Mr S. H. Towner, 3321

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ELECTRICAL COMMUNICATION

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SOSTHENES BEHN

In Memoriam

SOSTHENES BEHN, founder of the International Telephone and Telegraph Corporation, died of a heart ailment on June 6, 1957, in New York City. He was 75 years old.

Born on January 30, 1882, in St. Thomas, Virgin Islands, of a Danish father and a French mother, Colonel Behn later became a citizen of the United States.

He first came to the United States in 1898 to learn the banking business. Six years later, he and his brother, Hernand, formed the banking and brokerage firm of Behn Brothers in Puerto Rico. The need for rapid communication aroused their interest and they purchased some small local telephone companies that were consolidated into the Porto Rico Telephone Company in 1914. The Cuban Telephone Company was acquired in 1916, Colonel Behn becoming its president as one of the conditions of the sale.

On the entry of the United States into the first world war, he was commissioned a captain in the Army Signal Corps. In several administrative posts and also as commander of the 322nd Field Signal Battalion, he saw action at Chateau Thierry, St. Mihiel, and the Argonne. He was discharged in 1919 as a lieutenant colonel, having received the Distinguished Service Medal and the French Legion of Honor.

In 1919, the Cuban American Telephone and Telegraph Company was formed to lay and operate a submarine telephone and telegraph cable between Cuba and the United States.

The International Telephone and Telegraph Corporation was established in 1920. A contract awarded by the Spanish government in 1924 for the rehabilitation, expansion, and operation of the Spanish national telephone network required that much of the equipment be manufactured in Spain. This led to the purchase in 1925 of the International Western Electric Company, which was renamed International Standard Electric Corporation. This bold stroke provided the International Telephone and Telegraph Corporation with one of the largest telecommunication research and manufacturing organizations in the world, having plants in Argentina, Australia, Belgium, China, England, France, Italy, Japan, Norway, and Spain. The Spanish telephone system was rebuilt and modernized within five years.

Colonel Behn had meanwhile been developing the corporation in other directions. All America Cables, Mackay Radio and Telegraph Company, Postal Telegraph Company, Commercial Cable Company, an interest in the Commercial Pacific Cable Company, and Federal Telegraph Company were all acquired in 1927 and 1928. Additional manufacturing and communication operating organizations were acquired both in Europe and the Americas until the depression of the 1930s, which was weathered well under his astute leadership. It was during this trying period that his brother, Hernand, died in 1933. Growth after the second world war was dominated by the expansion of manufacturing activities in the United States.

Colonel Behn relinquished the duties of president in 1948 and retired as chairman of the International Telephone and Telegraph Corporation in 1956 with the title of honorary chairman.

Among his decorations were: Grand Cross, Order of Isabel la Catolica, Spain; Grand Officer of the Order of St. Gregory the Great, bestowed by his Holiness, Pope Pius XI; Commander of the Royal Order of Daneborg, Denmark; Commander of the Order of Leopold, Belgium; Commander of the Order of Merit, Chile; Commander of the Order of Carlos Manuel de Cespedes, Cuba; Officer of the Order of Simon Bolivar, Venezuela; Heraldic Order of Cristobal Colon, Dominican Republic; Grand Cross, Cruz Roja, Cuba; Order Al Comendador Benemerito Industrial, Portugal; and the Medal for Merit, United States.

His passing marks the end of an era for the corporation and for those who knew the inspiration of his leadership, the warmth of his personality, and the greatness of the man.

General Considerations on Electronic Switching*

By GEORGES GOUDET

Laboratoire Central de Télécommunications; Paris, France

THE MODERN CONCEPT of telephone systems is that any subscriber in a large network should be able by dialing to reach speedily any other subscriber. These networks are continually increasing in size and complexity. In particular, they often extend beyond the geographic boundaries of a nation.

The principal requirements to be met by the exchanges in these networks are: low first cost, high degree of reliability, ease of maintenance, long life, high operating speed, high transmission quality, small volume and weight, and flexibility of operation.

In new systems, endeavor is being made to introduce improvements in all these aspects. In particular, in large towns where space is scarce and costly, it is possible to turn to better account the buildings already available for exchanges by reducing the volume of the switching equipment. During the last 40 years or so, these considerations have in varying degrees fostered the development of electromechanical devices having simplified and more-restricted mechanical motion.

In the older systems—Strowger, panel, rotary, Ericsson, and *R6*—are complex mechanisms using either ratchets or continuously rotating parts with clutches and brakes. The brushes have large circular or linear movements, or even a combination of both.

In more-recent equipments of the crossbar type, the basic element is the electromechanical relay and the only movement is that of the armature. This mechanical simplicity, combined with the absence of sliding contacts, makes the relays in crossbar systems exceptionally sturdy. They can remain in service for 20 years, or even longer, without adjustment. In this class are the Western Electric Company crossbar systems, the Swedish Telecommunications Administration and Telefonaktiebolaget L. M. Ericsson systems, the Pentaconta system of Compagnie Générale de Constructions Téléphoniques, and the *8B* crossbar system of Bell Telephone Manufacturing Company, Antwerp.

But the evolution toward quasistatic systems goes further; it is leading quite naturally to the introduction of electronic elements.

In this category are not only electronic vacuum and gas tubes and semiconductor crystal diodes and transistors, but also magnetic and ferroelectric elements; and, more generally, all the devices that fulfill their functions through the movement of electric or magnetic particles without displacement of weighable amounts of matter.

Let us examine the extent to which these elements have already been used and the role that they seem destined to play in the future.

1. Functions of a Telephone Exchange

In a modern automatic telephone exchange and, in principle, in automatic teleprinter switching exchanges, there are three essential categories of circuits, differentiated to a greater or lesser degree.

A. The *switching circuit* proper, or *speech circuit*, functioning to bring about the connection of any calling subscriber to any called subscriber. It must not only transmit the speech but also contribute to the signaling.

B. The *memory circuit*, its main role being to register the orders issuing from calling subscribers.

C. The *control circuit*, which has the task of bringing about the execution by the speech circuit of the orders.

In the oldest switching systems of the step-by-step type, such as the Strowger system, this differentiation is almost nonexistent. In particular, the memory function is carried out by the selectors themselves, which, during speech, remain where they were placed by the dial pulses of the calling subscriber.

* Presented before the Société Française des Radio-électriciens, Paris, France; October 20, 1956.

On the other hand, in more-recent systems there has appeared a *register*, a complex set of relays forming a memory; moreover, in crossbar systems, the control circuit includes the *marker*, a special part that is quite distinct from the selector.

It will be noted from these examples that there has been a tendency toward a specialization of functions, each category of circuit being thus better utilized and better adapted to the particular role that it must play.

2. *Semielectronic Systems*

The electromechanical systems in use at present have attained a high degree of perfection. It might be wondered in these circumstances whether the progress of electronics in other domains justifies its introduction in switching systems.

Electronic methods appear particularly serviceable in the memory and control functions: without going into detail, they are widely used for memory and control in large purely electronic computers, as well as automation, toward which industry is widely turning.

The prospects may appear less favorable as regards the speech circuit. The reason for this is the very-rigid requirements that must be met with respect to crosstalk, noise, and speech transmission. A satisfactory solution is already provided by metallic contacts that, in the precious-metal pressure-contact form, have reached remarkable levels of performance.

In the closed position, metallic contacts are equivalent to a 0.01-ohm resistance. In the open position they appear as a capacitor of the order of a few picofarads; they thus present an impedance of about 100 megohms at a frequency of 1000 cycles per second. The impedance ratio between the open and closed positions is therefore extremely high. Moreover, currents of up to 0.5 ampere, corresponding to a power of 150 watts in a 600-ohm load, could pass through these contacts without damage. Finally, their endurance is so great that they can give hundreds of millions of breaks.

In addition to these technical qualities, the price is comparatively low—about 6 cents for the pair of contacts themselves.

At the present time, a large variety of electronic switches is known: gas tubes, saturable inductances, and semiconductor crystal diodes and triodes. However, none of them seems to possess the above characteristics at a comparable price.

For this reason, telephone exchange manufacturers have retained electromechanical elements in the speech circuit, while introducing electronic elements in the memory and control circuits. The first example of this tendency was the 2000-line mechanoelectronic exchange[22, 24] installed at Ski, Norway, in 1954 by the Bell Telephone Manufacturing Company, Antwerp.

In the United States, the Bell Telephone Laboratories have produced experimental skeletonized models of two semielectronic exchanges. In the speech circuits, particularly reliable metallic-contact relays mounted in sealed hydrogen-filled tubes are used. They are called reed relays, and one may be seen in Figure 1.

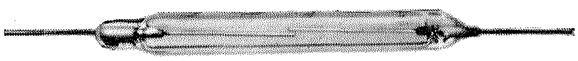

Figure 1—Reed relay.

The first of these exchanges was described[15] in 1952 under the name of ecass (electronically controlled automatic switching system). The second, described[17, 25] in 1953 and 1955, is called diad (drum information assembler and dispatcher).

The Swedish Telecommunications Administration is studying a toll exchange with 1000 incoming and 1000 outgoing junctions in which crossbar switches are associated with electronic control circuits.

All these semielectronic devices offer new solutions for switching problems. It should be noted that the use of costly electronic elements appears fully justified only if the greatest possible advantage is taken of their high operating speed. In particular, it is very desirable that the number of parts serving the same purpose be reduced to a minimum. It is even conceivable, in accordance with a suggestion by T. C. Fry of Bell Telephone Laboratories, that all operations that control the switching of a call could be carried out by a single circuit, the calls being handled successively in a sufficiently

[22] References appear in the bibliography, section 7.

short time. This is summarized by the expression, "one call at a time." In a 40 000-line exchange, taking into account traffic fluctuations, this would mean that a call must be handled in no more than a few milliseconds. This requirement has in fact been met in the diad system. However, it is clear that the parts that are common to all calls cannot be released until their orders have been carried out by the switching circuits; the speed of the latter's response is thus also a factor.

It is for this reason that semielectronic systems seem to represent only a transitional technique, at least as regards large exchanges. This can already be inferred by examining the speech-circuit contacts of the ecass and diad systems. A gas tube and an electromechanical reed relay are associated with the contact point; the gas tube causes the relay to close and only the latter is inserted in the speech circuit.

It seems that manufacturers have lacked an essential element to produce a perfectly homogeneous whole; namely, a purely electronic contact device usable in the speech circuit. Let us devote a detailed study to this.

3. Electronic Speech-Circuit Contact

The properties of some of the electronic devices mentioned above differ notably from those of metallic contacts. This is the case, for example, with hot-cathode tubes that must continuously consume a heating power that is rarely lower than 100 milliwatts to be ready to function instantaneously. For this reason, they cannot be used.

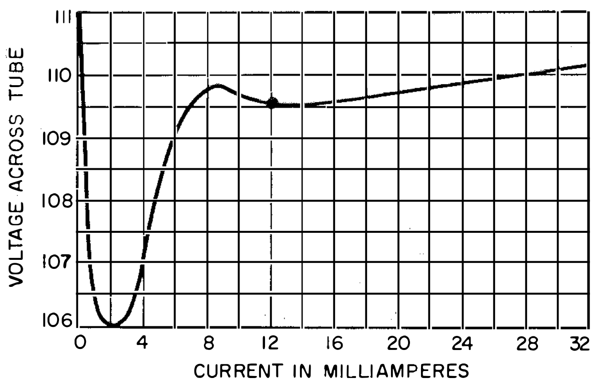

Figure 2—Static characteristic of a hollow-cathode gas diode. (Courtesy of *Bell System Technical Journal.*)

Turning to another field, it has so far never been possible to construct with magnetic materials devices having a sufficiently high impedance ratio between the conducting and nonconducting states. On the other hand, other elements have properties that are closer to those of metallic contacts, and they lead us to hope, *a priori*, that it will be possible to extend the switching methods now based on electromechanical means. The most-promising devices are cold-cathode gas tubes and semiconductor diodes and transistors.

3.1 Gas Tubes

Several cold-cathode gas tubes specially destined for use in telephone switching have been described in recent years.

3.1.1 Bell Telephone Laboratories

The first small neon-filled diode constructed in Bell Telephone Laboratories for telephone switching was detailed[29] in 1953. Its characteristic is shown in Figure 2. The breakdown voltage is 190 volts and the sustaining voltage for a 12-milliampere current is 109.5 volts. At this operating point, moreover, the dynamic resistance is negative, reaching about -180 ohms at 1000 cycles. This diode is therefore capable of compensating to some extent the unavoidable resistance in the speech circuits. When associated with a 300-ohm load, it can transmit a power of a few milliwatts in the audio-frequency band with a distortion of less than a few percent. When switched off, the interelectrode capacitance is 3 picofarads, corresponding to a 50-megohm impedance at 1000 cycles. The firing time is about 100 microseconds.

It does not generate a noise greater than 10^{-11} watt in the audio-frequency band.

3.1.2 N. V. Philips' Gloeilampenfabrieken

In 1954 the Philips' laboratories described[19] an argon-filled tube with an oxide-coated cathode and a main and two auxiliary anodes to control firing. The priming voltage of the main discharge is higher than 180 volts, and the sustaining voltage is about 60 volts.

In the audio-frequency range, the impedance of the cathode-anode space is greater than 500 ohms when the tube is fired. This seems to be a rather-serious drawback and requires the use of high load impedances.

On the other hand, its lifetime is quite satisfactory, being over 10 000 hours.

3.1.3 Standard Telecommunication Laboratories

Standard Telecommunication Laboratories disclosed[30] in 1955 the characteristics of a double diode for use in switching. As can be seen in Figure 3, it includes a central cathode in the

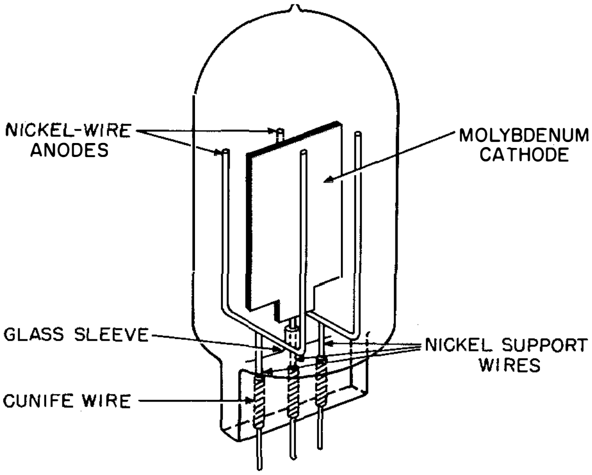

Figure 3—Gas diode of Standard Telecommunication Laboratories.

form of a molybdenum plate centered inside two **U**-shaped anodes.

In one design of this tube, helium is the gas filling; breakdown is at 288 volts; the discharge current is 10 milliamperes at 123 volts and the resistance from anode to anode is 120 ohms. The ionization time is of the order of 100 microseconds and the initial ionization is supplied by a continuously maintained auxiliary discharge.

It is convenient to have two anodes. The space between them can be used as a contact and the cathode as a control electrode.

3.2 Semiconductor Elements

Semiconductor technique is evolving rapidly. Germanium and silicon can now be used to produce diodes and triodes (transistors) that offer many advantages as crosspoint contacts. It is difficult to give a complete list of semiconductor devices, so this discussion will be confined to a few typical examples.

3.2.1 Laboratoire Central de Télécommunications

In 1952, Bell Telephone Laboratories published an article on *p-n* silicon junctions. With the same technique, Laboratoire Central de Télécommunications has obtained diodes usable as contact points in telephony. They are of very small volume as shown in Figure 4, being contained in a hermetically sealed cylinder 6 millimeters in diameter and 8 in height (0.24 by 0.31 inch). Figure 5 shows their static characteristic. In the conducting direction with 1 volt applied, the current is about 50 milliamperes and the slope corresponds to an internal resistance of 4 ohms. In the blocking direction, the resistance is about 1000 megohms until over 30 volts is applied. The parasitic capacitance is only 3 to 4 picofarads. On the whole, the impedance in the "open" position is higher than that of an electromechanical relay, whose capacitance between contacts can equal some 10 picofarads. The frequency limit as a switch

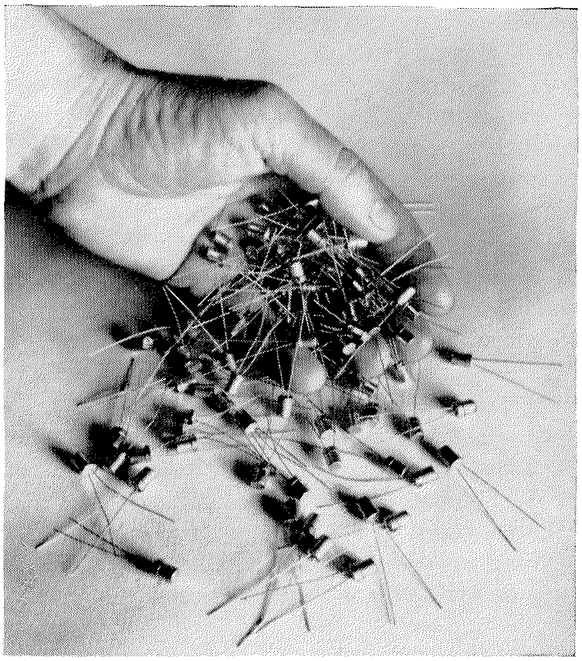

Figure 4—Silicon junction diodes for speech contacts by Laboratoire Central de Télécommunications.

is 1 megacycle. An alternating current corresponding to a power of 50 milliwatts in a 600-ohm load has been easily obtained with a distortion of less than 3 percent.

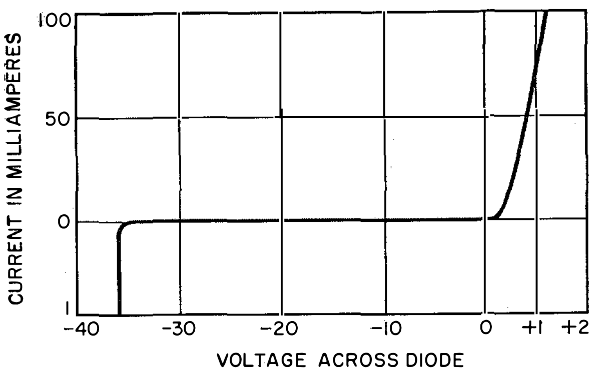

Figure 5—Typical characteristic of a silicon *p-n* junction diode by Laboratoire Central de Télécommunications.

3.2.2 Federal Telecommunication Laboratories

Federal Telecommunication Laboratories have constructed an original device[33] that can be substituted for *p-n* junctions in semiconductors. It is a germanium *p-n-p-n* diode consisting of 4 alternate *p* and *n* layers. Its outward appearance is similar to that of the preceding diode, but its current–voltage characteristic is quite different. Figure 6 is an example.

If this diode is supplied with about 30 volts in series with a resistance, there are three operating points defined by the intersections of the characteristic with the straight line representing Ohm's law. Only two of them, P_1 and P_2, are stable. The first corresponds to a voltage of 30 and a current of about 10 microamperes and the second to 1 volt and 20 milliamperes. In dynamic conditions, the slope amounts to a few megohms and a few tens of ohms, respectively. P_1 thus represents a blocking and P_2 a conducting condition that is quite different from the former. A switching time of the order of 100 microseconds can be attained.

Quite recently, Bell Telephone Laboratories devoted an article[35] to a similar device, which they have called a *p-n-p-n* transistor.

3.2.3 Symmetrical Transistors

Certain companies have at last succeeded in constructing symmetrical transistors that can be used in a way similar to the double gas diode already mentioned. It seems that it was this type of transistor[34] that was used by the Stromberg–Carlson Company to construct an electronic automatic exchange that will be discussed later.

3.3 Summary of New Devices

The various devices described above have been classified according to their physical properties. It is more important to the user to examine their functional aspects.

In this connection, electromechanical relays have different properties depending on whether or not they are fitted with a holding contact. In the first case, a momentary control voltage produces a permanent displacement of the armature. This is the *memory function.* In the second case, the relay operates only while the control voltage is applied; the memory function does not exist.

These two categories are also found in electronic devices. Gas diodes, *p-n-p-n* diodes, and, more generally, devices whose current–voltage characteristics can be intersected at least at two stable points by a load line, possess a memory.

Among the elements already mentioned, *p-n* junctions and symmetrical transistors lack a memory. Obviously, they must be complemented with devices that will perform the memory function for them before they are usable.

Devices can also be classified according to other factors: operating speed, power consumed, and life.

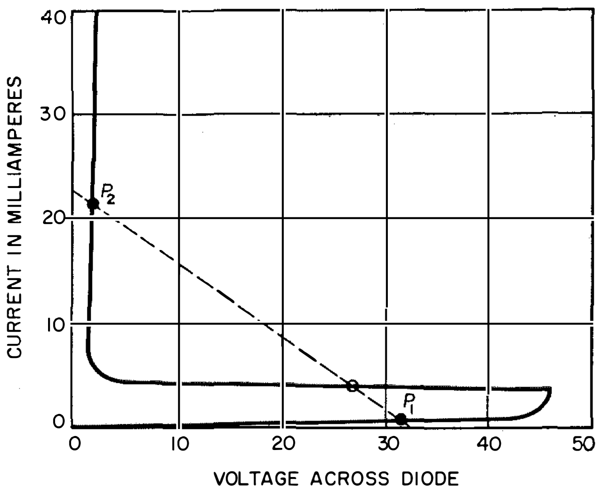

Figure 6—Typical characteristic of a *p-n-p-n* diode. Points P_1 and P_2 correspond, respectively, to the open and closed conditions when the diode is used as a switch.

The most-rapid operation is given by semiconductor devices: their switching time can be as low as 1 microsecond, whereas it is between 10 and 500 microseconds for gas tubes, and rarely below 1 millisecond for electromechanical relays. Semiconductors also provide the most-favorable switches with respect to power supply: this, of course, depends on the speech level to be transmitted. For reasons of economy the power should be limited to 1 to 10 milliwatts, which meets the needs of telephone receivers. This obviously implies a change in present circuits, as dialing and ringing now send as much as 1 watt through the speech contacts.

The power consumed is of the order of 1 to 10 milliwatts for semiconductor elements and 100 times greater for gas tubes as well as for electromechanical relays.

Information on the lifetime of the new devices is inaccurate owing to the time that must elapse before reliable statistics can be obtained. Gas tube seem to wear only during actual operation, so that an operating lifetime of 4000 hours may correspond to several decades of service. From certain projected estimates, it has been inferred that the lifetime of semiconductor elements might reach 100 years. However, this conclusion is based partly on conjecture and accordingly should not be considered completely reliable.

4. *Possible Design for Fully Electronic Exchanges*

4.1 Speech Circuit

4.1.1 Time or Space Switching

The foregoing examples show that electronic elements are available for speech circuits and their operating speed, which is 10 to 1000 times greater than that of electromechanical relays, corresponds to that of the electronic devices already in use for control and memory functions. The same observation applies to the power necessary to control them, which is of the order of 1 milliwatt or less; not more than a fiftieth of the power required by most electromechanical relays.

This naturally leads to an examination of the possibility of fully electronic exchanges.

Note that the number of successive elementary operations required to establish a connection through the speech circuit is much smaller than the number for the complementary control and memory circuits.

The increased rapidity of operation of the devices in the speech circuit easily enables the designer to take full advantage of the electronic control and memory circuits, as the time required for carrying out the order is almost negligible compared with that needed for its preparation.

One may wonder now whether the switching points themselves have been turned to sufficiently good use. This consideration has resulted in multiplex systems, which have been the subject of numerous patents, in particular those taken out by Deloraine as early[10] as 1945 and later[11] by Van Mierlo in 1947. The first experimental study of these systems was carried out[12] in 1949 by Deloraine.

Although both frequency- and time-division-multiplex systems are possible, consideration will be given only to the latter since, so far as is known, they are the only ones that have been constructed.

A wire-line or radio time-division-multiplex link is based on the principle illustrated in Figure 7 for the case of 10 simultaneous channels. The transmitter includes a generator that provides pulses spaced at regular intervals. They may be thought of as repetitive trains of 10 spaced pulses numbered within each train from 1 to 10. Each of the 10 pulses is assigned to one telephone channel. This is effected by a distributor timing system that also makes it possible for each channel to modulate the train of periodic pulses at its disposal.

When the pulses are received, a synchronized distributing system sends each pulse into the proper channel. For a given channel, therefore, the whole signal is not transmitted, only periodic samples of it. This is permissible if the repetition frequency of the pulses allotted to a channel is at least twice the highest frequency to be transmitted. For this reason a repetition frequency of 10 kilocycles is usually chosen in telephone links. The total duration of a pulse train is then 100 microseconds.

If it is desired to construct a multiplex system with 100 channels, 1 microsecond is available for each pulse.

In the device just described, a given transmitting line is always connected with the same receiving line. If, on the contrary, any two lines can be connected, the distributing system becomes a switch.

One way of doing this is to explore the incoming lines always in the same order, 1, 2, 3, . . ., and to assign an arbitrary time position to the outgoing lines. With electronic methods, memories can be constructed with this order marked in them; they act on pulse generators that open the gates of the outgoing circuits at the required moment. Use must be made here of electronic contact devices that possess the qualities necessary for speech-circuit switching. If the most rapid of those described can gate pulses of 1 microsecond, while a time margin at least equal to this must be observed between two consecutive pulses, it will be seen that unilateral multiplex switching devices with a maximum of 50 channels can be constructed. The usual switching network is completely replaced by a time distribution of calling and called subscribers. This is, then, *time switching* involving *high frequencies*, whereas the choice of a conducting path to link an incoming to an outgoing line is a classic network is *space switching* carried out at *voice frequencies*.

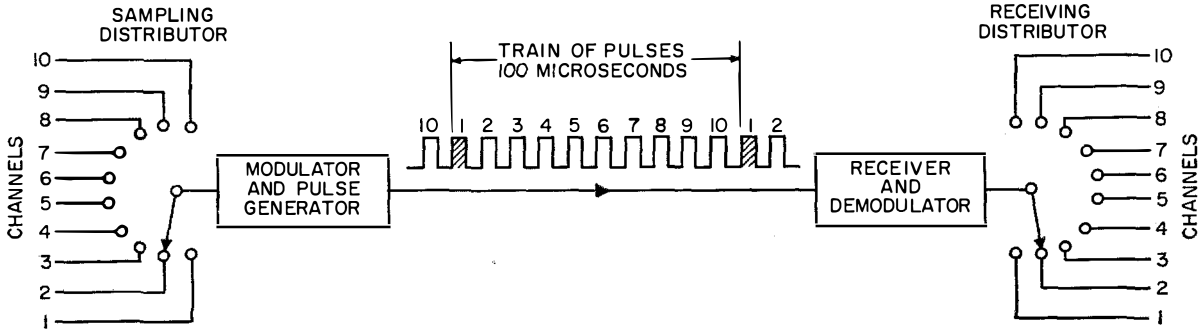

Figure 7—Principle of a time-division multiplex system.

Naturally, even with time switching, the number of simultaneously interconnected lines is much lower than the number of subscribers; to save on equipment, it is necessary to concentrate several lines on the same junction. This can be done easily by linking a greater number of subscribers than there are time positions actually available and modifying the exploration and distribution systems accordingly. Thus, for example, with pulses of 1 microsecond, a group of 500 lines can be offered 50 simultaneous unilateral connections. Of course, bilateral connections can be made by joining two unilateral ones.

To construct exchanges with more than 500 lines, it is possible in theory to apply the principles just outlined by reducing the duration of the pulse. For 10 000 lines, the pulse duration would be only 1/20th as long; that is, a maximum of 0.05 microsecond. The present electronic components do not attain this operating speed.

Using 50 time positions, 10 000 subscribers can be given 1000 simultaneous communications by combining space and time switching.[9]

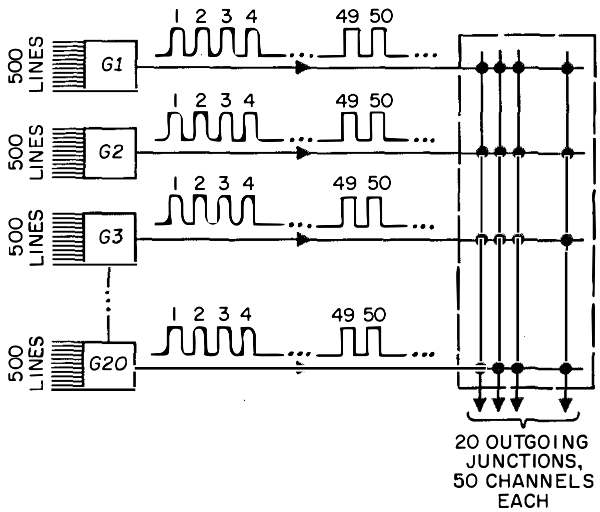

Figure 8—Combination of time switching with space switching.

This is shown in Figure 8, where the subscribers have been divided into 20 groups of

500 lines. In each group the traffic is handled by a single multiplex line with 50 time positions. A square switchboard enables the 20 incoming multiplex lines to be linked to 20 outgoing junctions. Each of these is designed to carry 50 time-distributed lines also, which have been taken from the whole of the 20 groups of subscribers in such a way as to give any caller access to any one of the time positions of any one of the outgoing junctions. The risk of crosstalk through pulses of the same time position but different groups appearing at an outgoing junction can only be eliminated by using gated contact points and ensuring that the groups of time positions allotted to two gates situated on the same vertical line in the diagram have no common element.

4.1.2 *Speech-Circuit Comparison*

Multiplex devices allowing several lines to be concentrated on the same junction will lead to a large reduction in the number of contact points in the speech circuit. In this consideration, these devices would seem to outclass voice-frequency space switching. In reality, however, a comparison cannot be limited to the speech circuit; the control and memory circuits must also be examined.

An important function of certain electronic contacts in the voice-frequency speech circuit is that of *end marking:* In a speech circuit consisting, perhaps, of several selection stages and consequently offering a large number of possible paths between a given inlet and an outlet, it is only necessary to apply the appropriate voltages to this inlet and outlet to find a free path, if there is one, to establish the connection by this path, and to prevent it from being used for another communication. If there are several free paths, only one should be seized.

In contrast with electromechanical networks, there is no need to mark the crosspoints of intermediate stages. Obviously, this property means that the control circuit is appreciably simplified in electronic space-switching systems.

However, a statistical study shows that the traffic flows less satisfactorily than with certain marking methods that are more complex, such as associated double-stage control.

4.2 Memory and Control Circuits

In establishing, maintaining, and ending a communication, there are three successive memory functions.

The first memory must record for the entire duration of the dialing the signals sent by the caller. One 7-digit number corresponds to 28 bits when translated into binary code. If 100 calls are received simultaneously in a 10 000-line office, the dialing memory must have a capacity of about 3000 bits.

The second memory plays the part of a dictionary and transforms the information dialed into the reference position of the lines in the exchange. It also keeps much long-term information, such as the list of absent subscribers, out-of-order lines, et cetera. This *permanent memory* must have a considerable capacity, amounting to several million bits for a large exchange.

A third memory, the *supervision memory*, is necessary. It must be aware of all the independent variables that determine the condition of the speech circuit; for example, the correspondence of the two ends of a path—and, where applicable, the intermediate points—and the assignment of time positions for the multiplex. This allows the speech-circuit path to be freed at the end of a communication.

The capacity of this memory varies considerably according to its position in the exchange. The number of instructions per communication that it must remember is the same as that for the dialing memory. But it is engaged during conversation and not during the dialing time; therefore about 40 000 bits are required for a 10 000-line exchange.

It has been observed that certain electronic contact points are endowed with a memory. They can then fulfil the supervisory function themselves provided that their switching state can be easily ascertained.

In the construction of these various memories, certain of which have a very-high capacity, the cost per bit is of primary importance. Table 1 shows information recently[40] published.

Of course, the various memories must be connected to the control circuit that uses the information held by them to take the necessary steps for completing the connection. The complexity depends to a large extent on whether space or time switching is used and on the structure of the speech circuit and its components. *A priori*, multiplex systems seem to

TABLE 1
COMPARATIVE COST OF INFORMATION STORAGE METHODS

Access Time	Component	Cost per Bit in Dollars
Arbitrary Access at Great Speed	Ferrite Cores	1
(10^{-6} Second)	Cathode-Ray Tubes (with Associated Circuits)	1
	Vacuum Tubes	10
Access at Medium Speed (10^{-2} Second)	Magnetic Drum	0.01
Slow Access (10 Seconds)	Magnetic Tape	0.0001

involve an additional complication since the speech circuit is cyclically switched off and cannot therefore be used to keep the memory of its condition. In this case, supervision is necessarily carried out by an independent memory. However, a detailed analysis of the properties of the electronic crosspoints used in space switching often leads to the same conclusion.

For this reason, therefore, it is difficult at present to state a preference for one or other of these types of switching.

4.3 Line Circuit and Subscriber's Set

For reasons of economy, it is essential to limit the power transmitted by the speech circuit to a few milliwatts, which is sufficient for the conversation itself. This means that the speech circuit cannot transmit dialing and ringing signals such as are in use today, as their power is of the order of 1 watt. Possibly, a new type of subscriber's set will be used with electronic exchanges.

A transistor could conceivably be used in the set to increase the ringing signals from a milliwatt to 1 watt.

It has been suggested that a reduction in dialing time would be an additional advantage; a push-button keyboard might be used.

The possibility of using voice-frequency signaling is also being studied; it has the advantage of facilitating passage of signals not only through the speech circuits of an exchange but also through all the transmission elements.

5. *Existing Fully Electronic Exchanges*

There is no large fully electronic exchange in operation at the present time. Known constructions to date have been either skeletonized models of large exchanges or automatic exchanges with a small number of lines. Both time and space switching are represented.

In the first category, a multiplex automatic exchange with 100 lines and 16 junctions was constructed at Laboratoire Central de Télécommunications and was described[21] in 1954. Germanium point-contact diodes were used as switching points and gas tubes as memories.

Some work has been carried out by the British Post Office or on its initiative. In particular, the theoretical publications[13, 16] of T. H. Flowers led to the experimental work of F. Scowen, who described[20] in 1954 and 1955 an automatic exchange with 99 lines and 99 time positions using various components—vacuum tubes, gas tubes, and germanium diodes.

In the second category, a 10-line automatic exchange with 3 junctions was constructed in the Philips' laboratories and described[18, 19] in 1954 by W. Six. The contact point was the gas tube described in section 3.1.2. This equipment has operated for several years in the Philips' laboratories.

Recently in 1956, the Stromberg–Carlson Company supplied an automatic exchange with 100 lines and 15 junctions to the United States Navy. The contact point of the speech circuit is probably a symmetrical germanium transistor. It has been stated that this equipment requires less than half the space occupied by an electromechanical exchange and that the weight is reduced by three-quarters.

Finally, the Laboratoire Central de Télécommunications has just completed a fully electronic automatic exchange with 20 lines for the French navy. This is described in detail in the accompanying paper by Dumousseau.

This list would not be complete without mention of an important project now under construction. In the United States, the Bell Telephone Laboratories has announced that a fully electronic exchange will be put in operation at Morris, Illinois, in the spring of 1959. It will probably have a 2000-line capacity, serving 4000 subscribers, and will use voice-frequency switching with gas tubes.

6. *Conclusion*

The above-described activities indicate the interest that the telephone manufacturing and operating industries are taking in electronic switching. Before setting out the advantages that they hope to gain from this new technique, two factors should be mentioned that tend to slow down the introduction of innovations, whatever they may be, in the field of telephone switching.

The first is that in industrially developed countries, a new telephone exchange must fit into the existing network, which means that it must respect numerous norms.

The second factor is the large amount of capital invested in the machinery and switching equipment in use at present; this equipment is, moreover, quite satisfactory.

On the other hand, the application of electronics in industrial and military fields has demonstrated the considerable advantages that it brings in the way of reduced volume and weight, facility of maintenance if the equipment is well planned, and reduced power supply needs. It is now certain that telephone switching can also profit from these advantages. According[6] to M. J. Kelly, it may be anticipated that the volume of a fully electronic exchange would not exceed a fifth of that of a corresponding electromechanical exchange. The weight would differ in the same proportion.

It is more difficult to give figures for the reduction in power consumption, which depends to a large extent on whether gas tubes or semiconductor elements are used.

All things considered, it is certain that fully electronic exchanges will not replace the classic exchanges in one sweep; these will continue to be manufactured for a long time, particularly for extension of existing exchanges. But, at the same time, electronic exchanges will inevitably be introduced by degrees. Taking into account the constant increase in the world telephone and teleprinter switching networks, they will in the end represent a much-greater capital investment than the present one.

It is therefore essential that efforts now be devoted to the development of electronic switching that will be in harmony with future prospects.

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Recent Telecommunication Development

"Les Semiconducteurs—Diodes, Transistors et autres Applications"

PROFESSOR GEORGES GOUDET, former dean of the school of electricity and mechanics at the University of Nancy, France, and now director of Laboratoire Central de Télécommunications, and Charles Meuleau, who is in charge of semiconductor development at that laboratory, have recently published a book on semiconductors. The book is divided into three parts.

Part 1—General Fundamental Theory
- Introduction
- Elements of Quantum Mechanics
- Motion in Terms of Quantum Mechanics
- Band Theory
- Fermi Dirac Statistics
- Flow of Electric Current Through Solids

Part 2—Technology of Semiconductors
- Constitution and Properties of Crystals
- Preparation of Crystals
- Practical and Fundamental Measurements of Semiconductor Properties

Part 3—Principal Applications of Semiconductors
- Thermistors and Varistors
- Diodes and Rectifiers
- Triodes and Tetrodes
- Other Semiconductor Applications.

This book is $6\frac{1}{2}$ by $9\frac{5}{8}$ inches (16 by 25 centimeters) in size, contains 439 pages and 108 illustrations, and also includes a bibliography of some 350 original publications. It may be obtained for 5720 French francs from Eyrolles, 61 Boulevard Saint Germain; Paris 5, France. The publishing rights of this book have been extended to Macdonald and Evans, Ltd., 8 John Street; Bedford Row, London W.C. 1, England, who are planning on publishing an English edition during 1957.

Fully Electronic 20-Line Automatic Telephone Exchange*

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THE INTRODUCTION of electronics in such a large field as telephone switching presents many aspects that are often contradictory. An equipment can therefore be constructed only on the basis of a series of compromises involving such elements as time for completion, cost of research, cost of manufacture, reliability, possibility of making extensions later, various operating features, et cetera. This article describes a fully electronic automatic telephone exchange meeting the requirements of the French Navy with emphasis on only one of these factors; that of reliability. This is a natural choice, being the essential requirement that is not present in sufficient degree in electromechanical systems to permit their use in this severe environment.

It is obvious that a design based on special naval requirements may not be suitable for regular commercial use. Consequently, no claim is made of solving the entire problem of electronic switching. It is hoped, however, that it will form one of the foundation stones in the complex structure of the electronic central office of the future.

What were the considerations that dictated the construction of this equipment, how does it compare with the other solutions possible at present, and how will it develop in the immediate future? These three questions are considered in this article.

1. *Choice of Components and Diagram*

The aim of reliability was a particularly difficult one to attain in view of the conditions in which the equipment had to function. It was for this reason that use was made of only those components that had proved their worth during many years, and the simplest and most conventional over-all diagram possible was adopted. From the different types of electronic switching analyzed[1] by Goudet, space switching, which involves only low-frequency transmission, was selected.

1.1 Choice of Contact Element

Our equipment therefore switches voice frequencies directly as in the usual electromechanical switching equipment. In the latter, the essential element is the contact. As the word "contact" conveys an idea of movement, it has been replaced in electronic language by the word "gate," which is commonly used in connection with digital computers.

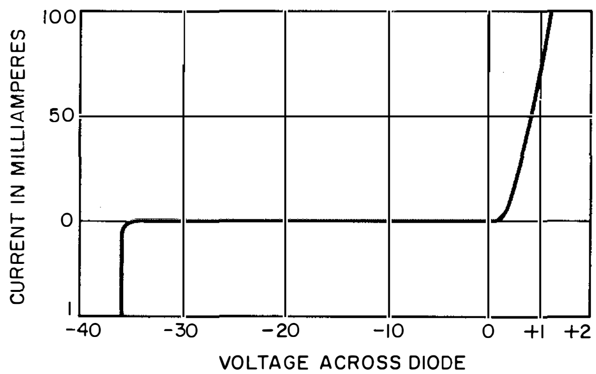

Figure 1—Current–voltage characteristic of silicon junction diode designed for telephone switching. Note change of scale for reverse current and voltage.

It might be thought that such a well-known element would be easy to obtain. As a matter of fact, this is not the case, as the quality of the gates that must be used in telephone switching is much superior to these generally used for calculating machines. In telephony, a gate must have at voice frequencies an impedance ratio between blocking and conducting of the order of 10^5. In the conducting condition, the attenuation must not exceed a fraction of a decibel and in the blocking state the crosstalk resulting from the gate being incompletely blocked must

* Presented before the Société Française des Radio-électriciens; January 12, 1957.

[1] G. Goudet, "General Considerations on Electronic Switching," *Electrical Communication*, volume 34, pages 80–91; June, 1957.

be inaudible; that is, of the order of -80 decibels referred to average conversation level.

Usually with digital computers, it is a question of knowing whether a signal is passing or not, and a gate impedance ratio of 10^2 is therefore quite sufficient. It is clear that the gates used in calculating machines would not be suitable for telephone switching.

Various semiconductor devices are used extensively as gates in calculating machines. Most of them have been used for several years in sufficient numbers and with few enough failures to leave no doubt of their reliability. Among these, the silicon junction diode is especially remarkable for three reasons.

A. Its impedance ratio between blocking and conducting is considerable: when conducting, the silicon diode possesses an almost-ohmic impedance of 4 ohms, while in the blocking condition, its impedance corresponds to 1000 megohms in parallel with a 5-picofarad capacitor.

B. Being simple in structure, it is adaptable to quantity production, reliable in operation, and particularly robust mechanically.

C. Among the commonly used semiconductors, silicon has the best thermal stability. Used as a gate in the voice-frequency band, its characteristics do not change appreciably between -40 and $+120$ degrees centigrade (-40 and $+248$ degrees fahrenheit).

For these reasons, the silicon junction diode was chosen as the basic element of the automatic exchange. It is made by alloying a fragment of silicon crystal with an aluminum wire. As the result of a special study undertaken for that purpose, this diode can now be manufactured so that it has the characteristics best suited for telephone switching.

Figure 1 shows the static characteristic of such a diode. The two operating points correspond to -5 volts for blocking and $+10$ milliamperes for the conducting condition.

1.2 Choice of Switching Principle

It is convenient to use crossbar representation in discussing switching diagrams regardless of the system under consideration. An electronic crossbar selector consists basically of 2 arrays of wires: a horizontal array of n wires and a vertical one of p wires as shown in Figure 2. Each of the $n \times p$ crosspoints of these two arrays is marked by a gate.

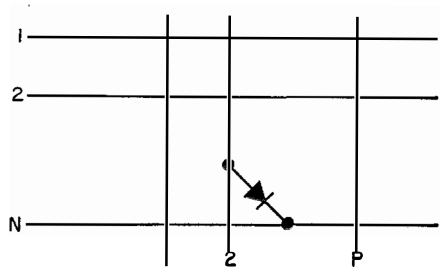

Figure 2—Elementary crossbar arrangement consisting of two arrays of wires with a gate at each crosspoint.

The simplest way of constructing this gate is to connect a diode at each crossing to the vertical and horizontal wires at that point.

To control the opening and closing of this gate, it is only necessary to apply a direct voltage between the vertical and horizontal wires connected to the diode. According to the sign of this voltage, the gate would be open or closed.

Unfortunately, with this method the two gates with the coordinates X_1Y_1 and X_2Y_2 cannot be made conductive simultaneously without two other gates with the coordinates X_1Y_2 and X_2Y_1 also being made conductive; this has the result of substituting for two separate connections, each between two subscribers, a common connection among four people.

It would be necessary in a practical system to provide such a crossbar selector for each conversation, which is not economical. There are two ways of getting over this difficulty.

The first is to separate the functions of making and of holding a connection. The marking of the gates through the wires of the crossbar selector should be done with a short impulse and this marking should be maintained afterward by the gates themselves. These gates then possess a memory function.

Such gates can be made of simple elements like gas tubes and certain 4-junction semiconductors such as n-p-n-p diodes, or more complex flip-flops composed of assemblies of diodes, transistors, magnetic materials, et cetera. Unfortunately, the silicon diode cannot be used as a gate in this method as it does not possess a memory.

The second method, which allows several simultaneous conversations through the same selector, consists in abandoning marking through the selector wires in favor of controlling the gates directly by means of an auxiliary device that maintains this marking.

A flip-flop may be connected to each gate or a complex network may connect a certain number of memory points to the gates that are conducting at any moment. When a memory is connected only to the gates, an appreciable saving can be made in the number of memory points.

However, this solution loses much of its interest through the complexity of the network. For a small equipment, it is probably more advantageous to have a memory, such as a flip-flop, permanently connected to each gate. This is the solution adopted in this case.

The problem of connecting a flip-flop permanently to each gate can be examined independently from the rest of the selector. In Figure 3, consider the elementary operation of

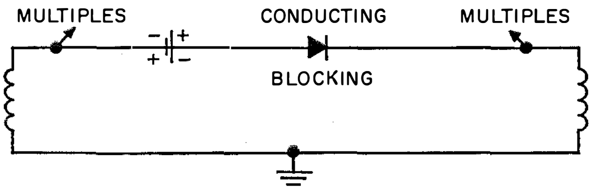

Figure 3—Diode and biasing battery connected between windings of two transformers to act as an opened or closed switch depending on the battery polarity.

a single diode gate between two transformer windings used as input and output for alternating-current signals. The control element is equivalent to a battery; the polarity of which can be reversed.

The battery need only have a low internal impedance, which is easily obtained by shunting it with a capacitor. When connected on the diode side of the transformer windings, it has the advantage of allowing the multipling of the two windings of the transformers and limits the number of transformers to the number of wires in the crossbar selector, that is, $n + p$. However, a battery placed in this position must not leak too much signal to ground or to adjacent circuits at the risk of causing losses and crosstalk.

Alternatively, the battery could be placed in the ground side with respect to the transformer windings as shown in Figure 4. The multipling

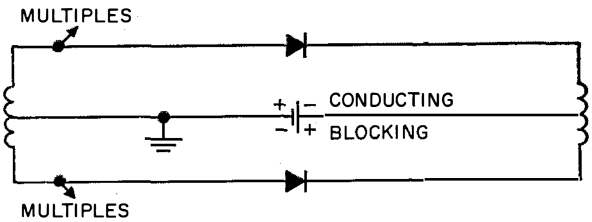

Figure 4—Adopted arrangement using bias source in ground lead and 2 diodes to keep voice currents out of the bias circuit.

can then be carried out on only one side, so that on the other there must be as many transformer windings as there are crosspoints.

The total number of windings is then $n + np$ or $p + np$. However, the battery is particularly easy to use. In addition, the 2-wire transmission circuit can be balanced by using a second diode. As no alternating current flows through the battery, it can have any impedance. This arrangement was chosen because of the ease with which it can be used.

The principles on which the design of the switching circuit is based can be summarized as follows.

A. Space switching, which requires only voice-frequency transmission.

B. Marking of each gate at the crosspoints by auxiliary flip-flop circuits.

C. Balanced transmission circuits.

D. Series connection of the gate-control flip-flops between the center taps of the transformers.

2. Description of Automatic Exchange

The over-all arrangement is that of a single-selection-stage crossbar equipment providing for 4 simultaneous conversations. This exchange serves 20 subscribers' lines. There can be 2 simultaneous calls in process of establishment.

In the simplified diagram shown in Figure 5, the horizontal lines represent 20 subscribers' lines and 2 registers, and the vertical lines denote 4 connection circuits that will be called "junctions."

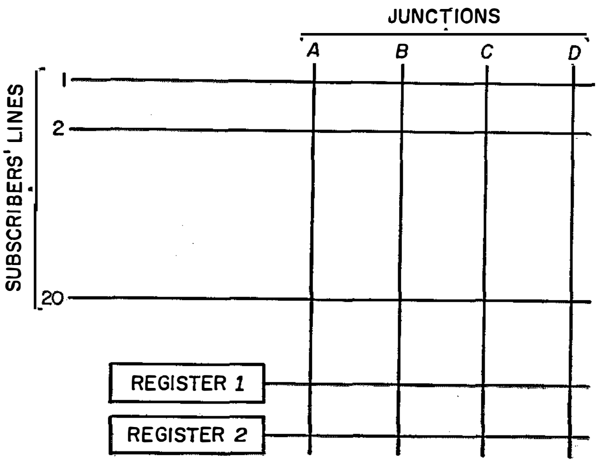

Figure 5—Simplified diagram of exchange.

Thus, a communication between subscribers' lines *2* and *20* can be established through path *2-A-20*, or if junction *A* is already occupied with another conversation, by an alternative path through any free junction.

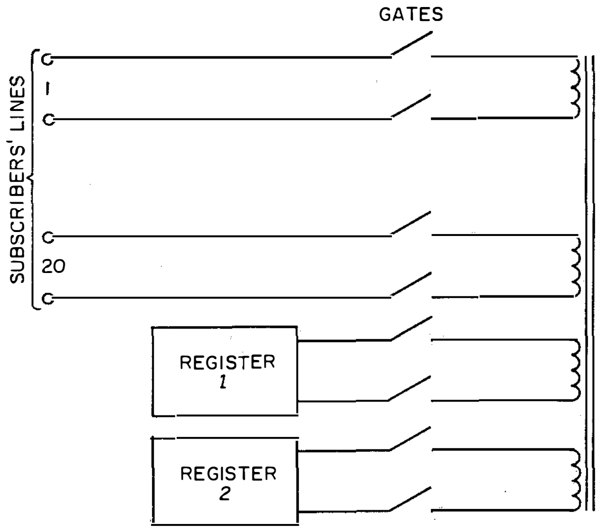

Figure 6—Magnetic circuit used as a junction connected to 20 subscribers' lines and 2 registers.

Figure 6 shows one of the junctions connected to the 20 subscribers' lines and to 2 registers. This junction consists of a common magnetic core with 22 transformer windings connected to the lines and registers by 2-wire circuits through the intermediary of 22 electronic gates, each composed of 2 silicon diodes.

As will be seen in Figure 7, the diodes are inserted between the windings of the line and junction transformers. A fixed bias battery and the control circuit are connected in series between the center taps on the transformers.

When the control circuit is not supplying voltage, the gate is normally blocked. When the control circuit is operating, it supplies a voltage that compensates for the bias battery and reverses the sign of the voltage applied to the diodes. These are then conducting and the subscriber's line has access to the magnetic core that constitutes the junction.

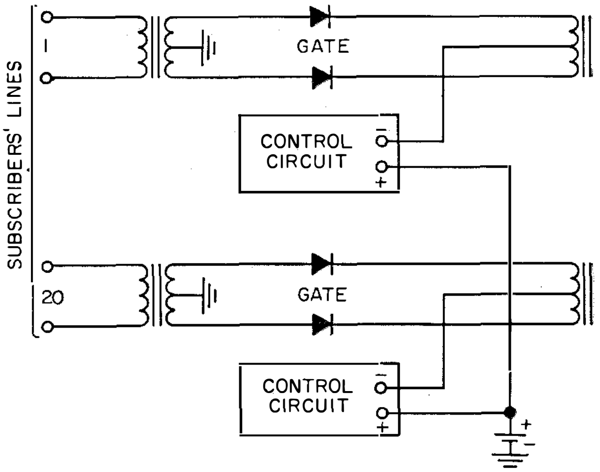

Figure 7—Method whereby individual control circuits can make the gate of a subscriber's line conductive by reversing the polarity of and exceeding the voltage supplied from a common battery that normally holds the diodes in blocking condition.

2.1 Ferroresonant Circuit

In designing the control circuit connected to each gate, reliability continued to receive first consideration. Only components that had been proved over the years were used and they are operated well below their ratings. These requirements were satisfied by a ferroresonant circuit or magnetic flip-flop that is shown in simplified form in Figure 8. It possesses two quite-distinct stable conditions, one with a low current and the other with a high current.

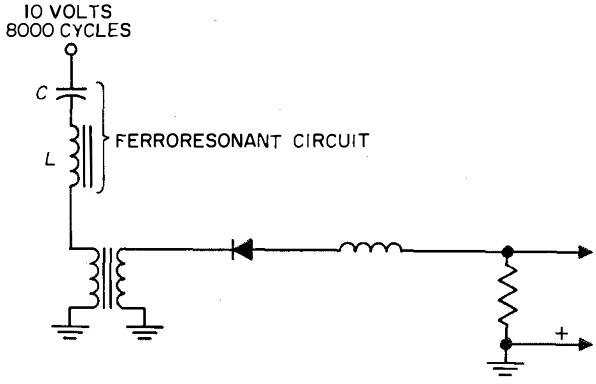

Figure 8—A capacitor in series with an inductor, the core of which can be magnetically saturated, are operated at 8000 cycles as a ferroresonant or magnetic flip-flop circuit.

In the low-current condition, it can be considered to be inoperative and does not interfere with the action of the bias battery in blocking the diodes. In the high-current condition, it produces a voltage that is higher than and of opposite polarity to the bias voltage to overcome it and make the diodes conductive.

In Figure 8, capacitance C and inductance L are in series and supplied with an alternating voltage at a frequency of 8 kilocycles per second.

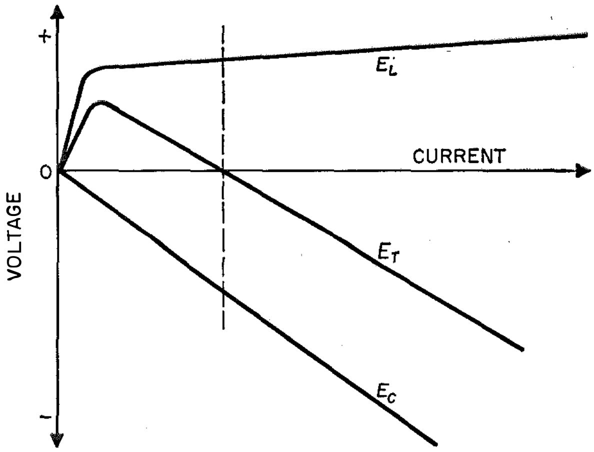

Figure 9—The voltages appearing across the capacitor E_C and inductor E_L as a function of the current through them are shown together with the total voltage E_T across both.

This circuit is well known in radio. When the frequency is varied, it gives rise to the phenomenon known as series resonance. However, series resonance is not involved in this design. The circuit is operated at a fixed frequency that is not the resonant frequency. Its performance is based on the magnetic saturation that occurs in the core of the inductance when the current increases.

In Figure 9, voltage E_L across the inductance first increases proportionally with the amplitude of the current. For the higher values of current, the effect of saturation becomes evident and E_L increases much less quickly, the curve being inflected. The voltage E_C across the terminals of the capacitor increases proportionally to the current. E_C is shown negatively on the graph to express the fact that the two voltages are out of phase with each other. The total voltage E_T across the terminals of the inductor and capacitor in series are added algebraically and the absolute values are plotted in Figure 10.

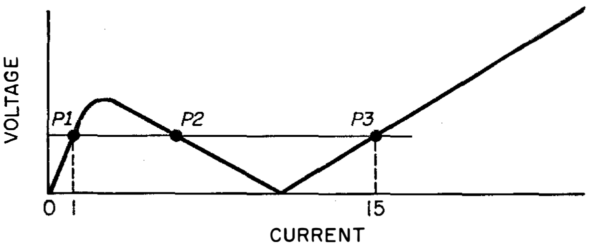

Figure 10—Absolute values of the algebraic sums of E_C and E_L are plotted above.

It is evident from Figure 10 that, over a certain range, a given alternating voltage applied to the terminals of the whole circuit will produce a current that can have three distinct values corresponding to the points *P1*, *P2*, and *P3*. Point *P2* is an unstable condition. Only *P1* and *P3* represent stable operating points. The current passsing through the primary of a coupling transformer induces a voltage in the secondary that is rectified to produce an output voltage that can assume two quite distinct values having the same sign.

When the circuit is placed in operation by applying the alternating voltage, the system assumes a low-current condition. To make it pass to a high-current condition, it is only necessary to saturate the magnetic core for a

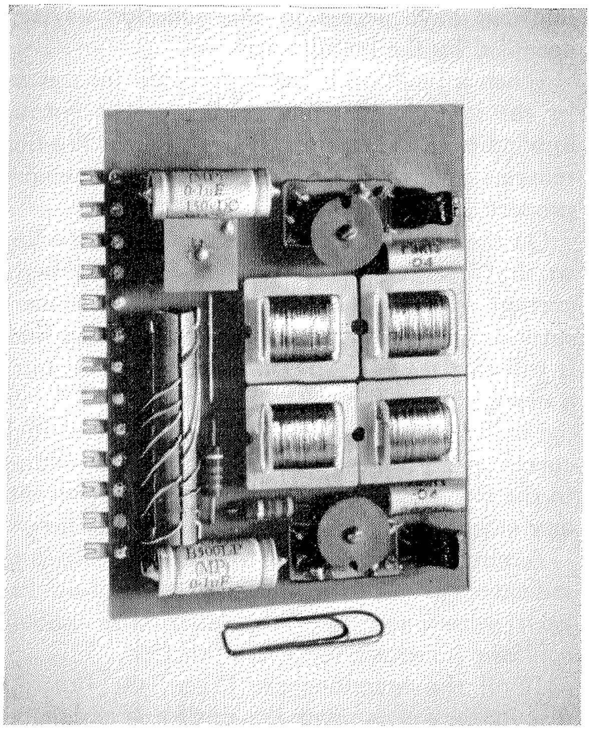

Figure 11—Front of flip-flop panel.

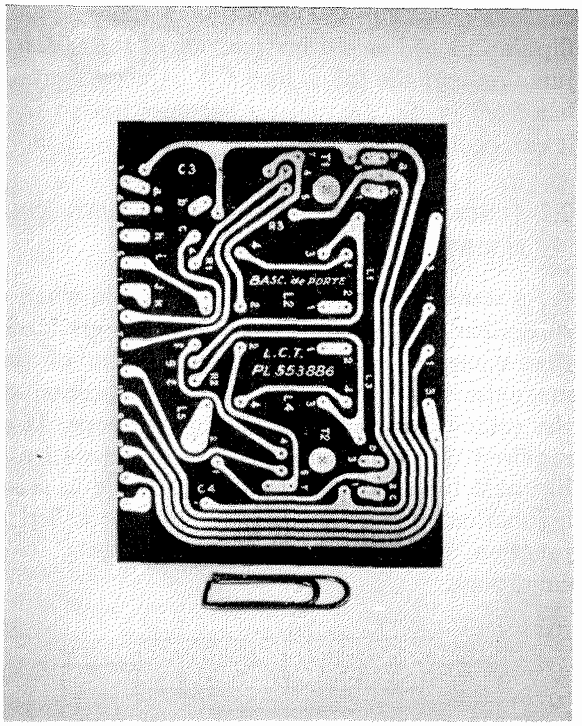

Figure 12—Rear of flip-flop panel.

moment by means of a current through an auxiliary winding. A return to the original condition can be obtained by cutting off the supply voltage for a moment.

Figure 11 shows a small panel on which one of these magnetic flip-flops is mounted. The printed-circuit connections are on the rear face as shown in Figure 12. In Figure 13 are the principal components consisting of capacitors, inductors, selenium rectifiers, and silicon diodes.

Now that the principal circuits have been described, the mechanism by which a connection is established in the automatic exchange can be considered.

Referring again to Figure 5, when a subscriber lifts the handset, a signal is produced that changes the condition of the magnetic flip-flop at the intersection of the calling line and one of the available junctions, supposing that there is one. The two diodes connected to it—one of which is connected by means of a line wire—then become conductive and the subscriber's line is thus connected to a junction. The latter is connected to a register, which also consists of magnetic flip-flops, and the number dialed is stored in the register. After this, a network of rectifiers known as a decoding matrix comes into play. For each number registered, it makes a signal appear on the wire allotted to that number. This signal

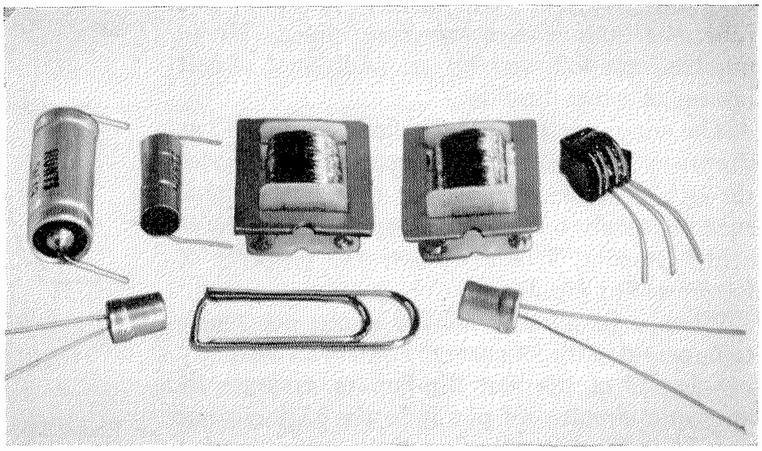

Figure 13—Components of a flip-flop circuit.

causes a change in the condition of the magnetic flip-flop placed at the intersection of the selected junction and the called line. Once the connection has been made, the register becomes free so that it can deal with new calls.

2.2 Junction Circuit to the Calling Subscriber's Line

As stated in the preceding paragraph, when a subscriber lifts the receiver, a signal is produced that causes a change in the condition of the magnetic flip-flop placed at the intersection of the calling line with one of the junctions. It is required that only one junction be seized by a line at a time and that a line be unable to seize a junction already occupied. A device called a junction distributor provides for these two conditions.

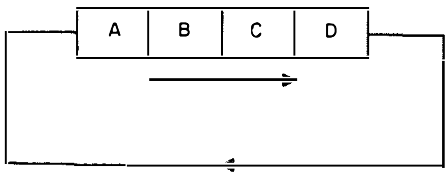

Figure 14—Junction distributor.

As shown in Figure 14, a junction distributor consists essentially of a 4-position counter closed on itself that can revolve and stop on the first free junction that it meets. This counter, also, is composed of magnetic flip-flops.

Its role is to prepare the junction so that it is ready to be seized by the next calling line. For this purpose, the gate flip-flops between the junctions and the subscribers' lines, 20 in number, are followed by an additional circuit known as a rest flip-flop.

The entire group of 21 flip-flops is supplied as shown in Figure 15 with current at 8000 cycles through a common capacitor that has a value such that only one flip-flop at a time can have a high current. This is an essential property of ferroresonant flip-flops.

When a junction is neither seized nor ready to be seized, a direct current flows in an auxiliary winding E of the rest flip-flop to saturate its magnetic circuit and put it in the high-current condition. No other flip-flop of the same junction can then also have a high current. Therefore no line can have access to this junction as it is occupied by the rest flip-flop.

When a junction is being prepared for seizure by the junction distributor, the current flowing in winding E is interrupted but the rest flip-flop remains at high current because of its memory property.

On the other hand, the flip-flop corresponding to the first calling line can assume the high-current condition as soon as a momentary saturating signal is sent to it through the line; it will then keep its high-current condition until a new order is sent to the junction.

Finally, when a junction is seized, a high current passes through the flip-flop corresponding to the line that seized the junction and prevents any other line from seizing the same junction.

A circuit common to the 20 line flip-flops indicates to the distributor if a junction has been seized and that the distributor should continue its search for a free junction.

If all the junctions are taken, the junction distributor keeps revolving until a junction becomes free. Its rotational speed is about 1 junction per millisecond, so that in the most unfavorable case the distributor takes 4 milliseconds to signal that a junction has just been freed.

2.3 Register Circuit

As soon as a junction has been seized, it searches for a free register. This operation is carried out in exactly the same way as the search made by a line for a free junction. The register distributor selects either of the two registers that is free.

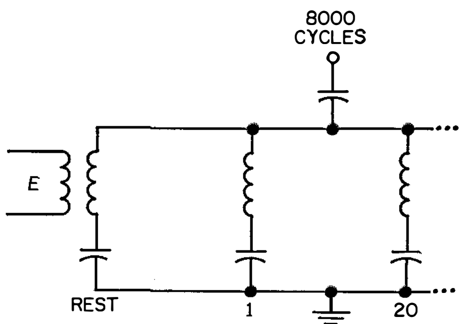

Figure 15—Application of voltage to 21 flip-flop circuits through a common capacitor to permit only one to be active at a time.

Each register consists of a 150-millisecond delay circuit, trains counter, tens counter, units counter, and a decoding matrix, as shown in Figure 16.

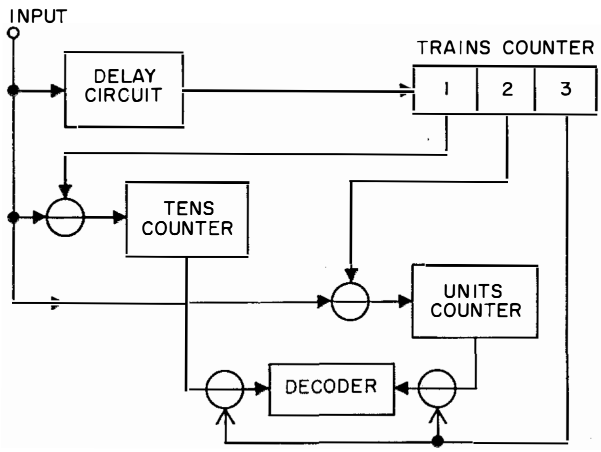

Figure 16—Register circuit.

The role of the delay circuit is to send a pulse to the trains counter after 150 milliseconds have elapsed since the last pulse in a series was sent by the subscriber's dial. This circuit therefore operates on all the trailing edges of pulse trains and allows the units to be separated from the tens.

The trains counter is in 3 stages and at rest is in position *1*. The first series of incoming dialed pulses go to the tens counter as the gate under control of position *1* is then open.

At the end of the first train of pulses, control passes to the second position, closing the gate to the tens counter and opening the gate to the units counter, which records the second series of pulses.

At the end of the second train, which corresponds to the end of the 2-digit numbering, control passes to the third position, which connects the decoding matrix to the tens and units counters.

This diode decoding matrix then supplies a voltage to the appropriate outlets of the register, thus connecting the called subscriber to the junction. The register then becomes free and all its counters return to rest.

2.4 Junction Circuit to the Called Subscriber's Line

The connection between the called subscriber and the junction is controlled by the decoding matrix of the register with the help of a second set of 20 line flip-flops assigned to the called subscribers and 1 rest flip-flop for each of the 4 junctions.

Thus, the operations involved when a junction is seized by a calling subscriber's line are completely separate from those involved in the connection of the called subscriber's line to the junction.

These 21 flip-flops are also energized at 8000 cycles through a common capacitor, so that only one of them can have a high current at a time. This will be either the rest flip-flop, when the junction is not connected to any called line, or the flip-flop corresponding to the subscriber's line called when the diode decoding matrix of the register has supplied a potential on the wire corresponding to this line.

It is evident that this separation of the calling from the called control circuits and the properties of the coupled ferroresonant circuits fulfil automatically the double-test conditions that are so important in telephone switching.

2.5 Ringing Circuit

The ringing function raises what is at present one of the most controversial questions with regard to the use of electronics in telephone switching.

All the circuits just described are capable of being supplied with, or of transmitting, a power of about 10 milliwatts. This is ample for normal speech levels. Unfortunately, however, a power of about 2 watts is required to ring the subscriber's station bell.

With presently available tools and techniques the electronic gates of the equipment cannot be made capable of transmitting such a power. The alternative is to use an amplifier in each subscriber's line circuit to raise the ringing level from 10 milliwatts, which normally flows in the equipment, to 2 watts.

This amplifier is costly: a magnetic amplifier is used because it is very robust and therefore very reliable. But the fact must not be disguised that this solution is not necessarily final as will be discussed later.

The line circuit with the magnetic amplifier is shown in Figure 17. The amplifier occupies three-quarters of the volume of the line circuit.

2.6 Supply

The exchange uses various power supplies for its operation. They include a direct voltage of 24 volts for the microphone, direct bias voltages of 6 volts and 24 volts, and an alternating voltage at 8000 cycles.

These various voltages are supplied from the 50- or 60-cycle main by selenium rectifiers for the direct voltages and from a 10-watt vacuum-tube oscillator for the 8000-cycle voltage. The total power consumption is about 100 watts.

3. Arrangement

Figure 18 shows the whole of the equipment in the form of a compact unit. To facilitate access to the different parts, they are mounted on two movable panels that can be swung apart.

Each panel is divided into shelves, visible in Figure 19, in which are housed the printed plates supporting the ferroresonant circuits. The first panel accommodates the 4 junction circuits and the second panel carries the 2 registers. The fixed part of the equipment in the base houses the 20 line circuits.

The whole of the equipment has been specially treated to resist rough mechanical handling and can endure the accelerations resulting from considerable shocks, such as those produced by the testing machines of the Navy's technical services, which employ a mass of 100 kilograms (220 pounds) falling from a height of 1.5 meters (59 inches).

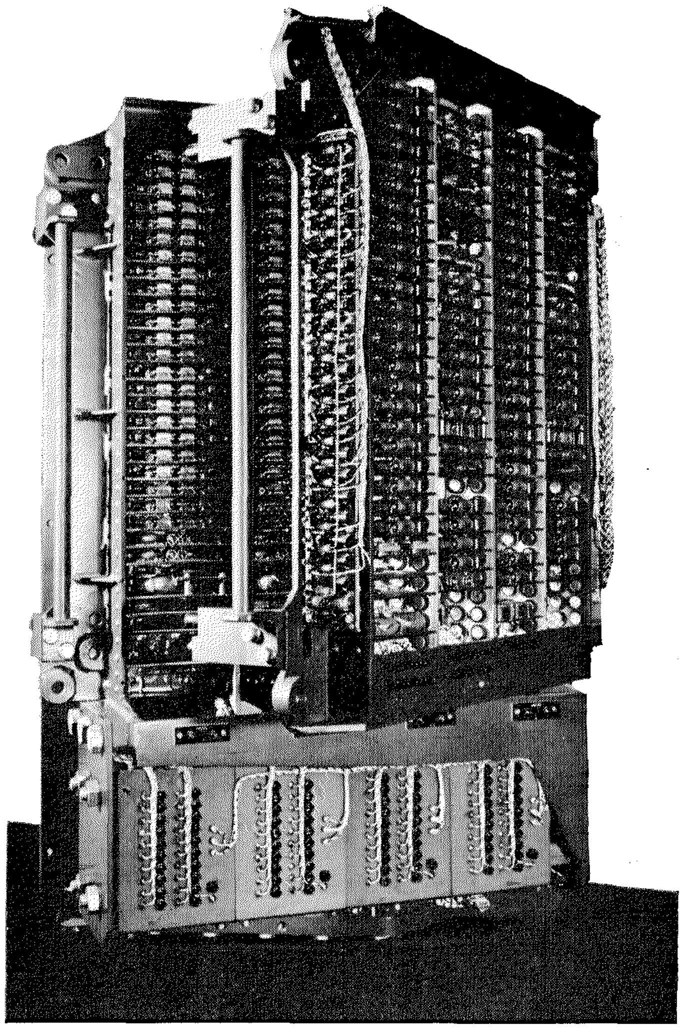

Figure 18—Complete switching equipment with one of the two panels slightly "open." Both panels may be swung apart from each other for access to the components.

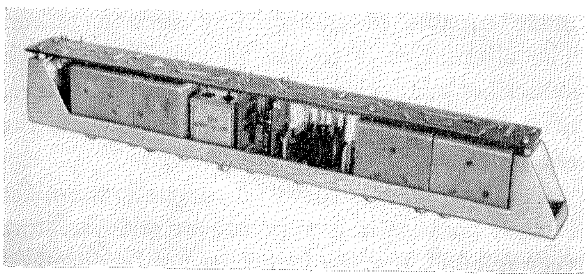

Figure 17—Line circuit including the magnetic amplifier for ringing.

4. Future Prospects

The equipment that has just been described fulfils the conditions set for it. However, numerous improvements are still desirable and include such things as a decrease in weight and volume and an increase in dialing speed.

It would be premature to attempt to give detailed solutions at this time because only preliminary studies have been made. It is, however, possible to present a few suggestions.

It is highly desirable to avoid the use of magnetic amplifiers for ringing the called subscriber as they occupy a third of the volume of the present exchange. One simple solution is to replace the bell or vibrator by an electromagnetic device similar to a receiver mechanism actuated by a voice-frequency current amplified by a transistor in the subscriber's set. The electronic switching circuits in the exchange would thus never have to transmit a power higher than that for speech.

Now that the electronic circuits in the exchange allow the switching operations to be almost instantaneous, the dial in the subscriber's set limits the speed of operation. The digits can be transmitted more quickly through the use of a keyboard with 10 keys; this reduces the length of the operation by at least 3 to 1. The keyboard could send voice-frequency signals instead of the usual numbering pulses and they would travel through all the transformers in the exchange and the repeaters in the long-distance lines without having to be transposed. Moreover, this keyboard would be much more resistant to mechanical shock than the present dial.

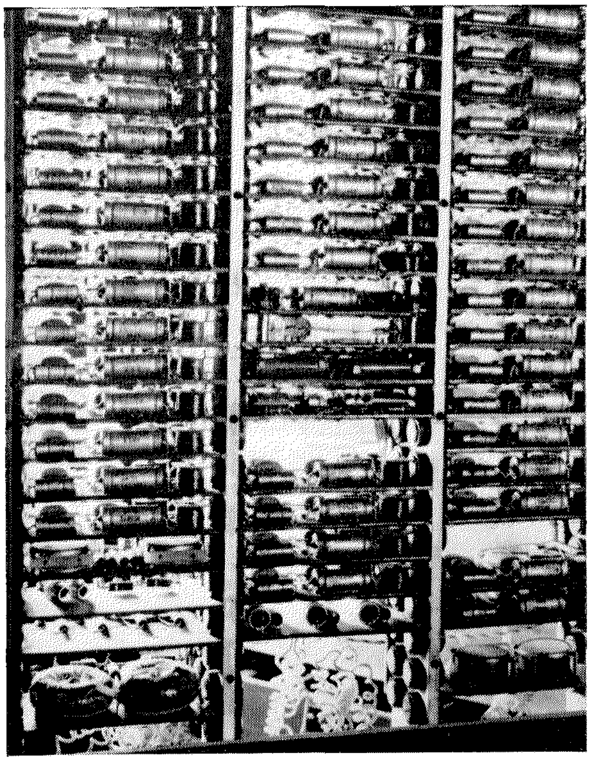

Figure 19—Method of mounting the ferroresonant circuits.

The present exchange consumes a substantial proportion of its power in the supply of direct current to the microphones of the subscribers' sets. Many experiments are being made to decrease this power.

For military equipment, a solution has been provided by the use of self-generating telephone sets, which do not consume direct current. These sets have, in addition, the advantage of being much more resistant to shock and vibration than carbon microphones.

If all the changes outlined were adopted, the power supply could be reduced in fixed installations to a 24-volt rectifier of a few watts and a small 8000--cycle oscillator composed of 2 transistors. In portable equipment, a small storage battery of 24 volts and the transistor oscillator would be sufficient.

In conclusion, it seems evident that although the equipment presented today possesses the merit of novelty, it still has to undergo a certain amount of development before it can be considered definitive.

The development of military equipment should be rapid as only exchanges of low capacity are required. Based on the present design and incorporating the improvements outlined, it is now possible to construct a small light equipment consuming very-little power and made of components, including the subscribers' sets, that will function reliably for a long life under naval conditions.

With regard to civilian needs, it is certain that in the future electronic switching will be the basic technique for large exchanges. However, the construction and introduction of such exchanges into the existing networks will pose many problems. Not least of these, will be the expense of equipment to interconnect electronic exchanges with the existing ones, and also that of staff training.

However, the experience acquired in the development of this naval equipment will be a useful starting point for more-important, although more-distant, applications.

Principles of Electronic Circuits in the Mechanoelectronic Telephone Switching System

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PARTICULARLY characterizing the *8A* mechanoelectronic crossbar switching system is the use for the first time in any commercial telephone switching system of electronic methods for all principal control functions, including the collection of information on the condition of subscribers' lines or switch outlets, as well as the transmission, processing, and storage of this information. This system has been described extensively in two articles.[1,2]

The advantages to be gained through electronic control may be enumerated as follows

A. Higher operating speed.

B. Time sharing permits the electrical condition and/or class of a large number of switch outlets to be signaled over a single wire.

C. New performance capabilities; for instance, all switch outlets and lines may be scanned continuously during 24 hours a day at a speed of 445 outlets or 5000 lines per second.

D. Reduced maintenance resulting from no mechanical wear.

E. Reduced space occupancy.

In developing electronic circuits for controlling the operation of an electromechanical telephone switching system, the designer meets with a number of specific problems, most of which are related to the combining of two techniques that have their own specific requirements and characteristics. Moreover, in both branches of the art of telecommunication, certain traditions have established themselves with a firmness related to the age of the art.

It is one objective of this article to indicate some of the problems that have been encountered in designing the *8A* system and to present the solutions that have been adopted, many of which may be widely applicable.

First, the basic concepts that have led to the system in its present form will be analyzed in relation to the choice of components, circuits, and circuit operation. Next, attention will be given to some of the problems resulting from the interworking between sensitive electronic circuits and electromagnetic relays and switches. This will be followed by some special features of the pulse generator. Finally, some of the principles set forth will be illustrated by a description of actual circuits used in the system.

1. Components and Circuits

1.1 Components

Four main factors are considered in selecting components: reliability, first cost, general availability, and ease of maintenance. Of all generally available components, miniature metallic rectifiers and carbon resistors stand out in reliability and robustness, uniformity of characteristics, small size, and low cost. Thermionic tubes, on the contrary, occupy considerable space, and though the price per tube may be reasonably low, they suffer from the following disadvantages.

A. Limited life, requiring regular replacement.

B. Variation in operating characteristics during lifetime, necessitating extensive routine checking programs, unless their use is limited to on–off switching applications.

C. Power for cathode heating is required for 24

[1] J. Kruithof and M. den Hertog, "Mechanoelectronic Telephone Switching System," *Electrical Communication*, volume 31, pages 107–150; June, 1954.

[2] E. Van Dyck and C. Weill, "Pulse Generator for the Mechanoelectronic Telephone Switching System," *Electrical Communication*, volume 32, pages 126–138; June, 1955.

hours per day and additional equipment may be needed to dispose of the heat.

In view of these objections, the use of thermionic tubes is limited preferably only to those circuits that are provided in groups in which a temporary failure will not unduly impair the switching service. In more-critical applications such as unduplicated control circuits serving a number of lines, provision must be made for immediate fault detection and location, through the use of either guard relays or automatic routine testers.

Cold-cathode tubes are in a much more favorable position, particularly in view of their life, stability, and the absence of heating power.

Logically, therefore, an electronic control system should be designed to use relatively large numbers of metallic rectifiers, a moderate number of cold-cathode tubes, and a small number of thermionic tubes. As an example, the *8A* crossbar exchange at Ski, Norway, for a total capacity of 2000 subscribers' lines but excluding the common pulse generator, uses 35 000 miniature metallic rectifier disks, 22 000 carbon resistors, 750 cold-cathode tubes, and 322 thermionic tubes.

It must be noted that another 290 thermionic tubes are used in the common pulse generator, but this number will not increase appreciably when the size of the exchange increases to a capacity of, say, 10 000 lines.

When thermionic tubes are used, it is advantageous to centralize them in one or a few common circuits per exchange so they may be provided with common guard or check circuits and with a common blower system. This facilitates their maintenance. The number of different types should be minimized. In the Ski exchange, all thermionic tubes outside the pulse generator are of the *13D1* type, which is equivalent to the *6SN7* with a 25-volt heater. A high heater voltage is advantageous as it permits conductors of reasonably small size without undue voltage drop. The use of double triodes is desirable as this reduces the number of sockets. The medium amplification factor appears to be a good compromise for the various applications required in a switching system. The same type of tube is used in the pulse generator, along with a limited number of *6V6* beam-power tubes and *2D21* thyratrons.

1.2 Circuits

The use of pulse techniques already described[1] aids in obtaining adequate performance from these components. It has been possible to concentrate the bulk of the electronics design in a few common circuits and to make extensive use of the possibilities offered by rectifier disks assembled in computer-type gate circuits and matrixes to collect, multiplex, and process information relative to the condition of switch outlets and subscribers' lines.

Cold-cathode tubes are used with rectifier gates to select and store this pulsed information. Thus the principal control functions are handled by components having generally recognized reliability and long life.

However, to keep the power dissipated in the rectifier networks within reasonable limits, these circuits must be operated at a high impedance level and this, unfortunately, is incompatible with an undisturbed and undistorted transmission of the pulses. Therefore, the transmission path must be associated with an amplifying means at the sending end and pulse-regenerating circuits at the receiving end. For these applications, vacuum tubes have been used as at the time of development, they constituted the only sufficiently reliable means capable of operating with the required speed and accuracy. With suitable improvements in transistor stability and circuit design, these functions could be performed by transistors.

To reduce the influence of their characteristics, these tubes are operated either as cathode-follower amplifiers or as on–off switching devices. In one case requiring voltage gain, the circuit was arranged to produce an excess of amplification and limiting diodes were employed to obtain output pulses of the desired amplitude.

To improve reliability, these vacuum-tube circuits have been designed so that failure of cathode emission in any tube results in a no-pulse condition of the output. This is particularly important where the on condition results in the successive engagement of all available circuits within a functional group, for instance, of all governor circuits. This may be achieved by the exclusive use of positive-going impulses and cathode output. In cases such as multivibrator circuits, where use of plate output is inevitable, double triodes are used with series-connected filaments, one section being employed as a cathode-follower output stage following the anode output, or else a nonconductive coupling must be included as is shown later in Figures 10 and 11.

2. Choice of Pulse Pattern

2.1 Pulse Frequency

The choice of the pulse cycles to control the rectifier networks was mainly determined by the design of the crossbar switch. As this switch has 100 outlets, pulses must be provided for at least 100 different time positions. To reduce the number of pulse sources, these time positions are obtained by the combination of a relatively small number of pulse trains.[1] There are many ways of achieving this, but the choice is restricted by the following considerations.

A. The number of pulse sources, which is equal to the number of decoding elements in the recorder, should be as small as possible.

B. The design of the pulse-generator output transformers and of all coupling circuits is simplified by using pulses of a uniform duration, preferably equal to the basic time interval of 0.2 millisecond, thus reducing bandwidth requirements to a minimum. This, however, means that the numbers of pulses in the various cycles may not have a common denominator.

C. The crossbar switch should be under direct control of the recorder without intermediate code translation.

The operation of the switch depends on the successive selection of one of 25 vertical bars, one of two supplementary bars, and one of two servomagnets. Accordingly, a pattern of $5 \times 5 \times 4$ has been adopted, which is an acceptable compromise between the second requirement and the other two considerations. This arrangement is made up of 1 series of 4 pulses and 2 series each of 5-pulse sources, the pulses of one cycle of 5 being five times as wide as those of the other cycle of 5. Cycles d and e, which serve for grouping the outlets of a selector into 11×3 levels in all, have been chosen on the grounds of similar considerations, cycle d alone providing for all levels, for instance in a switch with decimal division of the outlets, and the combination of d and e being used if more than 11 directions must be served.

2.2 Pulse Amplitude

The pulse voltage levels must conform to the following conditions prevailing in the circuits to be served.

Pulses to control the cold-cathode tubes in the recorder circuits (R pulses) must have an amplitude of 60 volts, to provide a sufficient margin for safe triggering. Pulses applied to rectifier matrixes must not exceed the reverse voltage rating of a single disk, thus avoiding the need for multiple-disk rectifiers. Pulses used in the subscriber-line explorer (N pulses) must not be active if the subscriber's b wire is in the normal condition of -48 volts. If this voltage rises toward ground potential, the pulses must be effective. Ground faults on the b wire will then result in a call being registered, and this permits an early detection of this faulty condition.

Pulses used for other explorers (P pulses) should be such that they are activated by a test potential indicating a condition of availability. This must differ from ground potential, which should render the pulses ineffective. In this way, when an outlet or a circuit is occupied, disconnecting the test voltage will mark its unavailability; a ground fault will have exactly the same effect. As positive-going pulses are preferable, this indicates the use of $+24$ volts with respect to ground.

2.3 Pulse Width

The minimum width of the pulses is dictated mainly by the triggering speed of the cold-cathode gas tubes, which are in the recorder. The gas tubes have a triggering time between 60 and 100 microseconds. Accordingly, the pulse width has been fixed at 200 microseconds, allowing for some pulse distortion and a liberal safety margin. This choice is also in good agreement with the requirements of a desirable design of the explorers. As each branch of the explorer contains series resistance and shunt capacitance (the latter being due to the inherent capacitance of selenium rectifiers connected in shunt), the output pulses will suffer considerable distortion. Measurements on a typical explorer have shown that the rise time of the output pulse is of the order of 100 microseconds as shown in Figure 1.

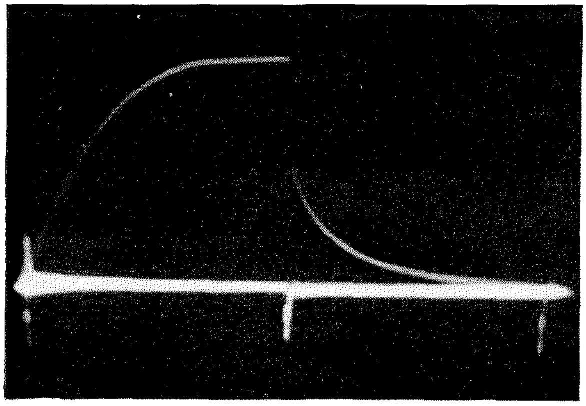

Figure 1—Distortion in scanner output pulse caused by the shunt capacitance of the gates.

2.4 Pulses Are Contiguous

To shorten the total exploring time, the pulses obtained from each cycle of pulse sources are contiguous. In effect, the transmission over a single conductor of two adjacent pulses in a cycle produces the equivalent of a single pulse lasting twice as long. This affects the design of almost all the electronic circuits, particularly the pulse transmission circuits. As pulse leads may be required to transmit pulses in any sequence, a variable and at times substantial direct-current component may exist, and capacitive or transformer coupling would have to be designed for a pass band extending far into the low-frequency region. To avoid these difficulties, direct coupling is used throughout. The use of single-wire transmission follows and avoids unduly complicated terminating circuits. This again necessitates special precautions to protect the transmission circuits against interference. Fortunately, this protection can be achieved relatively easily by providing separate pathways or separate cable forms for the sensitive pulse leads at a sufficient distance from the relay-operating wires to avoid damaging coupling.

Direct coupling also requires that any reference levels used as threshold potentials for pulse detection must be equal in all circuits liable to be connected together. Such reference potentials should be distributed throughout the exchange over bus bars that carry substantially no current. In practice, this bus, though insulated from the battery ground leads, is connected to the same earth electrode. It also serves as a ground for screens and screening boxes. It is called the "silent earth."

From such a reference potential, secondary reference levels may be derived by means of high-grade, high-stability voltage-dividing networks. These networks also compensate for supply-voltage fluctuations.

If, however, some loss of scanning time could be tolerated, the pulses could be separated to avoid these difficulties and permit the use of capacitive couplings and pulse transformers together with direct-current restorers.

3. *Interworking Between Electronic and Switching Circuits*

3.1 Reliability

The introduction of electronic circuits into a switching system must be studied first from the reliability point of view. Although the design of electronic circuits to perform various switching functions generally presents no special difficulties, often there are conditions imposed by the operation of the electromagnetic switching circuits that compel revision of the normal electronic design to make the system compatible.

A thorough knowledge of these limiting conditions must be obtained by careful study and experience. It must include both normal operating conditions as well as transient and all possible kinds of fault conditions.

The design, then, must be such that in all normal operating conditions correct performance is assured, that transient conditions cannot produce any persistent damaging effects, and that any possible fault condition exerts no detrimental influence outside the circuit in which it occurs while providing for rapid detection and location of the fault. Some examples of the conditions to be met will now be considered.

3.2 Normal Operation

3.2.1 Protection Against Interference

Electronic circuits, particularly quick-acting sensitive trigger circuits, are liable to interference from electric and magnetic fields. For instance, the release of highly inductive relay coils will produce sharp peaks of many hundreds of volts

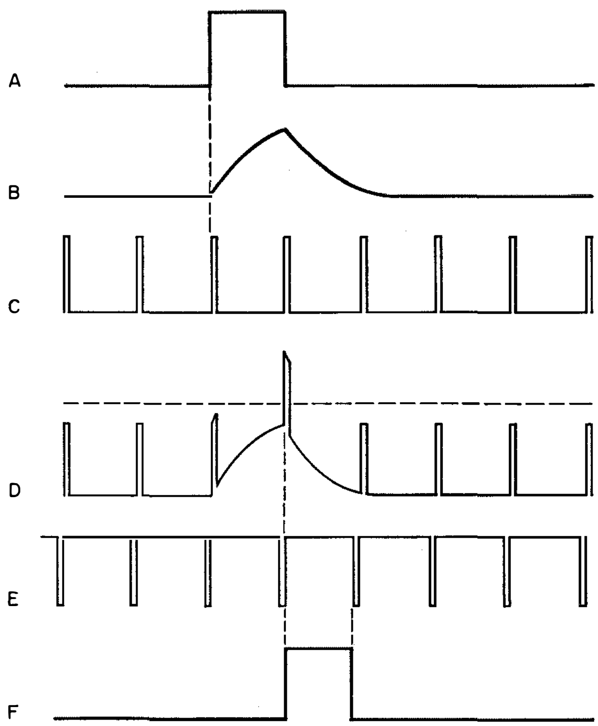

Figure 2—The original pulse at *A* is distorted by filtering action to the shape shown at *B*. *C* are start marker pulses, one of which is lifted at *D* by the distorted pulse of *B*. The lifted pulse triggers the regenerator which produces a new clean pulse *F* until it is stopped by the reset marker pulse at *E*. The new pulse is exactly one interval later than the original pulse.

that can generate both low-frequency and high-frequency waves that can propagate over great distances along the wiring of the exchange to be coupled through conductive, inductive, or capacitive paths into the high-impedance electronic circuits. A cold-cathode tube mounted near a relay is sometimes fired when the relay is released, this firing being due to the electromagnetic disturbance propagated through the air space.

This influence could be considerably reduced by the use of spark quenchers across the relays, but this would be costly, as it involves equipping thousands of relays to protect a few electronic circuits. In addition, the condition of a defective spark quencher cannot be detected readily and could remain unnoticed for a long time, causing elusive spurious operations of the electronic circuits. Actually, only the heavy clutches and some of the largest relays are provided with spark quenchers. However, the protection of the electronic circuits does not depend on them.

This protection is ensured by the following methods.

A. Electronic circuits are concentrated to permit their segregation from relay circuits. Short straight connections are made between the tubes and their associated components.

B. Suppressor resistances are connected to the grids and/or cathodes of amplifier tubes.

C. Each electronic circuit is enclosed in a metallic box that is insulated from the supporting structure and grounded by a short heavy conductor without loops.

D. All conductors going into the box, including battery and plate-supply leads, are provided with adequate means to prevent high-frequency interference from entering with them. Direct-current leads from batteries and some signaling circuits are equipped with low-pass filters; a simple resistance-capacitance filter with a time constant of 20 to 30 microseconds has proved adequate in most cases. Usually, these filters are mounted with the resistor just outside and the capacitor just inside the box. In alternating-current and pulse circuits, screened wire or coaxial cable is used.

E. Screened wires supplying the electronic circuits from a centralized power source have their screen grounded at the source end and not at the equipment end to avoid loops. Pulse-carrying output wires emerging from the box are preferably screened, the screen being connected to the box.

F. Conductors leading to electronic circuits are kept out of, if necessary even screened from, the cable forms belonging to relay circuits.

3.2.2 *Pulse Regeneration*

The probability of spurious action of trigger circuits is further reduced by disabling them except for a short interval within each time unit. This is achieved with the aid of a train of time-marker pulses, which sensitize the trigger circuits during 25 microseconds at the start of each 200-microsecond interval, as illustrated in Figure 2. Pulses like that shown at *A* are distorted in shape due to the inherent capacitance of the gates. In passing through a low-pass filter that is inserted in the input lead to the trigger circuit to reject high-frequency interference, the pulses are further distorted as shown at *B*. Therefore a regenerator is provided to produce new pulses having the required shape. The new pulse obtained from the regenerator will inevitably be later in time than the original pulse, and it is arranged to be delayed exactly one time position. One series of time-marker pulses *SM* is called starter markers and is shown at *C*. The pulses are repeated at 200-microsecond intervals and, when superimposed on *B*, produce *D*. Only the lifted marker, also shown in Figure 3, is able to pass a threshold and trigger the regenerator. A second series of time markers *RM* called reset markers trigger off the regenerator. As the reset markers are leading with respect to the start markers, there is no interference between them.

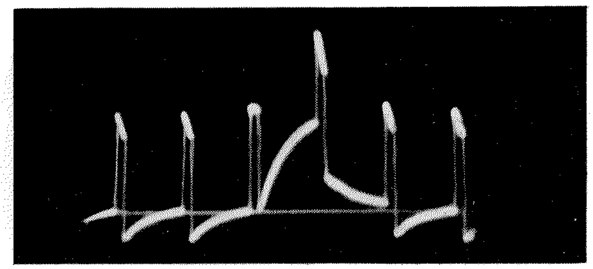

Figure 3—Oscilloscope display of a lifted pulse.

Thus, the operation of the regenerator depends on the arrival of a pulse from the scanner and of a time marker at the end of that pulse.

The application of time markers may be controlled by a comparator and one or more reference pulse sources connected to the comparator. In this way, the function of pulse regeneration may be combined with pulse selection.

3.2.3 *Pulse Circuits with Relay Coils*

Undesirable distortion of pulse waveforms may arise in trigger circuits or pulse amplifier circuits that include relay coils. For instance, in Figure 4A, a pulse arriving at the trigger electrode of the gas tube produces at the output terminal a voltage step having a sharp overshoot followed by an exponential decay or a damped oscillation. In the cathode-follower circuit of Figure 4B, the output pulse will have its leading and trailing edges rounded off by the influence of the relay

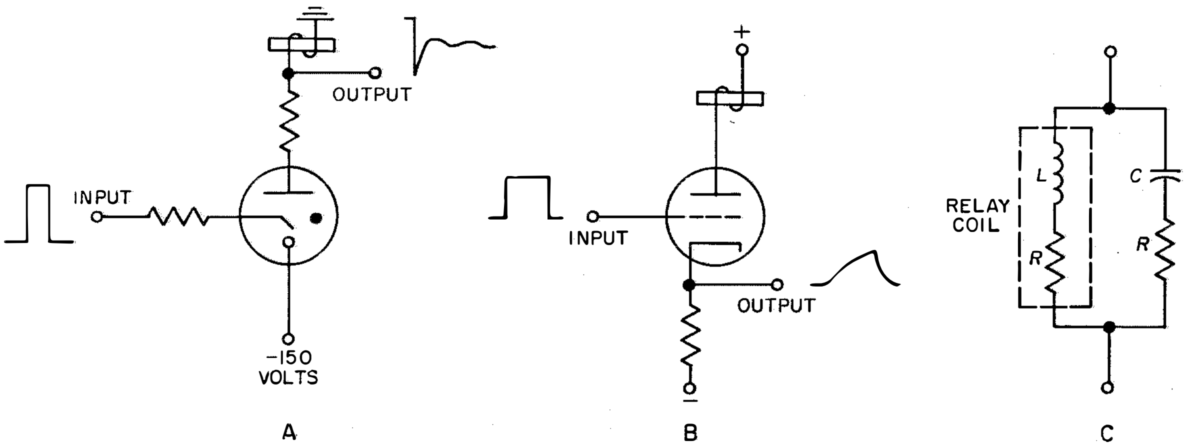

Figure 4—Effect of relay inductance on shape of pulse output of a gas tube at *A* and cathode-follower at *B*. The effect of the inductance can be compensated by the arrangement at *C* for which

$$\frac{1}{Z} = \frac{1}{R + j\omega L} + \frac{j\omega C}{1 + j\omega RC} = \frac{1}{R}$$

inductance. These effects can be avoided by shunting the relay coil with a series combination of a resistance equal to the relay resistance and a capacitor satisfying the relation $RC = L/R$. This combination presents a purely resistive impedance equal to R, that is independent of frequency.

3.3 Faulty Operation

3.3.1 Fault Conditions

Each circuit design must be carefully studied for the effect of any fault condition that may arise. These faults may occur in electronic components; for instance, tube failure, short-circuits within a tube, insulation breakdown of capacitors, and open- or short-circuiting of carbon resistors or rectifiers. They may also occur in the telephone switching equipment; for instance, bad relay contacts, contacts welded together, unwanted combinations of relays operated, ground faults, blown fuses, subscriber's line in accidental contact with a power conductor, and so forth.

In all such cases, the following conditions must be maintained.

A. The damage must remain localized. Preferably, the ratings of the components are chosen to withstand the abnormal conditions resulting from any predictable fault.

B. The operation of common supply circuits, such as the pulse generator, must not be endangered.

C. The circuit must not generate pulses or signals that can interfere with the normal operation of other circuits, or signals that will engage other circuits unnecessarily.

D. Means must be provided for detecting and signaling a fault condition and of suppressing any signals by which the faulty circuit normally indicates its availability to other circuits.

With respect to ground faults, it may be observed that in a telephone exchange any unprotected metallic parts such as soldering tags, bare wire terminals, and relay contacts are liable to be grounded, most often inadvertently by maintenance personnel. The circuits thus exposed must be protected so that no damage can result from grounding. Open wire lines may be subject to much more serious conditions if at any place they run near 220-volt mains supply lines.

In practice, it is not always economically feasible to provide for all conceivable fault conditions, particularly combinations of faults occurring simultaneously. In general, however, if adequate fault-detecting means are provided, the probability of two independent faults occurring at the same time is so small that it may be ignored.

Other categories of faults, such as loose connections, may be disregarded, provided the circuits are manufactured, tested, and inspected with sufficient care.

3.3.2 Fault Detection

Fault-detecting means of various degrees of perfection and concomitant complexity may be designed to meet the specific requirements of the circuits in which they serve. For instance, in common control circuits that are duplicated for handling simultaneous calls such as the governor circuits, the fault-detecting means simply consists of a timing device that operates whenever the control circuit is engaged for an abnormally long time.

A timing circuit used for fault detection is shown in Figure 5. As long as the circuit to be guarded is at rest, relay SFR is operated and the trigger of the cold-cathode tube is kept at cathode potential. When the circuit is engaged, ground is disconnected from relay SFR, which releases. Capacitor C is slowly charged through a 6-megohm resistor and its voltage is applied to the trigger of the gas tube. It will be discharged as soon as SFR operates at the end of the engagement period. However, if due to some fault condition the circuit does not restore within 7.5 seconds, the trigger voltage will become high enough to fire the tube, whereby relay TIR will operate. This in turn operates relay HOR, which by action of $HO1$ in discharging C and $HO2$ in interrupting the anode current to extinguish the tube, restores the timing circuit to its initial condition. HOR then releases unless key HOK is pressed whereby HOR is held operated and an alarm is sounded.

A feature of the *8A* system is that all control and switching operations and functions are linked in a unique sequential cycle, and any fault that may interfere with the progress of this cycle will result in the absence of a pulse or signal on which the completion of the cycle depends. In such circuits, if the timing device operates, an alarm is sounded and the check voltage that indicates the availability of the circuit is disconnected.

In cases where a single control circuit is common to a number of lines, an immediate alarm is preferred. For instance, in an esbo circuit, which contains only one vacuum tube, this tube is provided with a guard relay in its plate circuit, which is normally held operated but will release if the plate current drops below a permissible limit. It will then sound an alarm and cut off the check potential of the esbo circuit.

Another case is represented by the call detector, which is an all-electronic circuit employing 6 double triodes. For these, a routine test circuit continually checks all call detectors in sequence. Both tubes and other components are tested.

3.4 Transient Conditions

By transient conditions are meant those that are not due to a fault and that do not occur normally. For instance, when a circuit that has been out of service is reconnected for use again, the various supply voltages might become effective in an unintended order, resulting in a transient period of abnormal operation. When a jack-in unit containing vacuum tubes is plugged in, the plate and bias voltages are instantly effective although the cathodes are not yet at operating temperature. Similarly, abnormal conditions may arise if a fuse has blown or is missing from one of the supply leads. Also, at the instant of replacing such a fuse, a short transient occurs. In all such conditions, some of which are best found by test and experience, the following protection must be provided.

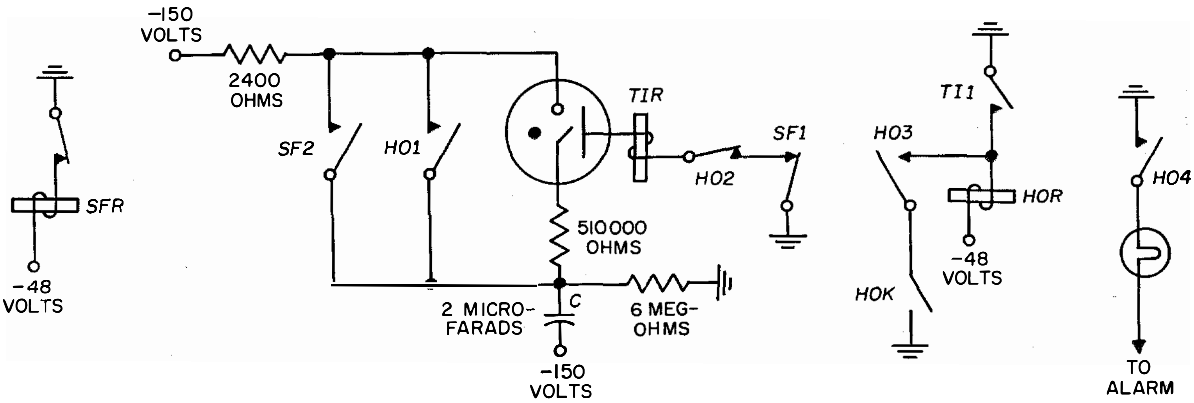

Figure 5—Timing circuit to actuate an alarm if the circuit being guarded does not complete its operation within a specified time.

A. No components may be damaged.

B. The circuit may not generate any pulses or signals that could interfere with the normal operation of other circuits.

C. The circuit must assume its normal operating mode after the transient occurs.

It is well known that the backward resistance of selenium rectifiers that are not regularly subjected to a reverse voltage will gradually decrease. Pulsed reverse-current measurements made on partially unformed disks have revealed that the reverse-current density doubles in about 3 seconds, continues to rise proportionally with the logarithm of time, and reaches 6 times its initial value after about one day. This is shown in Figure 6. When the reverse voltage is applied, the barrier layer is formed again, but it takes some time before the backward current reaches permissible limits. This reforming time is a function of the period during which the disk was idle as is illustrated in Figure 7. For instance, a reverse voltage must be applied for 170 milliseconds to rebuild the barrier layer of a disk that has been idle for 170 hours.

It is desirable, therefore, that all rectifiers be repeatedly subjected to a sufficiently high backward voltage to maintain their barrier layers. It may sometimes be necessary to apply voltage pulses for no other purpose. If no solution can be found and the reduced backward resistance causes any unwanted pulses or signals to be generated, some other kind of rectifying element, such as vacuum or gas diodes, should be employed.

4. Special Features of Pulse Generator

In the *8A* system, the common pulse generator might be referred to as the beating heart of the exchange. Here the reliability problem is posed in its utmost stringency and every other consideration has been subordinated to this one aspect. The considerations that have determined the general design of the pulse generator have already been fully explained[2] so only fault detection will be discussed.

A thorough study has been made of all predictable fault conditions and their consequences. A classification of such faults follows.

A. Inevitable faults, that is, faults due to the limited life of thermionic valves and similar components. Valve failures resulting from internal short-circuits, gasiness, and grid emissivity have been excluded from this category as they occur relatively seldom and are usually discovered during a preliminary operating test.

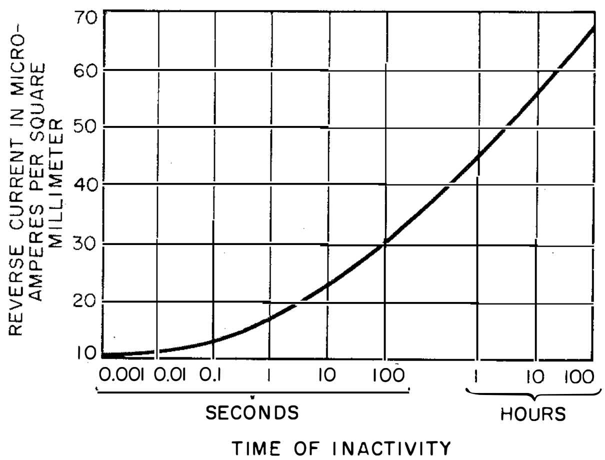

Figure 6—The rate at which the pulsed reverse-current density of a selenium disk increases while it is inactive.

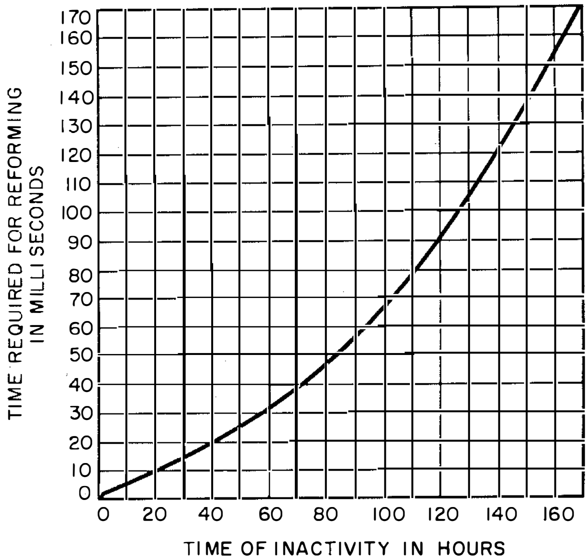

Figure 7—Time required to reform a selenium disk as a function of the idle time during which the barrier layer has deteriorated.

B. Rare faults due to failure of normally reliable components such as resistors, capacitors, transformers, and selenium rectifiers. These faults may be reduced to a minimum by using high-grade components and applying liberal safety factors in establishing the ratings for them.

C. Avoidable faults such as dry soldered joints, short-circuits, or excessive leakage in the wiring. These faults may be eliminated altogether by taking sufficient care in constructing and testing. As only one pulse generator is provided per exchange, this need for utmost accuracy does not constitute a major economic objection.

Consequently, the following requirements have been established for the guard circuits.

A. Despite an inevitable fault, uninterrupted and undisturbed service must be ensured. If the faulty circuit is an active one, that is, capable of generating pulses or similar waveforms, this requirement implies that the fault must be detected at once and that the faulty circuit must be prevented from interfering with the correct operation of the remaining circuits. It also implies that each active circuit must be associated with its own fault-detecting and blocking means, which must be sufficiently rapid to ensure that no abnormal condition can be perceived by any of the other guard circuits. Thus the need for interlocking circuits between different guard circuits is obviated. Actually, however, such interlocking means have been provided for additional security in the case of paralleled circuits, which have their guard circuits combined in a common control circuit; an example of this is the distributor circuits described in section 3.2 of a previous paper.[2]

B. With respect to rare faults, the guard system must offer at least the same facilities as specified in section 3.3 of this article. In these cases, continuity of service will not be exacted, though of course an alarm must be given.

C. Guard circuits must be able to discriminate against transient disturbances such as might be produced by a sudden drop of the mains voltage. This may, for instance, be achieved by providing an automatic recheck of fault conditions.

D. Guard circuits must not depend on any components having a limited lifetime; preferably, the circuit should be so designed that under normal conditions the components carry only a little or no current at all.

E. Nevertheless, the guard circuit should be as simple as possible.

The circuits of the generator have been designed with a view to reducing the variety of fault conditions that may arise due to any inevitable fault. For instance, the distributor has been so designed that, whenever a fault occurs, the instantaneous result is always the same. The master pulse generator in the pilot circuit (*Gd2* in Figure 2 of the previous paper[2]) is such that it can only generate pulses at the correct frequency or else nothing at all. For similar reasons, the monostable multivibrator circuits such as *Gd3*, *F1–F2*, *Gx*, and *Gc* are designed with fixed grid bias, rather than automatic cathode bias, for the cathode bias depends on cathode emission and therefore decreases as the tube ages until the circuit starts to generate uncontrolled pulses.

5. Security Features of Circuit Design

5.1 Call-Detector Circuit

The way in which the call-detector circuits are mounted is shown in Figure 8. Each tube and all the components that are closely associated with it constitute a subassembly that is fastened to the face plate of a metallic box by means of the screws shown at the top, which also serve to

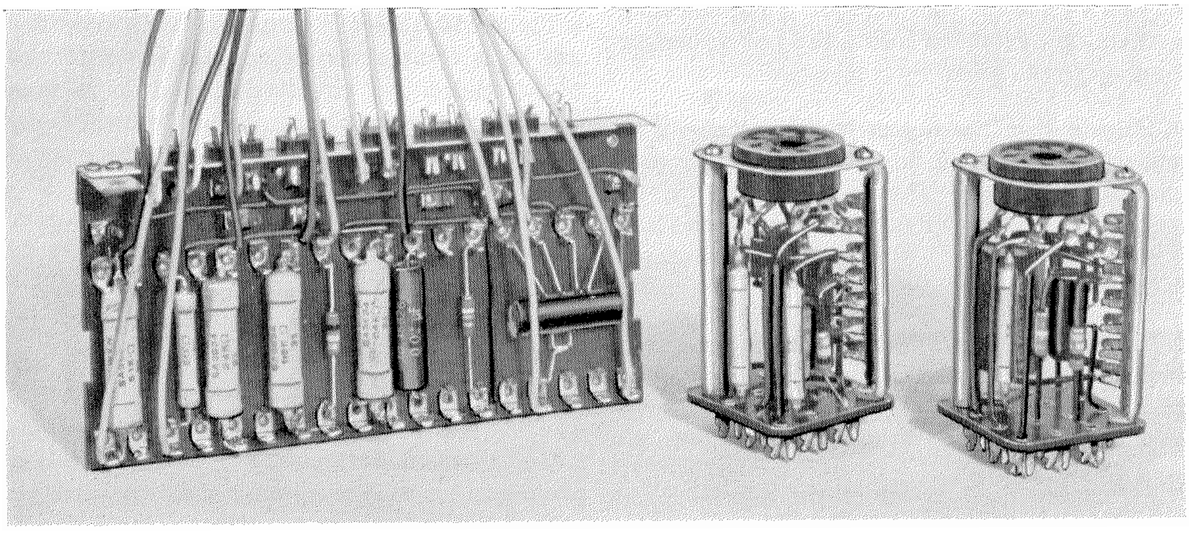

Figure 8—Method of mounting electronic components.

secure the tube socket to the lateral bars. One of these bars carries soldering tags to serve as a support for internal interconnections. Outside connections are soldered to these subassemblies, as this was thought to provide greater reliability than jack-in connections. Common circuits, such as supply filters, are mounted together on a strip as shown at the left. The strip is clamped in position against one of the lateral walls of the screening box.

5.2 Esbo Circuit

Schematically represented in Figure 9 are the electronic parts of an esbo for line finders and final selectors, shown in principle in Figure 14 of an earlier article.[1] The following security features are evident in the drawing.

A. A 30 000-ohm resistor has been connected between the *C* wire and the input terminal of the explorer to protect the rectifiers and the pulse sources against a ground fault on the *C* wire and against foreign voltages applied to the subscriber's line.

B. The apex of the explorer is connected to the grid of the amplifier tube by means of shielded wire having low distributed capacitance; the shield of the wire is connected to the metallic shielding box housing the amplifier.

C. As the cathode output leads of the amplifier are shielded only within the esbo circuit, they may pick up noise from without. Their shielding is, therefore, extended inside the box to reduce coupling to the grids.

D. Shielding on the heater leads also serves to connect the shielding box of the amplifier to a special ground bus. This bus is called "silent ground" and is separated from the grounded lead of battery to the point where both are connected to the common ground electrode.

E. The filament transformer has a grounded shield between its windings and the mid-tap of its secondary winding is connected to earth via a fuse.

F. Filters are used in all of the supply leads entering the shielding box and are usually of the resistance–capacitance type.

G. A guard relay *ALR* is connected in the anode lead of the amplifier tube. If the plate current drops below a determined level, *ALR* releases and interrupts battery to *CFR*, which operates an alarm circuit and also disconnects the +24-volt check potential.

The availability of the esbo to other circuits is indicated by the presence of this +24 volts on the check lead, and this in turn requires the presence of the +150-, −48-, and −150-volt supplies and normal operation of the tube.

H. Relay *ALR* together with the resistance–capacitance combination connected across it offers a purely resistive impedance.

J. If the +150-volt supply fails or if there is a high-resistance contact at the plate pin of the valve, the cathode voltage would drop towards −150 volts and a relatively strong current would flow into the grid. A 100 000-ohm resistor has been inserted to protect the grid as well as clamp rectifier *CR* against overload.

K. Blocking rectifiers isolate the cathodes from −48 volts unless the conditions for *J* occur when they conduct and prevent the output lead from dropping to −150 volts, which could be harmful to the detecting circuits connected to the other end of the leads.

5.3 Gating Circuit

Figure 10 shows a simple gating circuit for use as a comparator in conjunction with the pulse regenerator circuit discussed in Section 3.2.2. It serves to select a 25-microsecond time-marker pulse *SM′* out of a regular succession of such pulses recurring at the start of each 200-microsecond time unit. The particular marker pulse to be selected is determined by a reference pulse or a combination of reference pulses, one out of each of a number of pulse cycles. In the example shown, a combination of 3 pulses, one out of each of the 3 cycles *PA1–5*, *PB1–5*, and *PC1–4*, may be connected to the gates *CRGA*, *CRGB*, and *CRGC*, respectively, by the operation of one relay in each of 3 groups of relays, whereby a 200-microsecond pulse is created at the common lead by the coincidence of the selected 3 pulses.

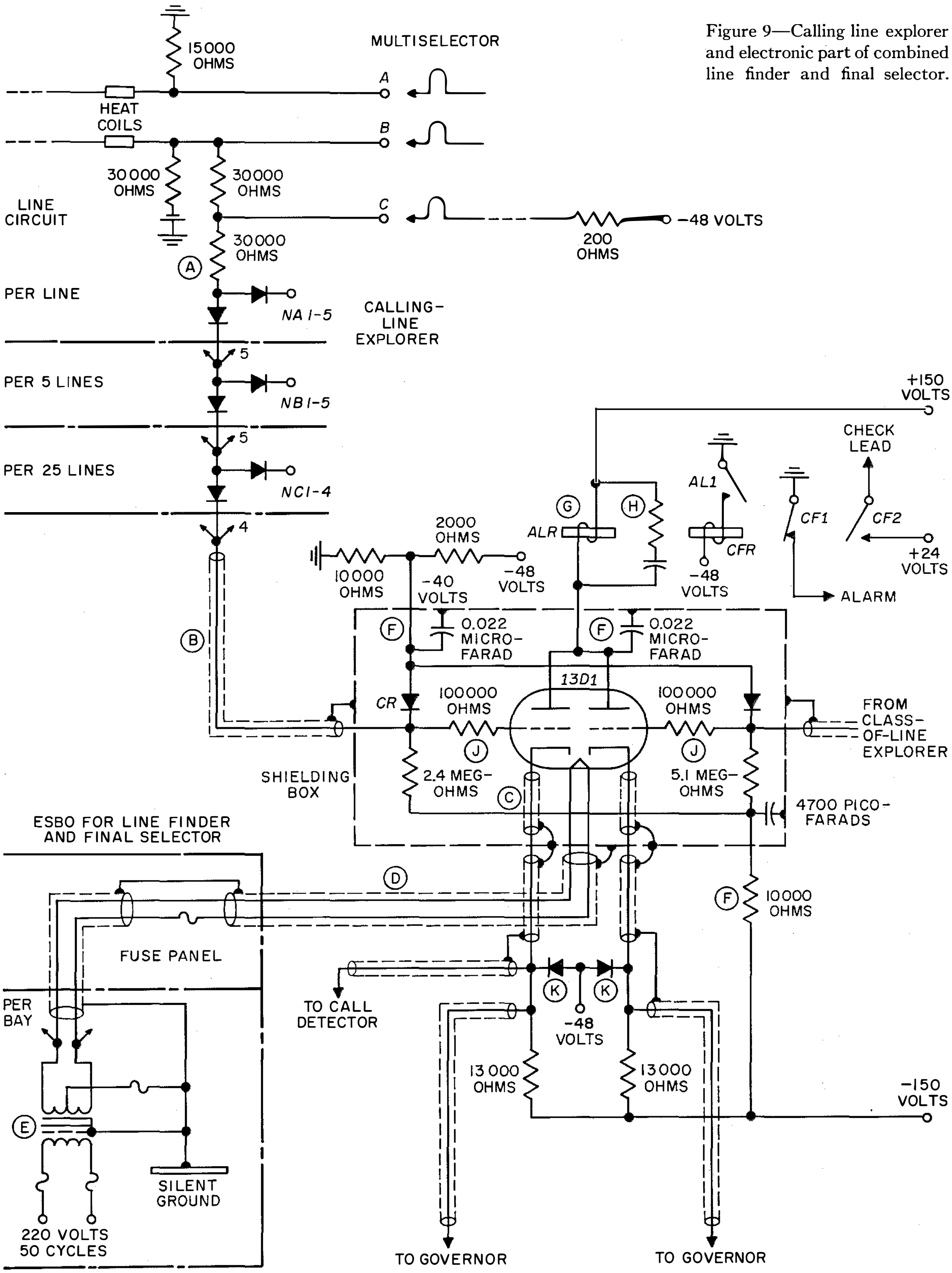

Figure 9—Calling line explorer and electronic part of combined line finder and final selector.

This pulse passes through a low-pass filter and is then superimposed on the marker pulse train *SM*. Only the lifted marker will be able to pass the cathode bias of the threshold tube. Thus an isolated marker *SM′* is obtained at the start of the time unit following the coincidence of the reference pulses.

In the practical circuit, the following requirements must be met.

A. No output marker *SM′* may occur unless one contact in each group of relay contacts (*AA1–AE1*, *BA1–BE1*, *CA1–CD1*) is closed. This implies that no marker may be issued if any one of the operated relays does not establish a firmly conductive path through its contacts for any reason.

B. If by some accident two or more contacts are closed in the same group, no marker *SM′* may be issued and no short-circuit between pulse sources may result.

C. The coincidence pulse resulting from the combining of the 3 pulses must have an amplitude of +28 volts which exceeds the +24 volts of the *P* pulses, and must be proportional to the voltage of the −48-volt battery supply.

Figure 11 is the circuit adopted. Each of the gates such as *CRGA* is provided with an absorption resistor *RA*, the lower end of which is connected to −150 volts. The upper end is maintained at about −28 volts by clamping rectifiers *CRA1* and *CRA2*. As long as no pulse is transmitted through capacitor *C* and rectifier *CRA2*, the potential of the common lead *L* will also be at −28 volts.

The reference pulses are taken from the *R* sources, which are of 60-volt amplitude, and applied through a 36 000-ohm dropping resistor and a coupling capacitor *C*. Each of the dropping resistors is shunted by a rectifier such as *CRA3*, pointing towards the source. In this way, if two contacts are closed simultaneously, both pulse sources connected will absorb the pulses transmitted by the other and no pulse will be applied to the gate. As long as no contact is closed, the left-hand plate of capacitor *C* is kept at −110 volts, which is the base level of the *R* pulses, to avoid the production of a transient pulse when a contact is closed.

When coincidence of pulses occurs at the gates *CRGA*, *CRGB*, and *CRGC*, the voltage on lead *L* rises until it is held at ground potential by the limiting rectifier *CRL*.

The clamping potential of −28 volts is obtained from a low-resistance voltage divider across the −48-volt battery and is isolated from the circuit by the clamp rectifier *CRO*. This measure safeguards against an insulation breakdown of a coupling capacitor such as *C*, whereby a low-impedance path would be established from the −28-volt source through rectifiers such as *RA1* and *RA3* toward one of the sources.

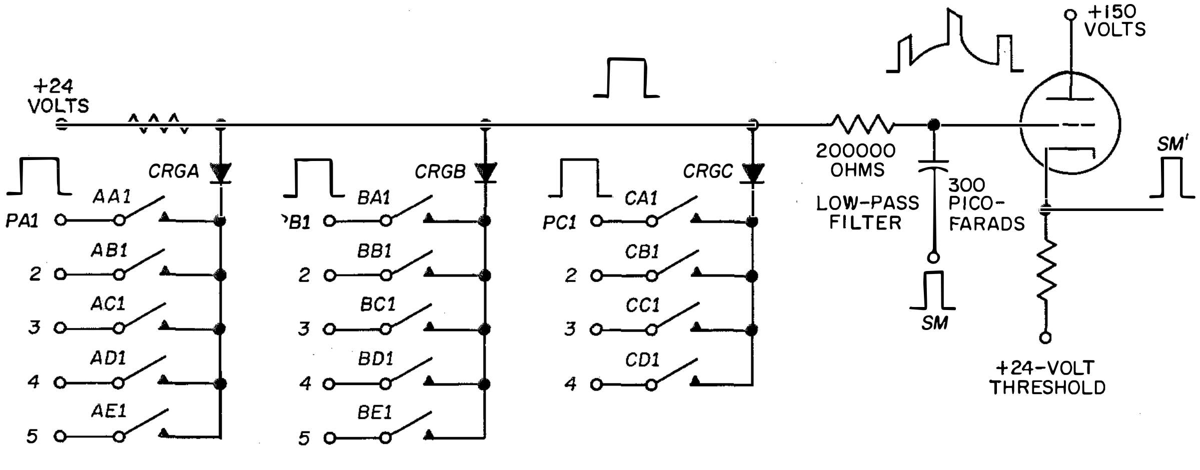

Figure 10—Simple gating circuit for use as a comparator in selecting marker pulses.

5.4 Call Detector Engagement of an *A* Governor

Figures 12 and 13 represent in block form the arrangement between the call detectors and the *A* governors. Figure 12 illustrates the principle of using a unique cycle of operations in electronic switching. Each group of 100 subscribers' lines is associated with a call detector capable of registering a calling condition whenever one or more of the 100 subscribers makes a call. In Figures 12 and 13, the calling-line explorer is represented symbolically by a triangle, the apex of which is connected with the call detector. Whenever one or more calls are made, calling pulses are received in the call detector, and this condition is registered on the call-storage circuit, a bistable device that has been represented symbolically by a telegraph relay having opposed windings.

As soon as a call detector has registered a calling condition, one and only one of the available *A* governors must be engaged. As explained[1] before, the *A* governors are common circuits functioning to set up a free path from the calling line through two line-finder stages to a free cord circuit, thence through a cord-chooser switch to a free register. Generally only a small number of *A* governors are provided.

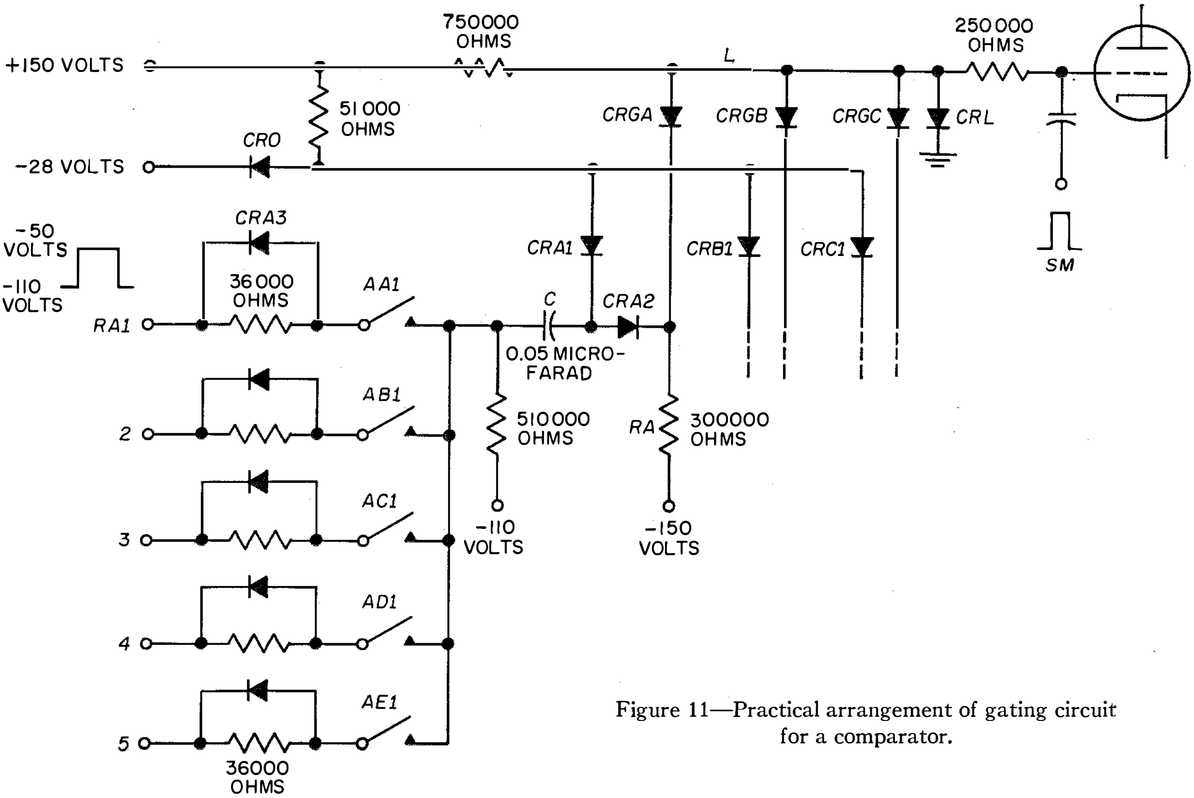

Figure 11—Practical arrangement of gating circuit for a comparator.

The call detectors and *A* governors are interconnected by an arrangement of explorers providing at any time a selective pulse path to each of the *A* governors from an equal number of call detectors. Each of these pulse paths shifts successively through the entire group of call detectors as described in sections 4.7 and 4.8 of the first-cited article.[1] Consequently, at any time one and only one pulse path is effective between a given *A* governor and one of the call detectors, and in the course of a complete cycle a given call detector is successively contacted by each of the *A* governors. Accordingly, if a call detector has registered a call, this may successively be signaled to each of the *A* governors.

However, to avoid engaging two or more *A* governors for a calling condition in one of the call detectors, the availability of a free *A* governor must be signaled immediately to the call detector so as to cancel the calling condition.

Two possible arrangements are shown in Figures 12 and 13. In the former, as soon as the call-storage circuit is reversed, a test potential is signaled to each *A* governor in succession, each at a different time. If the governor is free, this pulse is admitted through a suppressor gate to a recorder that uses gas tubes to detect the particular time position of the pulses.

resets the call-storage circuit and disables it during a sufficiently long period (400 milliseconds) to permit the governor to establish a direct-current path toward the call detector.

If in this arrangement either the return path for the disabling pulse or the disabling circuit is defective, the calling condition will not be cancelled and all free governors will be engaged successively. Consequently, the arrangement shown in Figure 13 has been adopted.

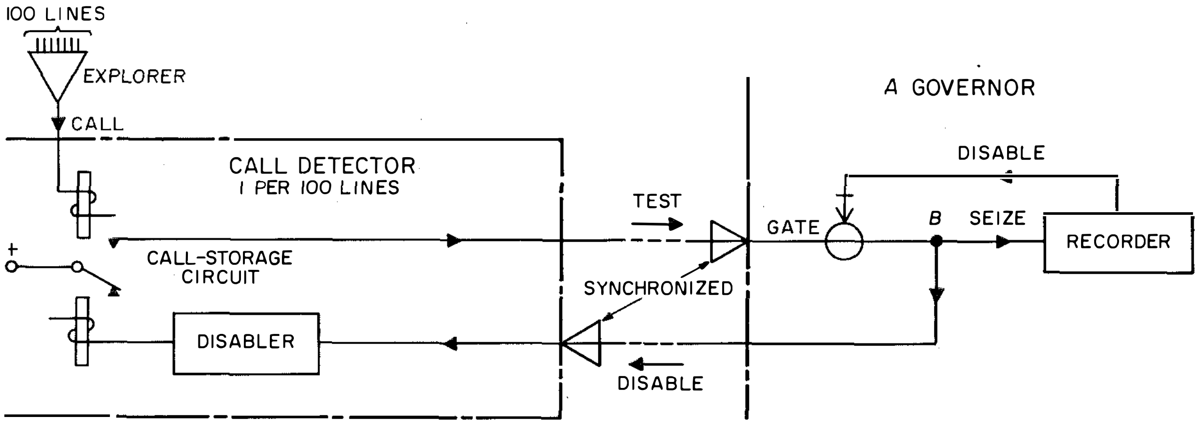

Figure 12—Simple arrangement for engaging an *A* governor by the call detector. The absence of a signal on the "disable" lead to the gate permits a test signal to reach the recorder.

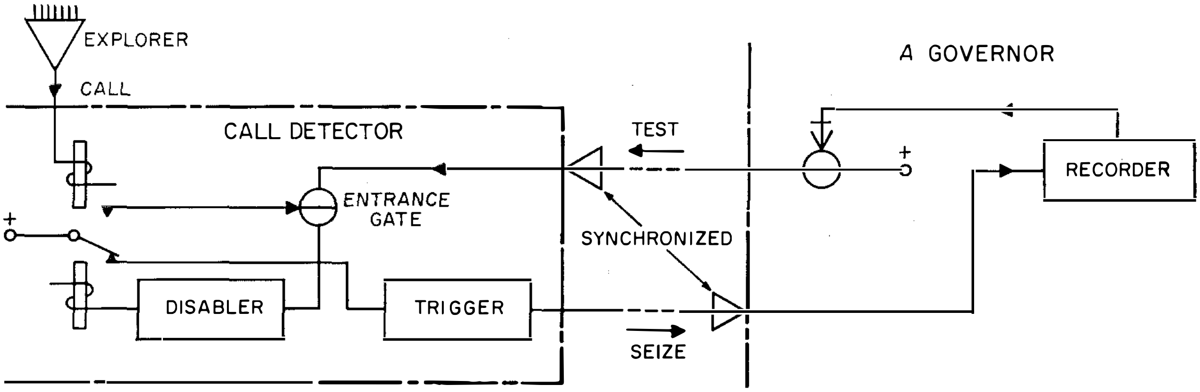

Figure 13—Improved arrangement whereby a call detector engages a free *A* governor.

As soon as the recorder operates, the suppressor gate is blocked and the governor is no longer available to other call detectors.

The test pulse admitted through the suppressor gate also travels back through another path simultaneously established toward the originating call detector, where it triggers a self-restoring timing circuit. This timing circuit

Here the call detector continually receives test pulses from all free *A* governors in succession, but these are not effective as they cannot pass the entrance gate. As soon as a calling condition is registered, the entrance gate is unblocked, and the first arriving pulse from a free governor is admitted to the disabler circuit, which then resets and holds the call-storage circuit in the disabled condition. The resetting of the call-storage circuit triggers a monostable circuit that emits one pulse of 200-microsecond duration. This pulse engages the originating governor. In this way, an *A* governor can be engaged only after the call detector has been restored. Figure 14 shows the series of waveforms occurring successively as a result of a call.

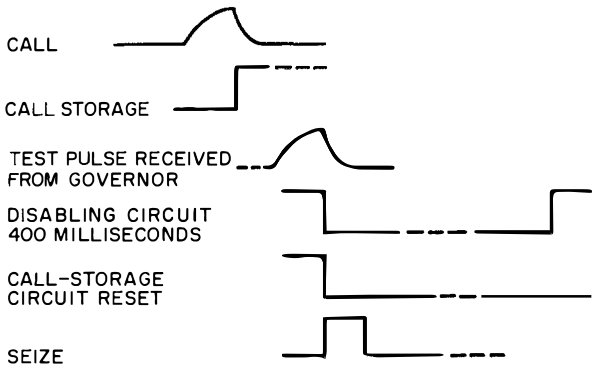

Figure 14—Series of waveforms during the engaging of an *A* governor by a call detector for the arrangement in Figure 13.

5.4.1 Routine Testing

A routine tester may be incorporated in the arrangement described above and Figure 15 shows the essential elements of it.

A gate circuit is connected to the input terminal of each call-detector circuit in parallel with the input wire along which the pulses from calling subscriber lines are normally conducted. These gate circuits, which are controlled by unique pulse combinations different for each call detector, are all connected to the routine tester through a common call wire. By sending a start pulse in a specific time position, the routine tester may bring any one of the call detectors into the calling condition.

The routine tester operates with the call detectors in a manner similar to that of the *A* governor. In a time position following that in which the start pulse has been sent, the tester sends a

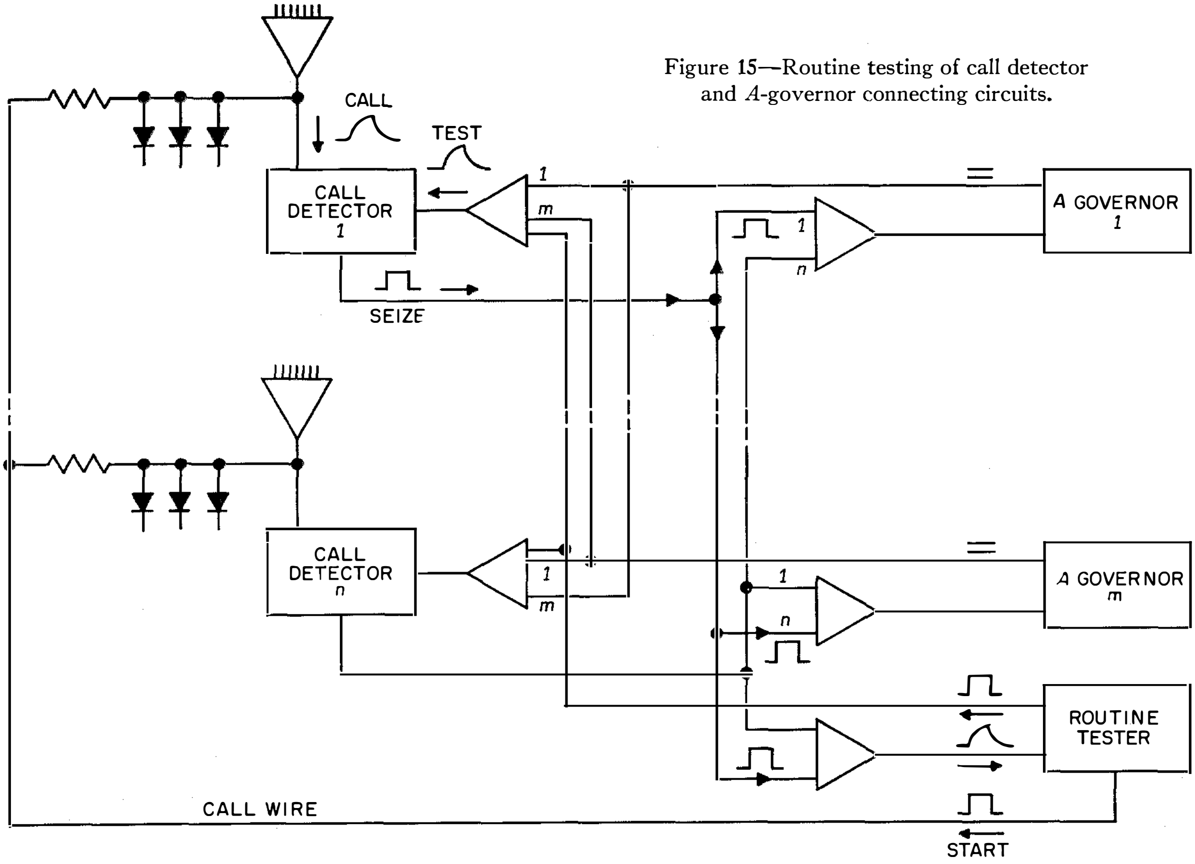

Figure 15—Routine testing of call detector and *A*-governor connecting circuits.

pulse over the call wire to indicate its receptive condition and then prepares to receive a seizure pulse from the same call detector in the next time position. If such a pulse is received, the tester stands by to receive a second pulse from the same call detector, and a timing device is started to check that no such pulse is received within a predetermined time interval of about 400 milliseconds. When the second return pulse arrives after the time interval has ended, the test is considered successful. The tester is arranged either to test all call detectors in a continuous cycle, or one particular call detector repeatedly. It may also be arranged that the pulses sent by the tester are marginal, so that incipient failures may be detected before they cause trouble. Spare time positions are used for the test, so that it can take place during normal service without interfering with the handling of subscriber calls.

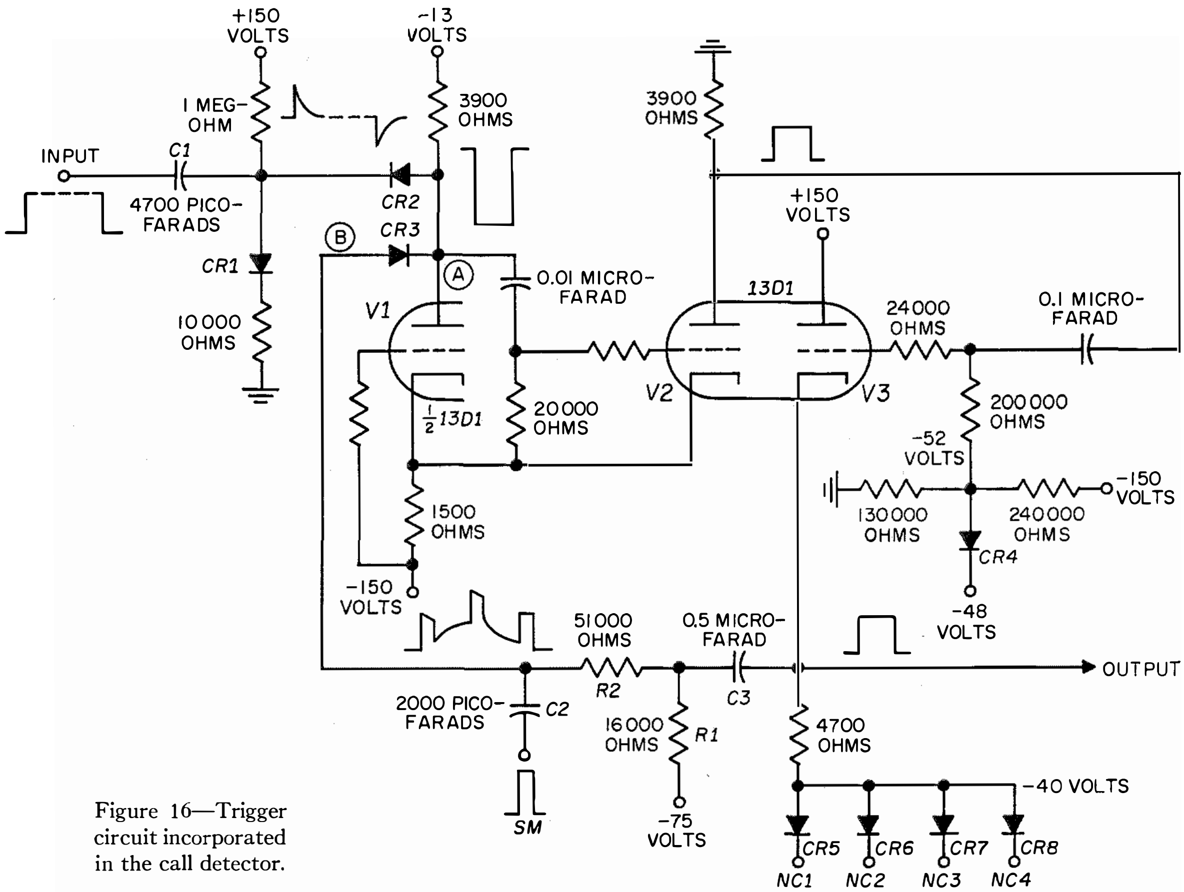

Figure 16—Trigger circuit incorporated in the call detector.

5.4.2 Trigger Circuit

The operation of the trigger circuit used in the call detector to send a seizure pulse is shown in Figure 16.

Normally, triode *V2* is conducting and *V1* and *V3* are biased to cutoff; rectifier *CR2* is blocked. When the potential at the input terminal rises, it charges capacitor *C1* via rectifier *CR1*; *CR2* remains blocked. However, when this potential drops again due to the resetting of the call-storage circuit, this drop is transmitted through *CR2*, *CR1* being blocked, and triggers the monostable circuit consisting of triodes *V1* and *V2*.

Thus, a positive step is produced at the anode of triode *V2* and reproduced at the cathode of output triode *V3*, which step coincides with the reset of the call-storage circuit; that is, with the start of a time unit. As a pulse lasting exactly

200 microseconds must be produced, positive time markers *SM*, repeated periodically at the start of each time unit, are injected at the anode of *V1*, via capacitor *C2* and rectifier *CR3*, to trigger the monostable circuit off again. Lest these markers should interfere with the on-trigger pulse arriving through *CR2*, rectifier *CR3* is normally kept blocked by a large negative bias applied via resistors *R1* and *R2*.

However, the step produced at the output of *V3* is transmitted via *C3* and *R2* to *C2*. The marker from *SM*, arriving 200 microseconds

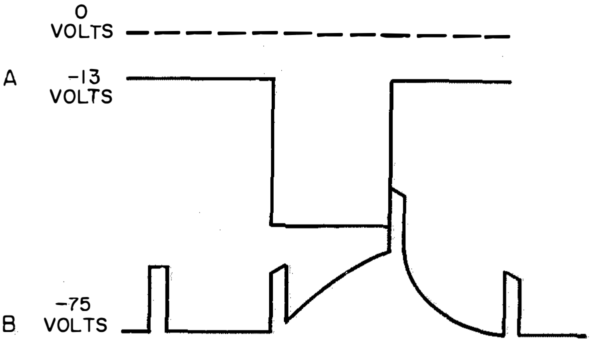

Figure 17—Waveforms at points *A* and *B* in Figure 16.

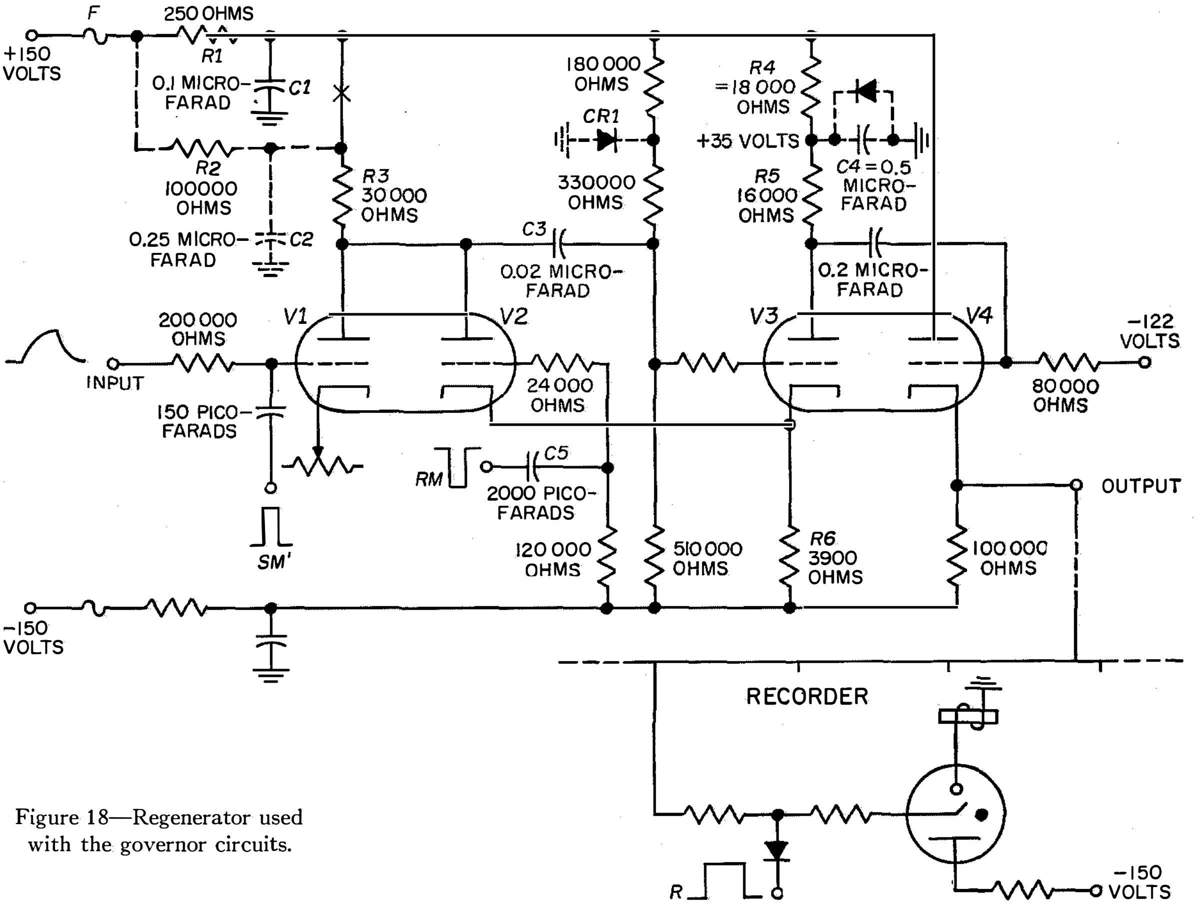

Figure 18—Regenerator used with the governor circuits.

after the step, will thereby be lifted sufficiently to penetrate via *CR3* to the anode of *V1* and thus trigger off the monostable circuit. As a result, a single pulse in a time position such as shown in Figure 14 is transmitted toward the *A* governor. The waveforms obtaining at points *A* and *B* are shown in Figure 17.

In case of failure of any power supply, which tends to reduce its voltage toward ground, no continuing output pulse with respect to the −40-volt steady-state output should occur.

To comply with this requirement, the cathode bias is derived from the pulse sources *NC1–4* by means of rectifiers *CR5–8*. The grid bias is derived from the −150-volt supply by means of a voltage divider, and it is clamped at −48 volts in case the −150-volt supply fails.

5.4.3 Regenerator for Governors

The regenerator arrangement used in the governors is shown in Figure 18, it consists of a cathode-coupled self-restoring trigger circuit made up of *V2* and *V3*, preceded by a threshold-biased triode *V1* and followed by a cathode-follower output triode *V4*.

Normally *V3* is conductive, while *V1* and *V2* are biased to cutoff; the cathode of *V4* is at −110 volts. The plate power at +150 volts is supplied through a filter made up of *R1* and *C1*. Plate voltage for *V3* is about +35 volts, derived from the −150-volt supply through a dropping resistor *R4* and a decoupling capacitor *C4*.

Explorer pulses arriving at the input terminal are superimposed on marker pulses *SM'* obtained from a comparator circuit such as was discussed in section 5.3. Only if a marker pulse *SM'* arrives at the end of an explorer pulse, will this marker be lifted sufficiently to unblock *V1*. A negative trigger pulse will then be transmitted through *C3* to the grid of *V3* and will trigger on the monostable circuit. It will be triggered off after 175 microseconds by the arrival of a negative marker *RM* applied via *C5* to the grid of *V2*, as was previously shown in Figure 2. The positive pulse produced at the anode of *V3* is reproduced at the cathode of *V4*, whence it is transmitted to the cold-cathode tubes of a recorder circuit.

In this circuit, the sudden failure of the +150-volt supply could produce the following undesirable results. The voltage initially drops exponentially toward +35 volts as *C1* discharges into *C4* (time constant = 1.5 milliseconds). In the meantime, *C4* discharges through the plate resistor *R5* of 16 000 ohms, the anode-to-cathode space of *V3*, and its cathode resistor *R6* of 3900 ohm toward −150 volts, at a much slower rate (time constant of about 15 milliseconds). The initial rapid drop is transmitted through the plate resistor *R3* of *V2* and capacitor *C3* to the grid of *V3* and thus triggers the multivibrator. Moreover, as the voltage across *C4* drops, the cathode bias of *V2* decreases until an unstable condition is reached in which the multivibrator becomes free-running. These phenomena cause a number of pulses to be produced at the cathode of *V4*, whereby a number of cold-cathode tubes are fired in an arbitrary way. These undesirable phenomena have been eliminated by modifying the circuit arrangement as shown in dotted lines in Figure 18.

A. Between *R3* and the +150-volt supply, a low-pass filter *R2–C2* is inserted. It has a time constant of 25 milliseconds, which is substantially higher than the 5 milliseconds of the coupling circuit that includes *C3*. In this way, when the +150-volt supply drops, *C2* discharges at a rate so slow that this drop cannot effectively be transmitted through *C3* to the grid of *V3*.

B. A rectifier *CR2* across *C4* prevents the latter from discharging below zero volts (opposite polarity) thus holding the plate of *V3* at ground potential. Another rectifier *CR1* prevents the grid potential of *V3* from dropping towards −150 volts. In this way, plate current in *V3* is maintained at such a level as to provide for a sufficiently high cathode bias for *V2* to keep it at plate-current cutoff.

5.4.4 Entrance Gate

Figure 19 represents the circuit arrangement of that part of the call detector designated the entrance gate in Figure 13. Pulses arriving successively from the *A* governors at the input terminal are controlled by gate *CR2*. As long as the call detector is at rest, the potential at control terminal *P* is about −90 volts; the potential at the gate is kept at −40 volts through the clamping rectifier *CR1*, while a current of 0.5 milliampere flows through resistor *R2*. Thus, any pulse arriving at the input terminal is shunted through gate rectifier *CR2*. When the call detector registers a call, terminal *P* is raised to −12 volts, whereby gate rectifier *CR2* is blocked, and any pulse arriving at the input terminal is then transmitted through low-pass filter *R1–C1*. This pulse is then superimposed on marker pulses *SM*, and the marker riding on top of the pulse will be able to trigger the disabler multivibrator.

In this circuit, rectifier *CR2* is biased in the reverse direction only during one 200-microsecond interval per call. Otherwise it is unbiased or even conductive. It thus tends to unform its barrier layer. If the step at *P* occurs while *CR2* is unformed, this step will be transmitted through *CR2* in the reverse direction and may therefore cause the disabler circuit to be triggered without a pulse being received at the input from a governor.

To keep *CR2* properly formed, the marker pulses from source *SM* are also applied to the cathode of *CR2* through a separating rectifier *CR3*, as shown in dotted lines.

6. Conclusions

The design of electronic circuits for telephone switching systems presents some unexpected problems, most of which are related to the necessity of ensuring the utmost reliability of operation over long periods of time, under normal as well as abnormal conditions. The design principles and special precautions adopted for the *8A* system, some of which have been illustrated, have proved their soundness in the trial exchange installed at Ski, near Oslo, Norway. This exchange has a capacity of 2000 lines and can be extended to 4800 lines. The exchange was placed in service in May, 1954, and has since provided continuous 24-hour-a-day service with a reliability of operation up to and even beyond the highest standards normally applied in telephone service.

The reports received on the performance of the electronic circuits during that time clearly demonstrate the effectiveness of the design principles. Although the thermionic tubes were kept in service until they actually caused a circuit failure, the over-all service was in no case impaired to any noticeable degree. Moreover, it was found that only a small part of the tube failures occurred before 8000-hours operation. Thus, by systematic replacement of these tubes after, say, 7500 hours, the number of failures due to tubes can practically be eliminated.

None of these failures nor the faults that were due to a few components of inadequate construction have caused any but local effects, there being no damage to other components nor blocking or unnecessary engagement of other circuits.

The possibility of large-scale application of electronic components to a telephone switching system has hitherto been subject to much discussion and speculation. The experience gained thus far with this first commercial system constitutes a convincing proof of the statement that such a system can provide a very satisfactory standard of reliability.

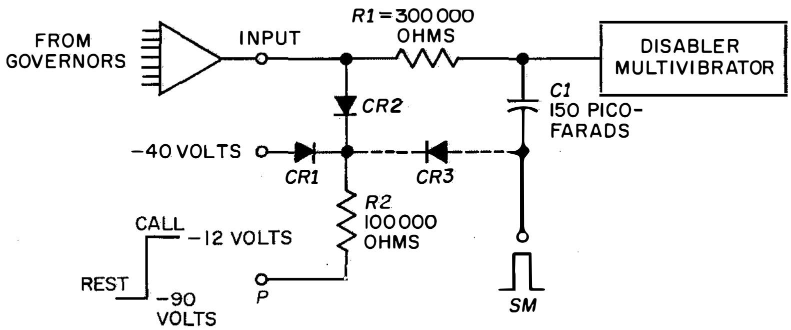

Figure 19—Entrance gate of call detector.

Helsinki-Tampere Coaxial Cable

By OLLI LEHTO and RAIMO PÖYTÄNIEMI

Finska Kabelfabriken; Helsinki, Finland

FINSKA KABELFABRIKEN received an order in 1952 from the Finnish Posts, Telegraph, and Telephone Administration for about 200 kilometers (124 miles) of 6-core coaxial cable to be laid between Helsinki, the capital, and Tampere, the chief midland industrial center of Finland. In addition to the main cable, there is a short spur from Herajoki to Riihimäki and a subsidiary 4-core coaxial cable some 68 kilometers (42 miles) in length from Hämeenlinna to Lahti[1]. A diagram of the route is shown in Figure 1.

In the main cable between Helsinki and Tampere, four of the coaxial cores are intended for ordinary long-distance communication, the other two cores being reserved for future television transmission. Moreover, since no short-haul loaded cable network exists in Finland, it was considered desirable to include short-haul circuits in this cable. Normally these would be provided by a layer of voice-frequency loaded quads; in this case, however, the Finnish administration decided that it would be more economical to use the interstice quads for a 2-way 12-channel carrier system.

It was appreciated that a composite cable might entail certain difficulties but in co-operation with Standard Telephones and Cables, Limited of London, it was decided that such a cable was practicable, and this proved to be the case.

The present nominal repeater-station spacing for coaxial cores is 10 kilometers (6.2 miles); later when the television circuits are used, intermediate repeaters will be installed at 5-kilometer (3.1-mile) intervals. The nominal repeater spacing for the carrier quads is 15 kilometers (9.3 miles), although because of local circumstances the spacing was sometimes reduced to 10 kilometers (6.2 miles). Manufacture was commenced in November 1952 and completed in July 1954.

[1] Since this article was written, the network has been extended to Jämsä and a number of spur routes have been added as shown in Figure 1.

1. Cable Lay Up

The coaxial cores are of the type standardize by the Comité Consultatif International Télé phonique for long-distance circuits. Six suc cores are laid up around a center consisting o 7 paper-insulated star quads with 6 simila quads laid in the outer interstices among th coaxial cores. In addition, 6 single conductor

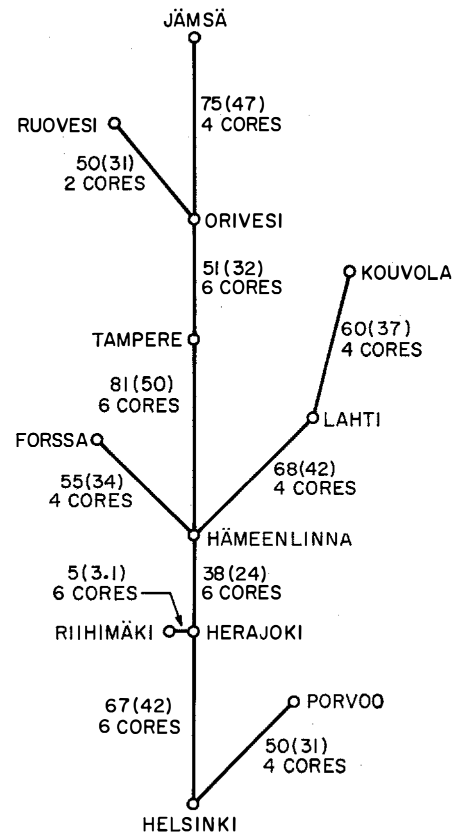

Figure 1—Route diagram of the Helsinki–Tamper coaxial-cable system. Repeater stations are spaced approxi mately 10 kilometers (6.2 miles) apart. The numbers indi cate distances between the adjacent places in kilometer (miles) and the number of coaxial cores is also noted.

of 0.9-millimeter (0.035-inch) diameter insulated with polyvinylchloride are placed in the inner interstices of the coaxial cores to facilitate fault location. Figure 2 shows a cross section and Figure 3 is a photograph of the finished cable.

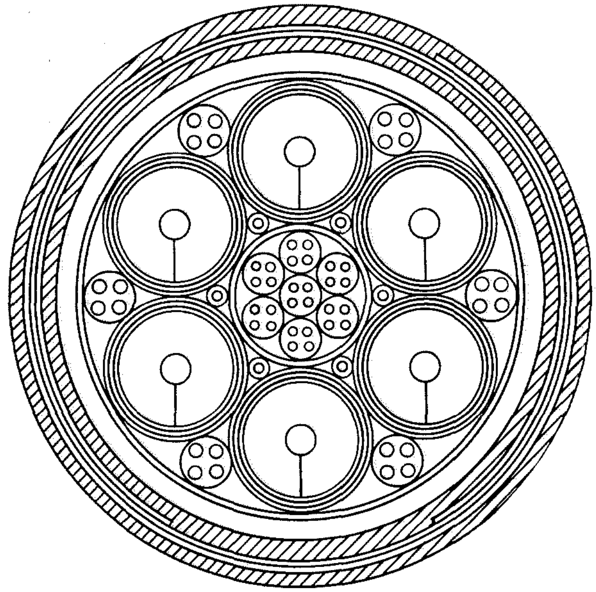

Figure 2—Cross section of cable. Of the 13 carrier quads, 7 make up the central core about which the 6 coaxial tubes are arranged. The remaining 6 single conductors are for fault location.

2. *Coaxial Cores*

The manufacture and electrical characteristics of coaxial cores for long-distance telephone transmission have been described in a recent paper[2]. The coaxial cores in the Helsinki–Tampere cable are in accordance with the 6th and latest design described in that paper and their manufacture need not therefore be described in detail. It will be sufficient to say that the quality of the factory lengths was quite normal; the mean of the end impedances, tested with a 0.05-microsecond raised cosine pulse was 75.05 ohms with a standard deviation of 0.12 percent. The worst reflection was 57 decibels while in 50 percent of the lengths, the reflections were better than 65 decibels return loss below the incident signal level.

[2] E. Baguley, "Modern Coaxial-Cable Technique in Great Britain," *Electrical Communication*, volume 30, pages 186–216; September, 1953.

3. *Carrier Quads*

The center quad of the 7-quad cable is intended for control and service circuits, thus leaving two carrier groups of 6 quads each, which are the outer layer of the center group and the 6 outer interstice quads.

It will be appreciated that the space available for the carrier quads is in effect fixed by the 11-millimeter (0.437-inch) outside diameter of the coaxial cores. The estimated nominal capacitance of the carrier quads was 0.0355 microfarad per kilometer (0.057 microfarad per mile); the value actually obtained was 0.0342 microfarad per kilometer (0.055 microfarad per mile) largely on account of the low capacitance of the outer interstice quads. This in turn was reflected in a difference in impedance and attenuation between the two groups and, although complete equality could not be obtained, suitable modifications of the design enabled a very-considerable improvement to be effected in this respect.

Preliminary factory results had indicated that the coaxial cores would provide effective shielding between the two groups but unfortunately this conclusion was not confirmed by the field results. The field tests also disclosed a considerable "spiral effect." Such effects result

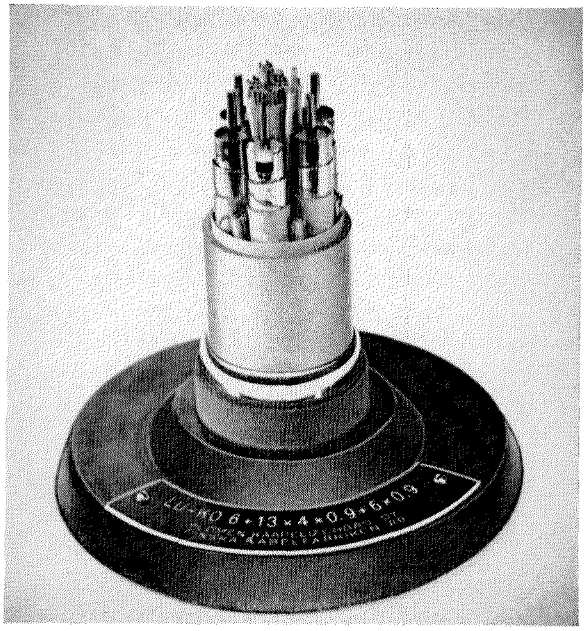

Figure 3—Specimen of cable.

from intermediate couplings via secondary circuits; in this case the spiral steel screen over the coaxial cores was assumed to be the cause and experimental work carried out by Standard

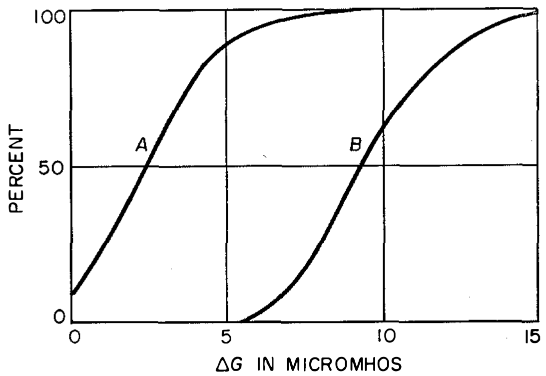

Figure 4—Distribution as a percentage of factory lengths of cable of the variation in side-to-side conductance component of the far-end admittance of the carrier quads for side-to-side capacitance unbalance of less than 20 picofarads for *A* and between 40 and 60 picofarads for *B*.

Telephones and Cables, Limited, showed that the spiral effect depends on the relative directions of the lays of the various units in the cable. For these reasons it was necessary to revise the design and to control the manufacture more carefully with the result that a very-considerable improvement was obtained in the far-end crosstalk on factory lengths.

In connection with subsequent balancing in the field, a study was made of the correlation between low-frequency side-to-side capacitance

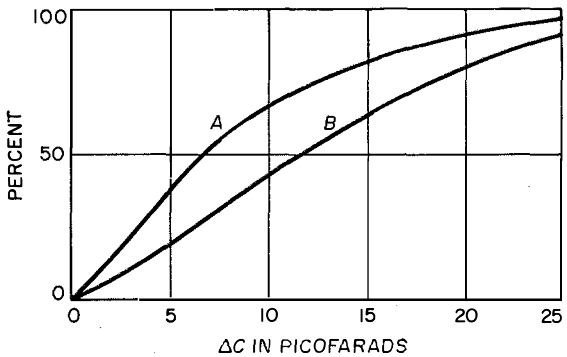

Figure 5—Distribution as a percentage of factory lengths of cable of the variation in side-to-side capacitance component of the far-end admittance of the carrier quads for side-to-side capacitance unbalance of less than the 20 picofarads for *A* and between 40 and 60 picofarads for *B*.

unbalance and carrier-frequency far-end admittance unbalance. As noted[3] by Kolk, a substantially linear relation was found to exist between the low-frequency side-to-side capacitance unbalance and the conductance component (ΔG of the far-end admittance unbalance), whereas the relation was much less marked in the case of the capacitive component ΔC. This is illustrated in Figures 4 and 5 in which curve *1* relates to side-to-side capacitance unbalances of less than 20 picofarads and curve *2* relates to capacitance unbalances between 40 and 60 picofarads.

The scales for ΔG and ΔC have been arranged so as to be equivalent in crosstalk value at 108 kilocycles per second. The inference is that low-frequency balancing in the field will improve the ΔG component of the admittance unbalance.

4. Installation and Jointing

The cable was installed jointly by the Finnish Posts, Telegraph, and Telephone Administration and the manufacturer. The Administration was responsible for the trenching, cable transport, and the like, whilst Finska Kabelfabriken was responsible for the jointing, terminating at the repeater station, and for all necessary electrical tests. The repeaters and terminal equipment were supplied by Standard Telephones and Cables, Limited.

The cable followed the Helsinki–Tampere highway only for part of the route and severely unfavorable conditions were met in some places. However, only small rivers had to be crossed and the swamps that were encountered were such that normal steel-tape armor could be used throughout with the exception of a short length of duct cable in Helsinki itself. Heavy 10-wheel trucks were used to transport the cables as near to the installation points as possible. The drums were then carried to their final position on semi-caterpillar trucks fitted with cable jacks and capable of operating off the road. Normally the cables were paid off from the truck. Figures 6 and 7 illustrate one of these trucks.

Mechanical trenching was used except in unusually difficult conditions such as river crossings, swamps, and dense forest.

[3] L. J. E. Kolk, "Het Balanceren van Draaggolfkabels voor 48-Kanalensystemen," *Het PTT-Bedrijf,* volume 3, pages 59–74; August, 1950.

Figure 6—Half-track vehicle used for laying cable in trench.

Two types of excavators were used, a wheel type for fields and light forest and a shovel type for hard and stony ground. The trench was refilled with plows attached to small caterpillar tractors. At river crossings, divers buried the cable about a meter deep in the river bed as a protection against logs and ice.

In inhabited areas, along the roadside, and in stony ground, protection against mechanical damage was provided by concrete cable covers.

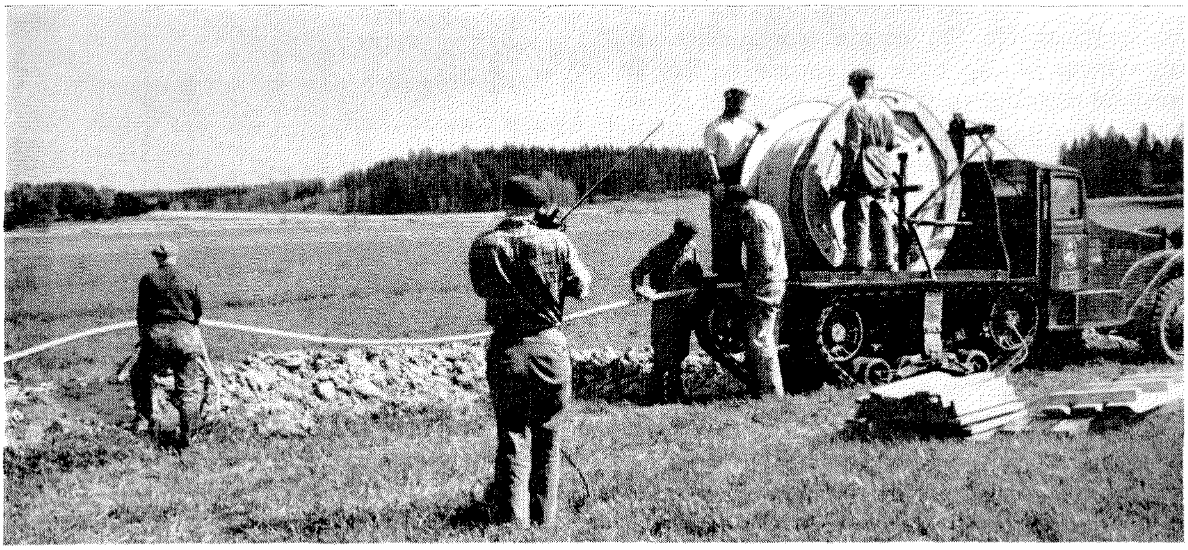

Figure 7—Rear view of vehicle showing mounting of cable reel and method of paying out cable into trench.

Moreover, since the conductivity of the soil in Finland is extremely low, 3 parallel copper wires were laid in the trench above the cable to reduce induced voltages from lightning and high-voltage transmission lines.

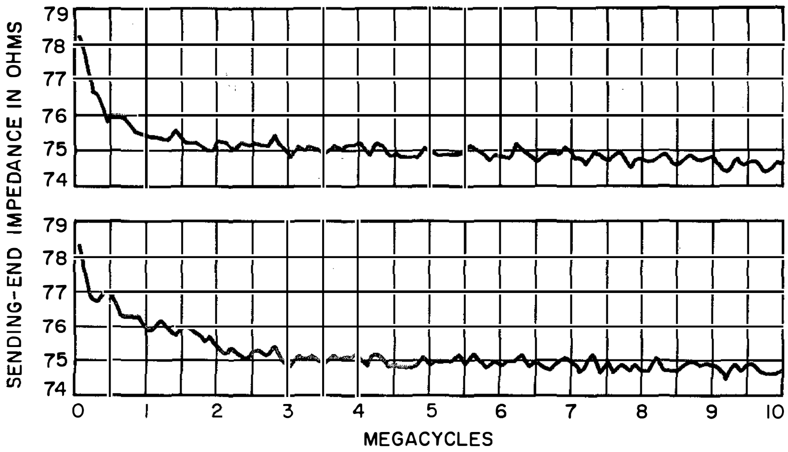

Figure 8—Typical impedance characteristics of two coaxial cores in a 10-kilometer (6.2 mile) section of cable lying between Hyvinkaa and Arolampi.

In general, jointing followed normal British practice but as an example of a rather unusual installation problem, two joints were made under water level in a flooded lake by building a wooden manhole after the lake had frozen and keeping the manhole dry by motor pumps.

5. Allocation and Balancing

Allocation was primarily determined by the requirements for the coaxial cores since the impedances of the cores in successive lengths must be matched to very close limits to obtain satisfactory impedance uniformity. These limits become more severe near the repeater stations. Moreover, consideration had to be given to the future installation of television repeaters that would require a large number of cables of 5-kilometer (3.1-mile) length containing coaxial cores of very-uniform impedance.

This restriction left very little choice in allocating the carrier quads. However, as far as circumstances permitted, the cables in the neighborhood of a carrier repeater station were selected so that the mutual capacitances of the carrier quads were approximately equal and at the same time had low values of near-end crosstalk.

For balancing purposes, the carrier repeater sections were divided into slings containing 8 cable lengths. The slings were balanced on the basis of voice-frequency measurements, the quads being joined together by antispiral crosses. The center group of quads was systematically randomed to prevent building up of pair unbalances but the interstice quads in the outside layer were joined straight through to take full advantage of the shielding effect of the coaxial cores.

The slings were connected together without further testing except that the 3 quarter-section joints were left open. At these 3 points, the quarter sections were poled together on the basis of far-end admittance-unbalance tests at 108 kilocycles per second.

The results obtained are summarized in section 8. No doubt, an improvement could have been obtained by commencing the high-frequency tests at the sling joints but the increased work involved on a cross-country cable under difficult conditions would not have justified a more-complicated balancing method.

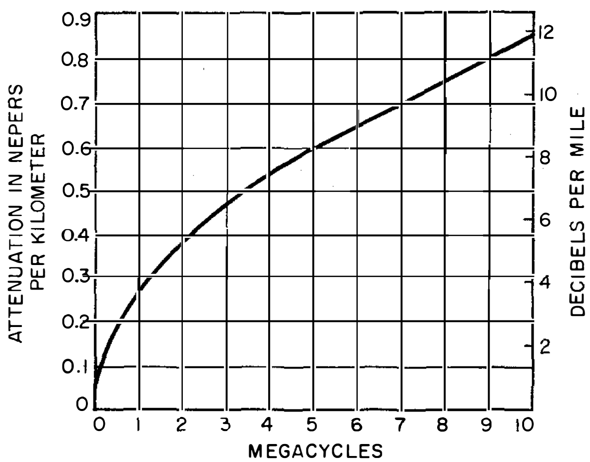

Figure 9—Attenuation at 10 degrees centigrade as a function of frequency for a coaxial core in the section between Noppo and Hyvinkaankyla.

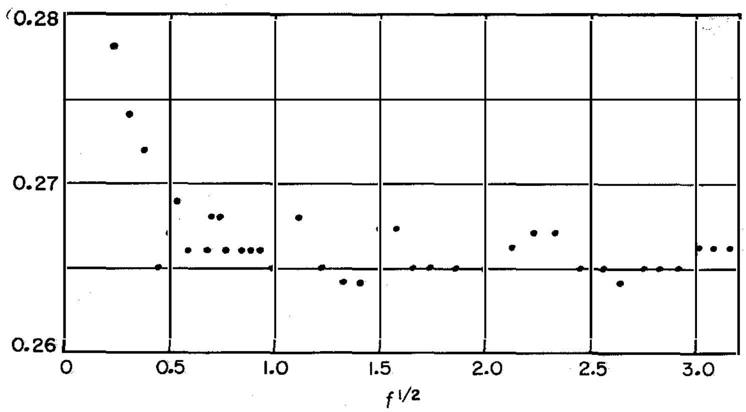

Figure 10—Values of $\alpha/f^{1/2}$ plotted against $f^{1/2}$ for coaxial cores.

The final balancing, which will be effected by means of balancing networks, is awaiting the installation of the balancing frames.

6. *Results on Coaxial Cores*

Table 1 indicates the degree of impedance uniformity obtained on completed repeater sections. It is interesting to note that the values

TABLE 1

IMPEDANCE UNIFORMITY OF COAXIAL CORES

Year of Manufacture	Mean Impedance in Ohms			Maximum Deviation in Ohms		Standard Deviation in Ohms	
	Minimum	Mean	Maximum	Mean	Maximum	Mean	Maximum
1953	74.69	75.08	75.43	0.53	1.02	0.20	0.30
1954	74.69	74.98	75.31	0.51	0.81	0.19	0.30

obtained in Finland practically coincide with those given in Table 2 of the Baguley paper.[2]

Typical impedance curves for two coaxial cores of a 10-kilometer (6.2-mile) section is shown in Figure 8, while a typical attenuation characteristic is shown in Figure 9. Another form of Figure 9 is given in Figure 10, where $\alpha/f^{1/2}$ is plotted against $f^{1/2}$. These results also agree with those quoted by Baguley.

Typical near- and far-end crosstalk is plotted against frequency in Figures 11 and 12, the width of the plot covering the spread of the crosstalk values over the 6 cores in the cable.

7. *Crosstalk Between Coaxial Cores and Carrier Quads*

Since the frequency bands for the coaxial and carrier circuits overlap between 60 and 108 kilocycles, a number of crosstalk measurements were made

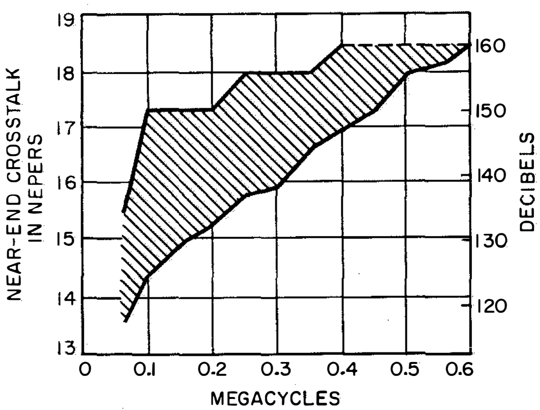

Figure 11—Range of near-end crosstalk attenuation versus frequency for all 6 coaxial cores in a 10-kilometer section between Hyvinkaa and Herajoki. Tests were made from both ends of the section.

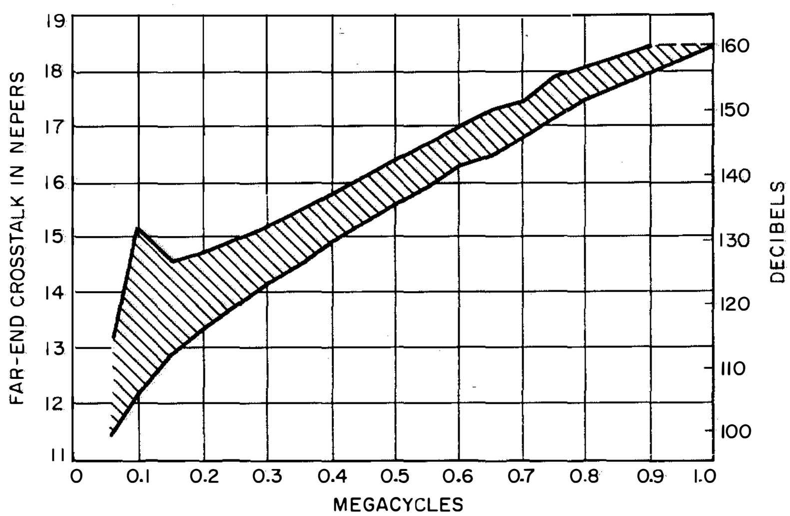

Figure 12—Far-end crosstalk over 10 kilometers of cable between Hyvinkaa and Herajoki. The values have been corrected for line attenuation.

between these circuits. Typical results are shown in Figure 13 for near-end crosstalk and in Figure 12 for far-end crosstalk.

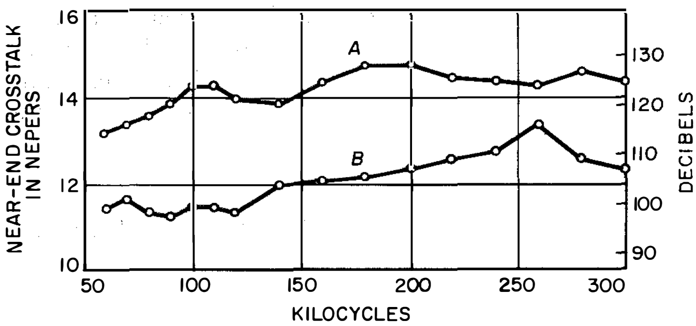

Figure 13—Near-end crosstalk as a function of frequency between coaxial cores and carrier quads. Curve *A* is for an inner interstice pair to a coaxial core and *B* is for an outer interstice pair to an adjacent coaxial core.

It will be noted that there is a striking difference in the far-end crosstalk versus frequency characteristics depending on whether a coaxial core or a carrier-quad pair is the disturbing circuit. This stems from the difference in attenuation between the two types of circuits as is illustrated by Table 2, which is based on a repeater-section length of 10 kilometers (6.2 miles).

The column labelled "Crosstalk" is the difference in average measured far-end crosstalk between sending on coaxial cores and sending on carrier quads while "Attenuation" refers to the difference in line attenuation between coaxial cores and carrier quads.

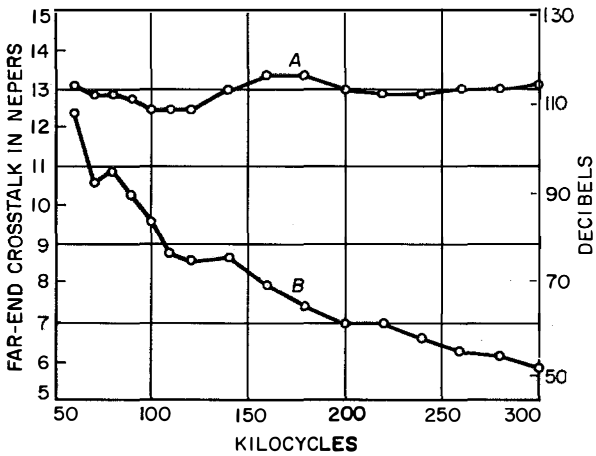

Figure 14—Far-end crosstalk versus frequency. Curve *A* is for crosstalk from a coaxial core to a carrier pair and *B* is from a carrier pair to a coaxial core.

A theoretical discussion of this effect has been given[4] by Schelkunoff and Odarenko.

8. Results on Carrier Quads

As mentioned in section 3, the two groups of carrier quads differ in impedance and attenuation, and for this reason they have been separated in Table 3, which gives a summary of the impedance and attenuation on completed repeater sections.

Figure 15 shows impedance and attenuation as a function of frequency for a typical carrier pair. By impedance deviation is meant the deviation of an individual impedance value from the mean of all impedance values tested from both ends of a repeater section.

[4] S. A. Schelkunoff and T. M. Odarenko, "Crosstalk Between Coaxial Transmission Lines," *Bell System Technical Journal*, volume 16, pages 144–164; April, 1937.

TABLE 2

CROSSTALK VALUES FOR A REPEATER SECTION OF CABLE

Frequency in Kilocycles	Crosstalk		Attenuation	
	Nepers	Decibels	Nepers	Decibels
60	2.3	19.9	2.1	18.2
150	4.1	35.6	3.8	33.0
300	6.3	54.7	6.1	53.0

TABLE 3

COMPLETE REPEATER SECTIONS

	Inner Carrier Quads *2–7*	Outer Carrier Quads *8–13*	All Carrier Quads
Average Impedance in Ohms			
60 Kilocycles	149.1	158.5	153.8
108 Kilocycles	144.9	151.9	148.2
Average Attenuation at +10 Degrees Centigrade and 108 Kilocycles			
Nepers per Kilometer	0.390	0.388	—
Decibels per Mile	5.460	5.432	—
Impedance Deviation in Percent	—	—	8.8

Table 4 gives the far-end repeater-section crosstalk at 108 kilocycles without balancing networks. The values include both side-to-side and pair-to-pair couplings.

The final performance of the carrier system cannot be stated because the balancing networks have not yet been installed. However from a study of the admittance-unbalance results, it is concluded that, with the possible exception of quite a few cases, the ultimate far-end crosstalk values will not be worse than 7.5 nepers (65.1 decibels) at the maximum frequency of 108 kilocycles.

TABLE 4

FAR-END CROSSTALK IN NEPERS (DECIBELS)

Year of Manufacture	Inner Carrier Quads 2–7		Outer Carrier Quads 8–13		Inner-to-Outer Carrier Groups	
	Minimum	Average	Minimum	Average	Minimum	Average
1953 7 sections	6.1 (53.0)	7.8 (67.8)	6.4 (55.6)	9.7 (84.3)	6.4 (55.6)	9.1 (79.0)
1954 7 sections	6.8 (59.0)	8.5 (73.8)	6.5 (56.5)	9.7 (84.3)	7.3 (63.4)	9.6 (83.4)

9. Conclusions

The cable described above differs from the normal coaxial cable in that the interstice quads are used for carrier operation. Although this does not affect the use of the coaxial cores, it does introduce several difficulties that are not encountered in normal carrier systems. Nevertheless, it can be concluded that an acceptable crosstalk level between the carrier circuits has been obtained.

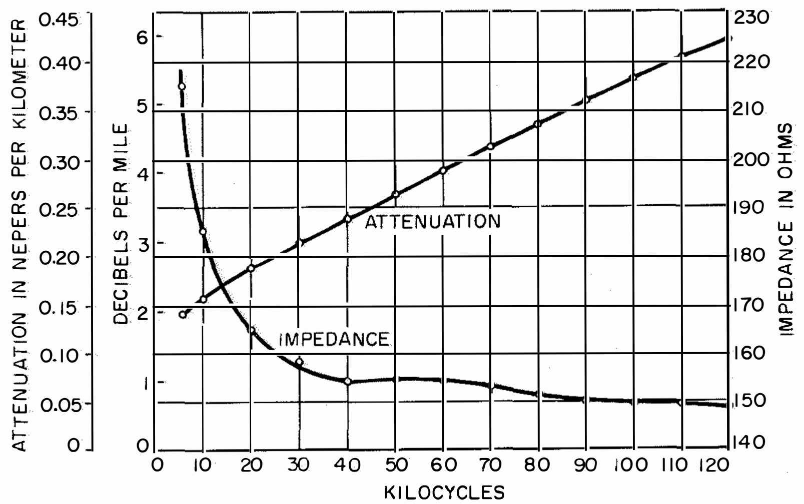

Figure 15—Impedance and attenuation versus frequency for a typical carrier pair.

Luminescence Decrease of Phosphor Screens by Electron Burn*

By K. H. J. ROTTGARDT

C. Lorentz, AG; Stuttgart, Germany

INVESTIGATIONS were made on the cause of electron burn of cathode-ray-tube nonaluminized screens. This effect is produced under certain conditions of vacuum, anode voltage, and beam current, the latter two having no effect at anode voltages below 4 kilovolts. The decrease in luminescence caused by alpha particles and ultraviolet quanta is also discussed; the quality of the glass used is considered as well as the possibility of luminescence regeneration by thermal treatment. The luminescent substance tested was cadmium sulphide–copper for most of the experiments; the characteristics are plotted for this and various other substances.

• • •

Television picture tubes of early design developed burned areas of their luminescent screens that were characterized by a reduced brightness. Such ion burns[8] were evidence of decay of the phosphor luminosity caused by ions hitting the screen and may be prevented by applying an aluminum coating to the screen or by applying an ion trap to the electron gun.

The ions originate at the cathode of the cathode space[6] and are accelerated toward the screen by the anode voltage. When they hit the phosphor particles of the tube screen, discontinuities are created in the crystal lattice. These discontinuities are responsible for the decrease in luminescence. Hanle and Rau[7] showed this by bombarding zinc sulphide–silver, zinc silicate–manganese, and magnesium tungstate phosphors by ions of hydrogen, helium, neon, argon, and xenon. The ions not only excite the phosphor, but particles hitting the screen can also displace lattice ions from their positions. Also, an additional strong ionization of a structural member of a crystal lattice may, according to these authors, cause a reorientation of the affected lattice area through a mutual interaction with the surrounding ions and, hence, a discontinuity.

Broser and Warminsky[13] investigated thoroughly the decay of the luminescence of single crystals by alpha particles. They proved by means of differential equations derived on the basis of the band model of crystal phosphors that their calculations coincide with measured results if the decay of the luminescence is attributed to the creation of deep traps. Electrons may use these traps to enter the occupied band without producing radiation. The traps are generated by discontinuities created in the crystal lattice by alpha particles.

Electron irradiation also may bring about a decrease of luminescence. However, this effect is not important for ordinary television tubes used at present, as its effect does not exceed 10 to 15 percent during a life span of 1000 hours. A number of papers has already been written concerning the decay of luminescence by electron beams. Schnabel[2] experimented with the stability of phosphors exposed to electron irradiation in a demountable tube. Of all the phosphors he used, zinc silicate–manganese was found to be the least sensitive to damage by electrons. Grotheer[4] and Hagen[5] used zinc silicate for the same experiments in a demountable tube and found that the luminescence of zinc silicate–manganese screens settled on small glass plates decreased quickly. Using a demountable tube, we were able to reproduce the measurements of these two authors.

It is well known that the results of experiments with electron beams are markedly affected by the quality of the vacuum tube. Gas, water molecules adsorbed at the tube walls, and the luminescent-screen carrier can seriously influence

* Originally published under the title, "Lumineszenzzerstörung an Leuchtschirmen von Kathodenstrahlröhren durch Elektronen" in *Zeitschrift für angewandte Physik*, volume 6, number 4, pages 160–163; 1954: and in *SEG-Nachrichten*, volume 2, number 3, pages 40–43; 1954.

[8] See bibliography at end of paper.

the measured results. Kordatski, Schleede, and Schröter[1] pointed out that phosphors, among others zinc silicate, can be intensely excited even for long periods without any decrease in luminescence providing the vacuum is of high grade. When the vacuum was bad, however, the phosphors showed fatigue very soon.

Based on the knowledge of this fact, we repeated the investigation on luminescence decrease of the zinc silicate–manganese phosphor in sealed-off, baked, and gettered tubes. The phosphor had been settled on the face of the experimental tube in pure methanol without using any binder. As was expected in these tubes, the brightness as a function of the charge density of the electron beam scanning the phosphor screen differed from that obtained with demountable tubes. The phosphor did not turn black as it had in the demountable tube.

Figure 1 shows a comparison of the results obtained from a demountable tube with those from a sealed-off tube. The luminescence is plotted as a function of the number of beam electrons hitting the screen. In the sealed-off tube, the luminescence initially increases to a certain value; this effect has been called "bright burn" by American authors who ascribe it[11] to recrystallization on the phosphor surface during excitation. After this steep rise, the luminescence in a sealed-off tube slowly decreases with an increasing charge density. This decrease is so

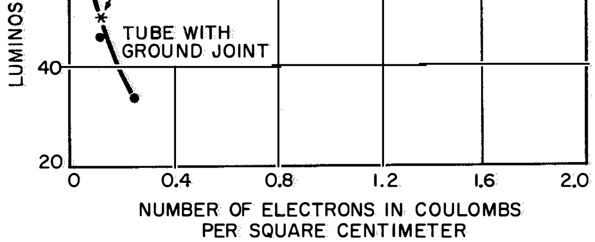

Figure 1—Reduction in luminosity as a result of electron radiation on zinc silicate. Compare sealed tube with tube having ground joint (electron microscope).

small that the luminescence retains 98 percent of the maximum value at 0.2 coulomb per square centimeter when it has dropped to 40 percent of the maximum in the demountable tube.

This varying behavior of phosphors under various operational conditions might be the cause for the opinion, sometimes found in the literature,[10] that manganese-activated phosphors are less stable at lower than at higher anode voltages. The experiments on which these measurements were based were conducted by Grotheer using a demountable tube operated at low voltages; hence, the increased "instability" is due to the fact that a demountable tube was used. Leverenz summarized[11] the results of the measurements of the phosphor stability against electron burn as follows: "Large crystals are more stable than small crystals; oxygen phosphors are more stable than sulphide phosphors; phosphors with high binding energies are more stable than those with low binding energies." Moreover, he states that at constant current densities, the decrease of luminescence with time is reduced by lower anode voltage, and that densely packed screens show a minimum of luminescence decay. The latter observations are explained by Leverenz on the basis that the increased anode voltage causes a greater depth of penetration of the electrons, the power released per volume unit of the phosphor crystal is smaller; and a densely packed layer has better thermal contact, which ensures better thermal conduction from the excited crystal to adjacent crystals and to the phosphor carrier.

Our tests were conducted to contribute to a solution of this question. As already indicated, only baked, gettered, and sealed-off tubes were used. Thus, any effect of charging the phosphor crystals by gas or water was avoided. No binder was employed. On top of that, our electron guns had ion traps to avoid confusing the behavior of electrons on the screen with ion effects. First of all, various commercial phosphors were compared as to their luminescence stability as a function of electron irradiation. The results are shown in Figure 2. Here again, the decrease of luminescence is plotted as a function of the density of electrons hitting the screen.

To find the effect of crystal size on stability of luminescence, three phosphors of an identical mixture but different distribution of grain sizes were tested. The phosphor used was zinc sulphide–silver. Sample *1* had a medium grain size of about 5 microns; sample *2* (by the same manufacturer) of about 10 microns. Sample *3* of same mean grain size as *2* was made by another manufacturer. These curves are also plotted in Figure 2. The behaviors of various phosphors and the effect of crystal size on stability of luminescence will be seen readily.

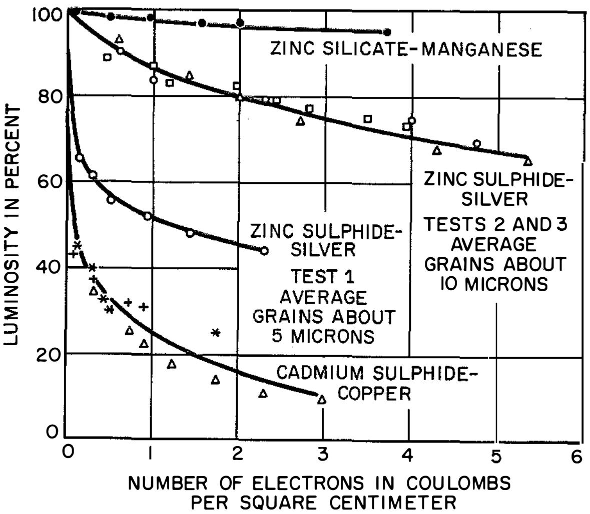

Figure 2—Reduction in luminosity as a result of electron radiation on technical luminescent material in sealed tubes.

A comparison with the luminescence decay caused by alpha particles is of particular interest. This was described by Broser and Kallmann.[12] The luminescent matter was zinc silicate and zinc sulphide–silver powder. To facilitate comparison, Figure 3 shows the decrease of luminescence as a function of the number of absorbed alpha particles (solid lines, by Broser and Kallmann) as well as our own measurements of luminescence decrease as a function of the number of irradiated electrons (solid dots), the phosphors being the same. It should be noted that the scale for the abscissa differs by the factor of 2.5×10^6 for electrons and alpha particles. The relatively good coincidence of the curves with the measured points (at least as far as the powdered luminescent matter is concerned) seems to indicate that the effect of alpha particles is higher by the factor 10^6 than that of electrons in destroying the luminescence. However, attention is drawn to the fact that these tests were conducted under different operational conditions: In one case, the phosphor was exposed to the destructive irradiation in ambient room air, while in the other case it was in the best possible vacuum. The deviations in the case of cadmium sulphide might be explained by the difference in crystal size of the phosphors used.

Wollentin, Wei, and Nagy have reported[14] on the decay of luminescence caused by ultra-

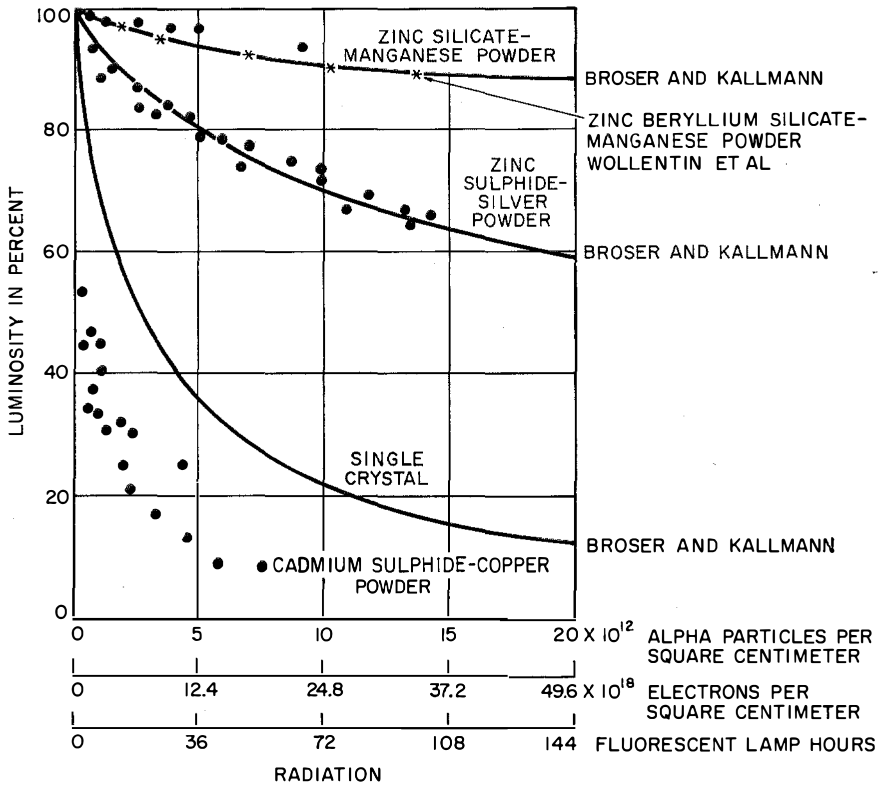

Figure 3—Comparison of luminosity reduction by alpha particles (solid curves), electrons (dots), and ultraviolet quanta (asterisks).

violet light. Figure 3 also contains the curve for zinc-beryllium silicate found by these authors (see stars in Figure 3). The decrease of luminescence is plotted as a function of the lighting time of a 40-watt fluorescent lamp in which the phosphor was placed to produce visible light. (The authors had supplied a plain curve without indicating the measured points; the stars in Figure 3 are only to locate the curvature of this graph.)

The coincidence of the curve recording the decay of luminescence caused by light, electron beams, and alpha particles suggests that the true cause in all three cases might be the same.

When the luminescence decreased under the influence of electron irradiation in sealed-off tubes with zinc fluoride–manganese screens, it was revealed that the measuring values could well be represented by the equation set up by Broser and Warminsky.[13] At the time of this test, it was concluded that the electrons produced discontinuities either directly or indirectly. It was further concluded that these discontinuities assume the shape of deep traps in the band model of the crystal phosphors and that radiation-free transitions were thus possible.

Since electrons cannot destroy the crystal lattice by directly hitting its structural members, it will have to be assumed that they act by excitation, ionization, or chemical reduction; the same effect must be ascribed to the light quanta. On the other hand, the thermal effect of electrons on luminescent matter should also be considered, even if the thermal effect of the electron beam cannot be assumed to be the sole effect, for ultraviolet quanta also causes decay of luminescence. In addition, an equal amount of electron-beam power does not cause an equal amount of decay, as will be shown below. On top of that, it is possible by thermal treatment to restore the luminescence of a damaged screen to its original brightness and even to remove discolorations of certain phosphors occurring at the time of the luminescence decay. Thus, it is possible to remove ion burn and damage by electrons by heating a sealed-off tube up to 400 degree centigrade for half an hour. It might become necessary, after this treatment, to activate another getter;[15] at any rate, this thermal treatment completely removes the damage.

It is even possible to remove an ion burn by the heat imparted to the phosphor by an electron beam. Figure 4 shows an ion burn (round black patch) on an excited picture-tube screen and the trace that was left on the screen by a powerful electron beam (thin white line). The disappearance of the black discoloration along the electron-beam track shows to what degree the damage could be removed.†

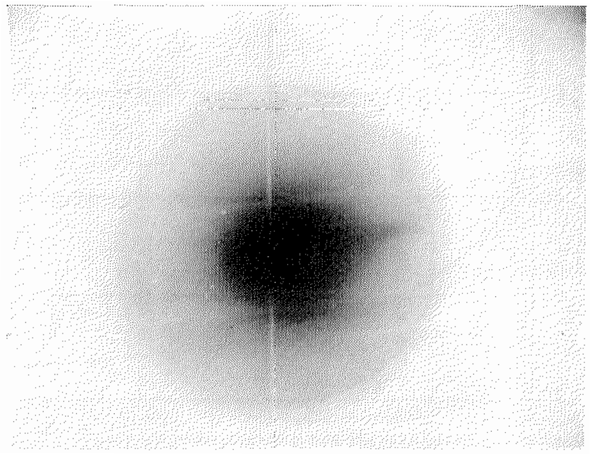

Figure 4—Ion spot on activated sulphide screen of a nonaluminized cathode-ray tube without ion trap.

On the basis of the described effects, it may be assumed that the thermal effect of the electron beam counteracts the decay in luminescence. This means that as the curve for luminescence decay becomes parallel to the abscissa, a balance is being reached between the harmful and moderating effects of the electron beam.

Nelson[3] has proved that the secondary-emission properties of phosphor screens change during tube life. He showed that due to a decreasing secondary-emission coefficient, the negative charge voltage of the zinc-beryllium silicate phosphor as against the anode voltage had increased from about − 25 volts to − 300 volts after 765 hours of operation at an anode voltage of 7.5 kilovolts.

This increase is greatly reduced (from about − 15 to − 70 volts) if the anode voltage is only 5 kilovolts or is below 5 kilovolts. Our tests usually employed an anode voltage of 4 kilovolts to keep the range of variation of the secondary-emission coefficient as small as possible.

† The author is indebted for these observations on ion burns to W. Berthold.

The damage to the luminescence of a screen does not depend on the number of electrons hitting the screen per time interval but is determined by the total number of electrons. This was already shown[17] for zinc fluoride. Figure 5 is the damage curve for a particular

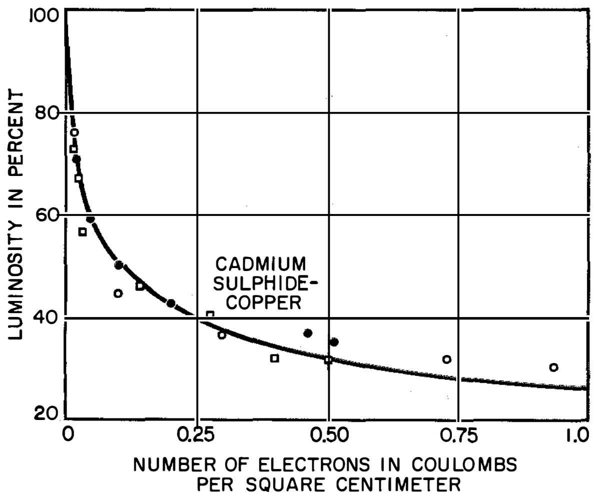

Figure 5—Reduction in luminosity as a result of electron radiation on cadmium sulphide–copper in a sealed tube for various plate voltages and beam-current densities.

cadmium sulphide–copper screen at various anode voltages. All values coincide quite well in the region where the decay of luminescence has not yet come to a constant value. This should prove the independence of luminescence decay from beam-current intensity and anode voltage and its sole dependence on the total number of electrons for cadmium sulphide–copper, too. The result is readily seen; with cadmium sulphide–copper and anode voltages below 4 kilovolts, the same beam power produces different degrees of damage.

The apparent similarity of the process of luminescence decay by alpha particles, electrons, and ultraviolet light has already been stressed. This fact, together with the independence of the decay on beam intensity and anode voltage, point to the different efficiencies of various agents, which however have a common mode of action. All of them cause ionization of the lattice structure that leads to the creation of discontinuities in the crystal. These discontinuities are in turn removed by thermal treatment. Discontinuities are the cause for the formation of deep traps in the band model of crystal phosphors, and these traps offer transition without radiation.

Conclusions

The decay of luminescence in cathode-ray tubes with screens of zinc silicate–manganese, zinc sulphide–silver, and cadmium sulphide–copper is closely related to the vacuum existing in the tube; experiments were therefore made with sealed-off highly evacuated tubes. Consideration was given to the effects on luminescence decay of a particles and ultra-violet quanta. For constant sizes of phosphor particles of cadmium sulphide–copper, the degree of the electron burn depends only on the total number of electrons hitting the screen and, for anode voltages below 4 kilovolts, not on the beam current and the anode voltage. Both electron and ion burns can be reversed by thermal treatment. It is assumed that electrons ionize the lattice structure elements and thus create discontinuities representing deep traps in the band model of the crystal phosphors where transitions can occur without radiation.

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Automatic Frequency Control for a Pulsed Klystron

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FREQUENCY stability is always one of the prime requisites of a radio-frequency signal generator. In the 3-to-5-centimeter bands, the most suitable low-power oscillator is the klystron. Klystrons can generally be divided into two classifications based on the number of resonant cavities employed. Multiple-cavity types display exceptional frequency stability but are difficult to tune over wide frequency ranges. Single-cavity types are not particularly stable, but are easily tunable over wide frequency bands.

To achieve both stability and tunability, an automatic-frequency-control system can be used in conjunction with a widely tunable type of klystron. This paper describes a system that automatically controls the frequency of a pulsed klystron by comparing its frequency with that of a stable microwave reference cavity.

Many automatic-frequency-control systems have been designed for stabilizing continuous-wave sources, or for coordinating continuous-wave or pulsed sources with other reference signals by means of difference-frequency or phase-comparison methods. In some systems, the automatic-frequency-control action is enhanced by alteration (for example, frequency modulation) of the characteristics of the signal source.

With pulsed sources, the problem of automatic frequency control is much more difficult than with continuous waves, since the pulse duration in the average pulsed microwave signal generator is usually only a fraction of a microsecond, making it almost impossible to correct any frequency error within the duration of a single pulse. To control such a pulsed system, it is necessary that the frequency-error information derived from any one pulse be delayed and then utilized to correct the frequency of succeeding pulses.

The system to be described is for use with a pulsed microwave source. It employs a Pound microwave discriminator, as is commonly used in other systems, in conjunction with reliable passive circuits to derive the pulse-frequency-error information from one pulse and to delay and apply this information to the next succeeding pulse.

In this system, no alteration or modulation of the signal source is necessary. Only four vacuum tubes (excluding power supplies) are used in addition to the required klystron pulse-modulator circuits and controls.

1. Design Requirements

The selection of this particular automatic-frequency-control system was influenced by the following design requirements.

A. Absolute frequency shift must be less than ± 1.0 megacycle over long periods under variable temperature and humidity conditions.

B. Frequency drift with respect to another similar system must be less than ± 0.5 megacycle over any 2-hour period under variable temperature and humidity conditions. This requires that each klystron be stable within ± 0.25 megacycle on an absolute basis to meet the difference-frequency tolerance of ± 0.5 megacycle.

C. Frequency of any system, or frequency difference between any two systems, must be easily controlled without the use of special auxiliary equipment.

D. Tolerance of frequency difference between two systems must not be a function of difference frequency.

E. Frequency difference between any two systems must be controllable even though klystrons might not be pulsed simultaneously.

2. Special Features

By using this automatic-frequency-control system, several special features are obtained without extra cost or complication.

A. Frequency variations between the klystron frequency and the reference cavity can easily be observed by monitoring the error signal. Errors of the order of tenths of a megacycle can be determined easily.

B. Should several pulses be used as in grouped-pulse systems, variations in frequency between the pulses of any one group can be observed.

C. Any frequency modulation of the klystron due to alternating-current operation of filaments, time-interval modulation of the pulse-repetition rate, et cetera, can be observed.

D. Any klystron pulling from variations of load can be detected.

Approximately 40 milliwatts peak pulse power is sampled from the main waveguide through the 10-decibel coupler to hybrid *1*. This power divides from hybrid *1* into a load and to hybrid *2*. Power from hybrid *2* divides into the reference cavity and a tunable short-circuit.

The power reflected by the cavity and tunable short-circuit recombines and goes to the positive-polarity crystal detector through arm *3* of hybrid *2* and a 3-decibel attenuator and to the negative-polarity crystal detector through arm *1* of hybrid *2* and arms *3* and *4* of hybrid *1*.

A 3-decibel attenuator is inserted in the positive-polarity crystal-detector line to equalize the power to each detector, since the reflected power to the negative-polarity detector must go

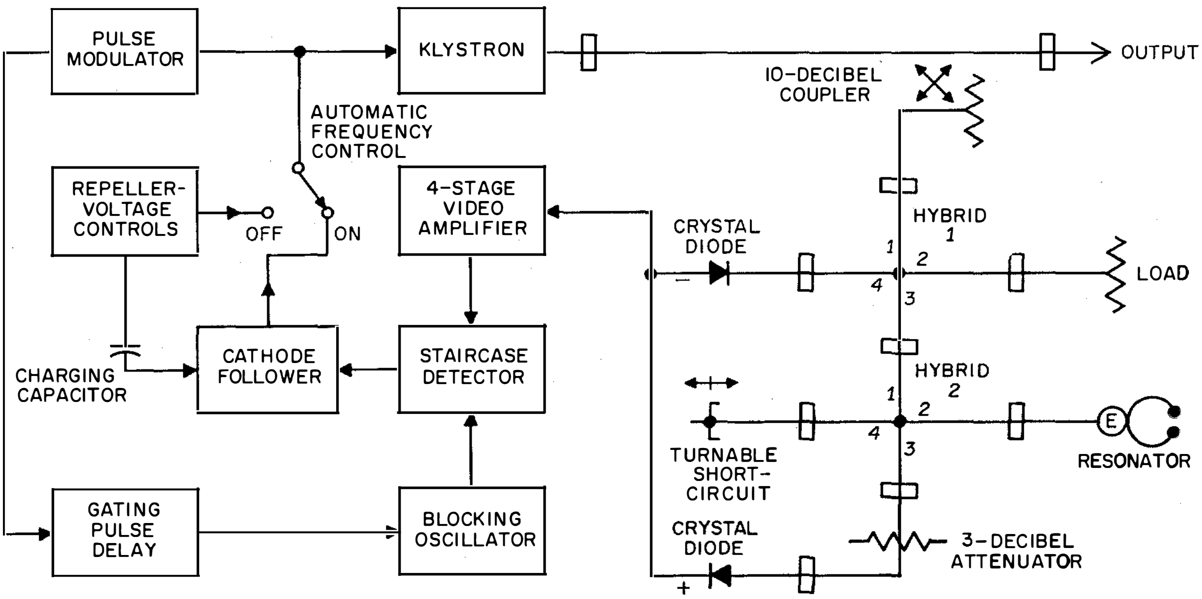


Figure 1—Block diagram of automatic-frequency-control system.

through one more hybrid circuit than the reflected power to the positive-polarity detector.

Division of the reflected power in hybrid *2* is determined by the relative phase of the reflected energies from the reference cavity and tunable short-circuit. If the effective length of the reference cavity at resonance is exactly $\frac{1}{8}$th wavelength closer to the center of hybrid *2* than the tunable short-circuit, the reflected signals will combine in phase quadrature and the power will be equally divided into arms *1* and *3* of

3. Theory of Operation

Figure 1 shows a block diagram of the automatic-frequency-control system.

3.1 Microwave Section

The microwave section develops a video pulse, whose polarity and amplitude vary versus klystron frequency in a manner similar to that of a conventional frequency-modulation discriminator.

hybrid *2*; the resultant amplitudes of the pulses detected by the positive- and negative-polarity crystals will be equal and opposite.

Since the reference cavity is a resonant circuit, the phase of its reflected signal near resonance will change rapidly with small changes in incident frequency. However, the phase of the signal reflected from the tunable short-circuit will not change rapidly versus frequency.

As a result of the relative phase change of the two reflected signals versus frequency, the reflected power divides unequally in arms *1* and *3* of hybrid *2* whenever the incident frequency is above or below the reference-cavity frequency. Due to this unequal division of power, the voltage from the positive-polarity detector increases and the voltage from the negative-polarity detector decreases when the signal frequency is greater than the reference-cavity frequency and vice versa.

By adding the outputs of the positive- and negative-polarity detectors, a resultant pulse is obtained whose polarity and amplitude indicate direction and magnitude, respectively, of the klystron-frequency error with respect to the reference cavity.

3.2 Electronic System

Basically, the function of the electronic circuit is to supply to the klystron repeller a frequency-correcting voltage that is developed from the microwave discriminator error signal.

Since the pulse duration is usually only a fraction of a microsecond, it would be almost impossible to correct any frequency error during a single pulse. Consequently, any frequency-error information derived from one pulse must be delayed by some means to correct the frequency of succeeding pulses. This is accomplished by the following circuitry.

The algebraic sum of the two short-duration pulses from the crystal detectors in parallel is impressed on a capacitor at the input to the first video amplifier stage. This capacitance and the back resistance of the crystals lengthen the pulse

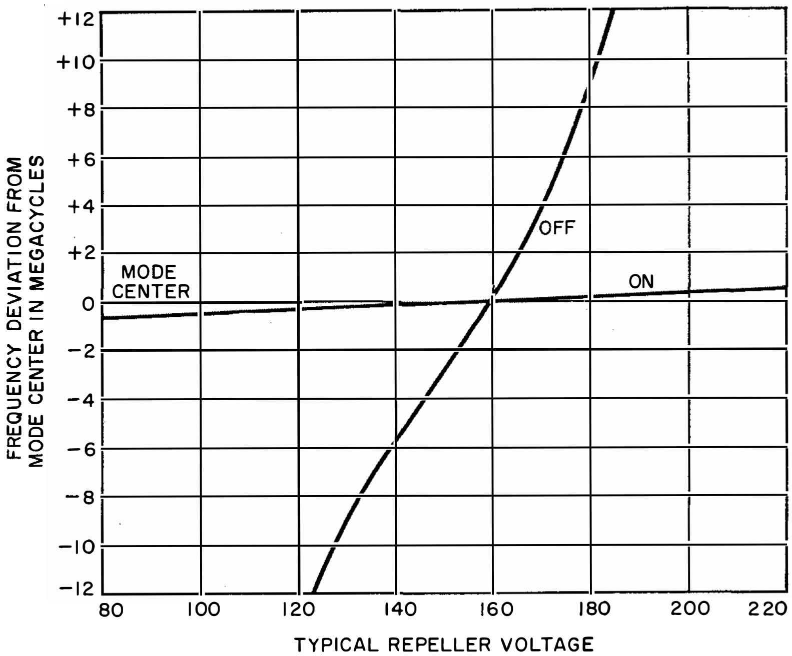


Figure 2—Variation of output frequency with automatic frequency control both ON and OFF for manually adjusted repeller voltages that are negative with respect to the cathode.

to approximately 10 microseconds. Four stages of amplification are used to amplify the stretched pulses before they are sampled by a staircase detector. The staircase-detector gating pulse is delayed approximately 2 microseconds with respect to the klystron pulse, so that sampling of the stretched pulses takes place well after the leading edge of the latter.

When the resultant positive or negative pulses are sampled in the staircase detector, a capacitor is charged positively or negatively according to the klystron frequency-error information.

Since the capacitor charges rapidly during the 1-microsecond sampling interval and discharges very slowly, the staircase detector stores the frequency-correction information from one pulse so that it can be applied to the next succeeding pulse. By adding the positive or negative frequency-correction voltage, which appears across the charging capacitor, to the repeller control voltage, the actual klystron repeller voltage is changed so that the frequency difference between the klystron and the cavity reference is driven towards zero.

The reduction in frequency error depends on loop gain in accordance with the following relation.

$$\Delta' = \Delta/(1 + A\beta), \quad (1)$$

where

Δ = frequency error with feedback loop open
Δ' = frequency error with feedback loop closed
β = feedback fraction
A = feedback loop gain = $S_1 S_2 G e$
S_1 = microwave-discriminator sensitivity in megacycles per volt
S_2 = repeller tuning factor in volts per megacycle
G = amplifier gain
e = pulse-stretcher efficiency.

Assuming, for example, $\beta = -1$, $S_1 = 0.086$ megacycle per volt, $S_2 = 2.0$, an amplifier gain of 3000, a pulse-stretcher efficiency of 0.2, and an error Δ of 14 megacycles with the automatic-frequency-control feedback loop open, the closed-loop error Δ' would be approximately

$$\Delta' = \frac{14 \text{ megacycles}}{1 + (0.086)\,(2.0)\,(3000)\,(0.2)} \approx 0.135 \text{ megacycle.}$$

These results show that the closed-loop error is approximately equal to the open-loop error divided by the loop gain.

By increasing loop gain, the error can be reduced proportionately. Two loop-gain factors that can easily be changed in any given system are the amplifier gain and the pulse-stretcher efficiency.

Loop gain versus frequency must be reduced sharply slightly above a frequency equal to half the sampling rate, since the staircase detector has a 90-degree phase shift at half-repetition rate that will tend to allow the loop to oscillate if the gain is sufficient.

4. *Performance*

4.1 Errors Versus Repeller Voltage

Figure 2 shows the frequency error to be expected with variations in repeller voltage with and without automatic frequency control.

4.2 Errors Versus Reference-Cavity Setting

The error between the reference-cavity frequency and the klystron output frequency versus the cavity setting is shown in Figure 3. These data were taken with the klystron tuned so that its normal uncorrected operation was in the center of its mode at zero error with respect to the reference cavity.

4.3 Hold-In Range

Hold-in range versus cavity setting is good. As the klystron power decreases on the sides of the klystron mode, the repeller sensitivity increases and tends to hold the loop gain constant, thus keeping the relative error linear.

When the klystron pulse has a good spectrum, the automatic-frequency-control system will hold the klystron on the reference-cavity frequency even though the klystron is operating 10 decibels down on the side of its mode.

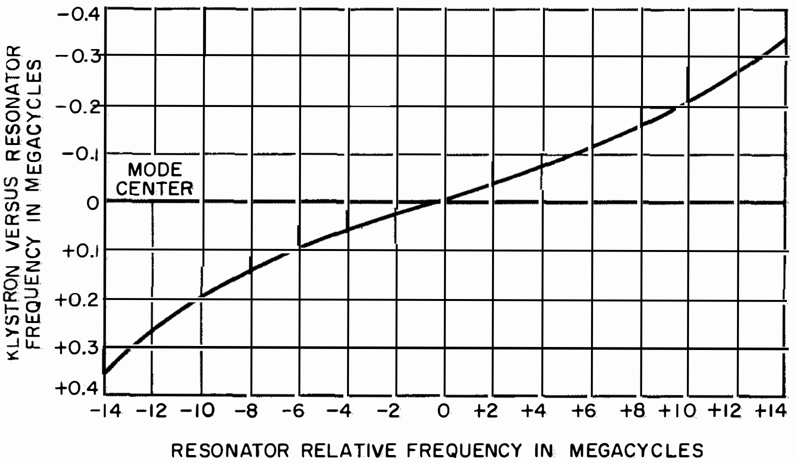


Figure 3—Ability of automatic frequency control to hold the output frequency of the klystron to that of the resonator over a range of resonator adjustments.

Caution must be exercised in some klystron-pulsing methods to insure that the correction voltage does not drive the repeller voltage into a continuous-wave operating condition, which will be a limiting factor in the hold-in and pull-in ranges.

4.4 Pull-In Range

Pull-in range is only 1 or 2 megacycles less than the hold-in range, if a balanced pulse spectrum is used.

4.5 Stability

Equation (1) shows several factors that will affect frequency stability with respect to the reference cavity. In addition to these, one other factor must be considered for absolute stability, that is the stability of the reference cavity itself.

Variation in the factors affecting closed-loop stability can be classified into three groups.

A. Factors that will affect frequency stability in direct proportion to their variations, such as reference-cavity drifts.

B. Factors that will affect frequency stability by a ratio of 1 divided by the loop gain, such as variations in open-loop error.

C. Other factors that affect frequency stability according to their relation in the above equation, such as amplifier gain, et cetera.

Of the three groups, the first is the most critical. By using an invar pressurized microwave cavity, variations due to temperature and humidity can be reduced to less than 0.1 megacycle for normal factory conditions.

The remaining parameters, such as amplifier gain, feedback ratio, et cetera, should not vary appreciably under normal conditions.

4.6 Random Jitter

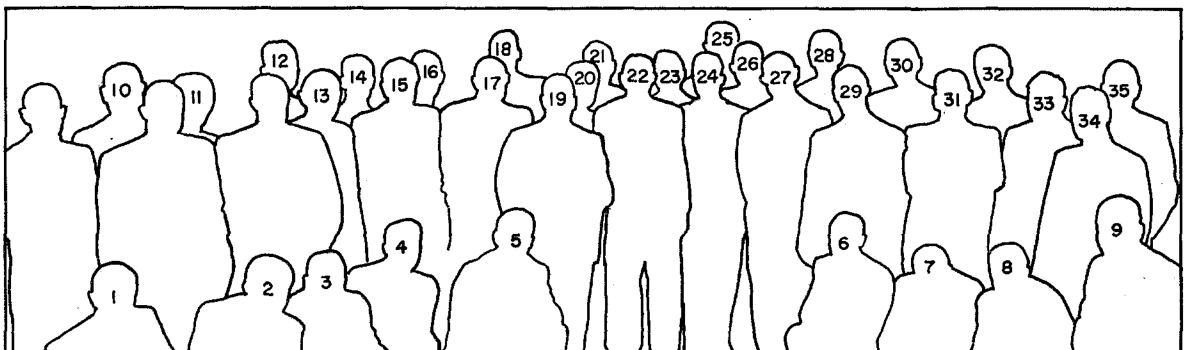
In the units tested to date, there is less than 50 kilocycles of random frequency jitter. The main sources of jitter are microphonics in the four-stage amplifier and in the klystron itself.

Recent Telecommunication Development

Federal Returns To Palo Alto

On December 15, 1956, Federal Telecommunication Laboratories division of International Telephone and Telegraph Corporation dedicated a new laboratory in Palo Alto, California, the city where, in 1912, Dr. Lee De Forest and his coworkers of Federal Telegraph Company discovered the oscillating properties of the audion and its operation in cascade amplifier circuits.

Some of those present at this dedication as shown in the above photograph were: 1. Frank Lawrence; 2. J. W. Halina; 3. Gerhard Fisher; 4. J. E. Bower; 5. G. L. Curtis; 6. W. G. Wagener; 7. Ivan Redeker; 8. Clark Sphar; 9. Foster Frazee; 10. C. E. Johansen; 11. Stephen Bobis; 12. K. R. Spangenberg; 13. George Everson; 14. D. I. Cone; 15. F. E. Terman; 16. Archie Brown; 17. R. M. Heintz; 18. P. R. Adams; 19. J. R. Mason; 20. Svend Holmstrup; 21. D. M. Perham; 22. Lee de Forest; 23. J. O. Ashton; 24. W. S. Chaskin; 25. Art Denz; 26. Leonard Fuller; 27. C. F. Elwell; 28. Don Lippincott; 29. J. A. Miller; 30. Hugo Romander; 31. R. B. Woolverton; 32. Joseph Pettit; 33. Harry Redeker; 34. Archie Brolly; 35. Robert Leconte.



United States Patents Issued to International Telephone and Telegraph System; November 1956–January 1957

Between November 1, 1956 and January 31, 1957, the United States Patent Office issued 70 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers follow.

P. R. R. Aigrain and G. B. A. Liandrat, Laboratoire Central de Télécommunications (Paris), Device for Storing Information, 2 773 250.

F. J. Altman, Federal Telecommunication Laboratories, Coherent Radar System, 2 776-425.

F. J. Altman, Federal Telecommunication Laboratories, Moving-Target Range-Tracking Unit, 2 776 426.

M. Arditi and P. Parzen, Federal Telecommunication Laboratories, Microwave Transmission Line, 2 774 064.

A. J. Baracket, Federal Telecommunication Laboratories, Cathode-Ray Electron-Discharge Device, 2 771 566.

A. C. Beadle, Standard Telephones and Cables (London), Telephone Subscribers' Sets, 2 770 679.

A. H. W. Beck, T. M. Jackson, and J. Lytollis, Standard Telephones and Cables (London), Electric Discharge Tubes, 2 775 722.

A. H. W. Beck and A. D. Brisbane, Standard Telephones and Cables (London), Ionization Manometers, 2 774 936.

J. F. Bigelow, Capehart–Farnsworth Company, Automatic Phase- or Frequency-Control System, 2 773 984.

J. F. Bigelow, Capehart–Farnsworth Company, Beam Cutoff Circuit, 2 774 007.

H. Boer, Mix and Genest (Stuttgart), Register for Receiving and Sending Connecting Orders, 2 770 796.

F. G. Bolte, Federal Telephone and Radio Company, Spring Binding Post, 2 770 789.

E. Bradburd, Federal Telecommunication Laboratories, Complex Pulse Communication System, 2 779 933.

F. H. Bray, R. G. Knight, and G. C. Hartley, Standard Telephones and Cables (London), Electric-Discharge-Tube Circuit, 2-774 820.

A. E. Brewster, Standard Telephones and Cables (London), Tape Recording Apparatus, 2 770 674.

J. H. Bryant and B. D. McNary, Federal Telecommunication Laboratories, Traveling-Wave Tubes, 2 771 565.

P. F. C. Burke, Standard Telephones and Cables (London), Electron-Discharge Apparatus, 2 774 002.

D. R. Carlo, Farnsworth Electronics Company, Image Tube, 2 774 002.

A. G. Clavier and D. L. Thomas, Federal Telecommunication Laboratories, Surface-Wave Transmission Line, 2 770 783.

L. A. DeRosa, Federal Telephone and Radio Company, Radio Detection System, 2-774 965.

M. J. DiToro, Federal Telecommunication Laboratories, Noise-Suppression Device, 2-771 586.

R. H. Dunn, Standard Telephones and Cables (London), Electrical Counting and Like Devices, 2 774 534.

E. L. Earle, Kellogg Switchboard and Supply Company, Flat-Bank Crossbar Switch, 2 773 129.

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C. L. Estes, Federal Telecommunication Laboratories, Communication System, 2 776-366.

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S. Greenberg and P. W. Sokoloff, Federal Telecommunication Laboratories, Detecting the Sense and Magnitude of a Direct-Current Source, 2 773 946.

D. D. Grieg, Federal Telecommunication Laboratories, Band-Pass Filter, 2 773 244.

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R. W. Hales, Farnsworth Electronics Company, Communications-System-Checking Apparatus, 2 773 977.

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J. A. Henderson, Farnsworth Electronics Company, Blanking Circuit for Electron Multiplier, 2 777 948.

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H. P. Iskenderian, Federal Telecommunication Laboratories, Electron-Discharge Device, 2 776 374.

A. G. Kandoian, Federal Telecommunication Laboratories, Ultra-High-Frequency Antenna System, 2 771 606.

W. J. Knuepfer, Kellogg Switchboard and Supply Company, Portable Equipment and Folding Legs Therefor, 2 776 180.

J. A. Kostriza, Federal Telecommunication Laboratories, Coaxial-Line Switch, 2 771 529.

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A. M. Levine and H. Altman, Federal Telecommunication Laboratories, Self-Gating Synchronizing Circuit, 2 771 507.

F. J. Lundberg, Federal Telecommunication Laboratories, Balanced Doublet Antenna, 2-774 967.

F. J. Lundberg, Federal Telecommunication Laboratories, Antennas, 2 770 800.

C. P. Majkrzak, Federal Telecommunication Laboratories, Point-Contact Device for High-Voltage Radio-Frequency Use, 2-773 964.

A. J. Marino, Jr., Federal Telecommunication Laboratories, Zone-Refining Boat, 2 776-131.

K. A. Matthews, Standard Telecommunication Laboratories (London), Electric Crystal Rectifiers, 2 770 763.

G. F. McCarthy and A. Gulnick, Federal Telecommunication Laboratories, Telephone Ringing Generator, 2 771 562.

S. Metzger, R. W. Hughes, and B. McAdams, Federal Telecommunication Laboratories, Multiplex Demodulator, 2 771 553.

H. G. Nordlin and P. M. Koerner, Federal Telecommunication Laboratories, Sizing of Thermoplastic Cable Cores, 2 770 014.

S. W. Pergunas and L. F. Cowan, Standard Telephones and Cables (London), Humidifying Process in Electric-Cable Insulation Making, 2 770 565.

S. B. Pickles and A. M. Casabona, Federal Telecommunication Laboratories, Instrument Landing System, 2 771 603.

L. C. Pocock and A. C. Beadle, Standard Telephones and Cables (London), Telephone Subscribers' Sets, 2 775 649.

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H. B. Rooks, Capehart–Farnsworth Company, Time-Delay Space-Charge Device, 2 774-008.

W. Reinhard, C. Lorenz (Stuttgart), Cathode-Ray Deflection Coils, 2 771 563.

J. O. Silvey and O. C. Booher, Capehart–Farnsworth Company, Tunable Coaxial Lines, 2 774 044.

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G. Stavis, Federal Telecommunication Laboratories, Phase Discriminator, 2 774 038.

L. R. Ullery, Capehart–Farnsworth Company, Display Amplifier and Method of Making Same, 2 773 992.

R. Urtel, Schaub Apparatebau (Pforzheim), Circuit Arrangement for the Generation of Saw-Tooth-Shaped Deflecting Currents, 2 774 911.

R. Urtel, C. Lorenz (Stuttgart), Frequency-Control Circuit, 2 770 730.

C. deB. White and K. A. Matthews, Standard Telecommunication Laboratories (London), Crystal Triodes, 2 770 762.

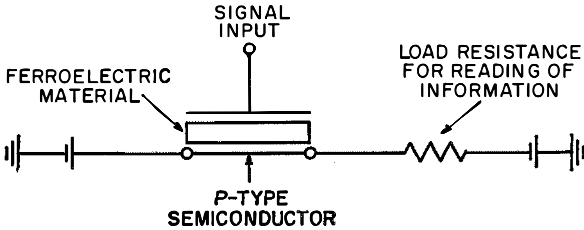
H. Wolfson and G. Elliott, Standard Telephones and Cables (London), Electrically Conducting Cements Containing Epoxy Resins and Silver, 2 774 747.

I. Yosano, Nippon Electric Company (Tokyo), Attitude-Compensated Echo-Sounding Device, 2 774 954.

Device for Storing Information

2 773 250
P. R. R. Aigrain and G. B. A. Liandrat

The invention covers a storage capacitor consisting of a pair of electrodes between which a ferroelectric body is supported. One of the electrodes is made of a material such that its resistance will vary with the change in potential

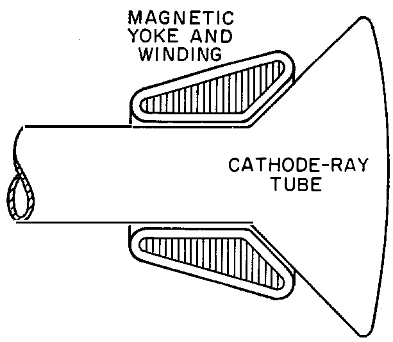


between the electrodes. This electrode may be a semiconductor containing impurities of the *P* type. With this type of storage, conductor current through the semiconductor electrode will permit the reading of information from the capacitor store.

Cathode-Ray Deflection Coils

2 771 563
W. Reinhard

A cathode-ray deflection yoke for obtaining a linear deflection over a wide-angle screen is the subject of this patent. The magnetic yoke and



the deflection windings are flared so that they will extend not only along the neck of the tube but an appreciable distance over the flared portion of the tube as well.

Crystal Triodes

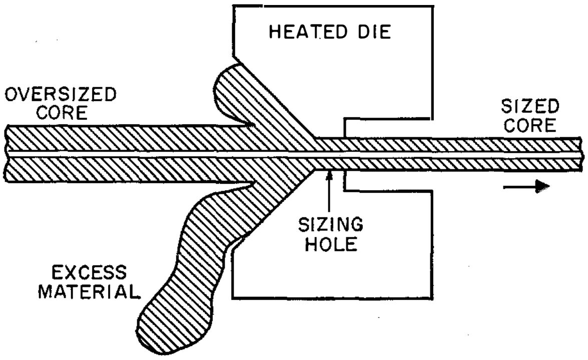
2 770 762
C. deB. White and K. A. Matthews

A crystal triode of the type known as a transistor is described. It has three point-contact electrodes, one of which serves as the base electrode. One of the three electrodes is relatively remote from the other two and the other two are relatively closely spaced with respect to each other. The relatively remote electrode is used as the base electrode and the spacing is sufficiently great that it will not react as a collector or emitter.

Sizing of Thermoplastic Cable Cores

2 770 014
H. G. Nordlin and P. M. Koerner

A process for reducing a cylindrical form of thermoplastic material to a given size is described. It consists in passing this cylindrical form through a heated die in which the sizing hole is maintained at a substantially uniform temperature along its length. This sizing hole is of uniform diameter and normally smaller than the diameter of the cylindrical plastic form. At the entrance to the sizing hole, there is provided a conical opening that assimilates the body fluid of the surplus thermoplastic material removed from the cylinder and that serves to preheat and maintain the cylindrical form substantially centered within the die. This method has been particularly useful in sizing polyethylene cores.



Electrical Counting and Like Devices

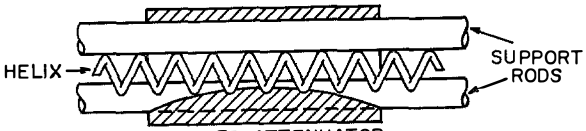
2 774 534
R. H. Dunn

This patent concerns an electrical counting device consisting of a first counting tube connected to provide a chain counting circuit coupled to a second tube similarly connected. The first counting-chain circuit is actuated directly by input pulses and the other by output pulses from the first chain. The two counting chains may be cross-connected for the purpose of producing a division between two numbers.

Traveling-Wave Tubes

2 771 565
J. H. Bryant and B. D. McNary

A traveling-wave tube having a helical delay line supported by a plurality of dielectric rods and an attenuating arrangement for waves transmitted along the helical line is the subject of this patent. The attenuator consists of a concentrated body of resistive material shaped so that only the central portion of this mass is in contact with the conductors of the helical line. Thus a high degree of attenuation is concentrated over a small length of the helical line and because of the taper an impedance match is also achieved.



Contributors to This Issue

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Claude Dumousseau was born in Ruelle, France, on March 17, 1917. He graduated as an engineer from Ecole Polytechnique, Paris, in 1941 and graduated as an engineer from Ecole Supérieure d'Electricité in 1942.

In 1941 he was employed by Le Matériel Téléphonique in Lyons and was transferred in 1945 to Laboratoire Central de Télécommunications in Paris, where he has worked on radio links, vacuum tubes, computers, and electronic switching. Since 1954, he has been in charge of electronic-switching studies and reports on a fully electronic telephone switchbord in this issue.

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Georges Goudet

Hans H. Adelaar was born on February 10, 1916, in Amsterdam, The Netherlands. He received the degree of electrical engineer from the Technical Institute at Delft in 1938.

On graduation, he became a patent examiner in the Netherlands Patent Office (Octrooiraad) in The Hague, where his activities were in the fields of radio, television, and carrier telephony.

He joined the switching laboratory of Bell Telephone Manufacturing Company in 1946, where he is now in charge of a development group on electronic switching.

Mr. Adelaar is a member of the Dutch Royal Institute of Engineers.

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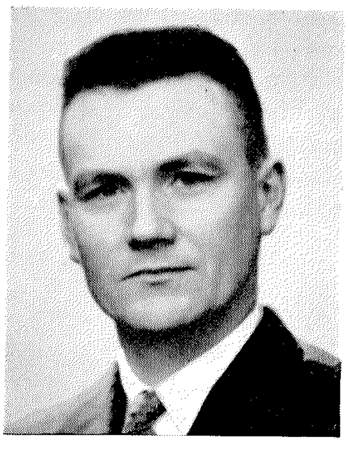

Claude Dumousseau

Georges Goudet was born in 1912 in Dijon, France. He received several scholarships at the Ecole Normale Supérieure. In 1936, he became an Agrege (fellow) of physical science at the university. After serving as an artillery officer during the war, he completed his work for a doctorate in physics in 1942.

During 1943 and 1944, he worked on microwave tubes at Laboratoire Central de Télécommunications. He then became the head of the ultra-high-frequency laboratory of the French Posts, Telegraphs, and Telephones administration. In 1951, he joined the staff of Nancy University as a professor and director of the special school of electricity and mechanics. He has served as a consultant to Laboratoire Central de Télécommunications and in 1955 became the director of that laboratory.

He is the author of numerous publications and a coauthor of three books. He discusses electronic switching of telephone circuits in this issue.

Dr. Goudet is a member of the Société Française de Physique, Société des Radioélectriciens, Société Française des Electriciens, and a Senior Member of the Institute of Radio Engineers.

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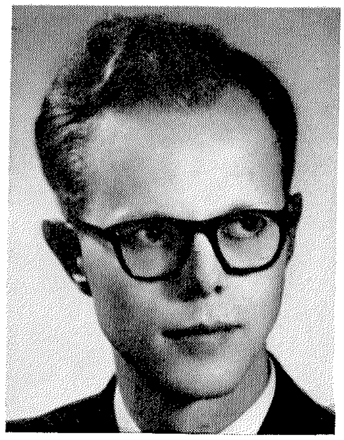
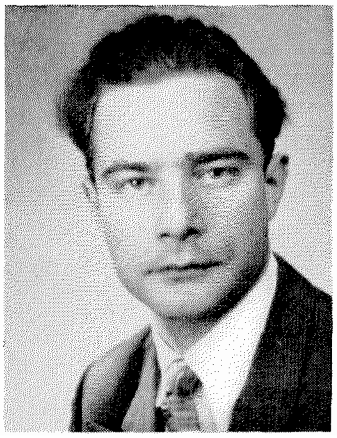
Olli Lehto was born on May 30, 1925, in Helsinki, Finland. He received the M.A. degree in 1947 and the Ph.D. degree in 1949 from the University of Helsinki. In 1951, he joined the University of Helsinki as a lecturer in mathematics and now holds the position of professor of mathematics. He has published some 20 mathematical papers, mainly on the theory of analytic functions.

Dr. Lehto joined Finska Kabelfabriken in 1947 and has been engaged principally in work on telephone cables and on quality control. In this issue, he is joint author of an article on the Helsinki–Tampere coaxial cable.

Dr. Lehto is secretary of the Finnish Mathematical Society, a member of the Finnish national committee of the International Mathematical Union, a member of the American Mathematical



Olli Lehto



RAIMO PÖYTÄNIEMI

Society, and a member of the reviewing staff of *American Mathematical Review.*

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RAIMO PÖYTÄNIEMI was born on December 30, 1927, in Vaasa, Finland. He studied electrical engineering at Finland's Institute of Technology, graduating in 1952.

Following graduation, he joined Finska Kabelfabriken, where he now is in charge of the telephone cable laboratories and of development work on high-frequency telephone cables. In this issue, he is joint author of an article on the Helsinki–Tampere coaxial cable.

Mr. Pöytäniemi is a member of the Association of Finnish Engineers.

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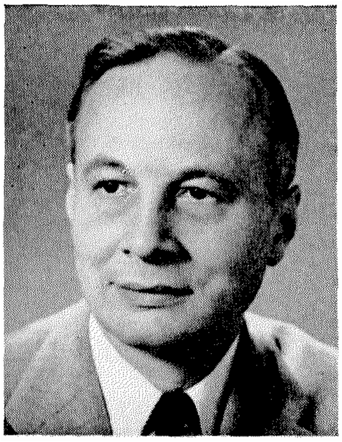
K. H. JUERGEN ROTTGARDT was born in Berlin, Germany, on May 24, 1913. He studied physics at the universities of Tuebingen and Berlin and received the Ph.D. degree from Berlin University.

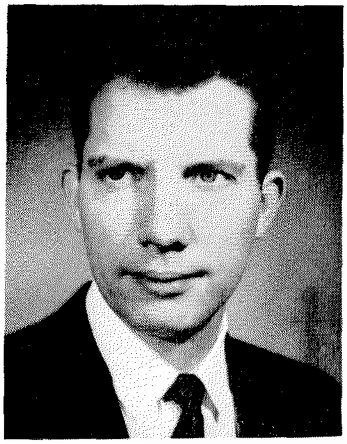
From 1936 to 1937, he was an assistant at the First Institute of Physics of Berlin University. Later he worked on the development of magnetron tubes at the Deutsche Versuchsanstalt. During the war, he was engaged in the development of special cathode-ray tubes like the Sciatron.

In 1952, Dr. Rottgardt joined C. Lorenz. He has done research on cathode luminescence and on television picture tubes at Standard Central Laboratories and became head of the development laboratory for cathode-ray tubes. He reports here on cathode-ray-tube luminescence.

Dr. Rottgardt is now chief of development work on rectifiers and components at Süddeutsche Apparatefabrik, Nürnberg.



K. H. J. ROTTGARDT



PAUL D. ULM

PAUL D. ULM was born in Butler, Indiana. He received his degree from the University of South Carolina in 1946.

He has since specialized in the field of test-equipment design and development with the Magnovox Company, the Applied Physics Laboratory of Johns-Hopkins University, and Farnsworth Electronics Company.

Since 1952, he has been with the missile test equipment department at Farnsworth Electronics Company, producing development, factory, and field test equipment for use on the Terrier, Talos, Regulus, and Bomarc missile systems. His paper in this issue on "Automatic Frequency Control for a Pulsed Klystron" resulted from one of these projects.

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