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Telegraph Development

Automatic Private-Line Teletypewriter Switching System

Just as long-distance telephone calls must be routed and controlled by an integrated toll switching system, so must teletypewriter messages be routed and controlled by a central switching point. In the 81D1 private-line system, teletypewriter messages are picked up from stations all over the country and re-transmitted to their destination by a few strategically located switching centers. One important feature of the system is that temporarily undeliverable messages are stored at the switching center and then transmitted over the next link when it becomes free.

Within the past two decades, private-line teletypewriter networks supplied by the Bell System have assumed an increasingly active role in the conduct of modern business. Prior to 1940, teletypewriter messages had to be transferred manually between the various lines that comprised these networks. In that year, however, the situation was changed when the Bell System introduced the first automatic message switching system for teletypewriter networks. That first system has undergone many improvements, especially since World War II, and from it has evolved the latest version – the 81D1 teletypewriter switching system.

These teletypewriter switching systems have many points of similarity with long-distance telephone switching systems, but there is one major difference. When a telephone call cannot be completed, because either all circuits to the called station are busy or the called station is busy, the caller disconnects and waits until a circuit is free. However, when a teletypewriter message cannot be delivered to its destination immediately, it must be stored somewhere along the way and later sent on in its original form when a path becomes free. The 81D1 system not only stores and retransmits messages originating in any part of the system, but it also automatically transmits messages from the various stations as they become available, and delivers them only to the station or stations addressed. Urgent messages receive priority treatment. Messages addressed incorrectly, or to a machine temporarily out of service, are automatically intercepted and held for further handling. When several stations normally receive the same messages, they may all be reached by a single group code preceding a message. Further, when desired, an automatic address unit will properly address messages to selected stations or groups of stations simply by the operator pushing a button.

A typical 81D1 installation is that serving Trans World Airlines, Figure 1. The illustration at the head of this article shows the switching center at La Guardia Airport. L. E. Oatman of TWA operates the control panel while the authors look on. Miss Jean M. Cooper, Lead Switching Center Operator is at the desk.

Two switching centers, one in New York and another in Kansas City, are connected together by four two-way trunk lines and one one-way trunk line. These centers control numerous stations across the country. All major switching operations for the network are concentrated in the two switching centers, the outlying stations having only a minimum of equipment. Each switching center consists of input equipment for all incoming trunks and lines, output equipment to distribute messages to the proper outgoing trunks and lines, and cross-office paths to connect the equipment together. These cross-office paths, using crossbar switches and various control circuits, provide a maximum of system flexibility.

Switching centers connect with other stations in the 81D1 system over four different types of facilities: (a) trunk lines; (b) single-station lines; (c) local-outlet lines; and (d) multi-station lines.

Trunk lines connect switching centers together directly, and serve no other stations. A trunk-group may comprise as many as ten trunks when desirable, access being through crossbar switches and a multiple-trunk circuit. When a single trunk is used, two cross-office paths feed two outgoing circuits, and they in turn feed the trunk alternately. This arrangement keeps traffic moving at a high rate.

Single-station lines are used where a separate line to a station is more economical because of traffic loads and the additional control equipment required at each station on a multi-station line.

Local-outlet lines connect the switching center with teletypewriters in the center itself and at various locations near the center. For example, the down-town ticket office of an airline would be a local outlet for a switching center located at the airport. Machines in local outlets are arranged for receiving only.

Most interesting, perhaps, is the multi-station line. This is used where the expense of separate lines outweighs the cost of additional control equipment at each station, and where traffic loads to and from the stations permit sharing a line. As an example, a multi-station line between San Francisco and Kansas City, Figure 1, is considerably more economical than separate lines to each of five stations

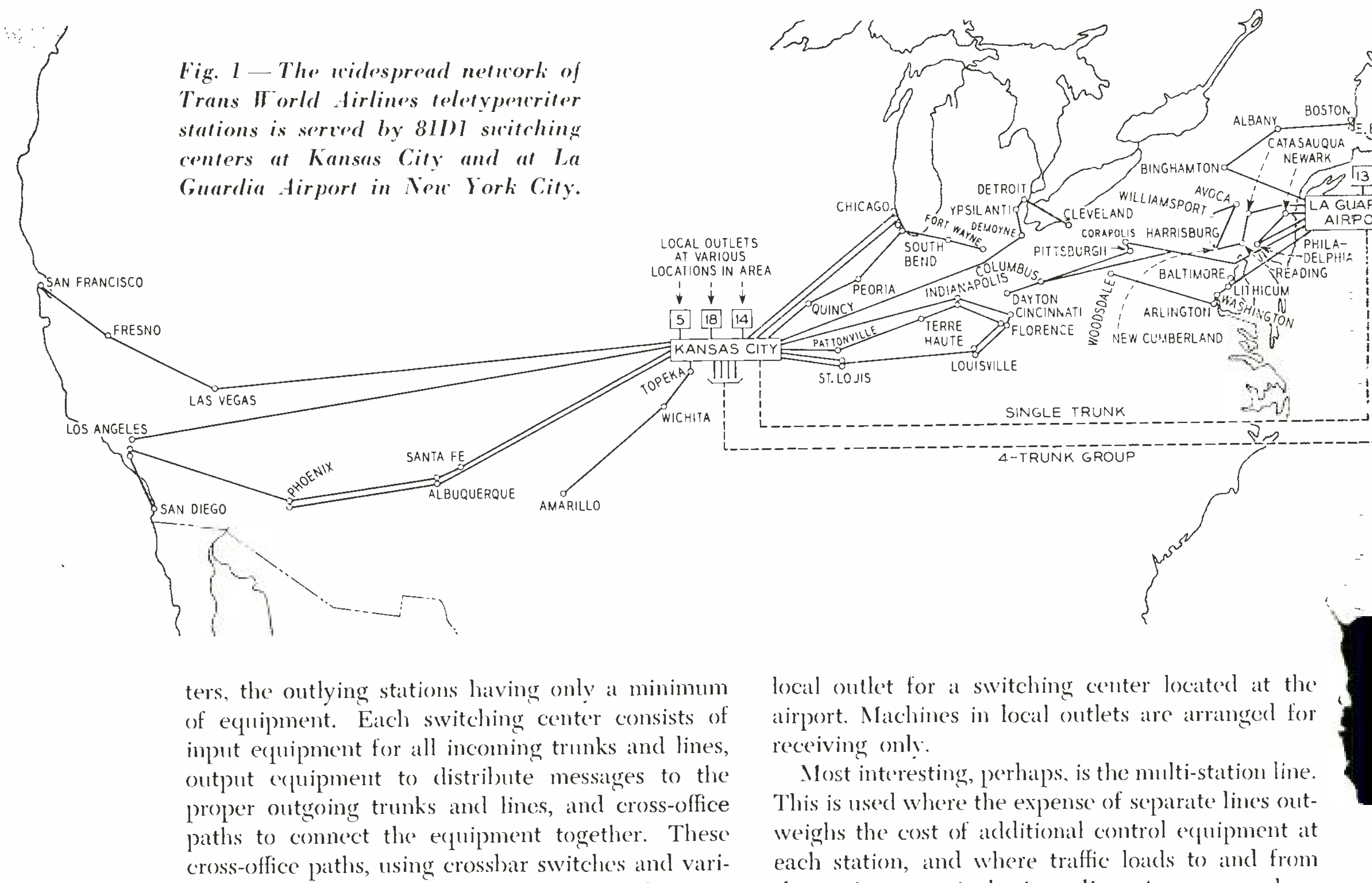


Fig. 1 — The widespread network of Trans World Airlines teletypewriter stations is served by 81D1 switching centers at Kansas City and at La Guardia Airport in New York City.

served at the three locations shown on the map. The job of the switching center is to pick up traffic from the various stations on the line as it becomes available, and distribute it only to the station or stations addressed, even if they are on the same line.

The entire system is operated from punched paper tape. An originating operator types an address code and message on a perforator, which has a keyboard very similar to that of an ordinary typewriter, and the perforator produces a punched tape. This tape is then placed in an automatic transmitter that is under control of the switching center. Once the message has been prepared in this way, the operator can forget about it and do something else; the message will be sent automatically when the line is free. Often a message will be addressed to more than one station; the operator merely precedes it with a two-character code to indicate that it is a multiple-address message and types the addresses in code form; the system does the rest.

At the switching center, the heart of the system is a machine called a reperforator-transmitter, or simply R-T. This combines a typing reperforator — which both punches and prints the message on a tape — and a tape transmitter. An important feature of the machine is that tape can be punched and temporarily stored until an outgoing line is free. With the exception of those originating at the switching center, all incoming messages are received on an R-T through an incoming line or trunk circuit, Figure 3. When desired, an incoming line circuit may be arranged so that messages destined for the switching center are printed directly on a receiving teletypewriter, instead of tying up an R-T.

As soon as tape is punched by an incoming R-T, a circuit known as a director reads the address and determines the availability of a path through the office. These directors are connected to crossbar switches through a sequence circuit, to prevent two or more directors seizing a cross-office path at the same time. A message with a correct single address will be directed through the switches to the appropriate outgoing line or trunk. When multiple outgoing trunks are provided, the message is transmitted directly over a trunk to the next switching center. For single trunks and single- or multi-station lines, the message is fed to one of a pair of R-T's through an outgoing trunk or line circuit. This R-T then stores the message and transmits it when the trunk or line becomes available. The two R-T's feed outgoing messages alternately to the trunk or line.

On a multi-station line, the handling of messages

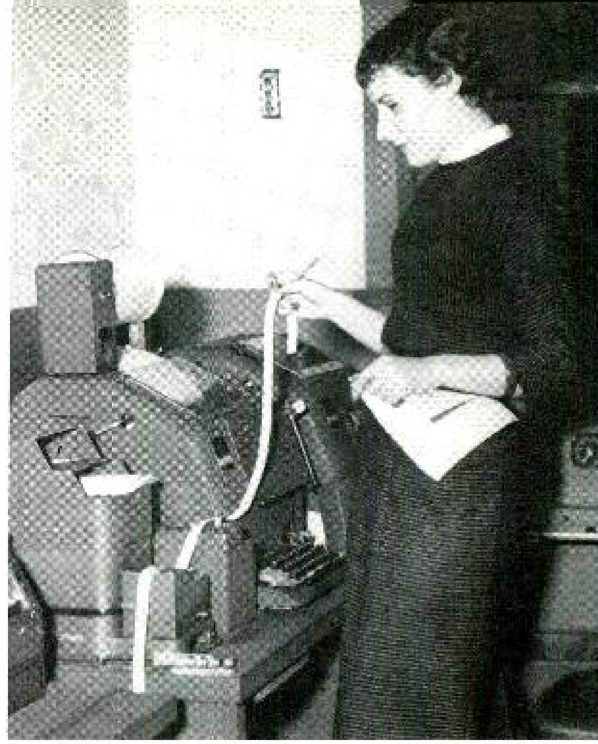
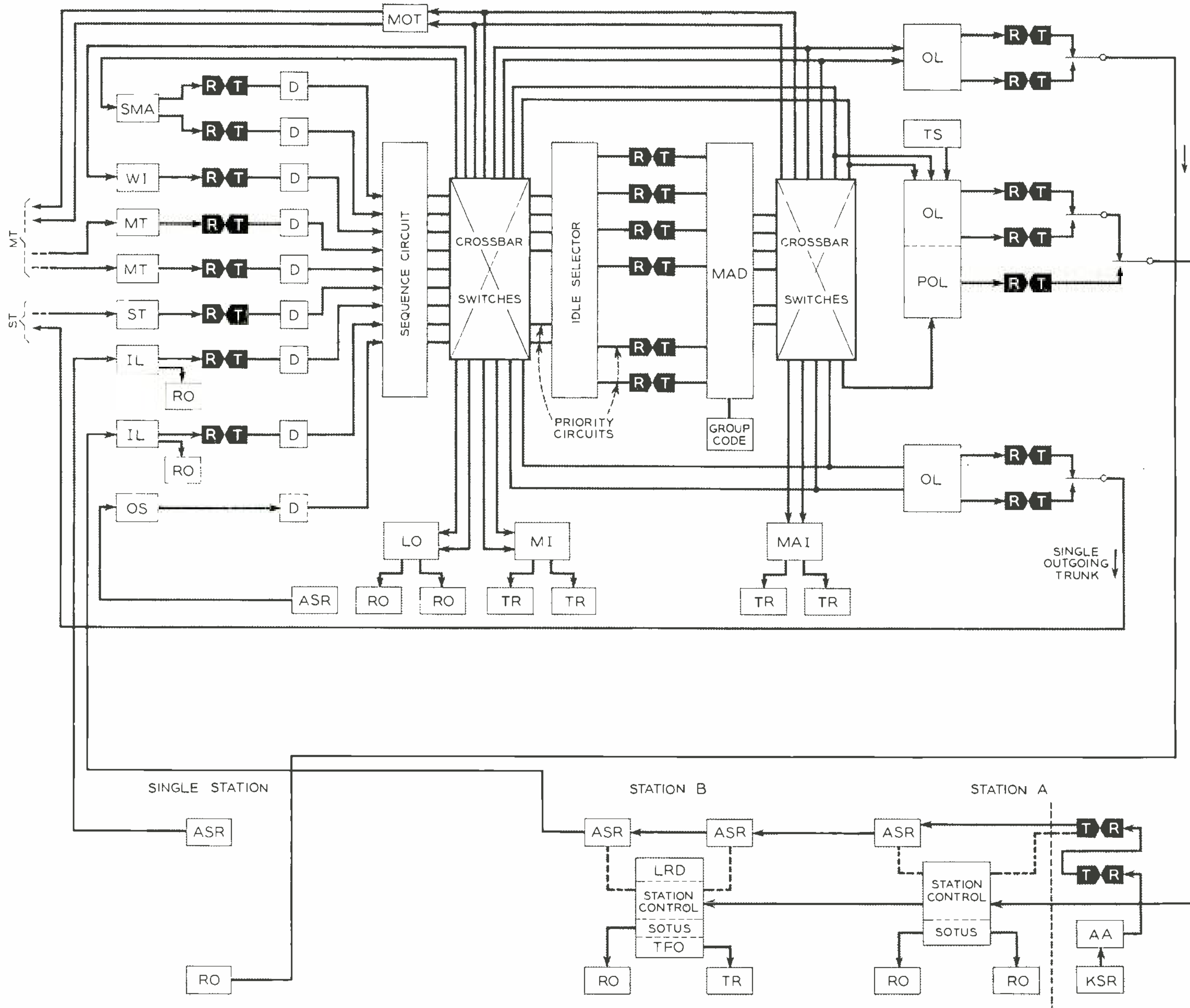


Fig. 2 — An outlying station on a multi-station line at La Guardia Airport in New York City. The operator is Miss Joan C. Walker.

involves more than simply feeding them to the line. The teletypewriter lines are arranged for full duplex operation — messages can be transmitted in both directions simultaneously. Two paths are used, one for each direction of transmission. If two teletypewriters on a multi-station line were permitted to transmit to the switching center at once, both messages would be on the same path and would interfere with each other. To prevent this, transmitters at the outlying stations are automatically started by signals generated by a transmitter-start circuit at the switching center. Moreover, to prevent receiving teletypewriters on a multi-station line from recording a copy of all messages that are fed to the line, the individual receiving teletypewriters must be kept disconnected from the line at all times except when messages are addressed to them. A control unit at each station on a multi-station line, Figure 3, includes a mechanical device called a SOTUS (Sequentially Operated Teletypewriter Universal Selector) to read switching codes and act upon them.

When no traffic is being received at the switching center from a multi-station line, the transmitter-start circuit automatically makes a roll-call of the transmitters on the incoming line, "asking" them in turn if they have any messages. Such an inquiry can be sent to the stations only over the outgoing line, which may be busy delivering a message to some station at the time. Therefore, the transmitter-start



LEGEND

R T	REPERFORATOR-TRANSMITTER	WI	WILLFUL INTERCEPT	ST	SINGLE TRUNK
ASR	AUTOMATIC SENDING EQUIPMENT (19-TYPE)	MI	MISCELLANEOUS INTERCEPT	MT	MULTIPLE TRUNK
D	DIRECTOR	MAI	MULTIPLE ADDRESS INTERCEPT	MOT	MULTIPLE OUTGOING TRUNK CIRCUIT
RO	RECEIVING ONLY (15-TYPE)	LO	LOCAL OUTLET	TFO	TAPE FEED-OUT CIRCUIT
KSR	KEYBOARD SENDING-RECEIVING (15-TYPE)	OS	ORIGINATING STATION	AA	AUTOMATIC ADDRESS CIRCUIT
TR	TYPING REPERFORATOR (14-TYPE)	TS	TRANSMITTER START CIRCUIT	LRD	LINE RELEASE DELAY CIRCUIT
SMA	SUPPLEMENTARY MULTIPLE ADDRESS CIRCUIT	OL	OUTGOING LINE CIRCUIT	POL	PRIORITY OUTGOING LINE CIRCUIT
MAD	MULTIPLE ADDRESS DIRECTOR	IL	INCOMING LINE CIRCUIT		

Fig. 3 — A typical switching center with three types of outlying stations.

circuit first interrupts transmission of the message, then sends a pattern of characters that causes the SOTUS units to remove temporarily any connected receivers from the line, and finally follows this by a single-character code that is assigned to a particular station.

Each transmitter remains inoperative until its code is recognized by its SOTUS unit, and then starts sending. When a station has no more traffic to send, the transmitter-start circuit interrogates the next station. If it has no traffic ready, its SOTUS generates a single character to so notify the switching center, and the roll-call continues. When no traffic remains at any station on the line, the transmitter-start circuit restores any receivers that were disconnected, and then remains inactive for a short period before starting another roll-call. Meanwhile, the sending of outgoing traffic is resumed. Thus, interruption of outgoing traffic is accomplished without mutilation of the copy at the receiving stations.

Messages are often addressed to more than one station, and frequently to the same group of stations. Such traffic is handled at the switching center by a multiple-address circuit, through an additional group of R-T's. Multiple-address messages are directed through the crossbar switches and a selecting circuit to an idle R-T in the group. From the transmitting side of the R-T, copies of the messages are fed to the proper outgoing lines through additional crossbar switches, the multiple-address circuit determining which lines are required. Priority traffic, whether single- or multiple-address, is also handled by the multiple-address circuit for preferential treatment and some of the associated R-T's are assigned only to such traffic.

When a large volume of multiple-address traffic is being handled, a supplementary multiple-address circuit can be called into use. Certain types of multiple-address messages are directed to this circuit, which feeds them to the receiving side of as many R-T's as there are addresses, breaking each message down into several single-address messages. Each R-T then sends its copy of the message to a particular station.

When messages are frequently sent to the same group of stations, an originating operator need not send all the addresses of the group. Associated with the multiple-address circuit is a group-code circuit. When an operator sends a predetermined two-character code, the group-code circuit recognizes the code and instructs the multi-address circuit to send the message to all stations in the group.

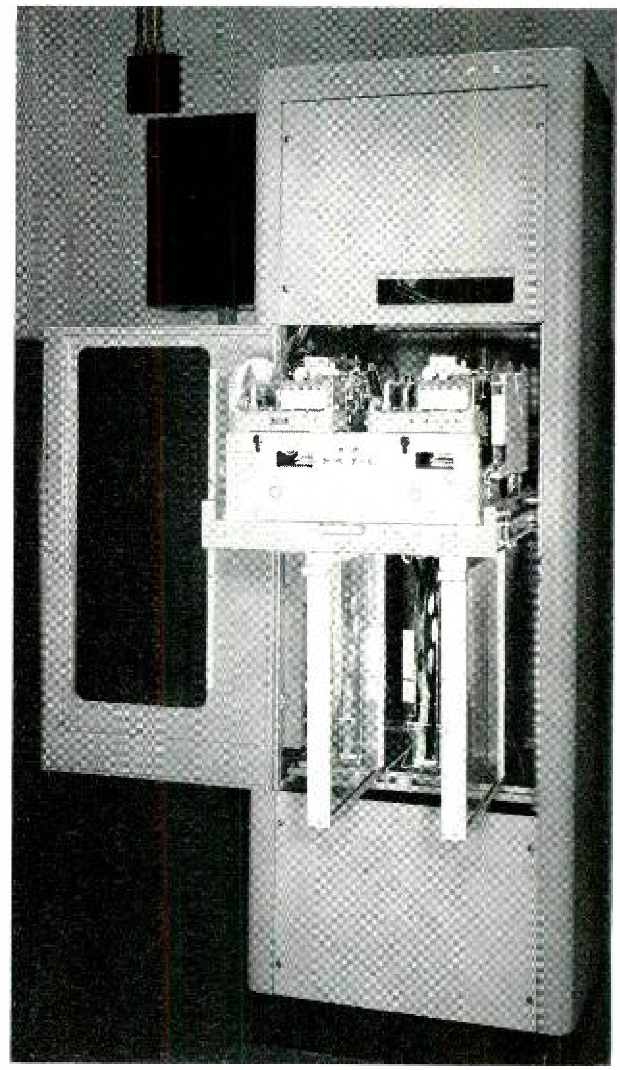


Fig. 4 — An automatic-address unit used at some outlying stations.

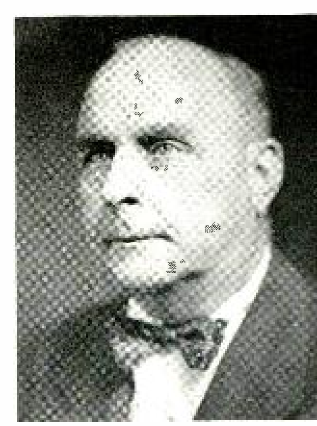
In certain instances an operator may be required to send a message without knowing its destination until the message is completely typed. For faster service under such conditions, an automatic-address circuit has been included in the 81D1 system. The operator types the message, omitting all address codes, which punches tape in one of two non-typing R-T's. When the message is completely typed, he simply presses an address button on the automatic-address unit. This causes an "end of message" code following the message to be punched in the tape of the first R-T and, immediately thereafter, all addresses corresponding to the chosen button are automatically punched in the tape of the other R-T. The first R-T then transmits the entire message, including the "end of message" code, to the second R-T where it is punched following the addresses. While this is in progress, and while the resulting final tape is being transmitted over the line, the operator can be typing another message. Although developed to supplement air-to-ground communications, the automatic-address feature can be used wherever message coding at a station involves fixed groups of addresses.

To safeguard all messages, each switching center has several types of intercept circuits. Should a message be addressed to an office temporarily out of service, or to one that has closed for the day, a "willful-intercept" circuit, Figure 2, permits attendants at a switching center to hold the message in an R-T until it is deliverable. Two other intercept circuits – one for single-address and one for multiple-address messages – automatically intercept messages received at the switching center incorrectly addressed, and messages whose addresses may be garbled by line or equipment trouble. These two circuits sound an alarm when the message is intercepted, warning the attendant that something is wrong. He may then properly address the message and send it on its way.

Naturally, any automatic system will encounter occasional trouble. In the 81D1 system, each switching center is equipped with a testing center for testing and repairing all the various components. A test bench provides the necessary facilities for testing and repairing the teletypewriter machines. In addition, the operational circuits can be patched to a test unit for checking, and spare circuit units can be substituted in cases of trouble. Periodic checks of the lines and stations are made by the transmitter roll-call feature. All observation and control of traffic in the portion of a network served by one switching center is handled through a central control board.

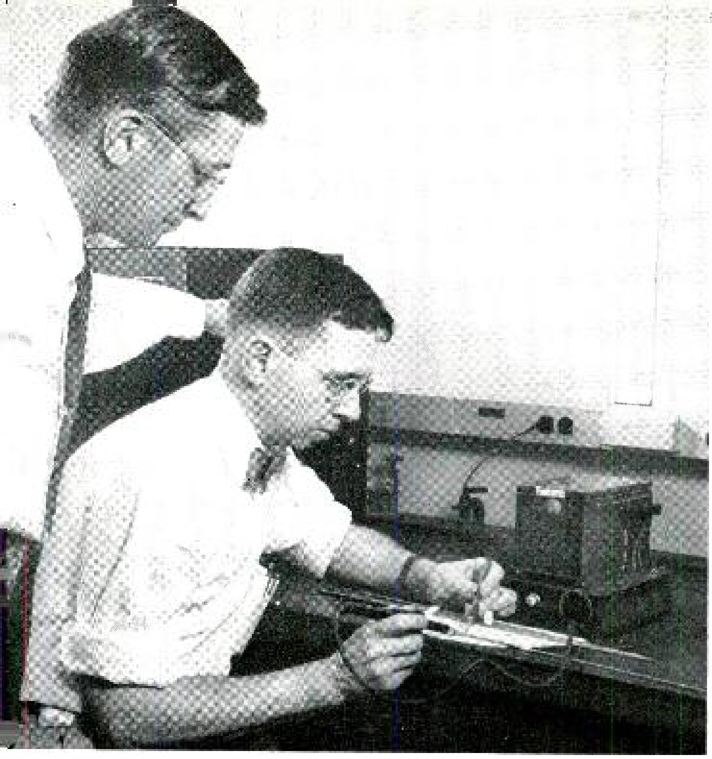
The versatility and popularity of the 81D1 system can be seen by the fact that six are in service and several more are on order. Three serve major airlines, one serves E. I. du Pont de Nemours and Company, and one serves the Federal Reserve System. The sixth will be used by the Civil Aeronautics Administration, together with a magnetic drum storage arrangement, to evaluate this method of handling weather information and flight plan data for military and civilian aircraft.

THE AUTHORS



GEORGE A. LOCKE entered the Bell System through the New York Telephone Company, transferring to the Engineering Department of Western Electric, now the Laboratories, in 1916. He received the Bachelor of Science degree in 1920, and Electrical Engineer in 1923, from Cooper Union. He has been a licensed Professional Engineer in the State of New York since 1925. Since joining the Laboratories, Mr. Locke has been concerned with the development of teletypewriter circuits and uses, including the design of circuits and apparatus to permit the use of teletypewriters on trans-oceanic telegraph cables. In 1928 he was placed in charge of circuit design for the Bell System Teletypewriter Switching System (TWX) and Automatic Teletypewriter Systems for private-wire networks. Mr. Locke became Telegraph Development Engineer in 1953.

EDGAR R. ROBINSON received the degrees of B.E.E. in 1929 and M.S. in 1930 from Ohio State University, and then joined the Long Lines Department of A. T. & T. in Cleveland. He transferred to New York City in 1941 and then to the Laboratories in 1953. Since 1934 he has been concerned with teletypewriter station equipment and maintenance, later supervising teletypewriter station installation and maintenance methods, costs, and performance results in private-line services. Since coming to the Laboratories, Mr. Robinson has engaged in special services engineering relating to the development and application of private-line teletypewriter switching systems, both automatic and manual.



Purification of Silicon

H. C. THEUERER
Chemical and Metallurgical Research

When the invention of the transistor was first announced by the Laboratories, most semiconductor research was based on the use of germanium as the principal raw material. With new techniques, ultra-pure silicon has also been made available for research and development purposes. As a consequence, the highly useful properties of silicon can now be explored more effectively, and many entirely new semiconductor devices may well result.

The invention of the transistor, the alloy diode, and the Bell Solar Battery has stimulated intensive research in the field of semiconductors. One such semiconductor, silicon, has a number of desirable characteristics, but like germanium, it must be of almost fantastic purity to be usable. Any impurities present must be held at concentration levels as low as one part in one hundred million, and levels of one part in ten billion are desirable. To obtain silicon of this purity, research chemists and metallurgists at Bell Telephone Laboratories and elsewhere have had to contend with a variety of difficult problems.

Ordinarily silicon is prepared in an electric arc furnace from a mixture of sand and carbon. At the high temperatures produced in such a furnace, silicon dioxide is reduced by carbon to form silicon and carbon monoxide. This silicon is cast into ingots, and is about 97 per cent pure. The principal impurities are iron, aluminum and carbon, and from a semiconductor standpoint, significant traces of boron and phosphorus. Silicon with these impurities is of little use as a semiconductor, although isolated regions of a crystalline piece may have rectification properties. In fact, crystals with such active regions were prized possessions in the "cat's whisker" days of radio.

This arc furnace silicon can be purified considerably by an "acid leaching" process. The principle involved in this process depends on the fact that many impurities segregate along crystal grain boundaries while the silicon is solidifying. These impurities are segregated as silicides or as silicates which are soluble in acid solutions that do not attack the silicon itself. In using this process, crude silicon is granulated and then soaked first in hydrochloric acid, and later in a mixture of hydrofluoric and sulphuric acids. After washing, to remove residual acids, and drying, silicon about 99.8 per cent pure is obtained. This silicon contains the same impurities as before but at much lower concentrations. In the illustration of the head of this article, the author (left) and J. M. Whelan check the rectification type of silicon.

Silicon of this grade has been used extensively in the manufacture of point contact diodes for radar and other microwave applications. For such use, the silicon, usually with small amounts of boron added, is melted in a silica crucible. The liquid silicon is then carefully solidified to insure a controlled impurity distribution in the ingot; major portions of such ingots have usable rectification properties. In manufacture, small wafers are cut from the ingot, and mounted in detector cartridges of various designs. In these diodes, a pointed tungsten wire is brought in contact under light pressure with the silicon surface and fastened in place. This is possible because the entire surface of the silicon is active, and it is therefore unnecessary to hunt for a sensitive region.

Although this acid-leached silicon is satisfactory for point contact diodes, it is useless for many newer applications, such as transistors. For these devices, silicon of much higher purity is required, and an entirely different technology is necessary.

Many elements, as for example aluminum, can be effectively removed from silicon by zone refining,* a method which is extremely useful for germanium. However, one of the important impurities in silicon is boron, which is not easily removed by zone refining. The distribution of boron between solid and liquid silicon during freezing is such that a large number of zones would need to be passed through the silicon to reduce the boron to the desired concentration. Moreover, silicon melts at 1420°C; and at this high temperature, if the silicon is melted in crucibles, contamination from the crucible itself presents difficulties. For these reasons chemical methods for purifying silicon have been investigated. The method most generally used is the reduction of silicon tetrachloride. This is an effective procedure, since silicon tetrachloride is a volatile liquid boiling at 57.6°C, whereas most metallic chlorides are solids, or liquids having high boiling points. In consequence, silicon tetrachloride can be readily purified by fractional distillation – a complex process in which silicon tetrachloride is separated from impurities by taking advantage of their boiling point differences. One method of reducing this purified silicon tetrachloride, using zinc as the reducing agent, is now in commercial operation, and fairly large amounts of silicon are being produced. The process involves the reaction of zinc vapor with silicon tetrachloride in a quartz vessel heated to about 1,000°C, the reaction being:

$$SiCl_4 + 2Zn = Si + 2ZnCl_2$$

Fairly large aggregates of crystalline silicon grow out from the walls of the reaction vessel and the unused zinc vapor and zinc chloride collect at the cool end of the chamber. This silicon is washed in acid and water to remove traces of zinc and zinc chloride, and is finally dried. Silicon produced in this manner is more than 99.99 per cent pure. However, it does contain extremely small amounts of boron and phosphorus at levels of about one part in 100,000,000. Alloyed with small amounts of other elements, usually from the third and fifth groups in the periodic table, silicon of this type is being used in alloy diodes and experimental transistors.

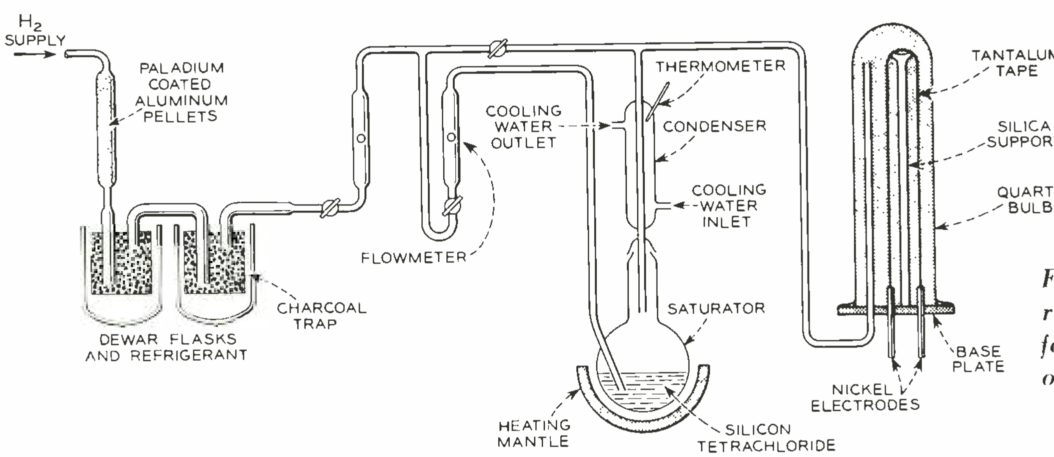


Fig. 1 — Laboratory apparatus used for the preparation of pure silicon.

Still purer silicon is required, particularly for transistor use, and research at the Laboratories is directed toward providing this material. In the previously described method of reducing silicon tetrachloride, more than five pounds of zinc are required for every pound of silicon produced. Since even the purest zinc contains traces of impurities which are a source of contamination in the reduction process, the method developed at the Laboratories substitutes hydrogen for the zinc. The advantage of this method lies in the fact that hydrogen is a gas and

* Record, *June*, 1955, *page* 201.

therefore can be purified much more readily than zinc. The primary reaction in the reduction is:

$$SiCl_4 + 2H_2 = Si + 4HCl$$

To carry out the reduction, a controlled mixture of hydrogen and silicon tetrachloride at 1,100°C is passed over a hot filament, usually of tantalum, though other metals can be used. The apparatus required for the reduction is shown schematically in Figure 1. As a first step the hydrogen must be purified. To do this, electrolytic-tank hydrogen is passed through a tube containing aluminum oxide pellets coated with palladium which remove traces of oxygen from the gas, and convert it to water vapor. The hydrogen passes through refrigerated traps containing activated charcoal which remove water vapor, carbon dioxide and other condensable gases. Controlled amounts of silicon tetrachloride are then added to the purified hydrogen with the aid of flowmeters, a silicon tetrachloride saturator, and a condenser system. By controlling the temperature of the saturator and condenser, and the ratio of hydrogen which passes through the saturator to the total flow of hydrogen through the system, any desired ratio of hydrogen to silicon tetrachloride can be obtained.

In this operation, the saturator temperature is maintained at a higher level than that of the condenser. In consequence, the hydrogen passing through the saturator carries an excess of silicon tetrachloride into the condenser. Because of the lower condenser temperature, the excess silicon tetrachloride liquefies and drips back into the saturator. In addition to ensuring close control of the gas composition leaving the condenser, this step has some value as a final stage of purification for the silicon tetrachloride.

The mixed gases then enter the reaction vessel which consists essentially of a quartz bulb and metal base plate. Suspended in the bulb is a tantalum tape several thousandths of an inch thick, one-eighth inch wide and about 40 inches long. The tape is attached to nickel electrodes connected to insulating bushings through the base plate. The temperature of the tantalum tape is controlled by 60-cycle power supplied to the electrodes through a variable transformer. As the hydrogen-silicon tetrachloride mixture passes over the hot filament, the

Fig. 2 — J. E. Jamieson installing the tantalum tape upon which silicon will be deposited during the reduction process.

THE AUTHOR

Henry C. Theuerer joined the Laboratories in 1928, and until 1936 he was engaged in the development of physical testing methods to evaluate the durability of finishes. For the next two years he was occupied with studies on residual gases in graphite in connection with electron tube research. Since 1938 he has participated in research and development of magnetic alloys and semiconductors such as germanium and silicon, the latter for use in transistors and various devices. Mr. Theuerer received a B.S. in Chemical Engineering from Cooper Union in 1933, and an M.A. in Chemistry from Columbia University in 1939. He is a member of the American Society for Metals.

silicon tetrachloride is decomposed and silicon in a finely crystalline form deposits on the tape. The rate of deposition is dependent on the hydrogen flow rate and gas ratios used. Under usual conditions, a silicon rod about one-eighth inch in diameter is built up on the tape, and about 30 grams of silicon are deposited in 12 hours. The silicon at this stage contains a tantalum core which must be removed. This is done by cracking the silicon to expose the tantalum which may then be dissolved in hydrofluoric acid.

Silicon produced by the hydrogen reduction of silicon tetrachloride is believed to be the purest ever made. The principal impurities are again boron and phosphorus at concentration levels of 1 to 5 parts in 1,000,000,000. Single crystals prepared from this silicon are n-type and have resistivities between 100 and 150 ohm-cm. The residual boron and phosphorus in such crystals may be reduced to levels of about 1 part in 10,000,000,000 by subsequent refining treatments. The refined silicon is p-type with a resistivity of 3,000 ohm-cm.

Silicon of this purity is not being made in commercial quantities because of the very high cost and small yields of this process. At present it is being used only at the Laboratories for transistor research. In the metallurgical area of the Laboratories, work is continuing toward the preparation of still purer silicon which should ultimately lead to improved transistor performance.

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Announcements that require frequent repetition are being recorded for automatic transmission more and more frequently. Today, for instance, customers in many areas can dial special numbers to hear recorded time or weather messages. Similiarly, the 6A announcement system takes over some of the operator's work of informing customers of special line conditions. When a customer dials a number and reaches a disconnected or unassigned terminal, a recorder-reproducer tells him that the number he has reached is not in use, and asks him to be sure he is calling the right number. The system is expected to effect savings in operating costs and, in addition, release operators for other services.

A. R. BERTELS *Switching Systems Development*

Intercepting with Recorded Announcements

"What number are you calling, please?" is a phrase that may occasionally be heard by a customer who has just finished dialing a number. After answering the question he is usually informed that one of three conditions exists. These three conditions are: (1) that the number he is calling has been disconnected or is unassigned in that office; (2) that the number has been changed or is affected by some other special or temporary condition such as, temporarily disconnected, or out of order; or (3) that, although he intended to call a working number, he reached an unassigned or disconnected terminal for some reason such as improper dialing.

Supplying this information is an important and necessary function in every central office. It is known as "intercepting service" and until recently has been handled entirely by intercepting operators. To route these calls to intercepting operators, trunks to the intercepting desk, or to switchboard positions equipped to handle intercepted calls, are connected to groups of terminals that represent the disconnected, unassigned and changed numbers, and the lines affected by the other special or temporary conditions.

After the development of systems using recorded announcements for weather and time of day,* it was realized that substantial operating savings could be attained if certain types of intercepting service could be handled by a machine announcement. Specifically, it appeared that machine announcements would be adequate to supply information on the first of the three conditions; namely, when the customer is calling a disconnected or unassigned number. Since, in this situation, the number called is not in use and no other helpful information can be supplied, the reply given to the customer by the intercepting service can always be the same. Thus, a message to the effect that the number is not in use, coupled with a request that he be sure he is calling the right number, can be recorded on a machine and transmitted as needed to a customer calling the unused number.

This is not true, however, of calls for changed numbers or for numbers affected by other special or temporary conditions. A customer calling such a number needs to be supplied with further informa-

* Record, *November*, 1939, *page* 70; *September*, 1953, *page* 356.

As their names suggest, the erase and record keys are used to set the machine in an erase or record condition. The reset key is used to reset the amplifier alarm once it has operated, and the make-busy key is used to prevent transfer to the machine while a recording is being made or while maintenance work is being carried on. Also located on the panel is an "on line" key for each machine, which is used to transfer traffic from one machine to the other when a recording is to be changed or when maintenance work is to be performed. When this key is operated, transfer takes place between announcements. Lamps are provided to give an indication of which recorder-reproducer unit is in service, when a unit is removed from service, when the "erase" key is operated, or when a unit is in the recording interval. Other lamps light when the output level of an amplifier falls below a predetermined value or fails entirely. In this event, transfer is made automatically to the other announcement machine and a minor alarm signal is given to the office alarm system. A major alarm signal is given if voice failure occurs on one machine while the other machine is out of service for any reason.

Fig. 3 — Mrs. Ruth H. Stock of the New York Telephone Company recording an announcement. Message can also be recorded in a remote room.

The distributing and alarm circuit consists of two sets of relays, one set being used for emergency operation. The circuit provides a means of connecting and releasing calls to and from an announcement machine at the proper time, and of giving alarms if the machine or distributing system fails to operate properly. This unit has a panel containing lamps that indicate which of the two sets of relays is in use, and keys for switching from one set of distributing relays to the other.

THE AUTHOR

A. R. BERTELS entered the Engineering Department of the Western Electric Company in 1917 as a laboratory assistant. In 1923 he became a Member of the Technical Staff and for the next few years his work concerned the design and development of central office circuits. During this time he studied at Cooper Union for two years. After 1929, Mr. Bertels was engaged in the solution of special problems of central office installations and the design of special telephone circuits. During this time he also designed operators' training equipment. During World War I, Mr. Bertels served in the United States Navy as a signalman aboard a mine layer in the North Sea. He entered World War II as a First Lieutenant and served at Fort Monmouth as an instructor and as a technical writer. Released with the rank of Major, he returned to the Laboratories, where he has been concerned with circuit development on manual and common systems.

Along with its numerous other functions, a modern telephone switching system must be capable of storing information. For example, the digits of every number dialed must be stored until the connection is completed to the called customer. Billing information, too, must be recorded and stored for automatic message accounting systems. Consequently, a continual search is being made to find new and better devices and circuits that may be used for storage or memory in switching systems. The ferroelectric memory crystal is one of these new devices on which exploratory studies are in progress.

W. J. MERZ and J. R. ANDERSON
Physical and Switching Research

Ferroelectric Storage Devices

Storage of information in telephone switching circuits is accomplished in several ways. Probably the most familiar is in the memory of the operator in a manual central office; she receives the called customer's number and remembers it as she completes the connection. In machine-switching central offices, electromagnetic devices perform this function.

Ferroelectric materials offer promising means for automatic storage of information, and have the advantages of small size, low power consumption, and a wide range of operating speeds. Their operation depends upon the physical properties of certain substances. Before showing how they can be used as storage devices, it is necessary to explain what these materials are — their physical structure and their electric properties.

By definition, a ferroelectric crystal shows a spontaneous electric polarization due to an alignment of electrical dipoles. This can be considered as the electrical analog of a ferromagnetic crystal such as iron or nickel, where we observe a spontaneous alignment of magnetic dipoles.* In fact, quite a few properties of the two types of crystals are very similar; both show an extremely high permeability (electric and magnetic, respectively), a hysteresis loop, and domains. We also find in ferroelectric crystals a critical temperature, called the "Curie" temperature, above which the crystals lose their ferroelectric properties.

Among the known ferroelectric crystals, such as Rochelle salt, barium titanate ($BaTiO_3$), potassium dihydrogen phosphate (KDP), and potassium niobate, barium titanate appears to be one of the more practical for use in memory and switching devices. First, this crystal has a Curie point at about 120° C; thus it is ferroelectric at room temperature. Second, we can grow large single crystals, and third, its electrical properties are suitable, as will be discussed later. In the illustration at the head of this article, a barium titanate crystal grown by J. P. Remeika is being examined by the authors (W. J. Merz, right, and J. R. Anderson). Mr. Remeika has succeeded in growing single crystals of very good quality up to about 1½ inches in length. To use the crystals, they must be cut to size, etched to a desired thickness, and have electrodes placed on opposite faces of the resulting crystal plate to form a ferroelectric storage cell.

* Record, *October*, 1952, *page* 385.

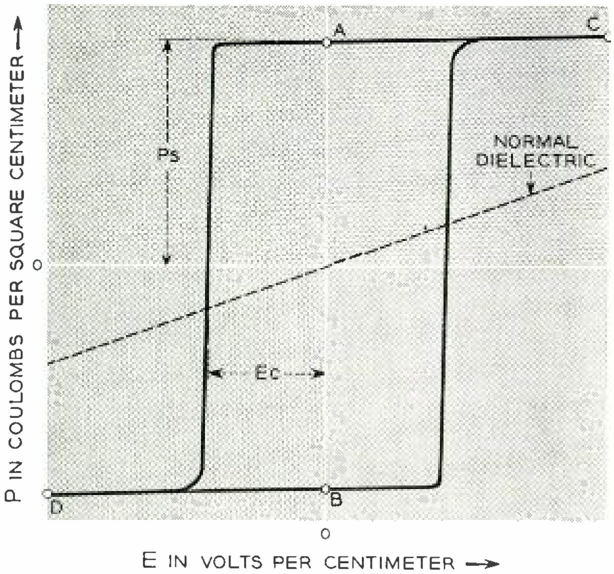


Fig. 1 — A ferroelectric crystal has a hysteresis loop similar to that of ferromagnetic substances.

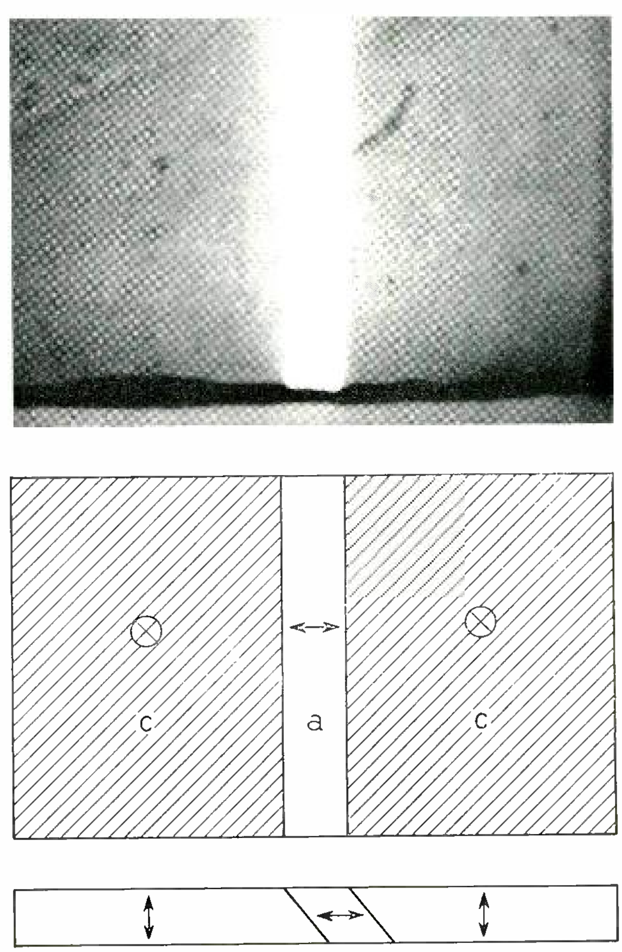
One may ask why ferroelectrics can be used as memory devices in contrast to regular dielectrics. One of the most typical properties of a ferroelectric crystal is that, if an electric field is applied to it, the resulting polarization, or displacement of electric charges, does not increase linearly with the applied field. Instead of a straight line (the slope of which would measure the electrical susceptibility, or dielectric constant), a hysteresis loop is obtained (Figure 1). If we polarize the crystal in one direction, let us say the positive one, and then remove the field and short circuit the crystal capacitor, we still find a polarization P_s (point A), which is called the "spontaneous polarization". This is in contrast to a regular dielectric material where we do not observe any polarization when the field is removed and the capacitor is short-circuited. Since we can polarize a crystal plate in two directions with a positive or negative field, we find two stable states A and B (Figure 1) which can be used to represent the binary numbers "0" and "1". The more nearly rectangular the hysteresis loop is, the easier it is to detect the difference between the states representing the binary "0" and "1", as will be shown later.

For storage applications, the following properties are desirable in the crystal:

1. A rectangular hysteresis loop;
2. Small coercive field E_C to obtain low power consumption;
3. Fast switching; and
4. Stability of the material.

As long as there is perfect contact between the crystal and the electrodes, the shape of the hysteresis loop is determined primarily by the ferroelectric domains in the crystal. To understand and control the loop for barium titanate, it is therefore necessary to discuss the domains a little more extensively. A ferroelectric domain is a region in which all the electric dipoles point in the same direction. In barium titanate, this direction of polarization can be along any one of the six directions of a cube edge. Since barium titanate is transparent, and since the optical properties of a crystal depend upon the orientation of the domains, we can see them with a microscope when polarized light is passed through the crystal. If, in a domain, all the dipoles are perpendicular to the surface of the crystal plate (paral-

Fig. 2 — Domains in barium titanate. The actual appearance under the microscope, using polarized light, is shown in the upper view. The lower views indicate domain boundaries and axes of polarization, as seen looking down on the crystal plate, and the edge view.



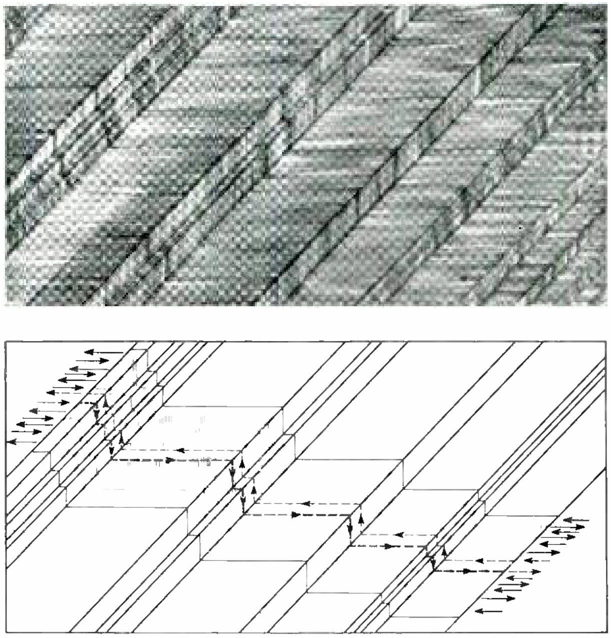


Fig. 3 — Antiparallel domains in a barium titanate crystal. Upper view as seen through the microscope; the lower drawing illustrates the direction of some of the domains that are shown in the photomicrograph.

lel to the light beam) and if the crystal plate is placed between crossed polaroid lenses, no light will pass through into the microscope — just as if the crystal were not there. We call this type domain a "C-domain". But if the axis of polarization of a domain is parallel to the crystal plate surface, the domain appears bright through the microscope — even with the polaroid lenses crossed. We call this type of domain an "A-domain".

The boundaries between domains are called "walls". In Figure 2 we can see two C-domains (dark) and one A-domain (bright). The boundaries between these domains are called "90-degree walls" because they form the boundaries between domains polarized at 90 degrees to each other. The direction of polarization in the different domains is shown in Figure 2; notice that the walls pass through the crystal at an angle of 45 degrees. As will be discussed later, this prevents the formation of a surface charge on the domain walls.

In contrast to the 90-degree walls, it is much more difficult to see 180-degree walls — the boundaries between antiparallel domains. With regular optical means one cannot determine the sense of the direction; hence two antiparallel domains look the same all the time. There are ways, however, to make the antiparallel domains distinguishable. For example, an external dc field perpendicular to the polarization rotates the direction of the polarization of the antiparallel domain in opposite directions and then makes them distinguishable. Figure 3 shows a crystal surface — with sharp 90-degree walls (diagonal lines). With the application of an external electric field, we observe many fine zig-zag lines, which represent the antiparallel domains, such as those indicated in Figure 3. Every band represents a true single domain. The average width of these domains is small, being in the order of 10^{-4} cm. Notice the head-to-tail arrangements of the dipoles in order to prevent surface charges from forming on the walls. A similar example is shown in Figure 4. In this case we are looking at the edge of a C-domain crystal. The dark and bright lines represent domains polarized upwards and downwards, respectively.

Electrical measurements show that we obtain the desired rectangular hysteresis loop with a small coercive force when we use a perfect C-domain crystal with no A-domains. A crystal with many A-domains behaves very much like a polycrystalline ceramic where we find, in addition to many do-

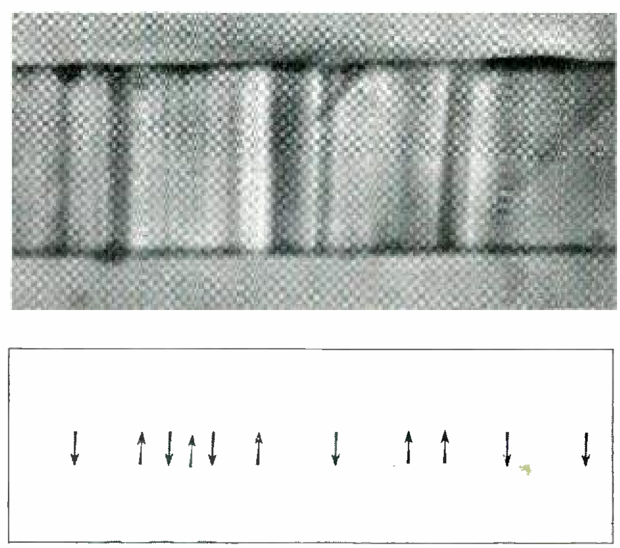


Fig. 4 — The edge of a "C" domain crystal under the microscope with its interpretation.

mains, very small crystals with different orientations. A rectangular hysteresis loop of a good C-domain crystal is shown on the cathode ray tube of Figure 6. The coercive force E_c is about 1,000 volts per centimeter; the spontaneous polarization P_s is about 26×10^{-6} coulombs per square centimeter; and the slope of the flat part of the loop corresponds to a dielectric constant of 160.

The operation of a basic ferroelectric storage circuit can be explained by referring to the ferroelectric hysteresis loop in Figure 1. If we designate point A on the loop as a state in which a binary "0" is stored, point B will then be the state in which a binary "1" is stored. To detect in which state the crystal has been placed, a positive pulse, called a "read-out" or "sensing" pulse is applied. If the crystal is in state A before the read-out pulse is applied, the loop is traversed from point A to point C and back again to A upon removal of the pulse. The change in polarization will be very small, and thus the charge which flows to the crystal will also be small. However, if the crystal is in state B and a positive pulse is applied, the loop is traversed from B to C and then back to A when the pulse is removed. This corresponds to a very large change in polarization and thus the charge which has to flow is very large. In order to measure this charge flow as a function of time, a resistance is used in series with the crystal. Current versus time curves, as shown in Figure 5, will then be observed. The areas of the two lower curves represent the charges which

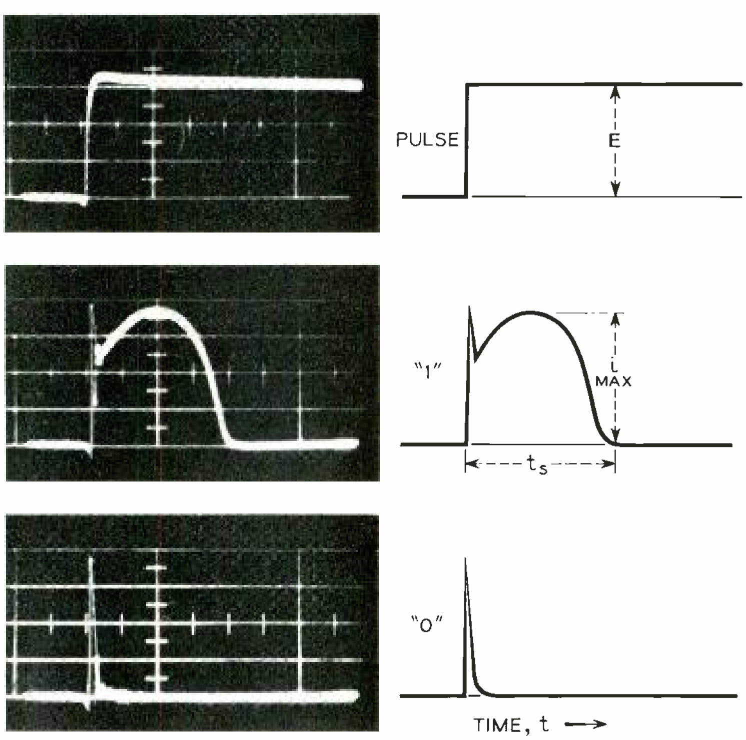


Fig. 5 — Read-out pulse and current versus time curves produced on the oscilloscope when the read-out pulse is applied. At the top is the applied driving pulse; center, the current pulse from the crystal due to the rotation of the electrical dipoles when a binary "1" is read out; bottom, the current pulse from the crystal when a binary "0" is read out, in which case, no electrical dipoles are reversed.

Fig. 6 — W. T. Thomason examines a rectangular hysteresis loop of a C-domain crystal.

flow when a positive pulse is applied. It is apparent that the more rectangular the hysteresis loop is, the larger the ratio of areas of the two output pulses.

The switching time t_s, shown in Figure 5, is the time required to reverse the electric dipoles of the crystal. This is the minimum time required for storing or reading-out a single storage cell. The switching time t_s depends upon the applied field E, the coercive field E_c and the thickness d of the crystal plate; it is shown in Figure 7 plotted against E for d=0.002 inch.

At high field strengths the current varies linearly with the field. The switching resistance (the inverse slope of the linear part of the curve in Figure 8) depends upon the square of the crystal thickness, rather than the thickness itself, because the current is inversely proportional to the switching time for a given amount of charge. The maximum current is proportional to the polarization (P_s in Figure 1) and the area of the crystal electrode.

It follows, therefore, that a thin crystal should be used to obtain fast switching, and a small electrode area A is necessary for low switching currents. In practice, a crystal plate 0.002 inch in thickness is usually used, with an electrode area of 0.004 by 0.004 inch. For units of this size, the coercive force at 60 cycles is about 5 volts, and the total charge switched is about 5×10^{-9} coulombs. With 50 volts applied, switching times of about 0.24 microsecond and switching currents of about 54 milliamperes are obtained. For 20 volts, the switching time is 1.0 microsecond and the peak current about 12 milliamperes.

Several different types of storage circuits have been designed to use ferroelectric materials. In practice, a shunt capacitor and diode can be used across the output load resistance of the basic circuit described above, as shown in Figure 9. The diode shunting the load resistance holds the output at ground potential when the dipoles are reversed during the storage process. This diode also provides a means for obtaining gain with the ferroelectric, between the power required for the storage pulse and the power delivered to the load resistance during the "read-out" pulse. The storage pulse need only be large enough to reverse the polarization of the crystal in the desired switching time t_s, since the load is short-circuited by the diode when the storage pulse is applied. The read-out pulse may be considerably larger than the storage pulse so that a large current pulse is delivered to the load resistance when the dipoles are reversed. Thus, the power delivered to the load resistance can be greater than the power used for storage. The load capacitor C of Figure 9 serves to integrate the output pulse to give a large ratio between the peak output voltages for a binary "1" and a binary "0". It should be noted that after reading-out or sensing the crystal, it is always left in the binary "0" state, i.e., the process of reading-out destroys the stored information. In practice, auxiliary circuits are used for regenerating or restoring the information after the process of read-out.

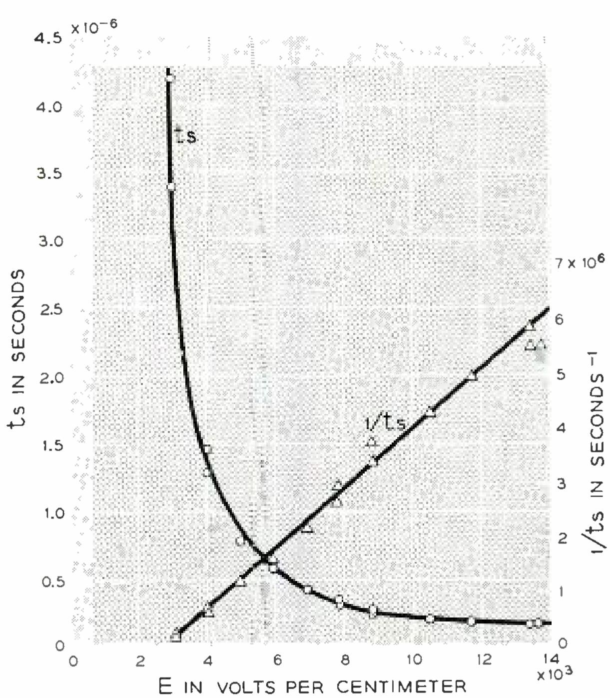


Fig. 7 — The switching time t_s is proportional to $d/(E\text{-}E_c)$ and is here plotted for a barium titanate crystal 0.002 inch thick.

A number of these basic storage circuits have been connected in tandem to form a ferroelectric stepping register or "shift" register. Circuits of the shift register type can be used as a basic part of present-day telephone circuits which perform a counting function. Shift registers are also widely used for storing and counting operations in digital computers. Ferroelectric shift registers offer advantages of lower power consumption and simpler construction over competing devices at operating speeds below a few thousand pulses a second.

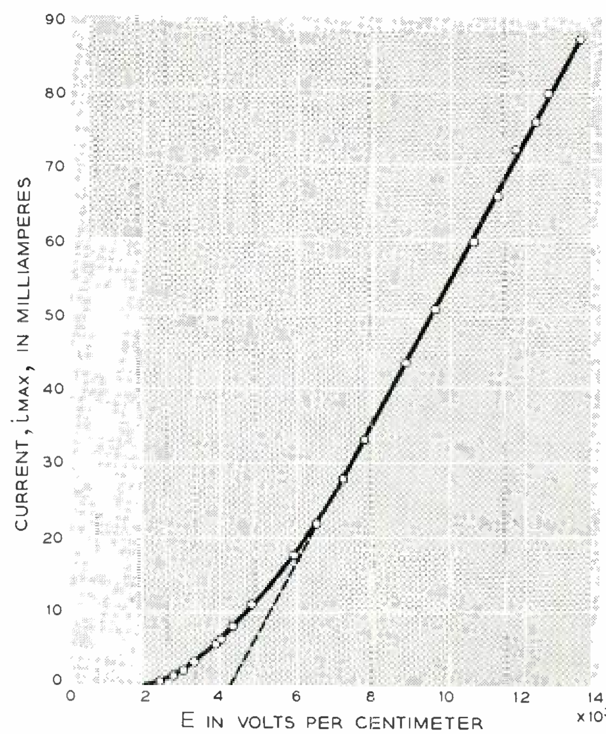


Fig. 8 — Peak switching current versus applied electric field strength. In the linear range, where the crystal is actually used, the switching resistance is proportional to d^2/A, where d is the thickness of the crystal and A is the electrode area.

A relay coil may be used in place of the capacitor-resistor load of Figure 9. The output current obtained when sensing or reading-out a binary "1" is sufficient to operate a relay directly, provided the electrode areas are of the order of 0.01 square inch. The switching time of the ferroelectric when operating the relay may be several milliseconds whereas in other storage applications, it may be a microsecond or less.

A two-dimensional type of storage arrangement makes possible the compacting of a large number of storage cells into a small space and eliminates the requirements for individual output capacitors and diodes or resistances for each storage cell. This arrangement consists of a large single crystal hav-

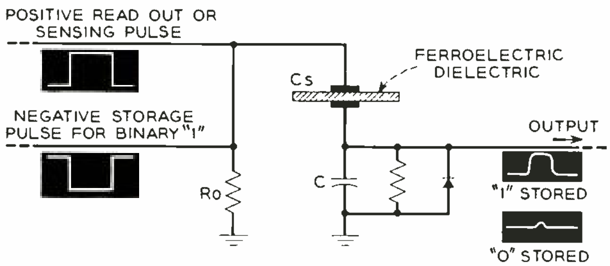


Fig. 9 — Basic circuit for ferroelectric storage.

ing a set of parallel-line electrodes on one face perpendicular to a set of parallel-line electrodes attached to the other face, as illustrated in Figure 10. The electrodes may be deposited on the surfaces by evaporating metals through slits cut into masks placed over each crystal face. Individual storage cells are formed at each cross point of the top and bottom electrodes. Thus, if there are n parallel electrodes on each face, n^2 total storage cells will be formed. It has been found that sections of a single crystal separated by only a few thousandths of an inch can be used as independent storage cells without interference with each other. An experimental crystal 5/16-inch square and 0.002 inch thick having 16 electrodes on each face and therefore forming 256 cross points for storage cells is shown on the cover of this issue.

One method of storing and reading-out information in a two-dimensional array is to use a "coincident" voltage system. In this system, a voltage $+V/2$ is applied to one of the electrodes of a selected storage cell, and $-V/2$ is applied to the electrodes on the opposite face. The total voltage V across the selected cell is that required for switching. Other cells in the array connected to either of these electrodes would then be subjected to a disturbing voltage $V/2$, which is smaller than the voltage required for switching. This system is somewhat analogous to the coincident current type of magnetic - core, two - dimensional storage system.*

Another method of operating the array is to sense or read-out from all of the cells connected to each row electrode simultaneously, and then to store simultaneously in all of the same cells. This system has the advantages that precise control of all sensing voltage amplitudes is not required and the disturbing voltages on unselected rows due to these sensing pulses may be kept below one-half the voltage applied to selected rows. One type of circuit for this system is shown in Figure 12. For simplicity, only the storage cells connected to rows 1 and n and columns 1 and n are shown in the circuit schematic. Assume that a binary "1" is to be stored in C_{s11} and a binary "0" in C_{s1n}; a sensing pulse is applied to the selected row "1" of the array. The sensing pulse will always pole all the connected cells positively, or in the direction to store a binary "0". When the negative storage pulse is applied, no cur-

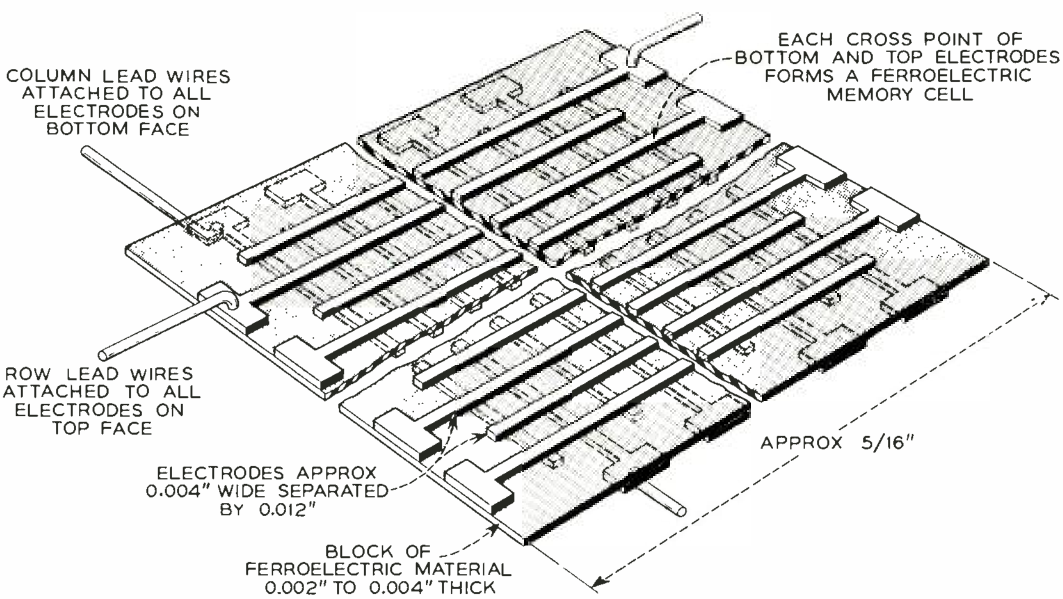


Fig. 10 — Schematic drawing of a two-dimensional storage arrangement on a single barium titanate crystal.

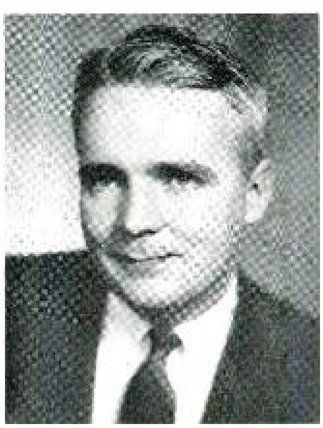
* Magnetic storage systems have been built using ferrite rings as small as 0.060 inch in diameter. See Brown and Alber-Shoenberg, Ferrites Speed Digital Computers, ELECTRONICS, 26, No. 4, pp. 146-149, April, 1953.

rent can flow through any storage cells and their polarity cannot be reversed to store binary "1's" unless the bias is removed from diodes D_1. Since a binary "1" was to be stored in C_{s11}, an input pulse is applied to pulse generator No. 1 which puts out a pulse on lead 11 to remove the back bias from D_1 (bringing the lower end of D_1 to essentially ground potential) during the storage pulse. Thus current can flow through D_1, and C_{s11} will be poled negatively, storing a binary "1". After initially storing the information, it may be desirable to read it out or sense it many times before storing new information. Each time the sensing pulse is applied, positive pulses will appear on the column output leads attached to cells in which a binary "1" is already stored. These pulses trigger their associated pulse generators so the back bias on the associated D_1 diode is removed to allow a negative current to flow during the storage pulse. The polarization is thus reversed automatically after a binary "1" is read out, and a new binary "1" is stored.

Although they are still in an experimental stage

Fig. 11 — A barium titinate crystal being examined with a microscope in order to determine the domain structure.

THE AUTHORS



J. Reid Anderson received the A.B. degree from Dennison University in 1938, the M.S. degree in Physics from the University of Michigan in 1939, and the M.S. in electrical engineering in 1940, also from Michigan. He then joined Electrical Research Products, Inc., in New York, where he worked in the field of acoustics, on noise and vibration studies, acoustic filters, and instrumentation for noise and vibration. During World War II, he served with the Navy as a minesweeping development officer.

Since 1946 he has been with Bell Telephone Laboratories, where he became concerned with the design and development of mechanical and magnetic recording instruments; more recently, in Switching Research, he has been engaged in fundamental studies of digital storage devices such as ferroelectrics and delay lines.

Walter J. Merz received a Diploma in Physics (equivalent to the Master's degree) from the Swiss Federal Institute of Technology, Zurich, in 1944. In 1947, he was awarded a Ph.D. by the same institution. From 1948 to 1951 Dr. Merz was a Research Associate at the Massachusetts Institute of Technology, and from January to October, 1951 was a visiting professor of physics at Pennsylvania State University. In November 1951, he came to the Laboratories, where, as a member of the Physical Research Department, he has been engaged in ferroelectric crystal research. He is a member of the American Physical Society and of the Swiss Physical Society.

of development, the ferroelectric storage devices show considerable promise as a new method for digital storage in switching systems and computers. Some problems in fabrication and in switching stability of barium titanate crystals at high repetition rates remain to be solved. This latter problem is indicated by a gradual reduction in output amplitude after a few million cycles of dipole reversals. The widespread application of ferroelectric materials depends upon obtaining a solution to this problem.* However, in their present stage, these devices have the advantages of extremely small size, fast operation, low power consumption during switching, simple fabrication of matrices, and storage for long periods of time without regeneration. Of all the present storage devices, ferroelectrics and magnetic cores are most comparable in access times, switching speeds, and switching power consumption. Both can be operated by transistors. However, the ferroelectrics have the following advantages over magnetic core storage devices: they do not require assembly of individual units; they can operate over a very wide range of speeds, from microseconds to milliseconds, and at lower speeds, require considerably less peak power.

*A promising new ferroelectric material, Guanidine Aluminum Sulphate Hexahydrate $(CN_3H_6)\ Al(SO_4)_2 \cdot 6H_2O$, which is in the early stages of research, shows some promise in the solution of the problem of switching instability. The initial study of this material was reported in a Letter to the Editor of the Physical Review, **98**, p. 546, April 15, 1955, by A. N. Holden, B. T. Matthias, W. J. Merz, and J. P. Remeika.

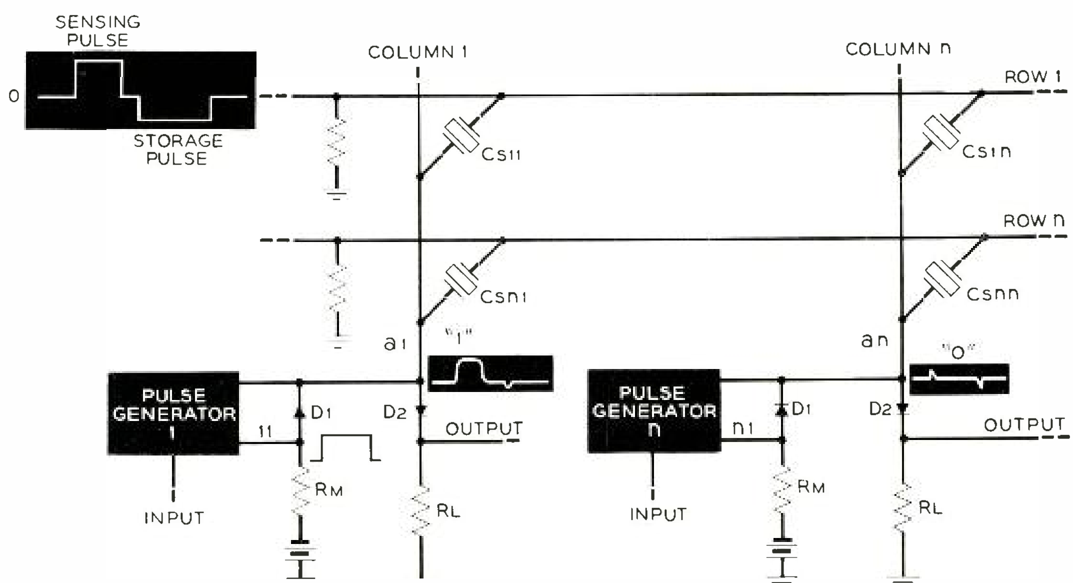
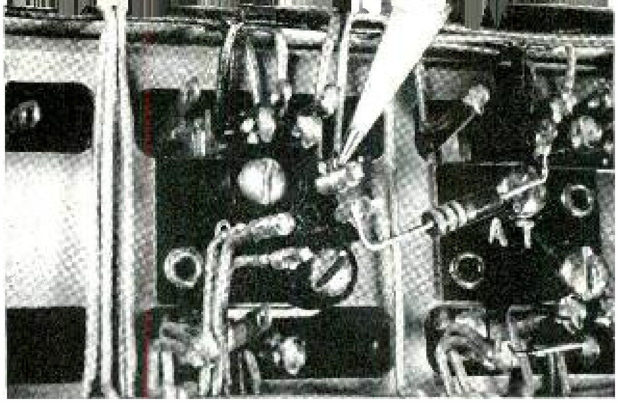


Fig. 12 — Typical circuit for matrix storage system.

Molded Plastic Jack Mountings and Terminals



A 210A terminal is used with both soldered and solderless connections.

Plastics are finding an ever-increasing use in the telephone business, as exemplified by molded plastic apparatus items of recent design such as the 252A jack mounting and 208A and 210A terminals.

New designs and the redesign of relay-rack equipment are based on the use of units with 1- or 2-circuit connections instead of the previous 5- and 10-circuit equipment units. This led to the development of inexpensive molded jack mountings to replace the older, most costly mountings. In addition, the smaller units provide the necessary adjustment space for relay springs, permit the use of surface wiring, and save over-all relay-rack space.

Molded in one piece of plastic, the 252A jack mounting is used on 2-inch relay mounting plates and mounts on ¾-inch horizontal centers. The mounting, Figure 1, is intended primarily for use with C-type jacks since there is no limitation to the number of contact springs in the pile-up. Certain A-type jacks can be used but the number of springs must be limited to five B- and D-type jacks cannot be used because of the twin mounting lugs. The code letter identifies the particular location of the mounting lug in respect to the spring pile-up. However, several types of keys, the 47B lamp socket, and 99-type jacks can be used with the new mounting.

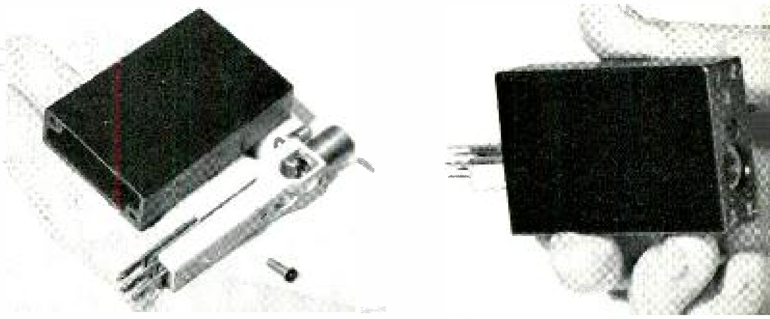
In addition to the substantial space and cost savings made possible by the new mounting, the insulating qualities of the plastic material greatly reduce the possibility of trouble crosses or grounds. Also, shop assembly of C-type jacks has been simplified; a small stud is attached to the jack mounting lug and the jack may then be inserted into the mounting and bolted in place from the front. Previously, the jacks were mounted from the rear, with the possibility of damage to the pile-up springs.

Molded plastic has also been used in the construction of the 208A and 210A terminals, designed to replace the more costly fabricated types. In the 208A terminal, at the left in Figure 2, a single piece of square cross-section, tin-plated brass is molded into the plastic body of the terminal. After molding, the ends of the brass piece are bent to form a U-shape, providing two terminals for wiring. The 210A terminal uses two brass pieces and provides four terminals. Both types are mounted by screws through the plastic terminal body.

Conventional soldered connections or machine-wrapped solderless connections can be used; the headpiece shows a 210A terminal with both types of connections. Capacitance to ground is low, the breakdown voltage is relatively high, and the plastic material reduces possibility of crosses and grounds.

The use of molded plastic for such standard items as jack mountings and terminals is an indication of how plastics can provide improvements in telephone apparatus, and at the same time reduce costs.

R. Morse
Switching Apparatus Development



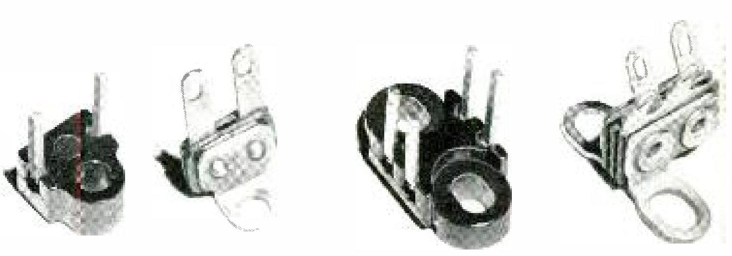
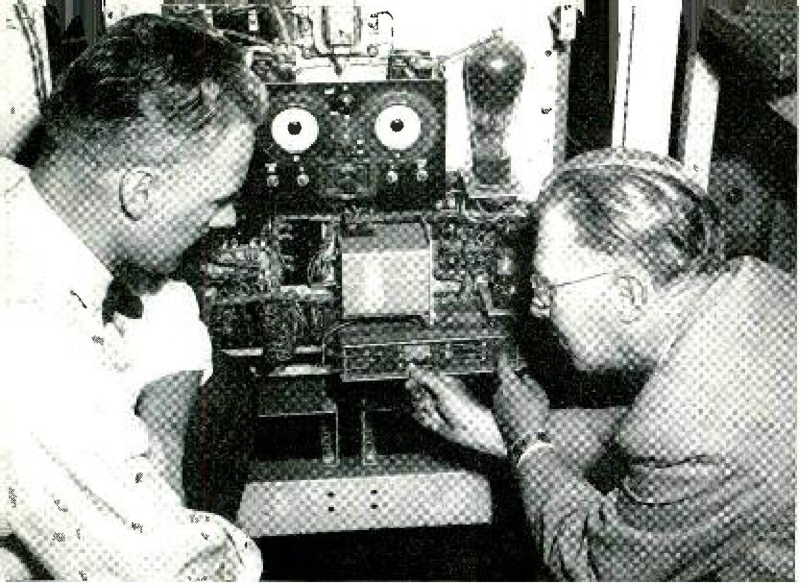


Fig. 1 (above) — A 252A jack mounting with a C-type jack, before and after assembly. Fig. 2 (below) — The 208A and 210A plastic terminals with their fabricated counterparts.



Since their announcement by the Laboratories in 1948, transistors have found many uses in communications, computers, and military equipment. Through the efforts of the Laboratories, new and better types of transistors are continually being produced to fulfill various circuit requirements. In the telephone business, a major requirement is that well-regulated direct current be available to operate the equipment. Heretofore electron tubes have been used for this operation but now the versatile junction transistors and diodes are invading this field. Used alone or in conjunction with other devices, they can regulate power supplies of widely different sizes and types.

Junction Transistors and Diodes for Power Regulation

F. H. CHASE *Power Engineering*

Although semiconductor devices have found widespread acceptance in communication and computer circuitry, little mention has been made of their possible uses in power conversion and regulation. Most Bell System circuits require dc, and since power companies today usually provide only ac, it is necessary to convert what is available to what is ultimately used. Although electron-tube, selenium, and copper-oxide diodes have been used for power conversion, the resulting dc must usually be closely regulated, and only electron-tubes have been employed with any success for power regulation.

Semiconductor diodes and triodes, stemming from early research by the Laboratories, offer a possible "new look" in power conversion and control circuits. For each power conversion circuit using electron-tube, selenium, or copper-oxide diodes, there is a similar – usually more efficient – circuit using power-sized junction diodes. Likewise, for each power regulation circuit using tubes, there appears to be a similar – usually simpler – circuit using control-sized junction diodes and triodes.

The particular devices of interest are junction transistors and silicon junction diodes, both based on the solid-state physics of semiconductor junctions. These have been described in detail previously,* but a brief resume of their characteristics pertaining to power control circuits is included here. In the illustration at the head of this article, the author points out to F. W. Anderson how a transistor-regulated power supply has replaced a bias battery in a thyratron power supply.

Certain semiconductors, primarily germanium and silicon, can be "grown" into large single crystals under closely controlled conditions. The electrical characteristics of the crystal can be changed by the addition of certain impurities, with two general types of semiconductor resulting – *n*-type and *p*-type. The two types both conduct electricity, but in different ways;* when an abrupt change from one type to the other occurs within a crystal, a rectifying junction is formed. Such a *p-n* junction will conduct readily from *p* toward *n* but offers a high resistance to current in the opposite direction – it has a low forward resistance and a high reverse or "back" resistance. Provisions must be made to keep the temperature below critical limits – approximately 70° C for germanium and 200° C for silicon.

A silicon junction diode has an extremely high back resistance within its normal operating current range. If, however, the current is increased, a region will be reached where the voltage drop across the diode, Figure 1, becomes almost constant for a wide range of currents. This "saturation" voltage, since it is nearly constant, may be used as a standard of reference for voltage; a diode so operated is a reference-voltage diode.

A crystal grown with a thin wafer of one type interposed between two sections of the opposite

* Record, *June*, 1954, *page* 203.

type may be used as a junction transistor. Depending on the crystal formation, the transistor may be *n-p-n* or *p-n-p*. To correspond with point-contact transistor nomenclature, the end sections are called emitter and collector and the connection to the central wafer is called the base. The characteristics of both types of junction transistors are the same except for reversed polarities. Circuits designed for one type may be used with the other type if the polarities are changed, and these two types of junction transistors are thus said to have "reversed" symmetry. This reversed symmetry permits considerable flexibility in the design of power regulation circuits using transistors.

For purposes of power regulation, transistor action need only be considered as current multiplication. The power regulation circuits described use transistors as "grounded-emitter" current amplifiers, permitting the simplified diagram of Figure 2 to be used in interpreting their operation. This diagram characterizes transistors by means of a "two-rectifier" analogy. Although a transistor may be somewhat over-simplified by this analogy, it permits the power engineer to approximate transistor operation on terms with which he is very familiar. Experience in circuit development has proved that the analogy is valid where transistor operation as a dc amplifier is of interest.

Whichever type of junction transistor is used, a *p-n* junction rectifier occurs between emitter and base and another between collector and base. With a battery connected to the collector and emitter terminals, a current flows through both rectifiers in series — through the emitter rectifier in its forward direction, but through the collector rectifier in its reverse direction. If a second battery is applied between base and emitter, a second forward current flows through the emitter rectifier and transistor action takes place. This action is equivalent

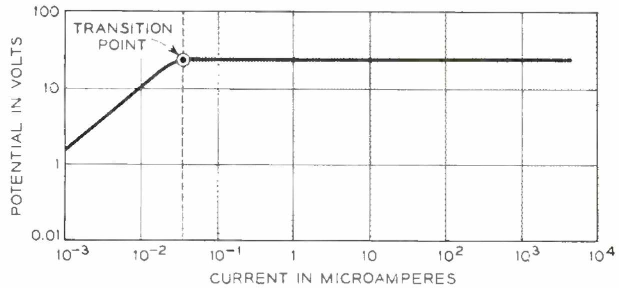


Fig. 1 — Reference-voltage diode characteristics.

to dividing the collector reverse resistance by approximately the current gain of the transistor. Variations in base current then appear as amplified current variations in the collector circuit.

Two things are necessary in power-regulating circuits: a constant reference voltage with which the power-circuit voltage may be compared, and a circuit element having controllable characteristics. A reference-voltage diode provides a constant voltage; a junction transistor has controllable characteristics. Thus, these two devices can be used in several types of power-regulating circuits.

A shunt regulator is a variable resistance circuit shunted across a load, wherein both the shunt element and the load draw current through a common resistance. As load-current requirements decrease,

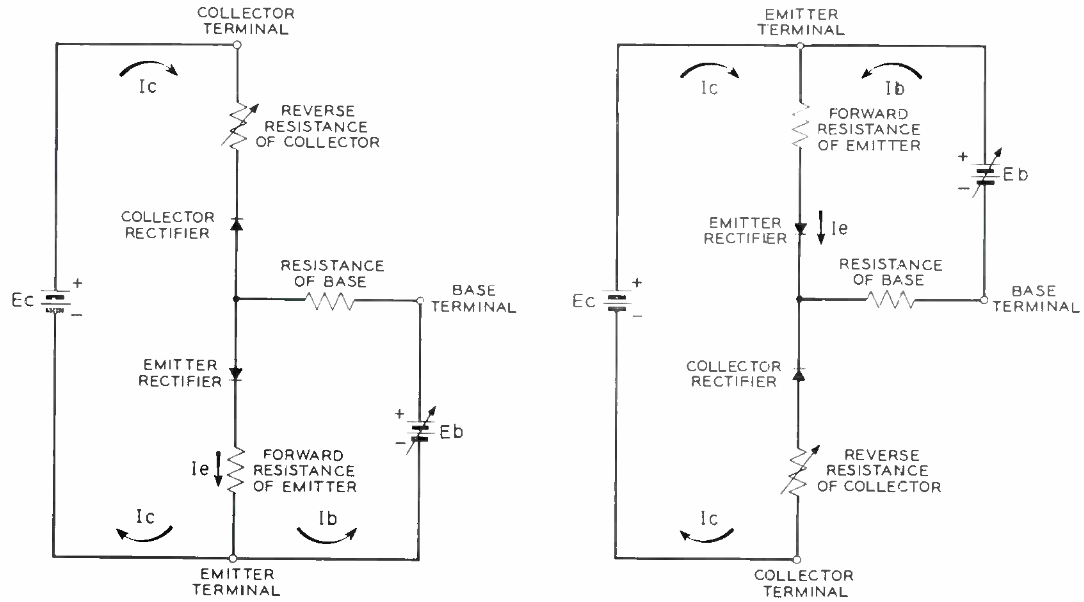


Fig. 2 — For power purposes, the two junctions of a transistor may be thought of as simple rectifiers. Left, n-p-n transistor, right, p-n-p transistor.

the shunt element draws more current; if load requirements increase, the shunt element draws less current. The net result is a practically constant total current and hence a constant output voltage. A familiar example of this type of regulation is the use of a gas-tube as the shunt element. Here, the output voltage is the ionization voltage across the gas-tube. A reference-voltage diode is the semiconductor equivalent of such a gas-tube, and may be used in exactly the same way to provide a constant output voltage. Unfortunately, the regulated output voltage is the saturation voltage of the diode and cannot be adjusted to any other value. Figure 3 shows a shunt regulator circuit where the output voltage is made adjustable by the addition of a transistor as a control element. A shunt regulator is used in the power supply shown in the headpiece.

An *n-p-n* transistor is used as a current amplifier, its emitter current also flowing through a reference-voltage diode. The effective base-to-emitter voltage is then that portion of the output voltage appearing across the lower part of the potentiometer, minus the constant voltage across the diode. With the base slightly positive with respect to the emitter, an increase in output voltage will increase the base-to-emitter voltage and therefore the base current. The collector current is the shunt regulating current, and will increase by an amount equal to the base-current change multiplied by the current gain. The increased shunt current in turn causes a larger voltage drop across the series resistance, lowering the output voltage. Similarly, a decrease in output reduces the base current, reduces the collector current much more, and increases the output.

The regulation possible with such a circuit is primarily determined by the constancy of the refer-

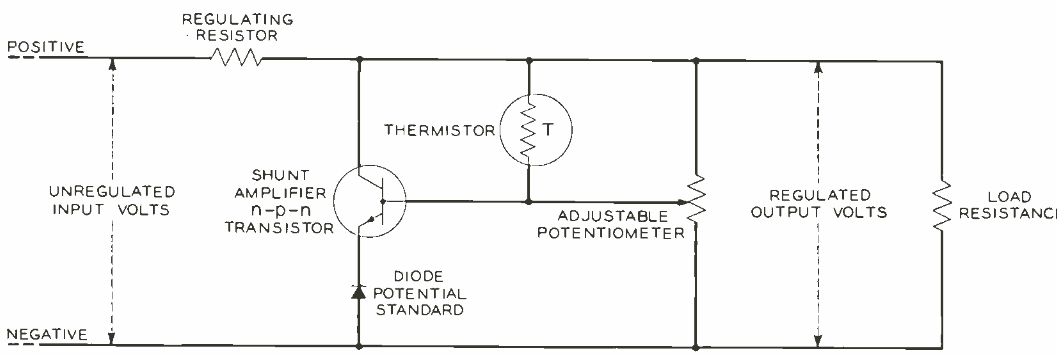


Fig. 3 — A simple shunt regulator uses a transistor and a reference diode.

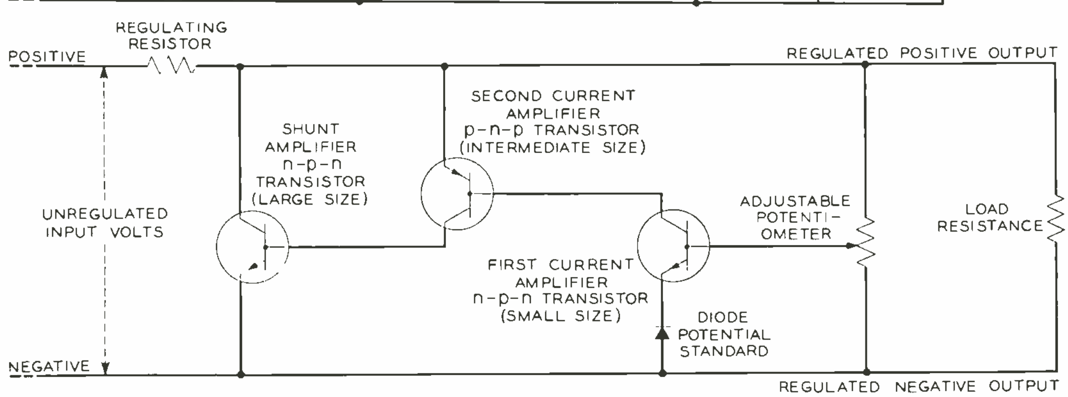


Fig. 4 — An improved shunt regulator uses two additional current amplifier stages.

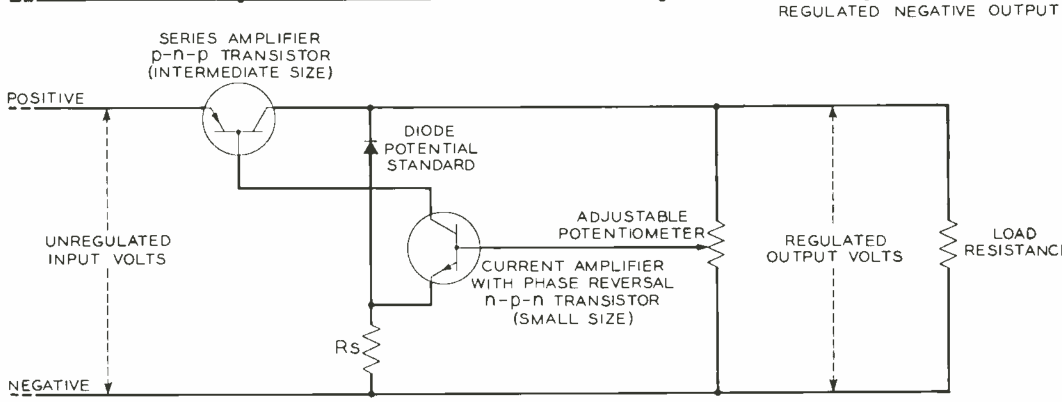


Fig. 5 — A series regulator uses two transistors and a diode.

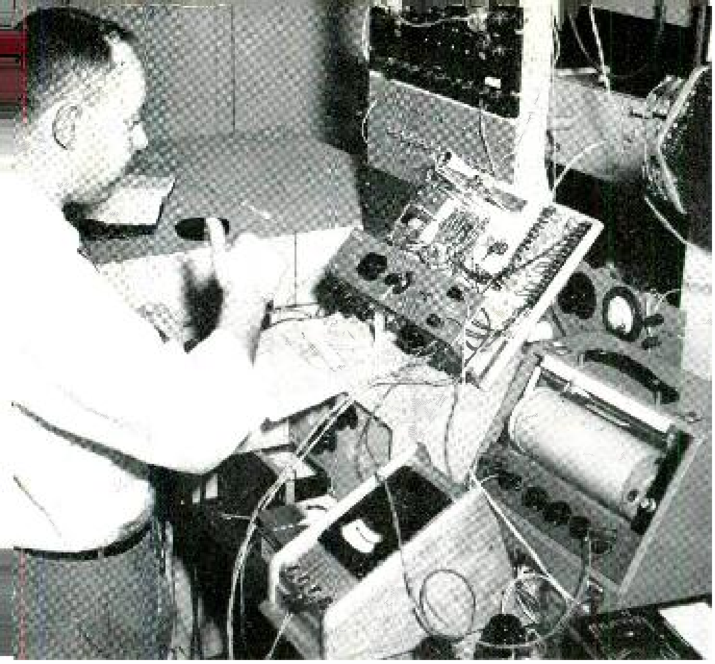


Fig. 6 — *Tests on a power supply are made using a series current regulator. J. J. Wilson checks the circuit.*

ence voltage. Although the voltage across a reference-voltage diode is nearly constant, it does change very slightly with changes in current or ambient temperature. Adding a transistor does not improve the regulation; it merely provides a means of adjusting the output voltage to a value other than the saturation voltage of the diode. The range of adjustment, of course, is determined by the maximum safe voltage that may be applied between emitter and base. A properly chosen thermistor may be connected across the upper part of the potentiometer, to offset any variations arising from changes in the ambient temperature. Although this temperature correction is not shown on succeeding figures, it may be used with any transistor-diode regulator.

In Figure 4, two more transistors have been added to the circuit of Figure 3 to improve regulation. The transistor where the output potential is compared to the reference potential is now called the first current amplifier. Except for the collector connection, its operation is identical with that of the shunt transistor amplifier in Figure 3. However, collector current for this first *n-p-n* transistor is also the base current of the *p-n-p* transistor in the second amplifier. This results in current amplification in both transistors, because of their reversed symmetry.

A similar connection is used between the collector of the *p-n-p* transistor and the base of the *n-p-n* shunt transistor amplifier. This third stage of current amplification is called a shunt transistor amplifier because its collector current, flowing through the series resistance, is the variable shunt current that regulates the output voltage. Now, base current variations in the first current amplifier are multiplied by the current gain of this *n-p-n* transistor, again by the current gain of the *p-n-p* transistor, and a third time by the current gain of the final *n-p-n* shunt transistor to obtain the shunt regulating current. The total current gain is, for all practical purposes, equal to the product of the current gains in each of the transistors. The circuit shown in Figure 4 is a better regulator than that of Figure 3 because of this added amplification, and because only a small fraction of the variable shunt current flows through the reference-voltage diode.

In Figure 4, different sizes are specified for the three transistors. The small *n-p-n* transistor shown for the first current amplifier might be one that will safely carry a maximum collector current of 5 milliamperes. Then the allowable base current of the *p-n-p* transistor cannot exceed 5 milliamperes and, with an assumed current gain of 20, its maximum collector current will be 100 milliamperes. Such a transistor is not yet commercially available.

With 100 milliamperes of base current in the large *n-p-n* transistor, and a current gain of 20, the shunt current will be a maximum of 2 amperes. Two amperes of shunt current will regulate a small-sized power plant but, as far as is known, transistors handling this amount of current are not yet commercially available. For opposite polarity, the circuits of Figures 3 and 4 can be modified to use the reversed types of transistors.

Shunt regulator circuits are good voltage regulators, but series regulator circuits are usually more efficient. A shunt regulator wastes its shunt current plus the voltage drop across its series resistor, whereas a series regulator wastes only the voltage drop across its series regulating device. Under light loads, the power dissipated in a shunt circuit is usually greater than that in a series device. With a transistor as the series device, this difference in efficiency is more pronounced because of the small collector voltage that can be used. This collector voltage, as shown in Figure 5, is the voltage drop across the series transistor.

Figure 5 is a simple transistor series regulator circuit, similar to Figure 4, but with the *p-n-p* transistor in the second current amplifier connected in series with the load so that its collector current is the load current. Comparison of the output voltage to the reference voltage in the first current amplifier is the reverse of that used in the first current amplifier of Figure 4. The emitter is held at a fixed potential with respect to the positive output rather than the negative output. This change in the reference-voltage connection results in a phase reversal of the base and collector current variations.

The potentiometer is adjusted so that the base of the first current amplifier is slightly positive with respect to its emitter as before. Now, when the output potential increases, the base-to-emitter potential, the base current, and the collector current all decrease. This collector current is multiplied by the current gain of the *p-n-p* series transistor to decrease the load current, reduce the output voltage, and thus regulate it. The ohmic value of the R_s resistance keeps the current through the reference-voltage diode within its saturation voltage range while the potentiometer adjusts the output voltage.

In Figure 5, the series transistor is inserted in the positive lead; this circuit can be modified to insert the series transistor in the negative lead by using reversed-type transistors. The simplest form of transistor series regulator, Figure 5, requires two transistors whereas the simplest shunt regulator, Figure 3, uses only one transistor. But, the added current gain of the second transistor results in better regulation, and this can be further improved by additional transistors as in Figure 4.

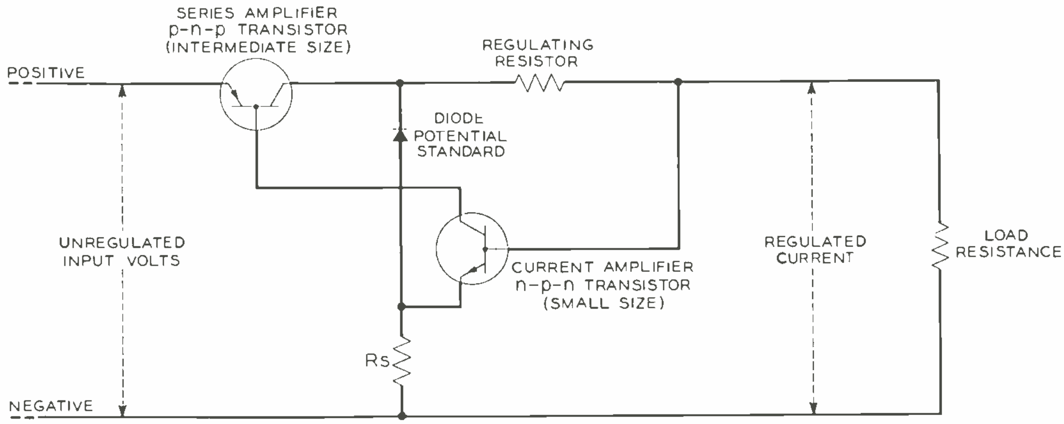


Fig. 7 — A series regulator for constant current output.

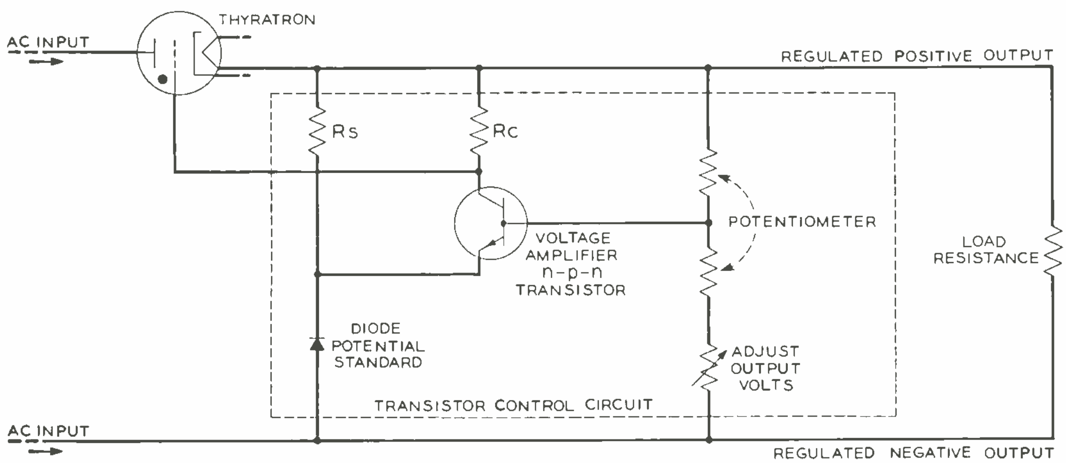


Fig. 8 — A transistor and diode control a thyratron rectifier.

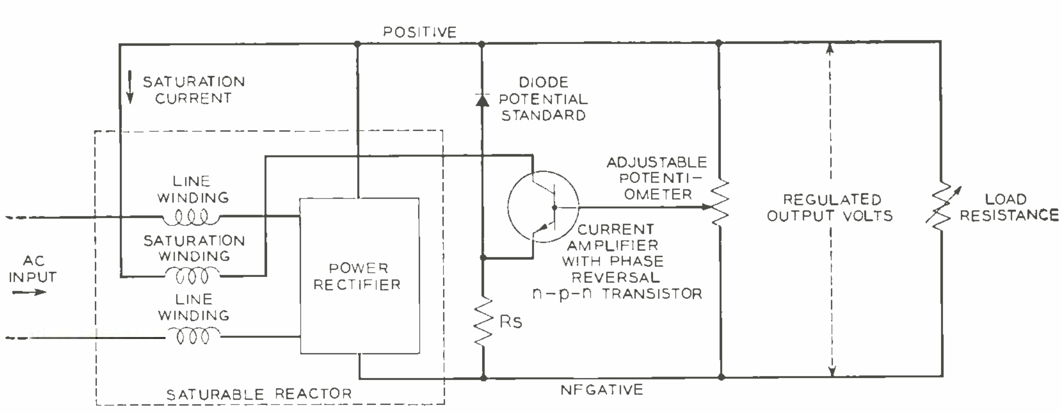


Fig. 9 — A transistor and diode arranged to control a saturable reactor circuit.

A transistor series regulator that will regulate for constant output current instead of constant voltage is shown in Figures 6 and 7. In this circuit, the load current produces a voltage drop across the regulating resistor and, in the *p-n-p* transistor, this voltage drop is compared to the reference voltage. The difference between these two potentials controls the *n-p-n* transistor base current; this base current is multiplied by the current gain of both transistors to produce the load current. The regulated load current value can be varied by using an adjustable regulating resistor. Additional current-amplifier stages can be included, or the circuit can be modified to use the series transistor in the negative lead by using reversed type transistors.

Transistors can directly control small amounts of dc power but, with transistors now available, only moderate voltages and moderate currents can be controlled. Where regulation of higher power is required, it is necessary to combine transistor circuits with other devices. Figure 8 shows on *n-p-n* transistor used as a voltage amplifier with a magnitude-controlled thyratron tube rectifier. Comparison of the output voltage to the reference voltage is the same as in Figure 3 and an increase of output voltage results in an increase of collector current. This collector current flows through resistance R_c and the resulting voltage drop across R_c is used as a negative grid voltage for the thyratron tube, to control its firing point. An increase in output voltage will delay firing of the tube until later in its conducting half-cycle, to reduce the output voltage.

Transistor circuits also may be combined with magnetic amplifier devices to control high power outputs. This is a useful combination for applications where a high-speed response is not required, since the amount of power that can be controlled may be much larger than for any of the methods previously described. Figure 9 illustrates a constant-voltage regulated circuit; a similar circuit will regulate for constant current output.

The transistor circuit is very similar to the first current amplifier in Figure 5. Comparison of the output voltage to the reference voltage is identical as is the phase reversal of base and collector current variations with respect to output voltage variations. Collector current flows through the saturation winding of a three-winding saturable reactor; the phase reversal decreases the saturation current whenever the output voltage increases. In the saturable reactor circuit, decreased saturation current produces a decreased ac voltage at the rectifier input, regulating the output potential. A change in output voltage does not instantaneously produce a change in saturation current; this is characteristic of all saturable-reactor regulating circuits. Delay in the transistor can be neglected.

Additional amplification to improve regulation can be added to Figure 9 in two ways; transistor current amplifier stages can be added as in Figure 4 or magnetic amplifier stages can be used. Additional magnetic amplifier stages will further lower the speed of response; the delay of several transistor stages is negligible compared to that of the saturable reactor. A saturable-reactor regulated rectifier with constant output current can be obtained by using the *n-p-n* current amplifier stage of Figure 6 in place of the *n-p-n* stage of Figure 9.

These are only some of the methods by which transistors can be used to regulate dc power. Many other circuits have been worked out but, in general, they are modifications of those described. Of course, use of these circuits depends upon the availability of proper transistors and reference-voltage diodes. Although these devices are still in the early development stages, specific circuits are now being designed for five power projects where the use of transistors seems particularly desirable.

THE AUTHOR

F. Harold Chase entered the Bell System at Western Electric's Hawthorne Works in Chicago, while attending the University of Illinois. After receiving the degree of B.S. in Electrical Engineering in 1921, he transferred to the Engineering Department at West Street in New York City, which subsequently became the Laboratories. After doing design work on type-C and type-D carrier, he wrote maintenance practices on toll equipment and for a time was supervisor of a central office maintenance instruction group. Mr. Chase joined the power engineering group in 1943 where he was concerned with the development of power equipment. Since 1951 he has been developing new uses for transistors in the control of power equipment.

Measuring Relative Phase Shift at VHF

J. T. Maupin adjusting "line-stretchers" on precision phase-shift difference measuring equipment.

When carrier frequencies are sent over a transmission line, the phase of the current or voltage is delayed or shifted relative to the input signal. The amount of phase shift and its behavior with respect to frequency and other variables is of concern in most systems using transmission lines. In general, the phase shift is proportional to frequency and to the length of the transmission line; it is also influenced by the physical makeup of the line. Because of normal manufacturing variations, line structures are never expected to be exactly alike in physical and electrical properties.

When a recent military project required that the coaxial lines in reel lengths of a special cable have phase shifts equal to within one-eighth of one per cent, precision equipment had to be devised for factory measurements of phase-shift difference. The usual resonant or standing-wave detector methods

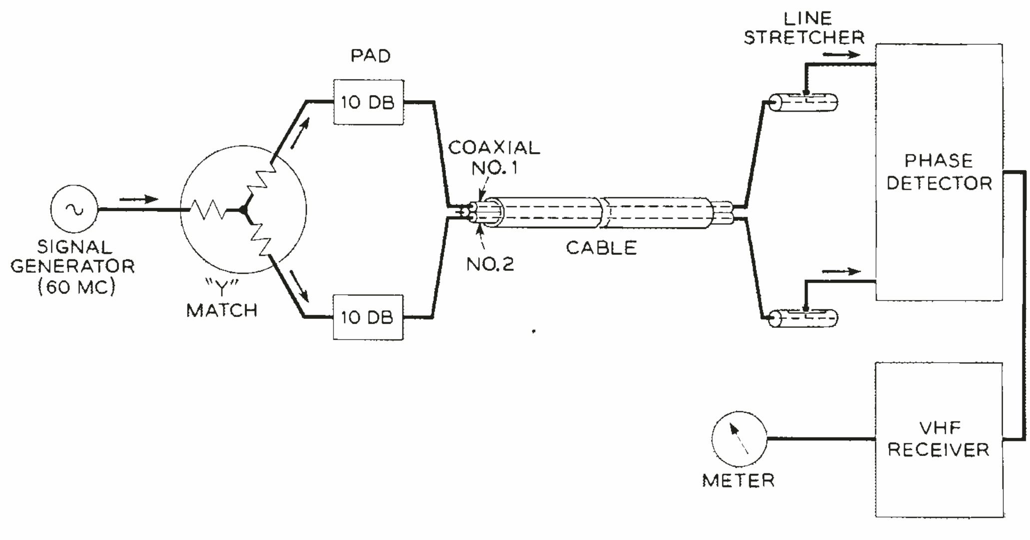


Fig. 1 — Schematic representing arrangements for measuring the difference in phase shift of coaxial cables.

of measuring phase shift or electrical length do not readily meet this accuracy.

A comparison test was therefore employed to achieve the necessary precision. This method is illustrated in the simplified schematic of Figure 1. A very high frequency (60 mc) signal in the region of the actual operating frequencies is supplied to the input ends of two coaxial lines, which are nominally equal in physical length. The coupling network consists of a "Y match" and two 10-decibel pads, which isolate the two lines under test to prevent interaction between them. Since the two input signals are in phase, the desired accuracy is obtained by a simultaneous comparison of the output signals at the far end.

As seen in Figure 1, the output signals from the two coaxials are first delivered to "line-stretchers." These are short calibrated sections of variable length, constant impedance, air dielectric coaxial lines. Signals from the two coaxial lines pass through the line-stretchers and are combined by the phase detector. This detector is so arranged that its output is zero (indicated by a minimum reading on the meter) if the signals are equal in phase and amplitude. A VHF receiver is used to detect this null point. The amount that the line-stretchers must be adjusted to obtain a null balance when the coaxials are in the circuit, compared with the settings of the line-stretchers for balance when the coaxials are not in the circuit, is a measure of the difference in phase shift of the coaxials. An assumption is made, of course, that the difference in phase shift does not exceed 180 degrees, since ambiguity arises if the unknown difference is greater than this value. At the test frequency of 60 mc, the range of differences encountered in these tests was much less than 180 degrees.

The phase detector circuit is shown in Figure 2. The two input signals are fed to this circuit from the line-stretchers. Input number two, however, is phase-shifted 180 degrees in a half-wave section of matching coaxial line. Because of this phase shift, the sum of the two signals is zero if they are equal in phase and magnitude at the input to the phase detector. A potentiometer in the plate-supply leads permits the balancing out of small attenuation differences that may occur in the coaxials under test, with negligible effect on the phase.

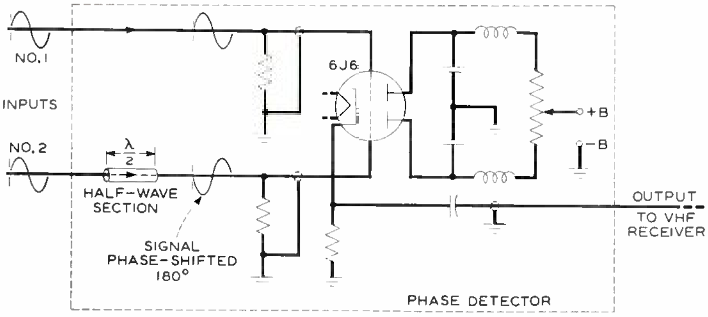


Fig. 2 (above) — Circuit of phase detector, showing function of half-wave section of coaxial line.

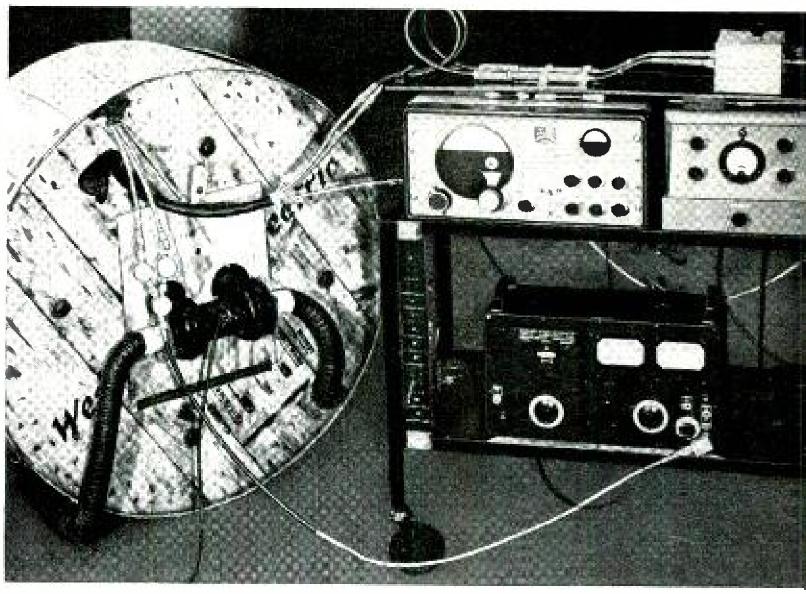
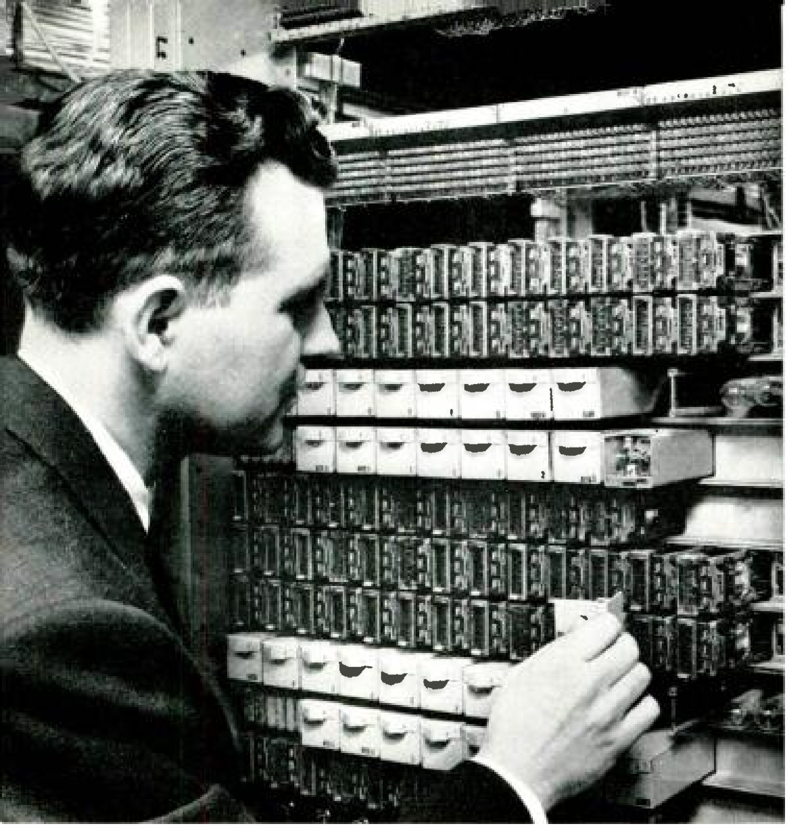


Fig. 3 (right) — Phase-difference test equipment: the coaxials are tested to maintain a phase-shift difference within one-eighth of one per cent.

To meet the test limits, the three coaxials that are stranded into a given length of cable core are manufactured in consecutive operations so as to be as nearly alike as possible. The tensions on the three coaxials during stranding are closely equalized to produce a symmetrical core. This is necessary to ensure that the physical lengths of the coaxials in the completed cable are very closely equal. With these precautions, there has been practically no difficulty in meeting the phase-difference limit. If a coaxial cable does not meet this limit, however, it is discarded.

J. T. Maupin
Outside Plant Development



A PBX Allotter for No. 5 Crossbar

A. C. MEHRING *Switching Engineering*

The No. 5 crossbar switching system was initially developed for central offices serving Private Branch Exchanges (PBX's) having only a small number of lines. But because the field of application of the No. 5 crossbar system has rapidly expanded, some of the newer central offices now serve PBX's having so many lines that it is desirable to distribute traffic to them over more than one number group. To provide for this distribution, a PBX allotter has recently been developed.

In the original design of the No. 5 crossbar system, all of the lines of a particular Private Branch Exchange (PBX) were served by a single number group circuit.* Since this circuit identifies switching apparatus associated with a given directory number, with this arrangement the selection of an idle line of a PBX is straightforward; it is not necessary to advance from number group to number group to test all lines of a PBX. Since a single number group is associated with a block of a thousand numbers having the same thousands digit, all lines of a particular PBX are restricted to these numbers. This was considered satisfactory because the No. 5 crossbar system was initially intended to serve offices where PBX's having relatively few lines would be encountered.

As the field of application of No. 5 crossbar expanded, some of the offices were required to serve PBX's having a large number of lines, 50 or even more. Under this condition, all the lines of such a unit should not be concentrated in one number group; a trouble condition making this number group inoperative would cut off all incoming calls to the entire PBX. This concentration of lines might also contribute to overloading the number group and so cause unnecessary marker delays with consequent delay of calls to other lines.

A PBX allotter has recently been developed for the No. 5 crossbar system to eliminate the concentration of the lines of a PBX within one number group. This new allotter permits the lines of each PBX to be spread over two to eight number groups. In one office, as many as ten large PBX's can be handled in this way. One such allotter is associated with each marker and is functionally a part of the marker circuit, although the allotter equipment is not incorporated in the marker bays.

In a No. 5 crossbar office that is not equipped with a PBX allotter, the dialed number of a termi-

* Record, *July*, 1950, *page* 298.

nating call to a PBX is transferred to a marker which connects to the number group indicated by the thousands digit of that number. The last three digits of this number are then transferred to the number group to mark the first number at which testing for an idle line will start. The marker tests all the lines of the PBX throughout the number group to determine which are idle. One of these idle lines is then selected, and the number group translates this number into line equipment location information which is in turn transferred to the marker.

In an office equipped with a PBX allotter, that circuit examines the dialed number of each terminating call. The "allotted number identifier" in the allotter circuit compares the called number with the numbers that are assigned to allotted PBX's recorded in its memory unit. If the dialed number matches an allotted PBX number, the allotter and marker are informed of this so that an appropriate idle line may be selected. If the dialed number is not associated with an allotted PBX, however, the marker is signaled to proceed without further action by the allotter. A simplified functional diagram of this allotter operation is shown in Figure 1. The illustration at the head of this article shows the author inspecting a polar relay in an "allotted number identifier" of a PBX allotter.

When the allotted number identifier determines that a dialed number is associated with an allotted PBX, the identity of this PBX is referred to a "busy test identifier" to determine which of the number groups have one or more idle lines. This is accomplished as follows: Within each number group containing lines of an allotted PBX, a busy test relay associated with each line is operated when the line is busy. If in one particular number group all of the busy test relays associated with the allotted PBX are operated, this number group will send a "PBX lines busy" signal to the allotter. The allotter simultaneously examines these signals from all of the assigned number groups and determines which ones contain at least one idle line. If all lines are busy, the PBX allotter signals "all busy" to the marker which thereupon initiates the transmission of a "busy" signal to the calling customer. For this "all lines busy" condition, no connection to the number group is necessary as it is for non-allotted PBX's.

If all lines are not busy, the "number group selector" of the allotter selects one of the number groups from among those that contain idle lines. The allotter then informs the marker which number group has been selected, and the marker connects to that circuit. To insure that one particular number group will not carry more than its share of this traffic, the number group selector of each PBX allotter circuit has a different order of preference. Also, if a trouble condition prevents the PBX allotter and the marker from completing their work, the selector circuit changes its order of preference, and another attempt to complete the call is made.

If the selected number group is the one associated with the thousands digit of the dialed number, that number is itself transferred to the number group. Busy line testing starts with this number and advances to subsequent numbers of the PBX in this number group until an idle line is found. If some other number group is selected, however, a number different from that dialed must be transferred to it. Therefore, new numbers must be provided to indicate where busy-line testing shall start in each of the number groups. To accomplish this, a "number memory" circuit has assigned within it the number of the

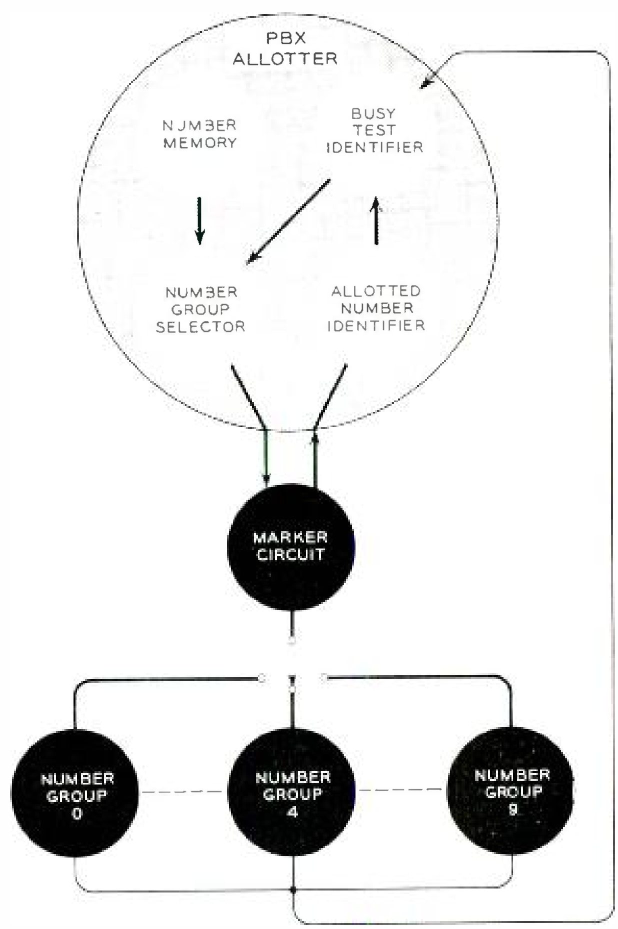
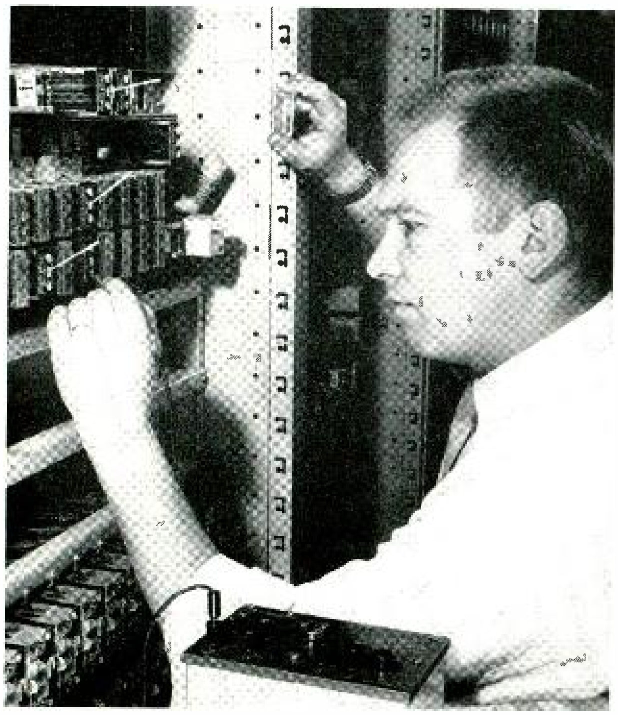


Fig. 1 — Pictorial representation of PBX Allotter operation in a No. 5 crossbar office.



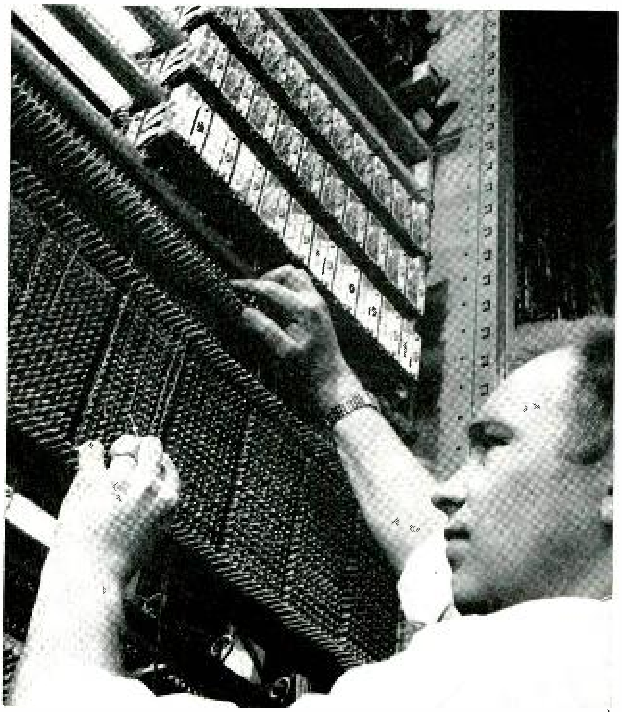


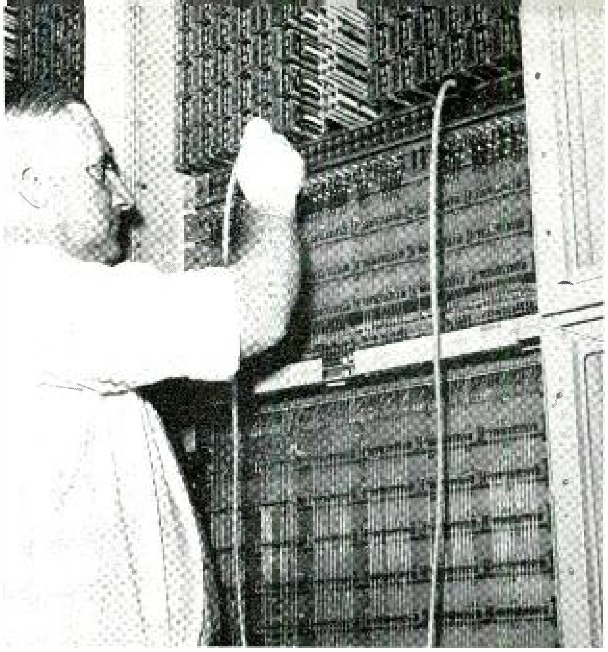
Fig. 2 — At the left W. R. Rupp is shown in the No. 5 crossbar laboratory using a 1A fault locator to test the number group circuit. At the right he checks the cross connections of the equipment translator in the number group circuit.

first line of the particular PBX in each number group. When this memory circuit is informed of the particular alloted PBX and of the number group selected, the number of the first line of the allotted PBX in this number group is indicated to the marker. The marker, in turn, transfers this number to the selected number group, and the line test is started to select an idle line.

Essential to service operation of the PBX allotter are such secondary features as recycling and trouble detecting. For example, if the selected number group or selected line link frame is "plugged" busy for maintenance purposes, or if the selected line is seized by another call, the allotter and associated circuits will recycle to select another number group, line link frame, or line. These and other secondary features incorporated in the No. 5 PBX allotter are of importance to a complete understanding of allotter operation; they have been mentioned only briefly in this description of the overall system.

THE AUTHOR

A. C. Mehring received a B.S. degree in Electrical Engineering from the University of Maryland in 1941 and then joined the Westinghouse Electric Corporation as design engineer of power protective devices. In 1945 he joined the Technical Staff of the Laboratories as a member of the Switching Systems Development Department. He has since been principally engaged in analyzing and developing switching circuits for the No. 5 crossbar system. Mr. Mehring received an M.S. in Electrical Engineering from Stevens Institute of Technology this past June.



Sealed Switch Relays for AMA

O. M. HOVGAARD *Component Development*

Modern telephone switching systems use thousands of electromagnetic relays, and any improvement in their design is of major importance to the telephone companies. A recent advance in switching apparatus is the dry-reed sealed switch element which, together with a coil, forms a relay. Several of these switches can be combined to form a more complex relay, and two such complex relays have been specially developed for automatic message accounting applications.

Relays — arrangements of electromagnetic switching elements — are one of the major building blocks of an operating telephone plant. Improvements in relay effectiveness are of primary importance to the economic welfare of a telephone system that is growing in size and complexity. Bell Laboratories, therefore, is constantly examining the worth of new principles that might advantageously be applied to electromagnetic switching elements. One result of these studies is the development of a sealed switching element;* two new relays based on its use are described here.

In 1936, Dr. O. E. Buckley, then Director of Research, requested Dr. W. B. Ellwood to explore the possibility of designing a more efficient electromagnetic means to operate electrical switch contacts. Ellwood realized that improved efficiency could be obtained by locating the operating gap of the magnetic circuit in the center of the operating coil. For simplicity, he designed the movable magnetic elements in the form of long slender reeds, supported at opposite ends as cantilevers with their free ends overlapping. It was evident that the free ends of the reeds could also serve as electrical contacts for the working circuit of the switch. To support the magnetic reeds and position them properly with respect to each other, they were mounted in a glass tube. The ends of the tube were then sealed to the individual reeds to provide support for the cantilever reeds, the glass tube serving as a support for the operating coil surrounding the switch.

This design decision turned out to be very important. It provides the necessary magnetic and mechanical features, plus a means for freeing the contact-making portion of the device from the effects of environment. This makes it possible to surround the electrical contacts with the most advantageous atmosphere. Freeing the electrical contacts from the consequences of normal environment is an economically significant contribution toward the reduction of operating expense. The use of long slim reeds and a magnetic gap of small dimensions results in a switching element of high magnetic efficiency, and capable of unusually high operating speeds.

Figure 1 illustrates the construction of the switch and indicates symbolically an operating coil surrounding the switch. Current through the operating coil results in a magnetic flux within the coil that

* Record, *September, 1947, page* 342.

magnetizes the reeds. Since the free ends of the two reeds become unlike magnetic poles, they are attracted to each other. Given sufficient flux, they will close and complete a circuit through the switch. This type of switch is generally referred to as a dry-reed type in order to distinguish it from other designs wherein the switch elements are wetted with mercury.

A major application of the new switching element is in a combined assembler-computer for automatic message accounting (AMA), where it contributes to space savings and higher operating rates. The illustration at the head of this article shows E. W. Flint working on a combined assembler-computer.

Two circuit elements of an assembler-computer are based on the use of dry-reed switches. Digits

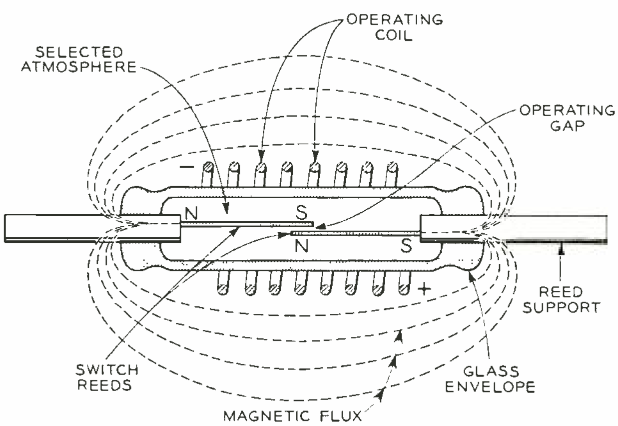


Fig. 1 — Magnetic flux produced by the coil makes the reeds into magnets. The drawing is not to scale. The unlike poles at the free ends of the reeds attract each other to make the connection.

representing the answer and disconnect times of customer-dialed calls are stored on digit registers by the operation of two out of a group of five relays per digit. The other circuit element is a connector relay, used to connect the registers to the remainder of the circuit as needed. In effect, connector relays are electrical "gates," giving the computer selective access to the registers. The physical design goals for the digit registers and connector relays were that they be sufficiently compact that facilities for storing ten digits could be mounted on a single two-inch mounting plate, and that the connector relay terminals be arranged to permit economical strapping of their common connections to the computer.

A digit register is an assembly of five relays into a single unit. As shown in Figure 2, each relay is composed of an operating coil, a current-limiting resistor and a dry-reed switch. Terminals 1 to 5 are the connections to the individual relays. To store a digit, a connector relay supplies ground to the appropriate relays in the commonly-used "two out of five" code.* The switches in these relays then act as holding contacts and are left operated after the connector relay is disconnected. When it is subsequently desired to retrieve the stored digit entry, reclosure of the connector relay identifies the desired digit by those relays showing ground on their terminals.

The primary objectives in the design of these registers were compactness and ease of assembly. The internal part of the assembly, Figure 3, shows the folded metal shield around the relays. This supplies shielding against external magnetic fields and is an inexpensive mounting for the fifteen circuit elements. This register subassembly plus a magnetic shield cover (left) is slipped into the metal case, which then provides both physical protection and the means for mounting the registers.

A connector relay, Figure 4, uses twelve switches mounted side by side within a single flat operating coil. Since the terminals of each dry-reed switch appear at opposite ends of its glass envelope, the terminals of a connector relay appear in two rows — one on each end of the relay. The switches are so placed relative to each other that the terminal

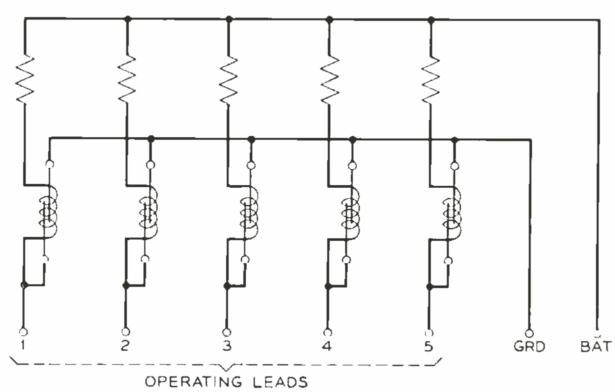
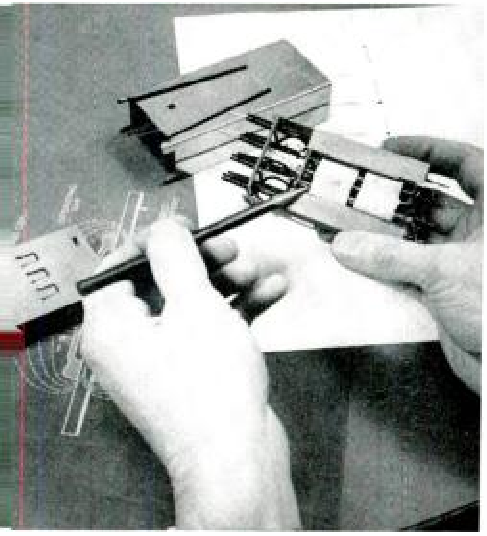
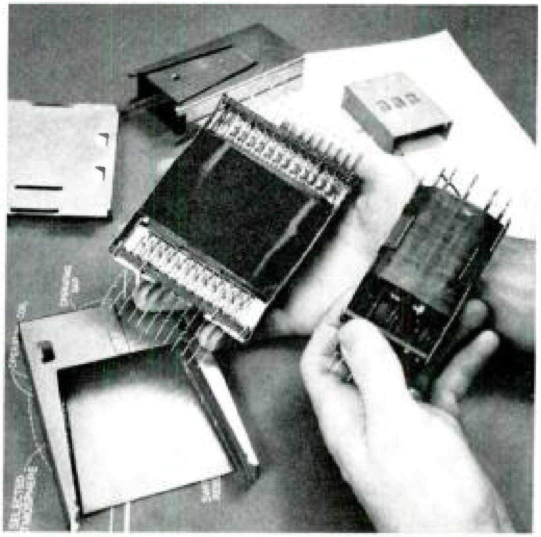


Fig. 2 — Wiring diagram of digit register.

spacing of the relay is just right to accept strap, or "banjo," wiring as shown in the headpiece. It is easy to see why the relay wiring is called "banjo" wiring. This is installed on one side of the equipment frame, leaving the other side clear for local wiring. Interference in assembly is thus avoided. and circuit maintenance is easier because of easier access to the relays. The twelve switches are used to connect to their associated digit registers and for control and checking purposes.

* Record, *January*, 1952, *page* 9.





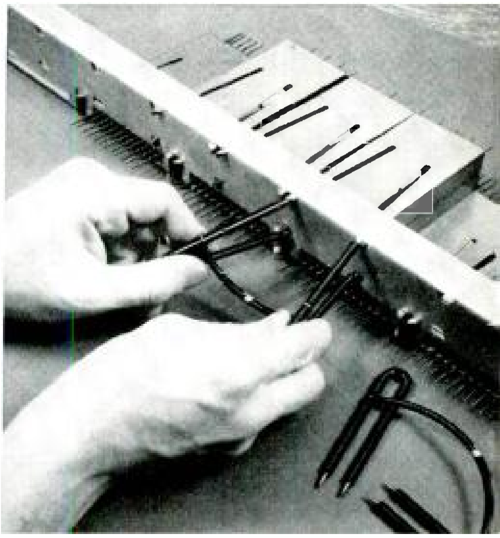


Fig. 3 (left) — The metal shield cover (left) fits over the register to complete the magnetic shielding, and the assembly slips into the metal case. Fig. 4 (center) — Assembly of a connector relay is similar to that of a digit register except for an insulating sheet. Fig. 5 (right) — A special tool is used to remove digit registers from a frame. A similar tool is used for connector relays.

Digit registers and connector relays are mounted by a novel means, developed to eliminate the mounting space ordinarily needed for mounting screws. The metal case of a digit register, Figure 3, shows the method of mounting the units. Two of the side faces of the case are slotted lengthwise, and the four corners projecting beyond the rest of the case are provided with notches. The long edges of the case become, in effect, cantilever springs. When the four corners are pushed through suitable holes punched in a mounting plate, the cantilever sides force the notches over the mounting plate, and the notches then act as detents. The spring action holds the notched corners firmly in place, and a special tool, which is illustrated in Figure 5, is provided to force the corner detents apart in order to remove a unit from the frame.

The compactness and simplicity of this equipment is obvious. A combined assembler-computer uses 1,040 digit registers (5,200 dry-reed switches) and 624 connector relays (7,488 dry-reed switches). It may easily be seen that the dry-reed switch is an important apparatus item in modern telephone equipment. The design and development of both the digit register and the connector relay, including the useful and novel method of mounting, are the work of the late P. E. Buch, on whose behalf this account has been prepared.

THE AUTHOR

OLE M. HOVGAARD received the degree of B.S. in E.E. from Massachusetts Institute of Technology in 1926 and, after working in private industry, joined the Laboratories in 1928. His activities have encompassed various fields, including the design of broadcast transmitting antennas, the development of quartz crystals, the engineering of precious-metal contacts, and developments for the military. The author of several technical papers and a Senior Member of I.R.E., Mr. Hovgaard is presently concerned with the development of sealed switches.

Dr. Kelly Vice Chairman of Naval Research Advisory Committee

Dr. Mervin J. Kelly has been elected Vice Chairman of the Naval Research Advisory Committee, the Office of Naval Research announced recently. Dr. Kelly succeeds Dr. J. A. Stratton, Provost of the Massachusetts Institute of Technology, who has been elected Chairman of the committee. Retiring Chairman is Dr. John A. Hutcheson, Vice President and Director of Westinghouse Electric Corporation.

The committee consults with and advises the Chief of Naval Operations and the Chief of Naval Research on research matters.

W. H. Doherty Accepts Post with A. T. & T. Company

W. H. Doherty, Director of Research, Electrical Communications at the Laboratories, has accepted a position as Assistant Vice President, Merchandising, with responsibilities for Facilities and Instru-

W. H. Doherty

mentalities, with the American Telephone and Telegraph Company. He undertook his new duties August 1, reporting to B. T. Miller, Vice President, Merchandising, of A. T. & T.

Mr. Doherty replaces W. H. Nunn, who continues as Assistant Vice President in Merchandising, also reporting to Mr. Miller, but with responsibilities for Marketing Methods and Techniques.

J. R. Pierce, Director of Electronics Research, succeeds Mr. Doherty as Director of Research, Electrical Communications. Mr. Doherty, a member of the Laboratories since 1929, became Director of Electronic and Television Research in 1949 and Director of Research, Electrical Communications in 1952.

Landing Site Selected for Alaska Underwater Telephone Cable

A location near Port Angeles, Washington, has been selected as the United States landing site for the A. T. & T. underwater telephone cable to Alaska.

Long Lines, which will construct the new communications route, has applied to the state of Washington for a permit to place the cable in the Strait of Juan de Fuca, off Port Angeles. The cable will extend from Port Angeles to Ketchikan, Alaska, where it will interconnect with a submarine cable between Ketchikan and Skagway, also designed and engineered by the Laboratories. The latter cable is now being constructed by the Alaska Communications System, a division of the Army Signal Corps. The over-all cable system will link the telephone network of the Alaska Communications System with the U. S. network of the Bell System.

The 640-mile Bell System segment of the system will consist of twin deep-sea cables – similar in design and construction to those now being placed across the Atlantic between Newfoundland and Scotland. The cables will be laid several miles apart – one for northbound and the other for southbound transmission.

The entire project is expected to be in service by late 1956. Telephone service between Alaska and the United States is now provided by the Alaska Communications System over several radio and land line circuits.

Telephone Cable Planned to Link Hawaii to Mainland

The American Telephone and Telegraph Company and the Hawaiian Telephone Company recently announced plans for a submarine cable communication system connecting the United States mainland and the Hawaiian Islands to be ready for service early in 1958.

The repeatered, twin-cable system, designed by the Laboratories, will have practically the same design as that of the transatlantic cable now being constructed and of the cable to be laid in 1956 between Ketchikan, Alaska, and Port Angeles, Washington. Engineering work on the Hawaiian project will get under way immediately. To meet the 1958 completion schedule, it will be necessary to start some of the manufacturing operations within the very near future.

Present telephone service between Hawaii and the mainland is furnished jointly by the American and Hawaiian companies by means of radio circuits. The demand for service is expanding rapidly, making it necessary to supplement existing facilities. The companies believe that the best way to do this is by cable rather than by additional radio installations. The radio spectrum is becoming crowded and future growth in this medium is necessarily limited. Also, continuity of service is more definitely assured when two means of transmission, radio and cable, are available.

Emergency Reporting System Developed at Laboratories

Direct line telephones connected to a centrally located control desk constitute a new municipal emergency reporting system recently designed at the Laboratories.

The new system may eventually become as commonplace as the familiar red fire alarm boxes in which a handle is pulled to send out a telegraphic signal. Unlike these alarm boxes, however, the new call boxes can also be used for summoning police or ambulance service.

The new system enables firemen or policemen to talk directly with the person placing the alarm. They can immediately determine the exact location of the emergency, its extent and the best type of equipment to dispatch.

A number of cities, including Omaha, Neb., Indianapolis, Ind., Miami, Fla., Syracuse, N. Y., and Sioux Falls, S. D., have approved use of the system and Omaha expects to have it in operation this month. Similar systems are expected to be made available to other Bell System communities.

Outdoor telephone sets encased in brightly painted cast aluminum housings are mounted at street corners. The spring door can be quickly opened and the receiver taken from its hook to summon aid in any emergency.

In a typical installation, when a call is made, a light flashes on a console at alarm headquarters until the call is answered. The light shows the box number and its location. There are no switches or dials; the caller is in direct contact. The console light remains on after the dispatcher answers until released by the operator so he knows where the alarm is coming from even if the person reporting the emergency is too excited to talk.

If the call is for police, the fire department operator immediately transfers the call to the police department switchboard. Calls may be relayed from one switchboard to another. When the call comes in an automatic voice recorder starts to take the caller's report. Another recorder can be provided which marks the time and box location.

All reporting lines are under continuous electrical test which signals the operator and the telephone company in the event of damage to the circuits.

A model system will be exhibited by the Northwestern Bell Telephone Company at the International Association of Fire Chiefs convention in Omaha, September 18 to 21.

Donald A. Quarles Appointed Secretary of the Air Force

President Eisenhower last month named Donald A. Quarles, Assistant Secretary of Defense for Research and Development for the past two years, as the new Secretary of the Air Force.

D. A. Quarles

A former Vice President of the Laboratories, Mr. Quarles left the Laboratories in 1952 to become President of the Sandia Corporation and a Vice President of Western Electric Company. He left Western to join the Defense Department in 1953.

A native of Van Buren, Arkansas, he attended the University of Missouri for three years and was graduated from Yale University in 1916 with a B. A. degree. He is a member of Phi Beta Kappa and Sigma Xi. During World War I he enlisted in the Army and served overseas two years before he was discharged with the rank of captain in the Field Artillery, whereupon he joined the Bell System.

Before becoming Vice President of the Laboratories, he served as Director of Outside Plant Development, Director of Transmission Development and Director of Apparatus Development. He served as President of the American Institute of Electrical Engineers in 1954.

Patents Issued to Members of Bell Telephone Laboratories During the Month of June

Bangert, J. T. – *Interstage Coupling Network* – 2,710,944.

Blackman, R. B., and Bode, H. W. – *Artillery Computer* – 2,710,720.

Bode, H. W., see Blackman, R. B.

Dahlbom, C. A., and Weaver, A. – *Speech Transmission System* – 2,710,892.

Edson, W. A. – *Mode Suppression in Resonant Cavities* – 2,710,945.

Fitch, K. E., Neiswinter, J. T., Purvis, M. R., and Vanderlippe, R. A. – *Telegraph Service Board Circuits* – 2,710,891.

Hines, M. E. – *High Frequency Oscillator* – 2,710,922.

Kock, W. E. – *Metallic Lens Directive Antenna Systems* – 2,712,067.

Mason, W. P. – *Delay Line* – 2,711,515.

Melsheimer, R. S. – *Frequency Divider Apparatus* – 2,710,921.

Neiswinter, J. T., see Fitch, K. E.

Pietenpol, W. J. – *Electrical Hygrometer* – 2,711,511.

Purvis, M. R., see Fitch, K. E.

Vanderlippe, R. A., see Fitch, K. E.

Weaver, A., see Dahlbom, C. A.

Weeks, J. R., Jr. – *Testing Circuit for Dielectric Material* – 2,712,112.

Talks by Members of the Laboratories

During July, a number of Laboratories people gave talks before professional and educational groups. Following is a list of the speakers, titles, and places of presentation:

Transistor Applications Symposium, University of Michigan, Ann Arbor

Baird, J. A., Applicational and Circuit Design Problems Involving Large-Signal Continuous Operation of Transistors.

Blecher, F. H., Applicational Circuit Design Problems Employing Small-Signal Principles of Analysis.

Ryder, R. M., Ratings, Reliability, Reproducibility, and Future Prospects for New Devices.

Sumner, E. E., Further Consideration of Transistors for Pulse Functions Including Point Contact Devices.

Other Talks

Baker, W. O., see Winslow, F. H.

Bommel, H. E., Ultrasonic Absorption in Superconducting and Normal Conducting Tin at Low Temperature, American Acoustical Society, Pennsylvania State University, State College, Pa.

Bommel, H. E., see Mason, W. P.

Darrow, K. K., The Hall Effect, Los Alamos Scientific Laboratories, New Mexico.

Eder, Miss M. J., see Veloric, H. S.

Felker, J. H., The TRADIC Transistor Digital Computer, Sandia Base, Albuquerque, N. M.

Gohn, G. R., The Fatigue Properties of Wrought Phosphor-Bronze Alloys, American Society for Testing Materials, Atlantic City.

Heidenreich, R. D., Application of Electron Instrumental Methods to the Study of Metal Surfaces, Gordon Research Conference on Corrosion, New London, N. H.

Mason, W. P., Bommel, H. E., and Warner, A. W., Jr., Dislocation Relaxations and Anelasticity of Crystal Quartz at Low Temperatures, American Acoustical Society, Pennsylvania State University, State College, Pa.

McKay, K. G., Mechanisms of Breakdown in Rectifiers, A.I.E.E. Summer General Meeting, Swampscott, Mass.

Olmstead, P. S., Production and Statistics, National School of Statistics, Rio de Janeiro; and Quality Control and Operations Research, International Statistical Institute, Rio de Janeiro.

Paterson, E. G. D., An Over-All Quality Assurance Plan, Chemical Corps Matériel Command, Baltimore.

Pfann, W. G., Transport of Solutes by Zone-Melting, Gordon Research Conference, New Hampton, N. H.

Prince, M. B., see Veloric, H. S.

Reiss, H., Methodology of Irreversible Thermodynamics, and Solubility and Movement of Impurities in Semiconductors, Gordon Research Conference on Physics and Chemistry of Metals, New Hampton, N. H.

Talpey, T. E., Noise in Grid Control Tubes, Massachusetts Institute of Technology, Boston.

Veloric, H. S., Prince, M. B., and Eder, Miss M. J., Avalanche Breakdown in Silicon Diffused Junction as a Function of Resistivity and Impurity Gradient, Semiconductor Research Conference, Philadelphia.

Warner, A. W., Jr., see Mason, W. P.

Winslow, F. H., Baker, W. O., Odd Electrons and Electrical Conductivity in Polymer Molecules, Gordon Research Conference on Polymers, New London, N. H.