this instance, the change in resistance after 1000 hours on load is reduced from the order of from 1 to 2 per cent change for tantalum films to the order of 0.01 to 0.05 per cent for nitride films. As a result, tantalum-nitride-resistor stability is considerably better than that of deposited carbon resistors.

Tantalum nitride films retain the ability of tantalum to be anodized in a controlled fashion. This permits the precise adjustment of resistors to their nominal value, since conductive metal is uniformly reduced in thickness and replaced by insulating tantalum oxide during anodization. By monitoring the resistance during anodization, the process may be terminated automatically when the proper value is obtained. Precision of the order of .01 percent has been achieved using these techniques. The tantalum resistor manufactured in this way has high stability, low temperature coefficient, and the capability of adjustment to high initial precision.

Since both capacitors and resistors can be fabricated by using essentially the same technologies, the next step is to produce circuit modules con-

taining all resistors, capacitors, and as far as possible, interconnections. What additional procedures are required, then, to make circuits which can take full advantage of the properties of the individual components?

In the individual resistor, pattern precision was of no great importance, since the value desired was obtained by adjustment. In the case of circuits which have many resistors of either the same or different value, it becomes advantageous to depend upon the pattern for resistance ratios, with the adjustment becoming circuit wide for the proper level of resistance. This calls for the generation of patterns whose precision is better than the tolerance asked for in the circuit. Laboratories engineers have developed techniques which allow for the production of line patterns in tantalum with a tolerance of ± 0.0001 inch on line width. Thus, with 0.010-inch line width, a pattern precision of ±1 per cent is achieved, or for 0.0050, ±2 per cent etc.

These patterns are made by photolithographic techniques. Tantalum is deposited over the entire substrate and a photosensitive "resist" is applied to the surface. The pattern is then developed in the resist, and the substrate etched in hydrofluoric acid. The limits in resolution mentioned above are dependent upon the production of the master pattern through which the resist is exposed. The master pattern is reproducible in the tantalum to smaller tolerance limits. The initial art work and its photographic reduction to full scale are then the steps which set the geometric precision.

The initial master is made on an x-y plotter with a precision of ±0.001 inch. By making the master 10 times full scale, this then becomes equivalent to an error of ±0.0001 inch. By using good control on the photography, this precision is transferred to the master photographic plate. If the initial tantalum nitride film were perfectly uniform, resistance ratios on a given substrate could be determined to the order of one per cent by geometrical control alone, and the over-all level of resistance would be adjustable by anodizing. Unfortunately, tantalum nitride films are not perfectly uniform, and variations in resistivity do occur on a single substrate. The magnitude of the variations depend upon the size of the substrate. Over an area approximately 1-inch square, variations of about two to three percent may be expected. With a linear dimension of about 5 inches, the total variation may be as much as ±10 per cent. Because of the high stability exhibited by the films, however, these initial variations are not appreciably changed at "end-of-life."

If a particular circuit requires higher precision,
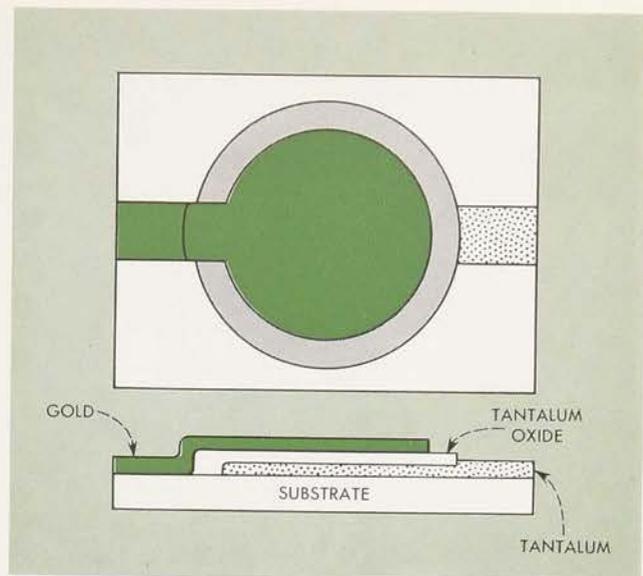
Side and top views of a tantalum thin-film capacitor. Each layer is approximately 2000-Å thick, making a total thickness of less than one micron.

each resistor may be individually adjusted. Another alternative for large substrates is selected area adjustment, where the total circuit may be broken into sections for the purpose of adjustment. The method chosen would depend upon the actual tolerance required by the circuit. Laboratory researchers are attempting to control the uniformity of the initial tantalum to within closer limits.

Several all-resistor circuits are being developed; the most ambitious is a portion of an arithmetic unit based on direct-coupled transistor logic. One of the substrates, shown on page 50, has 48 resistors. Circuit requirements in this case were for ±8 per cent limits on the resistor values. The dimensions of the substrate are 1.7 x 3 inch; the resistors are scattered over the entire area. The film uniformity was sufficient to allow for the adjustment of all resistors with a single anodization. This particular circuit is an excellent example of one of the aspects involved in strictly two-dimensional circuitry. If the active components had to be mounted completely external to the substrate, there would be insufficient edge areas available to bring all the required leads off the substrate. Consequently, the efficient use of area exhibited in two-dimensional circuits would be completely lost.

An experimental transistor package was developed at the Allentown and Laureldale Laboratories which does permit transistors to be directly applied to the substrate. This eliminates many edge terminations, and an even larger number of connections which would have to be made in the
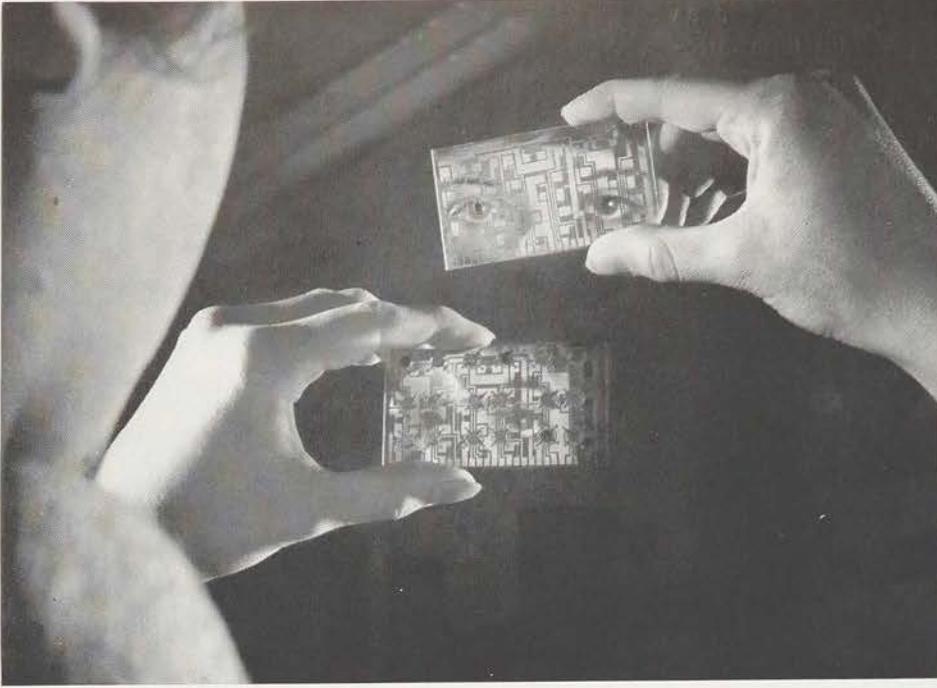
The two thin-film circuits shown here are part of an eight-bit arithmetic unit for a computer. Each circuit contains 48 resistors; lower circuit shows transistors bonded in position.

final assembly of a computer. Approximately 40 such slides with transistors bonded to them were fabricated to form an eight-bit arithmetic unit.

To fabricate networks containing both capacitors and resistors requires a few additional processing steps, but does not alter the over-all process. The first consideration is the thickness of the tantalum film. In general, the capacitor anode areas should be thicker than the resistive areas. By simple masking techniques during film deposition, additional tantalum is deposited in these particular areas. The other additional process required is the capacitor anodization. Consequently, the resistor areas and wiring must be isolated from the electrolyte. This is done by the use of a grease, silk-screened onto the substrate to prevent the electrolyte from contacting any area other than the capacitor anodes. The capacitors, and therefore the circuits, are completed by evaporating the counter-electrodes through mechanical masks.

A representative circuit of this type is the modulator pad in the modem unit of the A-5 channel bank which was designed to be compatible with existing equipment. It consists of 10 resistors ranging in value of 65 ohms to 5000 ohms, and two capacitors of 0.02 μf each. Even in the case of this small bit of circuitry, the number of external connections required is cut by a factor of two. The inherent increase in reliability resulting from this reduction is one of the major advantages of this approach. A large number of these circuits have been fabricated, and 500 of them are operating in field equipment on a trial basis.

Another circuit which has been fabricated is a portion of a clock for an experimental switching system. In this case, equipment design had not been completed, so greater freedom was permitted in the design of the layout and the package. The clock consists of a multivibrator, two binary counters and 16 phase generators. The layout was designed so the multivibrator and binary counters were on two identical substrates and the clock phase generators on four identical substrates. These were terminated so they could be mounted on a printed-wiring board for interconnection to the active devices for the circuit. The fabrication of the complete clock was a joint effort with the Transistor Development Laboratory. The active devices for this clock were multi-encapsulated, so that the clock—consisting of 88 resistors, 14 capacitors, 60 transistors, and 4 diodes—was fabricated from a total of only 44 packages.

Initial estimates indicate that tantalum thin-film components and circuits will be competitive with their conventional conterparts. This approach presents the system designer with a means to incorporate increased reliability in complex systems without a cost disadvantage, with the possibility of reduced size, and with a real advantage in the simplicity of assembly. It also provides systems with devices having superior electrical characteristics relative to conventional components.

A. E. Bachelet and H. J. Michael

SS1 Selective Signaling System

OVER THE PAST DECADE, the use of multiparty long-distance private-line telephone facilities in the Bell System has increased a great deal. A typical reason is illustrated by the commercial airlines which provide transportation between many cities. Airline representatives in each city must communicate with personnel at other locations for ticket reservations, information for flight plans and many other purposes. The Federal Aviation Administration, pipeline and trunking companies, utilities, and others also have similar requirements.

These communications needs are generally satisfied by the use of one or more multistation private lines. Such lines require special signaling arrangements for selectively calling stations on the line or to perform a multiplicity of control functions at remote points on the line. These arrangements must be simple, inexpensive and fast.

To meet the needs of these customers, Bell Laboratories engineers developed the SS1 Selective Signaling System as a standard Bell System service offering. Considering the important characteristics such as signaling speed, flexibility, engineering effort required by the Operating Companies, and cost, this system has several advantages over other systems which have been used to provide multiparty selective signaling. These are:

1. Faster service—requires dialing only two digits per function.
2. Economy—achieved by using low-cost high-demand apparatus, like wire-spring relays and single frequency (SF) signaling units.
3. Building-block design—permits the use of minimum equipment at all installations.
4. Packaged design—reduces job-engineering effort.

The SS1 system allows personnel at stations bridged to a four-wire private line circuit to selectively signal other stations bridged to the line. The system operates over voice-frequency facilities on an SF basis and uses frequency-shift signaling to minimize the effect of line echoes.

T. A. Smith uses a dial test set to check out operation of the SS1 unit at the Laboratories.
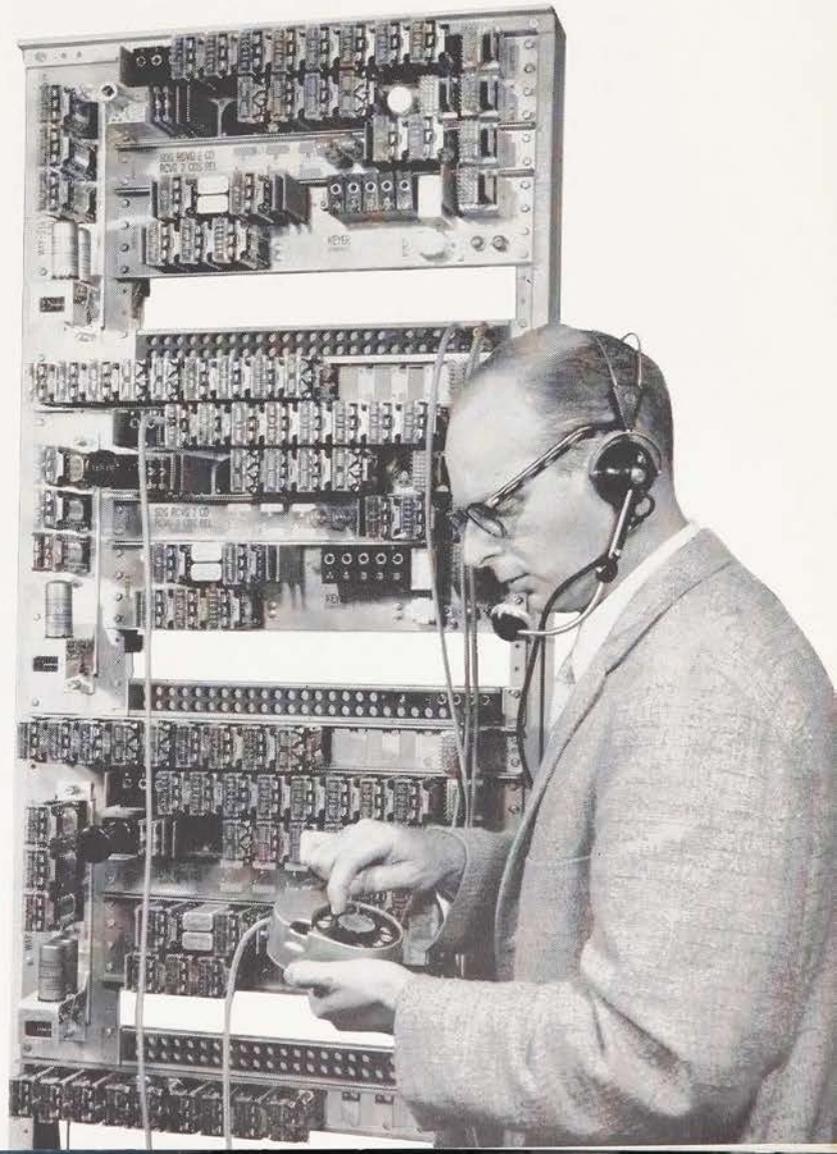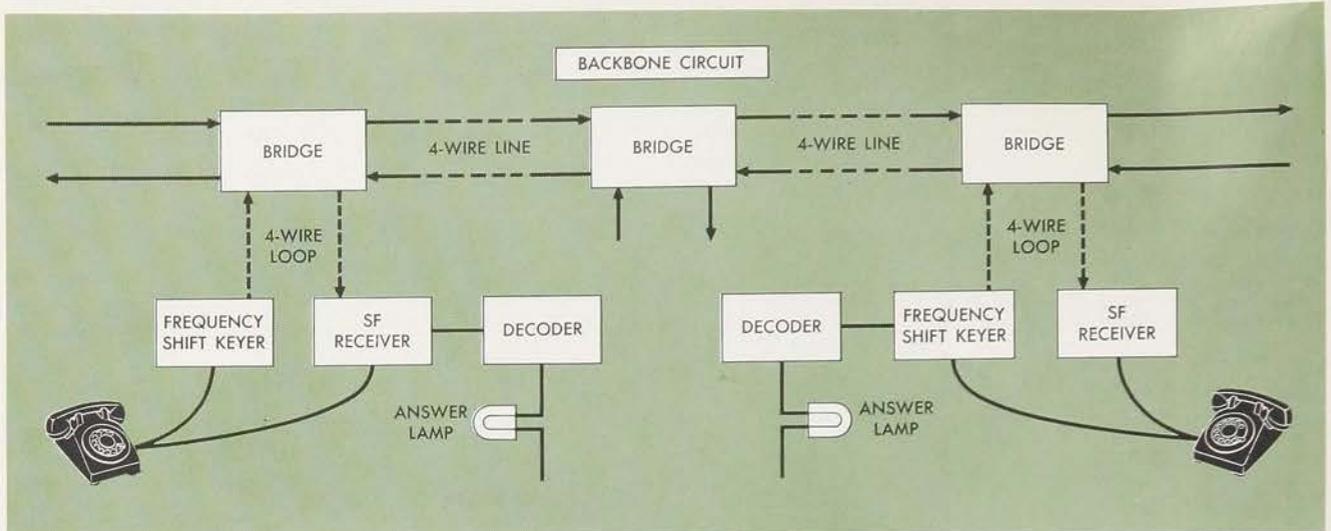
Block diagram of the SS1 Selective Signaling System showing how subscribers are connected along the backbone circuit. The frequency shift keyer converts dial-pulse to frequency-modulated *signals for transmission over the backbone circuit. These signals are recovered by SF receiver, demodulated, and passed on to decoder, which selects correct signals for a particular station.*

In addition to selective calling, SS1 systems in service include other useful features, such as the ability to correct dialing errors by canceling previously-dialed digits, and controlled privacy and lockout. Future systems will include the capability of duplicating codes in SS1-equipped lines which may be connected together. These will be described later.

The diagram above shows a multistation line communication system using the SS1 pulse signaling technique. A "back-bone" transmission facility provides two one-way transmission line pairs. Two-way stations are connected to the backbone facility by two one-way local loops, each pair of local loops terminates in a four-wire telephone set.

Transmission Equipment

The transmission facility often interconnects many telephone offices and associated stations which are sometimes widely separated geographically. The communication links may be made up of voice transmission lines, carrier transmission lines, radio relay links, or a combination of these telephone facilities.

Each station has a conventional telephone dial and an oscillator keying unit. A single frequency signaling unit and a decoder are used to receive the dialed digits. The keyer unit is a two-frequency oscillator (2400 and 2600 cps) which is shifted in frequency by dial pulses. It is adapted to convert dc dial pulses to equivalent tone signals for transmission over the backbone facility.

The heart of the system is the SF unit which is widely used in the message telephone plant. With SS1 signaling, the SF unit is not used in the same manner as in message service. The receiving equipment functions in the usual way, however, a separate sending circuit, arranged for frequency-shift operation, replaces the regular sending circuit. The SF receivers, except during dialing, are therefore always in the "high-guard," or talking, condition to prevent interference from speech. In the high-guard condition, the SF sensitivity is low to tone signals and the receiver requires pulses to be of longer duration to be recognized as legitimate pulses. Hence, it is not possible to dial reliably in the high-guard condition. To obtain reliable dialing, the SF receivers are shifted into the dialing or low-guard condition upon receipt of the first pulse of 2600 cycles. This is accomplished by lengthening the first pulse of each digit to insure the operation of the SF receiver.

The system is ready for dialing as soon as the handset is picked up. If the line is free, the calling party dials two digits to call any one of 81 codes. The keyer converts the dial pulses to 2400- and 2600-cps tone pulses and sends them to all other points where they are received by SF units and then decoded.

The decoder contains pulse-counting, translating and registering equipment for decoding and recognizing any one of the codes dialed from any one of the station circuits. Each decoder registers all codes but is wired to produce an output

only when the digits received correspond to the code identification of the associated telephone station. When this code is received, a direct-current pulse actuates other signaling or control equipment associated with the station terminal.

Upon receiving the first pulse of any digit, the decoders at all locations, except the sending station, open the transmitting circuit and apply a busy tone to the receive line. This busy signal persists until two digits have been received or for six seconds following receipt of the first digit, which is the time allowed for dialing the second digit. Thus, if another party picks up the phone during the dialing interval, he hears a busy tone and cannot interrupt the signaling by talking or attempting to dial.

The 81 codes for identifying the stations or functions are made up of various combinations of the digits except "1." Because it is not possible to use standard "off" signals to release the decoders at the control points along the backbone route, the digit "1" is used as an error-correction signal. All decoders are wired so that the receipt of the digit "1" will release them. Thus, if a mistake is made in dialing, the customer dials the digit "1," thus erasing the erroneous digit and the decoders are restored to their normal condition immediately without waiting for the six-second timeout.

Special Features

The flexibility of the SS1 system is enhanced by (1) the capability of dialing from one system to another, (2) the capability of increasing the number of stations within such an interconnected system, and (3) an automatic lockout circuit to insure privacy as well as an unlocking circuit for use in emergencies.

By dialing a code to set up a transmission path and then following the usual procedure, personnel at one SS1 system can dial into a second system. At the end of such a conversation, a code is dialed to release the interconnection. Systems connected in this way cannot have conflicting codes. In some situations, the 81 codes are inadequate to serve an entire interconnected network. More stations could be added by merely increasing the number of digits in the signaling codes beyond two. Such an increase, however, requires that each of the decoding circuits at the control points be capable of registering the larger number of digits. However, as the number of digits to be registered increases, the amount of equipment required to do the registering may be uneconomical compared with other types of communication systems.

A feature is presently being developed so that by utilizing a simple pulse-deletion circuit, the number of stations which can be selectively signaled over a common transmission line is doubled without a significant increase in the amount of equipment required. Two identical 81 station systems can then be interconnected.

The use of the interarea switching and deletion circuit will permit increasing the number of stations which can be accommodated in a single interconnected system. One group of stations, identified by various two-digit code combinations, is signaled in the conventional manner by dial pulsing. A second group of stations outside of that area may have the same codes as the first group. This second group of stations is signaled by interposing the error-correction digit "1" between the first and second digits. The two groups are interconnected by dialing a special interarea code.

For example, to reach a station in area B from area A, where codes in two networks have been duplicated, the procedure is as follows: to reach code 7-3 in area B, we first dial an interconnect-
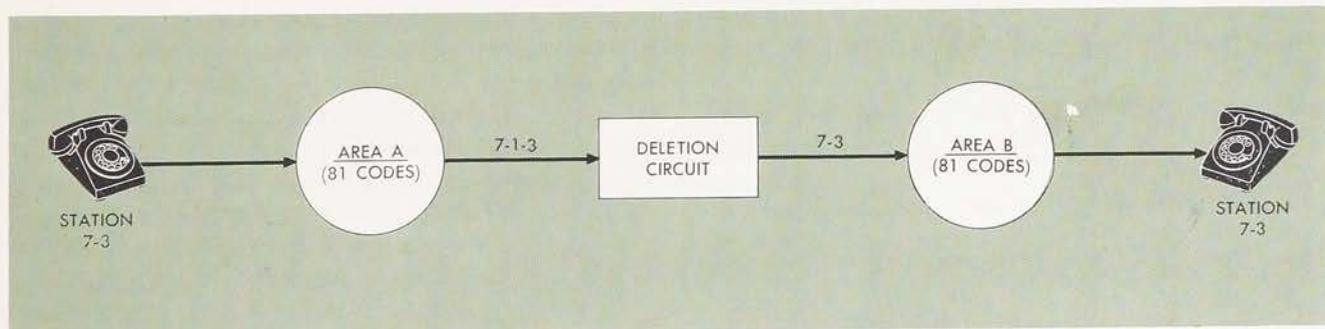
This diagram shows how two areas equipped with SS1 units can be interconnected. To tie the two areas together, the customer first dials a connect code. To reach code 7-3 in area B, a customer in area A dials 7-1-3. The deletion circuit drops out the 1 and sets up connection to the 7-3 station.

ing code which ties the two networks together. Then, instead of dialing 7-3, we now dial 7-1-3 to reach the code 7-3 in area B. The interposed digit "1" is automatically deleted by the deletion circuit associated with the interconnecting switch between the two areas. The digit "1" also cancels the initial "7" in area A and when the "3" is received, nothing happens and the circuit times out and restores to normal. To break such a connection, a customer uses a disconnect signal. To reach a station within an area, the usual two-digit codes are still used. This dialing system is shown on page 53.

Lockout Circuit

Privacy is another feature which has been included in the system design. This system incorporates this feature to permit a customer to lock out all but the party he is calling. Either party, by dialing, may add others to the connection as desired. When the originating party hangs up, a long tone pulse is transmitted automatically to all stations as an unlock signal.

Certain designated stations may be equipped to break privacy for emergency calls. This is done by operating of a local key to perform the unlocking function. When this is done, a tone is simultaneously applied to the line as a warning that a previously locked out station is now connected to the line.

Each station on the SS1 circuit may be arranged to send only, receive only, or send and receive. Each receiving station may be called individually or in groups. Group and conference calls may be set up by dialing a two-digit group code to call a predetermined number of stations simultaneously, by dialing a number of different station codes in any sequence without a waiting period, and by dialing other station codes during an existing call to add stations.

The equipment has been arranged for either central-office or station installation. A building-block design permits use of only those units required for a particular station application. The photograph on page 51 shows a typical packaged station installation including both send and receive capabilities.

Many terminals of SS1 equipment are now in service. Reports from customers and telephone operating companies alike indicate that performance is uniformly good and that the system has become an important adjunct to Bell System service. It is a measure of the flexibility, economy, and convenience that the telephone industry has been able to pass on to further the business needs of its customers.

Telstar Report

Telstar detected large increases of localized radiation in space following the Russian high-altitude nuclear tests of October 22 and 28, 1962, according to a recent report by a Bell Laboratories scientist to the annual meeting of the American Physical Society in New York City.

Two concentric belts of intense radiation, the Van Allen belts, bulge upward from the earth's atmosphere for thousands of miles. Walter L. Brown, Head, Semiconductor Physics Research Department, reported that immediately after the blasts, the "gap" or "slot" between the two belts was nearly "filled up" with energetic electrons. There was a concurrent increase of electrons in the belts themselves, but less than that in the slot.

The number of electrons added by the blasts gradually diminished during succeeding weeks. However, the decrease in the center of the slot was more rapid than it was on the sides of the belts, and more rapid than would have been expected. Scientists do not yet know the reason for the existence of the natural gap in the intense radiation between the two Van Allen belts— that is, they don't know why the region of radiation is not one continuous belt.

Mr. Brown and John D. Gabbe, of the Satellite Systems Engineering Department, have deduced from the rapid decay in the slot that some sort of yet-unknown "slot-cutting mechanism" is at work, in addition to "atmospheric scattering." Particles throughout the radiation region are

gh Russian Blasts
used Surge of Radiation in Space

scattered when they impinge on molecules of the upper atmosphere. This tends to balance the gradual, natural increase of particles in the belts.

Telstar showed that the October 22 blast nearly filled up the slot, increasing the number of electrons there a hundred- to a thousandfold. The electrons then decreased in the center of the slot at the rate of 50 per cent per day, but much more slowly elsewhere. The October 28 blast again nearly filled up the slot, and again the number decayed at approximately the same rate as before.

Scientists are not agreed about the precise results of the U. S. nuclear test in space on July 9 (called "Starfish") at altitudes above 600 miles because there were no radiation-measuring satellites in orbit that high at the time of the test.

After Telstar was put into its 600-to-3500-mile high orbit on July 10, however, it measured an electron intensity in July in the slot even higher than the intensity later recorded after the Russian blasts—but how much of the July intensity was produced by the Starfish test is still a subject of debate. Large fluctuations are known to occur naturally. From July until October the electron intensity in the slot showed a decay rate somewhat slower than that after the Russian tests.

The Bell System's experimental communications satellite in its elliptical orbit passes through portions of both the belts. Since its launching by the National Aeronautics and Space Administra-

tion, it has sent telemetry data on radiation to the Bell System station at Andover, Me., to the Bell Laboratories station at Cape Canaveral, and to NASA's worldwide tracking stations (RECORD, *November*, 1962).

As demonstrated graphically by the interruption in Telstar's command function (RECORD, *January*, 1963), radiation in space can produce severe effects in electronic equipment. The Van Allen radiation can be considered somewhat like a vast uncharted ocean of protons and electrons; it is, however, an ocean whose very presence was discovered only recently and whose properties are not yet completely understood. Moreover, the study of radiation in space is difficult for several reasons. First, the region is still not easy to reach. Also, satellites, which are always in specific orbits, obviously cannot be everywhere at once when changes take place rapidly in the character of the radiation, such as the changes brought about by events on the sun and by man-made nuclear explosions.

The Van Allen belt radiation is made up of fast-moving, or high energy, electrons and protons trapped by the earth's magnetic field. How they got there is still not completely known. Some of the particles apparently come as ionized gas from the sun, for increased radiation has been observed following nuclear "storms" on the sun's surface. It is believed also that some of the particles are produced by the interaction of cos-

mic rays with the outer atmosphere. Secondary particles that go back out into space are called the "albedo". The neutrons in the albedo decay into protons and electrons, some of which are trapped.

The trapped particles travel spirally along the earth's magnetic field lines, which arch high over the equator and come back to earth. As a particle nears the earth, the magnetic field around it increases. As the field strength increases, the spiral becomes flatter until eventually the particle is reflected and goes back out along the magnetic line of force. The process is then repeated on the other side of the magnetic field. The points of reflection are called mirror points.

Mechanisms are also at work removing the particles from the belts. There are still a few molecules of very rarefied atmosphere in the Van Allen belt region, and the energetic particles impinge on these gas molecules. The molecules then scatter the particles and release them from entrapment in the magnetic field.

Other mechanisms are also apparently at work reducing the number of trapped particles in some regions of space around the earth to create a gap, or slot, of lesser radiation intensity and thus separate radiation into inner and outer belts. Telstar data show that the number of electrons in the slot decreased more rapidly after the Russian high altitude tests than would be expected if atmospheric scattering were the only effect reducing the number of particles.

Knowledge of trapped radiation in space is very recent indeed. It was discovered only in 1958 by Dr. James A. Van Allen, of the State University of Iowa, for whom the radiation belts are named. The discovery was made through experiments carried out by the satellites Explorer I and Explorer II, with additional information from Explorer IV and Pioneer III and general confirmation by Russian satellites. The artificial addition of electrons to the radiation belts by high altitude nuclear explosions was predicted

by N. C. Christofilos of the Atomic Energy Commission, and demonstrated in the Argus high-altitude explosion of 1958.

The flux and spectrum of Van Allen belt radiation are known to vary from one region of space to another, and to vary in each region from one time to another. The aim of space radiation experiments is to try to measure these properties with appropriate instruments placed aboard satellites and probes. The measurements are then analyzed in an attempt to arrive at charts of the Van Allen belts and eventually an understanding of the mechanisms that produce them. With greater understanding, the deleterious effects of radiation on equipment can be minimized, and long-lived satellites can be built and orbited.

Basically the instruments attempt to separate the particles into different energy ranges and to count the numbers of particles in each of these energy ranges being encountered at that time and at that location in space. To do this, the scientists and engineers who design the instruments must make assumptions about the kinds and energies of particles expected, and then design and calibrate instruments accurately. When the measurements are received on earth, these men must take into consideration the location and orientation of the satellite at the time of each measurement; the measurements must then be translated into terms compatible with measurements obtained from other satellites. This can become a massive project—Telstar, for example, has already reported almost two million measurements of radiation in space.

Further, the instruments in one satellite report in terms different from the instruments of another. Their orbits also differ. Proper interpretation of the data frequently is a subject of scientific debate.

The measurements from Telstar showed that prior to the Russian nuclear tests in October, fluxes of electrons were relatively stable in Telstar's orbit. The flux was about 3 million electrons per square centimeter per second on a magnetic field line that crosses the equator at 4,500 miles altitude. After the second explosion the flux there was about 500 million electrons per square centimeter per second. This line is on the high-altitude side of the inner Van Allen belt.

The relative increase was even greater in the center of the slot region between the two belts. Electrons in the slot increased about 1000 times.

In July, when Telstar went into orbit, radiation was also high. Then the flux of electrons at the peak of the inner Van Allen belt was about 800 million per square centimeter per second.

The energy spectrum of the added electrons is roughly what would be expected from a nuclear fission explosion, but is apparently slightly "softer," or of lower energy, than the spectrum in some parts of space before the October tests.

The over-all change of spectrum as a result of the October tests had the peculiar effect of raising the net flux in the middle of the spectrum —at about 0.5 Mev—with respect to the upper and lower ends of the spectrum.

A detailed scientific report of some of Telstar's measurements will appear in an article by Brown and Gabbe in the February issue of the *Journal of Geophysical Research*.

RADIATION GLOSSARY

Over the years a special vocabulary, based on the physics and mathematics of radiation, has been evolved among scientists and engineers to describe radiation generally, and some of the terms have a special utility in discussing radiation in space.

The *electron volt* is a unit used to describe the energy of a particle. It is the energy transferred to or from one electron when it passes between two regions having a difference of electric potential of one volt. Particles with greater amounts of energy have greater instantaneous velocity.

The electrons that strike the face of a typical television picture tube to produce the picture each have an energy of about 15,000 electron volts. The particles in the Van Allen belts have energies in the millions of electron volts, abbreviated "Mev." Other units sometimes used are a thousand electron volts, "kev," and a billion electron volts, "Bev."

Flux of particles in space refers simply to the number of particles that pass through a given surface (of given area and orientation in space) per unit of time.

The particles in a flux may have many different energies. The distribution of energies of particles in this flux is referred to as its *spectrum*.

The *intensity* of radiation is the total energy of particles flowing through a unit area per unit of time, and is dependent on both the flux and the spectrum of the flux.

The *direction* of movement of a particle is implied in velocity, and the direction in which particles are moving in various parts of space is important to an understanding of the Van Allen belts.

Modern applications of circuit components are more demanding than ever before. To meet the need for sealed contacts that can bear the tilt and vibration of mobile installations, Bell Laboratories engineers are now developing . . .

Position-Independent Mercury Contacts

C. E. Pollard

RELAYS employing mercury wetted sealed contacts have been in Bell System use for many years. The exceptionally long life and favorable load capability of these contacts have invited an extension of their use. Present models are limited by their sensitivity to position and shock; they must be mounted in a substantially vertical position and cannot be fitted to vibrating units. In order to overcome these limitations and extend their use, engineers in the Switching Apparatus Laboratory at Bell Laboratories began an investigation into contact design principles. This study has now resulted in the development of an experimental mercury contact which is position-independent, as well as quite resistant to shock.

The new contact, while embodying several improvements, still operates on the same principles. The contacting surfaces are thin films of mercury adhering to a substrate of solid metal. As the contacts close, the mechanical impact forces excess mercury out of the interface in the form of minute globules which impinge upon the glass walls and internal metal parts. When the contacts open, the mercury at the interface is drawn into a thin ribbon, which is eventually ruptured by the surface tension forces. A mercury cusp momentarily forms on each contact face and a free globule of mercury flies away from the gap. In a conventional, vertically mounted contact, the mercury lost at each operation returns by gravity to
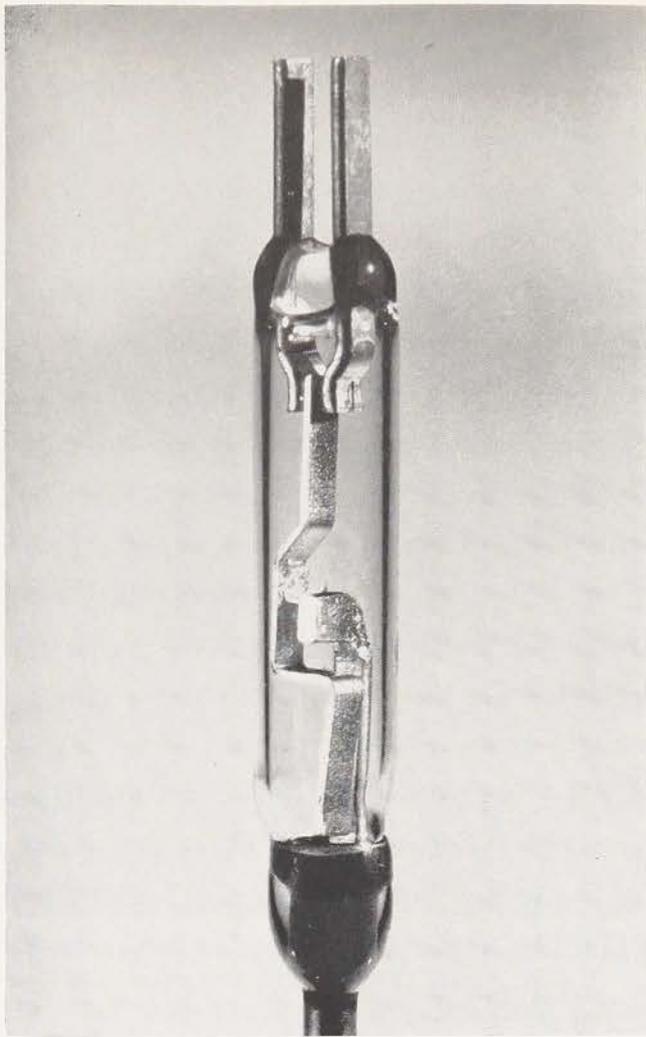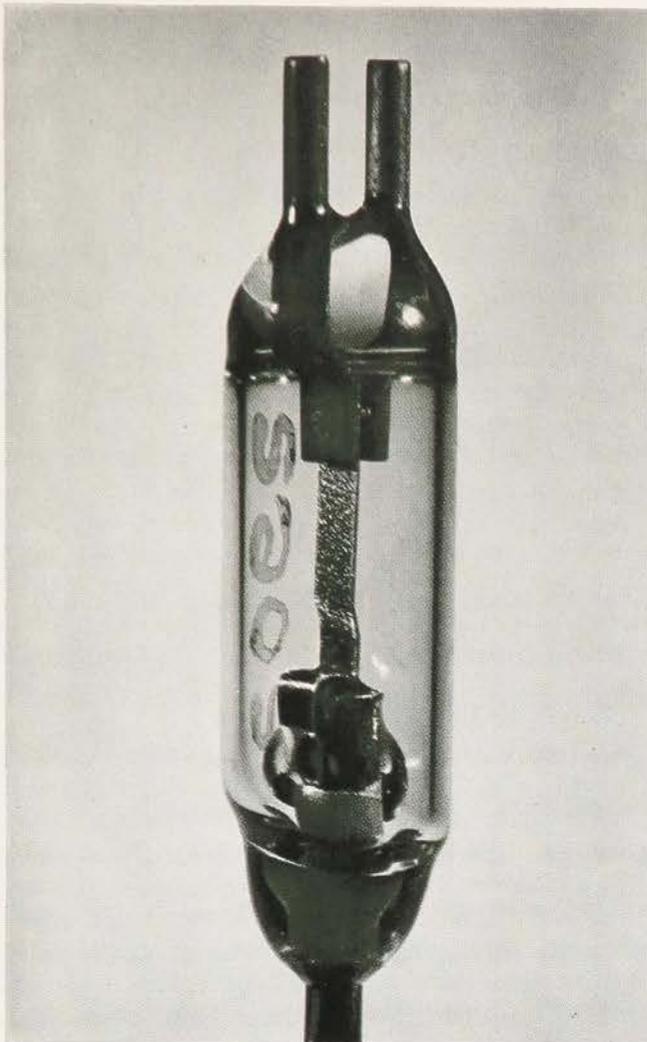
A conventional mercury contact (left) contains liquid mercury which limits its tilt. At right, the new, position-independent contact with no free volume of mercury. Both models are about one inch tall.

the bottom of the enclosure. From this reservoir it is returned to the contact interface by way of capillary paths through the armature.

Function of Reservoir

The reservoir is the chief factor distinguishing old contacts from new. In conventional contacts, this reservoir serves two functions. Not only does it replace the mercury lost at each operation, it also determines the hydraulic forces at the interface. These forces are opposed by surface tension, which is itself controlled by contact geometry. The balance between surface tension and hydraulic forces determines the amount of mercury at the interface, and thus the operating properties of the device. At the time when some mercury is returning from the walls of the capsule to the reservoir and some is returning to the contact area, enough mercury must remain in the reservoir at all times to maintain the necessary hydraulic forces.

To insure that operating characteristics remain stable, the design of the reservoir includes a generous volume of mercury. This liquid, however, limits the permissible tilt of the sealed contact from its vertical axis: Excessive tilt would create excessive changes in the hydraulic forces at the interface, thus destroying the balance. Restricting the tilt has generally been acceptable in connection with stationary installation, but it excludes mobile applications where tilt, shock and vibration may be encountered. A development program was initiated to overcome this limitation.

One of the first methods explored for achieving position independence is that of reducing the vol-
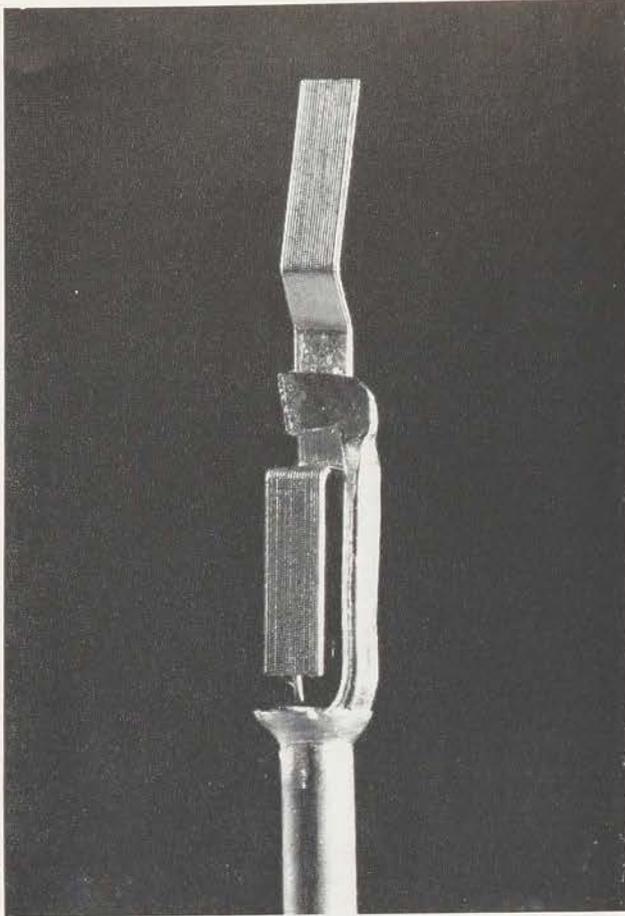
A greatly expanded view of the contact armature or "reed" shows the tiny capillary paths which carry the mercury to the contact area.

ume of mercury in the contact to the point where none remains freely movable. In the completed device there is only enough mercury to wet specific metal parts of the contacting mechanism and only to the degree desired. If only the stationary contacts of precious metal and the moving armature are coated with mercury, the mercury is held in place by adhesion to the metal surfaces and by the surface tension. Forces due to gravitational hydraulic effects are negligible in comparison with these forces and the device becomes position independent.

In the operation of a contact with this design, as with previous designs, a small amount of mercury is lost from the contacting surfaces at each operation. Since no reservoir is provided, most of this mercury cannot return to the contacts. The life of the device is therefore largely limited by the amount of mercury initially provided. As these contacts operate, the lost mercury is replaced from that adhering to the armature. The decrease in volume increases the surface tension

tending to hold the mercury to the armature and the armature to either of its fixed contacts. The surface tension configuration is also changed.

Changing Sensitivity

This has two consequences in terms of contact performance. First, the ampere turns required to operate a relay having such a contact will change with use. As mercury is lost, more power is required for operation. Second, the device will be sensitive to acceleration forces in proportion to the amount of mercury initially supplied: The more mercury, the greater the sensitivity. As the contact is used and the amount of mercury decreases, the resistance of the device to shocks and vibration improves. Thus, increasing mercury extends contact life and improves operational stability while decreasing mercury improves shock resistance and position independence. In order to attain desired device characteristics for a particular application, we must therefore control the amount of mercury included.

Many ways can be conceived to effect this control. For example, the desired amount of mercury could be established by weight or volume before its insertion into the sealed contact. Then again, a distillation process could be adapted to increase or decrease the amount of mercury. In our experimental work, however, we have elected to insert more than the required amount of mercury initially and then to centrifuge off the excess. Centrifugal forces are readily adjustable to any desired value, thereby providing close control of the amount of residual mercury.

Two-Bulb Assembly Technique

For this technique, the contact is assembled as a two bulb unit, one bulb containing the contact

The new contact is initially assembled as this two-bulb unit. When the internal parts have been properly coated, excess mercury is centrifuged off into reservoir bulb, which is then removed.
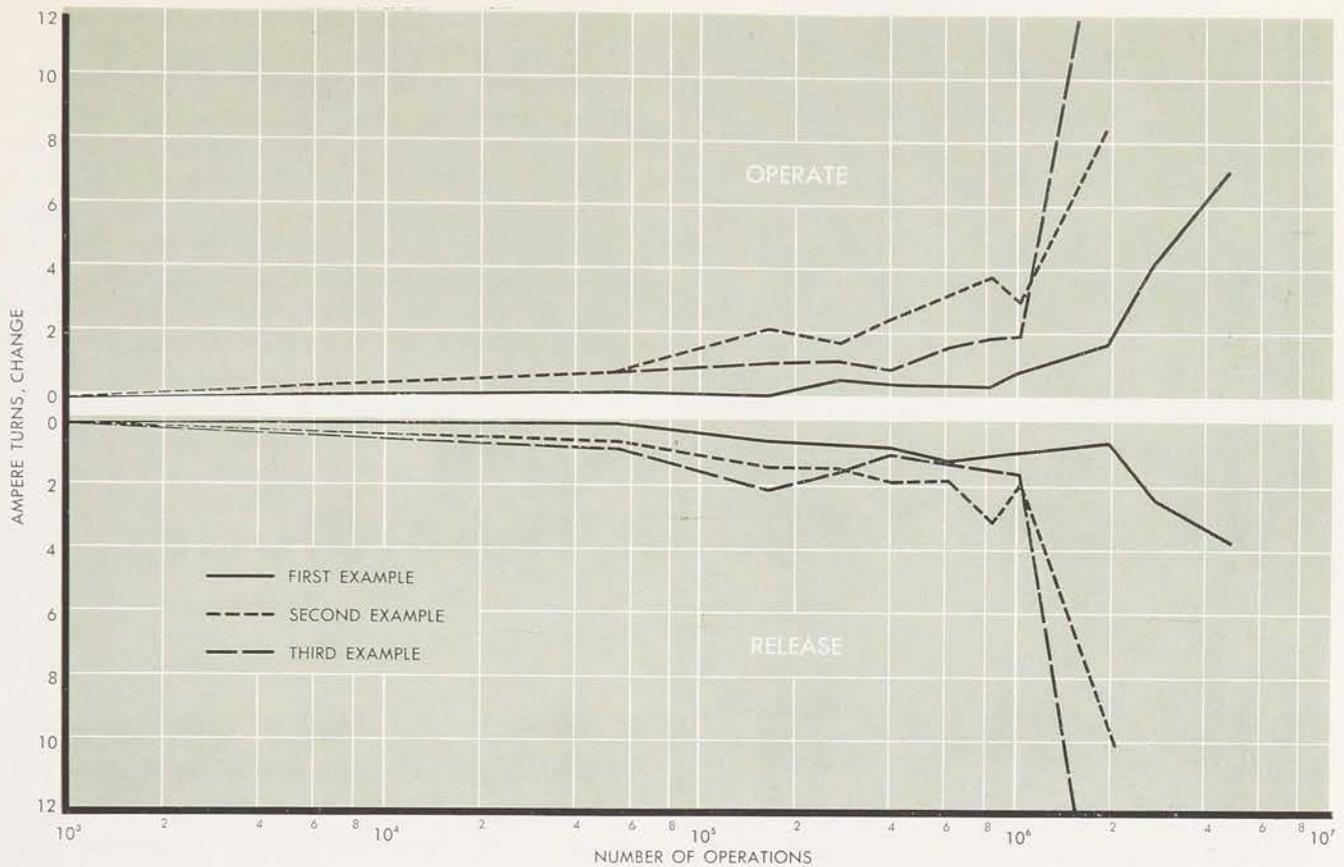
Graph shows the variation in ampere-turns required to operate the new contact as its "life" increases. Power demands can be anticipated and applications chosen accordingly. Improved models and more precise control of manufacture should bring future tests into closer agreement.

and the other a mercury reservoir. The mercury flows freely between them through a connecting tube. The whole assembly is pressurized, then sealed by closing the reservoir bulb. After processing to cause the mercury to wet the appropriate parts of the finished, sealed contact, the assembly is centrifuged to the desired degree, excess mercury collecting in the reservoir bulb. The tube between the bulbs is then closed by welding and the reservoir cut off. The short spring welded to the center of the reed and the contoured shape of the reed constitute a substantially balanced armature structure which is desirable if the contact is to have good resistance to shock and vibration.

Extensive Test Program

Numerous test runs were performed on contacts assembled in this manner. Centrifugal forces from 10 to 70G were applied for periods of one minute. The amount of residual mercury varied between 5.5 and 35.0 milligrams, with an appar-

ent logarithmic dependence on applied force over the range considered. Tests on the progressive change in operate-and-release ampere turns with life show a considerable spread in behavior, as shown in the graph above. The irregularity in these data probably results from differences in manually-prepared samples, but the expected trends are nevertheless evident. More information on these trends and their reproductibility will be available as the construction and testing of additional models continues.

The early results from this continuing program have confirmed our objective of designing a contact with significant new characteristics. Resistance to shock and vibration as well as position independence can now be controlled within a given range. Contact life and stability can also be regulated according to the amount of residual mercury present. Thus not only can we increase the selectivity for particular applications, but we can also considerably broaden the overall range of applications.

Christmas week saw a group of university and college professors gathered at the Holmdel and Murray Hill locations, for a . . .

Science and Engineering Symposium Held at Laboratories

On December 27th and 28th, the Laboratories was host to a group of 128 professors and instructors from the engineering and science departments of 94 different colleges and universities. These men spent a day each at Holmdel and Murray Hill listening to papers on the general subject of "Science and Engineering in Communication and Military Systems." Demonstrations and tours of pertinent areas at each location were also arranged.

The symposium was designed to foster a greater understanding in academic circles of Bell Laboratories' over-all aim in the advancement of communication systems and related military technology. The relationship between academic programs and basic research and device design programs at the Laboratories is well understood. Somewhat less clear, but equally important, is the need to couple closely the work on the design of large scale systems with the scientific and engineering concepts coming from the colleges and universities. Hopefully, the symposium will lead to an exchange of ideas in this field.

Transmission System Design

After a brief welcome by J. B. Fisk, President of the Laboratories, C. H. Elmendorf introduced the first morning session, devoted to transmission. In the first talk, R. W. Hatch discussed the general approach to the design of a transmission system, using as a particular example the design of a satellite communication system. First, an initial determination of the objectives is made in terms of the type and quality of service to be provided. Then, specific system configuration that look promising are considered, and an evaluation of the various possibilities is made. The initial evaluation is normally based primarily on technical considerations, but economic, legal and schedule factors also play an important role in the final choice. Detailed block diagrams and system requirements are then prepared to guide the development work which follows.

In the satellite communication system used as the example, there are two quite different approaches which have been proposed—medium altitude satellites in random orbits and high altitude satellites in "24-hour" orbits. Each presents advantages and disadvantages. For example, while the high altitude system could provide world-wide coverage with only three satellites, in contrast to the 30 to 50 required in the medium altitude system, there would be concurrent problems of "station-keeping" to keep the satellite properly positioned in orbit. Of particular concern is the need for a reliable, long-life means of propulsion. There is also the inherent transmission delay implied by the altitude—22,400 miles —amounting to 600 milliseconds per round trip, which would give rise to problems in echo suppression.

For the purposes of illustration, the decision was made to provide enough bandwidth to carry television; this bandwidth would automatically

provide enough capacity to carry all other types of communication signals envisioned at the time. The quality of performance desired was set at a weighted signal-to-noise ratio of 55 db. Because of the extreme distances involved, and the consequent weak received signals, this particular objective has a major effect on system design and was therefore selected for specific consideration in this example. Mr. Hatch showed graphs indicating the effects of variations in various system parameters, including the effects of satellite altitude, communication frequencies, and the type of modulation. He also discussed the various possible combinations which could be built into a medium-altitude satellite system using frequency modulation to achieve the desired 55 db S/N, as shown in the chart at right.

In conclusion, Mr. Hatch pointed out that the design approach is similar for all transmission systems. However, each has its own unique and challenging problems.

Submarine Cable Laying

In a paper on submarine cable laying R. D. Ehrbar discussed the rapid expansion of repeatered submarine cable systems for multichannel telephony during the past decade. Radical new methods which have recently been developed for laying such systems were described, along with possible approaches for even more advanced techniques. The problems associated with laying the new non-armored cable and its companion two-way repeaters (RECORD March 1962) were detailed.

The major criterion in laying cable, according to Mr. Ehrbar, is that it must cover the bottom *exactly*: if the cable it too tight, it "hangs up" and is subject to damage from any dragged object, as well as to breakage; if it is too loose, cable is wasted and excessive attenuation results. Another major problem is that the cable must not be damaged during the laying process, either during the time that the cable engine is "pushing out" the cable in shallow water or holding it back in deep water, or when the engine comes to the discontinuity of the repeater.

The major problems in cable laying lie in the lack of knowledge of the environment, in the motion of the ship, and in the fact that cable, once laid, cannot be adjusted or repaired easily.

In discussing the current development programs in cable laying, he then discussed the fundamental forces acting on the cable during laying procedures, and the difficulty of obtaining meaningful data from scale model towing tanks. Some of these data were found to vary by as much as 30 per cent from the results obtained

	Telstar	A	B	C
Satellite Power in Watts	2	20	2	8
Orbit Altitude in miles	3500 max.	7000	7000	7000
Satellite Antenna Gain in db	0	0	10	10
Ground Receiver Antenna Gain in db	57	57	57	54
System Noise Temperature in Degrees K	50	50	50	100
Peak Frequency Deviation in mc	7	15	15	15
IF Bandwidth in mc	25	40	40	40
FM Breaking Margin in db (with Conventional Receiver)	4	6	6	6
TV S/N in db	34	46	46	46
Weighted S/N in db	43	55	55	55

Chart shows "trade-offs" possible in design of a communication satellite to achieve a desired S/N.

during sea trials. To try to find out why, a special sea trial will be made this summer with instrument packages built into a cable section. These instruments will measure such variables as pressure, tension and acceleration as the cable is laid, and hopefully will provide more precise knowledge of actual laying conditions than has been available heretofore. An illustration of the instrumented cable is shown on page 64.

Mr. Ehrbar also briefly described tentative design work being conducted on methods for burying submarine cable on the ocean floor, either as it is laid or afterwards, as a second operation. Such burial, to a depth of perhaps 12 inches, would eliminate much of the problems of breakage now associated with dragging operations of trawlers or anchoring ships. Little knowledge is available on methods for trenching under water, or even on the characteristics of the ocean bottom which would bear on such an operation. Only very tentative work has been done in this field so far, but indications are that such efforts will prove extremely valuable in submarine cable systems of the future.
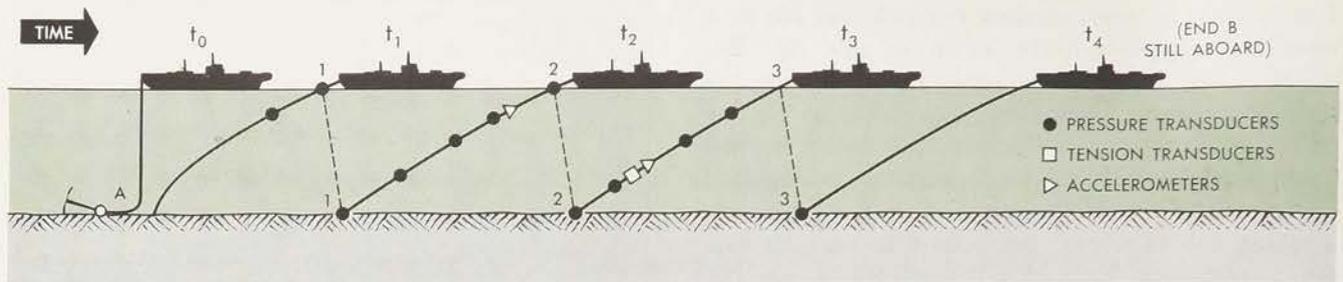
Schematic of cable instrumentation for sea trial, to determine meaningful cable-laying data.

Digital Transmission

W. O. Fleckenstein then presented a paper on the subject of digital transmission in communications, including both the transmission of typical analog signals encoded in digital form, and the transmission of data initially generated in digital form. An important consideration in meeting the data need is the existing communication network, including the nationwide switched network, which has evolved primarily to satisfy voice communication requirements but has much more general capabilities. Mr. Fleckenstein mentioned the background of communication theory that has built up to deal with these problems. He emphasized some of the factors which make it difficult to apply this theory to the practical situations encountered. One of the outstanding ones is the difficulty in characterizing the "channel" when dealing with any one of a large number of switched connections. He discussed various different modulation and detection techniques and their general speed capabilities.

These techniques include binary frequency modulation, a good choice for moderate speed transmission. This technique is embodied in the presently-available FM Data Sets which transmit at the rate of up to 1200 bits per second over the switched network and up to 1600 bits per second over private lines (RECORD *December* 1962).

For higher speed transmission, Mr. Fleckenstein indicated that theory suggests a technique which is efficient of bandwidth such as vestigial sideband transmission with coherent detection. Quaternary phase modulation, however, gives the same performance under ideal conditions and has two important practical advantages: 1) it is somewhat more tolerant of transmission distortions normally encountered, and 2) it can, at a small penalty in signal-to-noise ratio, avoid the problem of recovering a demodulating carrier by coding successive symbols into changes of phase rather than absolute phase. Mr. Fleckenstein suggested that the 4-phase data set represents a good balance of speed, performance, and complexity, and discussed the characteristics of the PM Data Set, (2000 bits per second over the switched network, 2400 bits per second over private lines). He also commented on the extension of these techniques to very much higher speeds on wideband channels.

Mr. Fleckenstein then turned to a discussion of the various methods of coding for error detection and correction that are possible in data transmission systems. This included a discussion of the statistics of errors as they occur in data transmission—whether they occur singly or in bursts— and how this affects the conception of the error detection or correction system being used. He reviewed the results of some recent experiments made over regular switched network connections with a partciular code involving error detection with retransmission of sections of the data in which errors are detected. He also reviewed the important parameters (efficiency, delay, and memory) of an error control system involving error control by detection and retransmission but with input and output at essentially fixed speed.

In the final section of his talk, Mr. Fleckenstein reviewed the principles of pulse code modulation, and described its current status in the transmission of analog information. The PCM technique is attractive for reasons of both economy and performance, he said. For example, the terminal equipment can be made economical by time-sharing complex equipment among a large number of channels. Also, since the signal being transmitted is a binary signal, capable of being regenerated, the system is very rugged in the transmission sense. For example, the T1 Carrier System described can operate over ordinary paper-insulated copper wires at speeds of over 1,500,000 bits per second with regenerative repeaters spaced at 6000 foot intervals. A third important point is that the digital line can be used

for various signals such as voice and data, up to the limit of its capability.

As in every type of transmission system, of course, PCM is not without its problems. Pulses cannot continue to be regenerated indefinitely, since in practise some degradation builds up due to imperfect timing of the regenerative repeater. There is also some "quantizing noise," which results from the discrete encoding of each sample to convert the analog signal into digital form. Also, as the techniques are extended to handle very wideband signals, the speeds and accuracies involved become severe. Mr. Fleckenstein commented on exploratory work being done on extremely highspeed PCM systems involving, for example, sampling times of less than one-half nanosecond—the length of time it takes light to travel about five inches! Obviously, the equipment involved in such systems must be extremely precise and the circuits very short to accomplish the required functions.
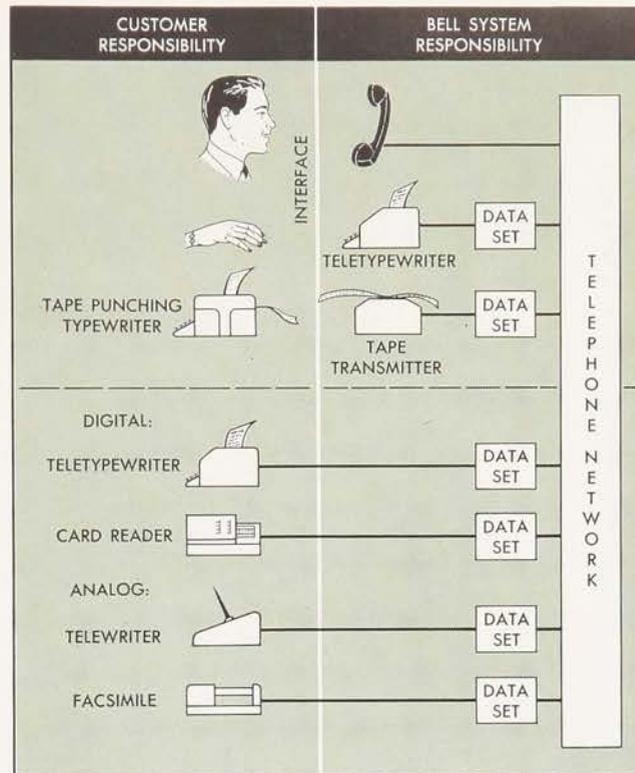
Speech Transmission

In the last paper of the morning session, E. E. David discussed the characteristics of human speech which suit it so admirably for communication. Not only does it incorporate an efficient linguistic code, but it defies the inroads of babble, reverberation and noise. Today, electrical communication devices and systems have extended its utility far beyond the speaker's immediate environment. However, speech in its raw form, according to Mr. David, requires a large transmission bandwidth and signal-to-noise ratio. Fortunately, speech can be represented in a more efficient form; significant bandwidth reduction can be realized by transmitting not speech itself, but a description of it, based on a knowledge of its production mechanism, the human voice tract. Mr. David described and illustrated a number of the methods of describing the vocal tract in a way useful for electrical transmission. He then showed how speech could be recreated at the receiver, from these descriptions, by a synthetic "talker."

He also described research aimed toward creating artificial speech from an input of phonetic symbols, and played samples of audio tapes produced in these experiments. The results, he said, have given us confidence that we now understand speech well enough to utilize artificial speech for voice read-out from information storage systems.

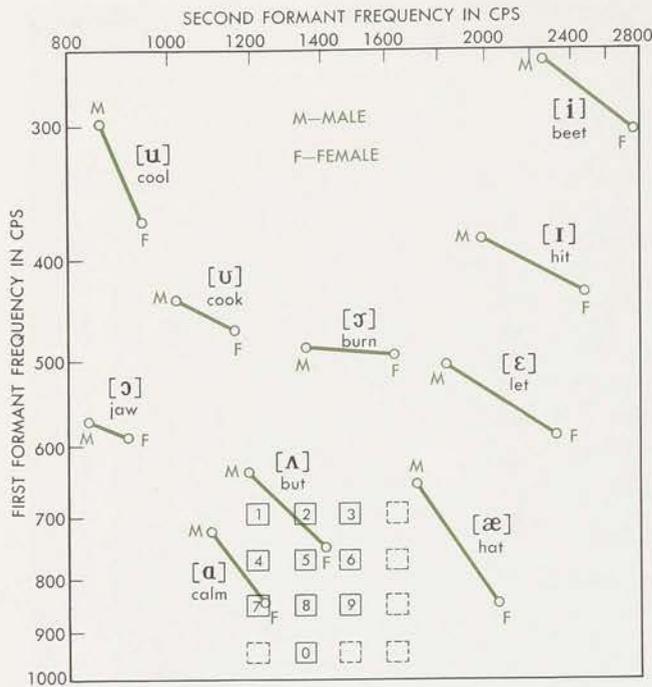### Telephone Switching Systems

Following lunch and a tour of the Holmdel laboratories, R. W. Ketchledge opened the afternoon session on Switching. In the first paper of

Typical inputs for digital transmission system.

the afternoon session, William Keister presented a broad-brush picture of telephone switching systems — how they are organized, how they have evolved, and what is in store for them in the future. With block diagrams and photographs, Mr. Keister showed how the first type of switching system—step-by-step—operated to connect a relatively limited number of telephone customers. He pointed out how, in the 1920s, the panel system—with more centralization and a decoder (for translating digits to a systems code) —achieved considerably more flexibility than the step-by-step system. The biggest advance in electromechanical telephone switching, according to Mr. Keister, came with the advent of crossbar systems in the late 1930s. With crossbar systems, small relay switches are able to make as many as 20 simultaneous connections. Great flexibility was achieved through a "marker", or central control which contains the logic of the interconnections made by the system.

Mr. Keister then explained how—with the discovery of the transistor in 1948—the door opened to electronic switching systems. "The trend in the evolution of telephone switching systems," said Mr. Keister, "has been to centralize functions." Electronic switching systems exemplify such centralization. A central processor routes information from a scanner through a

SECOND FORMANT FREQUENCY IN CPS

FIRST FORMANT FREQUENCY IN CPS

M—MALE
F—FEMALE

[i] beet
[u] cool
[I] hit
[ʊ] cook
[ɝ] burn
[ɛ] let
[ɔ] jaw
[ʌ] but
[æ] hat
[ɑ] calm

1 2 3
4 5 6
7 8 9
0

Comparison of the formant frequencies of typical vowel sounds contrasted with TOUCH-TONE *Signals.*

temporary and semi-permanent memory to a distributor and into the telephone trunks.

Electronic Switching

This briefing on the general aspects of electronic switching systems was followed by Mr. R. W. Ketchledge's talk on system techniques in electronic telephone switching. In designing an electronic system with stored program control, Mr. Ketchledge emphasized dependability as an absolute requirement. In this regard, he was referring not to the failure of a particular component, but to "outage"—that period of time during which a system is not functioning. "The most difficult thing the machine has to do is to stay alive," said Mr. Ketchledge. And he added, "Here we are talking about machine immortality."

Mr. Ketchledge discussed the trial of the experimental electronic central office in Morris, Illinois, and commented briefly on stored program control, automatic diagnostic techniques, duplicate switching organization, programming strategy, and hardware considerations.

TOUCH-TONE Signaling

As the last speaker of the afternoon at the Holmdel session, L. A. Meacham discussed a recent basic study related to TOUCH-TONE Calling. He explained how the signaling system, although using signals in the same frequency band as voice, is protected against digit simulation by speech. Although TOUCH-TONE field trials have

shown that a false digit is registered by speech or other sounds only about once in 10,000 telephone calls and no longer represents a serious problem, Mr. Meacham stated that an examination of such simulations (1) provides a direct check on the performance of the receiver, (2) determines the accuracy of certain voice wave theories, (3) presents an opportunity to eliminate simulation completely, and (4) may turn up information useful in the development of other signaling systems.

He then reviewed the organization of the TOUCH-TONE system and told how the receiver distinguishes between speech and wanted signals. Using what we know about the formation of voice sounds, Mr. Meacham showed how qualitative and quantitative tests were used to analyze 57 speech simulations of TOUCH-TONE digits recorded on tape at the Laboratories. In some cases, voice sounds were converted to digital data and analyzed on a computer. The results of these investigations proved that the receivers are performing as intended, and confirmed the theory on which TOUCH-TONE signaling is based.

Defense Projects

The following morning, the scene again shifted, this time to the Murray Hill location, where W. E. Danielson opened the morning session on defense systems with a discussion of defense work and contrasted today's technological defense problems with those of the second world war. "Today, ballistic missiles travel at 4 miles per second compared to World War II aircraft traveling at 0.1 of a mile per second. The destructive capability of weapons has increased about one million times and the range of weapons carriers has gone from 500 to 5000 miles." This tremendous change in weapon capability, he pointed out, necessitates a considerable difference in the technological approach to defense problems. The three basic aspects of such an approach involve an evaluation of (1) the nature of the threat, (2) the requirements for effective defense, and (3) system "trade offs."

The physical constraints placed upon defense systems were considered by Mr. Danielson to be governed by the reaction time and the limitations involved in the nature of the ballistic threat. Here, the trajectory route plays an important part in determining what kind of warning systems and what kind of interceptors will be effective in the case of attack. The potential use of decoys along with armed ballistic missiles poses another serious problem. Mr. Danielson discussed the need to distinguish the armed missiles

from the decoys within a period of less than 30 seconds before impact. In this time interval, the effects of the re-entry environment on the attacking missile must be analyzed and the interceptor launched. He stated that the successful interception of a target requires the absolute coordination of the detection radars, the attack verification equipment, the high-confidence discrimination apparatus, the precision track radar, and the interceptor itself.

The broader system problems he mentioned concern the location of radar equipment as well as the location of the interceptors. Such decisions are, in turn, based on strategic, political, and economic factors. "The threat we face," said Mr. Danielson, "is not a static one, but an evolving one; we must meet it with forethought, because there is no room for hindsight."

Information Gathering in Missile Detection

In discussing the engineering solution to efficient surveillance, J. W. Schaefer, the second speaker, discussed the requirements of surveillance by the NIKE-ZEUS anti-missile system and the manner in which they are fulfilled by the "Acquisition Radar". The Luneberg lens receiving antenna employed in this radar received special emphasis. The function of such equipment is to detect the position of the target and automatically establish a "track" so that the rest of the system can effect an intercept.

Mr. Schaefer used the basic radar performance equation to illustrate the constraints on the designer of a scanning-type surveillance radar. The design process is a long series of compromises between many desirable characteristics. It was clear that there is no "pat" solution to a radar design, but only an optimum balance of competing attributes.

Many configurations of radars were proposed in the early days of the NIKE-ZEUS project to meet the requirement of surveillance. Some of these were illustrated and described to show how the concepts evolved to the track-while-scan solution finally chosen. A unique application of the Luneberg lens as the receiving antenna for the system was described in some detail as well as the actual installation of the completed radar on Kwajalein Island.

According to Mr. Schaefer, the criteria for measuring the excellence of a radar system "is how far away can an incoming missile be identified as a target to be engaged, and this is dependent on the characteristics of the data processing gear as well as the radar proper." Mr. Schaefer demonstrated how the NIKE-ZEUS system rejects huge amounts of uncorrelated noise data

to discern the trajectory of an attacking missile. With slides, he showed how the total number of reports decreases as data is processed by the NIKE-ZEUS logic equipment and a proven "track" is obtained. He also pointed out the need for ultra-reliability and infrequent adjustment of equipment, and discussed the testing and calibration of the NIKE-ZEUS system.

Pulse-Compression Radar

The third speaker during this second morning session was C. W. Hoover, who talked about pulse compression radar, and how the flexibility which this technique provides is one of the means of keeping up with the rapidly evolving threat in the ballistic missile defense problem. He developed the analogy between the pulse compression process and the processes of beam formation and steering in array antennas, and derived the appropriate parameters characterizing the performance of both systems.

Following lunch and a tour of the Murray Hill facilities, K. G. McKay, Executive Vice President, contrasted systems engineering in the power, chemical, and aerospace industries with systems engineering in the communication industry. "Systems engineering in the communication industry," said Mr. McKay, "is influenced by (1) complexity and the need for integration and (2) the fact that the communication industry chooses to sell a *service* rather than a *product*." In the first case, Mr. McKay pointed out that complexity involves not only the number of customers served, but also the variety of services which they require and the need to integrate both the communication network and the services that network carries. In the second case, he explained that "the feedback from customer to the systems design engineer poses a continuous problem of anticipating future needs by a thorough knowledge of existing systems.

In considering the organizational features of systems engineering, Mr. McKay mentioned four steps which must be taken to satisfy most communications problems: (1) defining the objectives, (2) specifying the requirements for the system, (3) considering alternative proposals, and (4) writing a prospectus containing the overall requirements for the system. Once these steps are accomplished, development can be started and field trials initiated. In touching on the similarities of systems engineering and what is termed "operations research," Mr. McKay remarked that "In both cases, it is necessary to know the properties of existing systems, because this is the environment in which future systems must work."

PATENTS

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

Barrett, W. A., Jr. — *Magnetic Memory Circuits*—3,067,408.

Bobeck, A. H.—*Magnetic Memory Circuits*—3,069,665.

Bowers, K. D., Kompfner, R, and Mims, W. B.—*High Frequency Generator*—3,067,379.

Brooks, C. E., Crofutt, G. B., and Henry, J. L.—*Distributed Line Concentrator System* — 3,070,-666.

Butenbach, R. W.—*Radiant-Energy Translation System*—3,-069,546.

Ciccolella, D. F., Forster, J. H., and Rulsion, R. L.—*Semiconductor Diode*—3,067,485.

Crofutt, G. B., Jr.—see Brooks, C. E.

David, E. E., Jr.—*Autocorrelation Vocoder*—3,069,507.

DeLange, O. E.—*Signal Translating Circuits Employing Two-Terminal Negative Resistance Devices*—3,069,564.

DeMonte, R. W. and Kopp, W. J. —*Negative-Impedance Repeater*—3,068,329.

Feder, H. S. and Manasse, F. K. —*Switching System*—3,068,322.

Feinstein, J.—*Electron Discharge Devices*—3,069,594.

Fleckenstein, W. O.—*Pulse Frequency Divider*—3,067,363.

Forster, J. H.—see Ciccolella, D. F.

Fuller, C. S. and Whelan, J.M.— *Treatment of Gallium Arsenide* —3,070,467.

Fuss, P. S.—*Junction Transistor Pulse Generator*—3,069,563.

Gianola, U. F.—*Magnetic Memory Devices*—3,069,661.

Gilman, G. W., Pullis, G. A., and Spack, E. G. —*Transmission control in Two-Way Signaling Systems*—3,069,501.

Gyorgy, E. M. and Nesbitt, E. A. —*Permalloy With Gold Additions*—3,067,029.

Haas, H. H.—*Order Wire and Alarm Circuits*—3,070,672.

Hamilton, B. H.—*Current Supply Apparatus*—3,069,612.

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Kompfner, R.—see Bowers, K. D.

Kopp, W. J.—see DeMonte, R. W.

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Nesbitt, E. A.——see Gyorgy, E. M.

Oliver, B. B.—see Kolding, A. R.

Pullis, G. A.—see Gilman, G. W.

Roscoe, L. C.—*Sequential Pulse Generator Employing Two Sequentially Actuated Monostable Multivibrators*—3,067,343.

Rulsion, R. L.—see Ciccolella, D. F.

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THE AUTHORS

G. N. Vacca

George N. Vacca, author of "Rubber and Its Use in the Bell System," is a native of Newark, New Jersey. He attended Cooper Union in New York City while working for the Celluloid Company in Newark, and received his B.S. degree in Chemistry in 1924. In 1925 he joined the Tower Manufacturing Company in Newark, where he stayed until 1928, when he moved to the Chemical and Dye Corp. in Springfield, New Jersey. He joined Bell Laboratories in 1930, and has worked in the field of rubber-covered wire and cable since that time. Mr. Vacca is a member of the American Chemical Society, the New York Rubber Group, and of several committees of the ASTM. He has held numerous elective and appointive posts in each of the organizations.

Robert W. Berry was born in Atlanta, Georgia and received his

R. W. Berry

secondary education from the public schools in that city. In 1950, he was graduated from Clemson College with a B.S. degree in Chemistry. He received the Ph.D. degree in Chemistry from Michigan State University in 1956. From 1951 to 1953, Mr. Berry served as a lieutenant in the Chemical Corps with duties as a physical chemist. He joined the staff of the Bell Laboratories in 1956, and has been with the Component Development Laboratory since that time. He is currently supervising a group working in thin-film circuitry. Mr. Berry's experimental studies of tantalum oxide resulted in the invention of the tantalum thin-film capacitor for which he holds the patent. Author of "Tantalum Thin-Film Circuitry and Components," in this issue, Mr. Berry lives with his family in Berkeley Heights, N. J.

A. E. Bachelet

A. E. Bachelet, a resident of Greenwich Village, New York, was born in Tacoma, Washington. He joined the Engineering Department of the Western Electric Company (which was later incorporated as Bell Laboratories) in 1923. He has been chiefly concerned in the design of circuits for radio and television switching, signaling and alarm facilities for the maintenance of microwave relay systems, electronic circuits for dial telephony and military networks. More recently he has been concerned with

signaling and transmission studies for private line systems. Mr. Bachelet is presently supervisor, Customer Telephone Systems Laboratory and is a co-author of the article "SS1 Selective Signaling System" in this issue.

H. J. Michael, co-author of SS1 Selective Signaling System, joined the Laboratories in 1929. He was engaged in studies relating to transmission quality, including the physical characteristics of speech and the structure of telephone conversation, signaling and switching development, and during the war, the design of underwater weapons. Since the war, Mr. Michael has engaged in the design and development of the No. 5 crossbar system. Mr. Michael joined AT&T in 1952, and after two years in its Administration B Department, he rejoined the Laboratories in the Special Systems Engineering Department. He now heads a group concerned with Government Service and Special Commercial Systems. This group has engineered such services as the SAC primary alerting system, SAGE, Air-to-ground and voice-communications, and the JCSAN system—a global conferencing system for the Joint Chiefs of Staff. Mr. Michael a native of Long Island now residing in Rumson, N. J., is a graduate of New York University with degrees of B.A. in mathematics and M.S. in physics.

H. J. Michael