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ELECTRICAL COMMUNICATION

The Technical Journal of
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
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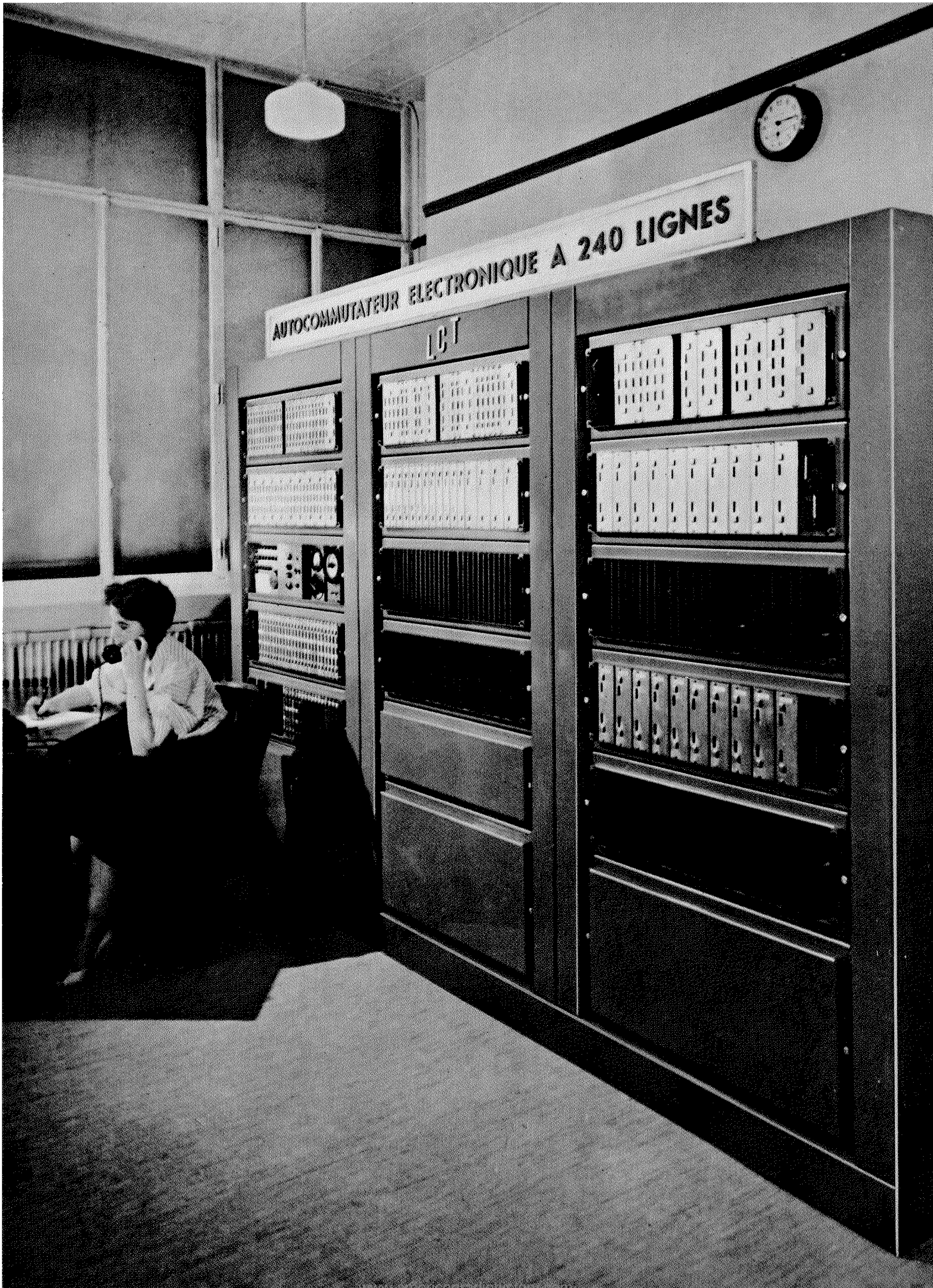
AUTOCOMMUTATEUR ELECTRONIQUE A 240 LIGNES
L.C.T

Introduction of Electronics in Telephone Switching[*]

By PRINCE LOUIS DE BROGLIE

Laboratoire Central de Télécommunications; Paris, France

THE possibility of controlling mechanical movement at a distance with the help of electric current was very quickly noted by the founders of electrical science. In the memorable research he did in 1820 and subsequently on electrodynamics, Ampère pointed out the principles of electrical telegraphy, a practical system of which was not developed until 30 years or so later. Quite a long time after, the motions of air constituting sound were transformed by a microphone into variations of an electric current that were retransformed in the receiver into sounds that were identical, or at least very similar, to those striking the microphone. This was the start of telephony.

The use of electromechanical devices to transform motions into electric current variations, and vice versa, afterward became very widespread and formed the basis for innumerable inventions. I shall only mention here Blondel's oscillograph, which by transforming variations of a current into movement of an oscillating mechanical system allows the waveform of the current to be recorded. This oscillograph, which at the time of its development was properly regarded as a remarkable measuring equipment, is today considered rather out-of-date and has been replaced by its electronic counterpart, the cathode-ray oscilloscope.

Since the beginning of this century, a new branch of electrical science, electronics, has rapidly developed. It originated with discoveries by physicists regarding the elementary particles of matter, and in particular the elementary particles of negative electricity called electrons. As physicists unceasingly increased their knowledge of the properties and role in the structure of matter of these elementary particles, technicians were able to make progressively more ingenious applications of these electronic elements in essential roles in a great variety of devices. To specify what an electronic element is, we can say, as did Prof. Goudet in a recent paper, that in this classification can be included "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 fulfil their functions through the movement of electric or magnetic particles without displacement of ponderable quantities of matter."

For the past half-century, we have witnessed the partial or even total intrusion of electronics in domains formerly occupied entirely by electromechanics. As an example of total substitution, we have seen Blondel's electromechanical oscillograph completely replaced by the cathode-ray oscilloscope, of which the prototype was Braun's tube. Another outstanding example is the development, at first rather slowly, of television techniques. Here, a problem was to transmit either by wire or by modulated radio waves, the currents generated by photoelectric cells on which were projected very rapidly in continuous succession all the points of an illuminated scene. The first pioneers of television tried to scan the picture by mechanical devices such as rapidly rotating disks and vibrating forks. Despite the ingenuity of their efforts, they did not succeed because mechanical parts have too much inertia to provide satisfactorily the extremely rapid rhythm necessary to scan the picture. The solution was Zworykin's iconoscope and its improvements. Today in television transmission and reception, everything is electronic.

The success of electronics in the techniques just mentioned and in similar ones can be explained by the fact that electronic devices have much-swifter operation and much-greater flexibility than mechanical or electromechanical devices. Nevertheless, despite their superiority from these points of view, their victory has not been complete in all fields in which their introduction was possible. Thus, in electroacoustics,

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[*] Opening remarks delivered by Prince de Broglie on January 22, 1960 at the demonstration of the 240-line all-electronic telephone exchange in Paris, France.

although electronics have been introduced in equipment like magnetic recorders, the basic transducers such as microphones, pickups, and loudspeakers remain electromechanical in nature. Similarly, in the very-important technique of telephone switching, the introduction of electronics has so far been only partial, and this problem brings us to the object of this meeting.

In the first developments in telephone switching, the devices used were exclusively electromechanical and the circuits of which we are going to speak were still not clearly differentiated. Now, specialists distinguish among three sorts of circuits in a central office.

(A) The switching or speech circuit, which must connect the calling and called subscribers and provide the speech path between them.

(B) The memory circuit, which must record and store the orders of calling subscribers.

(C) The control circuit, which must see that these orders are executed as rapidly as possible by the speech circuit.

This distinction among the various circuits clearly defines their respective roles so that the circuits may be better adapted to their functions. The electromechanical devices at present in use in central offices have reached such a high degree of perfection that it might be questioned whether there is anything to be gained through using electronics. It seems, however, that the reply must be in the affirmative.

Telephone switching equipment must possess great flexibility and great rapidity of operation; it must occupy as little space as possible so as to reduce the size of the premises where the exchange is installed; it must be easy to maintain; and it must have a long operating life. The electromechanical systems presently in use have been improved to the point where they fulfil satisfactorily most of these conditions. Nevertheless, it seems that the introduction of electronics in telephone switching, when sufficiently perfected, will allow them to be fulfilled even better. This evolution appears, moreover, consistent with the general trend toward electronic automation. No doubt it will be some time before purely electronic telephone switching becomes general practice, because its perfection will require long study and also because the present central offices, whose performance is very satisfactory, will not be replaced overnight. But, looking to the future, the technicians of today must strive to perfect purely electronic switching; that is why the Laboratoire Central de Télécommunications devotes part of its effort in that direction.

Let us now return to more-specific considerations. It is easy to introduce electronic elements in the control circuits and in the memory circuits —especially in the latter, where it is quite natural to use such memory elements as the ferrite cores currently used in electronic computers. Such applications have already been made, resulting in a mechanoelectronic switching system that is only semielectronic since switching of the speech circuit remains electromechanical. To obtain fully electronic telephone switching, the connections in the speech circuit must be made by purely electronic means.

The first question that then arises is the choice of the electronic elements to be used as contacts between calling and called lines. Recourse can be had either to gas diodes or to semiconductor elements. Since any method using hot-cathode diodes must be discarded because of the excessive energy needed to heat the cathode continuously, the two elements that have been most used, at least here at the Laboratoire Central de Télécommunications, are the silicon diode and the cold-cathode gas diode. These junctions, called gates in electronic computers, have quite different characteristics.

The silicon diode, very small and with practically indefinite life, consumes power of the order of only a few milliwatts. The cold-cathode gas diode, filled for example with neon, is without doubt more fragile and does not have such long life, but its characteristics are nevertheless quite satisfactory from these points of view. It consumes energy of the order of one watt, much higher than that consumed by the silicon diode. On the other hand, it possesses a characteristic that makes it very worthy of consideration, for it is a gate endowed with a memory. The silicon diode is a gate that opens when voltage is applied in the right direction and closes when subjected to a voltage in the opposite direction. But, as it obeys only the voltage applied at the moment, it does not possess any memory and therefore to secure satisfactory telephone switching, it is necessary to associate with each of these gates a memory of the flip-flop type, for example.

This complication does not exist with cold-cathode gas diodes. They are quiescent under an operating potential of about 105 volts, but are fired when the voltage at their terminals reaches about 170 volts. If a voltage pulse brings the 105-volt operating potential difference at the terminals to more than 170 volts, the diode is fired and remains fired after the voltage pulse ends. For this reason, it can be said that the diode remembers the firing order that was given to it. The same applies to an extinction order in which the voltage is dropped below 105 volts. This memory of the gas diode makes it a particularly advantageous type of contact.

Another general question that might arise in connection with telephone switching is the choice between space switching and time switching. The usual type of central office establishes a single direct connection between the called and the calling lines over a space path reserved for the conversation of these two subscribers. This may be said to be entirely space switching and, if it is desired to replace the electromechanical contacts with electronic ones, the simplest idea is to proceed in the same way.

However, considering the very-great rapidity of electronic controls, another process can be envisaged, that of using one of the principles of multiplex communication, in particular, time-division multiplex. In this system, we no longer have space switching but rather time switching. These systems have been the object of numerous patents, particularly those received by Dr. Deloraine 12 years or so ago, and have given rise to several experimental studies.

The principle of time-division multiplexing is well known and it is used in numerous branches of telecommunication. The transmitter sends a series of pulses at regular time intervals. Each pulse series reproduces the modulation of a current, for example a voice-frequency current, and many of these pulse series can be interleaved in such a way that many signals can then be transmitted on a single channel. On reception, a switching system distributes the different pulse series to their separate channels for reconversion to the voice-frequency signal.

The success of this method lies in the following fact: oscillations in a mechanical or electromagnetic system can be maintained by applying properly timed pulses. However, in the case of telephone switching, a complication arises that does not exist in normal multiplex transmission where each pulse series is always on the same incoming channel, which therefore corresponds permanently to this series. In telephone switching, it must obviously be possible for each pulse series to be directed to any of the incoming channels so that the desired communication can be established between the calling and called subscribers. This additional problem can be solved by accepting some complications.

Fully electronic telephone switching by time-division multiplex perhaps has an important future, but it raises complex problems and so far only preliminary studies have been made.

The Laboratoire Central de Télécommunications, which is studying these problems very closely, has therefore restricted its actual designs to telephone switching developments of the space type. After a certain number of attempts, which had been delayed by the difficulty of obtaining good crosspoints, it constructed a 20-line fully electronic automatic exchange in 1957 for the French Navy. On warships, telephone installations must be compact and must be resistant to shocks, as these are frequent and particularly violent when the ship is under fire. Fortunately, the exchanges on these ships serve only a very-small number of lines. These circumstances made it very desirable and relatively easy to develop a fully electronic installation. In the one constructed three years ago, the crosspoints were silicon diodes, to which were added, as we have said, flip-flops as memories.

To take another step in the same direction and to show the principles on which, no doubt, it will be possible to develop fully electronic exchanges of thousands of lines, the Laboratoire Central de Télécommunications is demonstrating to us today a 240-line fully electronic automatic telephone exchange, in which the contacts are gas diodes without auxiliary flip-flops. I shall not be so presumptious, I almost said imprudent, as to try and present to you this new development, in which technical problems of great complexity are resolved very elegantly.

240-Line Fully Electronic Telephone Switchboard*

By GEORGES GOUDET

Laboratoire Central de Télécommunications; Paris, France

ELECTROMECHANICAL switching system evolution shows a trend toward separation of the functional elements into two categories:

(A) Those elements that establish a connection between the calling and called subscribers—the *speech circuit.*

(B) Those that give the necessary instructions to the speech circuit—the *control circuit.*

The latter is simply a special computer and as such it must include *memories* containing the information describing the condition of the system and a *logic circuit* capable, according to the stored and new data, of preparing the instructions given the speech circuit. A modern switching system is therefore divided into speech circuit, logic circuit, and memories.

Functionally, these three parts have quite different characteristics, particularly regarding the time that each of them must devote to providing communication between subscribers. The logic circuit intervenes for the establishment or release of connections. Its action is transitory, the duration of its use depending only on its own speed of operation. The situation is different with certain memories; for instance, those registering the number of a called line. They must remain connected during the entire time necessary for dialing if the logic circuit is to have the desirable flexibility and speed.

The speech circuit in electromechanical systems must provide a path for the whole duration of each conversation.

The preceding analysis shows that the speed of operation of electronic components can be particularly well utilized in the logic circuit. In the most-elegant application, this speed eliminates all duplication of equipment, a single logic circuit being successively used for setting up all calls. The principle is called *time sharing.*

Naturally, electronic components can also be used beneficially in the memories, but in this case it is impossible to apply completely the preceding principle. Just as a crossbar central office includes a relatively high number of electromechanical registers, an electronic switchboard must include several electronic memories for handling several calls simultaneously.

Finally, for the speech circuit, there are three different types[1] of solution:

(A) There could be used mechanical contacts with sufficiently high speed and a low power requirement for operation from an electronic control circuit; this[2,3] is a *semielectronic switching system.*

(B) Electronic contacts could be used similarly to mechanical contacts. A connection is then established by choosing a conducting path between the calling and called lines in a complex network of contacts. This[4] is a *space-division electronic switching system.*

(C) There could be applied to the speech circuit the time-sharing principle as currently used in time-division multiplex links: samples of each conversation are taken periodically, the different sets of samples are interleaved and, finally, the complex train of pulses is sent over a transmission channel. Thus a number of simultaneous conversations can be handled on a single circuit.

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* Presented before the Société Française des Radioélectriciens, Paris, France, January 16, 1960; also the Winter General Meeting of the American Institute of Electrical Engineers, New York, N. Y. February 2, 1960. Reprinted from *Transactions of the American Institute of Electrical Engineers,* Part 1 (Communication and Electronics), volume 79, pages 232–241; July, 1960.

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

[2] W. A. Malthaner and H. E. Vaughan, "Automatic Telephone System Employing Magnetic Drum Memory," *Proceedings of the IRE,* volume 41, pages 1341–1347; October, 1953.

[3] S. T. Brewer and G. Hecht, "Telephone Switching Network and its Electronic Control," *Bell System Technical Journal,* volume 34, pages 361–402; March, 1955.

[4] A. E. Joel, Jr., "Experimental Switching System Using New Electronic Techniques," *Bell System Technical Journal,* volume 37, pages 1091–1124; September, 1958.

Following this principle[5] would give a *time-division electronic switching system.*

1. *Previous Developmental Work*

Several types of electronic switchboard can thus be conceived, differing in the extent to which the time-sharing principle is applied, from a single one-at-a-time control and a time-sharing speech circuit, to space-division speech paths and many logic circuits. The choice is heavily influenced by limitations in the speed of operation of available components.

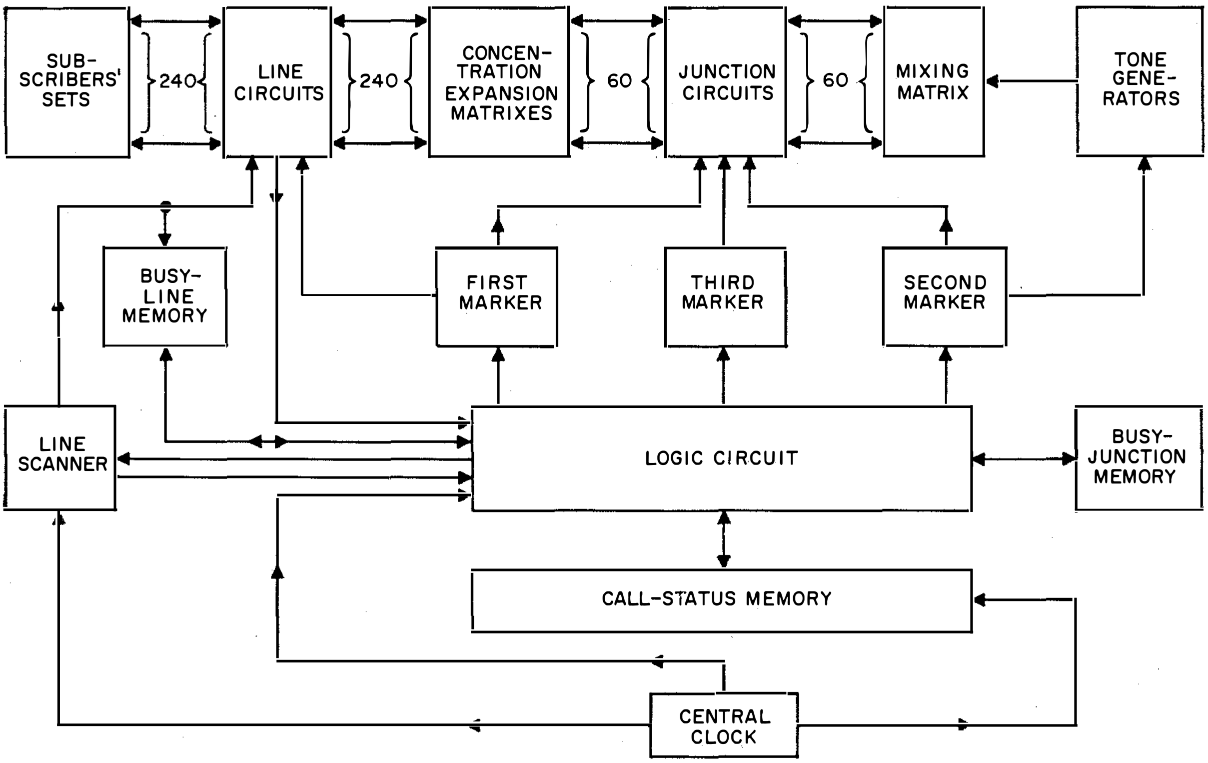

Figure 1—General block diagram.

Thus, in 1951 and 1952, the Laboratoire Central de Télécommunications constructed a laboratory model of a time-division 100-line switchboard with a single logic circuit. Unfortunately, the semiconductor elements available at that time precluded industrial use; but in 1957 they built, for the French Navy, a 20-line fully electronic space-division switchboard capable of four simultaneous calls and having two identical electronic registers.

In such a system, no equipment need operate within times shorter than 1 millisecond, which is very-easily satisfied by the electronic components used, especially by the silicon junction diode crosspoints in the speech circuit. This equipment has already been described.[6] It has proved its ruggedness and perfect reliability under the very-severe operating conditions on a battleship. It uses the principle of time sharing only to a small extent, certain parts of the logic circuit being permanently assigned to each of the 20 lines and other parts to each of the two registers. However, this is justified by the very-small capacity of the equipment.

The application of these principles in central offices of up to several thousands of lines would be economically inadmissible. It would lead to a multiplicity of identical elements that it is possible to replace by a single central logic circuit

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[5] H. E. Vaughan, "Research Model for Time-Separation Integrated Communication," *Bell System Technical Journal,* volume 38, pages 909–932; July, 1959.

[6] C. Dumousseau, "Fully Electronic 20-Line Automatic Telephone Exchange," *Electrical Communication,* volume 34, pages 92–101; June, 1957.

using the semiconductor devices presently available. To demonstrate this possibility, a 240-line private automatic branch exchange has been built. The techniques used can be extended to offices of up to several thousands of lines. This equipment will be described with the help of the general block diagram, Figure 1, and the detailed diagrams mentioned in the course of the text.

2. *Description of Exchange*

2.1 SPEECH CIRCUIT

2.1.1 Crosspoint

The speech-circuit electronic crosspoint is a cold-cathode gas diode. This diode is similar to a tube[7] developed at the Bell Telephone Laboratories. Its firing voltage V_f is about 170 volts and its sustaining voltage V_s is about 107 volts.

This type of crosspoint is advantageous for switching because if the tubes are permanently supplied at a voltage V_o, when $V_s < V_o < V_f$, to fire one of them it is only necessary to apply temporarily between its terminals an additional voltage greater than $V_f - V_o$. After this marking voltage, the tube will remain fired. For this reason, it is said that the tube is a crosspoint with a memory.

Furthermore, the gas diode used possesses a current–voltage characteristic having a negative slope at the operating point of 107 volts and 11 milliamperes. The average dynamic impedance is that of a negative resistance of 80 ohms and an inductance of 18 millihenries. Advantage has been taken of the negative resistance to compensate the unavoidable losses in the other parts of the speech circuit. When quiescent, the tube has a capacitance of 3 picofarads, which makes it possible to keep crosstalk between lines to a sufficiently low level.

2.1.2 Structure of Speech Circuit

The speech-circuit functional diagram is given in Figure 2. It is a one-wire circuit comprising two selection stages. In the first stage the lines are subdivided into 6 groups of 40 lines each. Each group of lines enters a rectangular matrix of $40 \times 10 = 400$ gas tubes, which gives access to 10 outgoing intermediate junctions. There are, therefore, a total of 60 such junctions. Any two of these junctions can be connected in a triangular matrix comprising $(60 \times 59)/2 = 1770$ tubes.

Communication between two subscriber lines can therefore be established by connecting each of them to an intermediate junction of its group and then connecting the two chosen junctions. Therefore the first stage fills the functions of both concentration and expansion of the lines. The second stage mixes the junctions. Each stage includes its own direct-current supply. In the concentration–expansion matrixes, the anodes of the tubes are connected to ground through the wires drawn vertically in Figure 2. The cathodes are connected through the horizontal wires to a supply of -115 volts.

In the mixing matrix, an intermediate junction must be connected to a horizontal and a vertical wire to obtain an intersection between any two junctions. To place the necessary bias on the horizontal wires and the vertical wires, a transformer is used to couple each junction to its two wires in the mixing matrix. In the example of the two junctions represented in Figure 2, this coupling is obtained by transformers T and T', each having two secondary windings.

In the mixing matrix, the cathodes of the tubes are connected to the vertical wires, the anodes to the horizontal wires, and the junctions are numbered in the directions indicated on the figure. The connection between two junctions is made by a tube having its cathode connected to the junction having the larger number. It is necessary to take this into account to mark in the suitable direction.

It can be seen that 30 simultaneous connections can be established. The possible traffic amounts to 9 erlangs with a loss probability of 1 percent.

2.2 CONTROL CIRCUIT

2.2.1 Main Functions

The main functions of the control circuit are:

(A) Scanning the lines to detect any new calls.

(B) Recording the dialed number for each call.

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[7] M. A. Townsend and W. A. Depp, "Cold Cathode Tubes for Transmission of Audio Frequency Signals," *Bell System Technical Journal*, volume 32, pages 1371–1391; November, 1953.

(C) Finding a free path between the calling and called lines.

(D) Establishing the connection by firing the proper three gas tubes.

(E) Supervising and releasing of the connection.

To these main functions must be added auxiliary functions, especially sending at the proper times of various tones: dialing, busy, ringing, ringback.

imperceptible the waiting time for the subscriber initiating a call. It can be assumed that the time necessary for a subscriber to pick up the handset is greater than 500 milliseconds. The period between two scans of a given line has, in fact, been set at 528 milliseconds. The time between two consecutive line scans is therefore 528/240 = 2.2 milliseconds (see Figure 3A). This concerns only the detection of new calls. It should be noted that the situation differs when a calling subscriber starts to dial as the scanning cycle is then modified.

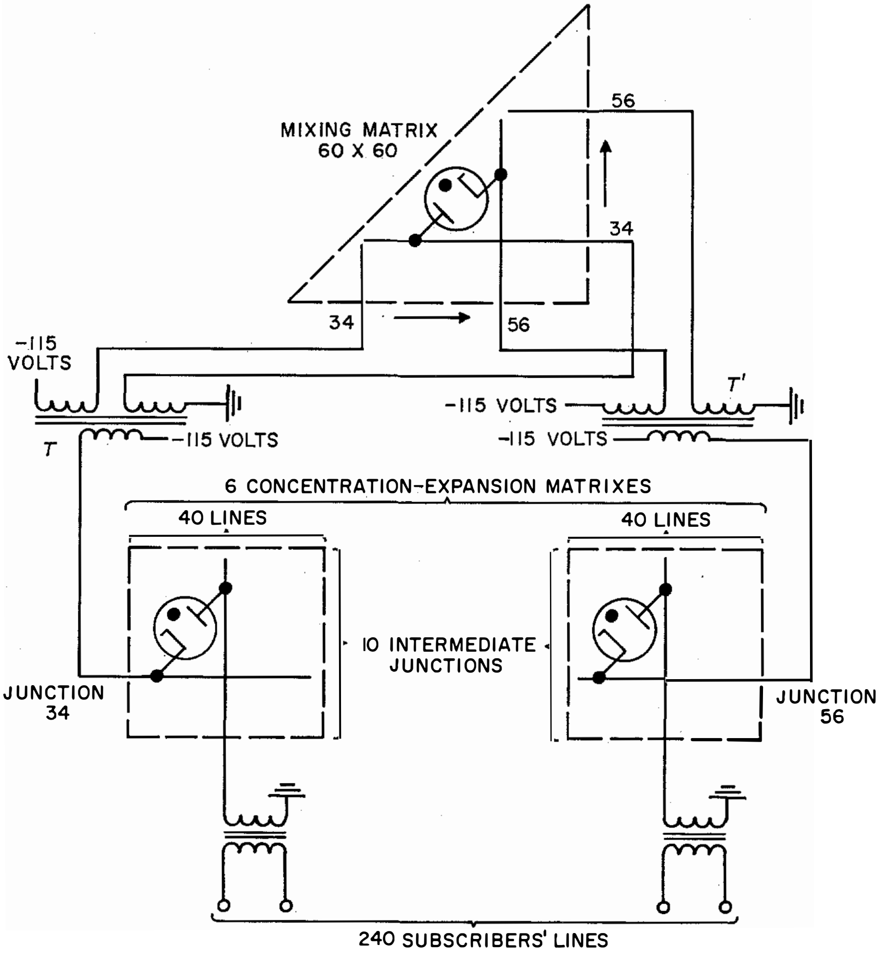

Figure 2—Operational diagram of the speech circuit.

2.2.2 Scanning of Lines and Registers

The principle of time sharing by a single logic circuit requires it to scan the lines continuously to detect new calls with a rapidity that makes

It was considered that, except for certain changes required by their use with electronics, it was not desirable to modify the conventional subscriber's set. We have, therefore, retained the conventional dial-produced current pulses of 33 out of every 100 milliseconds. It is necessary to scan the line at least once every 33 milliseconds during the dialing and to record the result obtained. For this purpose, when a line is identified as calling, it is connected to a register consisting of a row of ferrite cores. This register, being an extremely simple device, is not released as soon as the dialing is finished to use it for other calls. On the contrary, it is advantageous to assign it to a calling line for the whole duration of the conversation, the register gathering all the information concerning the connection. This facilitates supervision and especially the release. For this reason the number of registers equals the number of possible simultaneous conversations; namely 30. The registers are continuously scanned. According to the preceding, less than 33/30 = 1.1 milliseconds should be devoted to each of them. Therefore, during a line-scanning period (=2.2 milliseconds), more than two registers must be scanned. The choice of 3 (Figure 3B) leads to interleaving a line scan and three register scans. The duration of each scan is then 2.2/4 = 0.55 millisecond (Figure 3C). During this time, the logic circuit not only identifies the condition of the scanned element, but also carries out orders to make the system set up or release the connection.

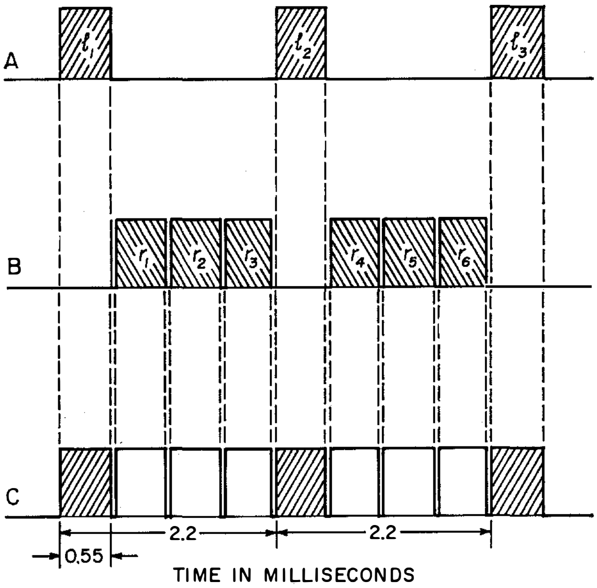

Figure 3—Scanning time relations. A = line scanning, B = register scanning, and C = line and register scanning

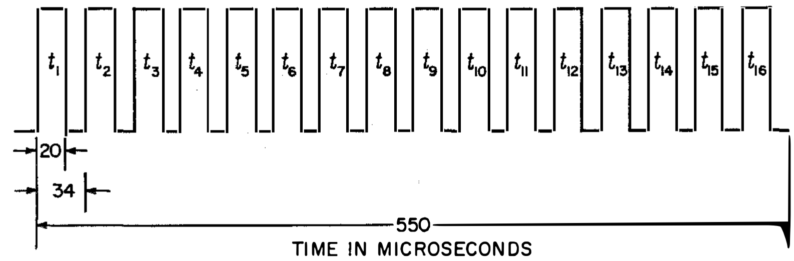

Figure 4—Division of 0.55-millisecond scanning interval into 16 time positions.

Such orders are:

(A) Searching for a free junction.

(B) Testing the called line.

(C) Firing or switching off a gas tube, et cetera.

An order is, in general, a complex operation subdivided into elemental steps. Each scanning interval is subdivided into 16 equal *time positions* of 34 microseconds (Figure 4). Each is devoted to a step initiated by a 20-microsecond *timing pulse* followed by a rest interval of 14 microseconds.

2.2.3 Central Clock and Decoding Matrixes

The operation of the whole control circuit is synchonized by a continuously running *central clock* (Figure 5).

The clock contains a 29-kilocycle-per-second sine-wave oscillator from which the timing pulses are derived. These pulses are recorded in binary code in a set of four flip-flops connected as a counter. This counter connects to two sets of flip-flops also arranged as counters. In the first, the line numbers appear successively according to the scanning pattern indicated in Figure 3. One line number consists of 3 decimal digits: the first indicates the group number (*1* to *6*), the second and third indicate the individual line number within the group (*00* to *39*). Each decimal digit separately appears in binary code. There are, therefore, 3 bits for the group number, 2 bits for the tens number of the line, and 4 bits for the units number of the line, making a total of 9 bits.

In the second counter the register number (*01* to *30*) also appears in accordance with the scanning pattern indicated in Figure 3. Here the number is translated into binary code as a whole; there is needed a capacity of 5 bits.

Each of the three preceding counters is connected to a diode decoding matrix having as many outlets as there are elements to be counted. The line or register to be scanned during a given 0.55-millisecond interval is therefore determined by marking the outlet that bears its number in the corresponding decoding matrix. The timing pulses are treated in a similar way: by means of a decoding matrix, each of them, t_1, t_2, . . . t_{16}, is sent at the proper time on an outgoing wire reserved for it to a number of diode gates in the logic circuit to open them and start an elemental step that depends on an *order* number indicated elsewhere.

2.2.4 Line Scanner

The main function of the line scanner is to determine whether each line is busy or free. It has three parts:

(A) The line-number decoding matrix already mentioned in the preceding paragraph.

(B) The individual testing circuit making it possible to test each line.

(C) A *line condition* flip-flop registering the closed or open condition as each line is scanned.

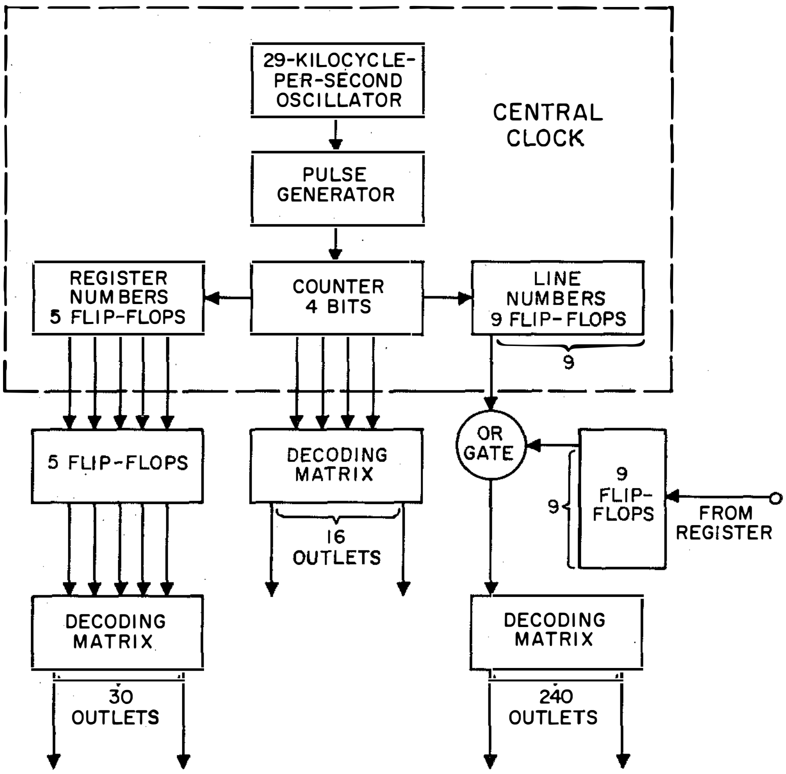

Figure 5—Central clock and its associated matrixes.

Because of the fairly large number of lines, the decoding is done in several stages (Figure 6).

The individual testing circuit associated with a subscriber's line is shown in Figure 7. When the line is closed, a voltage V appears across resistor r. An AND gate receives this information and the marking signal of the line as well as a timing pulse that passes only if the line is marked and closed. This pulse then places the line-condition flip-flop in condition *1*. This flip-flop is common to all lines and is thus driven through a set of OR gates. It is returned to condition *0* by a timing pulse at the beginning of each scan.

2.2.5 Busy-Line Memory and Provisional Store.

It is evident that the circuit described above is not sufficient for the identification of new calls. In fact, to identify a line as calling, it must be recognized not only that it is closed at a scan but also that it was open at the preceding scan. It is therefore necessary to use a *busy-line memory* in which the condition of all lines is recorded. It consists of 240 ferrite cores, one per line, arranged in 16 × 15 rectangular matrix. The address of the core on which either writing or reading must be performed is recorded in a set of 9 flip-flops connected to the line flip-flops of the central clock. For economic reasons, this address is decoded in several stages comprising four diode matrixes followed by two ferrite core submatrixes (Figure 8).

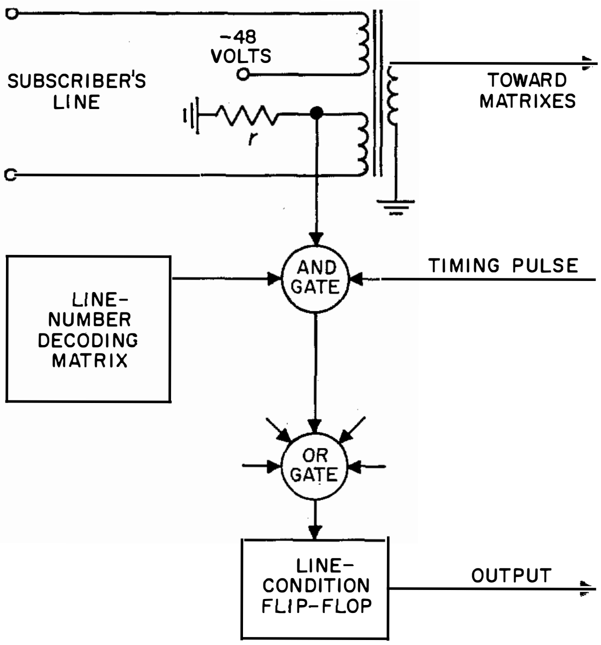

Figure 7—Line circuit of the line scanner.

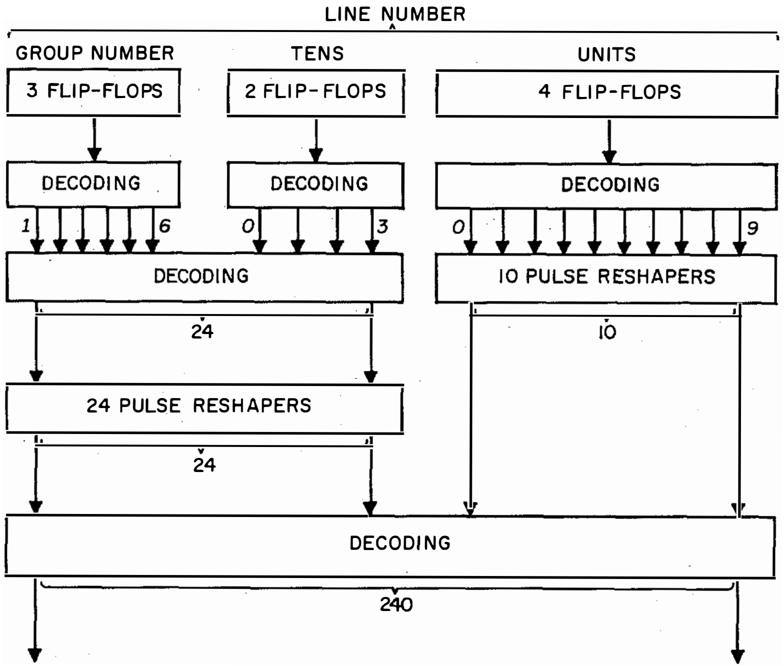

Figure 6—Decoding matrix of the line scanner.

During the reading of a core, its content is transferred to the *result* flip-flop and is directed toward an AND gate that is also connected to the line-condition flip-flop. Only when a *0* (line free at the preceding scan) is in the first flip-flop and a *1* (closed line) is in the second is a timing pulse permitted to pass through the gate and place a third *new-calling-line* flip-flop in position *1.*

When the new-calling-line flip-flop is in condition *1*, a timing pulse transfers the line number inscribed in the input flip-flops to a new set of 9 *provisional store* flip-flops where this number remains until a register scan indicates a free register.

Means are, of course, provided for writing or rewriting after information in the main ferrite core matrix is read out.

2.2.6 *Registers and Call-Status Memory*

When a calling line is identified, the first operation is to assign a *register* to it. A register is a row of ferrite cores that records all information for the establishment, supervision, and release of a call.

It contains:

The calling line number	9 bits
The called line number	9 bits
The units digit of the junction connected to the calling subscriber[8]	4 bits
The units digit of the junction connected to the called subscriber	4 bits
The code number of the order that must be carried out by the logic circuit (there are a total of 38 orders)	6 bits
The position of a duration counter for time notation and time measurement	3 bits
The condition of the calling or called subscriber's line at the last scan	1 bit
The indication that one dialing train was in course at the last scan	1 bit
Total	37 bits

To permit possible improvements after further experience, there is provided a capacity of 40 bits. The 30 registers are therefore a rectangular matrix of 30 × 40 elements having the usual means of writing and reading. This assembly, named *call-status* memory, is diagramed in Figure 9. A horizontal wire passes through the 40 cores of a register. The wire is one of the 30 outlets of the decoding matrix in the register scanner of Figure 5. A timing pulse sent on this wire at the beginning of each scan starts the reading that transfers the matrix information

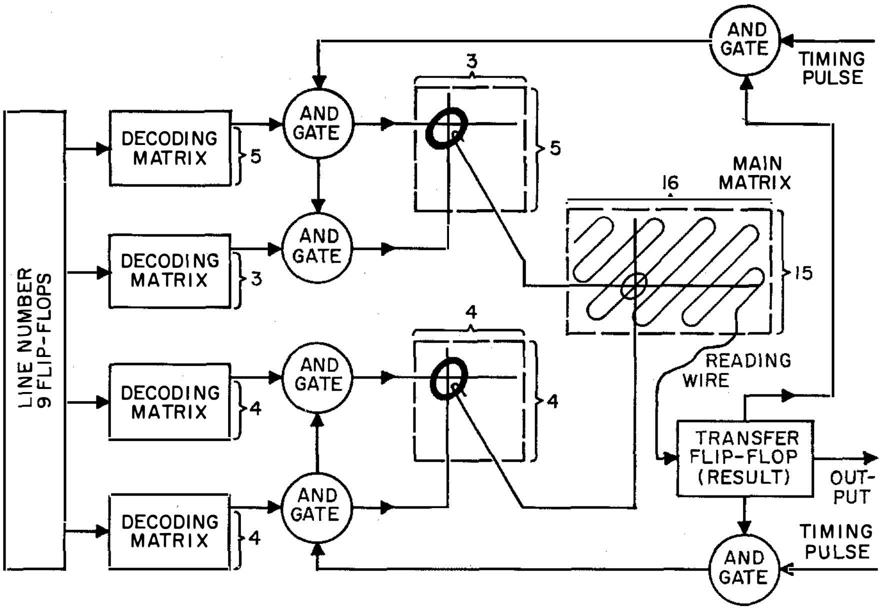

Figure 8—Busy-line memory.

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[8] The tens digit is not needed; each group possessing 10 junctions, the tens number is identical with the group number of the calling line.

to a set of 40 flip-flops called the *transfer memory.* The operations to be carried out depend essentially on the code number of the order; therefore the 6 flip-flops registering the order are connected to a 37-outlet decoding matrix (one outlet per order). There are 38 orders, but the first, order *0*, is the order to search for new calls and is executed at the start of each line scan without intervention of a register.

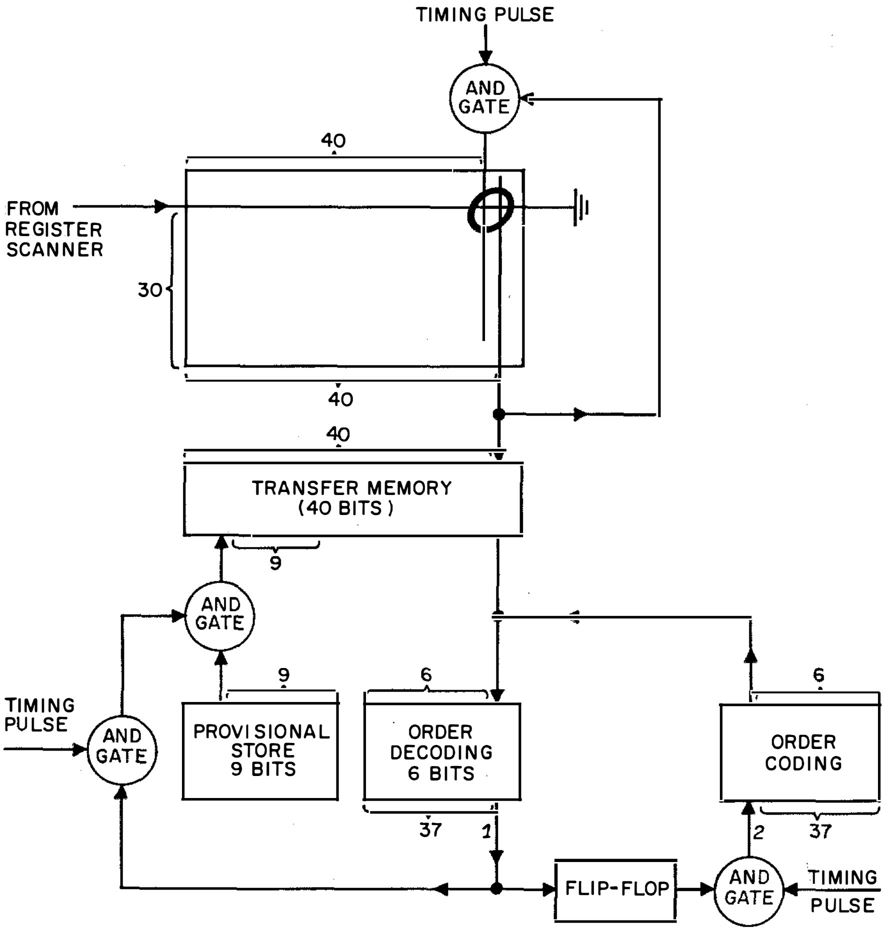

Figure 9—The call-status memory.

A free register is characterized by the presence of order *1*, "seize register." The marking voltage that then appears on the corresponding order wire causes a timing pulse to open gates connecting the provisional store, where a new-calling-line number is kept, to the 9 first flip-flops of the transfer memory. The calling line number is then recorded in this memory.

It is then necessary to replace order *1* by order *2* in the transfer memory. First, a timing pulse wipes out the inscribed order and then a coding matrix (having 37 inlets and 6 outlets connected to the order flip-flops) intervenes. Outlet *1* of the decoding matrix is connected to inlet *2* of the coding matrix through a flip-flop and an AND gate. A timing pulse passes through this gate when order wire *1* is marked and it inscribes order *2*. Similar arrangements are used for all sequences of orders irrespective of whether or not their numbers are consecutive.

The next step is to mark the horizontal wire in the reverse direction and to open, by a timing pulse, the input gates of the matrix to copy the contents of the transfer memory in the register, which, then containing order *2* and the calling line number, is reserved from that time on to the call on this line.

At each scan of the register, the calling line number is reproduced in a set of 9 flip-flops in the line scanner. These, which are different from the line flip-flops of the central clock, are at the right-hand side of Figure 5. They assure that the line is tested at each scan of the register, every 2.2 milliseconds.

2.2.7 Busy-Junction Memory and Priority Distributor

The next order (*2*) is the search for a free junction in the group of the calling subscriber. It is performed by a third ferrite-core memory, the *busy-junction memory*, a matrix of 6 × 10 cores, a row of 10 cores corresponding to each group of 10 junctions. It has means of writing and reading similar to those of the preceding memories. In the block diagram, Figure 10, there are:

(A) 3 flip-flops in which order *2* registers the group to be searched.

(B) A decoding matrix marking the corresponding row of cores.

(C) A transfer memory of 10 flip-flops.

A timing pulse initiates reading of the row marked by the decoding matrix at the beginning of the scan. The content of this row then passes to the transfer memory. It is then necessary to choose from among the free junctions and to avoid a consistent preference that would use some gas tubes more often than others.

This choice is performed by the priority distributor represented in the lower part of Figure 10. It is a 4-bit counter that steps by one unit at the beginning of each scan (every 550 microseconds) between *0* and *9*, thus designating a preferred junction. This number is detected by a 10-outlet matrix connected to 10 AND gates. These gates are also connected to the 10 outlets of the transfer memory. If a junction is both preferred and free, the corresponding gate passes a timing pulse to inscribe its number in the register. If the preferred junction is not free, a coupling device between the flip-flops inscribes the number of the next junction; and so on, until a preferred free junction is found. The junction chosen is recorded as busy in the transfer memory, then this information is copied in the busy-junction memory, the flip-flops of the transfer memory are brought back to *0*, and, finally, order *3* is inscribed in the register.

2.2.8 First Marker

The register assigned to the conversation now contains all information necessary for connecting the calling line to a junction by firing the gas tube located at the correct intersection in the concentration–expansion matrix. This is the role of the first marker when it carries out order *3*. The line and junction flip-flops of the call-status memory are represented in Figure 11. The numbers written there are first copied in the marker's flip-flops. Because the duration of the

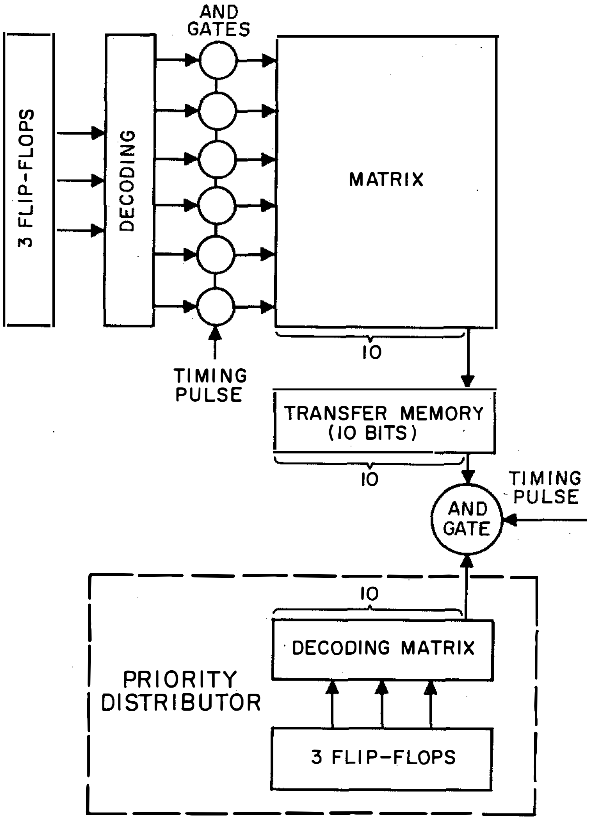

Figure 10—Busy-junction memory and priority distributor.

marking is normally 2 milliseconds, the input flip-flops of the marker are protected by AND gates under control of the register-busy flip-flop, which allows the signals to pass only when the marker is free. Then an order flip-flop intervenes, causing the decoding of the two numbers and therefore the marking of the line and junction to fire the suitable matrix tube. Certain precautions described in the appendix have been taken in the marking process.

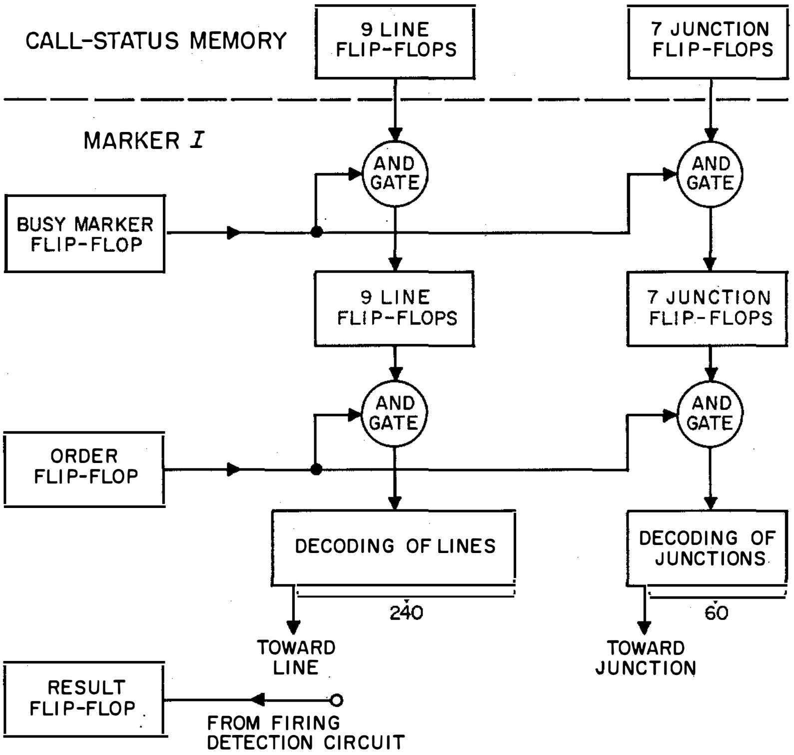

Figure 11—Block diagram of first marker.

The result of the marking operation is verified, according to order *4*, by a firing-detection device, which sends an end-of-marking order, bringing back to *0* all the flip-flops of the marker. If this signal has not appeared within 20 milliseconds, a delay device places the result flip-flop in position *0*, which means that the marking has failed. In this case, a search for a new free junction is started to mark another tube. This operation is repeated until a satisfactory result is obtained.

2.2.9 Second Marker and Tone Generators

The first marker having carried out its work, the calling subscriber is connected to a junction and the order counter is placed in condition *5*. A new (second) marker receives the order to connect the junction to the dial-tone generator. The 4 tone generators are connected to the 60 intermediate junctions through an auxiliary matrix of 60 × 4 = 240 gas tubes. In this matrix, the 60 vertical wires are those of the mixing matrix and the 4 horizontal wires are connected to the tone generators. To provide for the possible firing of several tubes in the same row, each tube has a series resistor to limit its current.

The second marker is of a construction and has a type of operation similar to the first marker. A firing verification is performed on order *6*. This verification completed, the order counter is placed in position *7*.

2.2.10 *Third Marker*

When the calling subscriber interrupts his line current as he begins dialing, order *7* operates the third marker, similar to the preceding ones. It switches off the tube by temporarily decreasing the applied voltage to 90 volts.

2.2.11 *Reception of Dialing*

The reception of dialing is based on detection of the current interruptions in a line. At each register scanning, it is necessary to compare the line-condition flip-flop with the transfer flip-flop associated with the core where the line condition was registered at the time of the previous scan. The current pulses are recorded in the called-subscriber flip-flops reserved for that purpose.

Order numbers *8*, *9*, and *10* correspond, respectively, to the recording of the dialed hundreds, tens, and units. A duration counter verifies the length of the pulses in each train as well as the time interval between two different trains. Counter release is thus obtained in case of incompleted dialing.

2.2.12 *Test of Called Subscriber*

For order *11*, the number of the called line is transferred into the input flip-flops of the busy-line memory to determine the free or busy condition of the line. If it is found to be free, the logic circuit marks it as busy from then on and places the order counter in position *14*. If it is busy, the logic circuit places the order counter in position *12* and wipes the called line number out of the register to prevent cutting off, at the time of release of the calling subscriber, the conversation in which the called party is engaged.

2.2.13 *Additional Orders*

The first orders were described in detail because they have provided a means of introducing the various parts of the exchange. There are also the following orders:

Order 12—Call of second marker to connect the calling junction J to the busy-tone generator.

Order 13—Verification of order *12*.

Order 14—Search for a free junction J' within the group of the called line L'.

Order 15—Call of first markers for connecting J' to L'.

Order 16—Verification of order *15*.

Order 17—Call of second marker to send ringing tone on J'.

Order 18—Verification of order *17*.

Order 19—Call of second marker to send ringback tone on J.

Order 20—Verification of order *19*.

Order 21—Determination of the moment that the called subscriber lifts the handset.

Order 22—Call of third marker for releasing the connection J'—ringing tone.

Order 23—Call of third marker for releasing the connection J—ringback tone.

Order 24—Call of second marker for connecting J and J'. (The second marker controls the firing of the tubes in the mixing matrix by marking a vertical and a horizontal wire. In this operation it is necessary to mark positively the junction having the smaller number. A comparison between the numbers of the two junctions must therefore be made. This function is fulfilled by the *ordinator*, which is a set of 7 decoding matrixes associated with diode gates. It makes the comparison bit-by-bit beginning with that of the highest rank.)

Order 25—Verification of order *24*.

Order 26—Surveillance of the conversation. (As soon as the called subscriber answers, the logic circuit starts alternate surveillance of the two lines, devoting to each of them one register scan out of two. This allows release by either of the two parties.)

Orders 27–30—Release by third marker.

Orders 31 and 32—Connection to the public network.

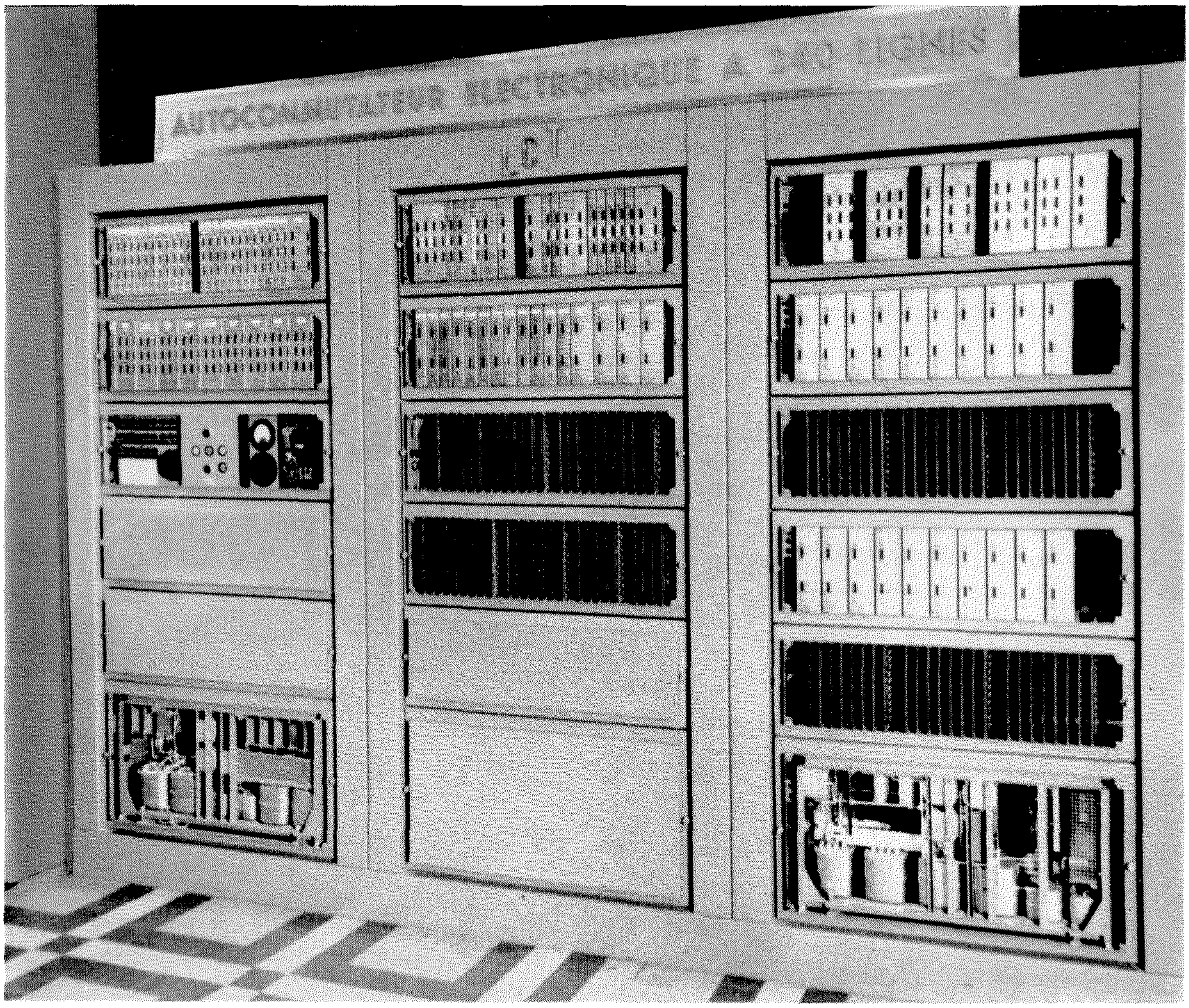

Figure 12—Over-all view of electronic exchange.

Orders 33 to 36—Repeated marking in case of failure of one tube.

Order 37—Sending ringback tone to a subscriber calling the operator.

Establishment of a connection requires 25 orders lasting 22 × 25 = 550 milliseconds. Release is done in 4 orders of a total duration of 22 × 4 = 88 milliseconds.

In the foregoing it will be noticed that the marking of the gas tubes has been performed stage-by-stage, whereas an end marking could have been obtained through simultaneous marking of three separate stages. The solution chosen was the only one providing sufficient operating reliability, taking into account the nonuniformity of the gas-tube characteristics and their ageing.

2.3 SUBSCRIBER'S SET

The subscriber's set used[9] has a novel ringing device. The sound signals are produced by an ordinary telephone receiver driven by a single-transistor amplifier. They are 0.5-second trains of two musical notes alternating 20 times per second. The frequencies are 1000 and 1600 cycles per second. A single-transistor integrating circuit provides protection against line noise. The ringing power is only 1 milliwatt.

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[9] Developed in cooperation with Standard Elektrik Lorenz; Stuttgart, Germany.

2.4 Connection to Public Network

Two orders are devoted to the connection of subscribers to the public telephone network. A subscriber who wants to be connected to the public network signals the operator by dialing *0*. The control circuit operates in the same manner as in the case of an internal call.

Calls from the public network are handled by the operator, who disconnects the called subscriber from the branch exchange when she plugs in and at the same time identifies him as busy. Operator intervention has been adopted mainly on account of the experimental character of the equipment.

2.5 Construction

The whole exchange is in three adjoining bays, shown in the frontispiece of this issue and in Figure 12. The over-all dimensions of the exchange are: 6.5-feet (2-meters) high, 11.1-feet (3.4-meters) wide, and 1.3-feet (0.4-meter) deep. Each bay contains 6 cases and each case contains circuit cards of approximately 7.9-by-11.8-inch (20-by-30-centimeter) dimensions placed vertically and bearing the basic circuits (Figure 13). On these cards, the wiring is of the conventional type except on those mounting the gas tubes where the connections are printed circuits on both sides (Figure 14). The cards are connected by cabling fixed on the bays, the connection between the cards and this cabling being by plug-in connectors. Printed wiring technique has been used for all basic circuits required a large number of times; that is, several tens.

The circuits are distributed among the bays and cases as follows:

(A) One bay contains the circuits grouping the subscribers' lines: the line circuits, the gas tubes

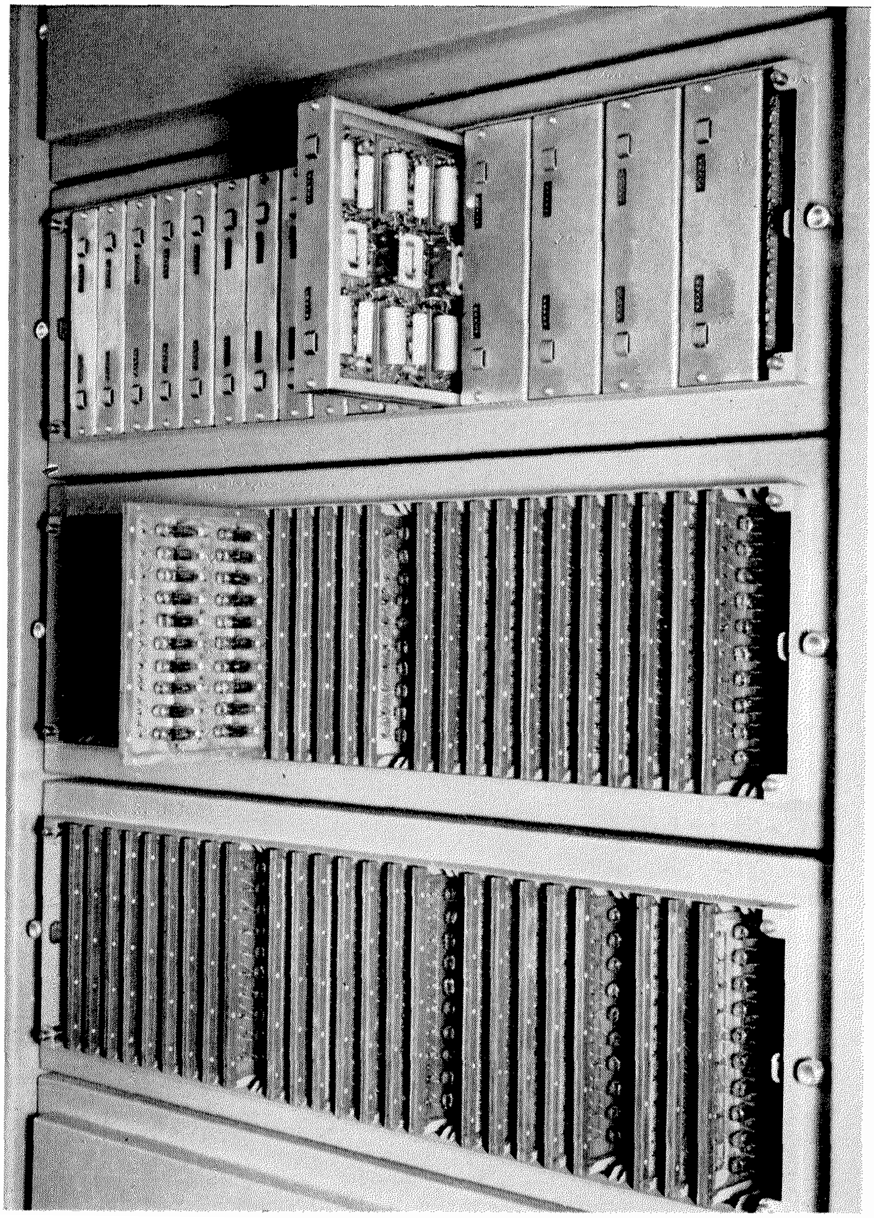

Figure 13—Circuit cards and method of mounting them in the cases.

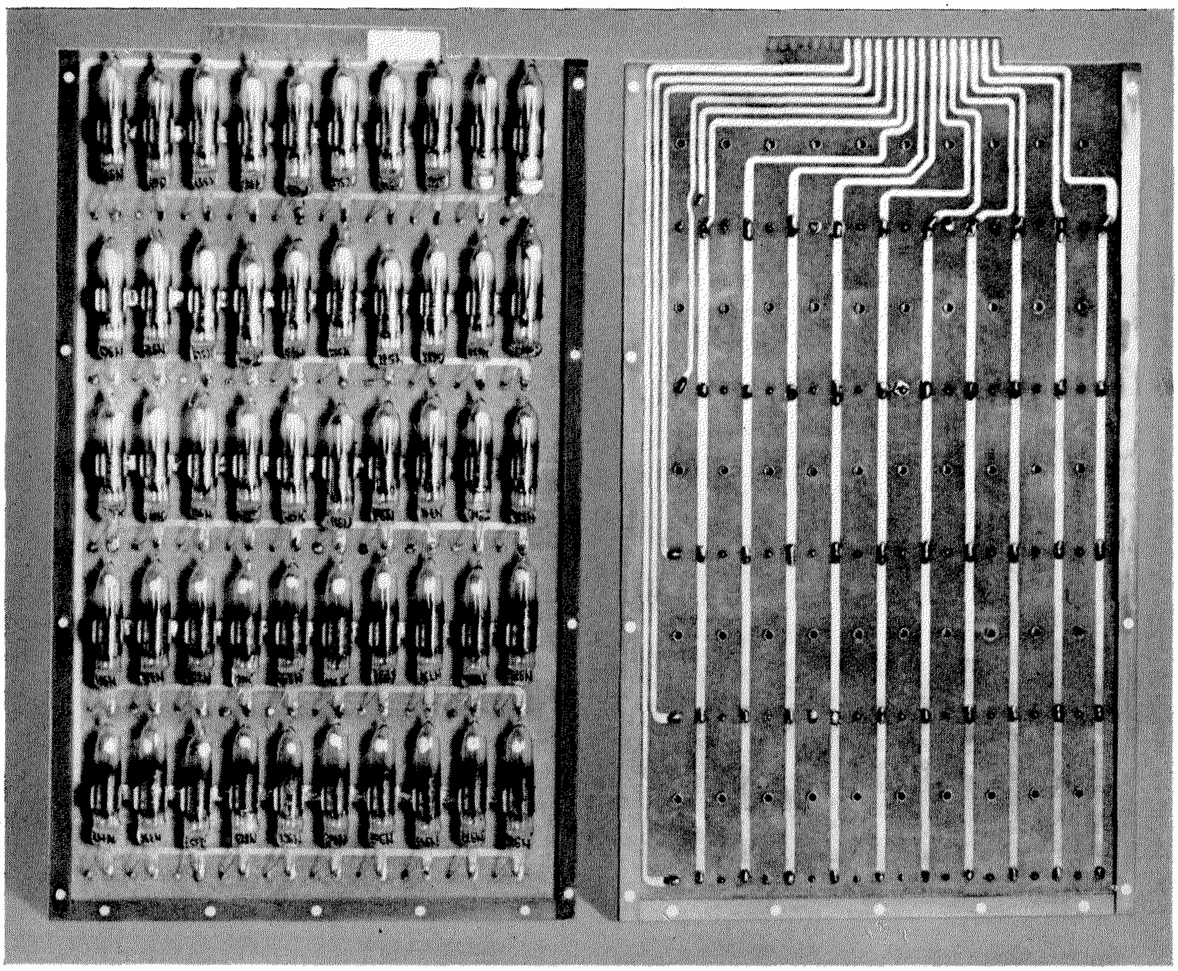

Figure 14—Gas-tube matrix on printed circuit cards.

of the concentration–expansion matrixes as well as the first marker, the busy-line memory, and the line scanner.

(B) The second bay includes all the junction circuits with their mixing-matrix gas tubes, second and third markers, and tone generators.

(C) In the third bay are the main elements of the control circuit: the logic circuit (which occupies a whole case), the call-status memory, the busy-junction memory, and the clock. Two cases in this bay contain the circuits required for connection to the public network.

The supplies draw their energy from a 50-cycle, 3-phase power network; they occupy two cases in the first and third bays.

2.6 OTHER DATA

Some numerical data are:

Over-all loss from subset to subset	
at 1000 cycles per second	<0.5 decibel
between 300 and 3000 cycles per second	<2 decibels
Crosstalk level	< −70 decibels
Power consumption	1 kilovolt-ampere
Traffic with loss probability of 1 percent	9 erlangs
Number of diodes[10]	7000
Number of transistors[10]	1500
Number of ferrite cores[10]	1300

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[10] Not including the circuits for connection to the public network.

2.7 EXPERIMENTATION

The private automatic branch exchange described has recently been put into operation at the Laboratoire Central de Télécommunications. Its capacity was chosen to correspond to the present needs of that organization. It is sufficiently large to permit the collection of useful statistical data during operation. One of the groups of lines will not be connected to subscribers but will be devoted to experimentation on new speech crosspoints presently under development.

3. *Conclusion*

The work already done at the Laboratoire Central de Télécommunications demonstrates that it is now technically possible to realize small all-electronic branch exchanges and even large offices. It is now known that the reliability of the former surpasses that of electromechanical devices, in particular when severe climatic or mechanical conditions must be met. They are especially promising in military applications.

Where large electronic offices are concerned, mainly in civil applications, they must successfully compete with the electromechanical exchanges that have evolved over many years and have reached a very-high level of quality.

Comparison between electronic and electromechanical solutions must be made from various aspects such as: first cost, maintenance cost, reliability, flexibility, and bulk and weight of equipment. Their respective capability of offering additional subscriber services should also be considered.

Another important point concerns transmission-path noise, in particular in relation to the problem of data transmission. In that connection, there must also be considered what methods of switching are best adapted to modern transmission techniques such as pulse-code modulation.

There is not a single approach to electronic switching, but a variety of approaches, including semielectronic ones, that must be compared. This increases tremendously the complexity of the problem of large electronic exchanges, which will not be solved without much exploratory work, theoretical as well as experimental. It is hoped that the experience gained in designing and operating this 240-line fully electronic private automatic branch exchange will be a valuable contribution to the solution of this problem.

3. *Appendix—Marking Process*

To understand certain precautions taken in the marking process, it may be helpful to give the major characteristics of the gas diode used.

Firing voltage	160 to 175 volts
Voltage applied for firing	188 volts
Corresponding firing time	10 milliseconds
Sustaining voltage	105 to 109 volts
Voltage for extinction	90 volts
Corresponding extinction time	200 microseconds

The direct-current supply of the tube is described by Figure 15 where it may be seen that the anode *A* is connected to ground through the line transformer and the cathode *C* is connected indirectly to two sources furnishing −113 and −140 volts, respectively.

To understand the roles of these two sources and those of resistors *r* and *R*, and of diode D_1, in Figure 16 is plotted the curve of potential $-V$ at point *B* against current *I* arriving at this point. With the numerical data shown, this curve has two linear segments *MP* and *PQ*. For currents

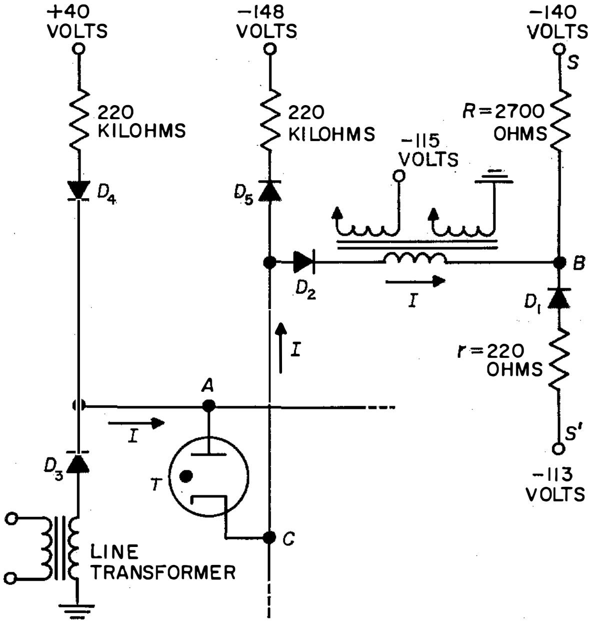

Figure 15—Supply and marking of a tube.

I larger than 10 milliamperes, the voltage at B is more positive than -113 volts and diode D_1 is blocked. Therefore, segment PQ is located on the load line of the -140-volt source in series with resistor R alone. For currents below 10 milliamperes, the voltage at B is more negative than -113 volts and both sources supply current. Segment MP has a much-smaller slope than PQ; it is approximately located on the load line of the -113-volt source in series with resistor r alone

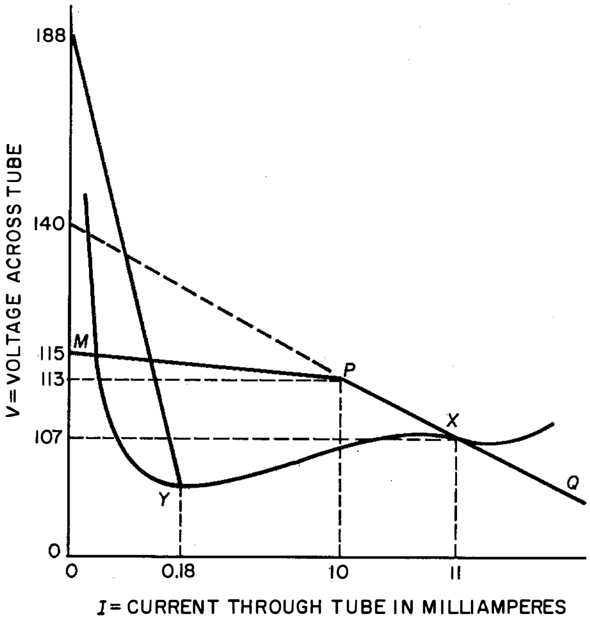

Figure 16—Voltage–current characteristic of a gas diode. For clarity, the scales are not drawn to linear proportions.

For $I = 0$, there remains a supply current circulating through the $S'BS$ loop and the voltage at B is -115 volts. Therefore, the quiescent tube is submitted to a voltage $V = 115$ volts.

If the tube is fired by a temporary voltage larger than the firing voltage, the operating point X is located at the intersection of V–I characteristic of the tube and the MPQ curve, at $V = 107$ volts and $I = 11$ milliamperes. It should be noted in particular that when the tube is operating, diode D_1 is blocked and the only supply is provided by the S source of -140 volts.

Complicating the circuit by the introduction of source S' gives an advantage in that after extinction the voltage does not go more negative than -115 volts. There is thus a larger safety margin against spontaneous firing of tubes whose firing voltage might be abnormally low.

For firing, marking is introduced in parallel with the main supplies, care being taken to provide decoupling by diodes D_2, D_3, D_4, and D_5. The line wire of the marker introduces $+40$ volts and the junction wire of the marker drops to -148 volts. Therefore the marking temporarily places 188 volts across the tube to prime the firing through a high resistance (440 kilohms) limiting the supplied current. At the beginning of the marking, the operating point of the tube is at Y (Figure 16), the current supplied being only 180 microamperes. In the course of the pulse, it moves toward the final point X.

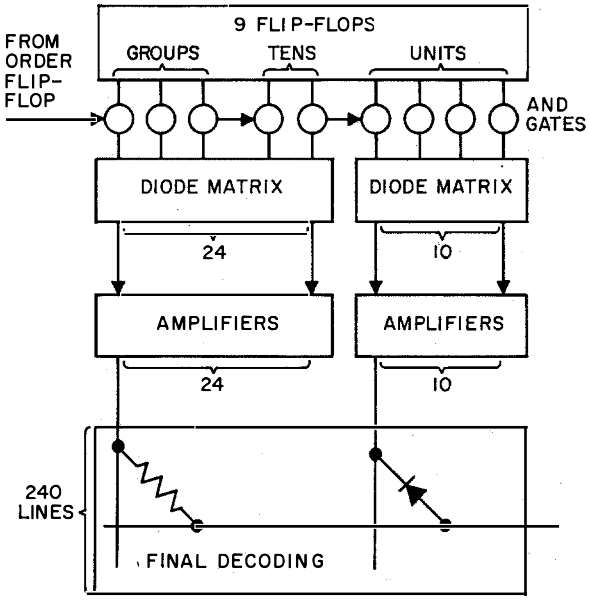

Figure 17—Block diagram of line decoding matrix of first marker.

Lastly, to complete the description of the first marker, it should be noted that the decoding of the line numbers is performed in several stages, according to Figure 17. The final stage, which has 240 outlets, is a matrix comprizing diodes with series resistors to reduce the current consumption. It can be demonstrated that an AND gate of two diodes draws a low current only when it performs the logical operation $1 \times 1 = 1$.

But an AND gate consisting of a diode and a resistor can be arranged to draw low current in all 3 other cases of logic multiplication. In a decoding matrix, only one outlet is marked at a time. If the first type of AND gate is used, this outlet is the only one drawing low current, whereas it is the only one drawing high current if the second type is used. With respect to current consumption, this second type is therefore much-more advantageous.

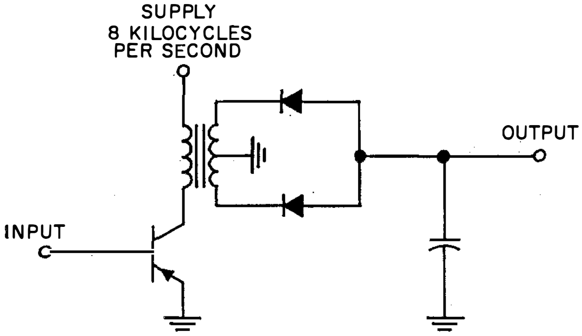

Figure 18—Amplifier used in decoding matrixes.

The circuit of Figure 17 includes amplifiers constructed according to Figure 18. An 8-kilocycle-per-second power supply is used and a coupling transformer is placed between the transistor and the output. This has the advantage of providing direct-current isolation and enables fairly high output voltages to be obtained with standard transistors.

Radio Communication Using Earth-Satellite Repeaters

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INTENSIVE interest in man-made earth satellites and their application to long-distance and even world-wide radio communication should not be surprising. Such satellites provide a means whereby still-available frequencies can be used for important services for which they would not otherwise be suited.

The need and feasibility of communication systems employing man-made earth satellites are considered first. The radio parameters of operating frequency, modulation, and type of response from the satellite are analyzed. It is concluded that a satellite in a 24-hour circular orbit carrying a transponder of 2 watts can relay 96 voice channels using pulse-code modulation of a 2000-megacycle-per-second carrier. On earth, 1-kilowatt transmitters and receivers having 1-decibel noise figures would be used with 60-foot (18-meter) paraboloidal antennas.

1. *Why Satellites?*

Skeptics may question the feasibility and even the need for radio repeaters utilizing earth satellites. Let the question of need be examined first.

Within the continental United States of America, parts of Canada, and in western Europe, a complex network of land lines and microwave links has been established.

According to figures released by the United States Department of Commerce, at the end of 1959 some 70 million telephones were interconnected in the United States. Any one of these phones can be connected to more than 65 million telephones distributed throughout the remainder of the world. However, the overseas trunk lines to interconnect this large number of subscribers is limited to approximately 200 channels.

In the decade or two prior to 1956, transoceanic voice communication was carried predominantly by high-frequency radio circuits. Growth in the number of circuits and traffic during the years 1945 to 1956 averaged about 8 percent per year. Experience with cable systems offering higher quality and greater reliability substantiated the expectation that transoceanic traffic would increase at least 10 percent per year if improved service was available. A report[1] of the hearings of the Congressional Committee on Science and Astronautics stated that present transatlantic cable capacity will be exceeded by demands for service in 1962 and by 1965 planned cable capacity will be inadequate.

Certainly then, any new system that allows rapid expansion of toll-quality intercontinental communication deserves careful consideration. A radio relay system using man-made earth satellites offers such possibilities.

2. *Communication Problems*

What are the communication problems in establishing a useful repeater on a man-made earth satellite.

2.1 OPERATING FREQUENCY

The selection of an optimum transmission frequency for the satellite system, whether passive or active, is limited to the propagation "window" between 100 megacycles per second and 10 gigacycles per second.[2]

Atmospheric and man-made noise decreases with increasing frequency becoming negligible above 100 megacycles per second. Cosmic noise decreases from a level of -160 dbw/kc (decibels referred to 1 watt per kilocycle-per-second bandwidth) at 100 megacycles per second to less than -180 dbw/kc at 1000 megacycles per second. Other effects, such as Faraday rotation of the plane of polarization and effects of nuclear explosions, become progressively less as frequency increases becoming negligible above 1 to 2 gigacycles per second.

At the upper bound, oxygen and water-vapor absorption increases with frequency from 0.01

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[1] Hearing Before the Committee on Science and Astronautics, House of Representatives, Report *9*; pages 98 and 99.

[2] Gigacycle = kilomegacycle = 10^9 cycles (per second).

decibel per kilometer at 10 gigacycles per second to greater than 0.1 decibel per kilometer at 20 gigacycles per second.

In the passive case, the path loss is given by

$$L = \frac{P_t}{P_r} = 16\frac{\lambda^2 d_1^4}{A^2\eta^2 D^2}$$

where

A = antenna area
D = satellite diameter
d_1 = geometric mean of distance between satellite and terminal
L = path loss
P_r = received power
P_t = transmitted power
λ = wavelength
η = antenna efficiency.

Note that the transmitted power is a function of the fourth power of distance and that the path loss decreases with increasing frequency for fixed ground antenna and satellite size.

In the active case, the satellite-antenna gain will be limited by the area of the earth to be covered and the error tolerance of the attitude-stabilization system. The beamwidth of the satellite antenna will be fixed for a given orbit. For this case of constant beamwidth at the satellite and fixed antenna size on the earth, the path loss is independent of frequency and is given by

$$L = \frac{P_t}{P_r} = K\frac{\theta d_2^2}{\eta A}$$

where

A = area of earth antenna
d_2 = distance from earth to satellite
K = constant
θ = beamwidth of satellite antenna

The quantity of information that can be transmitted over a communication system is proportional to bandwidth. Equipment-design considerations dictate bandwidths in the range of 0.5 to 2 percent of carrier frequency. For communication systems that use a modulation scheme yielding a large improvement factor, bandwidths will range from 10 to 40 megacycles per second. The equipment-design constraint is satisfied at 2 to 4 gigacycles per second. A further factor to be considered is that the size and weight of components, particularly radio-frequency amplifiers and the antenna, decrease with increasing frequency.

The selection of an operating frequency then becomes a matter of determining the highest useful frequency between 1 and 10 gigacycles per second based on equipment availability.

2.2 MODULATION SYSTEM

The optimum type of modulation is defined as that yielding the greatest power efficiency for a given signal-to-noise ratio. Since the satellite power is limited, the modulation scheme that will yield the desired channel signal-to-noise ratio, say 40 decibels, with the least transmitted power is the preferred method. Therefore, a type of modulation is desirable that allows substantial improvement of the channel signal-to-noise ratio over the carrier-to-noise ratio at the expense of bandwidth.

Since demodulation need not occur in the satellite, the type of modulation can be changed at will at the earth station if the translator or reflector is sufficiently broadband. Three principle types of modulation have been considered.

(A) Frequency-division multiplex with amplitude-modulated subcarriers that apply single-sideband modulation to the radio-frequency carrier (FDM-SSB).

(B) Frequency-division multiplex with amplitude-modulated subcarriers that frequency modulated the radio-frequency carrier (FDM-FM).

(C) Pulse-code modulation (time-division multiplex) with the pulses frequency modulating the carrier. Several carriers can be frequency multiplexed to obtain a larger number of channels (PCM-FM-FDM).

The signal-to-noise ratio for each system is given by the following equations.

(A) *Frequency division, single sideband:*

$$\frac{S}{N} = \frac{C}{N} = 10\log\frac{1}{KT} - 10\log b - L + 10\log P_t$$

where

b = signal bandwidth
C/N = carrier-to-noise ratio
K = Boltzman's constant = 1.38×10^{-23}
T = effective temperature of the receiver.

(B) *Frequency division, frequency modulation:*

$$\frac{S}{N} = \frac{C}{N} + 20 \log \frac{\Delta f}{f} + 10 \log \frac{B}{2b}$$

when C/N is 12 decibels or greater, and

$$\frac{C}{N} = 10 \log \frac{1}{KT} - 10 \log B - L + 10 \log P_t$$

where

B = intermediate-frequency bandwidth
f = highest modulating frequency
Δf = peak deviation.

The root-mean-square carrier to root-mean-square noise ratio of 12 decibels is the accepted threshold of a frequency-modulation system. Below this value, the noise improvement is not realized.

(C) *Pulse-code and frequency modulations:*

For this pulse-code method, the bandwidth of the system must first be determined.

By using a 6-bit code and sampling at twice the highest audio frequency, the bit rate for each voice channel will be 6 × 8000 = 48 000 bits per second and the video frequency will be 48 000/2 = 24 000 cycles per second.

To transmit the video information of a multichannel system with the least power, a gaussian shaped response is used. It can be shown that

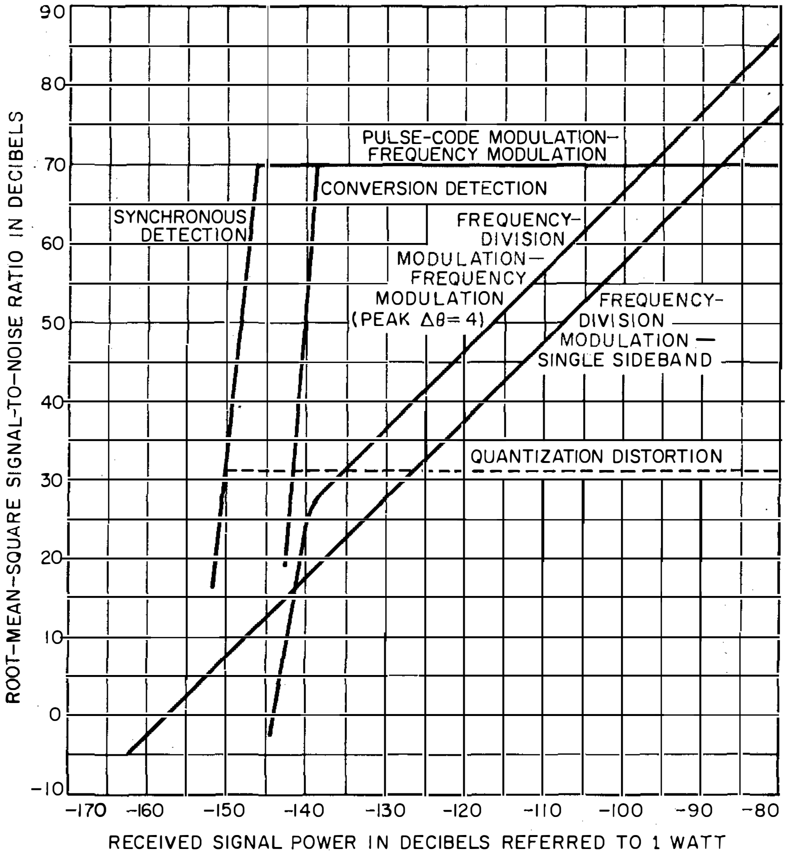

Figure 1—Required receiver power input levels for a system providing 12 voice channels (each of 3-kilocycle-per-second bandwidth) assuming a receiver noise figure of 1 decibel and an antenna temperature of 40 degrees Kelvin.

the 3-decibel bandwidth of the over-all system need equal only 2 times the video rate to obtain an acceptable interchannel crosstalk ratio. Therefore, a radio-frequency bandwidth equal to twice the pulse rate will be used.

Since the pulse information frequency modulates the radio-frequency carrier, the frequency-modulation threshold noted above must be exceeded. In addition, there is a pulse-code-modulation threshold below which the noise improvement fails. This point is reached when the pulse signal voltage cannot be separated from noise with great certainty.

A root-mean-square video signal to root-mean-square noise of 9 decibels is an acceptable threshold value. It should be noted that the pulse-code-modulation threshold is lower than the frequency-modulation threshold.

When the pulse-code-modulation threshold of 9 decibels is exceeded, the channel signal-to-noise is much greater than 40 decibels.

The carrier power then required for the pulse-code—frequency-modulation case, neglecting for the moment the frequency-modulation threshold, is

$$P_{th} = -10 \log \frac{1}{KT} + 10 \log B - 20 \log \frac{3^{1/2} \Delta f}{f} + 9 + L.$$

A class of demodulation referred to as synchronous or phase-locked demodulation will lower the threshold by from 3 to 6 decibels.

An analysis has been made on the basis of 12 voice channels. The satellite receiver and transmitter must, however, be capable of handling the total number of channels.

Figure 1 plots the received carrier power versus the channel signal-to-noise ratio for the three systems. It shows graphically the advantage of the system of pulse-code and frequency modulations with frequency-division multiplexing (PCM-FM-FDM). In the case of single-sideband frequency-division multiplexing, 40 decibels of signal-to-noise ratio is obtained with a carrier power of about -118 decibels referred to 1 watt. The frequency-division—frequency-modulation system with a peak modulation index $\Delta\theta$ of 4 requires 9 decibels less power.

Note the introduction of a threshold level below which the signal-to-noise ratio deteriorates rapidly. The pulse-code system offers considerable power reduction. The input level required here is -148 decibels referred to 1 watt or a 30-decibel improvement over the single-sideband system.

By using phase-locked detection, the frequency-modulation threshold carrier level is actually lower than the single-sideband carrier level required for the 40-decibel signal-to-noise ratio.

3. Satellite Classifications

Orbital radio relays can be classified into two broad groups depending on whether they are passive or active repeaters. These can be further categorized as near-orbit and 24-hour-orbit satellites.

The latter vehicle rotates in synchronism with the rotation of the earth when it is placed in an equatorial plane at an altitude of 22 300 miles (35 880 kilometers).

Near orbits are considered those with a period of 1 to 3 hours or at an altitude of 500 to 3000 miles (800 to 4800 kilometers).

3.1 PASSIVE SATELLITES

In the classical paper by Pierce and Kompfner,[3] the parameters of a passive satellite system have been thoroughly analyzed. They have shown that transatlantic communication could be established most efficiently by a number of satellites in a polar orbit at an altitude of 3000 miles (4800 kilometers).

The satellites, aluminized plastic spherical balloons, would assume random positions in their orbits. As the altitude of an orbit increases, the number of satellites needed to maintain a specified continuity of service decreases. The transmitter power required increases with orbit altitude.

For the 3000-mile (4800-kilometer) altitude and less than 0.1-percent service interruption, 30 satellites will be required.

Figure 2 illustrated the power required with a passive reflector. The curves are based on a

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[3] J. R. Pierce and R. Kompfner, "Transoceanic Communication by Means of Satellites," *Proceedings of the IRE*, volume 47, pages 372–380; March, 1959.

receiver noise temperature of 75 degrees Kelvin and an antenna temperature of 20 degrees Kelvin, which can be realized in the 1-to-10-gigacycle-per-second frequency range. The receiver noise figure is somewhat more pessimistic than that assumed by Pierce and is realizable at the present state of the art.

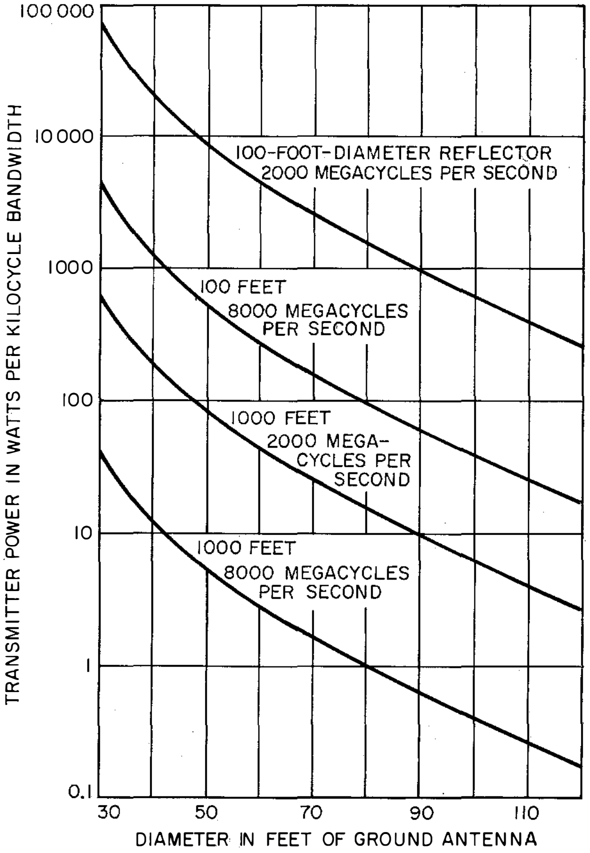

Figure 2—Transmitter power required per kilocycle of bandwidth for a passive reflector in a 3000-mile (4800-kilometer) orbit assuming a free-space loss of 2 × 177 decibels, receiver *KTB* of 208.8 decibels referred to 1 watt per cycle per second, and a carrier-to-noise ratio of 15 decibels. The satellite diameter and transmission frequencies are given for the four graphs.

The carrier-to-noise ratio is based on wide-band modulation techniques, as shown in the previous figure.

Using a 100-foot (30-meter) balloon, 2000 megacycles per second, and an antenna of 120-foot (37-meter) diameter on earth, a power of 130 watts per kilocycle per second of radio-frequency bandwidth is necessary. By using a broadband modulation system, such as pulse-code modulation, an information bandwidth of 4 megacycles per second can be transmitted with a radio-frequency bandwidth of 24 megacycles per second yielding a signal-to-noise ratio of better than 40 decibels. Such a system would require an increase of earth transmitter power of 34 decibels or to approximately 3 megawatts, an impractical level at this time. Raising the operating frequency 4 times to 8000 megacycles per second will decrease the transmitter power 16 times if the antenna efficiency can be maintained and atmospheric absorption is neglected.

Passive systems, then, are characterized by a large number of satellites, large antennas on earth, and high transmitter power to cover a relatively small area of the earth.

The passive system may have an important interim role in transoceanic communication during the development of reliable electronic systems and high-powered rocket boosters that will be required to launch active satellites.

This year, the National Aeronautics and Space Administration will launch a 100-foot (30-meter) aluminized balloon. The balloon will be inflated by the vapor released by a small amount of a sublimating solid in the balloon. The balloon is made of a 0.0005-inch (0.013-millimeter) thickness of Mylar. The sphere will orbit in a 50-degree plane at an altitude of 800 to 1000 miles (1300 to 1600 kilometers). A single voice channel will be attempted between Bell Telephone Laboratories at Holmdel, New Jersey, and Jet Propulsion Laboratories at Goldstone, California. ITT Laboratories has furnished the frequency-modulated transmitter to Bell Telephone Laboratories for the Holmdel terminal.

3.2 ACTIVE SATELLITES

A larger, more-sophisticated satellite reflector would reduce the required power on earth, but a controlled propulsion mechanism for maintaining optimum position and attitude would be needed. If we resort to such complication in a space craft, it is only a simple additional step to incorporate a transponder and thus evolve an active repeater.

3.2.1 Near-Orbit Active Satellites

Active satellites in near orbits are under development for the military. For their purposes, in addition to world-wide high-speed capability, communication facilities must provide continuity of service under conditions of jamming and interference.

The Advanced Research Project Agency through the Signal Corps is sponsoring a delayed communication repeater in project Courier.[4] ITT will supply the earth-based systems for the Courier project.

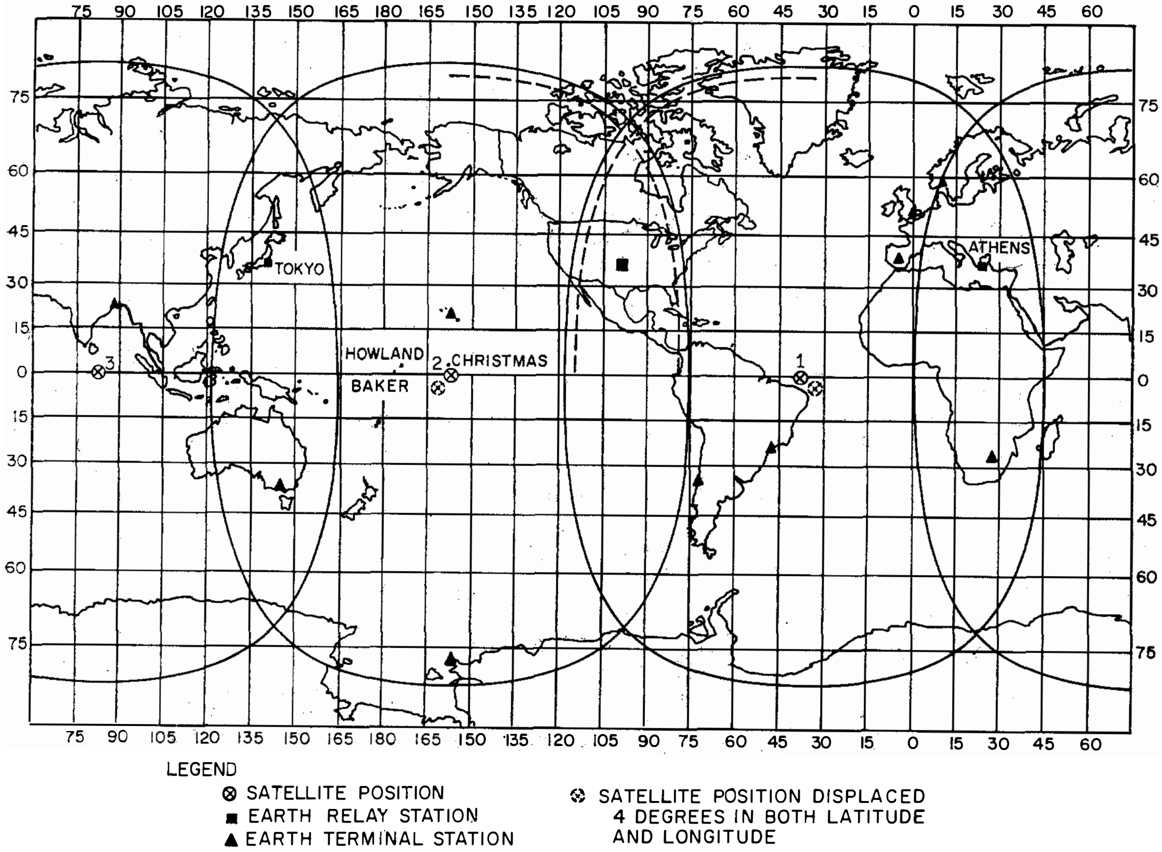

Figure 3—Line-of-sight coverage areas for 3 satellites on 24-hour orbits.

Under the Courier concept, a satellite in a 600-to-700-mile (965-to-1126-kilometer) orbit will be activated as it comes into the view of a ground station that has traffic for another ground station.

Teleprinter signals previously stored on magnetic tape are transmitted to the satellite at high speed. The satellite stores the message. When the satellite is in view of the addressed station, it will retransmit the message to the ground receiver at high speed when commanded to do so by a coded signal. During reception from the satellite of stored messages, the earth station can also transmit traffic for other stations to the satellite on a different frequency. By transmitting at a high information rate during the 4 to 5 minutes in which the satellite is reliably in view of the earth station, it is possible to transmit the traffic of 20 teleprinter channels operating continuously at the rate of 100 words per minute.

For an active operating time of 3 minutes when the satellite is within range of the earth station on each orbit, the traffic handling capacity

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[4] Committee on Science and Astrononautics, Report *9*, page 15; 1959.

would be 15 000 000 bits, the capacity of each satellite recorder. This corresponds to 428 000 words per satellite pass per station. For a 600-mile (965-kilometer) altitude and a 110-minute orbiting time, there would be 7 useful orbits per day at a ground station at the latitude of Puerto Rico or 2 996 000 words handled per day by such an earth station.

Near-orbit active satellites can be used in a real-time system and as in the passive case, a large number of satellites and steerable ground antennas must be used for almost continuous coverage.

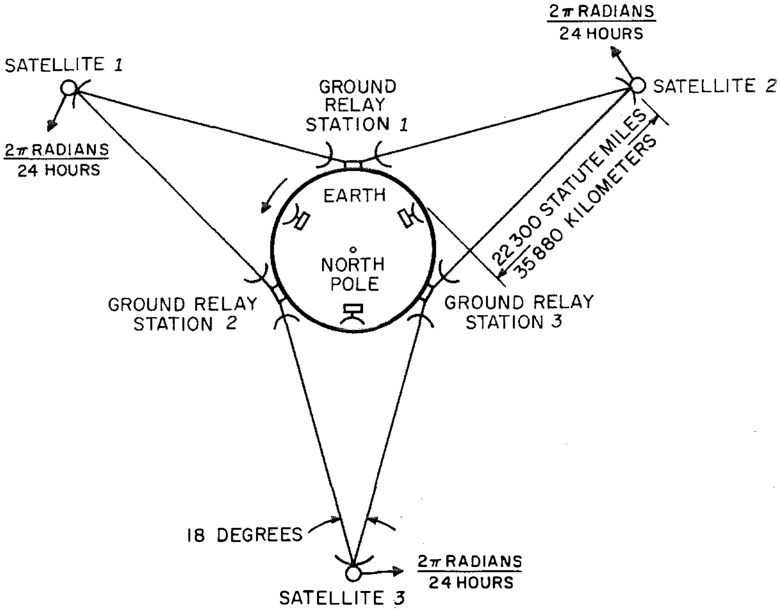

Figure 4—Geometry of synchronous-orbit satellite system. The orbital speed of the satellites and the rotational speed of the earth are all 2π radians per 24 hours and in the same direction. Thus, each satellite maintains constant position relative to the surface of the earth.

TABLE 1

Power Requirements for Different Modulation Systems

	Frequency-Division Multiplex		Pulse-Code Modulation—Frequency Modulation†
	Single Sideband	Frequency Modulation*	
For 12 4-Kilocycle-per-Second Channels			
Required received power for unity signal-to-noise ratio in decibels referred to 1 watt	−157.2	—	—
Required received power for threshold in decibels referred to 1 watt.	—	−138.4	−146.2
Net transmission loss in decibels	+127	+127	+127
Fading margin in decibels	+13	+13	+13
Carrier power increase in decibels to raise signal-to-noise ratio to 40 decibels	+40	+12.2‡	0
Satellite transmitter power output in decibels referred to 1 watt	+22.8 (peak)	+13.8	−6.2
For 96 4-Kilocycle-per-Second Channels			
Ratio of power between 12 and 96 channels in decibels	+3	+3	+9§
Satellite transmitter power output in decibels referred to 1 watt	+25.8 (peak)	+16.8	+2.8
Satellite average power output in watts	54‖	48	2
Satellite peak power output in watts	380	48	16

* $\Delta\theta = 4$.
† Synchronous detector.
‡ Carrier level above threshold.
§ Using 8 carriers for frequency-division multiplexing.
‖ Multichannel speech produces a peak-to-average power of 8.5 decibels.

The altitude of an attitude-controlled near-orbit satellite will limit the satellite antenna beamwidth. Path loss, gain of the satellite antenna, and coverage on the earth decrease with altitude. Therefore, in moving the satellite from a 3000-mile (4800-kilometer) orbit to a synchronous orbit at 22 300 miles (35 880 kilometers) and using an antenna beam tangent to the surface of the earth, only 5 decibels more power is required.

3.2.2 The 24-Hour-Orbit Active Satellite

Three satellites in an equatorial orbit at 22 300 miles (35 880 kilometers) can cover about 98 percent of the surface of the earth as shown in Figure 3. For a world-wide communication system, this would appear very attractive. The most severe limitations are the power output of the satellite transmitter and its life.

At the synchronous-orbit altitude, the satellite antenna beamwidth for hemispherical coverage is 18 degrees, see Figure 4. Allowing a margin for position error of ±4 degrees, a 25-degree beamwidth can be used yielding a gain of 16 decibels at 2000 megacycles per second. With 60-foot (18.3-meter) paraboloidal reflectors on the earth and a receiver noise figure of 1 decibel, a satellite transmitter rated at 2 watts will handle 96 voice channels, as shown in Table 1.

Note the large difference in peak power output among the various modulation systems previously compared. The peak power demand can be troublesome in the active-satellite transmitter, particularly if a klystron or traveling-wave tube is used in the output stage.

Figure 5 shows a possible configuration of the communication transponder in the satellite.

Figure 6 (on page 188) shows the circuit arrangement for use in an earth station in the system.

4. Conclusions

The factors affecting the design of a communication system using satellite repeaters have been briefly touched on, and a possible configuration of an active repeater has been examined. An active system to handle as many as 1000 voice channels can be implemented in two years. These satellites can compete economically and technically with other reliable systems such as submarine cables.

5. Acknowledgment

The author is grateful to Mr. William Sichak for many helpful discussions and review of the manuscript. He is indebted to Mr. Don Campbell and Mr. Paul Rodgers for the preparation of the figures.

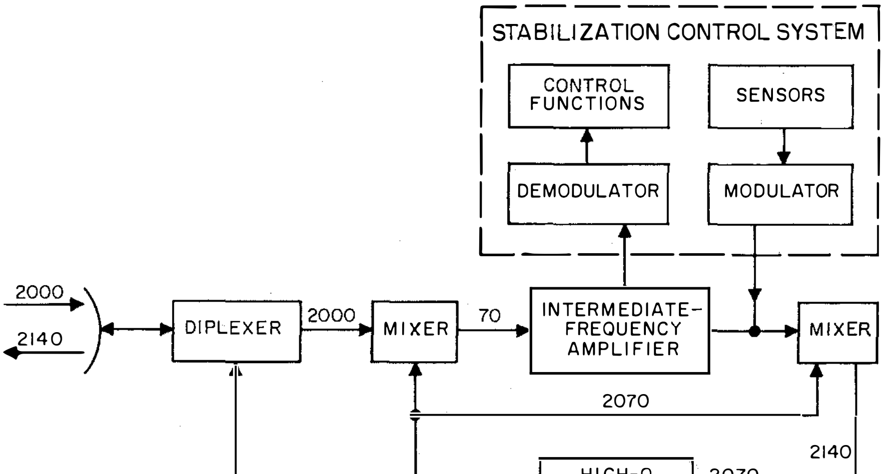

Figure 5—Satellite communication equipment using a traveling-wave tube. The numbers indicate frequency in megacycles per second.

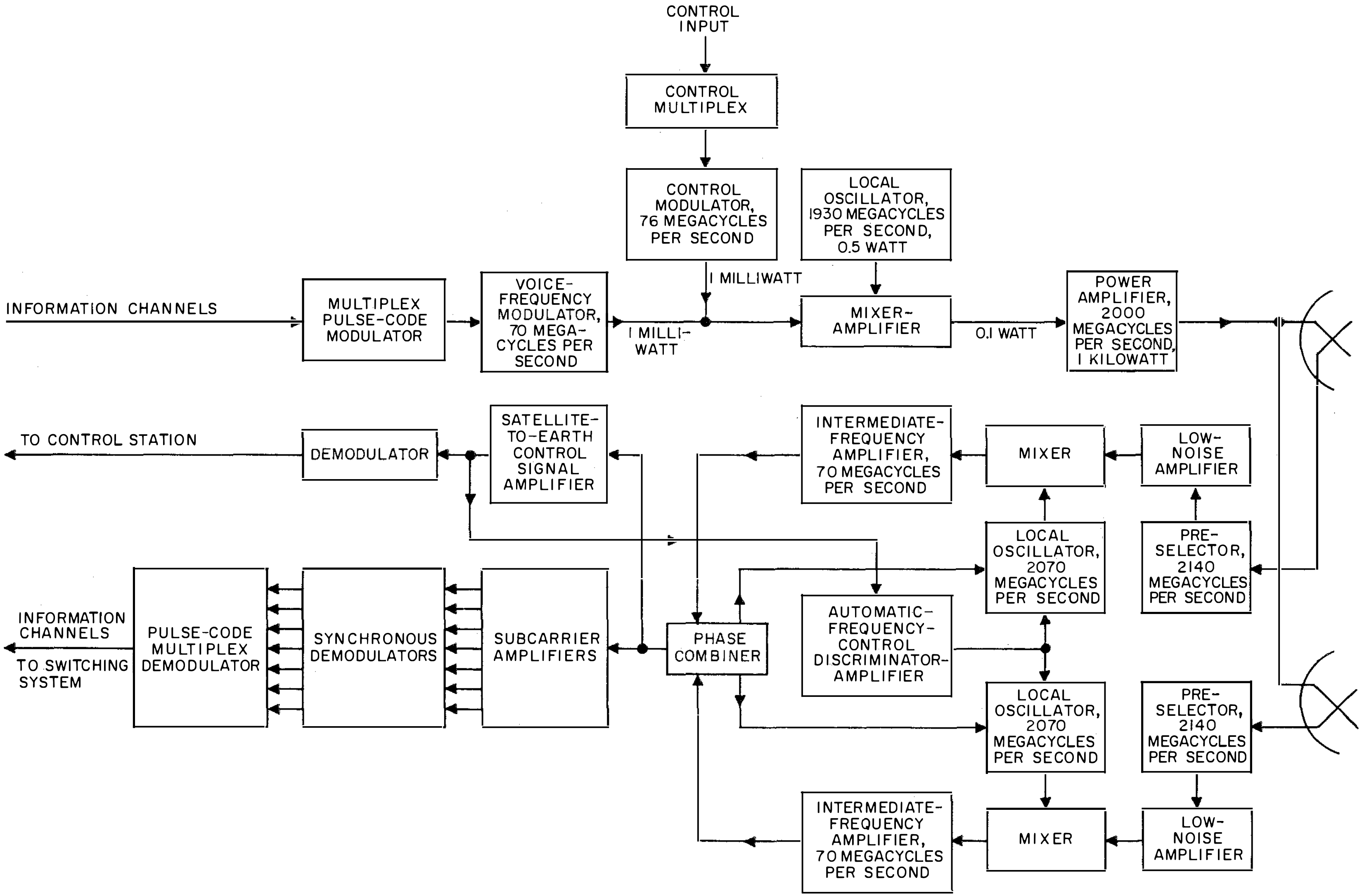

Figure 6—Circuit arrangement for an earth station.

Use of "Stantec Zebra" to Calculate a Traffic Table for a Three-Link Time-Division-Multiplex Telephone Exchange

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A BRIEF description of the time-division principle using amplitude-modulated pulses and a bidirectional gate is followed by a comparison of a 2-link and a 3-link system. For large (10 000-line) exchanges there is a worthwhile saving in switches if the 3-link system is adopted. It is shown that the need to align time channels is a source of blocking, which turns out to be greater for a 3-link than for a 2-link exchange; yet a typical circuit of a typical 3-link exchange can carry about 80 per cent of the traffic of its 2-link counterpart for a 1-per-cent lost-call rate. The use of a few overflow links in the 3-link exchange is expected to make the traffic-handling capacity of the alternative systems roughly equal for a slight additional cost.

Two formulae for blocking probability were programmed for a "Stantec Zebra" computer using its Simple Code. The first covers the general case of unequal traffic on all 3 links and was solved in about 7 hours of computer time for a particular value of the number of available channels; the second, which is restricted to the case of equal traffic on 2 of the 3 highways, involves much less work per channel number and was solved in about 100 hours for a range of values of the number of available channels.

Zebra Simple Code, although slower than Normal Code, is well adapted to this problem because it can handle in floating-decimal form numbers that vary greatly in size and because of its flexible counting and address-modification facilities.

Checking was done by using the two formulae to calculate the same result for a number of spot values, and this gave agreement to 7 or 8 decimal figures with 9-figure working; permuting the traffic values in the case of the general formula gave a similar agreement. The smoothness of the results from the second formula was tested to about 2 or 3 decimal figures by means of a Normal-Code program. The behaviour of the function is shown in graphs because the table is too large to reproduce.

1. *Introduction*

Fully electronic telephone exchanges are now feasible as a result of the development of fast and reliable switching elements, such as transistors, and of new storage techniques originally intended for computers.

The flexibility of these new techniques often leads to new configurations of switching network and control for which the traffic-handling capacity is not known, although analogues may exist in older systems. A study was made of a particular traffic problem posed by either a 3-highway system or the analogous 3-link array in a mechanical network.

It should be remarked at this point that the study is confined to the case of random and independent traffic offered to each of the 3 links. In practice the traffic offered to the 3 links is not completely independent, and so the results given for the blocking probability are approximate and are always larger than in reality. The overload behaviour is, as usual, unpredictable.

2. *Time Channels and Highways*

A single wire can carry many simultaneous conversations if it can be switched rapidly enough among the circuits concerned; such a wire is referred to here as a "highway," and the conversations that are transmitted over it are said to occupy "time channels" on the highway. In other words, a time channel is the time during which the wire is transmitting a particular conversation.

In a telephone exchange working on this principle, there is a great saving of switches, since each switch handles many conversations instead of only one.

3. *Modulator–Demodulator (Modem) Circuit*[1]

At the input the speech signals must be converted into pulse information and eventually reconverted at the output. The traffic results given in this article are valid whatever form of pulse coding is employed; in this case amplitude modulation.

The subscriber's line comes to a circuit that converts the speech signals into amplitude-modulated pulses on a wire called "a group highway." This wire handles all the traffic to and from a group of, say, 100 to 150 subscribers. (A conversation between two subscribers in the same group is a special case.)

At first sight the employment of time sharing in the speech path would seem to introduce a considerable transmission loss because only samples of speech are transmitted. This loss, however, can be avoided by using a filter network in the subscriber's line circuit. This network causes the speech energy to be accumulated on a capacitor in the interval between connections so that the total loss is reduced to an acceptable level.

The function of the network of switching elements in this exchange is to permit an interchange of speech-modulated charge between the 2 capacitors individually associated with each of the 2 subscribers in conversation. This is achieved by including in the switched path 2 inductors that, together with the 2 capacitors, form a tuned circuit. The charges on the capacitors will completely interchange if the network connection is made for exactly half the natural period of oscillation of the tuned circuit.

In practice there is a slight loss that may reach 4 to 5 decibels when an exchange using 4 switches in series is considered.

4. *Number of Channels per Highway*

To transmit the speech waveform at frequencies up to 4 kilocycles per second, the subscriber's line is examined at a 10-kilocycle-per-second rate, that is, once per 100-microsecond interval. The more time channels that can be accommodated in an interval of 100 microseconds the better, so far as traffic-handling capacity is concerned. A limit is set by the frequency-response characteristics and power-handling capacity of the transistor in the modem circuit.

Since the traffic table includes the number of channels per highway as one of the variables, it can be used to determine the optimum number of channels when other factors are known.

5. *2-Link and 3-Link Systems*

Although a highway replaces 100 subscribers' wires, in the case of groups of 100, quite a large cross-connector is required if any one highway is to be capable of being switched to any other highway: in a 10 000-line exchange, there would be 100 highways, and therefore to interconnect these with full availability, the number of crosspoints required is $\frac{1}{2}(100) \times (99) = 4950$. This number is the sum of the series $99 + 98 + \ldots + 2 + 1$.

Such an arrangement is a 2-link system, and, despite the full availability between links, has a certain amount of internal blocking. This is caused by the fact that there may be no time channel simultaneously free on incoming and outgoing highways.

The amount of the blocking produced can be appreciated from the fact that, for a grade of service of 0·01, the traffic-handling capacity of a 25-channel highway alone is 16 erlangs and of 2 such highways in series is 12·5 erlangs.

In a 3-link system the group highways are collected into bundles of, say, 10, and a new sort of highway is introduced to carry the traffic between "supergroups," as the bundles are called. By way of example, there might be 10 supergroups to be interconnected in a 10 000-line exchange and, for full availability among them, the number of "link highways" would have to be:

$$\tfrac{1}{2}(10) \times (9) = 45.$$

This is the number of "intersupergroup link highways", but there must be, in addition, another link highway to interconnect the group highways in each supergroup, or 10 more in all. Figure 1 shows a simplified diagram of this scheme.

There is a saving of interhighway switches here

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[1] K. W. Cattermole, "Efficiency and Reciprocity in Pulse Amplitude Modulation," *Proceedings of the Institution of Electrical Engineers*, Part B, volume 105, pages 449–470; September, 1958.

compared with the 2-link case. Ignoring the switches needed for tone signalling (more are needed in the 2-link case) there must be 20 switches for each of the first 45 links and 10 switches for each of the last 10 links. This makes 1000 crosspoints as compared with 4950 for the 2-link case.

The price paid for this economy is the reduction in the traffic-handling capacity of a group highway, and, as usual, a less-desirable overload performance. For a grade of service of 0·01, the capacity of a highway in the 2-link system is 12·5 erlangs and in a 3-link system, 10 erlangs.

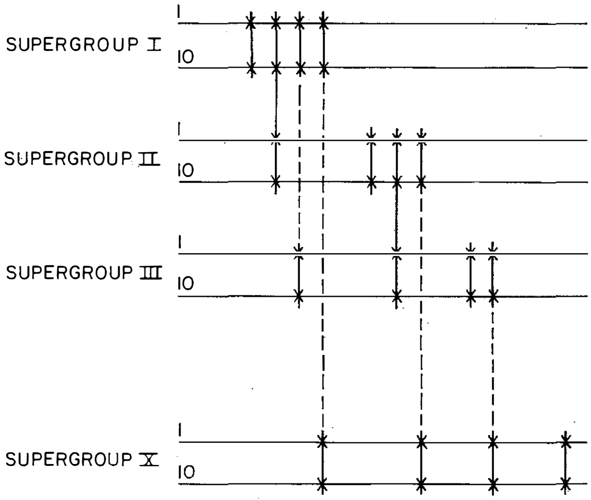

Figure 1—Simplified example of a 3-link (4-stage) switching network showing intergroup and intersupergroup highway links.

It is possible to provide extra links capable of serving all group highways to handle traffic peaks. By providing one or two such overflow links, at the moderate expense of 100 crosspoints per additional link, the blocking could practically be reduced to the figure valid for 2-link systems, and 12·5 erlangs could be handled. These overflow links could be restricted to serving only the busiest groups, if it is desired to economize to the utmost on crosspoints.

6. *Time-Channel Alignment*

In general a conversation passes through 3 highways in series, the incoming, the link, and the outgoing highways. When no speech storage is provided, the conversation must occupy the same time channel on each highway. There may be time channels available on one or two of the highways without a corresponding time channel being available on the third highway, thus causing blocking, and reducing the traffic-handling capacity.

It may happen that a calling subscriber is given a certain channel number while he dials, et cetera, which may later turn out to be unsuitable for completing the path to the called party. The control circuit then attempts to shift the conversation to a channel free on all 3 highways, a process called "time-channel alignment."

7. *Blocking Probability for Unequal Traffic on 3 Links*

In a recent publication[2] by M. Van den Bossche and R. G. Knight, formulae and tables have been given for the overall probability of loss due to congestion in a "3-link array."

What is termed "3-link array" in that paper really is a network comprising 3 switching stages, A, B, and C, that are interconnected so as to provide between any A switch and any C switch as many paths as there are switches in the B stage, one such path being associated with each B switch and comprising two interconnectable links extending between the A and B stages and between the B and C stages respectively.

There is here a similarity with a 2-highway time-division-multiplex system because the link groups correspond to the highways and the number of B switches corresponds to the number of time channels. The A and C switches are replaced by the modem circuits in the time-division-multiplex system.

Congestion in such arrays can be defined as the probability that for a call to be extended from a given A switch to a given C switch no two interconnectable AB and BC links are simultaneously free. As some AB and BC links may still remain free, no pair of a free AB link and a free BC link being however associated with the same B switch, the congestion so defined comprises a certain amount of internal blocking.

In computing this probability it has been assumed that in a group of paths extending between

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[2] M. Van den Bossche and R. G. Knight, "Traffic Problems and Blocking in a Three Link Switching System," Document *2*, International Teletraffic Congress, The Hague; July 7–11, 1958.

a given pair of A and C switches, both the group of AB links and the group of BC links are offered traffic from independent sources.

Assuming an Erlang distribution on both groups, the traffic offered to these groups being A and B erlangs respectively, the blocking probability has been evaluated to:—

$$P = \frac{A}{A - B} E_{N,A} - \frac{B}{A - B} E_{N,B}.$$

In the special case $B = A$, P is found to be equal to:—

$$P = (N + 1 - A)\, E_{N,A} + A\,(E_{N,A})^2.$$

The object of the present paper concerns the extended case of an array comprising 4, that is a first, a last, and two intermediate stages, A, B, C, and D, and having equal numbers of switches in both intermediate stages, in which the 4 switching stages are interconnected so as to provide, between any A switch and any D switch as many paths as there are switches in each of the B and C stages, each path being associated with a different switch in the B stage and in the C stage and comprising 3 interconnectable links extending between the A and B, B and C, C and D stages respectively.

The definition of congestion as well as the assumptions made with respect to the traffic distribution are the same as in the previous case, except that these are to be understood as referring to 3, instead of 2, interconnectable links. This case corresponds to the 3-highway time-division-multiplex system envisaged.

Let M be the number of paths thus extending between a given pair of A and D switches. Considering separately the links partaking in these M paths, these comprise a group of AB links, a group of BC links, and a group of CD links, each group containing M links. Let the traffic offered to these groups from independent sources be A, B, and C erlangs respectively.

To derive the overall blocking P, the loss probability $p(x)$ due to x links being busy in the AB link group will first be calculated. The overall blocking is then obtained as the sum of terms $p(x)$ in which x assumes successively all integral values between 0 and M inclusive.

The probability of x arbitrary links being busy in the AB group is given by:—

$$P_x(A,M) = \frac{A^x}{x! \sum_{x=0}^{M} \frac{A^x}{x!}}. \qquad (1)$$

If at the same time V arbitrary links are busy in the BC group, the probability of this combination is:—

$$P_x(A,M) P_V(B,M).$$

Supposing that out of these V links in the BC group, y are not interconnectable with the x links in the AB group, whereas the remaining $V - y = i$ are connectable with some or all of these x links, the probability reduces to:—

$$P_x(A,M) P_{y+i}(B,M) \frac{\binom{M - x}{y}\binom{x}{i}}{\binom{M}{y + i}} \qquad (2)$$

where i is any number $\leqslant x$, and $y \leqslant M - x$.

To take into account all possible values of i between 0 and x inclusive, the last expression is summed as follows:—

$$P_x(A,M) \sum_{i=0}^{x} P_{y+i}(B,M) \frac{\binom{M - x}{y}\binom{x}{i}}{\binom{M}{y + i}}. \qquad (3)$$

This, therefore, represents the probability that, x arbitrary AB links being busy, y links non-interconnectable with these x AB links, plus any number between 0 and x links interconnectable with these x AB links, are busy in the BC group. This means that of the M paths provided between the given A and D switches, only $z = M - (x + y)$ could still be used.

Blocking will therefore occur, if the links corresponding with the z remaining paths are busy in the CD link group, and besides any number j between 0 and $x + y$ inclusive of links corresponding with the $(x + y)$ paths already previously excluded.

The probability of this state is:—

$$\sum_{j=0}^{x+y} P_{z+j}(C,M) \frac{\binom{x + y}{j}}{\binom{M}{z + j}}. \qquad (4)$$

The combined probability:—

$$P_x(A,M)\sum_{i=0}^{x}P_{y+i}(B,M)$$

$$\times\frac{\binom{M-x}{y}\binom{x}{i}}{\binom{M}{y+i}}\sum_{j=0}^{x+y}P_{z+j}(C,M)\frac{\binom{x+y}{j}}{\binom{M}{z+j}}\qquad(5)$$

thus expresses the state of blocking in which x paths are excluded in the AB link group, a further number of y paths are excluded in the BC link group, the remaining paths being busied in the CD link group, including any possible combination of double and triple engagement of paths.

To obtain the probability $p(x)$ for the state of blocking, in which x paths are excluded in the AB link group, the remaining $M-x$ paths being busied in any way in the BC and/or CD groups, is obtained by summing for y, between $y=0$ and $y=M-x$.

Consequently the wanted overall blocking P is given by:—

$$P=\sum_{x=0}^{M}P_x(A,M)\sum_{y=0}^{M-x}\sum_{i=0}^{x}P_{y+i}(B,M)$$

$$\times\frac{\binom{M-x}{y}\binom{x}{i}}{\binom{M}{y+i}}\sum_{j=0}^{x+y}P_{z+j}(C,M)\frac{\binom{x+y}{j}}{\binom{M}{z+j}}.\qquad(6)$$

The last summation in this expression may be carried out as follows:—

$$\sum_{j=0}^{x+y}P_{z+j}(C,M)\frac{\binom{x+y}{j}}{\binom{M}{z+j}}$$

$$=\frac{C^z}{f(C,M)}\frac{(x+y)!}{M!}\sum_{j=0}^{x+y}\frac{C^j}{j!}=\frac{E_{M,C}}{E_{x+y,C}}\qquad(7)$$

in which $f(C,M)$ stands for $\sum_{t=0}^{t=M}\frac{C^t}{t!}$.

By inserting this result in the above expression and carrying out some further transformation the following expression may finally be obtained.

$$P=E_{M,B}\,E_{M,C}\sum_{x=0}^{M}\frac{P_x(A,M)}{P_x(B,M)}\sum_{y=0}^{M-x}\binom{M-x}{y}$$

$$\times\frac{1}{E_{x+y,C}}\sum_{i=0}^{x}P_i(B,M)\frac{P_{x-i}(B,M)}{P_{M-y-i}(B,M)}\qquad(8)$$

where

$$E_{x,C}=\frac{C^x}{x!\sum_{u=0}^{u=x}\frac{C^u}{u!}}.\qquad(9)$$

Note that $E_{M,C}=P_M(C,M)$.

When considering the method used in deriving this result, it will be readily understood that there is no particular reason why this procedure should be applied in this particular order; in other words one could, for example, start with the assumption that x links are engaged in the BC group and that a further quantity of y paths are excluded by busy links in the CD group. There would be no reason to assume that in this case the numerical result would be different. It follows, then, that the value of expression (8) is invariant for permutation of the traffic values, A, B, and C. Also, for any of the traffic values A, B, or C becoming zero, (8) should give the same results as the formula given in the introduction for the "3–link array".

8. *Equal Traffic on 2 of 3 Highways*

A formula has been derived by L. R. F. Harris and P. W. Ward[3] that applies to the special case where the traffic on 2 of the highways is equal. The formula is five or ten times as rapid for computation, since only two instead of three summations are required. With some transformations it becomes:—

$$P=\frac{\frac{B^M}{M!}}{\left(\sum_{u=0}^{u=M}\frac{B^u}{u!}\right)^2}\sum_{x=0}^{x=M}\frac{E_{M,A}}{E_{M-x,A}}\frac{x!}{B^x}$$

$$\times\sum_{y=0}^{y=M-x}\frac{B^{M-x-y}}{(M-x-y)}\binom{2x+1+y}{2x+1}\qquad(10)$$

where B is the traffic on 2 of the highways and A is the traffic on the third highway.

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[3] L. R. F. Harris and P. W. Ward, "Trunking of Time Division Multiplex Electronic Telephone Exchanges," International Teletraffic Congress, The Hague; 7–11 July 1958.

9. *Computation Using Zebra*

9.1. Programming Features

Zebra Simple Code was used because numbers are handled in floating-decimal form that eliminates the possibility of their exceeding the capacity of the computer in this problem. Simple Code has certain built-in counting facilities that are well adapted to handle "cycles-within-cycles" processes such as occur in any multiple-summation problem.

The time spent in testing the programs was considerably reduced by using the Simple-Code checking and "post-mortem" facilities. It should be remarked that, with all interpreted codes, a program fault is harder to diagnose by inspection of the displayed contents of selected registers than is a fault occurring when the Normal Code of the machine is used.

The storage capacity of the machine was adequate to accomodate several intermediate tables, which saved time by making it unnecessary to calculate certain functions repeatedly.

Since all the numbers to be summed are positive in both (8) and (10) there is no pitfall, such as loss of accuracy, caused by calculating with the difference of two nearly equal numbers.

The accuracy was checked by comparing the results of the two formulae, which showed agreement to 7 or 8 significant figures. There was also agreement to 3 figures with some values calculated by hand by A. Termote of the Bell Telephone Manufacturing Company, Antwerp.

Checking by differencing is not possible because the function changes so much in the tabular interval, but the results do form a smooth set of curves on logarithmic graph paper. This suggested that individual wrong entries in the table would be detected by forming the difference between an entry and the square root of the product of adjacent entries, which should be nearly zero for correct entries.

$$P(M,A,B) \sim \{P(M,A - \Delta A,B) \times P(M,A + \Delta A,B)\}^{1/2}$$

for the double-summation formula.

A program was written in Normal Code to read the paper tape of previously calculated results and to punch an output tape of the differences mentioned above. Normal Code is more suitable than Simple Code for this purpose, which is essentially data processing, since it is more flexible. This check revealed that, to the accuracy of the approximation mentioned above (2 or 3 decimal figures), there were no errors.

No parity failures were allowed to pass undetected.

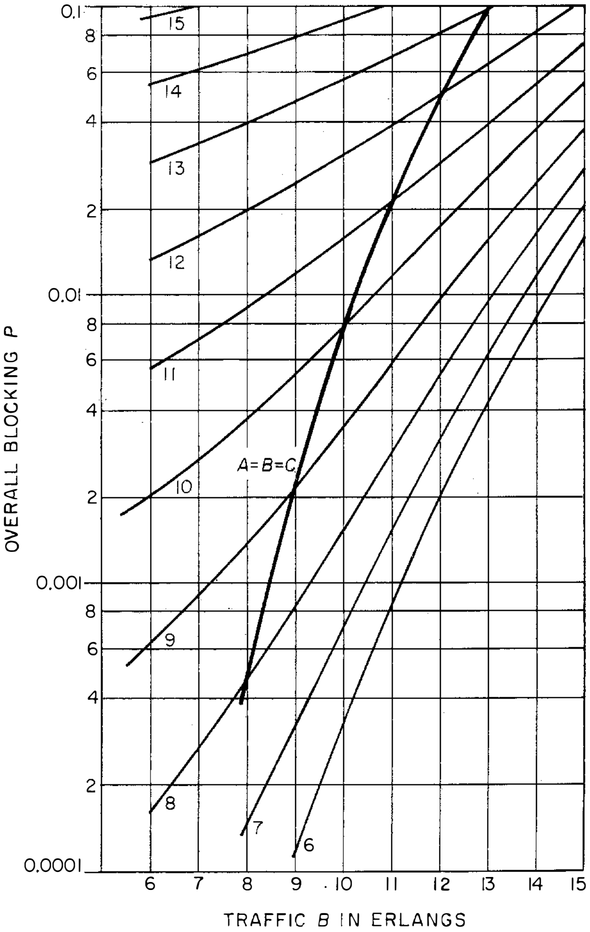

Figure 2—Overall blocking P for equal traffic on 2 of 3 highways if $A = C$. ($M = 25$.)

9.2 3 Independent Traffic Parameters A, B, and C

Examination of (8) reveals that if an arbitrary change is made to A, B, or C the most computation is necessary for a change in B, and the least for a change in A. Therefore it was arranged that B and C should change a minimum number of times during the working.

To avoid repeatedly calculating values of $\binom{n}{r}$ whenever needed, a complete table was worked out and stored as a preliminary to the main calculation. A table of roughly equal size was then calculated and stored, each entry of which was the result of performing the third summation on a function of B only. A third table was next produced by performing the second summation resulting in a function of B and C only. Finally, for every value of A, the first summation produced the required answer.

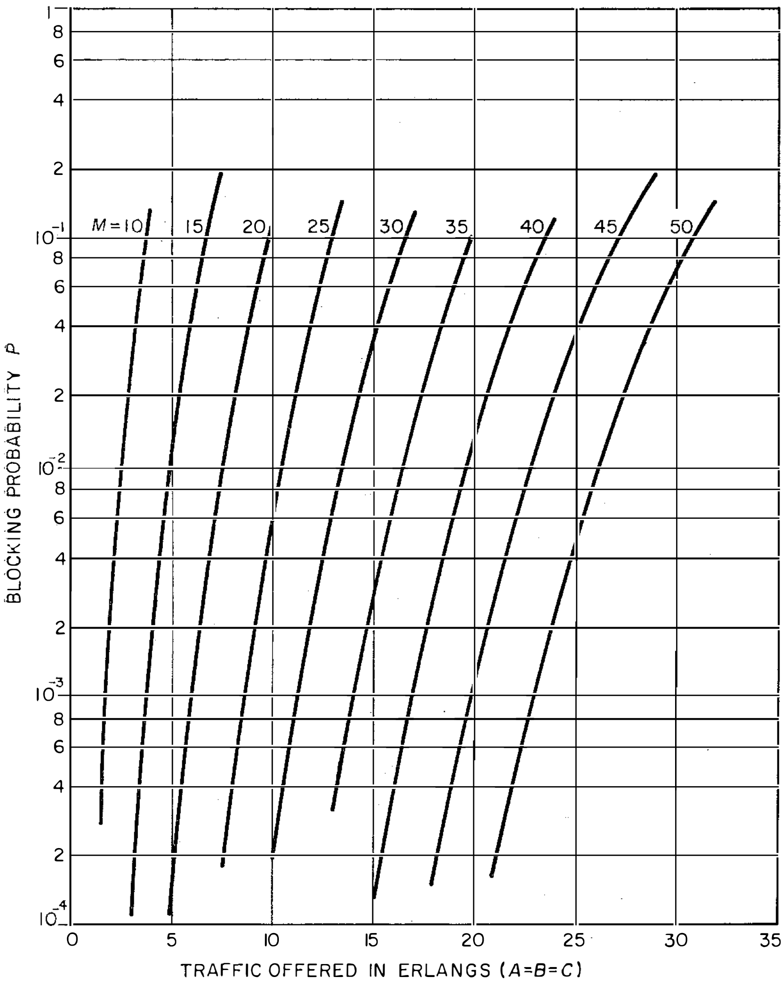

Figure 3—Blocking probability P as a function of the traffic offered and the number of channels M.

Values of blocking probability were required for all integral values of A, B, and C between 6 and 15 inclusive. The number of independent function values in this interval is not 1000 but only 220, since the problem is symmetrical in the three variables, although the function is not. To generate only these values the variables can be set to satisfy the following inequalities:—

$$6 \leqslant B \leqslant 15$$
$$B \leqslant C \leqslant 15$$
$$C \leqslant A \leqslant 15.$$

However, it was considered worthwhile to include a running check by repeating a function value formed by interchanging A and C. If in the above inequalities the last one is changed to

$$C - 1 \leqslant A \leqslant 15$$

the result is that the first value printed in each block by the computer should be equal to the second or third entry in the preceding block, depending on whether the latter is the first block for a new value of B or not.

The time required was about 7 or 8 hours, in which roughly 2×10^5 useful arithmetical operations were done.

Figure 2 shows the behaviour of the function restricted to the case of $A = C$.

9.3 EQUAL TRAFFIC B ON 2 HIGHWAYS

The double-summation equation (10) was coded to produce at least the following table:—

$10^{-4} < P < 10^{-1}$ for $10 \leqslant M \leqslant 25$ at intervals of 1 and for A and B at intervals of 0·5.

$10^{-4} < P < 10^{-1}$ for $26 \leqslant M \leqslant 50$ at intervals of 1 and for A and B at intervals of 1.

After some preliminary calculations to determine the range of values A and B should take for a given M to produce blocking probabilities in the desired range, the program was arranged to pick values for A_{initial}, B_{initial}, A_{final}, B_{final}, and M from a built-in table, and to advance automatically to the next channel number after completing the work for the current one. To break into this sequence at an arbitrary point it was arranged that the data tape should specify M, A_{initial}, B_{initial}, ΔA, ΔB, A_{final}, B_{final}, and a number indicating where to jump into the sequence. The end of the sequence was indicated by a dummy value for M, equal to zero, in the built-in table.

The time required was about 100 hours, of which about 60 hours formed a continuous run. Had the same table been produced by the triple-summation formula about 600 hours of computer time would have been necessary. About 3 or 4 million useful arithmetical operations were done, which would be the equivalent of, say, 5 years work for a person using a desk machine.

Figure 3 shows the behaviour of the function at intervals of 5 in M for $A = B = C$.

It has been shown by Adelaar that there is a 6-fold-summation formula that should yield the same result:—

$$P = \sum_a \sum_b \sum_c \sum_d \sum_e \sum_f \frac{P_{a+d+f+g}(A)\, P_{b+d+e+g}(B)\, P_{c+e+f+g}(C)\, M!}{\binom{M}{b+c+e}\binom{M}{a+c+f}\binom{M}{a+b+d}\, a!\, b!\, c!\, d!\, e!\, f!\, g!}$$

with

$$\begin{aligned} 0 &\leqslant a \leqslant M \\ 0 &\leqslant a+b \leqslant M \\ 0 &\leqslant a+b+c \leqslant M \\ 0 &\leqslant a+b+c+d \leqslant M \\ 0 &\leqslant a+b+c+d+e \leqslant M \\ 0 &\leqslant a+b+c+d+e+f \leqslant M \\ &a+b+c+d+e+f+g = M \end{aligned}$$

This formula would have occupied Zebra day and night for 4000 years, but a single value for $M = 6$ and $A = B = C = 1$ required only half an hour compared with 20 to 30 seconds using the double-summation formula. The agreement is to one unit in the 9th significant figure.

10. Acknowledgements

The authors express their gratitude for the considerable help offered by the staff of the information processing division of Standard Telephones and Cables and to Mr. A. Vitacolonna of Standard Telecommunication Laboratories.

Use of Statistical Moments for Specifying Noise in Long-Distance Telephone Circuits*

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THERE was presented at the first International Teletraffic Congress a brief paper[1] on probability theory in telephone transmission with special reference to noise specifications. The present paper treats the same problem: How should the tolerable noise power on a telephone circuit be expressed? The object is to make the specification simple, but at the same time to formulate it in a way that does not place any unnecessary restrictions on noise of any particular time distribution. An important requirement is that it should be realistic and in practice this means that very-intense noise must be accepted, but it must not occur too often or last too long.

It has been proposed[2] to specify the permissible amount of noise not by a distribution curve, but instead by its moments.

The first moment or the time mean of the noise power was already used in the paper[1] cited. The second moment with respect to zero noise power is the time mean of the squared noise power; the third, the mean of the cubed noise power. It has already been agreed[3] to specify for a hypothetical 2500-kilometre (1550-mile) circuit that the hourly mean noise measured in a certain manner must not exceed −50 decibels relative to 1 milliwatt.

The purpose of the present paper is to consider the effect of specifying the permissible noise by its first three hourly moments. The main interest is in the degree of control the moments have on the highest noise values.

It must be remembered that the noise in actual circuits is liable to fluctuate greatly, the ratio between the highest and lowest values exceeding 100 (20 decibels) even when the parameter being considered is the mean power over, say, a quarter-second interval, and that therefore the higher moments are likely to be large.

In what follows, all moments will be calculated (or measured) in terms of a unit equal to the recommended maximum mean power (−50 decibels relative to one milliwatt or 10^{-5} milliwatt). If the noise power is constant at unit value throughout the hour, all moments about zero will then be unity.

1. *Advantages of Expressing Requirements in Terms of Moments*

The mean (or first moment) and the root-mean-square deviation from the mean of a fluctuating quantity are used in many fields. The second moment about zero is very-closely related to these two quantities.

There are several advantages in using moment specification rather than distribution specification for noise.

One important advantage is that the moments could, in practice, be measured directly and expressed very simply. The moment specification also places a less-specialized requirement on permitted noise. It is believed that noise moments are capable of measuring correctly the interference value of noise. A particular advantage of a noise moment specification is that it permits easy subdivision of the overall 2500-kilometre (1550-mile) circuit specification into specifications for shorter circuits (partial circuits). Conversely, it is also easy to compute expected performance for a long circuit from the known performance of partial circuits in terms of noise power moments.

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* Presented before the International Teletraffic Congress, The Hague, Netherlands; July, 1958.

[1] B. B. Jacobsen, "Probability Theory in Telephone Transmission," *Teleteknik*, volume 1, number 1, pages 83–85; 1957: also *Electrical Communication*, volume 35, number 4, pages 266–268; 1959.

[2] B. B. Jacobsen, "Thermal Noise in Multisection Radio Links," *The Proceedings of the Institution of Electrical Engineers*, Part C, volume 105, pages 139–150; March, 1958: also, *Electrical Communication*, volume 36, number 1, pages 42–59; 1959.

[3] Comité Consultatif International Radio Recommendation *201*, Warsaw, Poland; 1956.

There is a still-further advantage; when moments are specified, it is possible to permit hourly moments to be "distributed"; that is, slightly higher moments could be allowed to occur during a very-few hours in a long period. This permits the specification to be made tolerant in one further respect, not only can a high noise be tolerated for a very-small part of most hours (limited by the noise moments) but by allowing the moments to be distributed, it is possible to permit higher noise to occur for rather more time per hour during a few hours of a long period.

The distributed moments do not necessarily mean more license; on the contrary, they make it possible to specify tighter requirements for the performance during the majority of hours—this will determine the quality of service for most of the time. For a few hours, however, the performance may be allowed to be rather poorer and this is preferable to having a single specification clause that would have to allow the poorer performance for any hour.

An alternative might be considered: namely, to specify the performance not per hour, but for a much-longer period (one month, for instance). This type of specification would cover many requirements of the situation, but would fail in one respect; subdivision of the overall (monthly) objective would not be possible because cyclic noise variation is likely to be present. That is, there will be correlation between the noise effects occurring in the individual partial circuits. (The question of cyclic effects is discussed[4] elsewhere.)

A further serious objection to the extended period is that it permits very-little control over the performance of the worst hours in the monthly period. This has been recognized by the Comité Consultatif International Radio who have set[3] a limit to the mean noise power for any hour.

In what follows, it will therefore be assumed that the moment specification is for periods of an hour.

2. *Comparison Between Noise Moment Specifications and Noise Distribution*

Noise distribution curves are much-more familiar than noise moment and, before it is possible to give a specification in terms of noise moments, it will be necessary to consider what distribution curves will be permitted by a particular noise moment specification. It will be assumed in an example that the noise moments have been specified with the following values:—

1st moment less than 1,
2nd moment less than 2·5,
3rd moment less than 10.

The problem of finding possible distributions will be attacked first by a very-simple approach giving an accurate estimate of the highest noise and the time it could last. It is assumed that noise can assume two values. One, a high one for a short time and the other a lower one for the remainder of the time. The higher of these two noise values is the one of interest. For a given moment value, it is now possible to draw the envelope curve of all distributions of the type under discussion that have the specified moment value. There will be one such envelope curve for each of the three moments. To simplify this problem, each moment will be considered independently.

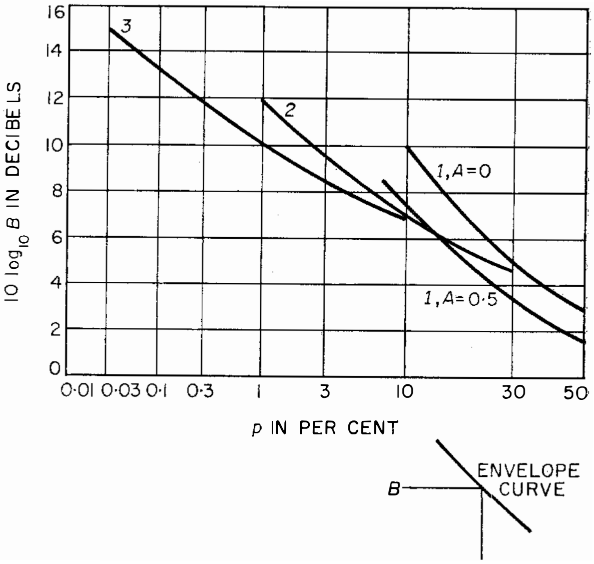

Figure 1—Locus of two-value distributions having specified moments.

3.1 Locus of Two–Value Distributions Having Unity First Moment.

Let us call the lower power value A and the higher value B and assume that B occurs for a

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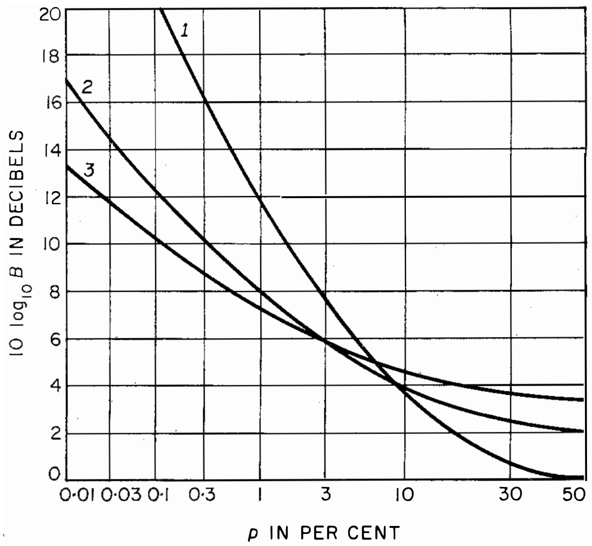
[4] Footnote reference 2, section 4.

fraction p of the hour; A therefore for a fraction $1 - p$. The first moment will be:—

$$M^1_1 = A(1 - p) + Bp = 1. \tag{1}$$

It is required to express B as a function of p. This is the required locus curve determined by the first moment. No distribution of whatever form can have any point above this curve. Figure 1, curve *1*, $A = 0$, shows the actual curve with B expressed in decibels. The assumption that $A = 0$ is an extreme one and for the purpose of orientation a further curve is shown for which it has been assumed that $A = 0{\cdot}5$; this is a reasonable assumption in many cases; in others it may be possible to assume a somewhat-higher value of A. Although, in the calculation, A is assumed to be a constant, the curves are also accurate when the power during the fraction of time $(1 - p)$ has an average power value of A.



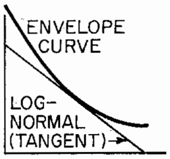


Figure 2—Envelope curves of log-normal distributions having specified moments.

These curves show that the first moment does not exert much control over the power distribution except when p values exceed 40 or 50 per cent.

3.2 LOCUS FOR TWO-VALUE DISTRIBUTIONS HAVING SPECIFIED SECOND AND THIRD MOMENTS.

If the extreme case $A = 0$ is assumed, the envelope curve *2* in Figure 1 applies when the second moment is $M^1_2 = 2{\cdot}5$.

It is often justifiable to assume that the mean power of the distribution is unity. This leads to the equation:—

$$(B - 1)^2 = (M^1_2 - 1)(1 - p)/p, \tag{2}$$

where M^1_2 is the second moment. The curve for this condition differs little from curve *2* and therefore has not been shown.

For the third moment, the extreme condition $A = 0$, gives

$$B^3 = M^1_3/p. \tag{3}$$

The corresponding curve for $M^1_3 = 10$ and with B in decibels measure is shown in Figure 1, curve *3*. In this case the curve is changed only very little even when it is assumed that $A = 1$.

Figure 1 shows that with the moment values chosen for this example, the third and first moments are controlling and the second moment does not cause any limitation except when the curve $A = 0$ applies for the first-moment locus. An actual noise distribution having moments as specified can never at any point intersect the curves shown.

It is obviously possible to choose other values for the moments and so to define different restrictions on the distribution curves. It must be remembered that curves of the type used in Figure 1 show only the highest value that the distribution can possibly attain; actual distributions must at most points be considerably below the three curves.

In the next section, an attempt will be made to determine more-likely limitations on distribution curves having specified moments.

3. Envelope Curve of Log-Normal Distribution Curves with Specified Moments.

It is not difficult to prove that log-normal distribution curves with unity rth moment are tangents to a curve:—

$$10 \log B = y^2/r = 2{\cdot}17 \text{ decibels}, \tag{4}$$

where y is the normalized variate. It is interesting to note also that the point of contact of the log-normal curve with the envelope curve divides the corresponding moment of the log-normal curve into two equal parts.

If the rth moment is increased, the tangent curve for that moment will be lifted by $(10/r)$ $\log M^1{}_r$ decibels.

In Figure 2, three envelope curves are shown corresponding to those in Figure 1, with the moments 1, 2·5, and 10 units. When all the envelope curves in Figure 2 are considered, it is again clear that the second moment requirement also exerts very-little control in this case. The general conclusion from Figure 2 is that if actual distribution curves with the specified moments are log-normal in their upper range, the distribution curve is likely to be approximately 3 decibels lower than the maximum possible values in Figure 1. The methods used in Figure 2 could be applied to other types of distribution, but this has not yet been attempted. It is believed that curves such as those in Figures 1 and 2 give a good first estimate of the higher levels of distribution when only the moments are specified.

If the noise power measurements are made with a time constant of 0·25 second, hourly distribution curves will tend to become flat near the left-hand side of the graph, since the probability of 0·01 per cent corresponds to only 0·36 second per hour. A noise surge lasting 0·36 second with a level of 13·3 decibels will contribute one unit to the hourly third moment. In practice, measured third moments are likely to fluctuate greatly since they arise largely from rare events.

4. *Practical Considerations*

Some actual noise values are likely to be very high and to exceed a value of noise that will cause failure, for instance, of signalling (the transmission of digits by voice-frequency signals), or of voice-frequency telegraph channels using the telephone circuit.

The effect of very-severe noise in a telephone circuit is similar to the effect of interruptions.

By providing automatic substitution of spare equipment, circuit interruptions from equipment failure can be reduced, but this increases the cost of the equipment.

An inflexible noise specification could, particularly for radio relay links, lead to increased equipment costs that might not be justified in view of the presence of other sources of interruptions.

Since the effects of severe noise and of circuit interruptions due to equipment failure are similar, they should be considered together both in the specification and when providing means for reducing interruptions.

If a noise level can be defined that causes almost certain failure while it lasts, then when calculating the moments, it would be reasonable not to take into account the effect of any increase of noise power above the specified value. Such a value might, for instance, be specified as approximately -30 decibels relative to 1 milliwatt. (10^{-3} milliwatt) or 20 decibels above the recommended hourly mean. Any noise value exceeding this should be taken at this value when calculating or measuring the moments (limit convention). The total time during which this power is exceeded should be measured or calculated. The introduction of this level and the convention about still-higher levels have the effect of limiting the moments. The second moment for instance, cannot possibly exceed 10^4 units and the third, 10^6 units.

For an actual specification, very-much-lower moment values must be demanded and the specification that the mean power or first moment must not exceed unity further limits the higher moments. In calculating the first moment, it is of course also necessary to use the limit convention. If the limit for the noise power is 100 units, the extreme performance would be 100 units of limit noise for 1 per cent of time which would produce unity first moment and no noise for the remaining time. The second and third moments in this case would be 10^2 and 10^4 units respectively.

If moments have been measured (with the limit convention), and the total fraction of time of the limit being exceeded has been measured, the measured moments can be corrected to give the moments for the time the limit was not reached. If the limit is 100 units and it was exceeded for a fraction a of an hour, the moments for the residual time are found by subtracting respectively $100a$, 10^4a, and 10^6a from the measured or calculated moments. The value a must in practice be very-small indeed to be tolerable.

There will then be little error in using the corrected moments for the residual time. The time *a* must also be subject to a specification, in this case there might be a maximum sum value for instance, for a month.

5. Conclusions

From the above it would appear that a three-moment specification is adequate for controlling a noise distribution. The next stage would be to find a set of moments corresponding to the actual requirements for the long-distance noise specification. This will not be attempted here since these requirements are not, as yet, fully determined, but it is expected that the requirement can be determined under at least three headings: that is, requirements for very-good service, for reasonable service, and for just-acceptable service, and the percentage of time for which each of these requirements should be satisfied would have to be agreed on. Moment values would be decided for each type of service.

It would then be possible to construct a distribution curve for each of the three moments over a monthly or preferably longer period. These curves could again be expressed in terms of their moments and such moments would constitute the final overall specification.

This type of specification is intended for a hypothetical reference circuit and will therefore primarily be used during design work when it is often necessary to check if a certain type of transmission equipment would provide a suitable overall performance. The specification could also be used as a basis for the calculation of acceptance test requirements for actual circuits.

Design and Operation of High-Power Triodes for Radio-Frequency Heating*

BY W. J. POHL

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THE PAPER sets out the important factors in the design of high-power triodes for use in radio-frequency heating equipment. The relations between class-*C* oscillator performance and valve characteristics lead to relatively simple design principles. These, in combination with modern methods of construction, have made it possible to achieve an unusually high conversion efficiency with relatively low dissipation on the grid, thus ensuring adequate grid safety under varying load conditions.

The design principles are embodied in a new range of industrial triodes that are briefly described.

• • •

1. Introduction and Synopsis

The symbology used in this paper is as follows:—

d = diameter of grid wires
I_a = peak instantaneous anode current per unit area
I_{1a} = peak value of fundamental component of anode current per unit area
I_g = peak instantaneous grid current per unit area
I_{dg} = direct grid current per unit area
I_{1g} = peak value of fundamental component of grid current per unit area
I_k = peak instantaneous total current per unit area
l_a = grid-to-anode distance measured to the centres of the wires
l_g = grid-to-cathode distance measured to the centres of the wires
p = pitch of grid wires
P_d = driving power (fed back from the output in an oscillator).
P_g = total grid dissipation per unit area of grid
$P_{g\max}$ = maximum permissible grid dissipation per unit area of grid
V = direct supply voltage
V_a = minimum instantaneous anode voltage relative to cathode
V_b = bias voltage
V_g = peak value of instantaneous grid voltage relative to cathode
V_s = peak value of grid voltage relative to bias voltage
μ = triode amplification factor
ϕ = angle of grid-current flow in electrical degrees

In the increasingly important field of radio-frequency heating, high-power triodes are generally used as class-*C* oscillators. The circumstances that prevail in most cases demand that the valve should give satisfactory service over a very-wide range of radio-frequency load conditions.

Unfortunately, a class-*C* oscillator that has been adjusted for high efficiency of operation at full load will, under no-load conditions, run with excessive grid drive, frequently followed by grid failure. The power dissipated on the grid with no load may be several times that dissipated at full load. It is therefore necessary that the full-load conditions be arranged so that the grid dissipation is low enough to allow an adequate safety margin.

In this paper it is shown that the grid dissipation is very critically dependent on the operating conditions. As the full-load efficiency of the oscillator is increased, the grid dissipation rises very sharply. Thus, the circuit engineer who, by adjustment of feedback and bias, derives the utmost power from his circuit, jeopardizes the valve grid safety. It is proposed here to use the concept of a *grid safety factor*, defined as the ratio of maximum rated grid dissipation to actual grid dissipation at full load.

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* Reprinted from *The Proceedings of the Institution of Electrical Engineers*, volume 104, part B, pages 410–416; July, 1957.

It would perhaps have been more logical to define this factor with reference to no-load conditions. Since, however, these depend not only on the valve but also on the circuit losses, and in any case are difficult to calculate, it is assumed for the purposes of the paper that the safety factors at full load and at no load bear a constant relation.

The valve designer is faced with the task of providing an acceptable grid safety factor at the highest possible anode efficiency. By examining the interdependence of these two parameters for various designs, it will be shown that this requirement is best met by the smallest mechanically reliable grid–cathode spacing (high slope), and the smallest grid–anode spacing (giving low amplification factor) compatible with freedom from flashover. The effects of variations in wire diameter and grid pitch are also considered and it is shown that, although it is advantageous to use fine wire, it is not worth while to make great efforts to reduce the wire diameter below that which is mechanically convenient.

These principles, together with modern methods of construction, have been applied in the development of a new range of industrial heating triodes and have resulted in considerable improvements in efficiency and grid safety factor.

2. *Class-C Oscillator Relations*

The performance equations describing class-*C* oscillator conditions will now be derived. These relations enable the circuit designer to carry out class-*C* calculations far more rapidly than by conventional methods.

A flow angle of 140 degrees will be used, this angle being considered representative of full-load operation with good compromise between adequate output power and efficiency. The flow angle merely determines the constants in the equations below, which are obtained by Terman's method.[1] Smaller flow angles lead to higher efficiencies at lower powers, but it will be seen that the generalized conclusions concerning valve design that are derived later are equally applicable to any angle of flow.

The available radio-frequency power is

$$\left(\frac{V - V_a}{2}\right) I_{1a} = 0{\cdot}2 I_a (V - V_a). \qquad (1)$$

The drive power is

$$P_d = \frac{I_{1g} V_s}{2} = \frac{I_{1g}}{2}(V_b + V_g),$$

where

$$V_b = \frac{V}{\mu} + 0{\cdot}52\left(V_g + \frac{V_a}{\mu}\right). \qquad (2)$$

Hence the drive power is

$$\frac{I_{1g}}{2}\left\{\frac{V}{\mu} + 0{\cdot}52\left(V_g + \frac{V_a}{\mu}\right) + V_g\right\}.$$

The ratio V_a/μ is generally small, so that

$$P_d = \frac{I_{1g}}{2}\left(\frac{V}{\mu} + 1{\cdot}6 V_g\right) \qquad (3)$$

is a good approximation, where $V_s = V/\mu + 1{\cdot}6 V_g$.

It is shown in section 10.1 that for practical purposes the grid flow angle in radians can be taken as

$$\phi = 2(2)^{1/2}\left(\frac{V_g}{V_s}\right)^{1/2}$$

$$= 2(2)^{1/2}\left(\frac{V_g}{V/\mu + 1{\cdot}6 V_g}\right)^{1/2} \qquad (4)$$

and $I_{1g}/I_g = 0{\cdot}17\phi$ is an adequate approximation. Hence the drive power is

$$P_d = \frac{0{\cdot}17 I_g}{2} 2(2)^{1/2}\left\{\left(\frac{V_g}{V_s}\right) V_s\right\}^{1/2}$$

$$= 0{\cdot}24 I_g \{V_g(V/\mu + 1{\cdot}6 V_g)\}^{1/2}. \qquad (5)$$

Subtracting this from the available radio-frequency power, the output power is

$$P_0 = 0{\cdot}2 I_a (V - V_a) - 0{\cdot}24 I_g \{V_g(V/\mu + 1{\cdot}6 V_g)\}^{1/2}. \qquad (6)$$

An expression[2] for the grid dissipation is

$$P_g = (\phi/4\pi)\, V_g I_g. \qquad (7)$$

Equations (4) and (7) then yield a useful expression for the grid dissipation in terms of peak grid voltages and currents as obtained from measured or calculated valve characteristics,

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[1] All references are in the bibliography, section 9.

$$P_g = 0{\cdot}225 \left\{ \left(\frac{V_g}{V_s} \right) V_g I_g \right\}^{1/2}$$

$$= 0{\cdot}255 \left\{ \frac{V_g}{(V/\mu + 1{\cdot}6 V_g)} V_g I_g \right\}^{1/2}, \qquad (8)$$

which is a satisfactory approximation for grid flow angles up to about 120 degrees. (See also section 10.2.) The anode efficiency is given by the quotient of output power and direct input power:

$$\eta = P_0/P_{di} = 4{\cdot}4 P_0/I_a V. \qquad (9)$$

To find the bias resistance, it is necessary to know the direct grid current I_{dg}, which is approximated[1] by

$$I_{dg} = 0{\cdot}09 \phi I_g.$$

Substituting for ϕ from (4),

$$R_{\text{bias}} = \frac{V_s - V_g}{0{\cdot}254 I_g} \left(\frac{V_s}{V_g} \right)^{1/2}. \qquad (10)$$

To summarize, the design is carried out by first considering (1). For any assumed value of V_a, the characteristic curves of the valve give V_g and I_g for the required current I_a.

The drive power required and the grid voltage swing V_s are derived from (3). Equations (6), (8), (9), and (10) then give output, grid dissipation, efficiency, and bias resistance, respectively. It may, of course, be expedient to provide some of the bias voltage by means of a cathode bias resistor.

It should be noted that the above procedure applies to earthed-cathode operation. At high frequencies (in the region of 100 megacycles per second) it will become necessary to employ the earthed-grid method.[2] For this it is necessary only to replace I_{1g} in (3) by $I_{1g} + I_{1a}$. The grid dissipation remains unchanged.

The constants in the equations can be readily modified[1] if an anode flow angle other than 140 degrees is required. In general, it will be found that smaller flow angles give higher efficiencies at lower output powers for given filament emission capabilities. This means that if a valve is under-run, very-high efficiencies can be obtained. An example of this is given in the measured test results in Table 1 where the valve type *3J/222E*, which is capable of 24-kilowatt output power, gives an efficiency in excess of 90 percent when only 17 kilowatts of power are required.

3. *Calculation of Valve Characteristics*

To establish design principles, expressions are required relating valve electrode dimensions to the peak currents and voltages used in the previous section.

A widely used relationship for the total space current is

$$I_k = \frac{2{\cdot}34 \times 10^{-6} (V_g + V_a/\mu)^{3/2}}{\{l_g + (l_g + l_a)/\mu\}^2} \qquad (11)$$

per unit area of cathode.

TABLE 1

TYPICAL MEASURED OSCILLATOR PERFORMANCE DATA*

	Low-Voltage Types *3J/222E* *3Q/222E*	High-Voltage Types *3J/252E* *3Q/252E*	Low-Voltage Type *3Q/202E*	High-Voltage Types *3J/232E* *3Q/232E*
Output Power into Load in Kilowatts	24	48	12	24
Grid Dissipation in Watts	120	200	60	100
Efficiency in Per Cent	78	80	78	80
At Direct Anode Voltage in Kilovolts	6·0	12·0	6·0	12·0
Direct Anode Current in Amperes	5·1	5·0	2·6	2·5
Direct Grid Current in Amperes	0·71	0·8	0·36	0·4
Grid Bias Resistance in Ohms	800	950	1600	1900
Peak Positive Grid Voltage	200	320	200	320

* Owing to their special characteristics, these valves show an unusually sharp increase in efficiency if the output power requirements are slightly reduced. For example, the *3J/222E* at 17-kilowatt output power gives 90-per-cent efficiency, with only 50-watt grid dissipation. Measured at approximately 2 megacycles per second with less than 5-per-cent circuit loss.

Output Power into Load in Kilowatts	17	Grid Current in Amperes	0·32
Bias Resistance in Ohms	2500	Peak Positive Grid Voltage	200
Anode Current in Amperes	2·9	Grid Dissipation in Watts	50
Anode Voltage in Kilovolts	6·5	Efficiency in Per Cent	90

For the grid current, the approximate relation for a parallel-wire grid,

$$I_g = I_a \left(\frac{l_g + l_a}{l_g} \right)^{2/3} \frac{d}{p - d} \left(\frac{V_g}{V_a} \right)^{1/2} \qquad (12)$$

is used. This is derived by assuming the experimentally verified relation

$$I_g/I_a \propto (V_g/V_a)^{1/2}$$

and finding the constant of proportionality.[2]

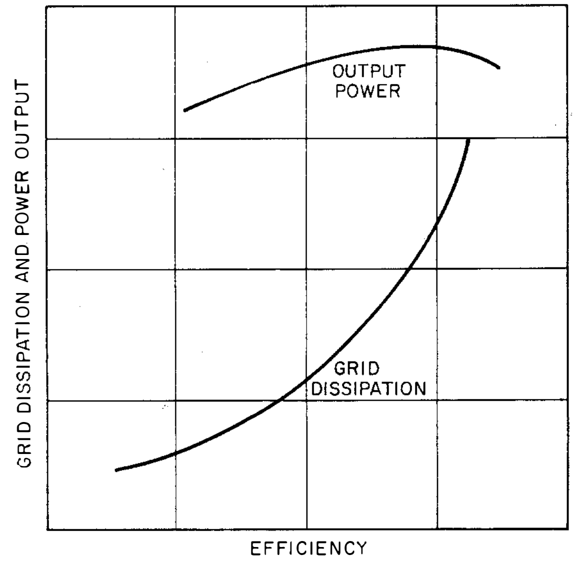

Figure 1—General form of performance curves.

Equation (12) is not highly accurate and has on occasions given rise to errors up to 20 per cent. Nevertheless, it suffices for use here, since we are looking for general design trends and seeking to achieve reductions in grid dissipation by an order of magnitude. (The characteristics of the square-mesh grid correspond to those of a parallel-wire grid having a pitch equal to 0·6 times that of the mesh.[6])

The calculation of μ has been carried out[3] from information given by Ollendorf.

4. *Method of Estimating Valve Suitability*

The foregoing relations will now be used to bring out something about the important factors in the design of high-power triodes for oscillators in industrial heating equipment. To this end, a method of estimating valve suitability is employed that has proved useful, not only for exposing the shortcomings of some existing obsolescent types and accounting for failures in the field, but also in establishing the valve design principles outlined in the following section. The method consists of calculating the output power, efficiency, and grid dissipation at a stipulated anode voltage, flow angle (as, 140 degrees), and *fixed peak cathode current.* This gives curves of which the generalized form is shown in Figure 1. Such curves are obtained from measured or calculated valve characteristics as follows:—

A number of values of V_a are assumed. For each of these, the peak grid voltages V_g required to give the fixed specified peak total current are found from the characteristic curves (preferably constant-current curves), together with the corresponding values of I_g and I_a. Equations (6) and (8) are then used to obtain output power and grid dissipation for each assumed value of V_a; these are readily expressed in terms of anode efficiency from (9). At efficiencies above about 60 per cent the output power will be found to remain substantially constant, and represents the maximum power that the valve will give at the voltage considered and at the available total

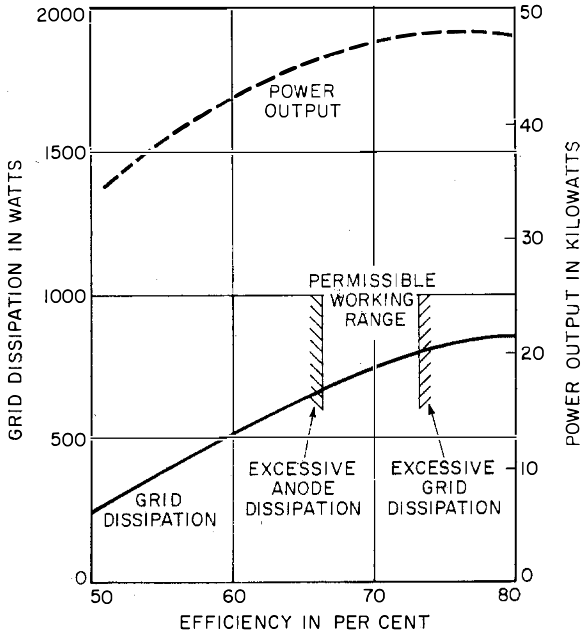

Figure 2—Performance curves of an obsolete triode unsuited for radio-frequency heating.

cathode emission. The grid dissipation will be seen to increase rapidly with efficiency. The maximum attainable efficiency is limited by the point at which the safe grid dissipation is exceeded.

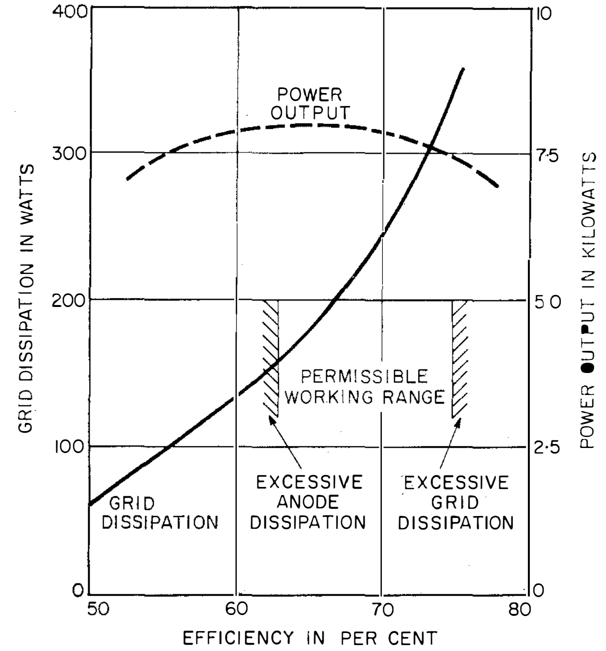

Figure 3—Performance curves of a triode satisfactory for radio-frequency heating.

As mentioned in section 1, it is desirable, for variable-load operation, to work with a certain grid safety factor at full load. Thus a merit figure of a valve could, for this aspect, be specified as the efficiency at full output power at which the grid has a given safety factor. If this factor were fixed at say, 2·0, then the valve relating to Figure 2 gives a 'merit figure' of 56 per cent. The information given here applies to an obsolescent broadcasting valve unsuitable for industrial heating; at 56-per-cent efficiency the anode dissipation would be exceeded. A safety factor of 2·0 is therefore not possible with this valve at full output power. In the same way Figure 3 gives a merit figure of 65 per cent and applies to a valve that has been satisfactory in the field. The valve to which Figure 4 relates gives a figure of 81 per cent and shows what has been achieved with the use of design principles outlined in the following section and modern methods of construction. It represents the *3J/222E* 20-kilowatt triode. A description of this and similar valves is given in section 7.

Figures 5 and 6 show some results obtained by applying the method to a hypothetical valve with calculated characteristics. These lead to important design conclusions discussed in detail in the following section.

5. Conclusions Concerning Electrode Design

Diagrams such as Figures 1–6 reveal immediately the causes of unsatisfactory service in industrial heating applications and indicate desirable trends in design, which will now be discussed with reference to each of the important electrode dimensions.

5.1 FILAMENT

It is well known that the emission life of the cathode is dependent on its running temperature. In the case of thoriated-tungsten filaments, the relations between running temperature, emission, and life are well known. In industrial heating applications, flow angles much less than 140 degrees are sometimes used to give improved efficiencies. In general, it is recommended that a

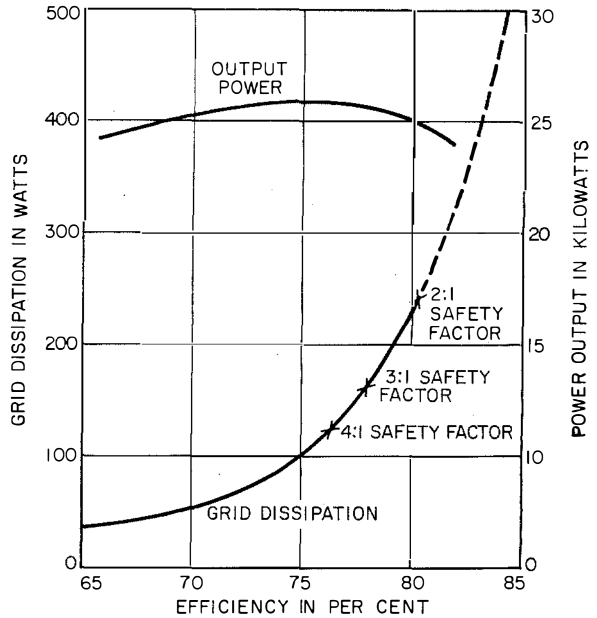

Figure 4—Performance curves of the *3J/222E*, a triode specially designed for radio-frequency heating.

flow angle of 90 degrees should be catered for, giving a peak current of approximately 6 times the mean space current. Allowances must also be made for deterioration of emission during life and for filament-voltage fluctuations.

5.2 Grid–Cathode Spacing

The choice of the smallest practicable grid–cathode spacing can be justified by the need to minimize the grid power, which is proportional to $V_g I_g$. For a given space current and current division, I_g remains constant. The value of V_g required to produce this space current diminishes with l_g, in accordance with (11). The grid–cathode spacing should therefore be as small as is practicable from a mechanical viewpoint; it is determined by the accuracy obtainable in the cathode and grid structures, their supports, and the overall dimensions.

5.3 Grid Pitch

Too many grid wires give an unnecessarily large intercepted current and thus decrease the anode current and hence the power. The grid safety factor is not affected because additional wires can dissipate additional power. If the grid pitch is too large, however, this gives rise to "island" effects and "high tail" characteristics leading to low efficiencies. A grid pitch equal to $(1/0{\cdot}7)l_g$ is a good compromise.[4]

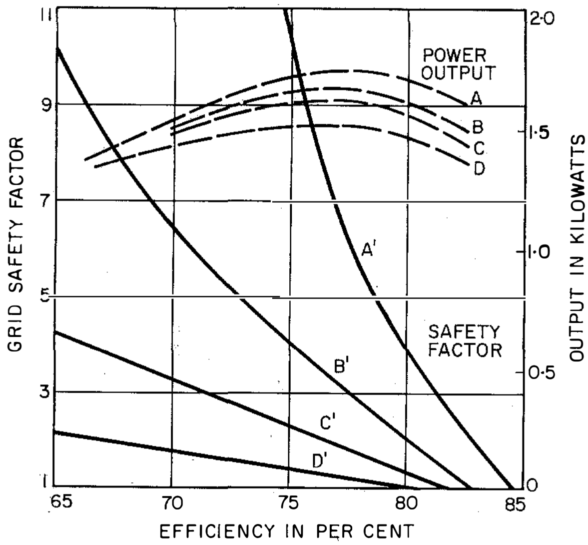

Figure 5—Effect of changing grid–anode spacing on grid safety factor and output power. These curves have been calculated for one square inch (6·45 square centimeters) of electrode area, with $V = 6000$, $l_g = p = 0{\cdot}060$, $I_a + I_g = 1{\cdot}6$, and flow angle = 140 degrees. $P_{g\max}$ = 40 watts per square inch (6·20 watts per square centimetre); that is, 12·8 watts for these curves. Curves A,A' for l_a = 0·1 inch (2·54 millimetres), B,B' for l_a = 0·15 inch (3·8 millimetres), C,C' for l_a = 0·25 inch (6·35 millimetres), and D,D' for l_a = 0·4 inch (10 millimetres).

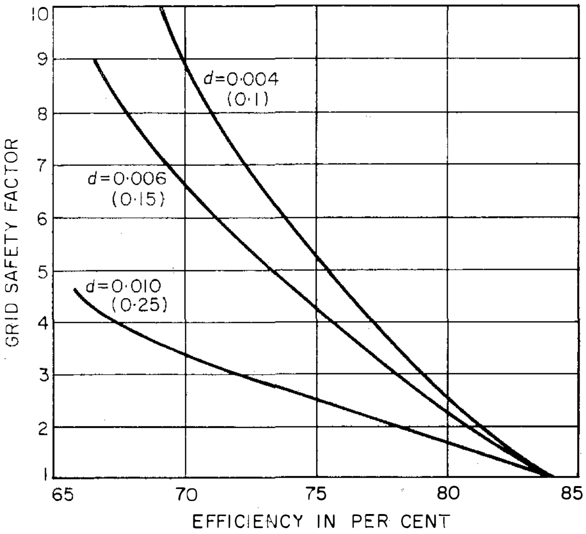

Figure 6—Effect of changing wire diameter. d indicated in inches (millimetres). These curves have been calculated as those of Figure 5, with l_a = 0·15 inch (3·8 millimetres).

5.4 Grid–Anode Spacing

The effect of varying the grid–anode spacing, keeping all other parameters constant, is shown in Figure 5. It is clear that to obtain good grid safety factors at the highest efficiencies, the ratio of grid dissipation to efficiency should be as small as possible. The conclusions drawn from Figure 5 indicate that it is desirable to reduce the grid–anode spacing until the tendency for flashover to take place enters into consideration. Doubts arise because the resulting low μ is usually associated with a high driving power. The driving power is, however, not as high as might at first be expected because it depends not only on μ but also on V_g and I_g, in accordance with (5). For a given space current, I_g and V_g are considerably reduced by reducing l_a. Thus the driving power increases only slightly as l_a is diminished below values normally in use. In any case, the increase in driving power due to low μ is diverted into the bias resistor, and not to the grid. As regards efficiency, the driving power is unimportant since, even with very-low values of μ, it represents a very-small fraction of the available radio-frequency power in grid-driven circuits.

5.5 EFFECT OF WIRE DIAMETER

Since the grid dissipation is proportional to V_gI_g and the maximum rated dissipation is proportional to d/p, the safety factor is proportional to d/pI_g.

From (12), I_g is proportional to $d/(p - d)$. Hence the grid safety factor is proportional to $(p - d)/p$. In Figure 6 the small effect of wire size on safety factor caused by change of μ, which has been neglected in the above arguments, is also taken into account. The curves show the effect of using different wire sizes in a design with $l_g = 0{\cdot}060$ inch (1·5 millimetres) and $p = 0{\cdot}060$ inch (1·5 millimetres). They demonstrate the general principle that the wire diameter should be as small as possible, but that little is gained by reducing it when it is already very-much smaller than the pitch.

6. Characteristics and Performance of a New Range of Industrial Triodes

The design principles outlined in the previous section have been applied in the development of a new range of power triodes, two of which are shown in Figure 7. The *3J/222E* is designed for a useful output of 20 kilowatts at an anode voltage of 6 kilovolts. Its characteristics are shown in Figure 8 and its calculated performance and grid safety factor for flow angles of 140 degrees are given in Figure 4. These are in good agreement with measured performance figures, some of which are given in Table 1.

The *3J/202E* gives roughly half the current and power at the same voltages and so has the same efficiencies and grid safety factors at full load. The *3J/232E* and the *3J/252E* types are designed for operation at higher voltages. The anode–grid spacing in these valves is increased in proportion to the direct supply voltage, whereas the cathode–

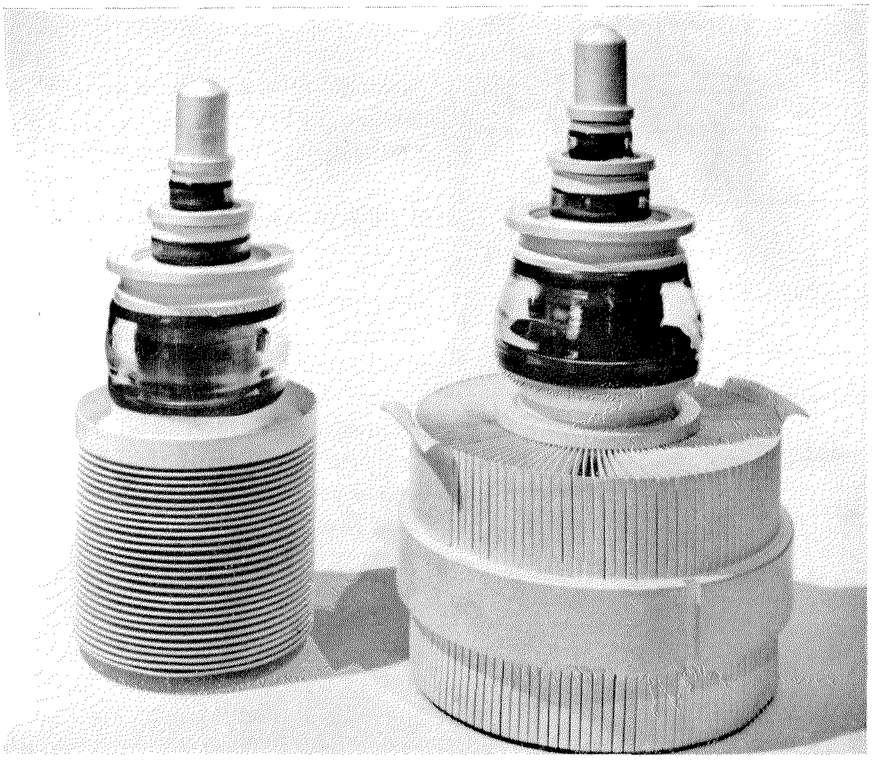

Figure 7—The *3J/202E* and *3J/222E* (10-kilowatt and 20-kilowatt output) industrial triodes.

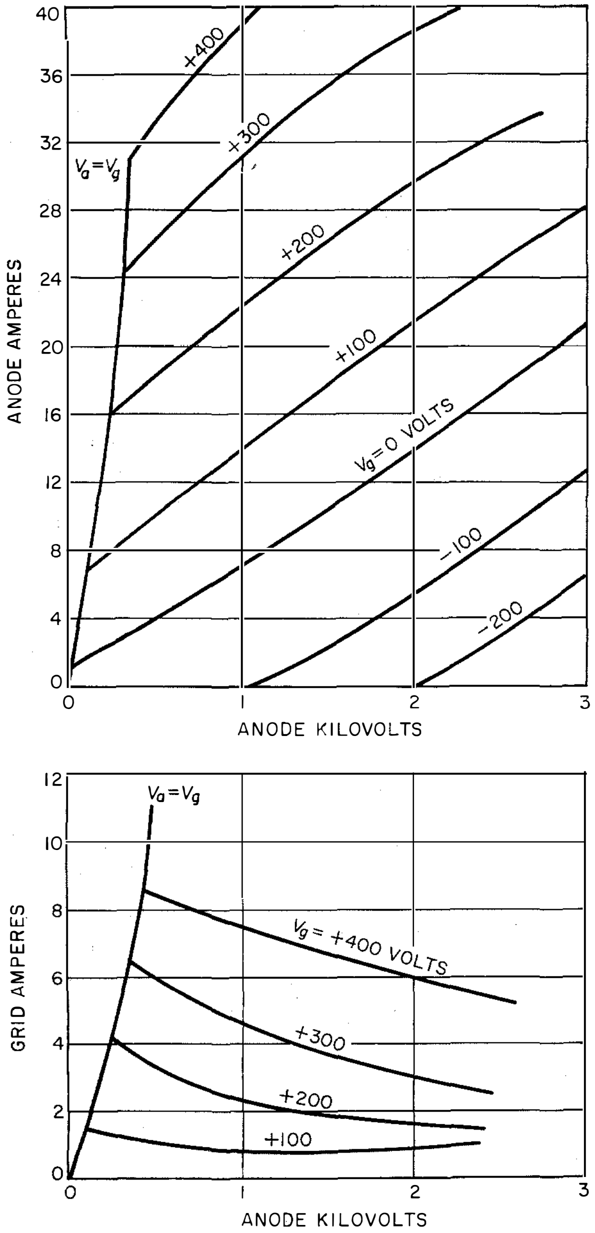

Figure 8—Characteristics of the *3J/222E*.

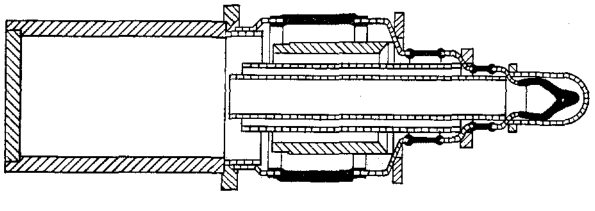

Figure 9—Envelope structure.

grid spacing is maintained at the same value. This gives about the same relationship between grid safety factor and efficiency. This can be appreciated by inspection of (11) and (8), remembering that μ is proportional to the grid–anode spacing.

7. *Mechanical Features of New Triodes*

7.1 ENVELOPE

One of the most-important requirements for valves used in productive industry is mechanical robustness both of the envelope and of the electrode structures. Although conventional pin-type valve connectors are adequate for the frequencies used in the majority of industrial heating applications, recent developments in the broadcasting field have pointed to the necessity of coaxial structures for higher frequencies. In this connection it was found during extensive trials that such structures not only can give reduced electrical losses and facilitate cooling, but also are many times stronger mechanically and exceptionally resistant to thermal shock. Figure 9 shows details of the construction used.[10] This construction facilitates accurate electrode alignment and, being entirely symmetrical, is free from warping during life. There are no vacuum-tight brazed joints and the glass seals are of a type acknowledged to allow the widest latitude in residual stresses. Thus the envelope can be manufactured to a high degree of reliability.

7.2 GRID

The square-mesh grid structure is shown in Figure 10. The wires are specially processed so that at the maximum rated dissipation, the emission from the grid is of the order of 2 microamperes per square centimetre of grid-wire surface area. This occurs at about 8 watts per square centimetre. The maximum rated value of grid dissipation is the figure that will be certain to ensure freedom from grid emission troubles. The grid itself, however, is capable of withstanding for short periods about four times more power before damage results.

The characteristics of the square-mesh grid correspond to those of a parallel-wire grid having a pitch equal to 0·6 times that of the mesh.[6]

7.3 FILAMENT

The filaments of these valves have a mesh construction. Structures such as this were first described and successfully put into practice by Müller.[7] The construction used here differs from these in so far as it is rigidly supported from one end only; this was found to give constructional advantages. The mesh consists of thoriated tungsten wire made from two layers of multifilar helices. An important merit of this structure is that the resistance to distortion is exceptionally great, which not only makes for mechanical robustness but also allows a smaller grid–cathode spacing. Electrically, the filament resembles a unipotential emitting surface rather than a collection of single filament strands with the same heating power. This characteristic and the mutual heating effect[8] between adjacent wires give an economy in filament power for a given peak current requirement. The filament is supported at one end by an inverted sleeve and at the other is connected to a series of tapes as shown in Figure 10. These are designed to give the maximum freedom to the filament in the transverse and axial directions, thus minimizing mechanical strain. A central tube is used for support and for conducting the heating current to the tapes.

This structure[11] has shown a hitherto unattainable resistance to distortion. Even if the filament is burnt out by applying approximately four times the normal filament power, no movement comparable to the grid–filament spacing takes place.

7.4 COOLING

The anode dissipation can be carried away by water, forced air, or evaporative cooling.[9] Valves equipped for evaporative cooling have grooves cut into the anode surface,[12] permitting for short periods the dissipation of twice the power considered adequate for most industrial purposes.

The radiators for forced-air cooling are also capable of double-power overloads for short periods, since the fin temperatures can under these conditions exceed 300 degrees centigrade without permanent damage to the valve.

8. Acknowledgments

The author is greatly indebted to a number of helpers, especially G. A. Morton, who made

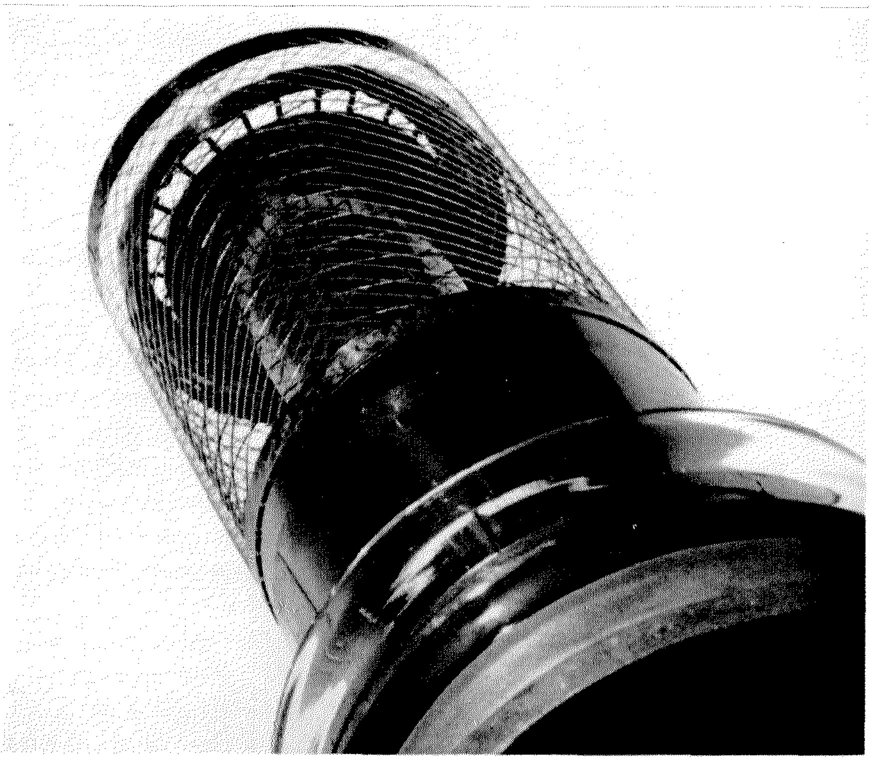

Figure 10—Grid–filament assembly.

prominent contributions to the mechanical development work, D. C. Rogers, for helpful criticism, and C. H. Foulkes.

9. References

1. F. E. Terman, "Radio Engineering," McGraw-Hill Book Company, New York, New York; 1932: pages 325 and following.
2. W. J. Pohl and D. C. Rogers, "U.H.F. Triodes. Design of Class C Earthed-Grid Operation," *Wireless Engineer*, volume 32, pages 47–52; February, 1955.
3. J. H. Fremlin, R. N. Hall, and P. A. Shatford, "Triode Amplification Factors," *Electrical Communication*, volume 23, pages 426–435; December, 1946.
4. J. H. Fremlin, "Calculation of Triode Constants," *Electrical Communication*, volume 18, pages 33–49; July, 1939.
5. R. B. Ayer, "The Use of Thoriated Tungsten Filaments in High Power Transmitting Tubes," *Proceedings of the IRE*, volume 40, pages 591–594; May, 1952.
6. C. C. Eaglesfield, "Triodes with Square Mesh Grids," *Wireless Engineer*, volume 19, pages 447–450; October, 1942.
7. W. Müller, "Die Siemens U.K.W. Fernseh Sende-röhren," *FTZ*, volume 5, pages 528–533; November, 1952.
8. W. J. Pohl, "Mutual Heating in Transmitting-Valve Filament Structures," *Proceedings of the Institution of Electrical Engineers*, volume 103, part *C*, pages 224–230 (Monograph No. 158 R); March, 1956.
9. G. Ashdown, "The Vapotron," *Electronic Engineering*, volume 25, pages 378–379; September, 1953.
10. British Patent Application 24 073; 1956.
11. British Patent Application 23 986; 1956.
12. British Patent Application 4976; 1957.
13. H. Köpke and E. Uredat, "Belastungsverhältnisse und Eigenshaften, von Senderöhren im Industriegenerator," *A.E.G. Mitteilungen*, volume 45, pages 523–528; November–December, 1955.
14. L. T. Apps, "Class C Amplifier and Oscillator Design," *Electronic Engineering*, volume 27, pages 30–32; January, 1955.

10. Appendix

10.1 APPROXIMATE EXPRESSION FOR GRID-CURRENT FLOW ANGLE

The grid-current flow angle ϕ is given by

$$\cos(\phi/2) = V_b/V_s.$$

With the anode flow angle of 140 degrees, $\phi/2$ is generally less than one radian ($\phi < 115$ degrees). In the described range of triodes with high slopes per unit area of cathode, ϕ is in the region of 90 degrees. Thus the approximation obtained by expanding

$$\cos(\phi/2) = 1 - (\phi/2)^2/2$$

is accurate enough for practical purposes. (The error is approximately 1 per cent at 80 degrees, and 4 per cent at 120 degrees.)

This gives

$$\phi = 2(2)^{1/2}(V_g/V_s)^{1/2} \text{ radians.}$$

From available curves[1], the approximation that I_{1g}/I_g is linear will be seen to be permissible for flow angles up to 120 degrees.

It is proposed to use a value $I_{1g}/I_g = 0{\cdot}17\phi$, corresponding to $\alpha = 1{\cdot}75$.

This relation is used in the derivation of a readily usable expression for the driving and output powers, (5) and (6).

10.2 GRID–DISSIPATION MEASUREMENT ON PRACTICAL CIRCUITS

The grid dissipation can be measured on a practical oscillating circuit by measuring I_{dg}, the mean grid current, and V_s, the grid voltage swing, with a valve voltmeter and using (7).

Replacing I_g in (7) by I_{dg}, and assuming a half-sine-wave current flow, an expression independent of flow angle:—

$$(I_{dg}/I_g) = (2/\pi)(\phi/2\pi) = \phi/\pi^2,$$

is obtained; that is,

$$I_g = I_{dg}\pi^2/\phi,$$

$$P_g = (\phi/4\pi)V_gI_g = (\pi/4)V_gI_{dg} = 0{\cdot}79\,V_gI_{dg},$$

where V_g is obtained from V_s by subtracting the bias voltage, $V_b = I_{dg}R_b$.

World's Telephones—1959*

THERE WERE 124 800 000 telephones in service throughout the world at the beginning of 1959. This was an increase of 7 000 000 telephones, or 6 percent, over the previous year's total.

More than half of the world's telephones were located in the United States. Alaska and Hawaii became states during the year 1959. Data relating to them are not included in these statistics inasmuch as the change in status occurred after the effective date of report.

Telephones in proportion to population afford a measure of the relative level of telephone development. Twelve of the countries or areas with more than 25 000 telephones had at least 15 telephones per 100 population. Listed in alphabetical order they were: Alaska, Australia, Canada, Channel Islands, Denmark, Hawaii, Iceland, New Zealand, Norway, Sweden, Switzerland, and the United States.

In general, the statistics reflect the situation as of January 1, 1959. In the table of telephones by countries, estimates are shown for those places that ordinarily report statistics but did not do so this year in time for publication. Where countries have not supplied data for five years or more, the official figures last reported are shown, and estimates for January 1, 1959 are used in computing continental and world totals.

Only those telephones are counted that have access to the general network. Included are main telephones (both individual and party line), extension, private branch exchange, public pay telephones, and official telephones.

Conversation data were not available in all cases. For those of the world's principal countries reporting these statistics, Canada led in the average number of conversations per person with 511, followed by the United States with 472, and Sweden with 346. For the world in general, this figure is estimated at 58.

TELEPHONES IN CONTINENTAL AREAS—JANUARY 1, 1959

Area	Number	Total		Privately Operated		Automatic	
		Percent of Total World	Per 100 Population	Number	Percent of Total	Number	Percent of Total
North America	71 803 700	57.6	37.2	71 014 300	98.9	65 477 500	91.2
Middle America	910 800	0.7	1.4	823 900	90.5	708 800	77.8
South America	2 999 600	2.4	2.2	1 457 600	48.6	2 575 000	85.8
Europe	37 593 900	30.1	6.6	6 216 400	16.5	30 634 700	81.5
Africa	1 768 600	1.4	0.7	32 400	1.8	1 285 200	72.7
Asia	6 855 500	5.5	0.4	4 418 100	64.4	3 968 400	57.9
Oceania	2 867 900	2.3	18.2	206 900	7.2	2 135 500	74.5
World	124 800 000	100.0	4.3	84 169 600	67.4	106 785 100	85.6

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* Abridgement from the 1959 issue of a booklet, "The World's Telephones," published yearly by the American Telephone and Telegraph Company, New York, New York.

TELEPHONES BY COUNTRIES AS OF JANUARY 1, 1959

Country or Area	Number of Telephones	Per 100 Population	Percent Automatic	Telephones by Type of Operation	
				Private	Government
NORTH AMERICA					
Alaska (1)	35 764	20.55	95.3	8 563	27 20
Canada	5 122 519	29.64	81.9	4 360 707	761 812
Greenland	0	—	—	—	—
St. Pierre and Miquelon	397	7.94	0	0	397
United States	66 645 000	37.97	91.9	66 645 000	0
MIDDLE AMERICA					
Bahamas	8 784	6.46	98.9	0	8 784
Bermuda	10 700	23.78	100	10 700	0
British Honduras	872	1.01	0	45	827
Canal Zone (1) (2)	7 670	28.41	100	0	7 670
Costa Rica	12 961	1.19	5.8	12 580	381
Cuba	170 092	2.62	90.2	170 092	0
Dominican Republic	16 592	0.58	87.4	16 292	300
El Salvador	11 973	0.48	78.5	0	11 973
Guadeloupe and Dependencies	2 533	0.97	0	0	2 533
Guatemala	11 717	0.33	85	0	11 717
Haiti	4 239	0.12	85.8	0	4 239
Honduras	5 862	0.32	83.6	0	5 862
Martinique	5 165	1.93	70.8	0	5 165
Mexico	447 984	1.36	71.8	446 404	1 580
Netherlands Antilles	10 706	5.49	97.1	3 426	7 280
Nicaragua (3)	7 000	0.50	70	0	7 000
Panama	23 937	2.37	84.6	23 337	600
Puerto Rico	76 693	3.29	76.4	71 377	5 316
Virgin Islands (United Kingdom)	1	0.01	0	0	1
Virgin Islands (United States)	3 011	10.04	0	0	3 011
West Indies Federation:					
Antigua	709	1.24	0	0	709
Barbados	8 110	3.42	100	8 110	0
Dominica	465	0.72	0	0	465
Grenada	1 339	1.46	100	1 339	0
Jamaica and Dependencies	29 901	1.81	96.9	29 901	0
Montserrat	110	0.79	0	0	110
St. Christopher-Nevis	325	0.61	0	0	325
St. Lucia	566	0.62	71	0	566
St. Vincent	426	0.53	0	0	426
Trinidad and Tobago	30 331	3.79	88.6	30 331	0
SOUTH AMERICA					
Argentina	1 223 509	5.99	86.1	92 230	1 131 279
Bolivia	19 909	0.60	92.8	19 909	0
Brazil	928 117	1.46	83	892 849	35 268
British Guiana	5 178	0.96	16.2	0	5 178
Chile	166 184	2.25	69.4	165 691	493
Colombia	247 298	1.81	96.2	17 311	229 987
Ecuador (3)	25 000	0.62	95	500	24 500
Falkland Islands and Dependencies	395	17.95	0	0	395
French Guiana	881	2.94	0	0	881
Paraguay	9 172	0.54	90.6	0	9 172
Peru	91 242	0.88	82.6	91 242	0
Surinam	4 762	1.77	95.7	0	4 762
Uruguay	135 777	5.01	76.8	1 350	134 427
Venezuela	158 575	2.47	96.4	158 575	0
EUROPE					
Albania	4 813	0.31	50	0	4 813
Andorra	100	1.67	0	0	100
Austria	615 328	8.75	93	0	615 328
Belgium	1 036 305	11.42	85.4	0	1 036 305
Bulgaria (4)	54 347	0.77	39.4	0	54 347
Channel Islands:					
Guernsey and Dependencies	11 565	27.21	27.9	0	11 565
Jersey	16 199	27.93	0	0	16 199
Total	27 764	27.63	11.6	0	27 764
Czechoslovakia (4)	350 708	2.88	59.4	0	350 708
Denmark	978 667	21.53	54.2	865 935	112 732
Finland	545 338	12.41	76.1	409 330	136 008
France	3 703 578	8.29	75	0	3 703 578
Germany, Democratic Republic	1 175 131	6.79	93.5	0	1 175 131
Germany, Federal Republic	5 090 102	9.30	98.2	0	5 090 102
Gibraltar (1)	2 132	8.20	100	0	2 132
Greece	168 993	2.06	92.7	0	168 993
Hungary (3)	425 000	4.30	78	0	425 000

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(1) Excluding telephone systems of the military forces.
(2) June 30, 1958.
(3) Estimated.
(4) January 1, 1948 (latest official statistics).
(5) January 1, 1947 (latest official statistics).
(6) Under government operation since 1949.
(7) March 31, 1959.

TELEPHONES BY COUNTRIES AS OF JANUARY 1, 1959—*Continued*

Country or Area	Number of Telephones	Per 100 Population	Percent Automatic	Telephones by Type of Operation	
				Private	Government
Iceland	36 050	21.08	67.9	0	36 050
Ireland	137 587	4.82	73.3	0	137 587
Italy	3 182 455	6.33	96.4	3 182 455	0
Liechtenstein	3 489	21.81	100	0	3 489
Luxemburg	42 411	13.17	90.7	0	42 411
Malta and Gozo (3)	10 900	3.37	56	0	10 900
Monaco	7 750	36.90	100	0	7 750
Netherlands	1 402 155	12.43	98.3	0	1 402 155
Norway (2)	672 406	19.08	68.8	57 914	614 492
Poland	446 236	1.54	71.3	0	446 236
Portugal	332 309	3.69	71.1	228 878	103 431
Rumania (5)	127 153	0.77	75.8	126 131 (6)	1 022
San Marino	400	2.67	100	0	400
Spain	1 490 151	4.98	78.8	1 470 913	19 238
Sweden	2 526 424	34.00	83.9	0	2 526 424
Switzerland	1 475 003	28.31	99.9	0	1 475 003
Turkey (3)	239 300	0.92	89	0	239 300
Union Soviet Socialist Republics (3)	3 700 000	1.77	50	0	3 700 000
United Kingdom (7)	7 524 789	14.53	80	0	7 524 789
Yugoslavia	217 542	1.19	73.4	0	217 542
AFRICA					
Algeria	164 636	1.59	81.1	0	164 636
Angola	6 235	0.14	98.7	0	6 235
Ascension Island	62	14.90	77.4	62	0
Basutoland (3)	1 000	0.15	10	0	1 000
Bechuanaland	400	0.12	0	0	400
Belgian Congo	24 951	0.19	86.7	0	24 951
Cameroons (French Administration)	4 852	0.15	56.3	0	4 852
Cape Verde Islands	120	0.06	0	0	120
Comoro Islands	0	—	—	—	—
Ethiopia	9 770	0.05	81.2	0	9 770
French Equatorial Africa	7 622	0.15	35	0	7 622
French West Africa	27 149	0 16	70.2	0	27 149
Gambia	591	0.20	98 6	0	591
Ghana	18 666	0.38	57	0	18 666
Guinea	2 779	0.10	71.5	1 702	1 077
Ifni	125	0.25	0	0	125
Kenya	34 397	0.54	79.3	0	34 397
Liberia (3)	2 000	0.15	100	500	1 500
Libya (3)	8 500	0.73	60	0	8 500
Malagasy	12 509	0.24	44.6	0	12 509
Mauritius and Dependencies	8 161	1.33	8.2	0	8 161
Morocco	128 133	1.23	84.5	19 977	108 156
Mozambique	9 973	0.16	87.8	0	9 973
Nigeria, Federation of, and British Cameroons	29 349	0.08	42.2	0	29 349
Portuguese Guinea	364	0.06	0	0	364
Reunion	5 374	1.68	0	0	5 374
Rhodesia and Nyasaland:					
Northern Rhodesia	19 888	0.85	93.3	1 604	18 284
Nyasaland	4 730	0.17	89.5	0	4 730
Southern Rhodesia	71 152	2.52	86.6	0	71 152
Total	95 770	1.21	88.1	1 604	94 166
Ruanda-Urundi	1 514	0.03	93.4	0	1 514
St. Helena	122	2.44	0	0	122
São Tomé and Principe	362	0.57	74	0	362
Seychelles and Dependencies	182	0.43	100	182	0
Sierra Leone	3 670	0.17	80.4	0	3 670
Somaliland, British Protectorate	383	0.06	0	0	383
Somaliland, French	851	1.22	100	0	851
Somaliland (Italian Administration)	1 400	0.11	0	0	1 400
South West Africa	13 039	2.39	41.7	0	13 039
Spanish Guinea	831	0.39	92.5	831	0
Spanish North Africa	6 991	4.54	100	6 991	0
Spanish Sahara	45	0.35	0	0	45
Sudan	20 727	0.19	75.3	0	20 727
Swaziland	1 300	0.49	38.5	0	1 300
Tanganyika	12 723	0.14	66	0	12 723
Togoland	1 329	0.11	58.5	0	1 329
Tunisia	23 843	0.61	52	0	23 843
Uganda	12 396	0.21	77.4	0	12 396
Union of South Africa (7)	887 601	6.08	68.7	0	887 601
United Arab Republic—Egypt	185 452	0.75	81.3	0	185 452
Zanzibar and Pemba	1 206	0.40	75.1	0	1 206

Telephones by Countries as of January 1, 1959—*Continued*

Country or Area		Number of Telephones	Per 100 Population	Percent Automatic	Telephones by Type of Operation	
					Private	Government
ASIA						
Aden Colony		4 227	3.06	100	0	4 227
Aden Protectorate		0	—	—	—	—
Afghanistan	(3)	7 000	0.05	30	0	7 000
Bahrain		2 657	2.13	100	2 657	0
Bhutan		0	—	—	—	—
Brunei		500	0.67	100	0	500
Burma		10 786	0.05	12.6	0	10 786
Cambodia	(3)	3 000	0.06	0	0	3 000
Ceylon		32 235	0.34	97.3	0	32 235
China, Mainland	(4)	244 028	0.05	72.9	94 945 (6)	149 083
China, Taiwan		58 528	0.58	59.4	0	58 528
Cyprus	(3)	16 700	3.01	90	0	16 700
Hong Kong		86 000	3.06	100	86 000	0
India	(7)	378 496	0.09	58.8	3 200	375 296
Indonesia		90 968	0.10	10.1	0	90 968
Iran		80 976	0.41	60.5	0	80 976
Iraq	(7)	44 310	0.65	76.5	0	44 310
Israel		90 373	4.45	93.6	0	90 373
Japan	(7)	4 334 602	4.69	54.4	4 334 602	0
Jordan		17 186	1.07	68	0	17 186
Korea, Republic of		67 398	0.30	47.5	0	67 398
Kuwait	(3)	2 500	1.18	80	0	2 500
Laos		668	0.03	53.9	0	668
Lebanon		42 290	2.64	92.2	0	42 290
Macao		1 935	0.92	100	0	1 935
Malaya		64 978	1.00	67.6	0	64 978
Maldive Islands		0	—	—	—	—
Muscat and Oman		159	0.03	100	159	0
Nepal		0	—	—	—	—
Netherlands New Guinea		1 576	0.23	0	0	1 576
North Borneo		2 413	0.58	96.3	0	2 413
Pakistan		63 905	0.07	69.1	0	63 905
Philippine Republic		87 515	0.38	69.7	76 353	11 162
Portuguese India		475	0.07	0	0	475
Portuguese Timor		484	0.10	0	0	484
Qatar		859	2.05	100	859	0
Ryukyu Islands	(1)	6 150	0.73	31.7	0	6 150
Sarawak		2 682	0.41	72.9	0	2 682
Saudi Arabia	(3)	20 000	0.29	10	0	20 000
Singapore		50 182	3.24	100	0	50 182
Thailand		31 927	0.15	82.6	26 374	5 553
Trucial Oman		0	—	—	—	—
United Arab Republic—Syria		43 800	1.00	83.3	0	43 800
Viet-Nam, Republic of		13 445	0.10	79	0	13 445
Yemen		0	—	—	—	—
OCEANIA						
Australia		1 998 704	20.08	74.4	0	1 998 704
British Solomon Islands		286	0.27	0	0	286
Caroline Islands		215	0.50	0	0	215
Christmas Island		50	1.67	100	50	0
Cocos (Keeling) Islands		59	5.90	100	0	59
Cook Islands		236	1.39	0	0	236
Fiji Islands		5 797	1.53	59.5	0	5 797
Gilbert and Ellice Islands		0	—	—	—	—
Guam		11 327	15.95	100	0	11 327
Hawaii		206 814	32.42	100	206 814	0
Mariana Islands (less Guam)		350	5.00	71.4	0	350
Marshall Islands		545	3.89	99.1	0	545
Nauru		0	—	—	—	—
New Caledonia and Dependencies	(3)	3 000	4.29	65	0	3 000
New Hebrides Condominium		280	0.54	0	0	280
New Zealand	(7)	641 342	27.57	66.3	0	641 342
Niue Island		85	1.70	0	0	85
Norfolk Island		50	5.00	0	0	50
Papua and New Guinea		4 992	0.27	80.7	0	4 992
Pitcairn Island		0	—	—	—	—
Polynesia, French		1 083	1.41	0	0	1 083
Samoa, American		370	1.76	100	0	370
Samoa, Western		765	0.75	0	0	765
Tokelau Islands		0	—	—	—	—
Tonga (Friendly) Islands		589	0.98	0	0	589

TELEPHONE CONVERSATIONS DURING 1958

Data were not available for all countries

Country or Area	Thousands of Conversations			Average Conversations Per Person
	Local	Long Distance	Total	
Alaska	105 000	1 000	106 000	609.2
Algeria	90 200	26 200	116 400	11.3
Argentina	3 575 800	45 000	3 620 800	178.8
Australia	1 295 300	112 700	1 408 000	143.0
Belgium	554 200	103 500	657 700	72.6
Bermuda	12 500	(1)	12 500	277.8
Brazil	5 214 000	66 900	5 280 900	84.2
Canada	8 517 000	194 200	8 711 200	511.0
Ceylon	75 900	5 200	81 100	8.6
Channel Islands	17 200	600	17 800	177.1
Chile	400 200	24 100	424 300	58.1
Colombia	774 000	9 000	783 000	57.9
Costa Rica	52 000	900	52 900	49.3
Cuba	489 900	6 700	496 600	76.8
Denmark	1 062 200	209 000	1 271 200	280.6
Dominican Republic	58 600	400	59 000	21.1
El Salvador	21 400	2 600	24 000	9.9
French West Africa	18 400	2 600	21 000	1.3
Germany, Democratic Republic	757 000	148 600	905 600	52.2
Germany, Federal Republic	2 964 800	812 600	3 777 400	69.5
Ghana	13 900	2 000	15 900	3.3
Greece	402 400	8 500	410 900	50.3
Hawaii	336 200	1 500	337 700	536.0
Iceland	80 300	1 900	82 200	486.4
Ireland	104 200	15 900	120 100	42.1
Israel	187 500	5 200	192 700	96.5
Italy	4 774 000	359 600*	5 133 600	105.3
Jamaica, West Indies	110 000	1 000	111 000	68.1
Japan (2)	11 400 000	771 000	12 171 000	132.6
Lebanon	64 700	10 000	74 700	47.4
Malagasy	7 700	1 000	8 700	1.7
Malaya	158 300	15 900	174 200	26.8
Mexico	911 000	14 800	925 800	28.6
Morocco	86 600	9 500	96 100	9.3
Netherlands	923 500	361 200	1 284 700	115.0
Netherlands Antilles	25 000	(1)	25 000	129.5
Nigeria, Federation of, and British Cameroons	26 100	2 400	28 500	0.8
Norway (3)	512 800	57 200	570 000	162.4
Peru	441 700	4 400	446 100	43.7
Philippines	537 200	1 100	538 300	23.3
Portugal	295 300	57 300	352 600	39.3
Puerto Rico	156 000	3 600	159 600	68.9
Singapore	155 200	1 900	157 100	103.7
South West Africa	12 700	1 800	14 500	26.9
Spain	2 895 000	107 500	3 002 500	101.2
Sweden (4)	2 466 300	109 300	2 575 600	346.4
Switzerland	585 900	484 600*	1 070 500	206.5
Trinidad and Tobago, West Indies	93 000	7 100	100 100	126.9
Tunisia	23 100	4 900	28 000	7.3
Union of South Africa (2)	948 300	69 500	1 017 800	70.6
United Arab Republic—Egypt	552 700	14 200	566 900	23.3
United Arab Republic—Syria	110 000	9 700	119 700	28.0
United Kingdom (2)	3 650 000	343 000	3 993 000	77.2
United States	79 230 000	3 040 000	82 270 000	472.4
Uruguay	372 300	7 600	379 900	140.7
Viet-Nam, Republic of	16 600	200	16 800	1.3
Yugoslavia	341 400	26 600	368 000	20.2

(1) Less than 100 thousand.
(2) Year ended March 31, 1959.
(3) Year ended June 30, 1958.
(4) Year ended June 30, 1959.
* Three-minute units.

United States Patents Issued to International Telephone and Telegraph System; May 1, 1959—October 31, 1959

BETWEEN May 1, 1959 and October 31, 1959, the United States Patent Office issued 128 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

R. T. Adams, ITT Laboratories, Diversity Receiving System, 2 903 577.

R. T. Adams and J. B. Harvey, ITT Laboratories, Sliding-Contact Device for Tuning Coils, 2 894 233.

F. J. Altman, ITT Laboratories, Diversity Receiving Combining System, 2 903 576.

M. Arditi and E. S. Nassor, ITT Laboratories, Variable Attenuators, 2 890 424.

G. W. Bain, ITT Laboratories, Polarized Electroluminescent Phosphors and Dielectrics, 2 887 601

G. W. Bain, Farnsworth Electronics Company, Delay Line, 2 892 104.

R. M. Barnard, D. S. Girling, and N. C. W. Judd, Standard Telephones and Cables (London), Manufacture of Electrical Capacitors, 2 903 780.

R. F. Baum, ITT Laboratories, Narrow-Band Discriminator Circuit, 2 889 458

A. H. W. Beck, T. M. Jackson, and J. Lytollis, Standard Telephones and Cables (London), Cold-Cathode Electric Discharge Tubes, 2 898 502.

E. M. Bradburd, ITT Laboratories, Pulse-Shaper Circuit, 2 890 420.

R. W. Brandt, Capehart–Farnsworth Company, Clipper Circuit, 2 896 077.

F. H. Bray, P. M. King, and J. Rice, Standard Telecommunication Laboratories (London), Timing Equipment, 2 899 500.

F. H. Bray and R. G. Knight, Standard Telephones and Cables (London), Electric Counting Circuits, 2 906 888.

J. H. Bryan, A. G. Peifer, and R. W. Wilmarth, ITT Laboratories, Radio-Frequency Coupling Arrangements for Traveling-Wave Tubes, 2 894 227.

H. G. Busignies, ITT Laboratories, Channeling System for Frequency Spectrum Transmission, 2 895 009.

R. Chapman and L. E. Robinson, Kolster–Brandes Limited (Sidcup), Semiconductor Amplifiers, 2 901 556.

R. F. Chapman, ITT Laboratories, Synchronization of Rotating Elements, 2 894 187.

W. H. Cooper, Federal Telephone and Radio Company, Crystal Contact Device, 2 891 201.

J. L. Culbertson, Kellogg Switchboard and Supply Company, Code-Ringing Call-Intercepting Telephone System, 2 888 519.

W. J. Curry, Federal Telephone and Radio Company, Process of Coating Cathode-Ray-Tube Screens, 2 888 361.

D. Davidoff, ITT Laboratories, Bias Power-Supply Source, 2 906 964.

C. L. Day, ITT Laboratories, Electron Discharge Assembly, 2 892 087.

C. L. Day, Capehart–Farnsworth Company, Electron Discharge Device, 2 894 164.

E. C. L. deFaymoreau and M. Mandel ITT Laboratories, Triggered Pulse Generator, 2 906 874.

M. Den Hertog, Bell Telephone Manufacturing Company (Antwerp), Relay Recorder, 2 887 624.

R. F. Durst and B. Jacobs, Federal Telephone and Radio Company, Housing Containing Electric Crystal Surrounded by Siloxane Resin and Calcium Chloride Composition, 2 902 633.

A. S. Epstein, ITT Laboratories, Mold for Fabricating Semiconductor Signal Translating Devices, 2 888 782.

L. G. Fischer and R. C. Neunzig, ITT Laboratories, Triggered Pulse Generator, 2 889 457.

H. W. Gates, Capehart–Farnsworth Company, Frequency-Modulating System, 2 887 663.

W. L. Glomb, ITT Laboratories, Synchronized Oscillators, 2 903 650.

W. L. Glomb, ITT Laboratories, Time-Delay Circuit, 2 894 153.

R. Goerlich, Mix & Genest (Stuttgart), Registry Card-Indexes, 2 908 278.

T. J. Goldan, ITT Laboratories, Microwave Energy Time-Delay Devices, 2 894 222.

L. Goldstein, P. E. Dorney, and M. A. Lampert, ITT Laboratories, Ultra-High-Frequency Amplitude Modulator, 2 903 652.

B. J. Green, Standard Telephones and Cables (London), Thermionic-Cathode Heaters, 2 885 334.

T. Grewe, Mix & Genest (Stuttgart), Oscillator Circuit for Transistors, 2 896 170.

H. Grottrup, C. Lorenz (Stuttgart), Mechanical Device for Reading and Storing the Working Positions of a Moving Machine Element, 2 890 301.

W. Hatton, ITT Laboratories, Party-Line Identification System, 2 889 410.

J. A. Henderson, ITT Laboratories, Charge-Storage Device, 2 908 836.

L. Himmel and H. F. Kuras, ITT Laboratories, Broad-Band Omnipolarized Multiple Antenna System with each Antenna Having Individual Detector and Low-Frequency Coupling Network, 2 894 124.

R. C. P. Hinton and B. Dzula, ITT Laboratories, Calling-Station Identification, 2 894 069.

H. W. Hoffman, American Cable & Radio Corporation, Tape Feed-Out Devices for Telegraph Apparatus, 2 892 032.

E. P. Hoyt, Capehart–Farnsworth Company, Television Tuning Indicator, 2 905 759.

U. Hubner, Mix & Genest (Stuttgart), Electromagnetic Impulse Counter, 2 896 191.

R. W. Hughes and H. K. Flesch, ITT Laboratories, Data-Processing Control System, 2 894 249.

M. Ito, Nippon Electric Company (Tokyo), Charged-Particle Beam-Focusing System, 2 902 622.

T. M. Jackson and E. A. F. Sell, Standard Telephones and Cables (London), Electric Discharge Tubes, 2 896 122.

W. Keilig, Mix & Genest (Stuttgart), Marking Device for Edgewise Conveyor Systems, 2 891 467.

W. Klein and W. Friz, C. Lorenz (Stuttgart), High-Compression Beam-Generating System Especially for Velocity-Modulated Tubes, 2 905 847.

W. Klein, W. Friz, and G. Osswald, C. Lorenz (Stuttgart), Coupling Arrangement for Traveling-Wave Tubes, 2 908 843.

G. F. Klepp, Standard Telephones and Cables (London), Gas-Filled Electric Discharge Tube, 2 894 164.

A. J. Knight, ITT Laboratories, Image-Storage Screens and Method of Making Same, 2 901 649.

J. Kruithof, L. J. G. Nys, and J. L. J. Donceel, Bell Telephone Manufacturing Company (Antwerp), Operating Mechanism, 2 892 134.

P. W. Kruse, ITT Laboratories, Image Intensifiers, 2 892 096.

J. A. Leno, Standard Telephones and Cables (London), Terminal Assembly with Cells for Electric Components, 2 902 628.

G. X. Lens, Bell Telephone Manufacturing Company (Antwerp), Conveyors, 2 886 166.

A. Lesti, Federal Telecommunication Laboratories, Diode Coincidence Gate, 2 897 355.

A. M. Levine, ITT Laboratories, Means for Reducing Noise Effects in Television Receivers, 2 906 829.

A. M. Levine and R. S. Bailey, ITT Laboratories, Automatic Frequency Control in Pulse Modulation Systems, 2 889 521.

A. Lieb, C. Lorenz (Stuttgart), Cathode for Electric Discharge Tubes, 2 902 619.

P. E. Lighty, ITT Laboratories, Selenium Rectifier, 2 889 500.

M. Linsman, Bell Telephone Manufacturing Company (Antwerp), Check Symbol Apparatus, 2 886 240.

A. J. Lombardi, ITT Laboratories, Resonant Cavity with Fixed-Contact Adjustable Plunger, 2 903 659.

F. T. Machalek, Farnsworth Electronics Company, Piano Action, 2 905 041.

C. P. Majkrzak, ITT Laboratories, Sliding-Contact Device for Tuning Coils, 2 895 115.

F. P. Mason, Creed & Company (Croydon), Facsimile Recording Apparatus, 2 889 398.

F. P. Mason and R. G. Stemp, Creed & Company (Croydon) Printing-Telegraph Transmitter Control, 2 903 106.

M. Masonson, ITT Laboratories, Correlation System, 2 906 956.

K. A. Mathews and R. A. Hyman, Standard Telecommunication Laboratories (London), Electronic Distributor Devices, 2 886 739.

J. Matthieu, Mix & Genest (Stuttgart), Relay Chains Comprising Magnetic Counting or Storing Relay, 2 896 129.

S. E. Mayer and J. M. Waddell, Standard Telephones and Cables (London), Magnetic Control Circuit, 2 907 885.

A. Mehlis, Mix & Genest (Stuttgart), Arrangement to Inspect Stacked Legendized Papers, in Particular to Read the Addresses of Stacked Letters, 2 889 941.

M. L. Miller, Farnsworth Research Corporation, Radio Guidance System, 2 892 189.

F. H. Mittag, Mix & Genest (Stuttgart), Arrangement to Produce Electric Signals Through Affecting a Magnetic Circuit, 2 901 676.

F. H. Mittag, Mix & Genest (Stuttgart), Circuit Arrangements for Originating Electric Currents or Potentials for Signal or Control Purposes, 2 906 942.

B. J. Norris, ITT Laboratories, Timing Circuits, 2 892 083.

A. D. Odell and G. I. Turner, Standard Telephones and Cables (London), Electric Circuits Employing Transistors, 2 906 890.

H. Oden, C. Lorenz (Stuttgart), Circuit Arrangement for Time-Zone Meters, 2 887 536.

R. K. Orthuber, Farnsworth Electronics Company, Checking Systems, 2 899 132.

R. K. Orthuber, Farnsworth Electronics Company, Detecting Apparatus, 2 892 078.

R. K. Orthuber and C. C. Larson, ITT Laboratories, Image Device, 2 892 095.

R. K. Orthuber, C. V. Stanley, and C. L. Day, Capehart–Farnsworth Company, Electron Discharge Devices, 2 894 163.

R. K. Orthuber, C. V. Stanley, and S. G. Fong, Farnsworth Electronics Company, Apparatus for Detecting Hot Journal Boxes, 2 906 885.

S. B. Pickles, ITT Laboratories, Aerial-Navigation Equipment, 2 889 551.

S. B. Pickles, S. H. M. Dodington, and G. Stavis, ITT Laboratories, Radio Navigation System, 2 890 449.

R. L. Plouffe, Jr., ITT Laboratories, Control Circuit, 2 885 476.

J. Polyzou and J. H. Brundage, ITT Laboratories, Discriminator Circuit, 2 906 873.

A. J. Radcliffe, Jr., Kellogg Switchboard and Supply Company, Negative-Impedance Repeater Using a Transistor Amplifier, 2 904 641.

A. J. Radcliffe, Jr., Kellogg Switchboard and Supply Company, Transistor Test Set, 2 907 954.

K. E. Raithel, Süddeutsche Apparatefabrik (Nuremberg), Crystal Rectifier or Crystal Amplifier, 2 906 930.

D. C. Rogers, Standard Telephones and Cables (London), Electron Discharge Apparatus, 2 889 478.

D. C. Rogers, Standard Telephones and Cables (London), Traveling-Wave Tubes, 2 890 370.

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Methods of Producing Silicon of High Purity

2 888 328

J. M. Wilson

A process is described for manufacturing silane by a reaction between silicon tetrachloride and lithium aluminum hydride. The reaction is carried out by adding silicon tetrachloride to an excess quantity of the lithium aluminum hydride and maintaining the excess of this hydride during the action so that the product of diborane as an impurity in the silane will be a minimum.

Production of Semiconductor Material for Rectifiers

2 910 394

T. R. Scott, G. King, and J. M. Wilson

This process is for producing a coherent body of a semiconductor such as silicon containing a predetermined minor amount of a significant impurity having the desired conductive characteristic. The body is produced by introducing into a limited heating zone a continuous stream of silicon hydride together with a controllable stream of a hydride of the significant impurity. These streams are directed onto a surface that is maintained at a sufficiently high temperature to cause the decomposition of the hydrides. The flow is so controlled that the decomposition takes place substantially wholly on the surface of this area.

Radio Navigation System

2 890 449

S. B. Pickles, S. H. M. Dodington, and G. Stavis

This patent covers a tacan radio beacon system in which the beacon transmitter is triggered by interrogation pulses from the craft and these pulses are re-radiated and picked up on the craft. Reference signal pulses are also transmitted from the beacon between replies to trigger pulses. On the craft there is an equipment for comparing the phase of the reference signal with the envelope wave of the re-radiated pattern to obtain azimuth and for comparing the interrogation pulses with the returned pulses to obtain distance measurements. The patent covers both the radio beacon and the airborne equipment.

Electric Pulse-Code-Modulation Systems

2 902 542

C. G. Treadwell

This pulse-code-modulation system is of the type using a multiple-element code in which each of the code elements is made up of pulses of opposite polarities. By using interspaced elements of different polarities the encoding of the signal is simplified.

Submarine-Cable Repeater Housings

2 894 055

W. Weston, G. W. Clarke, and R. J. M. Andrews

A submarine repeater in which the repeater proper is enclosed in a region of relatively low pressure is described. Bulkheads are provided between different sections of the repeater housing and the sections fastened to the cable are at a higher pressure to prevent collapse due to the water pressure. The bushings connecting the housing with the cable sheath are of slightly smaller internal diameter than the cable so that a moisturetight seal is assured.

Charge-Storage Device

2 908 836

J. A. Henderson

A screen is described for storing electrostatic charges in a mosaic pattern in response to the scanning of the screen by an electron beam. The screen is a perforate conductive plate with the edge portion of each perforation coated with secondary-emissive dielectric material. On scanning the screen by the beam, an electrostatic charge will be stored in the dielectric material depending on the instantaneous strength of the beam at the moment it strikes these areas. This screen construction permits very accurate location of the storage elements throughout the screen area.

Telecommunication Equipment

2 896 019

E. P. G. Wright, D. A. Weir, and J. Rice

The equipment is used in connection with the Strad system for measuring the succession of time intervals required for various stored messages. A storage device is moved past recording and reading devices at a substantially uniform speed. The recording device initially inserts a mark on the storing device and thereafter the reading device detects this mark, produces a time signal, and causes a recording device to record a further mark after a fixed time interval. This reading and re-recording is continued until a desired number of fixed time intervals have been measured. A plurality of these time-measuring recordings and readings may be in progress by one or more users of the system at the same time.

Crystal Rectifier or Crystal Amplifier

2 906 930

K. E. Raithel

This arrangement is for providing a terminal for a crystal rectifier or amplifier. The crystal is a semiconductor with a drop of impurity covering a small part of its surface. The terminal is made without spreading this drop of material further by having the conductive wire terminal provided with two parts separated so that it can be inserted into the molten impurity and by capillary attraction the impurity material will surround the conductor and fill this capillary space.

Arrangement to Inspect Stacked Legendized Papers, in Particular to Read the Addresses of Stacked Letters

2 889 941

A. Mehlis

An arrangement is disclosed for inspecting flat objects such as letters so that the location of the stamp can be ascertained regardless of the position of the letter. The letter is conveyed in an edgewise position along the belt and images of both sides of the letter are simultaneously produced on a screen. In accordance with the position of the letter, the stamp location is determined and the letter is switched to the proper conveyor so that all the stamps can be arranged in the same position.

Charged-Particle Beam-Focusing System

2 902 622

M. Ito

A slow-wave structure for a traveling-wave tube is made of three separate interspaced helical windings to which the carrier to be amplified is applied in parallel. The three separate conductors are also connected to a three-phase alternating source so the slow-wave conductors themselves produce the required longitudinal magnetic field. The structure therefore does not require an external magnet.

Delay Line

2 892 104

G. W. Bain

An arrangement is provided for taking signals from a delay line at desired points along this line by providing a gating circuit coupled across the line. The gating circuit is controlled by a series of pulses on a separate line and serves to prevent the passage of a pulse beyond this point. The pulses will be shunted out on the desired output line associated with the operated gate. For gating circuits, both ferromagnetic cores and transistors are disclosed.

Apparatus for Detecting Hot Journal Boxes

2 906 885

R. K. Orthuber, C. V. Stanley, and S. G. Fong

In this hot-box-detector arrangement, provision is made for assuring that an alarm is not effected should added heat be applied to the detector because of an open cover on a journal box. To inhibit operation of the alarm under such conditions, a light source is directed toward the point where the journal axle will be at the time the measurement is made and a light-sensitive detector positioned to receive light from the source reflected from the axle end. When such light is received a relay inhibits operation of the alarm signal.

In Memoriam

FERNAND P. GOHOREL

FERNAND P. GOHOREL was born on August 18, 1897, in Rouen, France. He received an engineering degree in 1918 from Ecoles Nationales des Arts et Métiers, which also conferred on him its Gold Medal. In 1919, he received the title of Ingénieur Diplômé de l'Ecole Supérieure d'Electricité de Paris.

His engineering career started in 1919 in the telephone department of the Compagnie Française Thomson–Houston, which in 1924, became a part of the International System and is now known as the Compagnie Générale de Constructions Téléphoniques. He served as head of the technical department from 1931 to 1936, as technical and commercial manager from 1936 to 1940, and as general manager from 1940 on. In 1953 he also became president of the company.

One of his outstanding contributions to the telephone field is the development and introduction on a world-wide scale of a new crossbar switching system named Pentaconta. He personally conceived this system and supervised its development.

Mr. Gohorel was made a Chevalier de la Légion d'Honneur in 1950.

Having served from 1948 to 1954 as president of the Association of French Telephone Manufacturers, he was made an honorary president of that group. His general activities in the industry were extensive.

Mr. Gohorel died at Memorial Hospital in New York City on April 30, 1960, after a lingering illness.

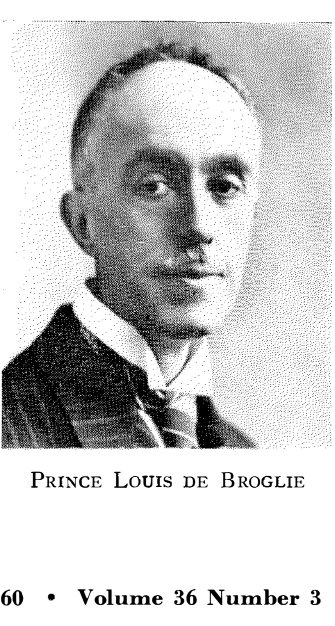
Contributors to This Issue

Hans H. Adelaar

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; he is now in charge of a development group on electronic switching. He reports in this issue on the use of a computer to calculate a traffic table for an electronic exchange.



Prince Louis de Broglie

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

* * *

Prince Louis de Broglie was born in Dieppe in 1892. After taking literary studies, he turned toward science and obtained his M.S. degree in 1913. During the first world war, he was assigned to military radiotelegraphy.

After the war, he specialized in theoretical physics and in 1924 presented a thesis of considerable importance, as the ideas contained therein, being confirmed by the electron-diffraction experiments of 1927 by Davisson and Germer, served as a basis for the development of wave mechanics.

Prince de Broglie was appointed professor of theoretical physics at the University of Paris in 1932 and each year since, has given a course on a different subject. He also conducts research in the field of wave mechanics.

He has published numerous papers and several books notably on Dirac's theory of the electron, the new theory on light, the general theory of particles with spin, and the application of wave mechanics to nuclear physics. Since 1951, in collaboration with young physicists, he has worked to give wave mechanics a causal interpretation in the conventional framework of space and time.

The remarkable work of Prince Louis de Broglie has brought him a great number of honors, notably the Nobel Prize in Physics, which he received in 1929 for "the discovery of the wave nature of the electron" and, in 1952, the Kalinga prize of UNESCO for his work to popularize high science.

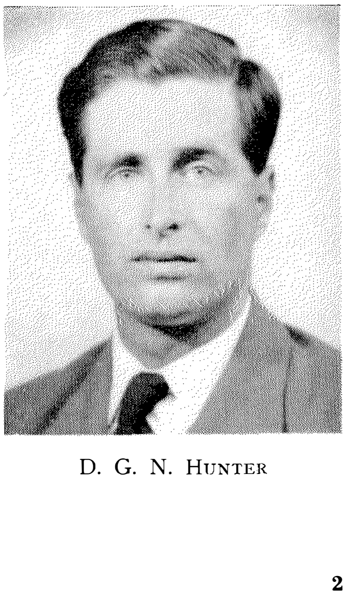
Prince de Broglie has been a member of the French Academy of Sciences since 1933 and perpetual secretary since 1942. He was elected to the Académie Française in 1944. He is doctor honoris causa of 5 universities and is a member of 17 foreign academies.

* * *

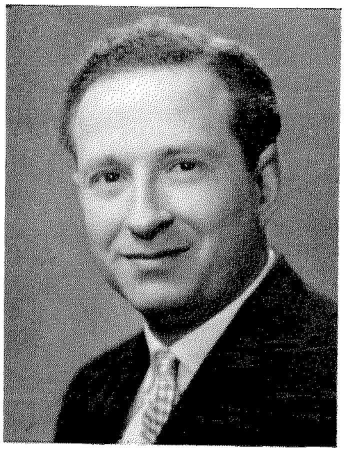
Georges Goudet

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



D. G. N. Hunter



W. J. Pohl

in 1955 became director of that laboratory.

He is the author of numerous publications and a coauthor of 7 books. He discusses a 240-line electronic telephone exchange in this issue.

Dr. Goudet is a member of the Société Française de Physique, Société des Radioélectriciens, a vice president of the Société Française des Radioelectriciens, and a Fellow of the Institute of Radio Engineers.

• • •

D. G. N. Hunter was born at Tsinan, North China, on January 8, 1928. He received B.A. and M.A. degrees in physics in 1949 and 1953, respectively, from Selwyn College, Cambridge.

He spent two years at the university mathematical laboratory working on magnetic drums and computing circuits. In 1951 he joined Standard Telecommunication Laboratories, where he has been engaged in work on magnetic-drum and ferrite stores and also on the design of computing circuits.

He is currently working on the application of programming to the simulation and control of electronic switching systems. He reports in this issue on the use of a computer to calculate a traffic table for an electronic exchange.

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Bent Bulow Jacobsen. A photograph and biography of Mr. Jacobsen, author of the paper on the statistics of noise in long-distance telephone circuits, appears on page 76 of Volume 36, Number 1, of *Electrical Communication*.

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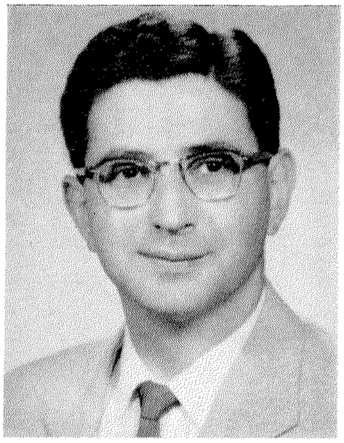
W. J. Pohl received from the University of Birmingham a bachelor of science degree in 1944 and a master of science degree in 1949.

After working for the General Electric Company and for Mullard, he joined the valve division of Standard Telephones and Cables in 1951. Three years later, he became section head of the department concerned with power-tube development and design, a subject on which he reports in this issue.

He came to the United States in 1959 and is now with the General Electric Company at Schenectady, New York.

• • •

Louis Pollack was born on November 4, 1920, in New York City. He received his batchelor's degree in electrical engineering from the College of the City of New York in 1953.



Louis Pollack

From 1941 through 1943, he was a chief engineering aide at the Fort Monmouth Signal Development Laboratory and the Alaska Defense Command, engaged in the installation and maintenance of electronic apparatus.

Mr. Pollack joined ITT Laboratories in 1943 and has engaged in the development of microwave equipment and television apparatus. He is presently project manager of space communication systems and communication systems for antisubmarine warfare. In this issue, he describes long-distance communication systems using artificial satellites.

He is a member of the Institute of Radio Engineers, the American Rocket Society, and has been active in the engineering work of the Electronics Industries Association.

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