Mr. A. Ramsay

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International Telephone and Telegraph Corporation
and Associate Companies

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ELECTRICAL COMMUNICATION

Technical Journal of the
International Telephone and Telegraph Corporation
and Associate Companies

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Photograph courtesy of "The Times," London.

Her Majesty Queen Elizabeth is shown leaving the Annexe to Westminster Abbey after her Coronation. Standard Telephones and Cables, Limited, was greatly privileged to supply and operate much of the sound-reproduction, public-address, television, and broadcasting equipment that enabled this great event to be heard and seen throughout the world.

Teleprinter Installation for Hotel Room Service

OPENED IN 1951 in Oslo, Norway, the Hotel Viking (Figure 1) is not only one of the newest hotels in Scandinavia, but it is also one of the largest, having accommodation for 600 guests.

In planning the appointments of this modern hotel, particular attention was given to the design of an efficient and speedy system for handling the guests' room-service orders. Various methods of communication were evaluated, and

Figure 1—Hotel Viking, Oslo, Norway; first hotel using a Creed and Company teleprinter system to expedite room service.

it became evident that the installation of a system of Creed and Company teleprinters would provide the ideal answer, offering the speed and flexibility of telephone service with the accuracy and permanence of the printed record.

The installation in the hotel, as indicated in Figure 2, consists of one sending-receiving page teleprinter in the telephone exchange. There are 15 receiving-only page teleprinters placed at the service stations on the various floors of the hotel; one is installed in the main kitchen, and another in the cashier's office. All 17 receiving teleprinters are under the control of the sending–receiving machine; the receiver in the cashier's office is permanently connected to the transmitter, but connection to any of the other receivers is established at will by use of a simple switchboard.

The system operates in the following manner. A guest staying, for example, in room 1123 on the 11th floor might desire a luncheon. On picking up his telephone and asking the operator for "room service," he would be connected with the operator at the sending–receiving teleprinter (Figure 3). This operator would immediately connect her machine with the receiving teleprinters in the kitchen and at the 11th-floor

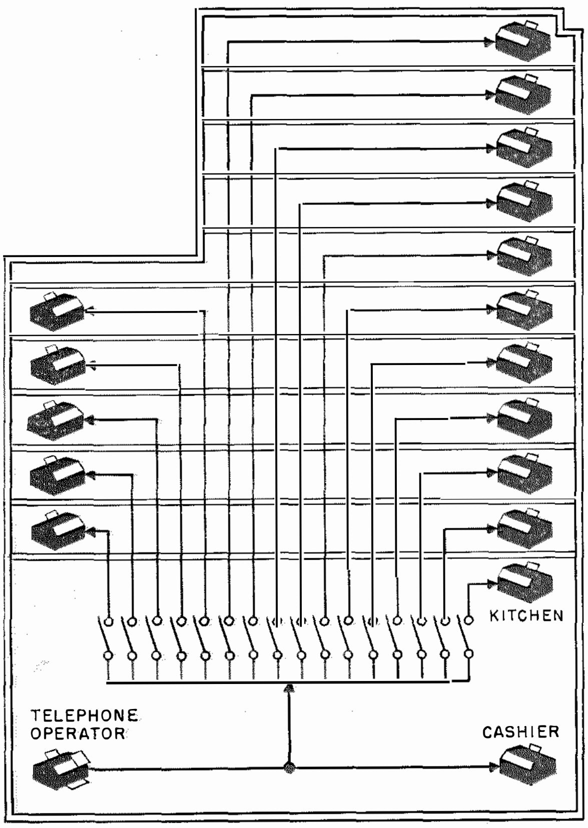


Figure 2—The system incorporates a sending–receiving teleprinter in the telephone exchange and 17 receivers located on various floors of the building.

service station. She then transcribes the guest's order on her machine. The connected receivers reproduce this order automatically. As the sending machine also prints a record of the order, errors are virtually impossible, since the operator need only look at the reproduced message to check her accuracy.

For the order under consideration, the sending machine and the receiving machines on the 11th floor, in the kitchen, and in the cashier's office would simultaneously print the following:

```
1123        168
1  COFFEE                  1.00 KR
1123        169
1  SHRIMP SANDWICH
1  HAM SANDWICH
1  CHEESE SANDWICH         4.30 KR
```

Billing control is facilitated by arranging for the service-station receivers to print all orders in black while the receiver in the cashier's office prints only in green. These two machines provide single copies of all orders, but the receiver in the main kitchen prints all orders in duplicate, one red copy and one black.

In the kitchen, the two copies of the order are separated, the red copy being retained there for record purposes while the black copy accompanies the food when it is sent by lift to the 11th-floor service station. Here the waitress in charge has already received a copy of the order on her receiver (Figure 4), and is thus able to double-check the order before delivering it to the guest. Meanwhile, the clerk in the cashier's office removes the green copy from his machine and books it to the guests account, thus completing the order cycle.

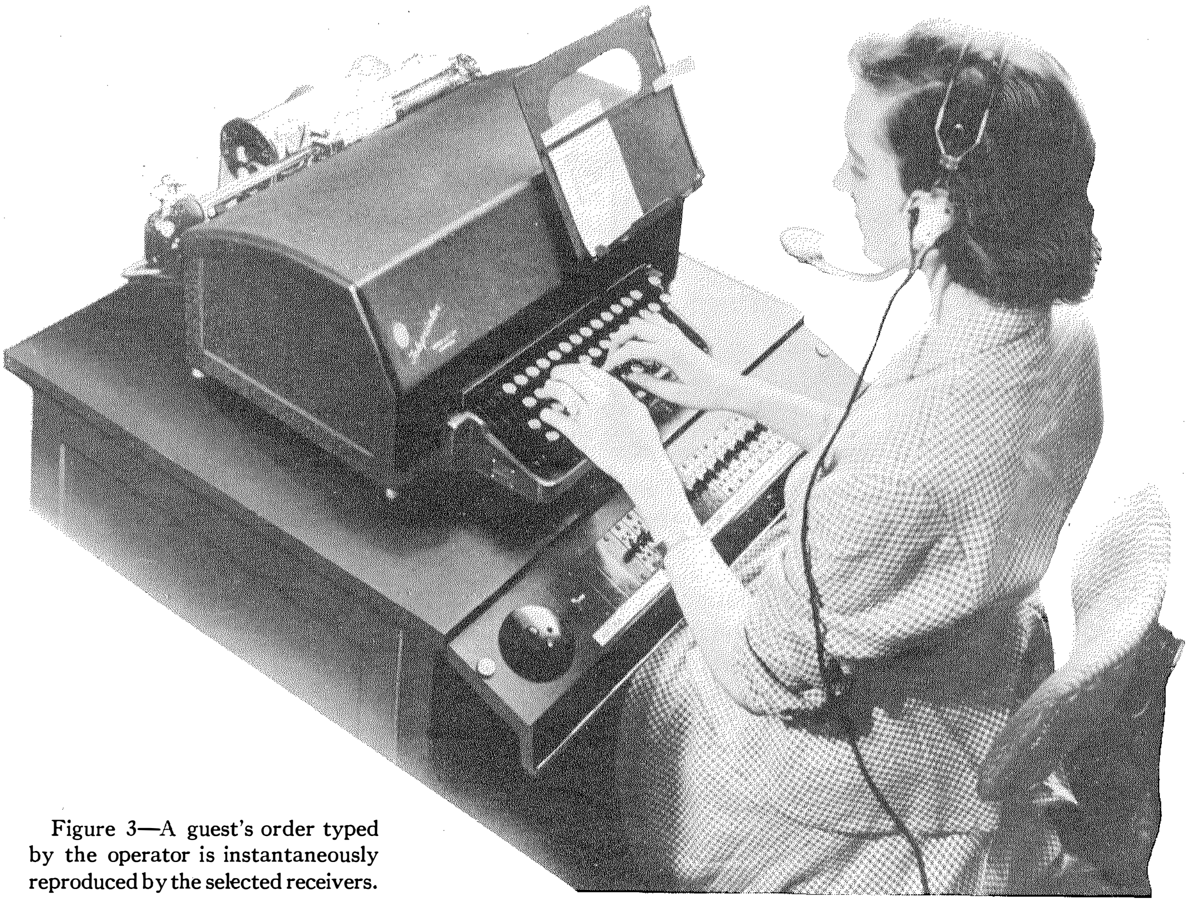


Figure 3—A guest's order typed by the operator is instantaneously reproduced by the selected receivers.

The service stations carry a small stock of beer, cigarettes, and other popular small items, and should a guest order items of this category only, the operator does not connect the kitchen receiver, communication being confined to the appropriate service station and the cashier's office.

For example, a guest staying in room 434 on the fourth floor may already have settled his account, but wishes a bottle of beer just prior to his departure. The exchange operator would then transmit the following.

Figure 4—A waitress removes an order from the receiving teleprinter at one of the room-service stations on an upper floor.

```
PASSANT
434        170
1 BOTTLE BEER        1.50 KR
BEER TAX             0.40 KR
```

In this case, the guest would be served by the 4th-floor waitress within a minute or so of placing his order. The word "passant" indicates to the waitress that the guest must pay on delivery, and at the same time the record in the cashier's office indicates the amount of cash that the waitress must later hand in.

There are other uses for the teleprinter system besides handling room-service orders. Let us suppose that a guest wishes to make a transatlantic telephone call shortly before leaving the hotel.

Immediately the call is completed, the telephone operator gives the teleprinter operator the necessary information, and the following message is transmitted to the receiver in the cashier's office.

```
806        171
BROWN TEL.      78.00 KR
12.00 HOURS
```

When the guest settles his account a little later, the call has already been charged against him and should any query arise, the time and duration of the call is permanently recorded. Telegrams sent by guests are handled the same way.

In constant use throughout the day, this Creed and Company teleprinter installation has proved itself dependable and simple in operation. With the system delivering instantaneously a printed message at any desired place in the hotel, the guest does not suffer the delays and errors that are all too common with other methods of communication.

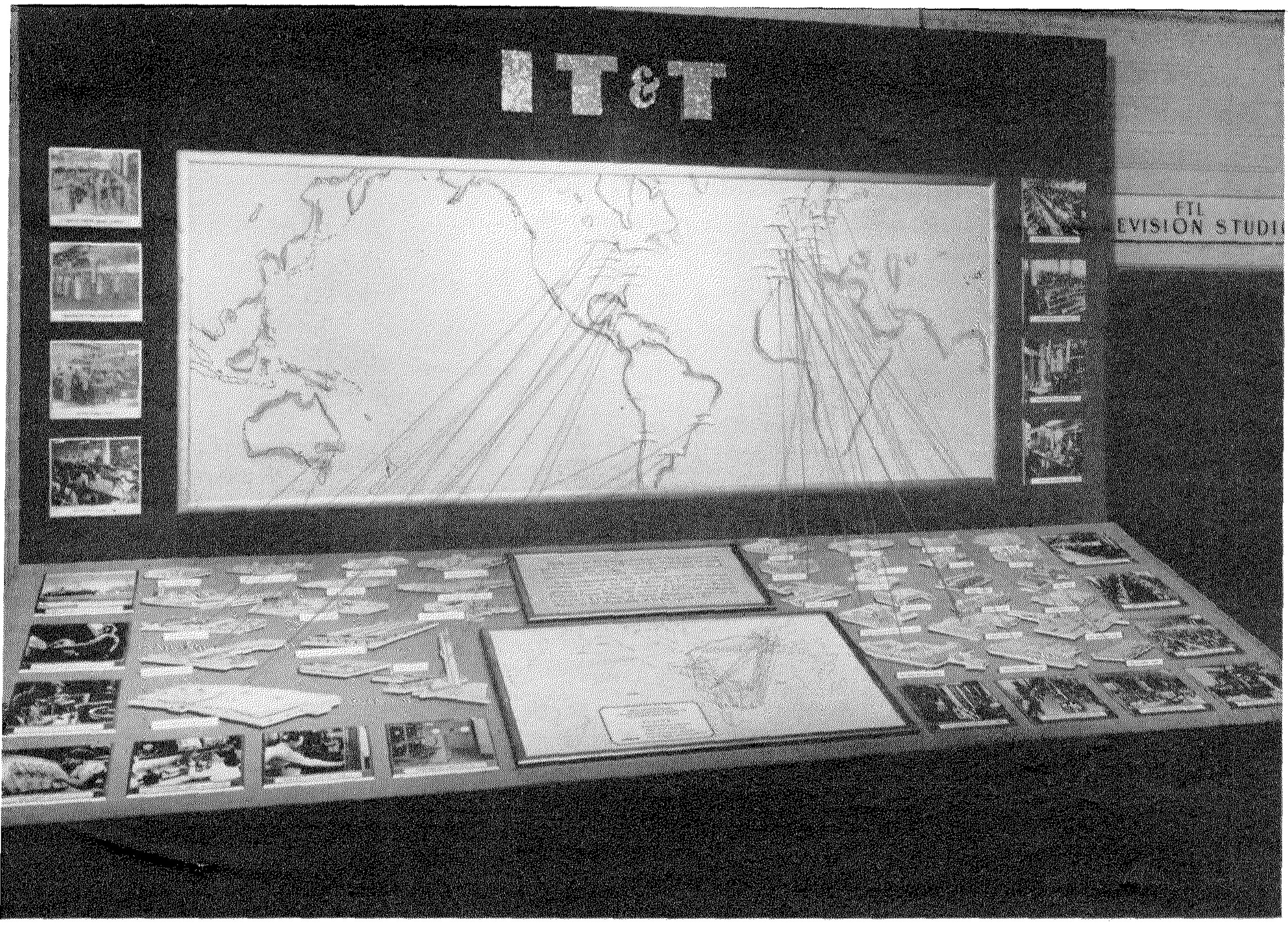
Acknowledgement is gratefully made to the Hotel Viking and to Mr. F. C. G. Lundh, consulting engineer of Oslo, Norway, for permission to use the accompanying photographs and for assistance rendered in the study of this new teleprinter installation.

Annual Meeting of the Corporation, 1953

THE 33RD annual meeting of the stockholders of the International Telephone and Telegraph Corporation was held in Nutley, New Jersey, on 27 May 1953. Over 700 stockholders attended the meeting, which was held in a large tent erected on the grounds of Federal Telecommunication Laboratories. Votes were taken on several matters presented to the stockholders, and great interest was shown in a proposal that was later approved at a special stockholders' meeting to merge five of the domestic associate companies into the parent corporation as divisions.

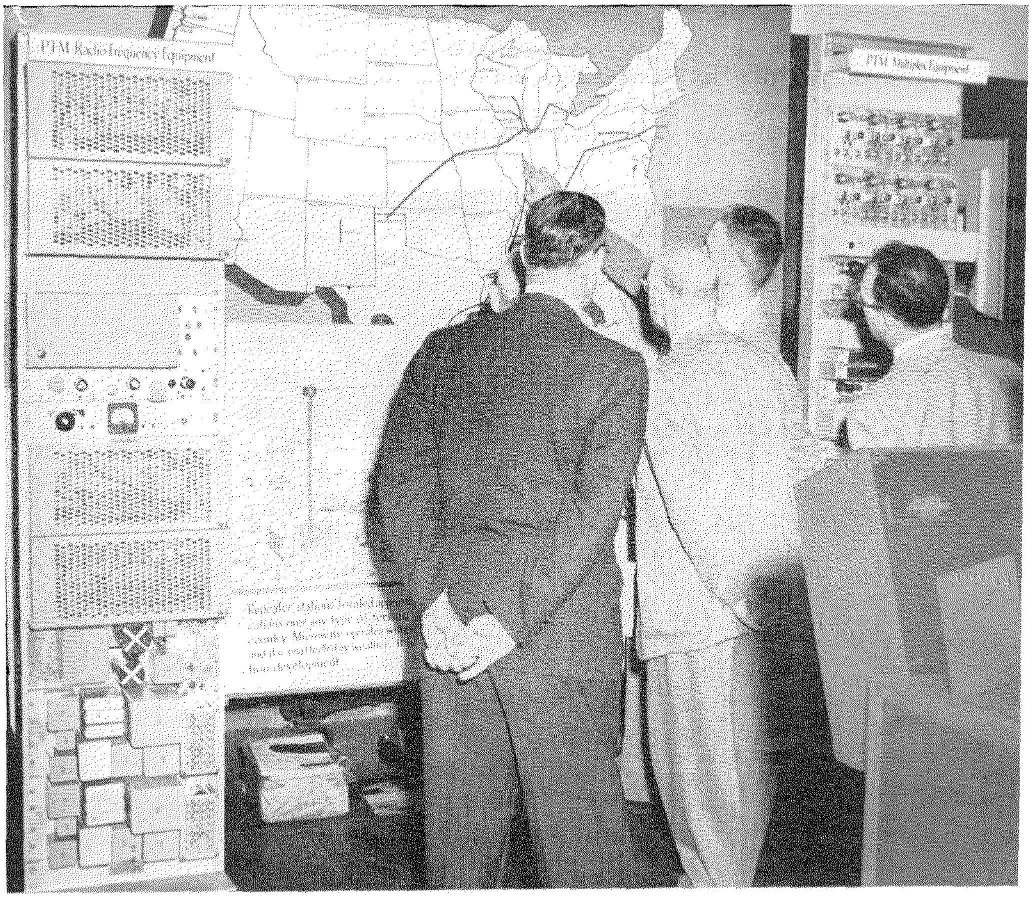
The address of the chairman of the corporation, Colonel Sosthenes Behn, featured an oral tour around the world to the various properties of the corporation and the answering of many interesting questions put to him from the floor.

Luncheon was served in another large tent. Many of the stockholders visited the observation floor of the microwave tower of the laboratories, to enjoy the excellent view that it affords of the countryside and of the New York skyline. Special



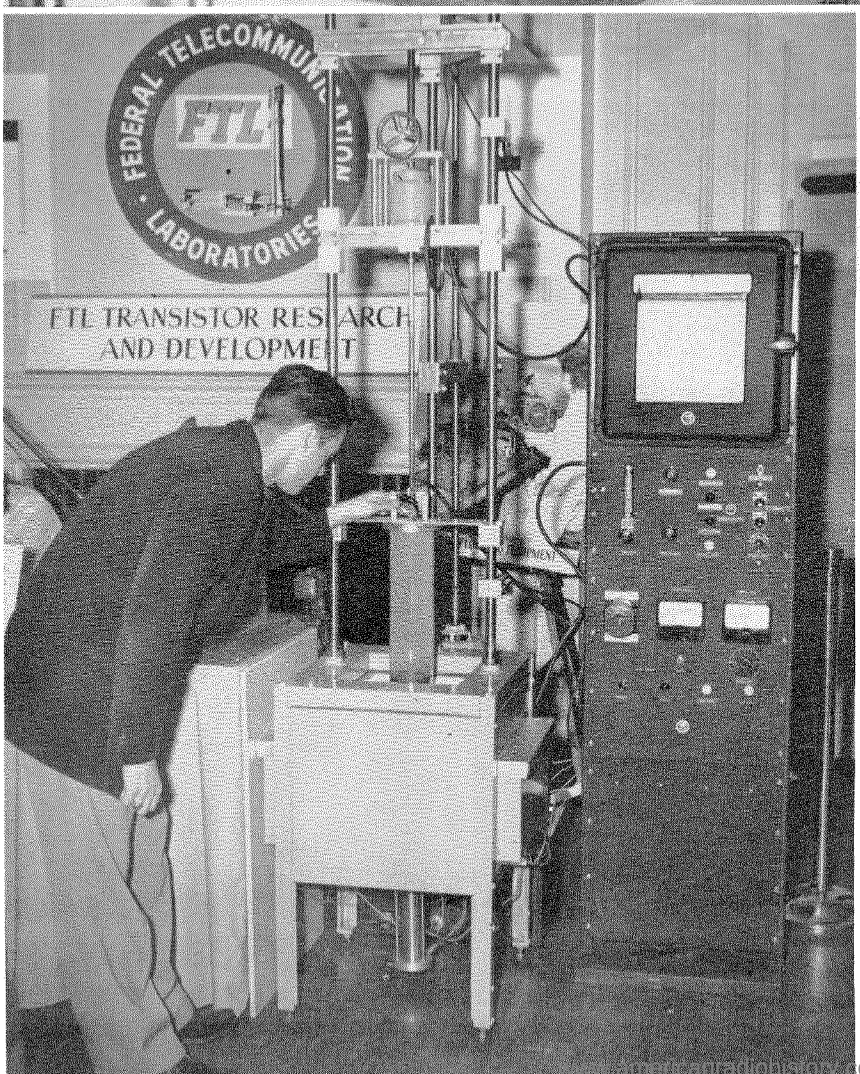
exhibits of the products and activities of the corporation were on display.

At the top of the opposite page is a view of the tables on the lawn near the luncheon tent. Below it is the annual meeting in session. At the top of this page is a map showing the appearance and location of the major properties of the corporation throughout the world. The map at the right shows the pulse-time-modulation relay networks installed in the United States by Federal Telecommunication Laboratories. Typical racks of equipment are at each side of the map.



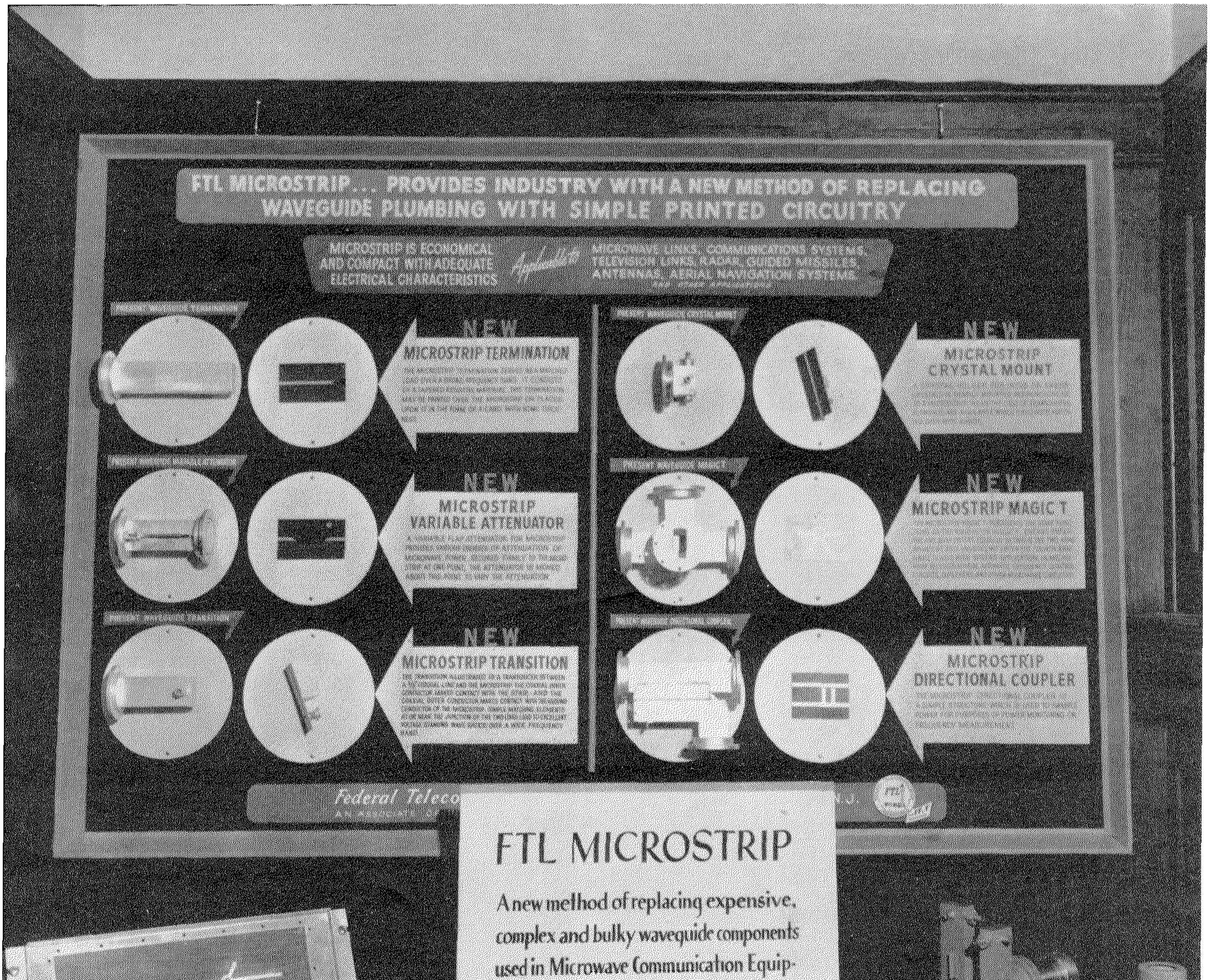
A major product of the corporation is television equipment. The transmitting and studio apparatus above, manufactured by Federal Telecommunication Laboratories, in conjunction with the camera being operated below permitted stockholders to see themselves in several Capehart receivers. Also below but at the right is the camera and monitor of the Capehart industrial television equipment.

These two pictures illustrate some domestic products. At the top is a display of the Coolerator Company, including large and small refrigerators, an electric stove, window-type air conditioner, and a deep-freezer. Below are Capehart-Farnsworth television receivers. Portable and table-model radio receivers may be seen on the nearest table.



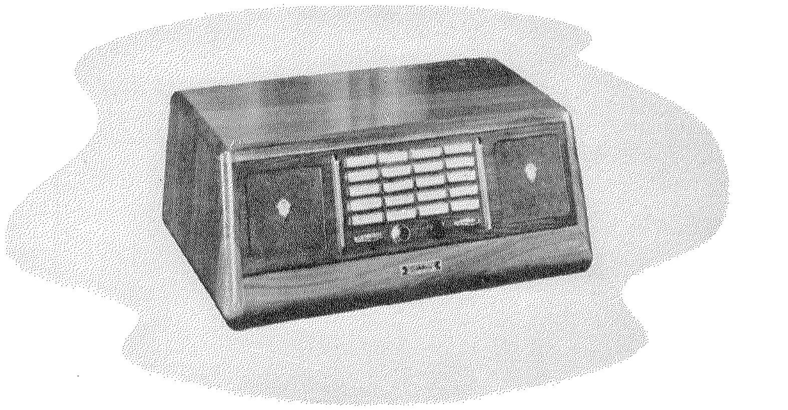
Transistors are a recent development and are the first important challenge to the vacuum tube as an amplifier of electric waves. Their operation is based on some unusual properties of germanium, one of the little-known materials called semiconductors because they are neither good conductors nor good insulators of electricity. Single large crystals are being slowly formed at a critical temperature from a pool of molten germanium in the apparatus at the left. In the upper picture, transistors are being completed with the soldering of connecting wires to small slabs cut from the large crystals.

Developed to a practical stage by Federal Telecommunication Laboratories, microstrip is a new application of old principles. It features specially shaped areas of copper foil fastened to one side of a sheet of insulating material, the other side of which is completely covered with copper. These simple structures replace the large, heavy, and expensive coaxial and waveguide components previously required at microwave frequencies.



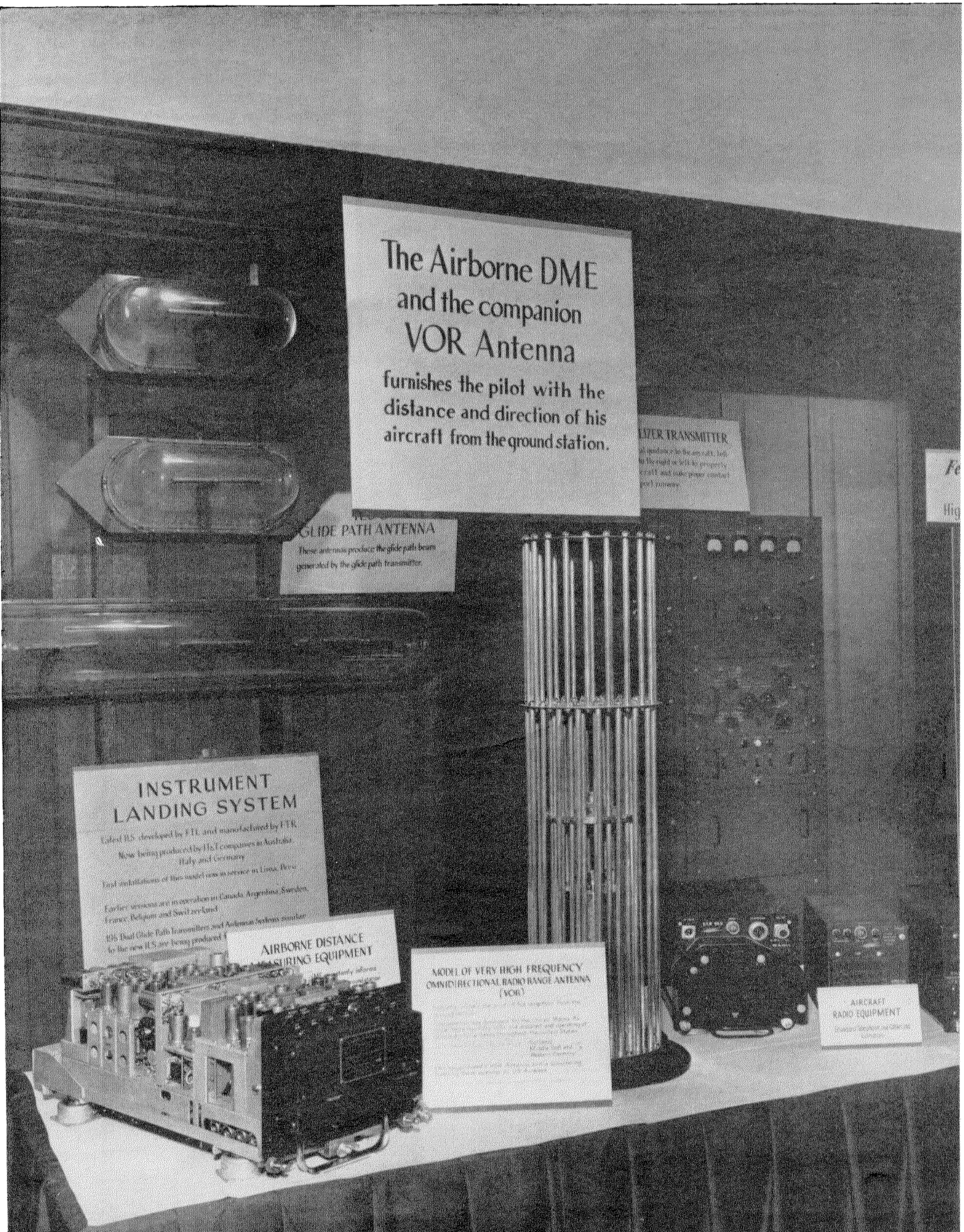
Many exhibits were of telephone equipment, a major product of the International System. Shown above is a display of crossbar switching equipment and telephone sets manufactured by Kellogg Switchboard and Supply Company. Telephone apparatus made by Belgian, French, and German associate companies was also exhibited.

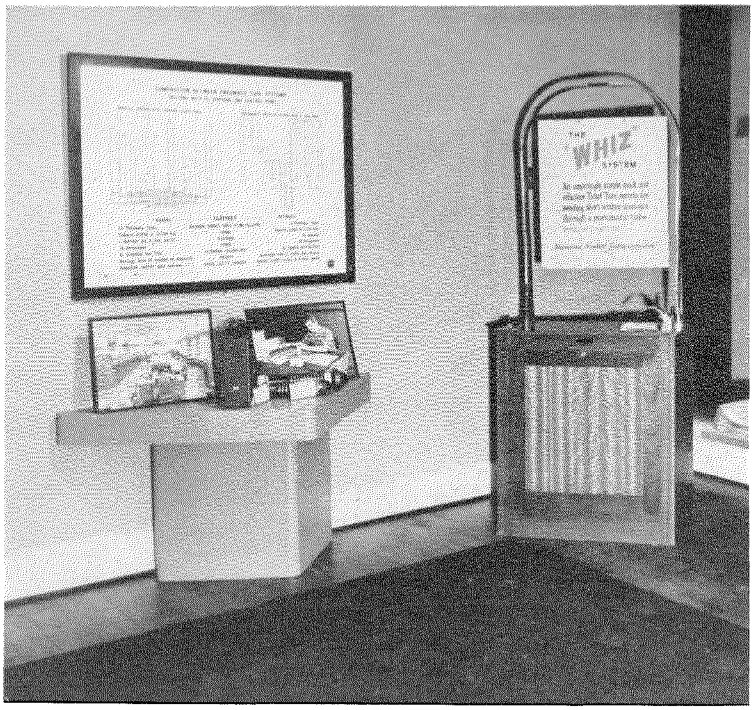
Telephone and radio components made by Standard Telephones and Cables, Limited, are at the left. An electromechanical mail sorter developed by Bell Telephone Manufacturing Company is pictured above them.



The Select-O-Phone executive station (left) is a new device developed by Kellogg Switchboard and Supply Company. Entirely separate from the regular public telephone system, as many as 55 extensions may be called by push-button individually or in conference groups. At the right below is the cabinet housing the automatic switching equipment for the system.

The safety and economy of modern air transportation are in large measure the result of applying electronic and radio devices to the navigation and landing of aircraft, particularly in bad weather. The International System has played a dominant pioneering role in this important field. It produced the first practical instrument landing system that permitted airplanes to land in fog, and these Federal Telephone and Radio Company equipments are now used all over the world. The above model shows how radio beams are arranged to inform the pilot of his position when making an instrument landing. The ground-station transmitting equipment for these beams may be seen at the left and a direction finder is in the background. On the opposite page, are several pieces of airborne equipment and some additional ground-station apparatus.


The Airborne DME
and the companion
VOR Antenna
furnishes the pilot with the distance and direction of his aircraft from the ground station.
GLIDE PATH ANTENNA
These antennas produce the glide path beam generated by the glide path transmitter.
INSTRUMENT LANDING SYSTEM
AIRBORNE DISTANCE
MODEL OF VERY HIGH FREQUENCY OMNIDIRECTIONAL RADIO RANGE ANTENNA (VOR)
AIRCRAFT RADIO EQUIPMENT



At the left are examples of a pneumatic-tube system that automatically routes each carrier to its indicated destination and of the "Whiz" carrierless ticket transporting system developed by Mix and Genest in Germany. Several installations have been made in the United States.

Below are typical examples of military-type multichannel carrier telegraph equipment manufactured by two divisions of the corporation. They provide 8 two-way 100-word-per minute telegraph channels over a pair of wires, or speech and duplex telegraph operations may be employed simultaneously.

On the opposite page is a view of a complete installation of all the radio facilities needed on a merchant ship. Various associate companies are active in the marine radio field.


American Cable & Radio System
AN IT&T ASSOCIATE
ALL AMERICA CABLES and RADIO Inc.
THE COMMERCIAL CABLE COMPANY
MACKAY RADIO and TELEGRAPH COMPANY Inc.

Modern Coaxial-Cable Technique in Great Britain

By ERIC BAGULEY

Standard Telephones and Cables, Limited; London, England

A BRIEF historical survey of the development in Great Britain by Standard Telephones and Cables, Limited of long-distance coaxial-cable technique is given from when the first cable of this type was manufactured and installed for the British Post Office in 1935 until the present day.

To assist in placing in perspective the merits of various designs of coaxial pairs, methods for quantitatively assessing the attenuation performance and the impedance uniformity are described and applied.

Against this background, our modern technique is then outlined; it covers design, manufacture, installation, testing, and transmission performance of the latest type of 0·375-inch (9·5-millimetre) coaxial pair produced at the cable factory in North Woolwich, London. For this cable, a guarantee of performance is given for all operating frequencies up to 10 megacycles per second.

In 1951, Standard coaxial cables were transmitting television programmes over the longest commercial circuit in Europe, that from London to Holme Moss, near Sheffield, a distance of approximately 250 miles (400 kilometres).

* * *

1. *Assessment of Performance*

1.1 Attenuation

The most-important transmission characteristic of a long-distance coaxial-cable circuit is its attenuation per unit length. The economic planning of a wide-band system, whether for telephony or for television, that is to be operated over coaxial circuits is primarily a matter of balancing the gain and cost of the repeater equipment against the loss and cost of the cable. The loss or attenuation per unit length is to a first approximation inversely proportional to the diameter of the cable. Any required value may be obtained from almost any design of coaxial pair by selecting the appropriate internal diameter for its outer conductor. To assess the relative performance of different designs of coaxial pairs a criterion is required that takes account of the attenuation per unit length per unit diameter.

It is well known that the transmission characteristics of a coaxial pair may be calculated accurately from its dimensions, the electrical characteristics of its two conductors, and its dielectric structure, provided that these data are accurately known.[1,2] A useful criterion of performance may readily be obtained from a comparison of the measured attenuation for a given design with the calculated attenuation of an ideal (but not necessarily realisable) reference design having the same internal diameter for its outer tube. An appropriate reference ideal is a coaxial pair with a smooth cylindrical inner conductor, a lossfree air dielectric, and a tubular outer conductor with a smooth cylindrical bore. The conductivity of both conductors is that of the best commercial copper and the ratio of their diameters, outer internal to inner external, is at the optimum value of 3·59 to produce minimum attenuation.

For values of diameters from 0·375 inch (9·5 millimetres) upwards and of frequencies from 1 megacycle per second upwards, here to be considered, it may be shown that the attenuation of the reference coaxial pair is given by the expression:–

$$A_D = \frac{1 \cdot 3455}{D} K^{1/2} f^{1/2} \left(1 + \frac{0 \cdot 00202}{D f^{1/2}}\right), \qquad (1)$$

where

A_D = reference attenuation in decibels per mile for diameter D at a temperature of 10 degrees centigrade (50 degrees Fahrenheit)

D = internal diameter of outer conductor in inches

---

[1] S. A. Schelkunoff, "Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields," *Bell System Technical Journal*, volume 13, pages 532–579; October, 1934.

[2] E. I. Green, F. A. Leibe, and H. E. Curtis, "Proportioning of Shielded Circuits for Minimum High-Frequency Attenuation," *Bell System Technical Journal*, volume 16, pages 248–283; April, 1936.

K = effective permittivity of dielectric ($K=1$ for air dielectric), and

f = frequency in megacycles per second.

For the stated ranges of values of D and f given above, although (1) is an approximation, it is not in error by more than about 1 part in 3000. It is based on copper having a conductivity $g=6{\cdot}0\times10^5$ mhos per centimetre, a value that is given by 99·6-per-cent-conductivity copper at 10 degrees centigrade (50 degrees Fahrenheit).

An assessment of the attenuation performance $\mathcal{E}_f$ of any realised design of coaxial pair may be obtained conveniently at any specified frequency. It is expressed as the ratio of the computed attenuation A_D of the ideal structure to the measured attenuation α_D of the realised design for identical values of D, f, and temperature. Thus, expressed as a percentage:–

$$\mathcal{E}_f=\frac{A_D}{\alpha_D}\times100. \qquad (2)$$

It should be noted that the reference attenuation A_D is wholly copper loss, since a lossfree dielectric is postulated. In practice the measured attenuation of a coaxial pair will consist of the combined copper loss and dielectric loss. To a first approximation a measured attenuation in decibels per mile is of the form:–

$$\alpha_D=K_1f^{1/2}+K_2f, \qquad (3)$$

where K_1 is a constant accounting for the copper-loss attenuation and K_2 is a constant accounting for the dielectric-loss attenuation.

From a series of attenuation measurements in the spectrum from 1 to 10 megacycles per second, for example, the values of the constants K_1 and K_2 may easily be determined by graphing $\alpha_D/f^{1/2}$ against $f^{1/2}$. The graph gives a straight line whose ordinate at $f^{1/2}=0$ is K_1 and whose slope is K_2. Five such graphs are given in Figure 1 and are based on results obtained at successive stages in the development of long-distance coaxial cables in Great Britain.

Such a group of graphs provides a simple visual assessment of the relative attenuation performance of the several designs. Reduced dielectric loss is indicated by reduced slope. If the graphs have an appreciable slope, e.g. *1*, *2*, *3*, and *4* of Figure 1, the values of K_2 determined from their slope give a reasonably accurate assessment of the dielectric-loss component of the coaxial pairs. When the graph is nearly horizontal as in *5*, the constant K_2 determined from the slope ceases to give an accurate assessment of the dielectric loss. This is because the approximation, equation (3), neglects a small component of the copper loss that is not a function of frequency. Taking equation (1) as a more-accurate expression for the copper loss, it will be seen that a factor of the form of that in the parentheses would be taken into account.

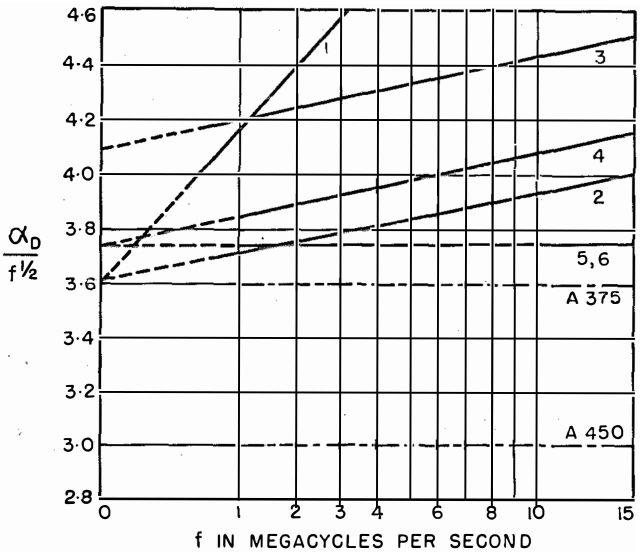


Figure 1—$\alpha_D/f^{1/2}$ plotted against $f^{1/2}$ for the corresponding indicated values of frequency in megacycles per second for coaxial pairs at 10 degrees centigrade (50 degrees Fahrenheit). The constant K_1 is obtained by extrapolating the curves to $f^{1/2}=0$. The upper 5 curves are for cables listed in Table 1. The curves *A375* and *A450* are for ideal coaxial pairs of 0·375 and 0·450 inch (9·5 and 11·4 millimetres) respectively.

Graphs of A_D for coaxials of 0·375- and 0·450-inch (9·5- and 11·4-millimetre) internal tube diameter are also shown in Figure 1. For the ordinate scale chosen they are for practical purposes straight lines with a small negative slope. For a more-accurate determination of the dielectric loss of graph *5*, the slope relative to the *A375* graph, rather than to the horizontal, should be measured. For this particular example the effect of the correction to the copper loss is to increase the value of the dielectric-loss constant K_2 from 0·003 to 0·009. This correction only qualifies the interpretation of the constants K_1 and K_2 determined from the straight-line graphs. It does not impair the usefulness of equation (3) or of the straight-line graphs as concise statements of measured attenuations versus frequency from 1 megacycle per second upwards.

From equations (1) and (3) it follows that the attenuation performance $\mathcal{E}_f$ defined by equation (2) will decrease in value with increase in frequency at a rate dependent on the relative value of the dielectric component of the measured attenuation. For the purposes of the present review of development it has been found sufficient to determine the attenuation performances at two frequencies, 1 and 10 megacycles per second respectively. The results obtained at the six major stages in development are shown in Table 1. For convenience the designs that have been exploited have been numbered *1* to *6* and each is described in Sections 2 and 3 of this survey.

TABLE 1

ATTENUATION PERFORMANCE OF LONG-DISTANCE COAXIAL PAIRS

Year	Cable	Internal Diameter of Outer Tube in Inches	Attenuation Performance $\mathcal{E}_f$ in Per Cent	
			1 Megacycle	10 Megacycles
1935	*1*	0·450	72·2	55·7
1936	*2*	0·450	80·7	76·1
1938	*3*	0·375	85·9	81·0
1944	*4*	0·375	93·7	87·9
1947 1950	*5* *6* }	0·375	96·2	95·7

A tabulation of the factor $\mathcal{E}_f$ is thus a convenient way of demonstrating the notable and progressive improvements in the attenuation performance of long-distance coaxial pairs that have been achieved during the first 15 years of their application.

1.2 Impedance Uniformity

The second important transmission characteristic of a long-distance coaxial-cable circuit is its impedance uniformity. All irregularities in impedance cause partial reflections of the transmitted signals. First-order reflection products, returning to the sending end, distort the sending-end impedance–frequency relation and upset accurate matching of the repeater or terminal equipment. This may add to the overall attenuation loss of the repeater sections. Second-order reflection products, from pairs of irregularities, are transmitted to the receiving end and arrive there after the main signal. These products are cumulative and with long lines may cause appreciable distortion of the received signal in the form of ghost or tail echoes.

Quantitative assessment of impedance uniformity is most conveniently carried out on the results of sending-end impedance–frequency tests made on installed repeater sections of the cable. The resistive component of the sending-end impedance of a long coaxial pair that is free from irregularities is of the form:–

$$Z_s = K_3 + (K_4/f^{1/2}), \tag{4}$$

where Z_s is the sending-end resistive component in ohms, K_3 and K_4 are constants that may be calculated from the dimensions and electrical characteristics of the conductors and dielectric of the coaxial pair, and f is the frequency in megacycles per second, which must not be lower than 0·5 if equation (4) is required to be accurate to within 1 part in 1000 over a wide band of frequencies.

If there are irregularities in a long coaxial pair the measured sending-end impedance z_s in ohms is of the form:–

$$z_s = K_3 + \Delta_f + \frac{K_4 + \delta_f}{f^{1/2}}. \tag{5}$$

Here Δ_f and δ_f are components of the deviation at frequency f of the measured impedance from the smooth-mean-curve ordinates of equation (4). For coaxial pairs not less than 0·375 inch (9·5 millimetres) in diameter, K_4 does not greatly exceed 1 per cent of K_3 in magnitude. Also the component δ_f is inherently a smaller fraction of K_4 than Δ_f is of K_3. It follows that for most practical purposes, the component δ_f may be neglected in comparison with Δ_f. This simplifies the form of z_s to:–

$$z_s = K_3 + \Delta_f + (K_4/f)^{1/2}. \tag{6}$$

An impedance test on a coaxial pair at a large number of frequencies n differing by small equal increments will give n values of z_s. From the known average dimensions and electrical characteristics of the coaxial pair a value for K_4 may be estimated. With this the measured value of z_s may be corrected by subtracting from each the appropriate value of $K_4/f^{1/2}$. The result is a group or population of n values each of the form:–

$$z_s - (K_4/f^{1/2}) = K_3 + \Delta_f. \quad (7)$$

This population conforms with the statistical requirements of the appropriate British standard[3] and by the method there demonstrated the average value K_3 and its standard deviation σ may be calculated. The standard deviation σ is the square root of the average of the squares of the deviations Δ_f of all the corrected observations. For impedance measurements it is also customary to note the maximum value of Δ_f in the group, i.e. the maximum deviation Δ_m from the average value K_3.

Analyses that are made in this way are available for the coaxial-pair designs obtaining at the six major stages in the development of British long-distance cables. Impedance tests have most commonly been made at 20-kilocycle-per-second increments in spectra ranging from 60 or 500 kilocycles per second to 1500, 2500, 4500, or 10 000 kilocycles per second. To facilitate comparisons of quality, a sample spectrum from 520 to 2500 kilocycles per second has been adopted with measurements at 20-kilocycle-per-second increments. This conveniently gives a group or population containing 100 values as in the standard noted above. These are always taken from sending-end impedance tests on completed repeater sections of the cables of not less than 5 miles (8 kilometres) in length. Representative results from the cables under review are given in Table 2.

A tabulation of the factors σ and Δ_m demonstrates that the improvements in impedance uniformity achieved during the first 15-year period are as notable as those of the attenuation performance in Table 1.

TABLE 2

IMPEDANCE UNIFORMITY OF LONG-DISTANCE COAXIAL PAIRS

Year	Cable Design	Diameter in Inches (Millimetres) of Coaxial Pairs	Average Impedance Analyses Results				
			K_3 in Ohms	Standard Deviation		Maximum Deviation	
				σ in Ohms	σ/K_3 in Per Cent	Δ in Ohms	Δ_m/K_3 in Per Cent
1935	*1*	0·450 (11·4)	71·9	1·16	1·6	4·4	6·1
1936	*2*	0·450 (11·4)	71·6	1·82	2·5	6·1	8·6
1938	*3*	0·375 (9·5)	74·9	0·56	0·75	2·1	2·8
1944	*4*	0·375 (9·5)	74·6	0·31	0·42	1·3	1·8
1947	*5*	0·375 (9·5)	75·0	0·23	0·31	0·9	1·2
1950	*6*	0·375 (9·5)	75·2	0·20	0·27	0·8	1·1

2. *Design and Manufacture*

2.1 First Design, 1935

The first long-distance coaxial cable in Great Britain was manufactured by Standard Telephones and Cables, Limited in 1935 and was installed for the British Post Office between London and Birmingham during 1935 and 1936. Being an historic first it was fully reported on in the technical press.[4,5] A brief description here will suffice to place it in perspective with present-day coaxial cables.

The coaxial pairs had an outer tube of 0·450-inch (11·4-millimetre) internal diameter with a 0·125-inch (3-millimetre) solid copper centre conductor supported within the tube by a spiral wrapping of two-ply esterified cotton cord.[6] A thin paper tape was formed into a tube over the cord. The outer tube was formed from

[3] "Quality Control Charts, British Standard 600R: 1942," British Standards Institution, London; see Case 2, Part 3, Appendix A.

[4] A. S. Angwin and R. A. Mack, "Modern Systems of Multi-Channel Telephony on Cables," *Journal of the Institution of Electrical Engineers*, volume 81, pages 573–606; December, 1937.

[5] A. H. Mumford, "London–Birmingham Coaxial Cable System," *Post Office Electrical Engineers Journal*, volume 30, pages 206–214; October, 1937: and volume 31, pages 51–56; April, 1938.

[6] A. A. New, "Esterified Fibrous Insulating Materials," *Electrical Communication*, volume 13, pages 216–225; January, 1935: pages 359–379; April, 1935: and volume 14, pages 213–231; January, 1936.

a spiral layer of 12 specially shaped interlocking copper tapes, giving a radial thickness of 0·030 inch (0·8 millimetre) to the self-supporting tube so formed. There was a binding of narrow brass tape over the tube and then a thin lead sheath. Four of these coaxial pairs were laid up with five groups of paper-insulated quads and screened pairs in the interstices.[7] The overall external diameter of the lead sheath was 1·74 inches (44·2 millimetres).

This coaxial pair was designed to have an attenuation not exceeding 6·4 decibels per mile (4 decibels per kilometre) at 2·1 megacycles per second and on average the requirement was successfully met. Its attenuation performance $\mathcal{E}_f$ was as Table 1 shows low at 1 and very low at 10 megacycles per second. From graph *1* of Figure 1 the reasons for this may be inferred. Firstly, the dielectric loss in the textile insulant was high despite the largely air-spaced structure adopted. Secondly, the copper loss was relatively high. The K_1 constant of equation (3) for this design is 11-per-cent higher than that given by an ideal copper–copper coaxial pair of the same diameter, 0·450 inch (11·4 millimetres), and the same dielectric permittivity, 1·15. Experiments have confirmed that this excess copper loss occurs in the outer tube of the pair because the current in it follows the spiral path of the twelve copper tapes and induces circumferential currents in the thin lead sheath immediately outside the copper tapes.

The high loss limitation of the textile cord dielectric was appreciated. It was adopted because up to the highest operating frequency of 2·1 megacycles per second then envisaged it was less costly than available alternatives, and because existing telephone-cable machines could easily be adapted to apply it to the centre conductor. All the manufacturing operations required to produce this coaxial pair were planned to conform with then-existing telephone-cable operations. Incidently, the machine used for making this coaxial pair is on the left of the laying-up machine shown in Figure 7.

There were no specified requirements for impedance uniformity. The standard achieved is shown in Table 2 and it was satisfactory in the sense that the wide-band telephone system planned for the cable gave and continues to give satisfactory service.

[7] British Patent 457 280; May 24, 1935.

2.2 Second Design, 1936

Experience with the first cable had shown that the sheathing of the individual coaxial pairs with thin lead was not a very satisfactory operation for routine manufacture. A small steel-tape head was fitted to the coaxial-pair machine to permit two mild-steel tapes, 0·5 by 0·005 inch (12·7 by 0·13 millimetre), to be spirally applied to the outside of the copper-tape tube in the manner of steel-tape armour. The complete coaxial pair was then made in one operation; the external diameter was reduced from 0·59 to 0·53 inch (15 to 13·5 millimetres) and that of the complete cable from 1·74 to 1·60 inches (44·2 to 40·6 millimetres).

For the dielectric, the two-ply esterified-cotton cord and paper tube were retained, but improvements in the esterification process yielded a cord with a greatly reduced dielectric-loss angle. In other respects the second design was the same as the first. The second cable was installed during 1936 and 1937 between Birmingham and Manchester.

It is clear from Table 1 and graph *2* of Figure 1 that a considerable improvement in attenuation performance was obtained as a result of the reduced dielectric loss. There was a small but detectable increase in the average excess copper loss from 11 to 12 per cent attributable to somewhat greater losses in the steel tapes than in the lead sheaths of the first design. The gain in attenuation performance was only obtained with difficulty. It was found that the new esterification process had been taken into an unsuspectedly critical region. Improved average dielectric characteristics were obtained at the expense of increased variations among batches of the processed material.

The effect of these variations is shown in Table 2 as a deterioration in impedance uniformity compared with the first design. There was at the time no adequate factory test for assessing the impedance level or uniformity of the coaxial pairs in drum lengths of cable. In consequence the variations among drum lengths, which must have been occurring, were not detected before installation. Had they been, an improvement in the field results could have been effected by allocating the drum lengths to minimise impedance mismatches at joints. This limitation was appreciated, and it was realised that improvements in testing technique would have to be a necessary corollary to improvements in coaxial-pair design. Satisfactory service was obtained and continues to be obtained from the wide-band telephone system operating over the cable containing the coaxial pairs of this second design.

2.3 Third Design, 1938

Development work on specialised machines for the manufacture of coaxial pairs was started as soon as experience with the new circuits had established that wide-band carrier telephone systems would become an essential part of the British trunk network. The first of the new types of machine to be introduced to telephone-cable technique was a disk applicator.[8]

Improved results had already been demonstrated by tests on hand-made sample lengths with a dielectric structure consisting of thin disks of high-quality hard rubber spaced at intervals equal to 3 or 4 times the outer-tube diameter. This structure gave more definite placing of the centre conductor coaxially within the outer tube and reduced the ratio of solid dielectric to air dielectric with a consequent reduction in the effective permittivity of the coaxial pair from 1·15 for the spiral textile to 1·08 for the spaced disks. Thus the design had been known to be good, but commercial application had to await the proving in of an efficient disk-applicator machine.

The first disks were punched from special-grade hard-rubber sheet and had a radial slot extending from the centre hole to the outer periphery. By making the slot somewhat narrower than the diameter of the centre conductor of the coaxial pair, the disks could be sprung sideways on to the conductor. By making the centre hole a little smaller than the conductor, the disks could be made to grip it sufficiently tightly to avoid longitudinal displacement during subsequent handling. Alternate disks were arranged to have their slots oppositely directed along a common diameter to prevent the conductor jumping the slots when bending during drumming and installing.

In the first manufacturing set-up, the hard-rubber disks were taken up from the punch press on to brass strips about 1 foot (300 millimetres) long, which fitted into the centre hole and slot in the disks. The disk-loaded strips were, after inspection, placed vertically in a magazine turret at the top of the disk-applicator machine, which now became part of the coaxial-pair-forming machine. The applicator comprised two thin wheels about 15 inches (380 millimetres) in diameter mounted in a common vertical plane one above the other with their axes horizontal. The centre conductor of the coaxial pair passed between them along their common horizontal tangent. In the peripheries of the two wheels were radial slots, spaced apart at the required interval between disks. The wheels rotated in opposite directions with a peripheral speed equal to the linear speed of the centre conductor. Disks from the magazine turret passed down guide strips to both applicator wheels, where cam mechanisms pushed them one at a time into alternate slots in the wheels. In passing the points where the conductor was tangential to the wheels the disks were forced on to it; alternate disks were applied from each wheel in turn to give the required oppositely orientated disk slots when in position on the conductor.

Given the manufacturing facilities for the disk-insulated coaxial pair, it was then necessary to decide on a suitable outer-tube diameter. It has been noted that for the first design (Section 2.1) an attenuation level of 6·4 decibels per mile (4 decibels per kilometre) at 2·1 megacycles per second was selected. The second design (Section 2.2) was well below this at 5·5 decibels per mile (3·4 decibels per kilometre) but, as there did not appear to be any marked advantage from the lower level, the British Post Office decided to revert to the original level by stating that for the third cable the attenuation must not exceed 6·7 decibels per mile (4·2 decibels per kilometre) at 2·5 megacycles per second and 60 degrees Fahrenheit (15·6 degrees centigrade) after installation. On this basis an internal diameter for the outer tube of 0·375 inch (9·5 millimetres) was decided on for the new coaxial pair. Thus in 1937 a dimension was fixed, the correctness of which subsequent developments

[8] British Patent 458 772; June 25, 1935.

have amply confirmed. The 0·375-inch (9·5 millimetre) coaxial pair is now the accepted standard for long-distance telephone and television circuits in both Europe and America.

This first 0·375-inch (9·5-millimetre) coaxial pair had a 0·104-inch (2·64-millimetre) centre conductor, slotted hard-rubber disks 0·050-inch (1·3-millimetres) thick spaced at intervals of 1·3 inches (33 millimetres). A thin paper tape was formed into a tube over the hard-rubber disks. The outer-conductor tube was a spiral layer of 10 interlocking copper tapes similar to those used in designs *1* and *2*. The screen was a double layer of mild-steel tapes as in design *2* and the overall diameter of the coaxial pair was 0·46 inch (11·7 millimetres). Four of the coaxial pairs were laid up together with five paper-insulated, 0·040-inch (1-millimetre) copper, star quads. Over the lead sheath, this cable was 1·35 inches (34·3 millimetres) in diameter compared with 1·74 and 1·60 inches (44·2 and 40·6 millimetres) for designs *1* and *2* respectively. It was first installed between Manchester, Leeds, and Newcastle-on-Tyne, about 136 route miles (219 kilometres), during 1938 and 1939. There were 20 repeater sections of an average length of 6·8 miles (11 kilometres) each.

The average attenuation obtained from this design after installation is shown in graph *3* of Figure 1. From the slope of the graph it is apparent that the dielectric-loss component of the attenuation was the same as that obtained from design *2*. Table 1, however, shows an improvement in the attenuation performance at both 1 and 10 megacycles per second and this derives from the reduced effective permittivity of the dielectric structure. Since no change had been made in the outer-tube structure, the excess copper loss attributable to spiralling remained at the same level. The K_1 constant of equation (3) for this design was on average 10 per cent higher than that given by equation (1) for a 0·375-inch (9·5-millimetre) coaxial with a permittivity of 1·08. Analyses of the attenuation results obtained indicate that the excess copper loss was of the order of 2·5 per cent on newly made drum lengths; it was 5·5 per cent when newly installed and on average became stable at 10 per cent some months after installation.

Design *3* was primarily acclaimed for its greatly improved impedance uniformity. As Table 2 shows, it gave a standard deviation of less than 1 per cent and maximum deviations of less than 3 per cent; these being respectively one-half and one-third the values obtained from its predecessors, designs *1* and *2*. There was now no doubt that long-distance coaxial cables could provide efficient circuits for wide-band carrier telephone systems.

This was the position at the beginning of the war in 1939. The state of emergency shifted emphasis from long-term development to the adaption and rapid extension of the trunk telephone network to meet the new demands made on it. The broader issues involved were the responsibility of the British Post Office and are outside the scope of this article. It suffices to state that coaxial cables were found to be particularly adapted to making the necessary increases in the traffic capacity of existing duct lines. Small cables, 1·14 inches (29 millimetres) in diameter, containing two coaxial pairs of design *3* and 12 paper-insulated quads were pulled into ducts already containing small-size trunk cables.

Composite cables containing 2 coaxial pairs and up to 68 quads were used in accordance with available duct space. Where space was available in two adjoining duct lines, small composite cables containing one coaxial pair and one of two layers of quads each were installed side by side. Composite cables containing one coaxial pair and a layer of 12 carrier-type quads were similarly used. Between 1939 and 1945 more than 2000 miles (3218 kilometres) of design-*3* coaxial pair were manufactured at the North Woolwich plant and installed in all parts of Great Britain.

2.4 Fourth Design, 1944

The next significant change in the design of the 0·375-inch (9·5-millimetre) coaxial pair was a change in the structure of the tubular outer conductor. The excess copper loss from the spiral-tape tube has been noted. Experience with design *3* also led to the conclusion that, although its impedance uniformity was reasonably good, the primary cause of the changes that were taking place was variations in the internal diameter of the spiral tube. In 1940 the Western Electric Company of New York introduced a new outer-tube structure for a 0·270-inch (6·86-

millimetre) coaxial pair.[9] This consisted of a single wide copper tape with teeth projecting from its two edges in staggered alignment. It was longitudinally folded into a tube with the two edges butting together. Only the projecting teeth overlapped the butt, and they prevented accidental overlapping of the tape edges proper. With this arrangement there would be no spiralling of the outer current and the internal diameter would be determined solely by the width and thickness of the copper tape.

The new design thus promised freedom from the two known limitations of the spiral tube and it was decided to develop a manufacturing technique for applying it to the 0·375-inch (9·5-millimetre) coaxial pair as rapidly as wartime conditions would allow. In 1942 a new machine was successfully making trial lengths of the new pair, design *4* of this survey. The machine was loaded with 0·104-inch (2·64 millimetre) copper centre wire, hard-rubber disks as used in design *3*, copper tape 1·3 inches (33 millimetres) wide by 0·010 inch (0·254 millimetre thick, and steel tapes. In one co-ordinated sequence of operations, the disks were applied to the centre wire. The copper tape was passed through a punch press to notch out the teeth on its edges. The notched tape was passed through a die block to form it into a tube with the disk-insulated wire inside it, and the coaxial pair was finally wrapped with two steel tapes and taken up on to a steel cylinder. The paper tape that in previous designs formed a tube immediately inside the copper tube was not retained.

The diameter of the coaxial pair, over the steel tapes, was 0·42 inch (10·7 millimetres), a reduction of 0·04 inch (1 millimetre) compared with design *3* as a result of the reduced radial thickness of the copper tube.

It was not until the end of 1943 that the design-*4* coaxial pair could be supplied commercially in place of design *3*. The first field trials were in 1944 in two 6-mile (9·7-kilometre) repeater sections of a coaxial cable then being installed in the west of England. Measurements were made on these two sections over a period of about one year. The results were up to expectations; and in particular there was no evidence of any attenuation instability. In 1945 design *4* was accepted by the British Post Office and it was first used on a cable installed between Newcastle-on-Tyne and Edinburgh during 1945 and 1946. No further cables to design *3* were manufactured thereafter.

The average attenuation result obtained from the Edinburgh cable and subsequent cables containing the same design of coaxial pair is shown in graph *4* of Figure 1. There was no change in the dielectric-loss component but there was a 9-per-cent reduction in the copper-loss component compared with design *3* over the whole frequency spectrum from 1 to 15 megacycles per second. In effect, the excess copper loss due to the spiral outer conductor had been eliminated, and a guarantee could be given that the attenuation of the coaxial pairs would not change by more than 1 per cent in the first 12 months after installation. Attenuation performance was correspondingly improved as shown in Table 1.

The improvement in impedance uniformity shown in Table 2 was greater than that in attenuation performance. The standard deviation was 45 per cent lower and the maximum deviation 35 per cent lower than was obtained from design *3* and it became possible to guarantee that the mean impedance at 2·5 megacycles per second would be within ±1 ohm of 75 ohms and that the maximum deviation between 0·06 and 2·5 megacycles per second would not exceed ±3 per cent on any 6-mile (9·7-kilometre) repeater section of installed cable.

During the immediate postwar period between 1945 and 1947 coaxial cables were increasingly in demand for the rehabilitation of the long-distance telephone networks in Britain and various European and Commonwealth countries. The output of design-*4* coaxial pair, supplied and installed principally in 4-core cables, exceeded 2500 miles (4023 kilometres) during this period.

2.5 Fifth Design, 1947

The next step was an obvious one; a reduction in the dielectric-loss component of the attenuation. Large-scale commercial production of polythene, a plastic dielectric material, had been pioneered in Great Britain during the war. It was known to be electrically superior to the best grades of hard rubber and no particular difficulty

[9] O. S. Markuson, "Stevens Point–Minneapolis Coaxial Cable," *Bell Laboratories Record*, volume 19, pages 138–142; January, 1941.

was anticipated from its different physical properties. Accordingly, the development of manufacturing technique for a polythene-disk-insulated 0·375-inch (9·5-millimetre) coaxial pair was one of the first postwar problems to be solved. The change-over from design *4* to design *5* could have been made before 1947, but for the necessity of maintaining an uninterrupted high output of coaxial cables.

The technique adopted was to punch complete disks from polythene strip of accurately controlled thickness. The disks had centre holes somewhat smaller than the centre-wire diameter, but were not slotted. They were hopper fed to the applicator[10] in the coaxial-pair-forming machine and after being picked up in the slots of an applicator wheel of the type already described they were slit by a knife edge along one radius. A wedge-shaped guide opened up the slit as the disk approached and passed over the centre wire. When free of the guide the disk was sufficiently resilient to spring back to its original shape and in doing so would firmly grip the centre wire. The 1·3-inch (33-millimetre) spacing between disks was maintained and the disk thickness was increased from 0·050 inch (1·27 millimetres) for the hard rubber to 0·075 inch (1·91 millimetres). A smaller increase in thickness would have been acceptable for physical reasons, but it was considered advisable to avoid a change in characteristic-impedance level, due to the lower permittivity of the polythene.

The attenuation result obtained from design-*5* coaxial pairs is shown in graph *5* of Figure 1. To a first approximation the dielectric-loss component is conspicuous by its absence. There is no excess copper loss and at both 1 and 10 megacycles per second the attenuation performance, Table 1, is better than 95 per cent.

In impedance uniformity, Table 2, there was a further improvement between design *4* and design *5*, but this is not attributable to change in design. It is the result of improved quality control during manufacture and installation, deriving from developments in pulse-echo-testing techniques, which are described later in this survey.

Manufacture of the first cable containing design-*5* coaxial pairs was started in 1947. It contained 4 coaxial pairs and 5 paper-insulated quads; about 200 miles (322 kilometres) was supplied to the Royal Swedish Telegraph Administration. Design *5* was accepted by the British Post Office and was first supplied and installed for them between Newport (Monmouthshire) and Cardiff in a full-size composite cable containing 4 coaxial pairs with paper-insulated quads arranged in five layers over the coaxials for audio circuits.

With the adoption of design *5*, it also became British practice to insulate the coaxial pairs from each other. Two layers of paper were applied over the steel tapes, the inner a plain paper tape and the outer a paper tape with identification numbers printed on it at frequent intervals. When laid up into 2, 4, 6, or more coaxial-pair cables, each bears a different number throughout its length. Prior to this, identification of the individual coaxial pairs in a cable depended on coloured paper wrappings applied to the interstice quads; a method that serves well enough during factory testing and when first jointing drum lengths together in the field. For maintenance or repair work on cables in service, the conditions are more onerous, and ambiguity of identification is likely to cause mistakes that by prolonging the interruption of traffic are costly in lost revenue. The numbered outer paper eliminates ambiguity under all circumstances. Insulating the outer tubes also extends the scope of acceptance tests, routine maintenance tests, and fault-locating tests. The conductor resistance of the outers and the insulation resistance between the outers are made available for measurement.

Between 1947 and 1950 the total output of the North Woolwich factory exceeded 3700 miles (5953 kilometres) of coaxial pair to design *5* in various sizes of cables, which were installed in England, Eire, and Austria. Of particular note was a composite cable containing 6 coaxial pairs and 188 paper-insulated quads, which was installed between Birmingham and Manchester[11] in 1949 and 1950. Two of the coaxial pairs in this cable now form the second part of the long-distance two-way television link between London and Edinburgh. This was the first British cable with standard 0·375-inch (9·5-millimetre) coaxial

[10] British Patent 631 914; August 29, 1947.

[11] R. J. Halsey and H. Williams, "Birmingham–Manchester–Holme Moss Television Cable System," *Proceedings of the Institution of Electrical Engineers*, Part 3A, volume 99, pages 398–410; April–May, 1952.

pairs to be used for the transmission of television signals, within the frequency band of 0·06 to 4·0 megacycles per second approximately in accordance with the recommendations of the Comité Consultatif International Téléphonique.

2.6 0·975-Inch Coaxial Pair

For the first part of the London–Edinburgh television link a coaxial cable of novel design was developed, manufactured at North Woolwich, and installed for the British Post Office between London and Birmingham during 1948 and 1949. It contained four 0·375-inch (9·5-millimetre) coaxial pairs to design *4* and two 0·975-inch (24·8-millimetre) coaxial pairs.

The principal requirement set by the Post Office Engineering Department for the 0·975-inch (24·8-millimetre) coaxial pair, based on the possibility of having to cater in the future for the transmission of high-definition colour television signals, was an attenuation loss not exceeding 24 decibels at 26 megacycles per second for a 3-mile repeater section. By reason of its large size, the design incorporated several novel features. The centre conductor was a tube of 0·25-inch (6·4-millimetre) external diameter formed by longitudinally folding a single copper tape. The dielectric structure comprised a continuous chain of interlocking short thin-walled cylinders of polythene having a disk at one end to support the centre conductor at 1·56-inch (39·6-millimetre) intervals. The outer conductor was a self-supporting tube formed from a single transversely corrugated copper tape. At the tape edges the corrugations were systematically offset to inhibit overlapping. The 0·975-inch (24·8-millimetre) coaxial pairs were completed with a binding of 4 steel tapes, one adhesive paper tape, and one numbered identification paper tape.

This was a special job and is indicative of the flexibility of modern British long-distance coaxial-cable technique, rather than representing a specific state in the general development here being surveyed. Its inception and execution[12] and the present method of operating[13] the 0·975-inch (24·8-millimetre) coaxial pairs are described in two papers.

3. *Modern Coaxial-Cable Technique*

3.1 Sixth Design, 1950

The present-day 0·375-inch (9·5-millimetre) coaxial pair is design *6* of this survey. It differs from design *5* in the method used to form the outer conductor from a copper tape. From the first adoption of the notched tape, it had been appreciated that the presence of a punch press in the coaxial-pair-forming machine set a limit to the speed of operation of the whole machine. This, and the need for careful maintenance of the notching tools, stimulated a new approach to the problem of forming a tube from a single copper tape. To maintain control over the diameter of the tube, and thereby control the impedance uniformity, the two edges of the tape must butt together without risk of gapping or overlapping. The tape is too thin for this to be achieved with plain cut edges. The problem has been solved by impressing marginal corrugations on the two edges of the tape prior to the tube-forming operation.[14]

Asymmetrical corrugations with a left-hand bias are impressed along one edge and corrugations with a right-hand bias along the other edge. Then, when the two corrugation patterns come together at the tube seam, they cannot interlock. This means that the two edges cannot overlap unless one edge is displaced radially with respect to the other by an amount equal to the tape thickness plus twice the amplitude of the corrugations. The apparent or effective thickness of the tape edges is increased to three or four times the copper thickness, sufficient to prevent overlapping of the edges during normal processing and handling of the coaxial pairs in the factory and during installation.

The components of design *6* coaxial pairs are illustrated in Figure 2. The centre conductor with the polythene disks in position is at the right. The formation of the outer tube from the corrugated-edged tape is next to it and the

[12] H. Stanesby and W. K. Weston, "London–Birmingham Television Cable," *Electrical Communication,* volume 26, pages 186–200; September, 1949: and *Post Office Electrical Engineers Journal,* volume 41, pages 183–188; 1948: and volume 49, pages 33–38; 1949.

[13] T. Kilvington, F. S. M. Laver, and H. Stanesby, "London–Birmingham Television Cable System," *Proceedings of the Institution of Electrical Engineers,* Part 1, volume 99, pages 44–62; March, 1952.

[14] British Patent 650 442; November 16, 1948.

completed coaxial pair with steel tapes and insulating papers, the outer paper being numbered, is also shown. At the left is typical cable containing 4 coaxial pairs with paper-insulated quads in the 5 interstices. This has a lead sheath, protected externally with compound-impregnated hessian tapes, and its external diameter is 1·5 inches (38 millimetres).

In most of the recently manufactured cables having 4 coaxial pairs, the quad in the centre interstice has been insulated with polythene instead of with paper. This gives control and test circuits that are proof against the accidental entry of water into the cable and that in consequence may save valuable time in organising emergency repairs to restore the coaxial circuits to service.

Examples of larger sizes of cables containing design-*6* coaxial pairs are illustrated in Figures 3 and 4. The two cables of Figure 3 are typical composite cables in which groups of 4 or 6 coaxial pairs are enclosed within layers of paper-insulated quads. This type of cable has been adopted by the British Post Office for heavy traffic on major trunk routes. Four 0·375-inch (9·5-millimetre) coaxials provide for 2 wide-band multi-channel telephone circuits and when required two additional coaxial pairs provide for a 2-way television circuit. The paper-insulated quads, up to about 190 in number, are coil loaded during installation and are used at audio frequencies for trunk circuits to distribution centres that are intermediate between the terminal stations of the coaxial circuits.

Figure 4 shows an 8-coaxial-pair cable with the coaxials stranded round a centre group of 24 paper-insulated quads; there are 8 similar quads in each of the outer interstices.

3.2 Manufacture

3.2.1 Raw Materials

The principal manufacturing operations required for the production of the various-sized cables containing design-*6* coaxial pairs are shown diagrammatically in Figure 5. The sequence commences with the processing of the 5 raw materials named at the top of the diagram.

For the centre conductor the normal ±1-percent commercial tolerance on diameter is not good enough. Fully annealed high-conductivity copper wire of a diameter greater than 0·104 inch (2·64 millimetres) is supplied to a sizing machine that subjects it to a rigorously controlled single pass through a special die. The

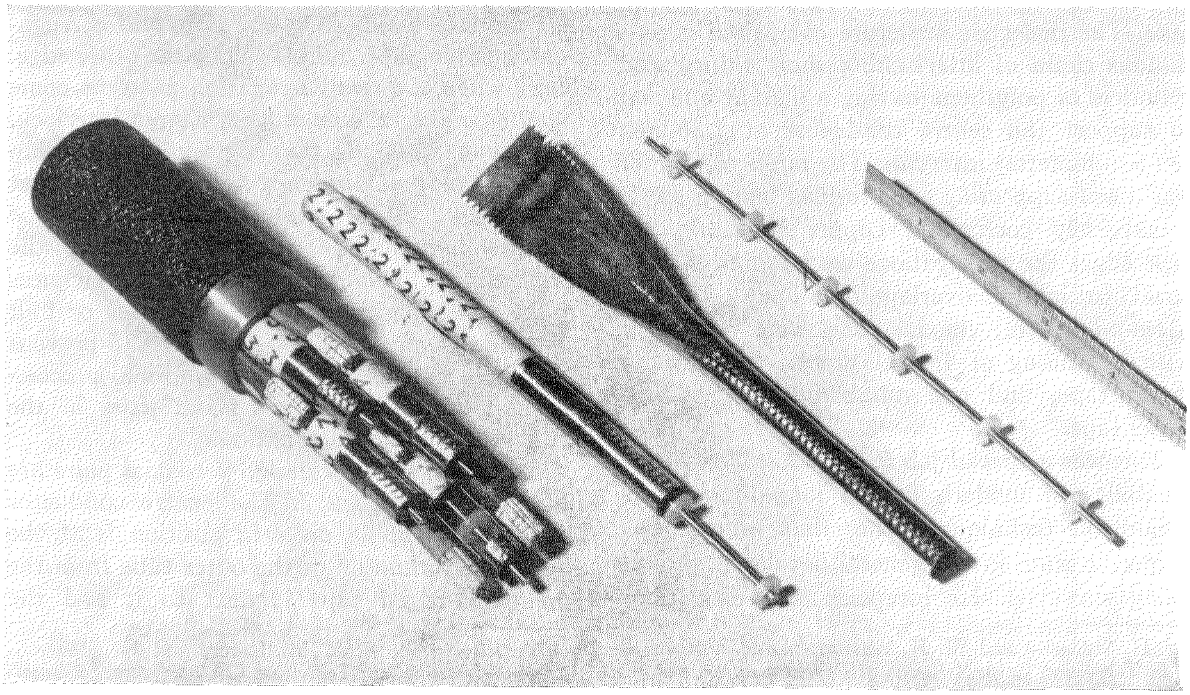


Figure 2—Structure of coaxial pairs of design *6*. The cable at the left includes 4 coaxial pairs and 5 interstitial paper-insulated quads.

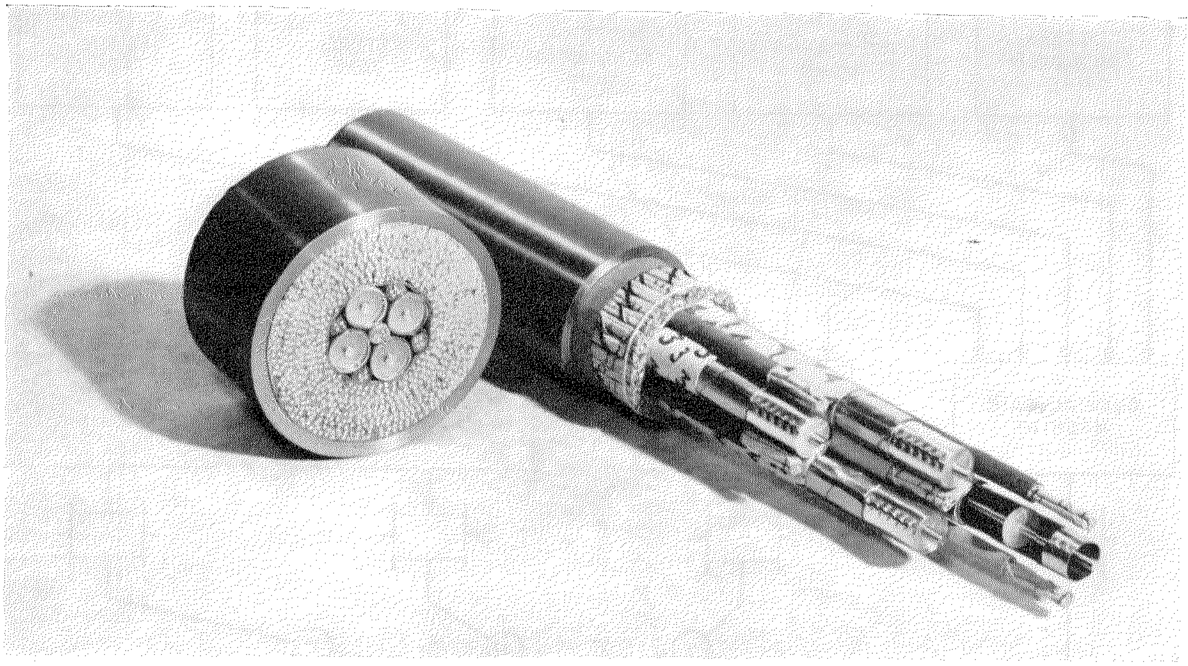


Figure 3—Two types of composite cables containing 4 coaxial pairs enclosed within layers of paper-insulated quads.

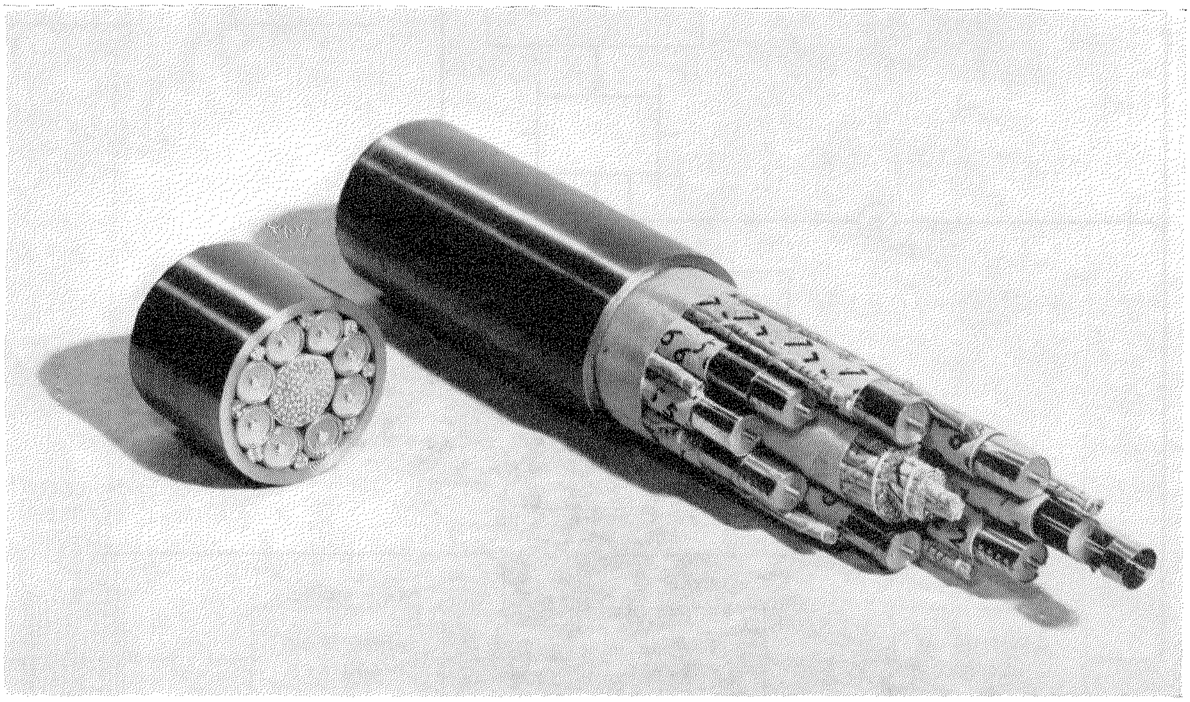


Figure 4—In this cable the 8 coaxial pairs surround 24 paper-insulated quads and there are 8 more quads in the outermost interstices.

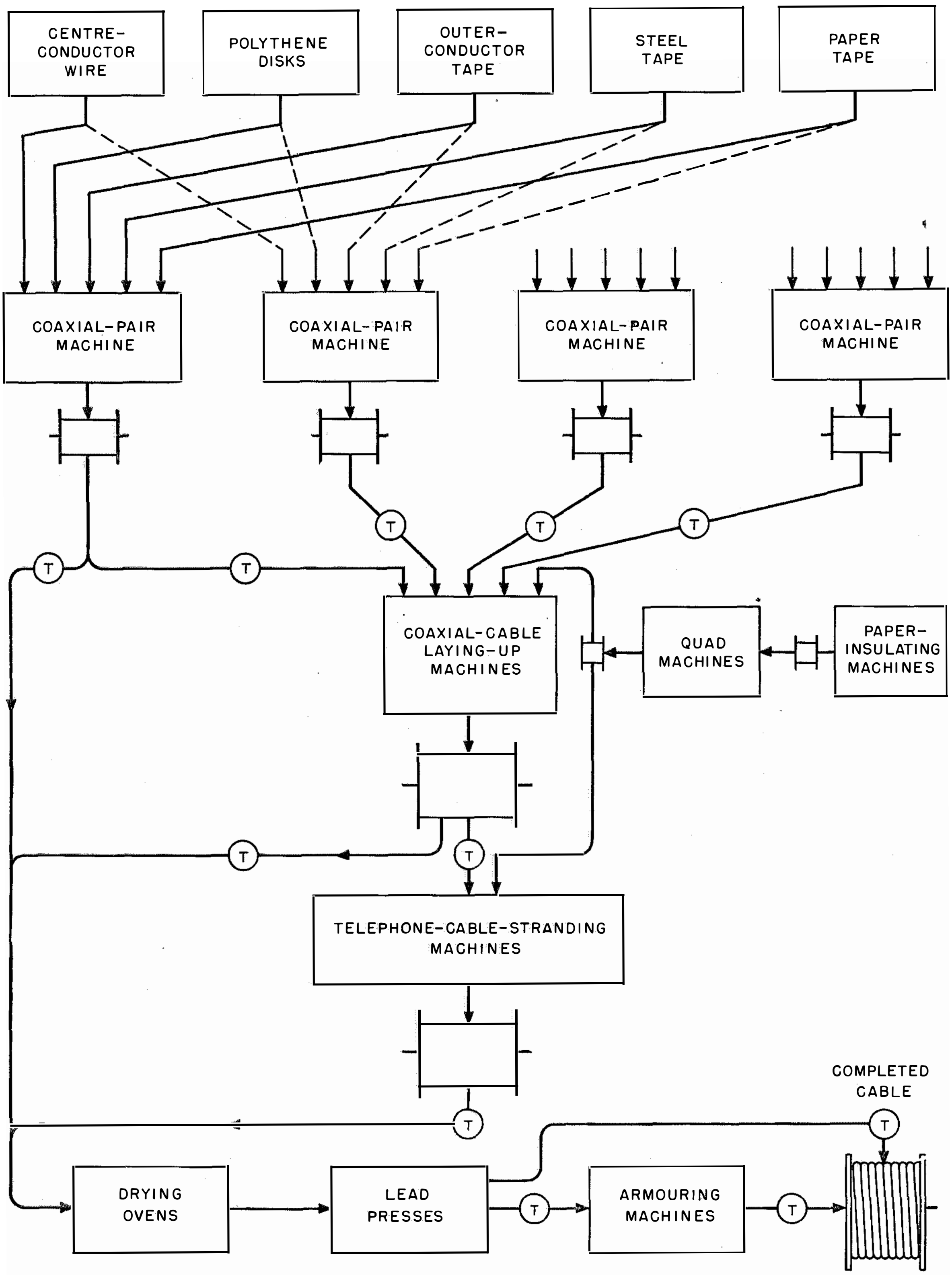


Figure 5—Manufacturing operations required for producing various sizes of composite cables including design-6 coaxial pairs.

output from this machine is a wire of diameter not varying more than one or two parts in a thousand from 0·104 inch. As it is important to avoid kinking or scoring the sized wire, it is wound carefully on to steel bobbins before it is taken out of the sizing machine.

Polythene for the disks is supplied in strip form between 2 and 3 inches (51 and 76 millimetres) wide and of a thickness within the specified tolerances of the required 0·075 inch (1·9 millimetres). The material is grade-2 Alkathene of the highest purity. These strips, wound into pads, are fed into specially designed multiple-impression automatic punch presses that produce disks having an external diameter and centre holes of an internal diameter within close tolerances of the specified dimensions. The completed disks leave the presses in air-tight cans.

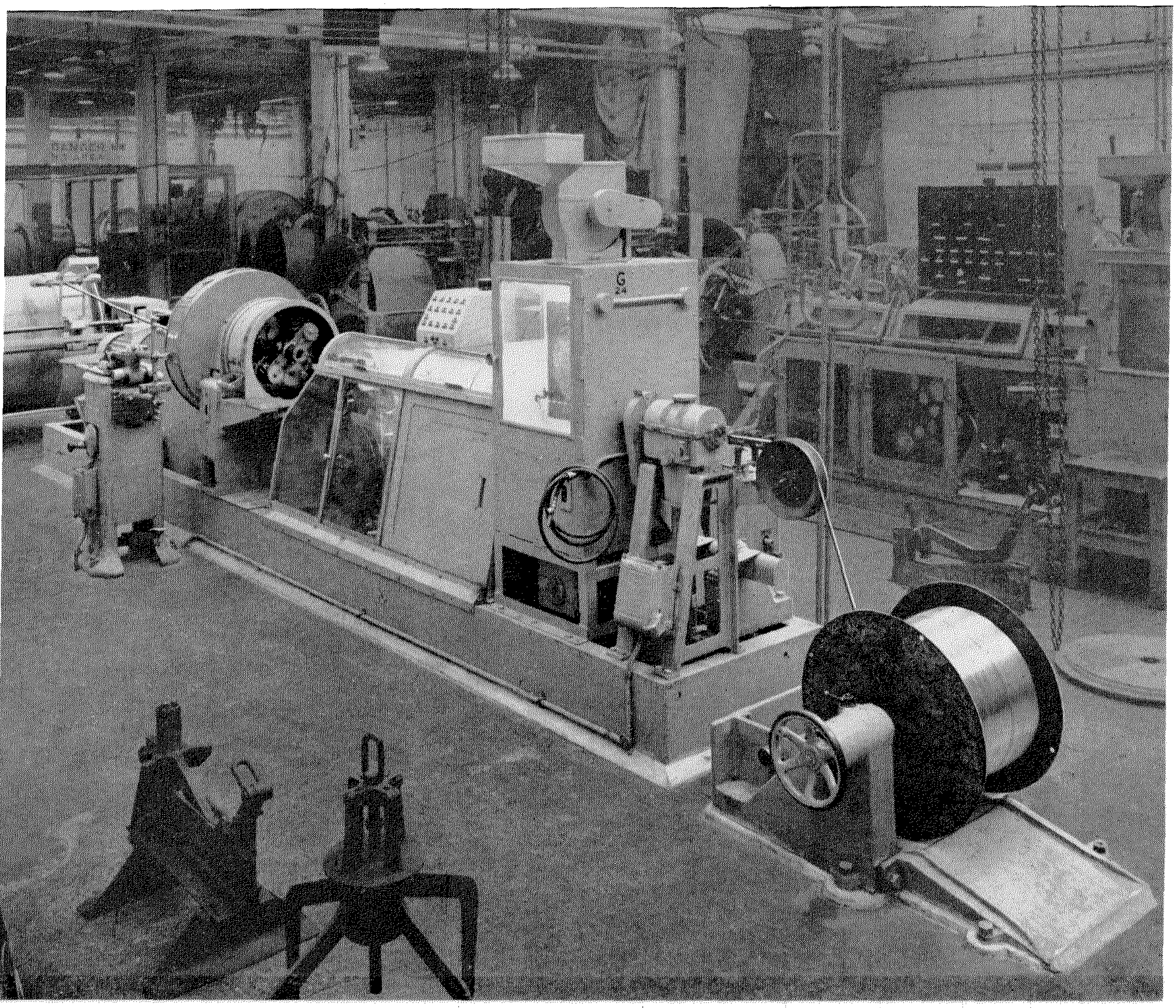
The tape for the outer conductor is made from high-conductivity copper and its width and thickness have to be kept within closer-than-normal tolerances since the internal diameter of the outer tube of the coaxial pair is a function of both dimensions. The sized tape is in the form of large pads enclosed within sheet-steel flanges.

By comparison with the foregoing, the requirements for the steel tapes and paper tapes are less exacting. The quality of the materials and the tolerances on the dimensions of the tapes are satisfactorily controlled by normal telephone-cable practice. The steel tapes are wound on to special steel bobbins that load into the high-speed taping heads in the coaxial-core machine.

3.2.2 Coaxial-Pair Manufacture

A recent type of coaxial-core machine is illustrated in Figure 6. The cycle of operations starts at the right of the picture, where the bobbin loaded with centre conductor is in

Figure 6—Machine for manufacturing design-6 coaxial pairs.



position on its stand. The wire is taken up to the main longitudinal axis of the machine, passes through a cleaning device, and enters the rectangular cabinet containing the polythene-disk applicator head.[10] Except for minor changes, the disks are applied to the centre conductor in the manner outlined in Section 2.5. Part of the applicator wheel may be seen through the perspex panel of the cabinet.

With the disks in position, the centre conductor then passes along under the perspex top of the copper-tape compartment. The large pad of copper tape is mounted on a horizontal arbor in the lower left end of the compartment. From the pad the copper tape passes through a roller device that imprints the corrugations on its two edges. It then goes up to the top of the compartment and moves forward horizontally alongside the disk-insulated conductor. During this transit, the copper tape is turned through 90 degrees from a horizontal to a vertical plane behind the centre conductor. Both then enter the tube-forming die, a steel block with a carefully profiled cavity, the general shape of which may be inferred from Figure 2.

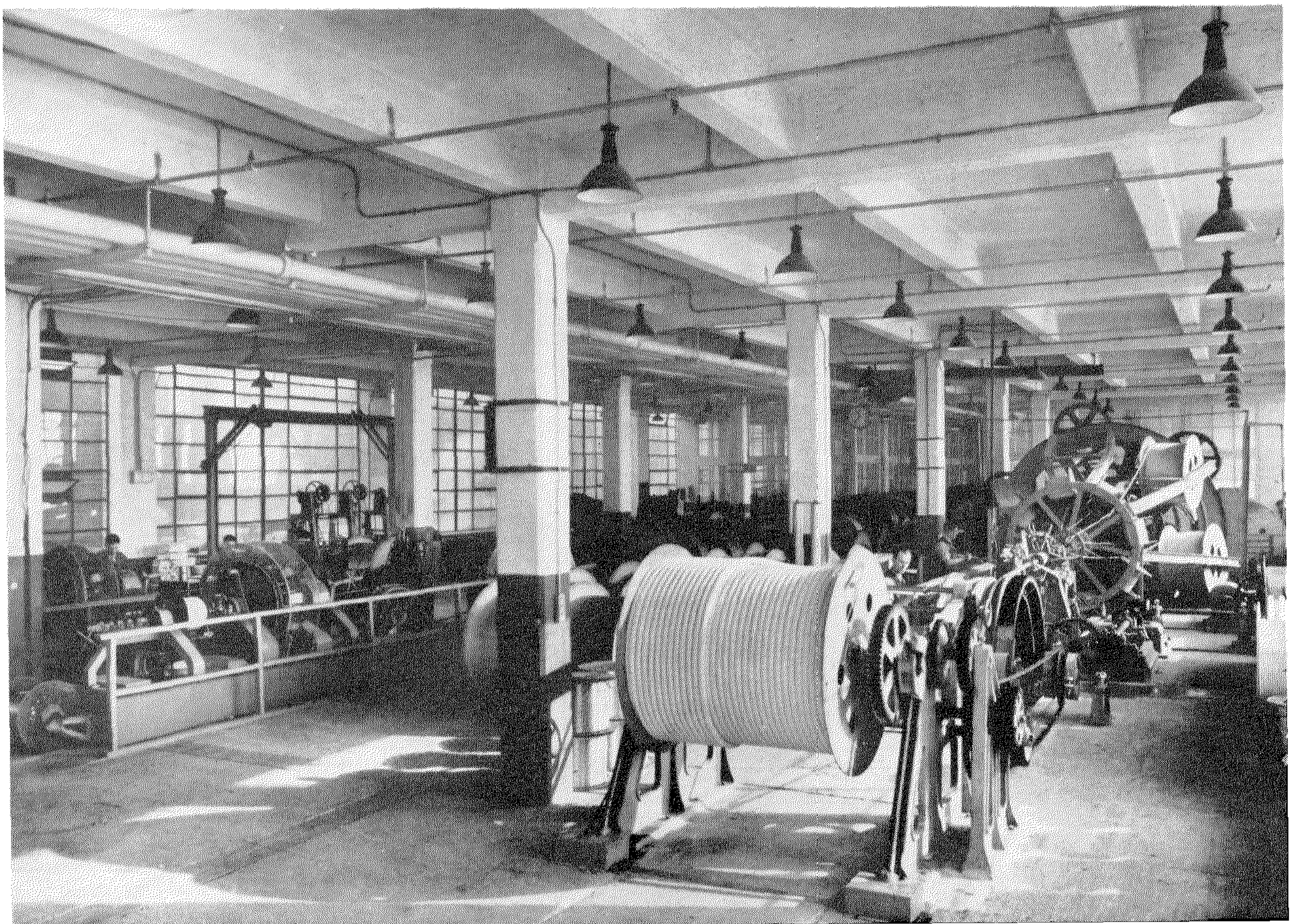
Because the copper tape is in a vertical plane on entering the tube-forming die, the butting-edge seam in the completed tube lies along the horizontal plane passing through the centre conductor axis. In this position the seam, which is the weakest part of the tube, is advantageously placed along its neutral bending plane during all subsequent drumming operations.[15] Experience has shown that the side-seam tube is less liable to distortion during these subsequent operations than the top-seam tube produced by earlier types of machine.

Next comes the high-speed steel-tape head in its cylindrical guard. The head carries two bobbins of steel tape with their axes parallel to its axis of rotation. The method of feeding the steel tapes on the outer tube of the coaxial pair ensures that the tension of application is kept within prescribed limits during the whole run from full to empty bobbins.

Behind the steel-tape head in the picture, is

Figure 7—Equipment used for laying-up several coaxial pairs and paper-insulated quads into a composite cable. The equipment at the left was used to produce the design-*1* cable described in Section 2.1.

[15] British Patent 668 950; February 21, 1950.



the larger guard housing the paper-tape head. From this, the completed coaxial pair passes round a capstan and through an automatic flaking device on the take-up cylinder, which is visible in the top left of the picture.

A feature of this machine is that in accordance with general telephone-cable practice the product moves through it at uniform linear speed through none but rotating devices. There are no reciprocating elements, nor are any of the major components of the product required to go through intermittent motions. As a consequence, the machine operates at high speed on a fully automatic basis. Adequate monitoring and alarm devices are fitted to ensure that all the operations are carried out correctly. These devices with their signal lamps are housed on the control panel, which may be seen in the picture behind the copper-tape compartment.

3.2.3 Laying-Up Coaxial Cables

As indicated in Figure 5 the next stage in manufacture, excepting single-coaxial-pair cables, is the laying-up of 2, 4, 6, or 8 coaxial pairs. This operation requires specially designed stranding or laying-up machines. A typical machine for up to 6 coaxials is shown on the right of Figure 7. In the design of these machines special care has been taken to avoid bending, twisting, or unduly stressing the coaxial pairs as they pass from their individual cylinders to the take-up cylinders containing the laid-up multi-pair groups. To this end the sub-carriages for the single-pair cylinders are mounted with their longitudinal axes of rotation inclined to the axis of the main carriage and converging towards the lay plates at the output end of the machine. Also, during rotation of the main carriage, the sub-carriages float in the sense that the spindles of the single-pair cylinders always remain in a horizontal plane.

The variation in angular velocity of the sub-carriages and cylinders deriving from their floating rotation and inclined axes does not cause significant variation in the tension applied to the coaxial pairs leaving the cylinders, owing to the comparatively low speed of rotation of the main carriage of the machine.

Small bobbins containing the paper-insulated interstice quads are mounted on fixed brackets at the output end of the main carriage. Centre quads or groups of quads are fed straight into the hollow shaft at the input end of the machine. The lay-plates, closing dies, paper heads, capstans, and take-up stands at the output end of the machines are generally in accordance with normal telephone-cable practice.

If 3 or 4 layers of paper-insulated quads are required outside the multi-pair coaxial groups, the cylinders from the laying-up machines are taken to the input end of normal telephone-cable-stranding machines. Through these the coaxial-pair centre group is passed whilst the layers of quads are stranded on to it to form composite cables of the type shown in Figure 3.

3.2.4 Drying, Sheathing, and Armouring

The drying technique for cables containing coaxial pairs differs only in detail from that used for dry-core paper-insulated telephone cables. It is necessary to set a limit to the maximum temperature obtaining during the process to avoid distortion of the polythene disks in the coaxial pairs. This, however, does not make it difficult to achieve satisfactory insulation resistance results from the paper-insulated pairs or quads in the cables.

Lead sheathing may be carried out on either the hydraulic or screw type of lead press in common use. For the smaller cables in which the coaxial pairs are immediately below the sheath the screw-type press is preferred because of its continuous action. When the hydraulic-type press stops to recharge, the cable then in the press gets hotter than it does when on the move. The risk of overheating has been successfully controlled by circulating a cooling medium through the point and dies during the recharging intervals.

Serving and armouring of coaxial cables may be carried out as required providing that a few special precautions are taken. In order to guard against overheating in the compound tanks, machine loading is planned to minimise the number of times the cable has to be stopped during the processes. Erratic twisting of the cables when passing through rotating heads and carriages has to be avoided particularly when the leading end or trailing end of a cable length is passing through the machines.

3.3 INSTALLATION

3.3.1 Cable Placing

The presence of coaxial pairs in a telephone cable imposes no insurmountable limitations on any of the accepted methods of cable placing, such as pulling into ducts or conduits, laying directly into trenches, laying in shallow water, or suspending overhead on pole lines.

In Great Britain practically all telephone cables are pulled into earthenware duct lines, of 3·25-inch (83-millimetre) internal diameter, of which a very extensive network covers the whole country. Recently built duct lines and jointing manholes have been designed to accommodate coaxial cables, which differ from multiconductor telephone cables in that they may not be bent or set round curves of small radius or be subjected to excessive twisting whilst being pulled into the ducts. With some of the older sections of the duct network, it has on occasions been necessary to make structural alterations before installing coaxial cables.

When a drum length of full-size 2·75-inch (70-millimetre) cable is pulled into a 3·25-inch (83-millimetre) duct, which may be up to 200 yards (183 metres) in length, the longitudinal stress on the forward end of the cable may be excessive and harmful if the duct line is not in good condition throughout. It is, of course, routine practice to pass a brush and mandrel through each length of duct immediately before pulling in a cable, to ensure that there are no gross obstructions, silt, or loose materials in the bore.

From the behaviour of the winch used for pulling in cables, a skilled operator can make a rough estimate, sufficient for record purposes, of each pulling operation and classify it as a light, medium, or heavy pull. Statistics correlating these records with the test results from the cables have shown that heavy pulls tend to impair the quality of the coaxial pairs in the cables. Any length of coaxial cable that has been subjected to a heavy pulling stress should be tested for quality before being passed for jointing.

3.3.2 Jointing

The development of jointing technique has been an essential concomitant of the improvements effected in the design and manufacturing techniques of coaxial pairs. In such matters as conductor and insulation resistance, tensile strength, etc., the requirements for a coaxial-pair joint are those generally applicable to all telephone-cable joints.

From the time of the first coaxial-cable installations it was necessary to retain the coaxial structure of the two conductors in the joints to avoid excessive crosstalk linkages between two or more coaxial pairs lying side by side in one cable. The resulting inconveniences of having the centre-conductor connector totally enclosed within the outer-conductor connector has had to be accepted. It was also considered advisable to block the space between the two connectors in the joint with wax or cemented plugs of hard rubber to form water barriers. The hollow tubular structures of spiral thread or slotted disks as distinct from slit-disk coaxial pairs are good water conduits. Water from a considerable source, gaining access to these older-design coaxial cables may flood several-hundred yards in a matter of hours and before repairs can be effected. By blocking the joints such damage would be limited to one drum length of the cable. For cables installed in duct lines in Great Britain it appears, however, to be somewhat improbable that a large puncture in the cable sheath due to external circumstances would occur when the cable and the duct line were under water in sufficient quantity to cause extensive flooding of the cable.

To assist in maintaining after installation the improved impedance uniformity of the factory product and to avoid undesirable double reflections from regularly spaced locations in long television circuits, it has latterly become necessary to design joints and sealing ends to match the impedance of the coaxial pairs. The joint structure is an electrically short length of coaxial line with long (drum) lengths of coaxial line on either side. It is neither practicable nor necessary to make the characteristic impedance of the joint structure of constant value throughout its length. A series of components of differing impedance can be proportioned to achieve the objective. The components may be considered to be lumped series inductances L_1, L_2, etc. and shunt capacitances C_1, C_2, etc. The n components taken all together will then match the coaxial pair of characteristic impedance Z_0, when:–

$$\Sigma L_n / \Sigma C_n = Z_0^2. \quad (8)$$

A detailed account of this method of approach has been published.[16]

An alternative approach that is equally applicable to joints and sealing ends, for which one or two advantages may be claimed, has been evolved around the concept of the effective impedance mismatch of a short insert of impedance Z_1 in an otherwise uniform line of impedance Z_0. In Figure 8 the insert of length

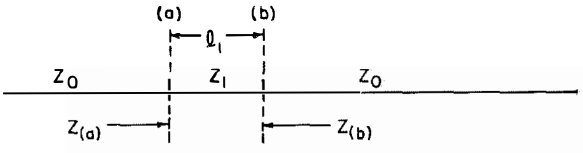


Figure 8.

l_1 is shown and the impedance of the line $Z_{(a)}$ at the point (a) for propagation to the right may be determined from the appropriate transmission equation for a line Z_1 terminated in Z_0. By postulating that the electrical length $\beta_1 l_1$ of the insert is not to exceed about 0·1 radian and that the attenuation $\alpha_1 l_1$ of the insert may be neglected, a considerably simplified but appropriately accurate expression for $Z_{(a)}$ in ohms may be shown to be:–

$$Z_{(a)} = Z_0 + i k_1 Z_0, \quad (9)$$

where

$$k_1 Z_0 = \left(\frac{Z_1^2 - Z_0^2}{2Z_1}\right) 2\beta_1 l_1. \quad (10)$$

The effective impedance mismatch of the short insert l_1 is ik_1Z_0 ohms and, as will be apparent from Figure 8, it has the same magnitude and sign for both directions of propagation. ($Z_{(a)} = Z_{(b)}$.) It is also reactive and of magnitude directly proportional to frequency. In these three respects it differs from the mismatch δZ_0 at the junction of two long lines of impedance Z_0 and $Z_0 + \delta Z_0$ respectively. At a given frequency kZ_0 and δZ_0 are comparable factors giving rise to irregularities in otherwise uniform lines.

[16] R. J. Turner, "Reflectionless Joints for Coaxial Pairs," *Post Office Electrical Engineers Journal,* volume 45, pages 72–76; July, 1952.

When there are two or more short inserts of differing impedance and length, as in Figure 9, it can be shown that:–

$$Z_{(a)} = Z_{(e)} = Z_0 + i(k_1 Z_0 + k_2 Z_0 + k_3 Z_0 + k_4 Z_0). \quad (11)$$

Hence the effective impedance mismatch ik_jZ_0 in ohms of a joint structure consisting of n differing components is:–

$$i k_j Z_0 = \sum_1^n i k_n Z_0 \quad (12)$$

and the joint matches the line Z_0 when ik_jZ_0 is zero.

It is a simple matter to estimate the values of k_nZ_0 for the several components of a coaxial joint from their dimensions and dielectric structures. All the impedances Z_0, Z_1, ... Z_n are of the form given in equation (4), and since the estimates are normally made at frequencies not less than 5 megacycles per second, the frequency-dependent term may be disregarded without appreciable error. It suffices to use the asymptotic value, which is a simple function of the diameters ratio and the dielectric permittivity.

Since the estimate of k_nZ_0 includes the electrical length of the component, a check is automatically provided against including components that are too long either for this method of assessment or for the method of equation (8). The estimated values k_nZ_0 for the several components give a clear picture of their relative importance as potential sources of impedance irregularities and facilitate the adjustment of the design of the joint to make $ik_jZ_0 = 0$.

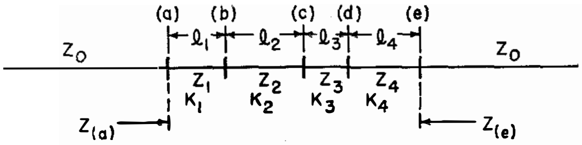


Figure 9.

Having dimensioned the joint to give this solution, the effect of the necessary manufacturing tolerances on the dimensions of the piece parts; copper tubes, ferrules, hard-rubber disks, etc. may be assessed by revising the estimates for the effective impedance mismatches to cover both the expected minimum and maximum dimensions. The summation of these separately in equation (12) will give an estimate of the probable range of ik_jZ_0 for a large number of commercially similar joints, from a positive value through zero to a negative value.

Two other factors affecting the probable range of ik_jZ_0 may be noted. The first is the expected variation in the magnitude of the characteristic impedance $Z_0 \pm \delta Z_0$ of the two coaxial pairs at the joints. The second is the variation in end impedances of a disk-insulated coaxial pair as a function of the length of tube from the end to the centre line of the first disk. When the end of a coaxial pair is cut for jointing, the distance to the centre line of the first disk from the cut end is a matter of pure chance between limits of zero and the disk-spacing interval [1·3 inches (33 millimetres) for design-*6* coaxial pairs]. The effect of this variable may be assessed by considering it to be an additional pair of components to be added to each side of the joint. Their effective impedance mismatches may then be estimated for the average and limiting dimensions and included in equation (12) for ik_jZ_0. By designing the joint for zero ik_jZ_0 when these two factors are at their average values, the range of ik_jZ_0 will remain symmetrically placed about zero but will be increased in magnitude. Their relative contributions to the range, compared with those due to the tolerances on the dimensions of the piece parts, will enable equable tolerances to be decided on.

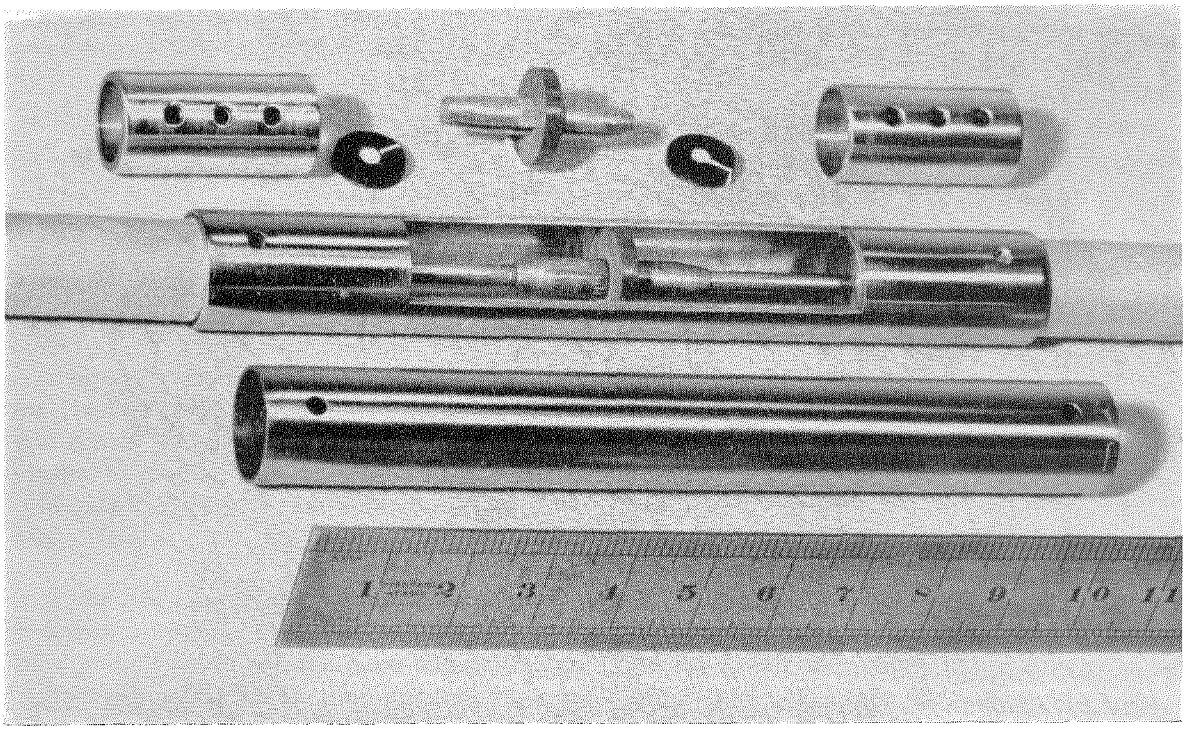


Figure 10—Joint for design-*6* coaxial pair.

In transmission studies of the effects of impedance irregularities in long lines, the magnitude of the irregularities are most commonly stated as voltage-reflection coefficients or return losses expressed in decibels below incident signal level. Mismatches at joints δZ_0 or ik_jZ_0 in ohms are readily converted to return losses A in decibels by means of the expression :–

$$A = 20 \log_{10} \frac{\delta Z_0}{2Z_0} = 20 \log_{10} \frac{k_j Z_0}{2Z_0}. \qquad (13)$$

A joint that has been extensively used with design-*6* coaxial-pair cables is illustrated in Figure 10 and in the cross-sectioned drawing of Figure 11, which is not to scale in order more clearly to delineate the components for which effective impedance mismatches are to be estimated.[17] Since the joint is symmetrical about its centre line the design work can be carried out on one-half of it and as indicated by Z_1, ... Z_8 there are 8 components to be considered.

There are 5 different piece parts in the joint. The coaxial pairs to be jointed together are cut to have their centre conductors butting together at the centre line of the joint. Each outer conductor is cut back from the centre line as shown. To avoid melting the polythene disks during subsequent soldering operations, 4 or 5 are extracted from the end of each coaxial pair. A copper end collar is soldered directly to each outer tube, with the steel tapes secured in its outer tapered end. Four hard-rubber disks are pushed into each coaxial at the normal spacing interval and with the last one in flush with the end of the outer tube. The outer-conductor ferrule is pushed over one end, and the two centre conductors are butted together inside the centre ferrule, which has the centre disk already mounted on it. This ferrule is securely soldered into position. The outer conductor ferrule is then moved into position and securely soldered to each end collar. It is a bimetallic tube with copper inside and mild steel outside to provide screening across the joint.

Each coaxial pair in a cable is jointed in this manner, and the paper-insulated interstice quads are jointed in accordance with normal telephone-cable practice. In composite coaxial cables, the jointing of the quads in the outer layers follows a special technique that ensures that in the event of the completed joint having to be opened for repairs the coaxial-pair joints are accessible without breaking down the quad joints.[18] Each completed joint is carefully dried out at a controlled temperature. It is then sealed up inside a lead sleeve that is plumbed to each cable sheath end. The joint is finally pressure tested with dry air at about 20 pounds per square inch (1·4 kilograms per square centimetre). In manholes where the joint and cables may be exposed to mechanical damage, they may be protected externally by robust troughing or flexible metallic tubing.

The estimated ranges of the effective impedance mismatches ik_jZ_0 at 20 megacycles per second for this joint are given in Table 3. They are given for variation in $Z_0 \pm \delta Z_0$ of $75 \cdot 0 \pm 0 \cdot 4$ ohms at 2·5 megacycles per second; variation in the internal diameter D_1 of the outer-conductor ferrule of $0 \cdot 510 \pm 0 \cdot 010$ inch ($12 \cdot 9 \pm 0 \cdot 3$ millimetres) and for variation in length l_7 of the disk-spacing component Z_7 of $0 \cdot 95 \pm 0 \cdot 65$ inch ($24 \cdot 1 \pm 16 \cdot 5$ millimetres) (see Figure 11). With each effective impedance mismatch in ohms is given its equivalent voltage reflection coefficient or return loss in decibels below incident signal level.

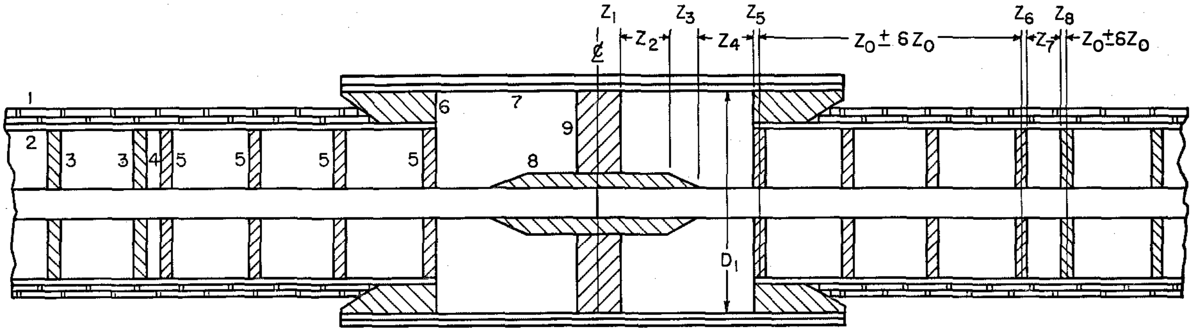


Figure 11—Cross-sectional drawing (not to scale) of coaxial-pair joint of design *6*. The two outer steel tapes are *1*, the outer copper tube is *2*, and *3* are the original polythene disks. A random space varying between 0·3 and 0·3 plus the normal disk spacing is at *4*, and *5* are hard-rubber disks inserted at normal spacings. A copper end collar *6* is soldered to the outer tube and *7* is the outer conductor ferrule having copper inside and steel outside. A copper ferrule *8* is for jointing the centre conductor, and *9* is a hard-rubber spacer. The distance between the inner ends of the copper collars *6* is 2·375 inches (60 millimetres).

[17] British Patents 642 540; March 24, 1947 and 642 576; August 9, 1948.

[18] E. D. Latomer and B. Ash, "A New Coaxial Cable Joint," *Post Office Electrical Engineers Journal*, volume 45, pages 1–4; April, 1952.

When all three variables in Table 3 are at their average values the joint has a negligible effective impedance mismatch of +0·002 ohm at 20 megacycles per second and a return loss greater than 90 decibels. For a ±0·01-inch (0·3-millimetre) change in D_1 the return loss drops to 68 decibels; for a ±0·75-inch (19-millimetre) change in l_7, it drops to 67 decibels; and for a ±0·4-ohm change in Z_0 it drops to 71 decibels. In the somewhat unlikely event of all three variables being at the limiting values that aid each other, the return loss would be between 58 and 60 decibels.

TABLE 3

Effective Impedance Mismatches and Return Losses of the Design-6 Coaxial-Pair Joint at 20 Megacycles per Second

Internal Diameter of Outer Ferrule D_1 in Inches (Millimetres)	$Z_0-\delta Z_0=74·6$ Ohms			$Z_0=75·0$ Ohms			$Z_0+\delta Z_0=75·4$ Ohms			Units
	Length l_7 of Both Sides in Inches (Millimetres)			Length l_7 of Both Sides in Inches (Millmetres)			Length l_7 of Both Sides in Inches (Millimetres)			
	1·60 (40·6)	0·95 (24·1)	0·30 (7·6)	1·60 (40·6)	0·95 (24·1)	0·30 (7·6)	1·60 (40·6)	0·95 (24·1)	0·30 (7·6)	
0·520 (13·21)	+0·177 58+	+0·098 64+	+0·019 78+	+0·126 62+	+0·058 68+	−0·010 83−	+0·085 66+	+0·017 79+	−0·040 71−	ohms decibels
0·510 (12·95)	+0·122 62+	+0·043 71+	−0·036 72−	+0·070 67+	+0·002 >90+	−0·066 67−	+0·018 78+	−0·039 71−	−0·097 64−	ohms decibels
0·500 (12·70)	+0·061 68+	−0·018 78−	−0·097 64−	+0·009 84+	−0·059 68−	−0·127 61−	−0·043 71−	−0·100 63−	−0·158 60−	ohms decibels

Measurements with a pulse-echo test set of the type described in a recent article[19] have confirmed that the estimated return losses in Table 3 can be realised with the joint described. It has been successfully used in long-distance coaxial circuits transmitting both wide-band carrier telephone signals and television signals for which guarantees of performance up to a frequency of 10 megacycles per second have been given and met.

A joint of similar design to that illustrated in Figure 10 but which has water-barrier rubber cup washers fitted around the first hard-rubber disk in each coaxial-pair end has also been extensively used in cables supplied to Administrations abroad.

[19] E. Baguley and F. B. Cape, "Pulse Echo Test Set for the Quality Control and Maintenance of Impedance Uniformity of Coaxial Cables," *Post Office Electrical Engineers Journal*, volume 44, pages 164–168; January, 1952.

3.3.3 Terminating

Wide-band long-distance coaxial circuits are repeatered at nominally 6-mile (9·7-kilometre) intervals. The repeater equipment may be installed in telephone exchange buildings or in small wayside buildings put up for the purpose. Cable-placing procedure follows similar lines in both types of building and in the terminal stations of each particular system.

Taking the large-size composite coaxial cables of Figure 3 as being typical of British practice, there will normally be 3 or 4 segregating joints at or near to each repeater station. The incoming cables are first segregated into their two principal groups of circuits, the audio circuits and the coaxial circuits, together with their supervisory circuits in the interstices.

At wayside repeater stations, one segregating joint outside the station connects the two main cables together. In this joint the audio circuits are jointed straight through but the two multi-pair coaxial groups and interstice quads are brought out separately through the two leading-in cables that are taken into the repeater station building.

For the other types of repeater and terminal stations, the north- and south-going main cables have a segregating joint each, from which separate cables containing the audio and coaxial circuits are taken to the appropriate equipment bays. The multi-pair coaxial leading-in cables, irrespectively of station lay-out, are taken to within a few yards of the repeater-equipment bays for the coaxial circuits. Here a second segregating joint is made from which each coaxial pair is taken out in a single-pair lead-covered or flexible tail-cable. All the interstitial circuits are taken out into a small quadded tail-cable and terminated in a test tablet. The coaxial tail-cables terminate in coaxial sealing ends, which are either fitted immediately above the repeater equipment or inside its top panel. The sealing ends are designed to match the impedance of the coaxial pairs in the manner outlined above for coaxial joints.

A photograph of the interior of an intermediate-repeater-station layout for a 2-coaxial-pair cable taken before the installation of the repeater bays is shown in Figure 12.

3.4 Testing

Tests are made on coaxial pairs at all significant stages during manufacture and installation, and most commonly in the factory at those distinguished by a *T* in Figure 5. It is known that the design-*6* coaxial pair has excellent transmission parameters when it is made and installed under ideal conditions. Under practical conditions there may be departures from intention or fortuitious interference with the structure. Testing techniques are planned to detect such events in the shortest possible time after their occurrence.

The 0·375-inch (9·5-millimetre) coaxial pair has most of the mechanical properties of thin-walled tubes. Excessive longitudinal stress, twisting, or bending may distort the outer-conductor cylinder or may displace the inner conductor axially, where it is not supported by the insulating disks. A transverse stress may cause dents or flats in the tube. Any of these causes may have two undesirable effects; a reduction in the spacing between the conductors, implying liability to contacts between them during subsequent handling; and a change in impedance over a sufficient length of core to constitute a significant deviation from impedance uniformity.

3.4.1 *High-Voltage Tests*

A high-voltage flashover test is the obvious choice for checking conductor spacing. A small portable set is used. Energy is derived from a built-in 7·5-volt dry battery that drives a vibrator whose alternating-current output passes through a step-up transformer. The high alternating voltage is fed to a voltage-doubler rectifier and smoothing circuit giving a direct-

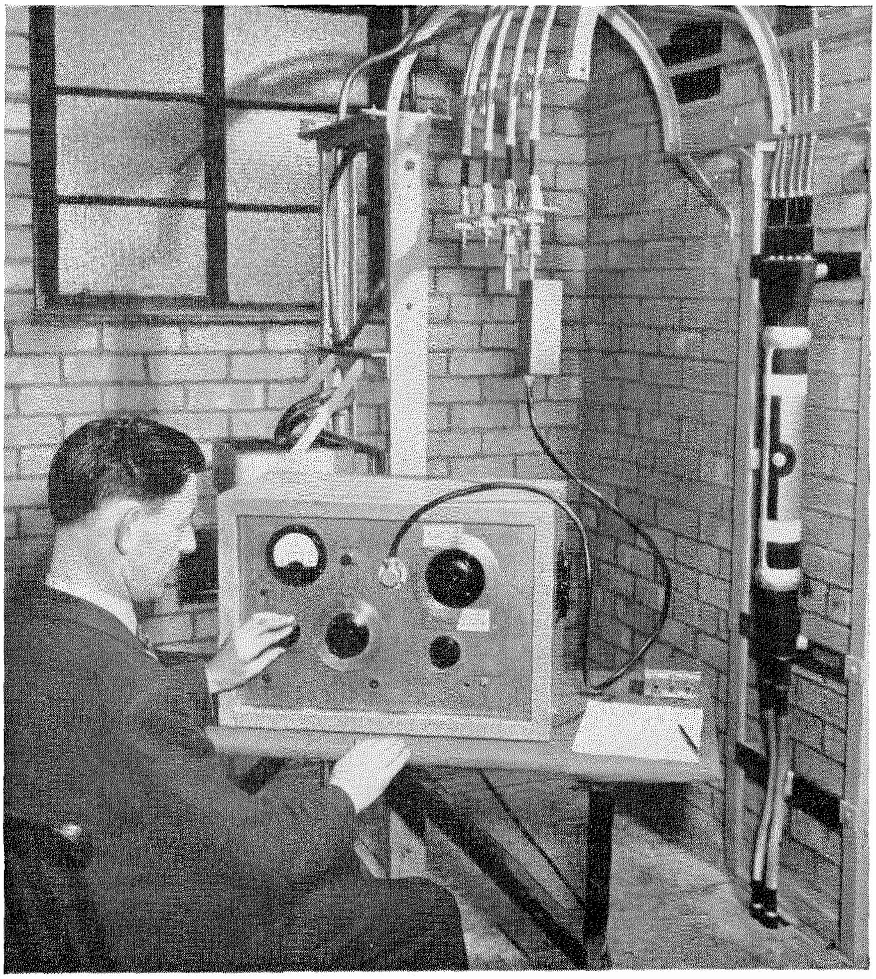


Figure 12—Interior of repeater station for 2-coaxial-pair cable before repeater bays were installed.

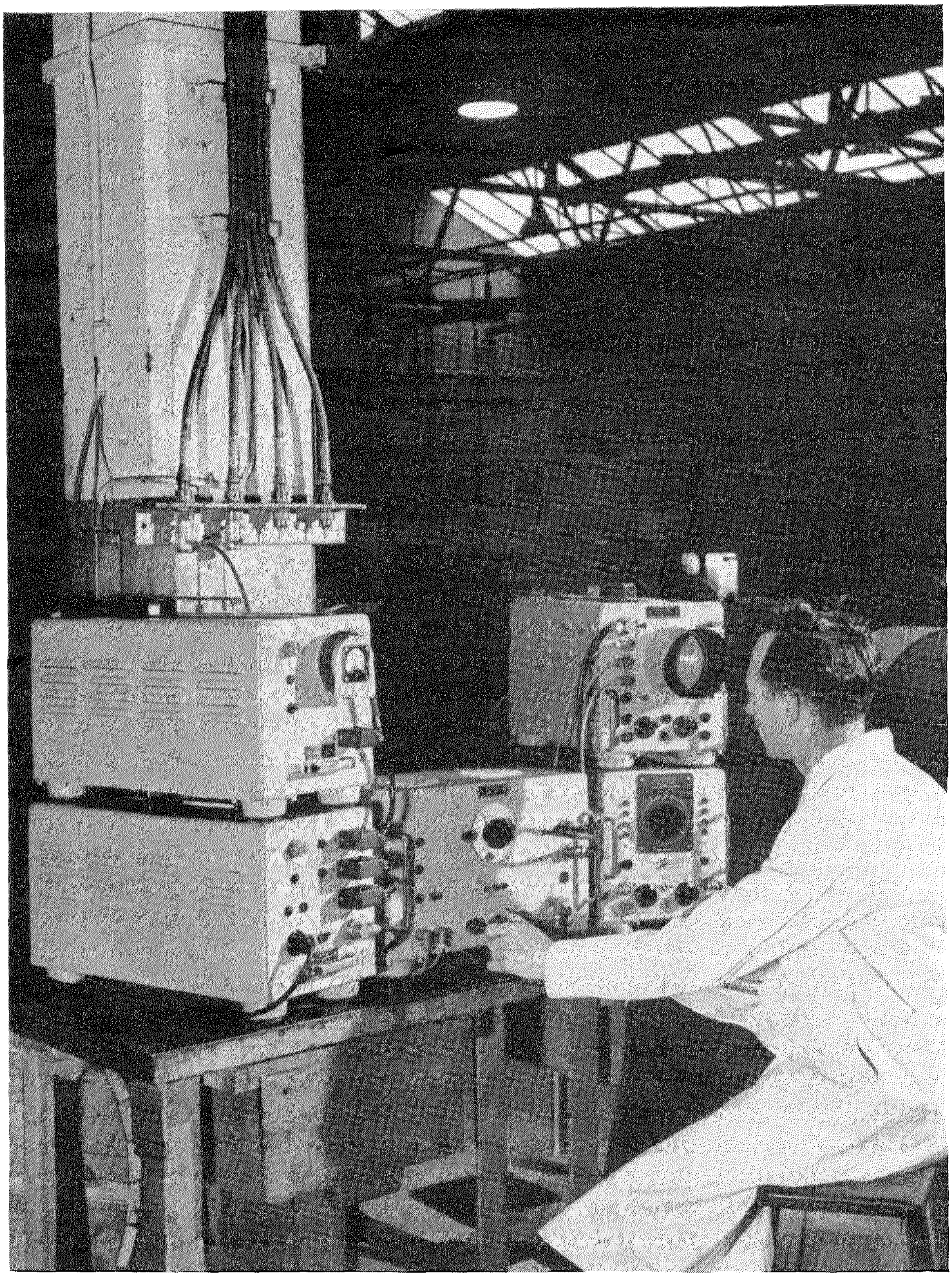


Figure 13—Pulse-echo test set for checking impedance uniformity.

voltage output controlled by a variable resistance in the transformer primary circuit. Voltage range is 700 to 5000 volts with a maximum current output of 1 milliampere. The set is taken to the cylinder or drum of cable to be tested, and the direct voltage is applied between the inner and outer conductors of the coaxial pairs in turn. It is run up from 700 volts, either until 5000 volts is reached or until flashover occurs, the flashover voltage being noted.

The very limited power output from the set yields two advantages. The discharge of energy at flashover is too small to damage the coaxial pairs and, as the set is not dangerous to personnel, cables may be safely tested without being enclosed in metal fencing. All coaxial pairs must pass a 3000-volt direct-current test, and the average flashover voltage is around 4500 volts. The same test is used for field tests during and after installation.

3.4.2 *Pulse-Echo Tests*

Pulse echoes provide the only practical method of detecting significant irregularities of impedance in a length of coaxial pair at any stage in its history. Since the first inception of this method of testing[20] it has been an essential factor in controlling the impedance uniformity of coaxial cables. The present-day pulse-echo test set is illustrated in Figure 13 where it is seen being used for factory tests. The set transmits a train of short direct-current pulses into the coaxial pair and displays on the screen of a cathode-ray tube as a stationary picture any echoes from impedance irregularities. The magnitudes of the echoes may be measured in decibels below incident pulse level, and their location may be scaled off the linear time base of the displayed oscillogram.

By balancing out the reflection from the junction of the test lead and the coaxial pair under test against a reflection from the junction of an identical test lead and a variable network (simulating the impedance of a coaxial pair), a measurement of the end impedance of the coaxial pair is obtained from a direct-reading dial. The impedance-measuring range is 73·5 to 76·0 ohms by 0·05-ohm sub-divisions.

[20] United States Patent 2 345 932; March 26, 1941.

For factory tests a pulse of 0·05-microsecond width between half-amplitude values is used, and this detects any irregularities giving reflections worse than 80 decibels below incident pulse level at frequencies up to about 15 megacycles per second thus giving a reasonable margin of safety for a top operating frequency of 10 megacycles per second.

For field tests, a pulse width of 0·1 microsecond is normally used since it attenuates less rapidly and yields more data about the coaxial pair a thousand or more yards from the test end. Field tests, after lengths have been jointed together, check that the joints have been correctly assembled and that they match the coaxial-pair impedance. It is routine practice to pulse-echo test from both ends each completed 2000-yard (1829-metre) length of installed cable before completing the jointing into 6-mile (9·7 kilometre) repeater sections. By this means, an assessment of the quality of each portion of the cable is obtained from test points not more than 1000 yards (914 metres) away. An assurance may then be given that the results from pulse-echo or impedance tests made from the terminals of completed repeater sections are representative of the quality of the whole section and not, as otherwise might obtain, preponderately assessments of the cable nearest the repeater stations.

A test with this set from both ends of a length of coaxial pair provides all the data needed to define its impedance characteristics. The magnitude of the impedance at each end is determined within an accuracy of the order of 0·05 per cent and all irregularities between the two ends that exceed 0·05 per cent in magnitude are determined both in magnitude and location. This set and the pulse-echo technique for 0·375-inch (9·5-millimetre) coaxial cables have been dealt with in greater detail in the contemporary paper[18] already noted. A pulse-echo-test oscillogram obtained from an installed 2000-yard (1829-metre) length of design-*6* coaxial cable is given in Figure 14.

3.4.3 *Attenuation Tests*

Completed drum lengths of coaxial cables are tested in the factory for attenuation at a stated single frequency, usually 2·5 megacycles per second. The attenuation of 200 yards or so of 0·375-inch (9·5-millimetre) coaxial pair is too small to be measured directly, and the test is made by the well-known quarter-wave or resonant-frequency end-impedance test with the far end alternatively open-circuited and short-circuited.

A radio-frequency equal-ratio-arm bridge is used with a specially designed oscillator and detector–amplifier covering the limited frequency band from 2 to 3 megacycles per second on direct-reading scales with 0·05-megacycle-per-second sub-divisions. This equipment is trolley-mounted as shown in Figure 15 and is taken alongside the cable to be tested, since it is not permissible to use a long test lead between the cable end and the bridge. The test is made at the

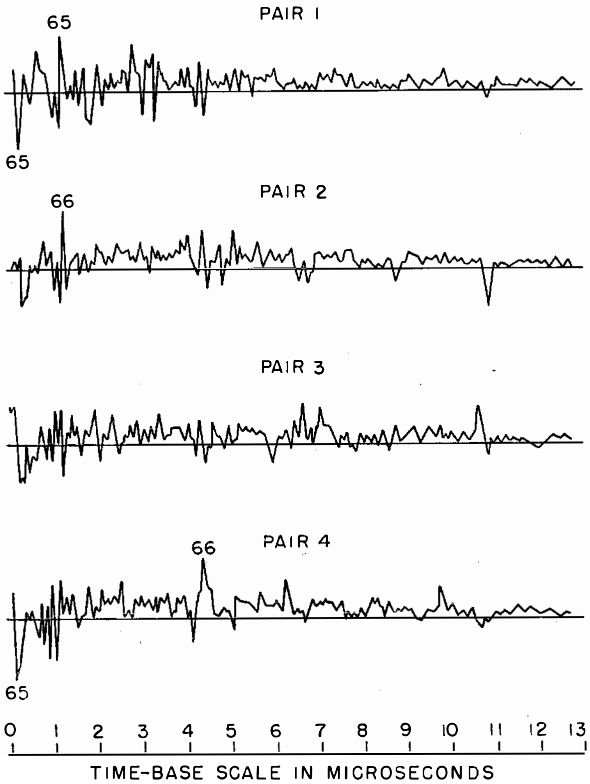


Figure 14—Pulse-echo test oscillograms from a 2000-yard (1829-metre) length of coaxial cable installed in 1951. A direct-current pulse of 0·1-microsecond width was used and the magnitudes of the strongest reflections are indicated in decibels below the incident pulse level.

nearest resonant frequency to the specified frequency, and corrections are made to the results in accordance with the known attenuation–frequency law for the coaxial.

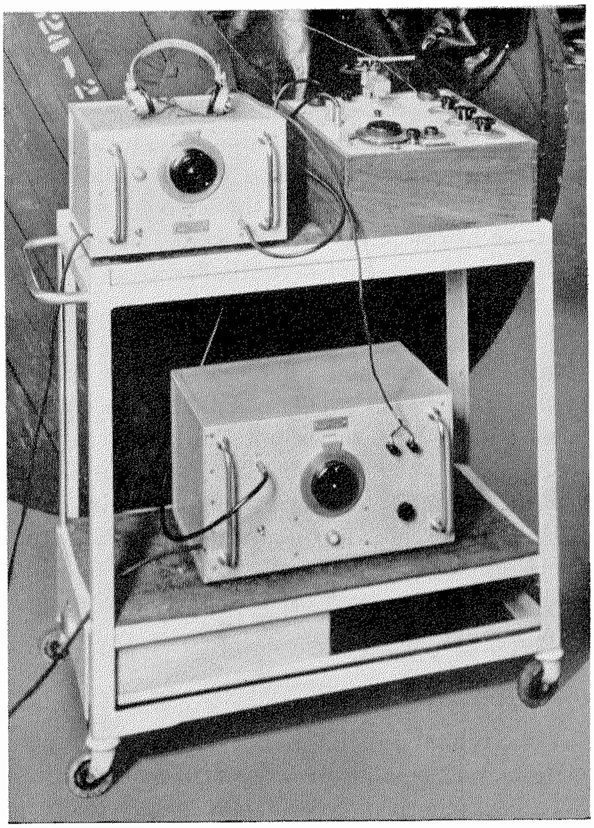


Figure 15—Attenuation test set used in the factory. To avoid long connecting leads, it is rolled to the drum of cable to be tested.

Field attenuation tests are made on completed 6-mile (9·7-kilometre) repeater sections from the coaxial sealing ends in the repeater stations. The principle of operation is to measure by a direct comparison method the attenuation that a signal undergoes when it is sent along one coaxial pair and returned from the far end through a second coaxial pair in the same cable. A variable attenuator, which incorporates key-switched pads of the asymmetric L and π types, is fed with the same signal as the first coaxial pair and its value is adjusted to give the same output signal as the second pair. A wide-frequency-range power signal generator supplies the input signal and a high-gain detector–amplifier is used to detect the output signal either visually on a meter or audibly in telephone receivers.

Briefly the principal features of the three instruments are as follows:–

A. *Power Signal Generator*. The frequency range of the power signal generator shown in Figure 16 is from 55 kilocycles to 10 megacycles per second in 9 bands on direct-reading scales. It provides an output of 20 volts into 75 ohms up to 5 megacycles per second and 10 volts above that frequency.

B. *Attenuator*. The attenuator, which may be seen in Figure 17, has a range from 0 to 160 decibels in steps of 0·2 decibel. It has an unbalanced 2300-ohm input impedance.

C. *Heterodyne Detector–Amplifier*. The frequency range of the heterodyne detector–amplifier is from 5 kilocycles to 10 megacycles per second in 5 bands. Its sensitivity is better than 1 microvolt input for mid-scale deflection on the meter.

To cater for varying field conditions the signal generator and the amplifier may be run from either a 230-volt, 40–100-cycle-per-second supply or from car-type 12-volt batteries.

3.4.4 *Impedance Tests*

The pulse-echo-test technique has eliminated the necessity for making steady-state impedance tests on drum lengths of cable at the factory, but since an impedance–frequency test is the accepted criterion of uniformity, completed 6-mile (9·7-kilometre) repeater sections are so tested. A self-contained impedance measuring set is used. The laboratory prototype of this set was described in a previous paper.[21] The frequency range of the set now in use is from 50 kilocycles to 10 megacycles per second and the impedance range is from 71 to 79 ohms with an accuracy better than 0·1 ohm. It is direct-reading, and its built-in oscillator has constant output over the whole frequency band. An impedance–frequency test from say 60 kilocycles to 5 megacycles per second at 20-kilocycle-per-second intervals. and from 5 to 10 megacycles at 40-kilocycle-per-second intervals can be made expeditiously at the terminals of all the coaxial pairs from the stations at both ends of the repeater sections of cable. A field test with the impedance-measuring set is shown in Figure 12.

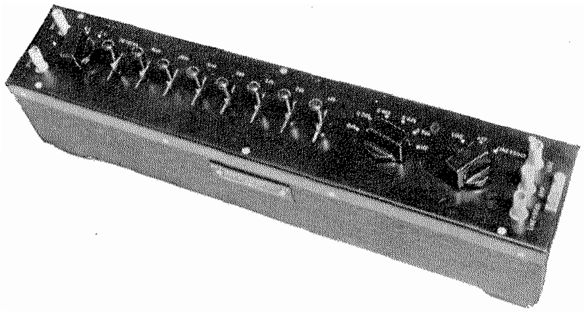


Figure 17—Attenuator used for crosstalk and attenuation measurements in the field.

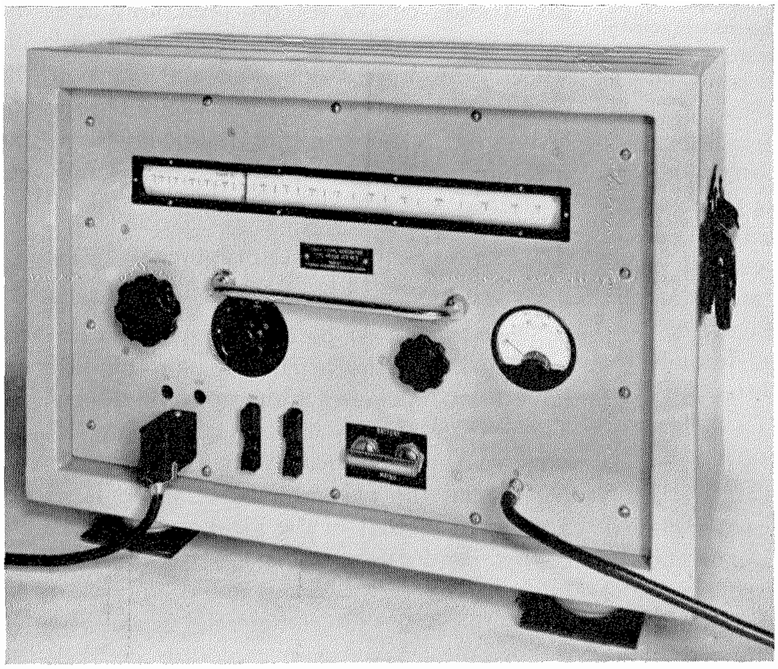


Figure 16—Signal generator of high output power for making attenuation and crosstalk tests in the field.

3.4.5 *Cross-Talk Tests*

In multi-pair coaxial cables the screening between the several coaxial pairs is required to meet agreed standards set by the type of system to be operated. Factory tests are not normally required when it is known that the physical structure of the outer conductor and screening tapes have the required transverse attenuation at the lowest operating frequency.

[21] A. F. Boff, "Test Set for Impedance–Frequency Measurement on Coaxial Cables," *Electrical Communication*, volume 27, pages 123–137; June, 1950: also British Patent 662 707; July 6, 1949.

A check test is made on the completed 6-mile (9·7-kilometre) repeater sections with the instruments used for the attenuation tests. The cross-talk test is an attenuation test in which the first coaxial pair is not physically connected to the second coaxial pair. Switching arrangements are provided on the set for making either near-end or far-end measurements. The test is made between all combinations of the coaxial pairs, taken two at a time. It usually starts at the lowest operating frequency, 60 kilocycles per second, and continues at increasing frequencies until the cross-talk attenuation is better than 160 decibels.

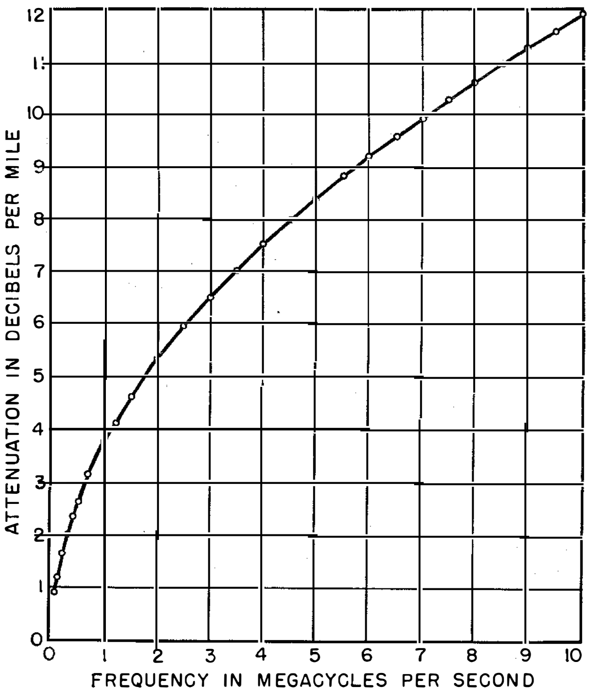


Figure 18—Attenuation as a function of frequency for a 6-pair coaxial cable installed in 1951. The measurements were made on a 6-mile (9·7-kilometre) repeater section and corrected to a temperature of 10 degrees centigrade (50 degrees Fahrenheit).

3.4.6 Miscellaneous Tests

This review of testing technique has included only those tests that are of major importance in controlling the quality and determining the transmission characteristic of long-distance coaxial pairs. Other tests, for example, conductor resistance, insulation resistance, and capacitance, which are normally made on all the circuits of telephone cables, are of course made on the coaxial pairs as well and by methods differing only in detail from generally accepted methods.

The direct-current resistance of the centre conductors of the coaxial pairs is accurately measured in the factory at known cable temperatures. The average value is 5·00 ohms per mile (3·1 ohms per kilometre) at 60 degrees Fahrenheit (15·6 degrees centigrade). When a field test for attenuation is made, the direct-current resistance of the looped centre conductors is again measured and expressed in ohms per mile. The ratio of this field result to the factory result gives an estimate of the average temperature of the cable at the time of the attenuation test. The attenuation results may be then corrected to any specified reference temperature such as 10 degrees centigrade (50 degrees Fahrenheit) using a coefficient of change of attenuation with temperature previously determined from factory attenuation tests at various known temperatures.

The capacitance per unit length of a coaxial pair is useful not so much for control purposes but as a factor enabling transmission parameters not normally measured to be estimated from those that are measured. It does not vary with frequency and may be determined accurately at, say, 1 kilocycle per second, preferably after the cable is installed. The phase constant, relative velocity of propagation, and the angle of the characteristic impedance, for example, may be estimated as functions of frequency from the measured attenuation, impedance, and capacitance.

3.5 Transmission Characteristics

3.5.1 Attenuation

The attenuation performance figures of present-day long-distance coaxial pairs of design *6* have been bracketed with those for design *5* in Table 1 and Figure 1 at the beginning of this survey. At all frequencies up to 10 megacycles per second the performance achieved is within 5 per cent of that of the ideal coaxial pair with copper conductors and a loss-free dielectric of unity permittivity. This would appear to be about the best that commercial exploitation of the simple coaxial-pair structure is likely to attain in the near future. To get $\mathcal{E}_f$ of equation (2) nearer to 100 per cent would require a dielectric material combining the electrical characteristics of a gas with some of the mechanical properties of a solid. To exceed 100 per cent would require a better conducting material than present-day high-grade electrolytic copper.

It may be concluded therefore that until commercial application of alternative structures, such as for example the laminated-conductor circuits recently proposed[22] becomes practicable, the design-*6* coaxial pair will continue to be one of the most-efficient circuits for wide-band long-distance systems.

The measured attenuation–frequency results from a test on a 6-mile (9·7-kilometre) repeater section of a cable containing 6 coaxial pairs, which was installed in England during 1951, are shown plotted in the conventional way in Figure 18. The spectrum covered is from 60 kilocycles to 10 megacycles per second and it will be noted that all the measured values fall on a smooth curve. That they do so is a rough check on the accuracy of the individual measurements at the various frequencies. A better check than this has been found to be desirable because theoretical work on the effect of irregularities in long coaxial transmission lines has indicated that deviations from a predictable smooth attenuation–frequency function should be of second-order magnitude compared with the deviations from a smooth predictable impedance–frequency function. It is known that the latter are very small for design-*6* coaxial pairs; the former should therefore be negligible.

Reference has been made to Schelkunoff's classical paper[1] on the electromagnetic theory of coaxial circuits. From the equations there given, detailed estimates have been made of the attenuation in the required frequency band of a 0·375-inch (9·5-millimetre) coaxial pair with a solid centre conductor, a tubular outer conductor of a finite thickness of 0·010 inch (0·25 millimetre) and the disk dielectric structure of design *6*. Plotting the estimated attenuations α in decibels per mile in the form $\alpha/f^{1/2}$ yields the family of curves shown in Figure 19. The lowest of these curves is the conductor-loss attenuation; the other three are for increasing amounts of dielectric-loss attenuation added to the copper loss. The advantage of this method of plotting over that of Figure 18 will be apparent from a comparison of the ordinate scales. An accuracy of entry to 4 significant figures is obtained compared with starting at 2 and finishing at 3 significant figures.

In Figure 20 the measured attenuations of Figure 18 have been plotted in the same form and scales as in Figure 19. The measured results can now be seen to be mutually consistent to within an accuracy averaging about 1 part in 1000 and falling to 3 parts in 1000 for one or two readings. If what may be termed the master graph, Figure 19, is drawn on transparent paper and is superimposed on the graph of measured results they will be found to fit one of the master curves. From this it can be established that the copper-loss attenuation of the 12 miles (19·3 kilometres) of coaxial pair tested is within 0·2 per cent of the estimated average value and that the dielectric-loss attenuation is $0{\cdot}01f$ decibels per mile. The turning point at approximately $f^{1/2}=0{\cdot}45$ in the curve drawn through the plots in Figure 20 is a check that the average thickness of the outer tubular conductor is near to its design value of 0·010 inch (0·25 millimetre).

Interpreted in this way the attenuation–frequency test is not a group of independent measurements of uncertain accuracy. It is a group of measurements integrated together to establish that the required average dimensions for the coaxial pair have been met and that the electrical properties of the copper and polythene have been maintained at the required quality. Except for a little uncertainty about the magnitude of the small contribution of the dielectric loss to the attenuation, long lengths of good-quality coaxial pair may be found to have an attenuation–frequency characteristic more accurately predictable than that of the variable attenuators used for testing them. It has been noted, for example, that tests with a given attenuator box on a number of repeater sections of cable when plotted as in Figure 20 display a certain consistency in what may be described as the ripple pattern about the smooth curves of Figure 19. The inference is that the attenuator box is slightly in error at some frequencies in the spectrum covered.

For accurate measurements at individual frequencies a piston-type variable attenuator is

[22] A. M. Clogston, "Reduction of Skin Effect Losses by the Use of Laminated Conductors," *Bell System Technical Journal*, volume 30, pages 491–529; July, 1951.

better than a resistance-network box but is not so convenient in operation for routine field measurements. A piston attenuator is used, for example, by the British Post Office[23] for checking that the attenuation of design-*6* coaxial pairs do not change by more than 1 per cent in the first 12 months after installation. More-general adoption of piston attenuators and crystal-controlled signal generators is expected to result from developments whose objective is appropriate robustness, portability, and operational convenience for field testing.

3.5.2 Impedance Uniformity

Table 2 indicates that design-*6* coaxial pairs are giving slightly better impedance values than design *5*. Responsibility for the improvement is no doubt to be shared by continued improvements in quality-control technique and by the adoption of the new outer-conductor design with its side seam as noted in Section 3.2.1. The standard deviation σ of 0·20 ohm in Table 2 is an average figure; it has been as low as 0·12 ohm and the maximum deviation Δ_m has been below 0·5 per cent.

The new coaxial pair has been used most notably to date for 11 repeater sections of the television cable connecting London with the British Broadcasting Corporation's new television transmitter at Wenvoe in South Wales. This cable contains 6 coaxial pairs and layers of paper-insulated quads. On one of these repeater sections, a special impedance–frequency test was made on two of the coaxial pairs that are to be used for television circuits. All 6 coaxial pairs in the cable are of course of the same

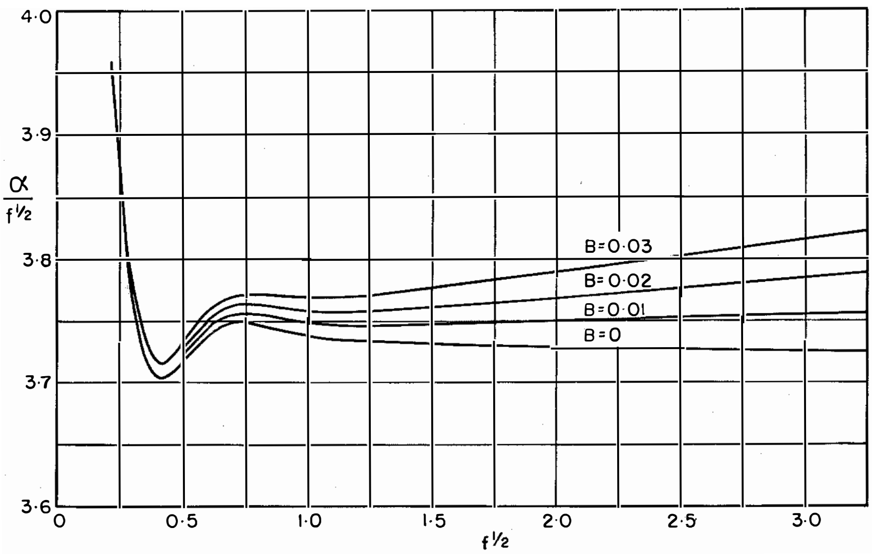


Figure 19—Here, $\alpha/f^{1/2}$ is plotted against $f^{1/2}$ for 0·375-inch (9·5-millimetre) coaxial pair having an outer conductor of 0·010-inch (0·25-millimetre) thickness.

$$\alpha/f^{1/2} = A + \phi(f) + Bf^{1/2}.$$

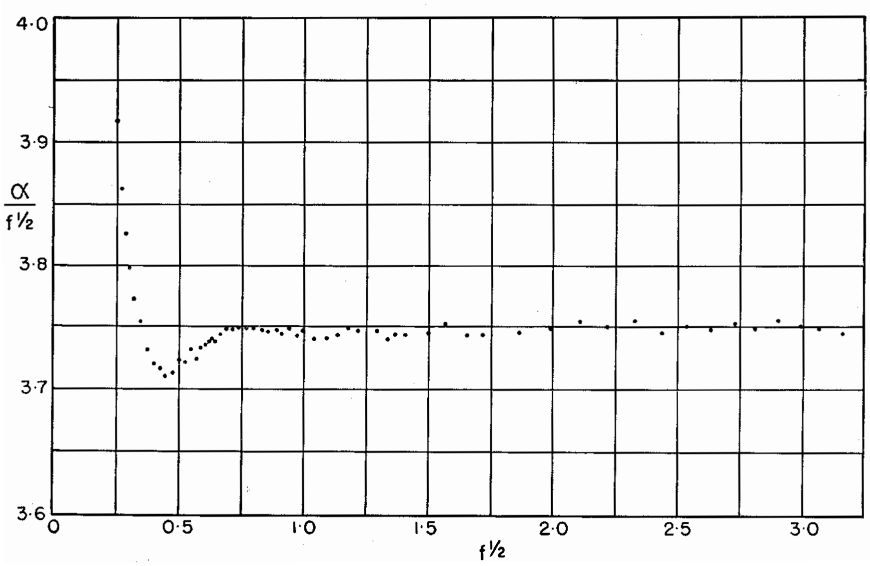


Figure 20—Data from Figure 18 plotted in the form of Figure 19.

[23] E. C. H. Seaman, D. A. Crow, and C. G. Chadburn, "Use of a Piston Attenuator for Cable Testing in the Frequency Range 1–30 Mc/s," *Post Office Electrical Engineers Journal*, volume 43, pages 195–197; January, 1951.

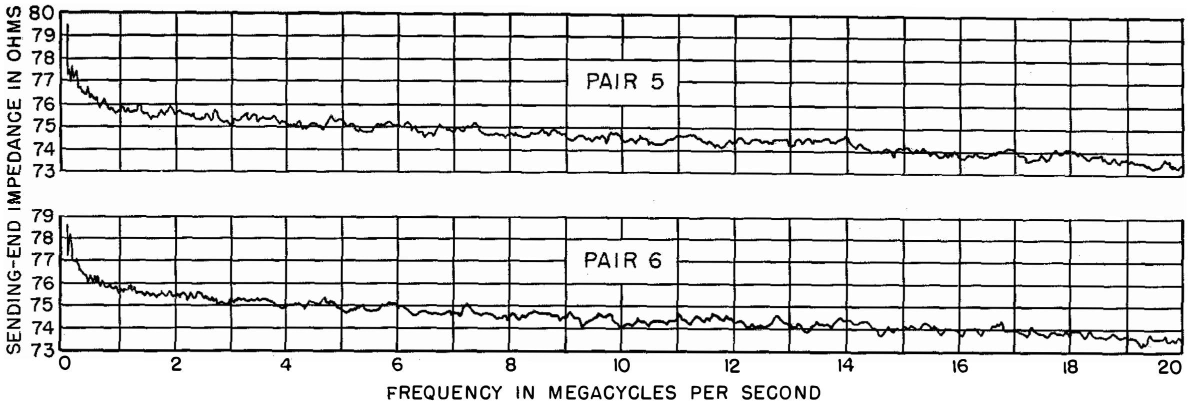


Figure 21—Impedance plotted against frequency for a 6-mile (9·7 kilometre) repeater section of a 6-pair coaxial cable.

quality. The normal Post Office test was made up to 4·5 megacycles per second and then it was extended to 20 megacycles per second at 40-kilocycle-per-second intervals. The results were graphed in Figure 21 and are of interest in that visual inspection of the curves demonstrates that there is no significant deterioration in quality at the upper end of the spectrum. For visual comparison with Figure 21, Figure 22 gives the results from a repeater section of design-*2* coaxial cable installed during 1937.

The 1951 test results, Figure 21, have been analysed by the method described in Section 1.2 firstly taking the 100 readings of the test in the spectrum there used for comparative purposes, namely 0·52 to 2·50 megacycles per second, and secondly taking the last 100 readings of the test between 16·04 and 20·00 megacycles per second. The estimated deviations are given in Table 4.

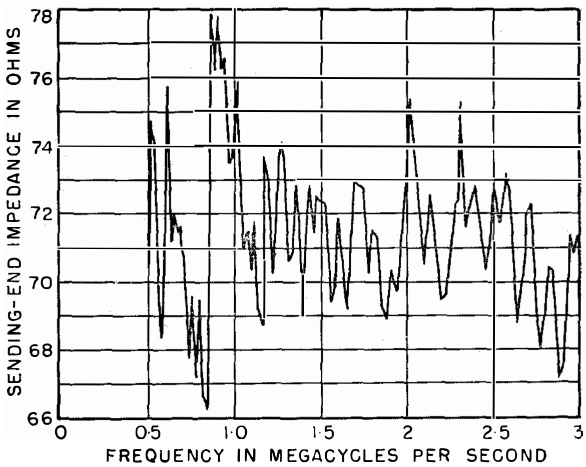


Figure 22—Impedance curve for repeater section of design *2* installed in 1937.

The change in K_3 from 75·4 at 2·5 megacycles per second to 73·6 at 20 megacycles per second is excessive and was due to the 3-yard (2·7-metre)

TABLE 4

Impedance Uniformity of a Typical Repeater Section of 0·375-Inch (9·5-Millimetre) Coaxial Cable of Design *6*, 1951

Sample Spectrum in Megacycles Per Second	Coaxial Pair	Impedance Analyses Results				
		K_3 in Ohms	Standard Deviation		Maximum Deviation	
			σ in Ohms	σ/K_3 in Per Cent	Δ_m in Ohms	Δ_m/K_3 in Per Cent
0·52 to 2·50 at 20 Kilocycle-Per-Second Intervals	5	75·4	0·14	0·18	0·38	0·51
	6	75·4	0·12	0·14	0·33	0·43
16·04 to 20·00 at 40 Kilocycle-Per-Second Intervals	5	73·6	0·16	0·22	0·42	0·56
	6	73·6	0·14	0·19	0·41	0·56

tail-cable and sealing ends at the test end not having been matched to the main cable sufficiently accurately for operation at 20 megacycles per second. Table 4 confirms that there is only a small decrease in quality at the upper end of the spectrum.

It has now been demonstrated that there has been a threefold improvement in the impedance uniformity of long-distance coaxial cables in Great Britain since the first coaxial cable of 1935. Firstly the reductions in standard and maximum deviations of the sending-end impedance curves in the spectrum 0·52 to 2·50 megacycles per second are shown in Table 2. Secondly the maintenance of the present high quality up to much higher frequencies is shown in Table 4 and thirdly, evidence is given by the pulse-echo-test oscillograms from each 2000-yard (1829-metre) portion of a repeater section that the sending-end impedance test results are truly representative of the quality of the whole repeater section of cable as noted in Section 3.4.2.

3.5.3 Crosstalk

Since the adoption of the single-tape outer-conductor structure the crosstalk attenuation between two coaxial pairs lying side by side has been set by the transverse or radial attenuation in the metals between the inner surface of the outer conductor and the outer surface of the screen of steel tapes. A disclaimer is noted for the earlier designs with spiralled-tape outer conductors because spiralling of the outer current not only increased the effective resistance and attenuation, as has been described, but it also increased the crosstalk linkage. Better crosstalk was obtained after the change in structure, despite a reduction in the radial thickness of the copper tube from 0·030 to 0·010 inch (0·76 to 0·25 millimetre).

The transverse attenuation is directly proportional to the radial thickness of the metals and to the square root of the frequency. Because of the increase with frequency, the crosstalk between two coaxial circuits improves with increasing frequency whereas with all other telephone-cable circuits it gets worse. This well-known phenomenon is one of the principal reasons for the adoption of coaxial circuits for wide-band transmission systems.

In cables containing more than two coaxial pairs and having paper-insulated quads as well, crosstalk between any two of the coaxial pairs becomes complicated by linkages formed amongst the other circuits. There is then both direct and tertiary crosstalk, and it becomes difficult to forecast their combined magnitude for a given design of cable.

For present-day cables containing two or more coaxial pairs to design *5* or *6* the crosstalk results obtained from the terminals of 6-mile (9·7-kilometre) repeater sections are most conveniently summarised by stating that they are not normally worse than the values in decibels given by the empirical expressions:–

$$\alpha_{NE} = 90 + 73f^{1/2}, \qquad (14)$$

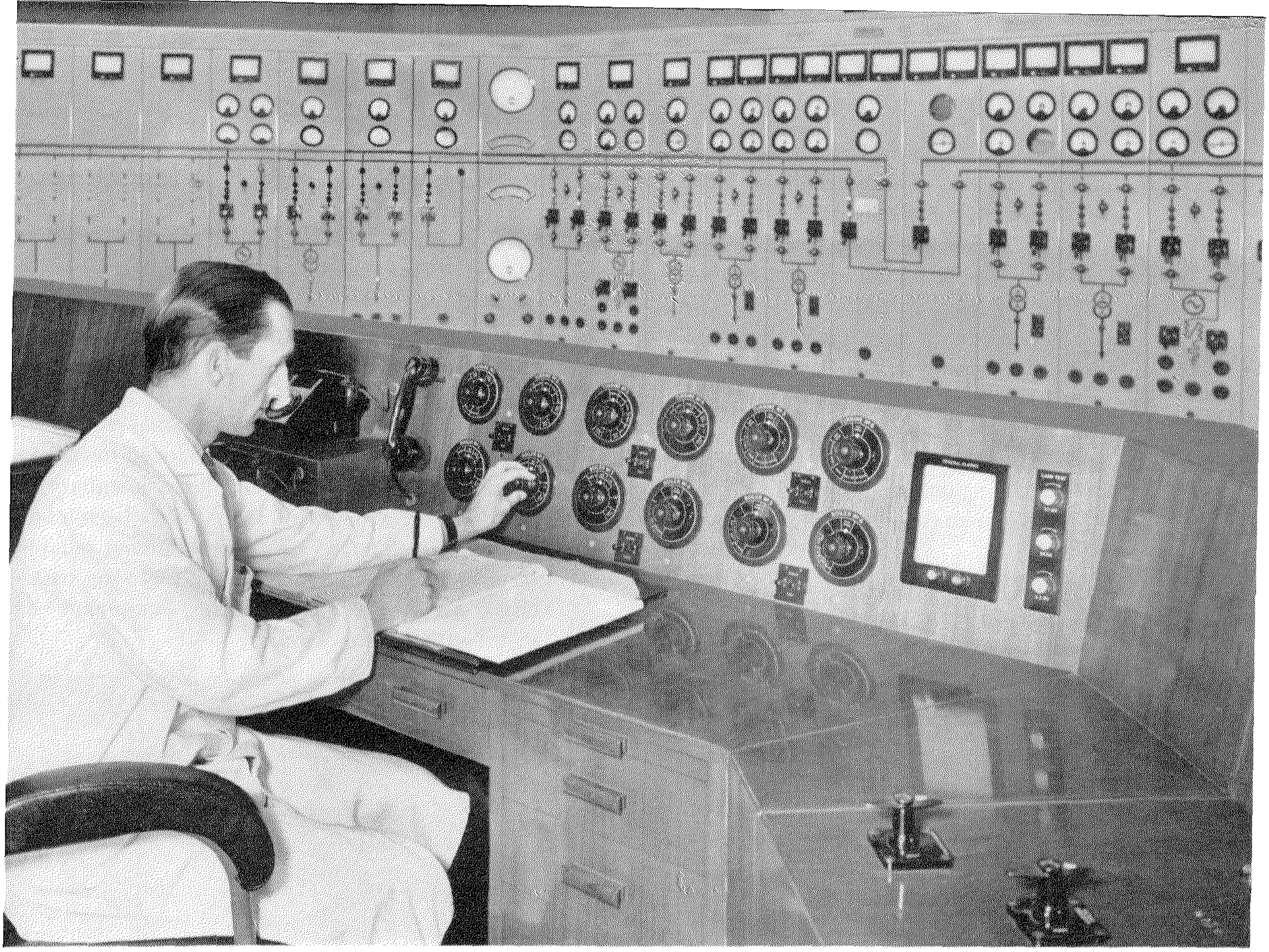
$$\alpha_{FE} = 76 + 73f^{1/2}, \qquad (15)$$

where

α_{NE} = near-end crosstalk per repeater section
α_{FE} = far-end crosstalk per repeater section, and
f = frequency from 0·060 megacycle per second upwards.

These are true crosstalk attenuation and include the attenuation of 6 miles (9·7 kilometres) of the coaxial pairs tested. At all frequencies for which equations (14) and (15) give results greater than 160 decibels it is to be understood that the tests on the cables have only demonstrated that the crosstalk is better than 160 decibels. It is not a simple matter to make accurate measurements of crosstalk at levels more than 160 decibels below the input-signal level.

These crosstalk levels are acceptable for all present-day wide-band coaxial systems but lower-level crosstalk could be catered for by increasing the effective thickness of the outer-conductor screening.



Remote Signalling with Telecommand Equipment

TELECOMMAND equipment for signalling between a power-station control room and the boiler house and turbine room is a recent development of Standard Telephones and Cables, Limited; London. The equipment employs telephone switching techniques to permit the control engineer to notify the boiler attendant or the turbine driver of new or changed requirements of the equipment under their charge.

A typical example of this equipment is given in the photograph above, which shows an engineer at the control desk at Ryehouse power station sending an order to one of the boiler attendants.

The number of stereotyped orders that may be designed into the equipment ranges up to ten. Selection of the particular order on which action is desired is made in the control room by means of a rotary selector switch; actual transmission of the order is accomplished by depressing the knob of the switch after selection of the required order.

At the receiving end, there are available a number of different methods of mounting the panel on which the orders are displayed. Depending on the turbine or other machine to which the panel relates, the panel may be mounted in a control-board panel, on a pedestal, hung on a wall, or suspended from the ceiling.

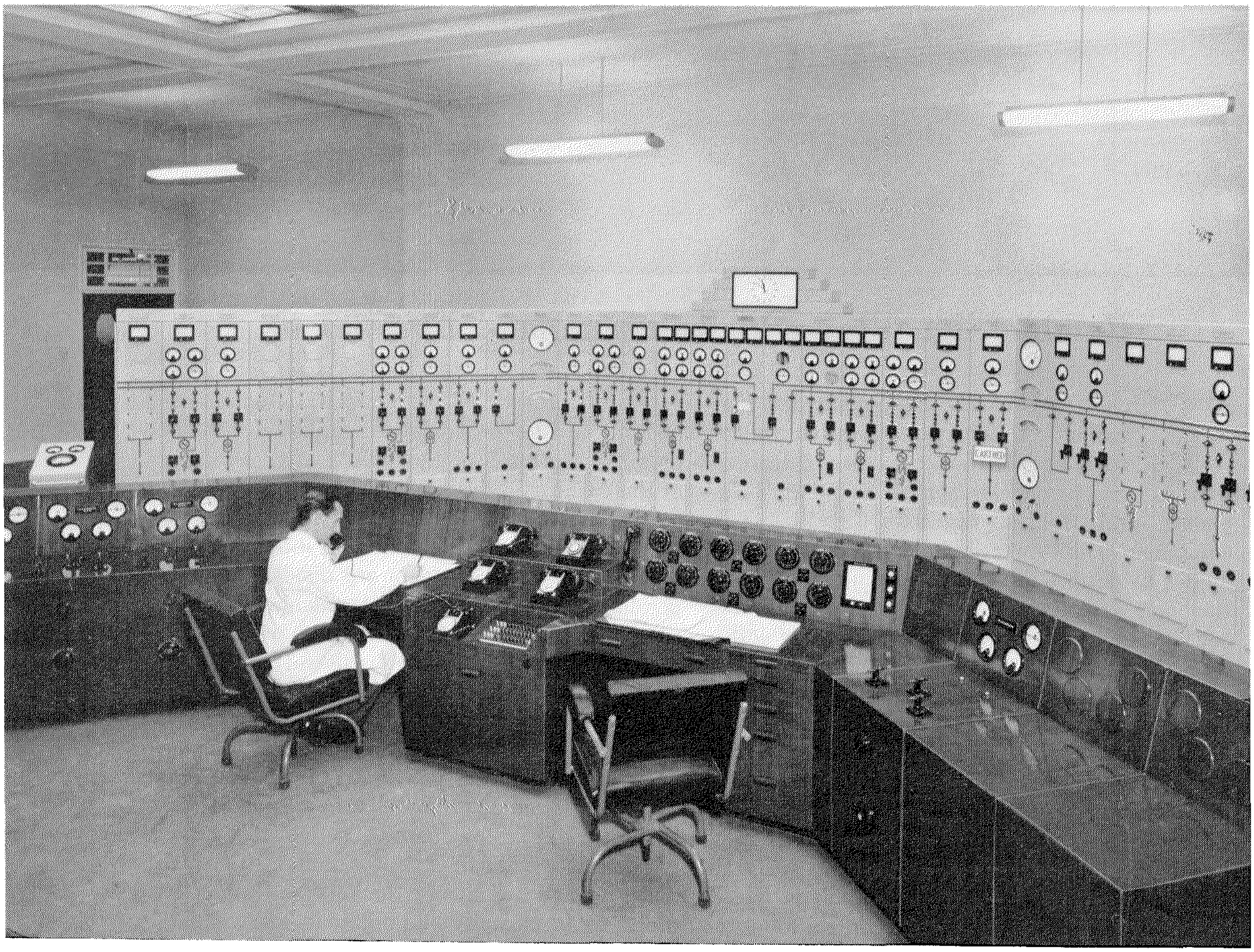
Reception of an order at the receiving end is called to the attention of the operators by lights flashing on the order panel and by a horn. This dual signal is an assurance that in noisy locations the order will not be missed. The receiving panel is equipped with an acceptance button, which when pressed will silence the horn and cause the order to be steadily illuminated. The sending switch in the control room is equipped with a small lamp in the switch knob that flashes in unison with the order panel until the acceptance button is pressed, when it will take on a steady glow to signify to the control engineer that his order has been noted.

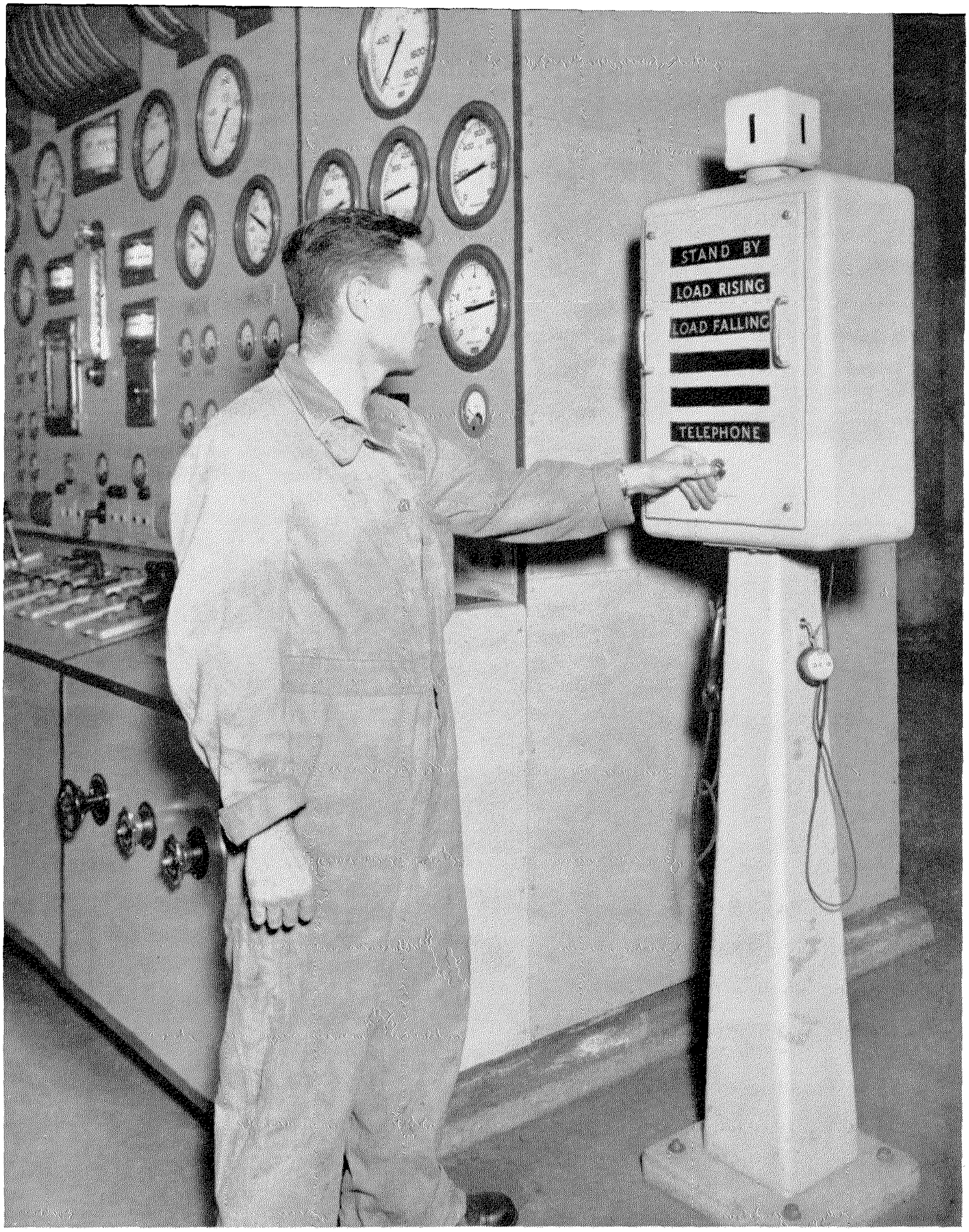
Repetition of any order, such as INCREASE SPEED, is accomplished by simply withdrawing the selector switch knob and immediately depressing it again. This causes the alarm to sound again, and the recipient must acknowledge the order again.

The system can also be supplied with both-way telephone service, in which calls can be initiated at either end of the circuit. An emergency signal that operates in the reverse direction has also been supplied in certain installations. The connection between the sender and receiver is made through multi-core telephone-type cables of 20-pound-per-mile capacity. A 50-volt direct-current supply is necessary for operation of the system.

As stated above, the system makes use of time-proven reliable devices developed for use in telephone exchanges. Over a dozen installations of this Telecommand equipment have been made in power stations, where they are giving reliable service. The photographs on the following pages show some examples of the equipment as installed in Great Britain.

Main control room of the British Electricity Authority steam power station at Ryehouse, showing the boiler and turbine Telecommand switches mounted in the centre of the control desk.

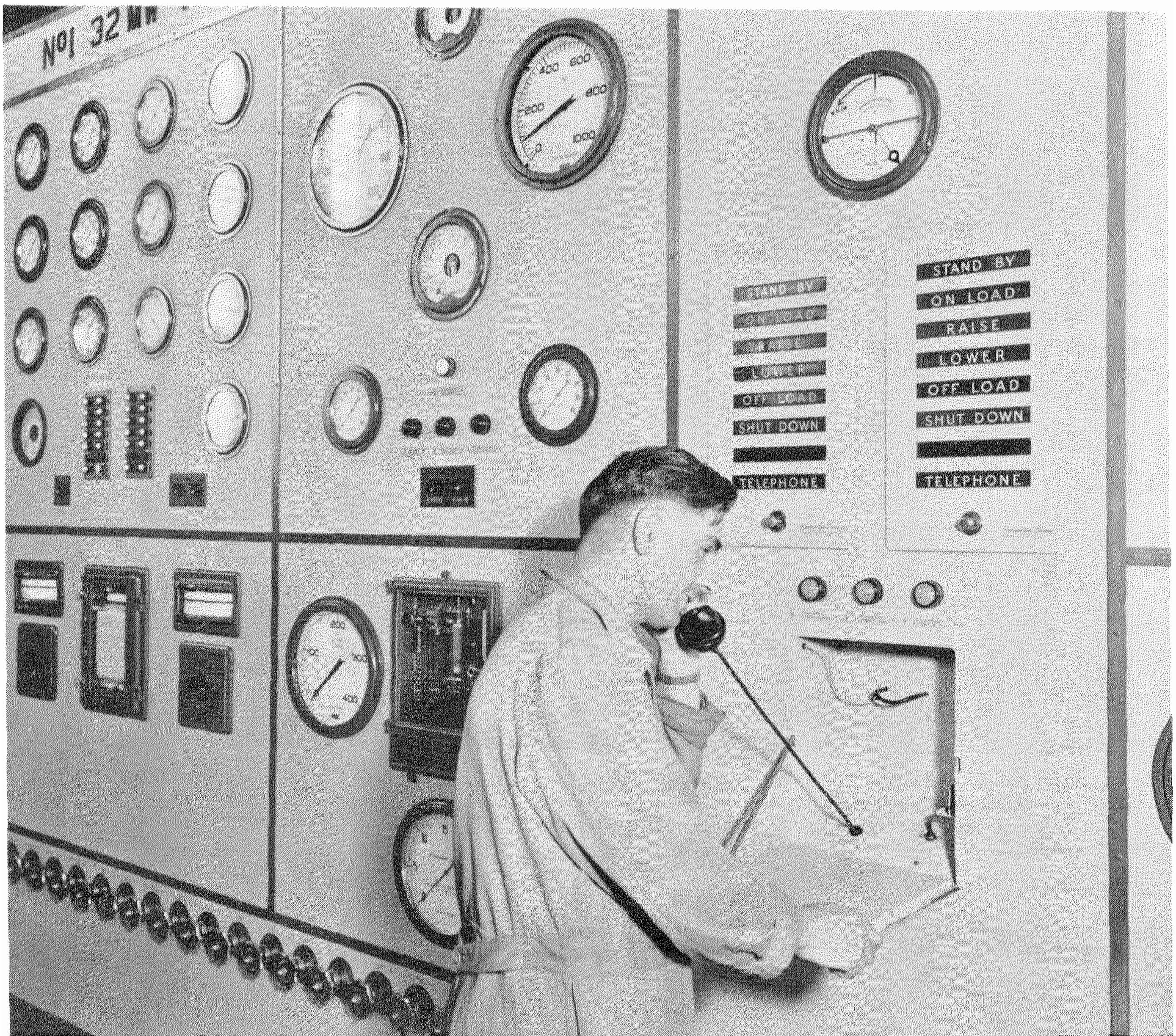


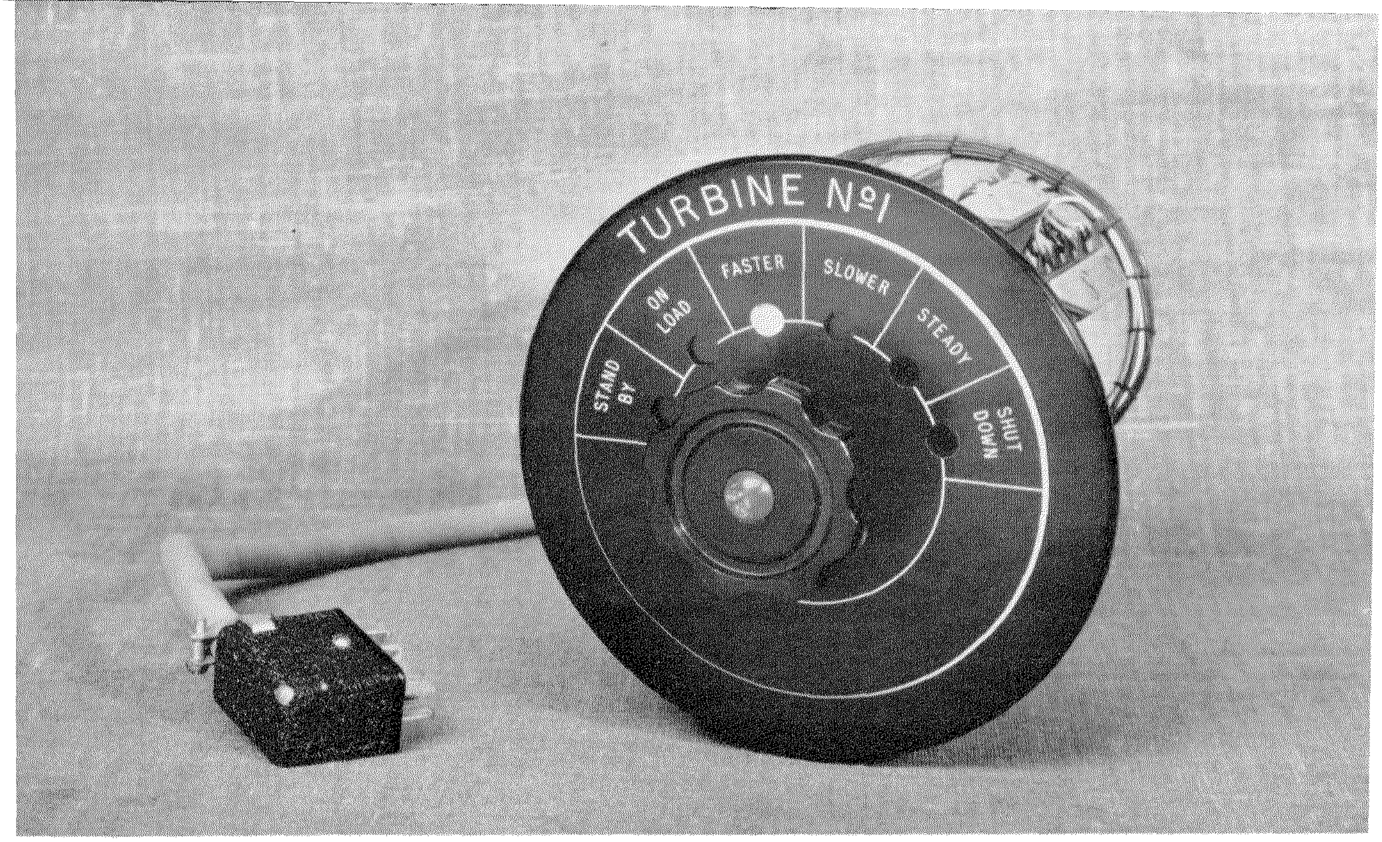


A pedestal-mounted receiving panel incorporating space for 6 orders and having a telephone connection with the control room. In noisy locations, the extra telephone receiver mounted on the right-hand side of the pedestal is used together with the handset to ensure adequate audibility. The glass cube at the top flashes when an order is received.

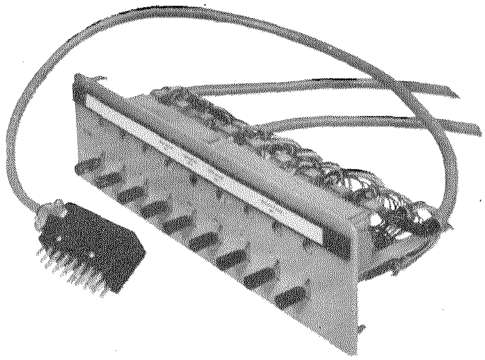
At left, a receiver that may be hung from the ceiling in the aisle of a boiler house. A wall-mounted cabinet is associated with the indicator panel and contains the telephone receiver and the acceptance push-button.

Two panel-mounted receivers with associated telephone. The receivers are built into the main turbine gauge board at Ryehouse power station.

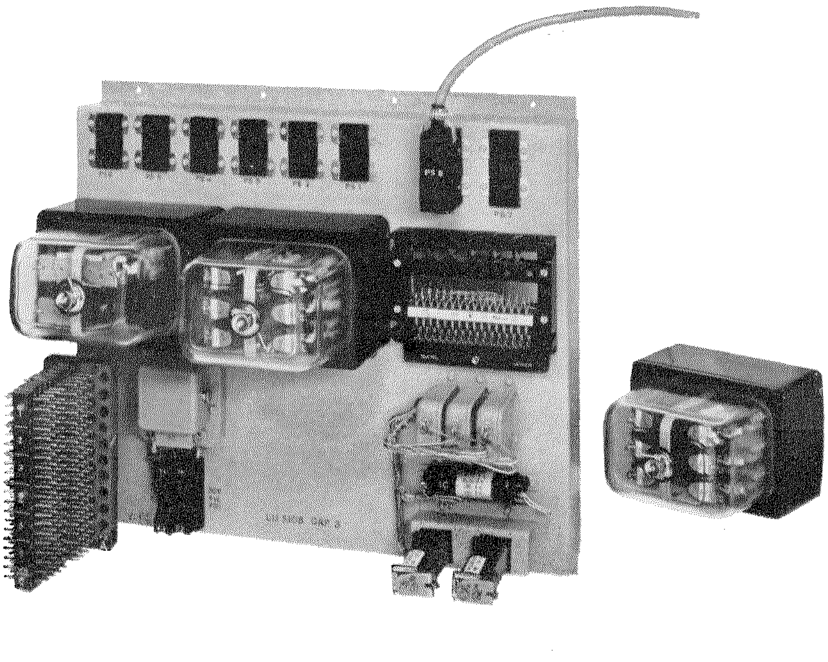




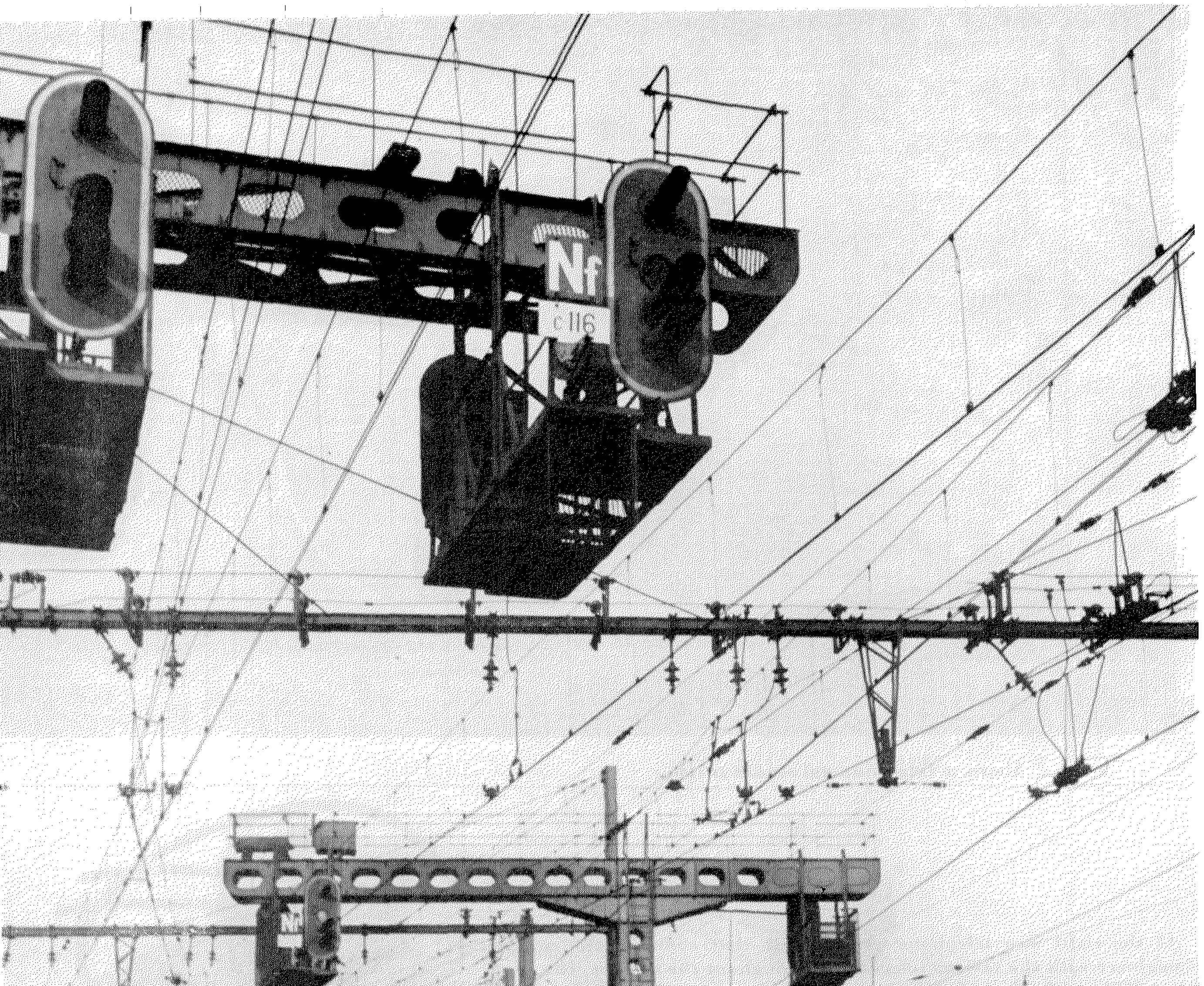
Above, a Telecommand sender switch.



At the right is a telephone control unit that connects the control engineer with the various telephones throughout the system. The plug connects with the relay apparatus frame in the main control desk.



At left is shown the apparatus frame that is mounted in the rear of the control desk and contains the sockets for the plug-ended connections from the sender switches. This rack accommodates the relay apparatus necessary for operation of the system. All relays are housed in special plug-in mountings fitted with glass covers to render the apparatus dustproof.



Electrified railway tracks at the Gare de Lyons in Paris.

Remote Control of Electrified Railways

By MARC LAUVERGEON

Compagnie Générale de Constructions Téléphoniques; Paris, France

ELECTRIC POWER continues to play an increasingly important role in modern life, and it is inevitable that the generation, transformation, and distribution networks must be constantly improved to provide the highest possible grade of service.

For many years, remote-control systems have permitted a central operator to supervise distant equipment and control its operation with a promptness that has improved both safety and service. This article describes some installations of remote-control equipment on electrified railroad lines. A description is given of the synchronous selection system, which is fundamental to the design of these installations.

• • •

For a long time, development programs have been directed at reducing to a minimum the number of human operators required to keep extensive and complex electrical systems in service. One feature of this program has been the development of methods of controlling equipments located at substantial distances from a central supervisory point.

Modern power-generating stations and their associated transformers and distribution networks are so designed that their supervisors are not called on to do the actual rearranging or adjusting of circuits so much as to decide what changes are needed and initiate the operation of auxiliary actuating mechanisms.[1] The basic principle of separating the functions of direction from those of execution stemmed logically from the development of reliable automatic telephone systems.

In the early stages of centralized control, the supervisor was supplied with a limited amount of information on what was happening in the system and used the telephone to instruct distant operators as to changes to be made in the equipments under their individual care. This type of remote control is quite imperfect since a man is used as a relay between the supervisor and the apparatus to be controlled. It was, however, an important step along the engineering path to reliable remote control based on modern telecommunication techniques.

Effective remote control requires that there be at the supervisory point a mechanism capable of receiving signals from all significant parts of the system and of providing a continuing display of this information on a network diagram. The mechanism must be capable of detecting when signals reporting to it have been distorted in transmission to an extent that could make them inaccurate, to refuse such signals, and to insist that the report be repeated until the accuracy of transmission is unquestionable. With full and accurate data available to the supervisor, his instructions for modification of the operating conditions should then be transmitted over the same system that supplied the information to the network diagram. The effects of these changes should show immediately on the diagram.

The evolution of remote-control systems has followed that of telephone systems. The connecting of two subscribers was first effected by manual switching operations; an operator received instructions from the calling subscriber, put up the necessary connections, and rang the called subscriber's bell. As the number of subscribers increased, the time required to make a call also increased, and the development of automatic-switching systems was inevitable. Such systems dispense with the service of operators, and any subscriber can ring any other subscriber by the simple process of dialling the proper series of letters and numbers.

The idea of supervising the operation of a system of remotely located power generation and distribution equipment from a central point naturally suggested utilization of the automatic-switching techniques of the telephone field.

A comparison of automatic-telephone and remote-control systems shows a basic difference

[1] M. Garreau, "Centralized Control of Traction Substations," *Bulletin de la Société Française des Electriciens*, series 6, volume 10, pages 19–26; January, 1950.

between them. This concerns the degree of accuracy to which each system must be engineered. In telephony, wrong calls can be permitted provided they do not occur so frequently as to irritate the subscribers. A power system is not so tolerant of errors and protective mechanisms must be included to ensure that they do not occur. Safety is, therefore, a dominant factor in the design of remote-control systems.

In some early designs of supervisory systems, telephone dials were used for selecting the apparatus to be controlled. It was soon found

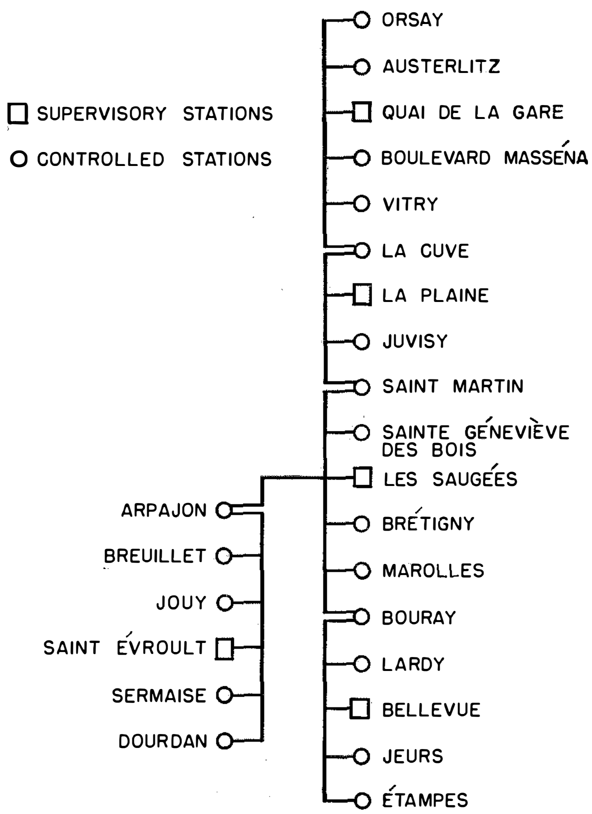


Figure 1—Arrangement of control and controlled stations in the Paris–Orleans railway system.

that the supervisor would dial inaccurately at times and that the proper recording of the dial pulses was an additional source of error. The consequences of these inaccuracies would be avoided by instituting some means whereby the apparatus answering the call would identify itself to the supervisor before instructions were given to it. However, as the size of installations increased, a greater number of digits had to be dialled and this method of calling was abandoned. Now, each piece of apparatus to be supervised has an individual control switch and a luminous signalling device that is inserted in a network diagram of the system.

For similar reasons, the switching circuits could not be exact replicas of those used in automatic telephony. The absolute necessity of safety requires that each elementary operation be checked; the systems now used detect any anomaly, regardless of its cause, refuse to continue in operation, and release all equipments involved in any call that has been made improperly.

All of our early installations were based on a synchronous selection system that in principle checks every elementary step in operation. It has proved to be very flexible and adaptable to all the problems met in this field.

1. *Major Installations in Railways*

By presenting descriptions of several railway installations in the chronological order in which they were designed and manufactured, a clear picture will be given of the evolution of the systems and operating methods.

1.1 1924, Paris–Orleans

In 1924, remote-control methods had not been developed to a point where full supervision of a complex system from a central office seemed practicable. When the Paris–Etampes railroad line was electrified, it was thought best that the control of the circuit breakers in the cut-off and shunting stations be concentrated in each of the substations that supplied power to them. This arrangement was justified in that each of the substations would be in charge of skilled personnel that would be capable of handling all operations in the sector to which the substation supplied power.

Figure 1 shows how the network was divided into 5 sections controlled by the substations at Quai de la Gare, La Plaine, Les Saugées, Bellevue, and Saint Evroult. The sections vary from 10 to 18 kilometers (6 to 11 miles) and have between 3 and 6 controlled stations, each of which has an average of 5 equipments to be supervised.

By present standards, the system was characterized by the small number of substations under the direction of each supervisory station, the small number of units within each substation, and the short distance between any supervisory station and its farthest controlled station, the maximum being about 10 kilometers (6 miles).

The design of the system reflected these conditions. The stations in a sector are connected by a 4-wire cable and transmission is with direct current, the polarity of which is significant. Operating with a common return wire, the other three wires are for synchronization, control, and signalling.

All stations in a sector are multipled (connected in parallel) to these 4 wires. The selecting elements of the supervisory and controlled stations operate in synchronism, when either signalling or controlling is in process. In each controlled substation, the capacity of the selective element corresponds not only to the local equipment, but also to that installed in the other stations operating in synchronism. Telephone-type equipment is employed and power is obtained from a 125-volt battery.

There is a control desk in each supervisory station. On an inclined portion of the desk is a group of telephone-type key switches for controlling the various circuit breakers and their associated equipment. On a vertical section of the desk is a network diagram. Each controlled piece of apparatus is represented and may be illuminated by either a red or a green lamp to show whether the unit is disconnected from the circuit or is in operation.

1.2 1937, Sceaux Line

In 1937, when the Paris Metropolitan Railroad was electrified to Sceaux and Massy–Palaiseau, remote control was installed from the traction substations to the circuit breakers of the section and shunting stations.[2]

This line was divided into two sections as may be seen in Figure 2. One group of 4 stations is controlled from Montsouris and forms a section about 11.5 kilometers (7 miles) long and 3 stations are supervised from Villaine and comprise a circuit of 8 kilometers (5 miles). A small number of circuit breakers, from 2 to 6, are associated with each controlled station.

Because the problems presented by this installation did not differ materially from those of the Paris–Orleans railway, a similar arrangement was used. A few improvements were introduced as a result of experience with the earlier design.

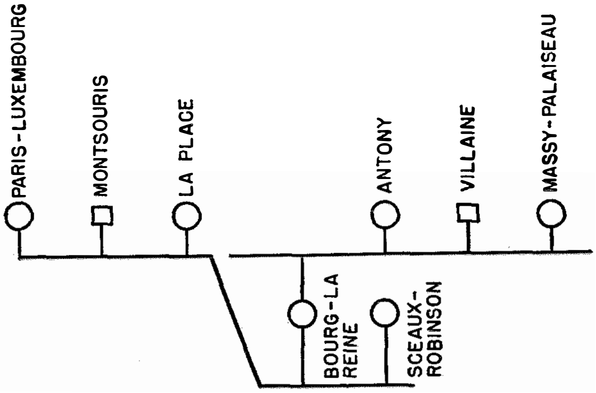


Figure 2—Two control stations at Montsouris and Villaine supervise the Sceaux and Massy–Palaiseau lines of the Paris Metropolitan Railroad.

The safety aspects of using a separate battery as a power source for the control equipment were retained. However, the relatively high voltage of the battery in the Paris–Orleans system called for the use of high-resistance relays to keep power dissipation to a low value. This required many turns of fine wire on the relay windings with the concomitant danger of breakage. The battery voltage was, therefore, reduced to 48 volts.

The new relays are equipped with twin contact springs. It was found that the dust-laden air resulting from train movements near the stations could cause intermittent-contact trouble when only one pair of contacts was used.

The switching equipment was mounted in metallic cabinets. Relays were assembled in groups on panels that could be removed readily, the connections to them being made by plugs and jacks.

The control boards were similar to those in the Paris–Orleans system.

1.3 1947, Nîmes–Sète Line

The two-track railroad line that goes from Tarascon to Sète by way of Nîmes was electrified

[2] P. Cornu, "La télécommande des disjoncteurs sur la ligne electrifiée du Chemins de Fer métropolitain de Paris à Sceaux," *Revue CGCT–LMT;* August, 1942.

in 1947. The trains are operated from a 1500-volt direct-current supply and there are 5 substations at Nîmes, Vestric, Lunel–Viel, Castelnau, and Mireval as is shown in Figure 3. The

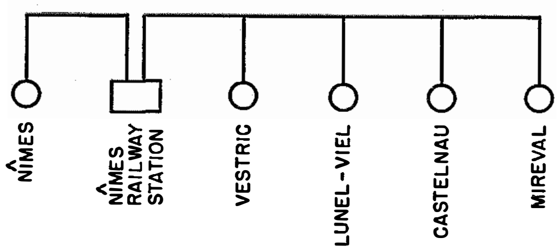


Figure 3—The Nîmes–Sète railway is operated from 5 substations that are controlled from the Nîmes railway station.

Société Nationale des Chemins de Fer Français decided that all these substations should be controlled from a single supervisory point at the Nîmes railway station.[3]

The substations in this electrification project were equipped with mercury-vapor rectifiers and it was possible to operate them without the attendants that were required for the substations in the earlier installations. In addition, the distances between the supervisory point and the substations were substantially greater, the longest span being 64 kilometers (40 miles) from Mireval to Nîmes. At each substation, a much-larger number of units had to be supervised. Independent of the 1500-volt circuit breakers and their associated equipments, it was necessary to supervise circuit breakers and section switches at the transformer installations at each substation, the operation of the rectifiers and their safety devices, various protective mechanisms, and the power supplies for the auxiliary apparatus.

The substations were to be of moderate importance as each contains a mercury-vapor rectifier capable of handling 2000 kilowatts of power. To take care of future extensions, the supervisory equipment installed in each substation would have to handle 70 two-position (operate and non-operate) equipments.

Each substation was considered to be a power-supply point that must be capable of being controlled at the same time that any other substation is under supervision. This differs from the previous installations, where the controlled stations were "party-line subscribers" of each control station. Each of the five substations is independently controlled from the Nîmes station.

Although the distance from Nîmes to the farthest substation is quite large, direct-current operation over independent circuits could have been effective. It would have been necessary to use a cable having suitable transmission characteristics, and the number of conductors would have increased in arithmetical progression from Mireval to Nîmes.

These conditions suggested the advisability of anticipating future installations having even a greater number of substations located more distantly from the control points. The transmission system should use a minimum number of conductors for the entire installation, and the signalling should be adapted to the characteristics of cables of the type usually installed along railroads for telecommunication purposes.

A straightforward solution was to use long-distance-telephone techniques. This permits the use of repeaters on lines over about 60 kilometers (37 miles) in length. Transmission would, of course, be limited to voice frequencies between 300 and 3000 cycles per second approximately. This would permit the number of conductors to be reduced by assigning particular frequencies to each substation.

The power that can be sent over a long-distance telephone circuit is of the order of a few milliwatts. As the telephone-type line relay requires about 100 milliwatts for satisfactory operation, it was necessary to provide vacuum-tube amplifiers to make the received signals useful. Vacuum tubes also provide a convenient means for generating the various voice frequencies that were required for the system. The techniques and equipments used in voice-frequency telegraphy are directly applicable to this system and by using the odd multiples of 60 cycles, starting with 420 cycles, some 16 to 18 independent transmission channels can be obtained over one pair in a long-distance cable.

The substations are connected in parallel over a quad in a long-distance cable, one pair being allotted to signals transmitted from the control station toward the substations and the other pair

[3] F. Chappee, "La commande centralisée des sous-station de traction de la ligne de Nîmes à Sète," *Revue Générale de l'Electricté*, volume 58, pages 503–514; December, 1949.

to signals transmitted in the reverse direction. The remote-control system for each substation requires four telegraph channels between terminal equipments (two in each direction). Thus, between Nîmes and Mireval, 8 voice-frequency carriers are transmitted over the first real circuit and 8 carriers over the second real circuit.

Several telemetering signals are transmitted by the substations toward the control station by voice-frequency carrier over the combined circuit of the remote-control quad.[4] The telemetering installation is thus quite independent from the remote-control installation.

The quad is in a mixed cable operated jointly by the Post, Telegraph, and Telephone Administration and the Société Nationale des Chemins de Fer Français. A branch is taken off the quad at each substation. The equipment connected to each branch presents an impedance of the order of 20,000 ohms, which is very much greater than the characteristic impedance of the quad and does not materially affect the transmission properties of the line.

Centralized control of traction substations places a relatively large amount of equipment under the supervision of a single operator. In this installation, the operator has supervision over about 100 pieces of equipment and there are some 150 more units that report their condition to him but are not directly controlled by him. The separation of the signalling lamps from the control keys, as was done at the Paris–Orleans installation, offers serious drawbacks in such a case. The Nîmes supervisory station is, therefore, equipped with a network diagram

[4] Telemetering equipment for the Nîmes–Sète installation has been supplied by the Compagnie des Compteurs. The basis of the system is the production of a signal, the frequency of which varies linearly with the quantity to be measured. The frequency is 12½ cycles per second for zero and 25 cycles for maximum value of the quantity under measurement. This variable-frequency signal amplitude modulates a low-frequency carrier.

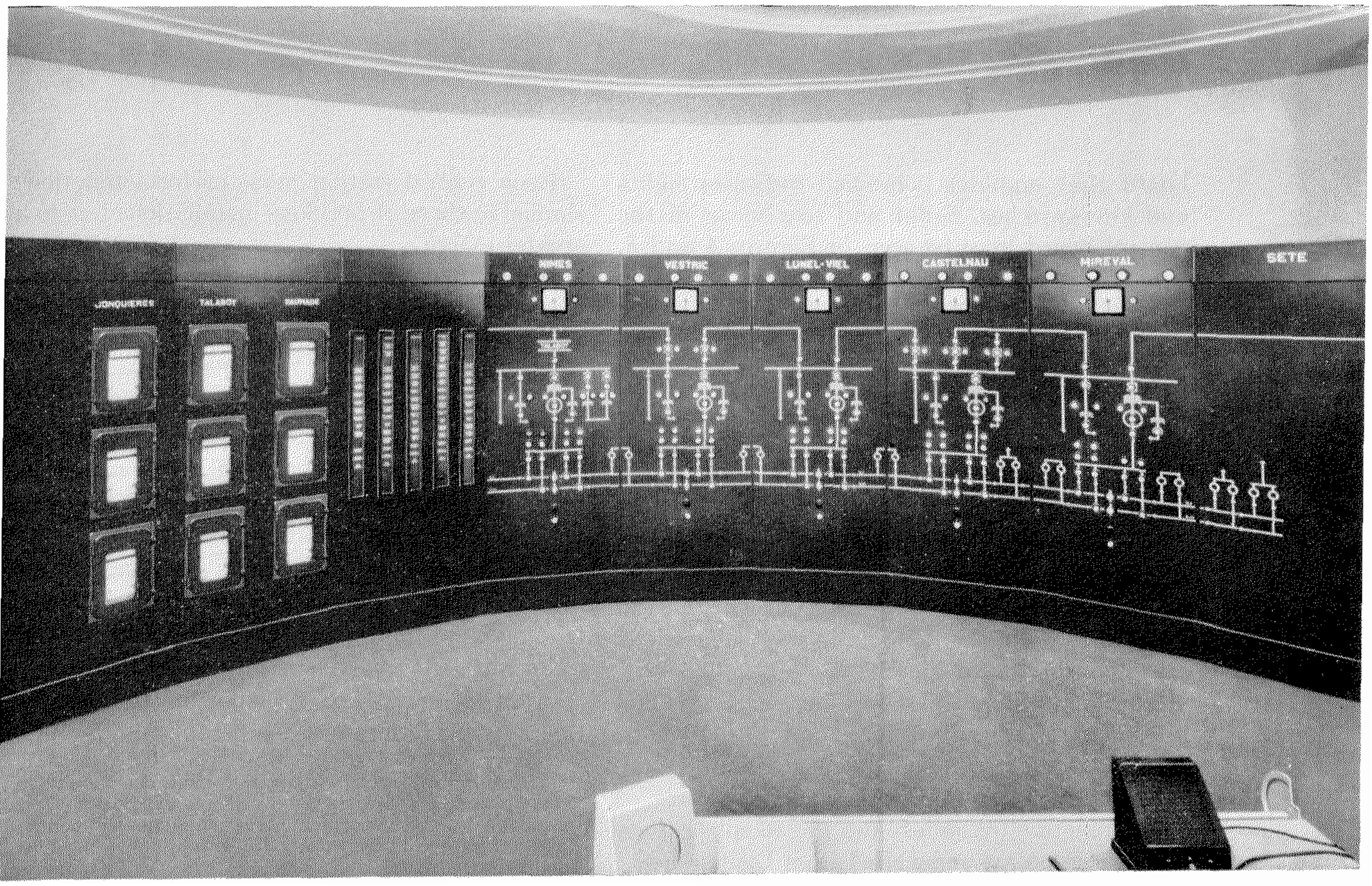


Figure 4—Front view of the control board at Nîmes. Each indicator light is housed in its associated switch key.

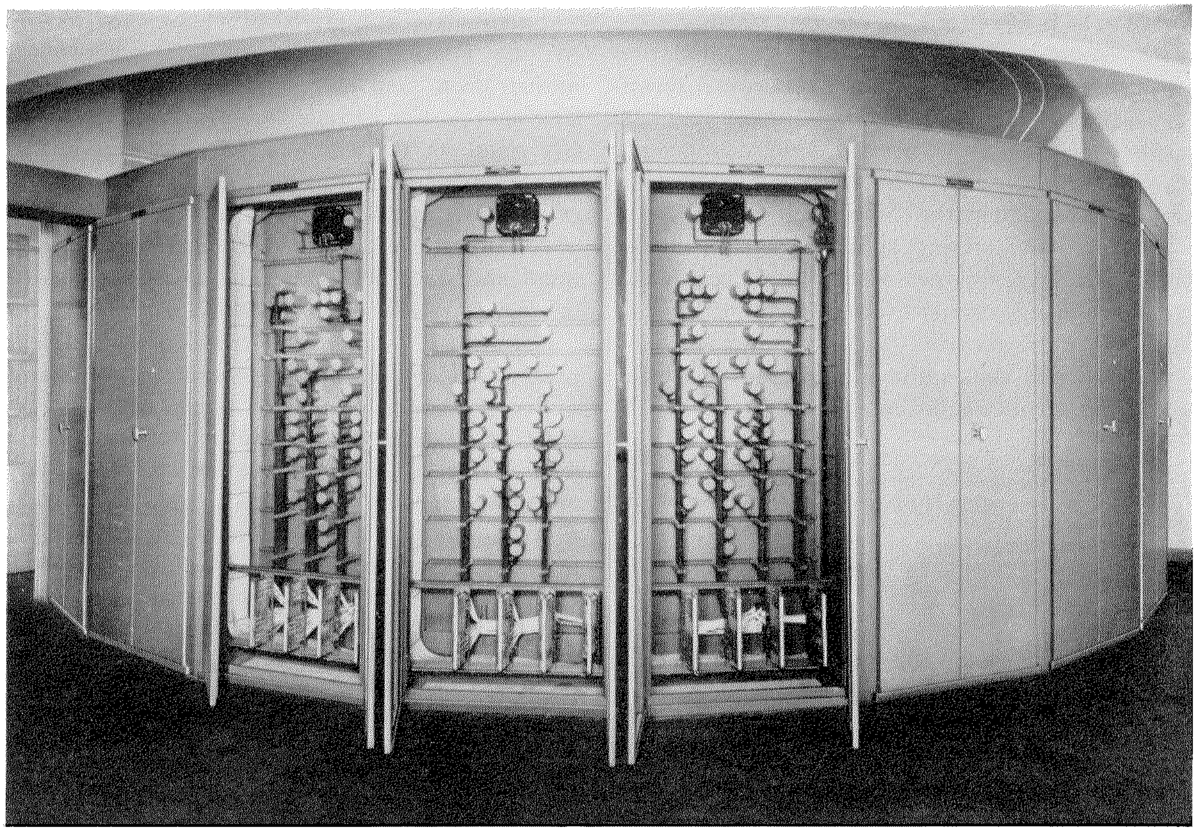


Figure 5—Rear of Nîmes control board.

board that employs combined indicator lights and key switches. Front and rear views of the control board may be seen in Figures 4 and 5.

1.4 1949, Paris–Lyons Line

Studies of the electrification of the railway line from Paris to Lyons immediately included plans for the centralized supervision of the electric power distributing system. Traction power is supplied through 52 substations and these are divided into three sections, each of which is controlled from a single point. Figure 6 shows the arrangement of the system.

The section from Paris to Laroche is 156 kilometers (97 miles) long and its 17 substations are supervised from Paris.

The Saint Florentin–Fontaines section is 203 kilometers (126 miles) long and has 19 substations that are controlled from Dijon.

From Chalon to Guillotière is a distance of 132 kilometers (82 miles) and the 16 substations in this section are supervised from Lyons.

Each central station must perform functions similar to those of previous installations but to a greater extent.

In contrast to the Nîmes–Sète system, some of the substations have two or three mercury-vapor rectifiers. They are equipped for the remote supervision of between 70 and 170 two-position units, some provision being made for later expansions. The maximum distance of 156 kilometers (97 miles) between the supervisory point and a substation is substantially greater than in previous installations.

The remote-control system is the same as that developed for the Nîmes–Sète installation. Transmission of signals is also effected by voice-frequency-telegraph channels.[5] Two quads are allotted to remote control, allowing the connection of a maximum of 18 substations. The tele-

[5] The telegraph transmitters and receivers were constructed by Lignes Télégraphiques et Téléphoniques. They are identical with the harmonic-telegraph equipment manufactured for the French Post, Telegraph, and Telephone Administration.

metering system is the same as that installed for the Nîmes–Sète line, with voice-frequency transmission over combined circuits.

The Paris supervisory station receives reports on and controls the operating conditions of 860

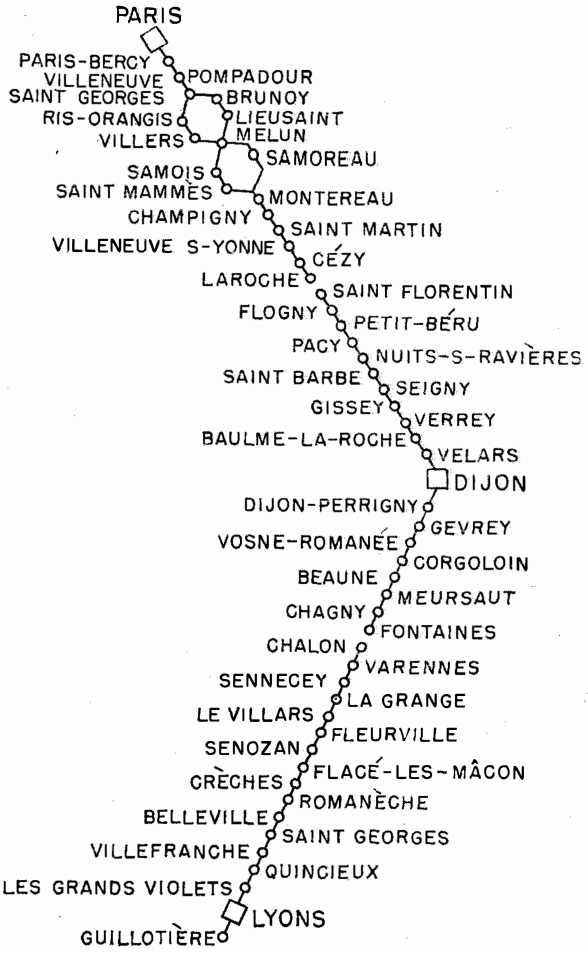


Figure 6—Paris–Lyons system.

pieces of apparatus and receives reports only on an additional 750 units. The network diagrams of the Saint Mammes and Montereau substations may be seen in Figure 7 and a view of the control room in Paris is shown in Figure 8.

In Dijon, full supervision is maintained over 920 equipment units and there are 740 additional pieces that report their condition to the control room. The Lyons station controls 650 units and receives reports on 440 more. A view of its control room is given in Figure 9.

Centralized control was put in service from the Paris station in May, 1950, and extended to the Dijon sector in October; the Lyons control room was opened in May of 1952.

2. *Synchronous Selection System*

At the supervisory station, there is an assembly of relays, which is called an individual control element, for each piece of equipment that must report to the supervisor and be controlled by him. This individual control element is connected to the corresponding lamp and key switch on the network diagram. Similarly, another individual control element in the substation is associated with the equipment itself. The number of relays in each individual control element depends less

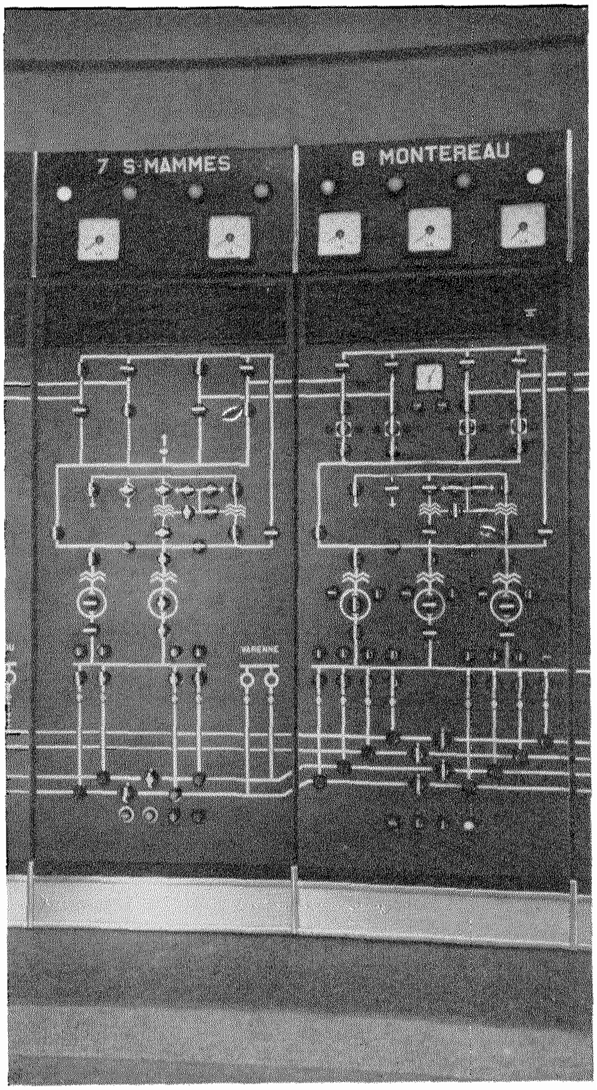


Figure 7—Two of the network diagrams in the Paris control room.

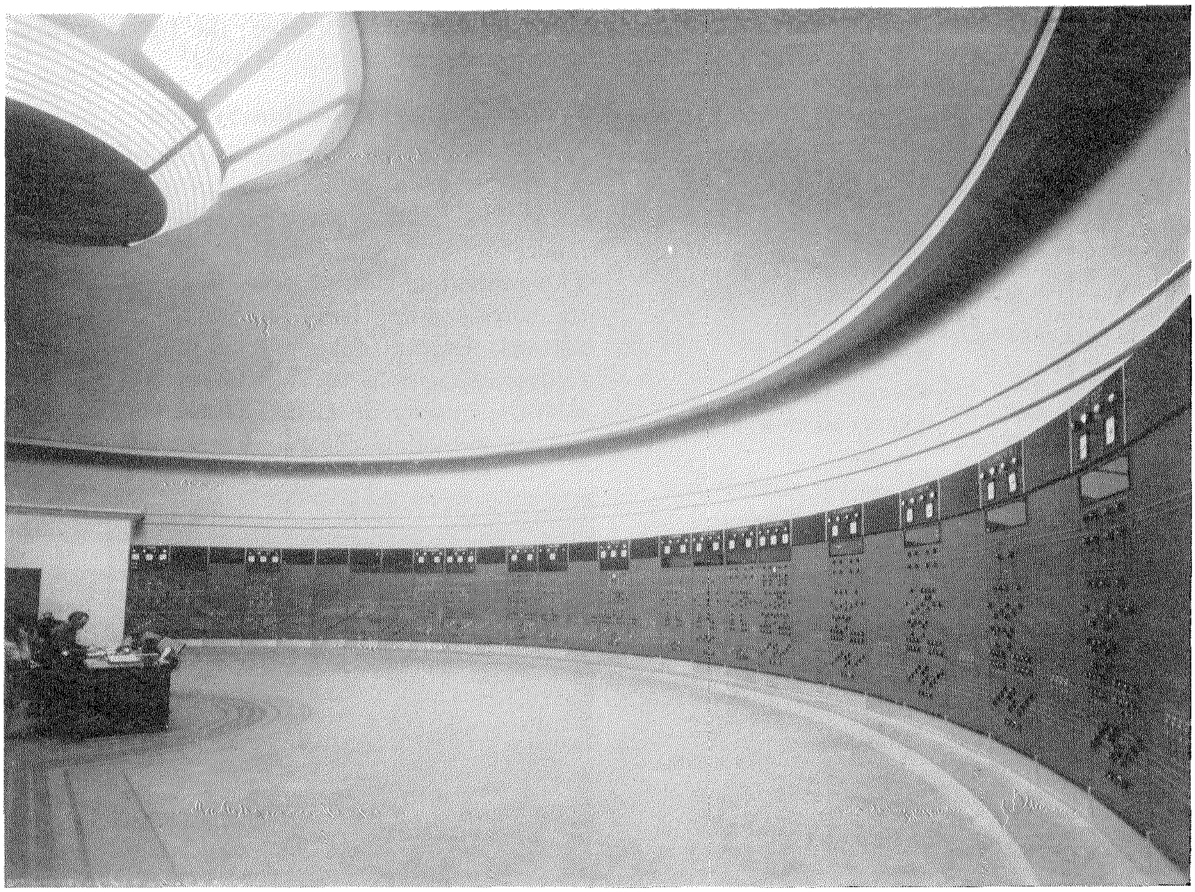


Figure 8—A view of the Paris control room.

on the system of transmission than on the characteristics of the device to be controlled.

At each end of the transmission system is a common element that has the duty of finding the individual control element of the device that is to be supervised and of connecting it through the corresponding element to the lamp and key switch on the network diagram. These common elements must be capable of passing messages in both directions if a report is to go from the substation to the supervisory point and instructions transmitted in return. Also, they must not be occupied for long on each message or the supervision of other units will be delayed and may impair the safety of operation.

In Figure 10, the equipment at the supervisory station and that at the controlled substation are substantially the same. Four simple conductive paths are shown between the stations and all frequency-generating, frequency-selecting, and amplifying circuits have been omitted for simplicity.

Boxes $1S_1 \ldots 1S_n$ represent the individual control elements that are connected to the appropriate lamps and key switches on the network diagram. Points *1* and *2* of the stop-and-hold level of the three-level stepping switch are connected to $1S_1$ and correspond to the OFF and ON positions of the equipment being supervised. Similar connections are made to the other individual control elements. Zero is the normal nonoperated position of the switch.

At the controlled substation, $1C_1 \ldots 1C_n$ are the individual control elements that are connected to the various pieces of apparatus to be supervised.

Suppose the supervisor wishes to put in the ON position the equipment represented by $1C_2$. He rotates and pushes the corresponding key switch on the network diagram to the ON position. This change puts voltage on the M wire,

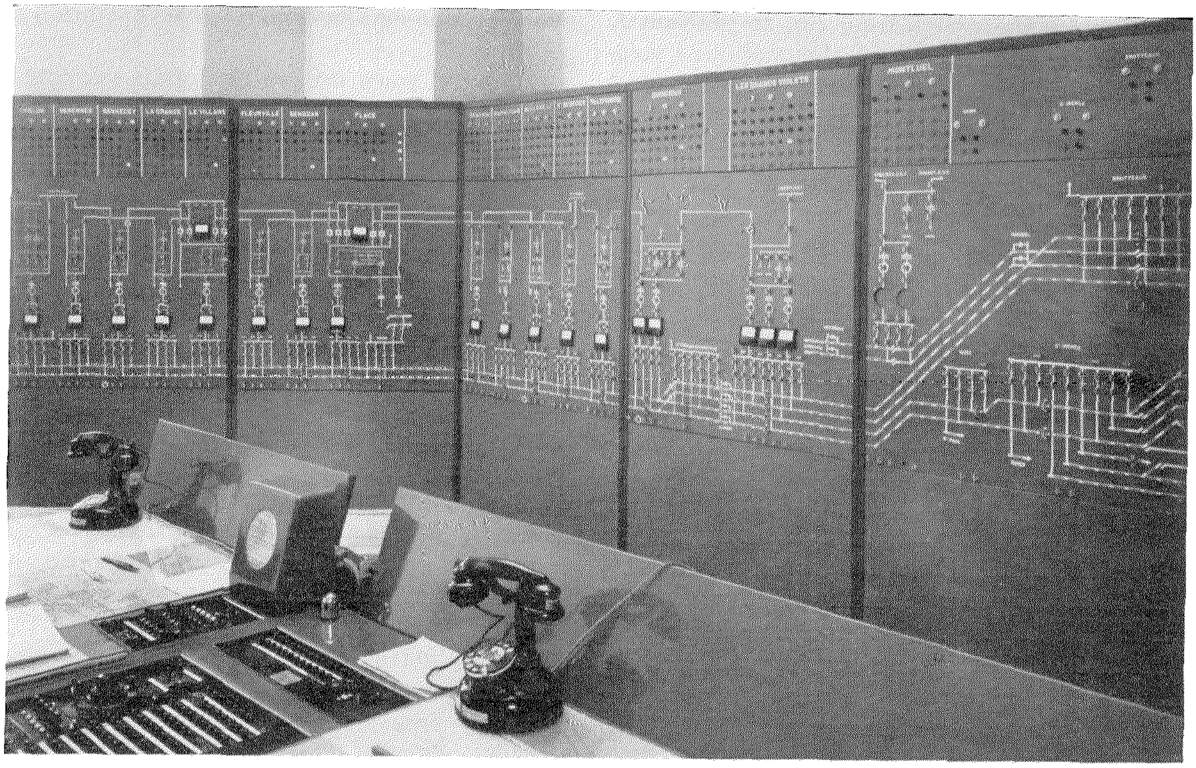
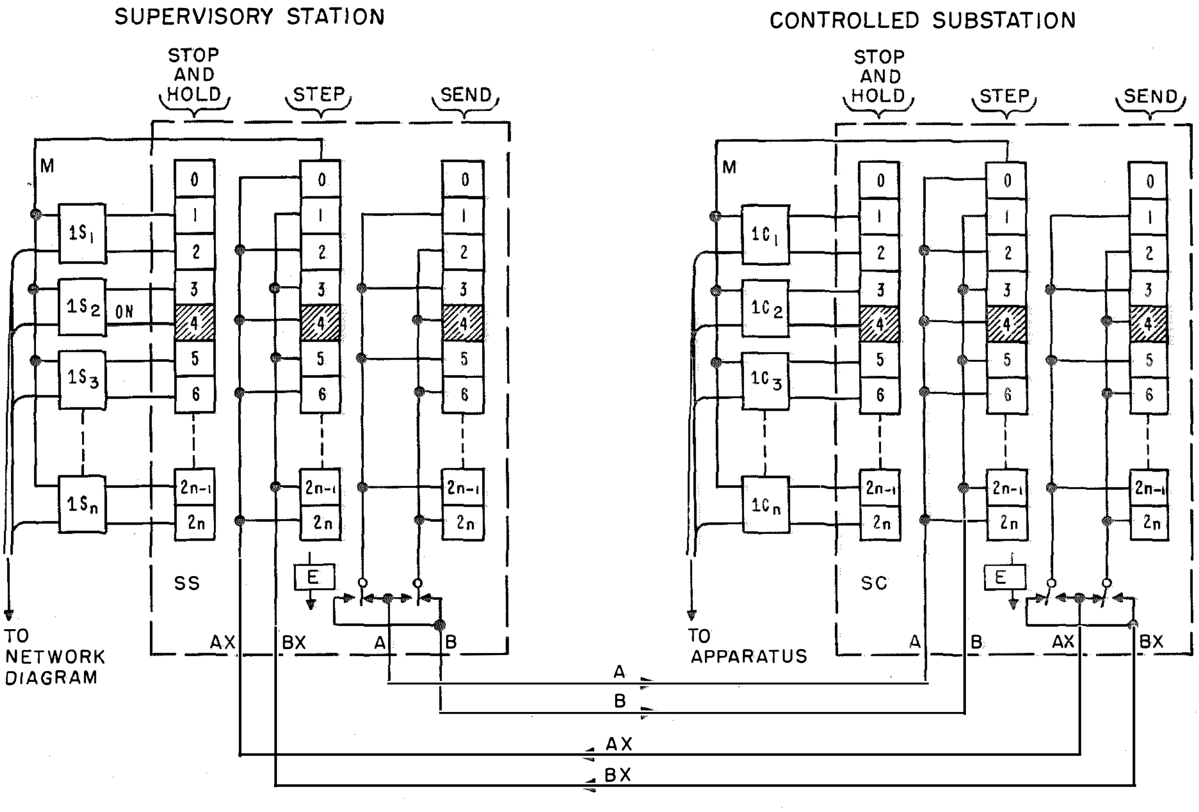


Figure 9—Above, Lyons control room using miniature network-diagram panels.

Figure 10—Below is shown a block diagram of the synchronous selection system.



which steps the switch from rest to position *1*. The send level of the switch then applies a voltage to wire *A* that, acting through the step level of the switch in the substation, advances it to position *1*. The send level of the substation switch then transmits a signal over *BX* (because relay *E* is operated) that steps the supervisory switch to position *2*. This alternate stepping continues until both switches are at position *4*. Further stepping is prevented by a stop voltage put on position *4* of the supervisory switch through the key switch of the network diagram.

A specific piece of apparatus in the substation is now connected through its associated individual control element $1C_2$ to the supervisory network diagram and the signal that will switch it to its other operating condition may now be transmitted. This control signal is transmitted simultaneously over wires *A* and *B* and, after an acknowledging signal has been transmitted over *AX* and *BX* to the supervisory station, the apparatus is switched to the new condition.

When the apparatus connected to $1C_2$ has actually placed itself in the ON position, revertive signalling is immediately transmitted; the common elements have already been set by the control operation and have no selective operation to perform.

Of course, when the position of an equipment in the substation is changed independently of remote control, the selection process is analogous to that previously described for the despatching of an order.

To provide for constant testing of the operating condition of the transmission system, an arrangement is used in which signals are always present on all four lines when the equipments are in the rest position. An interruption of any channel must be followed by a selecting signal or an alarm is given in the supervisory station.

Before any selection operation, signals are exchanged to check that the equipment to be controlled is in the receiving condition (relay *E* energized). In case of simultaneous operation at both ends, for instance, this exchange of signals gives priority to the control station.

The method of revertive signalling ensures that each stepping of a switch occurs after all the necessary previous actions have been taken in the other station. This places the transmitting station in constant control of the receiving station. If the revertive signal is not received, an alarm is given to the supervisor.

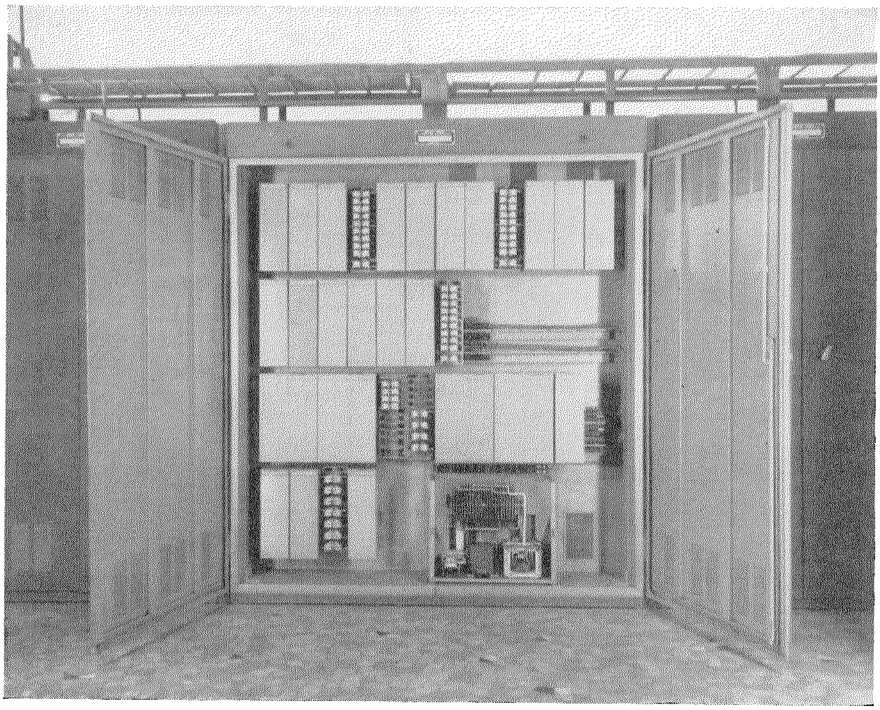


Figure 11—Substation supervisory cabinet. Some of the dust covers have been removed.

The length of each transmitted signal is determined by the operating time of the system. It will persist until the required action has occurred and only until then. Thus, all signalling will take place in the minimum possible time for the condition of the system. A slowing down of any element will result in the system adapting itself to that particular delay but other phases of the operation will continue at normal speed. In this way, the maximum capacity of the system is assured for every possible condition of operating speed.

The selecting mechanism not only finds the equipment to be supervised but provides for every possible order that may be needed and does these things in a single operation. It avoids the complexity that would result if these two functions were separated.

If more than one apparatus in a substation changes its condition, it is not necessary for the stepping switch to return to zero after giving the lowest-numbered report, it will continue its stepping after supplying that information and give the additional reports without unnecessary delay. This reduces the total time required to bring the network diagram up to date under such conditions. It also permits the supervisor to initiate changes in several pieces of equipment in rapid order.

As the time required for connection to a particular piece of equipment is a function of its position on the stepping switch, frequently controlled apparatus will be assigned to the steps nearest zero.

For catering to N two-position equipments, the stepping switches must provide for $2N$ contacts on each level. For 100 pieces of apparatus, 200-point switches will be needed. To reduce over-all operating time in such a case, a double selection is employed. The group-selecting stage would be capable of distinguishing among 20 groups of 5 individual control elements each. The maximum number of steps would then be 20 among the group selectors and 10 to read the extreme position of the final individual control element in that group. These 30 operations produce the same result as would 200 operations on a single stepping switch. The gain in speed of operation is evident.

3. Equipment

A typical cabinet of switching equipment for a substation is shown in Figure 11. It will handle supervisory circuits for 100 pieces of apparatus. The various relays and stepping switches are

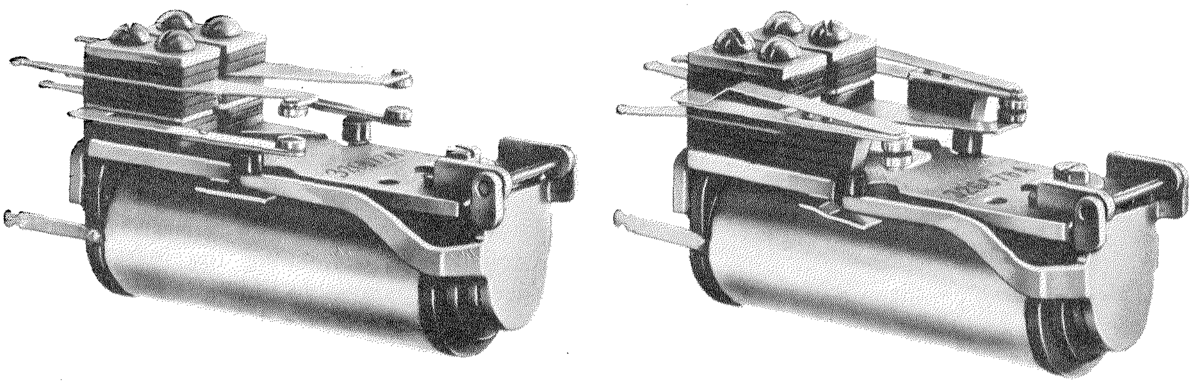


Figure 12—Remotely controlled relays that handle the operating currents for the power contactors.

mounted on perforated flanges and are protected by dust covers. Wiring is done from the rear of the flange and terminates in multiple-contact plugs. These plugs engage with the jaws of jacks to which the outside wiring is connected. Suitable mechanical supports are provided and each group of equipment mounted on a single flange can be replaced by another unit in a few seconds.

The use of plug-in groups of relays and switches is a real convenience for both installation and maintenance. It is not limited to the supervisory equipment and some of the circuit breakers in the Paris–Lyons substations are of this type despite their handling 3000 amperes at 1500 volts.

The experience over many years has fully justified the use of telephone-type relays for supervisory work. While the electricians who operated the early installations looked with doubt on these comparatively flimsy structures, time has shown them to be just as reliable as the more-robust power contactors with which this personnel were familiar.

The heavy contactors that control the various pieces of power equipment cannot be operated directly from a standard telephone relay. Their operating currents are of the order of 2 amperes drawn from a 115-volt battery. Two of the relays that are operated from the supervisory station and have been redesigned to handle the relatively heavy operating currents to the contactors are shown in Figure 12. These relays are used in pairs, one as the opening control and the other as the closing control. Several such pairs of these terminal relays may be seen in Figure 13, which is from one of the substations in the Paris–Lyons installation.

Figure 13—Group of terminal relays in a substation of the Paris–Lyons system.

It is convenient to mount all of the terminal relays in a separate cabinet. There is not a pair for each piece of power equipment because some of the apparatus is not controlled from the supervisory point but only reports its condition to that central office. All of this other equipment is associated with only the weak currents of the signalling system. The terminal relays are the only points where heavier currents are mixed with the signalling currents and by separating these relays from all others, suitable precautions can be taken for providing adequate insulation between these circuits.

In the Paris–Lyons system, a new arrangement was instituted for the joining of the substation wiring and the remote-control wiring. These circuits terminate at contacts that are bridged by removable U-shaped connectors mounted in plastic blocks. The conductors for the signalling and controlling circuits for each piece of power equipment are grouped on the distributing frame and may be disconnected for testing or other purposes by lifting out the junction block. Figure 14 shows this arrangement.

This system was found to be very convenient for testing before putting the installation in service. The removable link was replaced by a special fixture that permitted a changeover switch to replace the control from the supervisory station and a system of lights to indicate the opening or closing of the relay contacts. This saved much time in getting the substations in operation.

As the number of equipments in each substation and the number of substations increased, the physical size of the individual network-diagram control boards was reduced.

Each supervised unit is represented by a switch that may be rotated a quarter turn and that may be depressed to operate a different set of contacts. In addition, there is a lamp mounted in the center of the knob. Two versions of this switch were designed. The larger, used in the Paris and Dijon control rooms of the Nîmes–Sète line, is shown in Figure 15. The smaller types of switches and signal lamps may be seen in Figure 16. These were installed in the Lyons control room.

In operation, when the bar of the switch joins the ends of the connecting wires on the network diagram, the circuit represented is connected through or the piece of equipment is carrying load. When the bar is at a right angle to the connecting wires, the opposite condition holds. If the bar position actually corresponds to the operating condition of the apparatus, the lamp in the switch will not be lit. If there is a discrepancy between the switch position and the equipment condition, the lamp lights and notifies the supervisor of the situation. The use of two

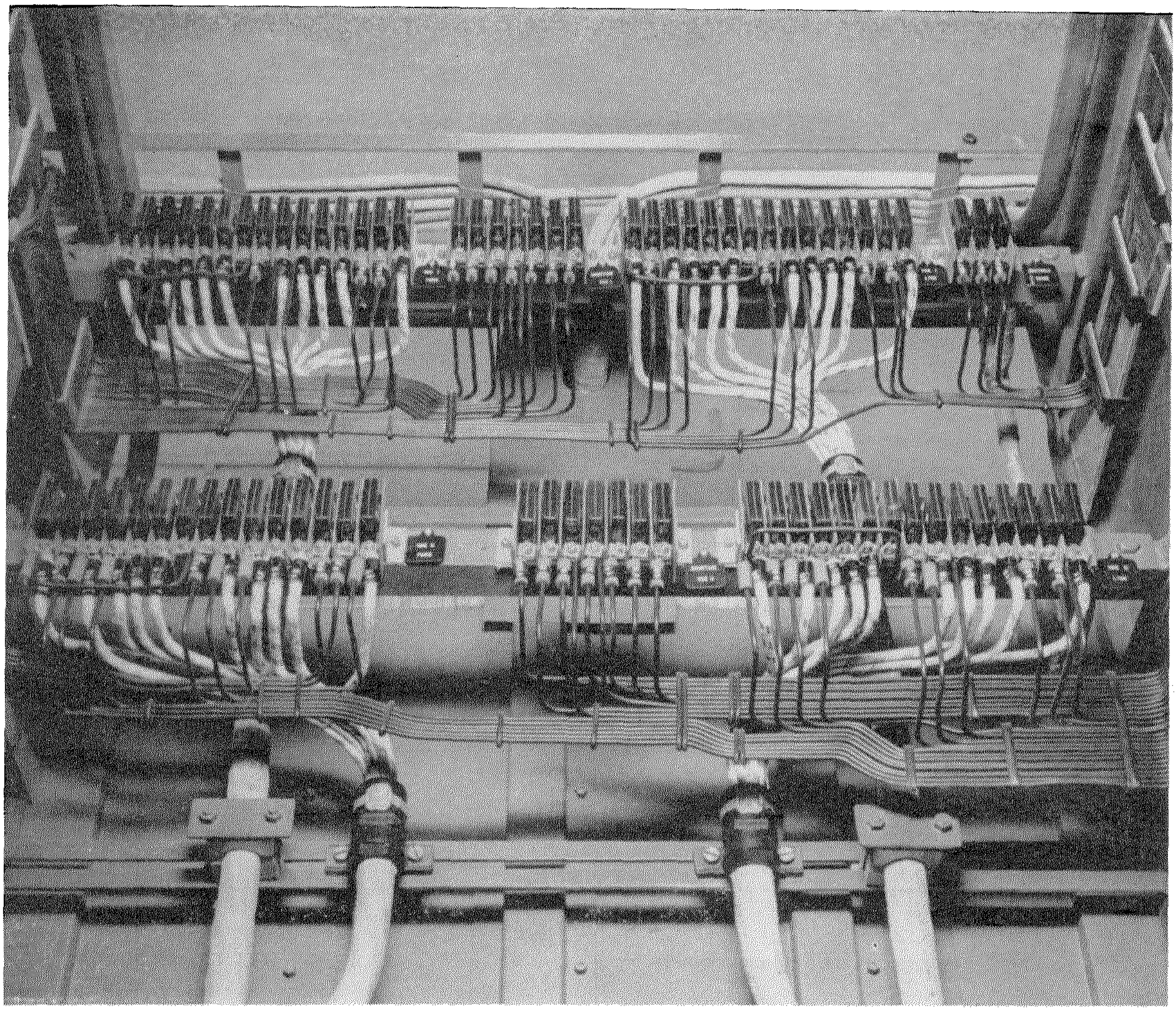


Figure 14—The removable plastic blocks permit circuits to be isolated for testing and other purposes.

lamps in each switch or indicator insures operation if one filament should burn out or permits two different colors to indicate the condition of the device.

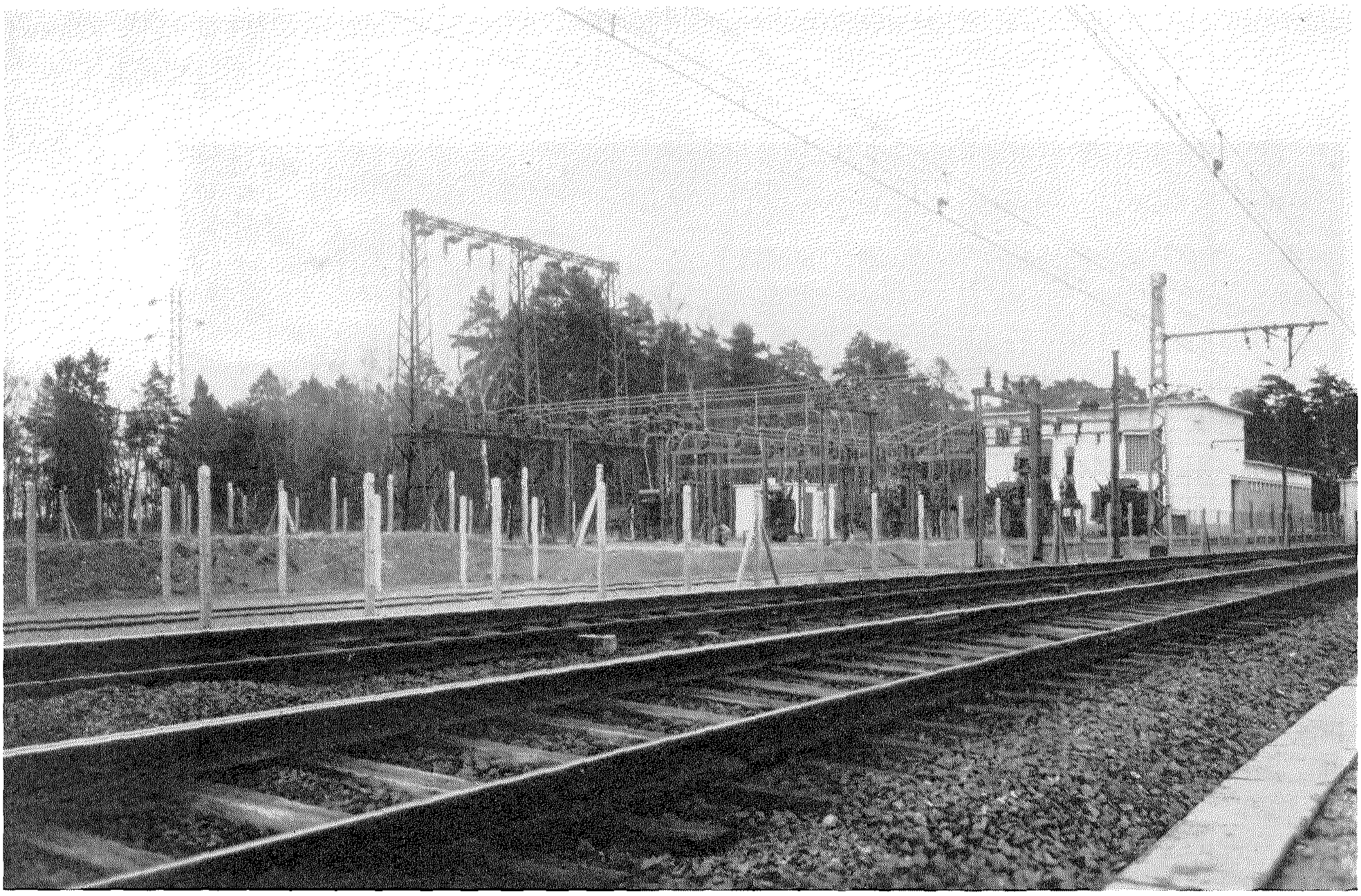
If a change is required, the supervisor will rotate the switch bar to the desired condition. There will then be a discrepancy between the network diagram and the actual equipment so the lamp will light. By pushing the switch, synchronous selection is initiated and when the equipment has been switched to the desired condition, the lamp will be extinguished.

Operational safety is insured by providing a means whereby all the lamps on the network diagram for each substation may be lighted at once for testing.

Every time a substation unit changes its condition, an audible alarm is sounded in the supervisory room in addition to the operation of the light in the corresponding switch on the network diagram.

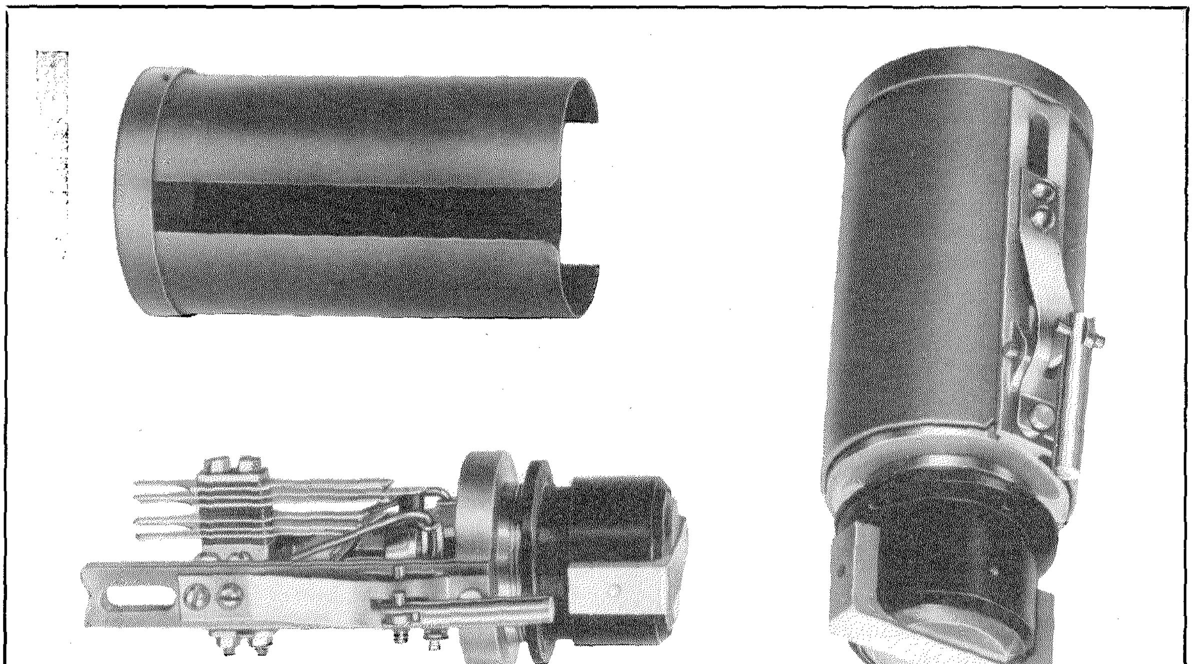
4. *Future Developments*

Because railway people deal continually with the transmission of thousands of kilowatts of electric power, it is not unreasonable for them to give little or no thought to the possibility of using the milliwatt powers of telephony for the control of these systems. The development of private automatic telephone exchanges did much to prove the practicality of the over-all design of these systems and of the reliability of the



Above, one of the substations and its outside switchgear on the Paris–Lyons line.

Figure 15—The larger *turn-and-push switch* used in the Nîmes, Dijon, and Paris control rooms.



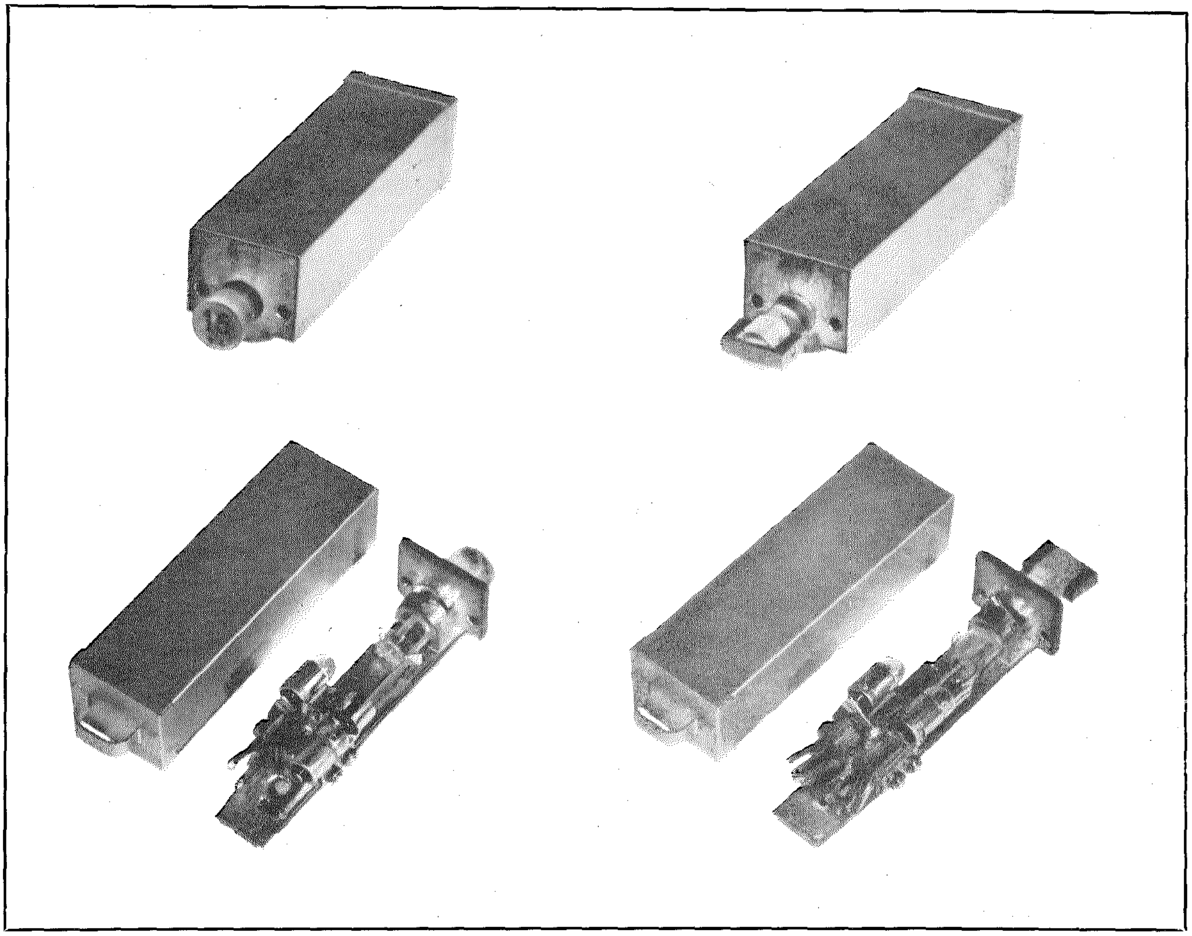


Figure 16—The smaller switch is at the right and a light indicator for signalling only is at the left. These are used in the Lyons control room.

component parts of which they were assembled. The ease with which a desired subscriber may be reached through a simple dialling procedure did much to encourage the railroads to try telephone-type facilities for remote supervision of important power systems.

The supervision of traction substations presents a severe test of any system since it plays an important role in maintaining time schedules, a high grade of service, and absolute safety. The present remote-control systems have met all of the demands of the railways. Nevertheless, constant improvement is being sought with regard to all important features and in particular to speed of operation and economy.

One important trend is toward reduced bulk, particularly for the network-diagram control boards. The so-called miniature board used in the Lyons installation is substantially smaller than the previous designs and permits a significant reduction in floor area of the control room.

The transmission methods described should be considered as being particular solutions to the problems presented. Any of the techniques of the telephone and telegraph fields may be applied to future installations. Any network that can be supervised by telephone calls among a multiplicity of operators can be converted to remote operation over the same telephone channels.

Telephone techniques bring to power systems a sensitivity and control mechanism that can do much to enhance their effectiveness. It is necessary only to see that the basic system is designed for the functions it is to perform and that a suitable intellect is provided to guide it in fulfilling its missions.

Computation of Impedance and Efficiency of Transmission Line with High Standing-Wave Ratio*

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ORDINARILY it is desirable to operate a radio-frequency or other transmission line with a standing-wave ratio as close as possible to unity. When the voltage standing-wave ratio is less than 10, means such as the Smith chart are available for making impedance computations with an accuracy sufficiently good for many purposes. However, in some cases it is desirable or unavoidable to operate the line with a high standing-wave ratio. When the voltage standing-wave ratio is around 100 the Smith chart is quite satisfactory for reactance but affords no degree of accuracy in reading resistance. This is due to the difficulty of reading even one significant figure on the resistance scale near the periphery, and also due to eccentricity in locating the movable arm or the dividers on the center point of the chart.

A simple method is shown for computing the resistive component when the impedance point lies close to the edge of the Smith chart. Attention is also given to precautions to be observed in computing normalized impedance. Similar procedures are shown for admittances. The effect of attenuation is taken into account.

In a related problem, the usual formulas for power and efficiency can lead to considerable error when the voltage standing-wave ratio is high. A precise formula is developed herein for the power flowing at a location in a network, in terms involving the magnitude and angle of the reflection coefficient of the load with respect to the source. This is accurate both for lumped-constant networks and for those with distributed constants. It is in a form that makes it of particular value in connection with transmission lines in the TEM mode.

On the basis of the power formula, another is readily derived for the efficiency of power transfer along a section of transmission line. The complete formula is more involved than necessary for most applications but can be reduced to various simpler expressions according to the nature of the problem. One of these is the usual formula found for a line with low or medium standing-wave ratio. Another is much more accurate than the latter for cases where the standing-wave ratio is high. It is simple to use, involving only the ohmic resistances and the normalized reactances of the load and input impedances.

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1. Symbols

The following list does not include some symbols that are defined where they occur in the text.

$A_0 = 8.686\alpha h$ = normal or matched attenuation of a length of line in decibels

B_0/G_0 = tangent of the phase angle of Y_0

$g + jb = Y/Y_0$

h = distance along line between two points in units of length

$r + jx = Z/Z_0$

R_0 = real part of the characteristic impedance

S = voltage standing-wave ratio

$Y_0 = 1/Z_0 = G_0(1 + jB_0/G_0)$

$Z_0 = R_0(1 - jB_0/G_0)$ = characteristic impedance in ohms

α = attention constant in nepers per unit length

β = phase constant in radians per unit length

δ = loss angle of dielectric, or power factor when $\delta < 0.1$

η = efficiency

$\theta = \beta h$

$\rho = |\rho| \underline{/2\psi}$ = voltage reflection coefficient

ψ = electrical angle to a point on the line, measured toward the load from a voltage standing-wave maximum.

2. Transformation of Impedance

The first step in solving a particular problem is to decide on the method that is simplest while satisfying the accuracy requirements. A typical case can be set up as follows with reference to Figure 1.

Given—The impedance $Z_1 = R_1 + jX_1$ at one end of the line, and the characteristic resistance R_0. Also α/β, B_0/G_0, and θ or h/λ, which are determined as indicated in Section 3.2 on attenuation and line length.

Required—To find the impedance $Z_2 = R_2 + jX_2$ at the other end of the line and the efficiency.

2.1 General Rules

Determine the simple normalized impedance $(R_1+jX_1)/R_0$ and set it up on the Smith chart. If the resistance component can be read accurately (say voltage standing-wave ratio less than 10 or 20), it is ordinarily satisfactory and simple to use the chart for the entire computation.

If the voltage standing-wave ratio is greater than 10 or 20 and the resistance component cannot be read on the Smith chart with the desired accuracy, the following method is recommended.

2.2 Procedure

The normalized impedance should properly be computed by use of (4) and set up on the Smith chart. However, in most cases the simpler expression $(R_1+jX_1)/R_0$ is sufficiently accurate for this first step. If working in admittances, use $(G_1+jB_1)/G_0$. Determine the normalized impedance r_2+jx_2 (or the admittance if required) at the other point of the line by the usual manipulation of the chart. Take account of attenuation by means of (9) and (10) and the remarks thereafter. The reactance $X_2=R_0x_2$ thus found is sufficiently accurate for most purposes. Then, subject to the conditions listed below, the resistance or conductance component can be computed by use of (1) and its modifications in (2) according to the given and required quantities.

$$R_2=R_1\frac{1+x_2^2}{1+x_1^2} + R_0(1+x_2^2)\left[\frac{\alpha}{\beta}\theta+\frac{B_0}{G_0}\left(\frac{x_2}{1+x_2^2}-\frac{x_1}{1+x_1^2}\right)\right]. \qquad (1)$$

Observe that R is the ohmic resistance, while x is the normalized reactance. The attenuation of the line in nepers is shown as $(\alpha/\beta)\theta$ but can be expressed in other ways, as in (10). It is positive when point *2* is on the generator side of point *1*, and negative in the converse case.

Equation (1) is not as tedious to use as its length might indicate, for the terms $(1+x_1^2)$ and $(1+x_2^2)$ are each repeated two or three times. Also, in many problems $B_0/G_0=\alpha/\beta$ affording further simplification.

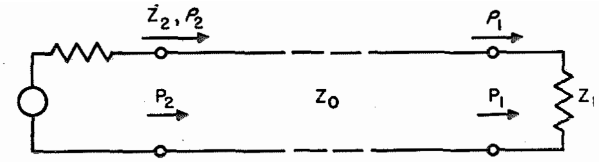

Figure 1—Transmission line of length h.

2.3 Conditions

Equations (1) and (2) yield results with an accuracy of the order of one percent subject to the following conditions.

A. Neither $1/S_1$ nor $1/S_2$ exceeds 0.17.

B. $|B_0/G_0| < 0.1$.

C. The normalized impedances $r_1 + jx_1$ and $r_2 + jx_2$ or admittances $g_1 + jb_1$ and $g_2 + jb_2$, whichever are used, must lie in the one-percent "permitted region" on Figure 2.

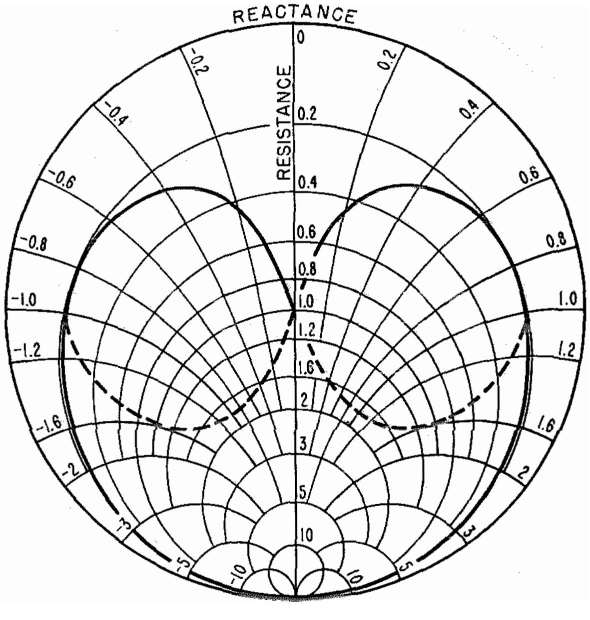

Figure 2—Permitted region for use of formula $S = (1 + x^2)/r$. Area outside solid heart-shaped curve drawn on Smith chart is where formula is accurate to within one percent. Area outside dashed curve is where reciprocal of $r + jx$ lies in permitted region; see Section 6.1

D. The line parameters and given impedance be known to one-percent accuracy. In many problems, this last condition is not satisfied.

2.4 Variations of Formula

Equation (1) gives R_2 when impedance is given. When admittance is given or required, similar formulas can be written with terms shown in the following tabulation.

$$\begin{Vmatrix} R_2 & R_1 & x_2^2 & x_1^2 & R_0 & x_2 & -x_1 \\ G_2 & G_1 & b_2^2 & b_1^2 & 1/R_0 & -b_2 & b_1 \\ R_2 & G_1R_0^2 & x_2^2 & b_1^2 & R_0 & x_2 & b_1 \\ G_2 & R_1/R_0^2 & b_2^2 & x_1^2 & 1/R_0 & -b_2 & -x_1 \end{Vmatrix} \quad (2)$$

The top row shows the terms in (1). The second row is for G_2 in terms of G_1, etc. Replace each term in (1) with the second-row term directly below the original term in the tabulation. Be sure to replace all the x_2^2 by b_2^2 and so on.

It may happen that R_2 is desired but r_2+jx_2 is not in the permitted region while g_2+jb_2 is in it. Compute G_2 using (1) modified by (2). Instead of taking the reciprocal of G_2+jB_2, use the formula

$$R_2 = R_0^2 G_2 |x_2/b_2|, \quad (3)$$

where x_2 and b_2 are read on the Smith chart in the usual manner for converting impedances to admittances.

Similarly, when G_2 is to be found and g_2+jb_2 is not permitted, compute R_2 and transpose (3) to find G_2. The same means is used to convert between R_1 and G_1 when necessary.

3. *Normalized Impedance and Other Preliminary Considerations*

3.1 Normalized Impedance

The characteristic impedance and admittance are

$$Z_0 = R_0(1+jX_0/R_0)$$
$$= R_0(1-jB_0/G_0),$$
$$Y_0 = G_0(1+jB_0/G_0).$$

The impedance and admittance looking toward the load at a point in the line are

$$Z = R+jX,$$
$$Y = 1/Z = G+jB.$$

Normalized and ohmic impedance are related by

$$r+jx = Z/Z_0 = (1/R_0)[R-(B_0/G_0)X+jX], \quad (4)$$
$$R+jX = Z = R_0[r+(B_0/G_0)x+jx], \quad (5)$$

accurate to one percent provided

$$R/|X| = G/|B| < 0.1,$$
$$r/|x| = g/|b| < 0.1,$$
$$|B_0/G_0| < 0.1.$$

The formulas for admittances are similar, with each impedance term replaced by the corresponding admittance term and the sign before B_0/G_0 reversed.

Caution must be observed to retain the proper sign with X, B, x, or b in the formulas. For example if $X = -300$, it must not be entered in the formula simply as 300. Take special care in this for the terms with coefficient B_0/G_0.

The B_0/G_0 term in these formulas can frequently be neglected leaving the customary simple formulas for normalized impedance. This is especially so in rough preliminary design computations. The B_0/G_0 terms are most important when the load Q is high, or B_0/G_0 is relatively high as in spiral lines and resonators, and with ordinary lines used at the lower frequencies.

3.2 Attenuation and Line Length

If the attenuation of the line is known in decibels per 100 feet, then

$$\frac{\alpha}{\beta} = \frac{0.115 \text{ (decibels/100 feet)}}{30.48} \frac{\lambda}{2\pi}$$

nepers per radian. Wavelength in meters for an ordinary line is

$$\lambda = v/f = 300/f\epsilon^{1/2}.$$

When attenuation data are not available, compute

$$\alpha/\beta = Rv/2\omega R_0 + \delta/2.$$

The resistance of a concentric line or of a balanced two-conductor line with copper conductors is

$$R = f^{1/2}(1/d+1/D)\times 10^{-3}$$

ohms per foot, where d and D are the diameters in inches of the active surfaces of the conductors and f is in megacycles.

The tangent of the phase angle of the characteristic admittance is

$$B_0/G_0 = \alpha/\beta - \delta.$$

The line length is

$$h/\lambda = hf\epsilon^{1/2}/984 \text{ wavelengths},$$
$$\theta = 2\pi h/\lambda$$
$$= hf\epsilon^{1/2}/156.5 \text{ radians},$$

where h is in feet and f in megacycles per second, while ϵ is the dielectric constant of the medium relative to air.

4. Derivation of Impedance Transformation Formula

The following formulas are well known:

$$1/S = (1-|\rho|)/(1+|\rho|),$$
$$|\rho_2| = |\rho_1| \exp(-2\alpha h)$$
$$= |\rho_1| \exp(-0.230A_0) = |\rho_1| 10^{-A_0/10}. \quad (6)$$

With respect to a fictitious load with $|\rho| = 1.00$,

$$|\rho_1| = \exp(-2\alpha h_1),$$
$$|\rho_2| = \exp(-2\alpha h_2),$$
$$h = h_2 - h_1.$$

It follows that

$$1/S_2 = \tanh[0.115A_0 + \tanh^{-1}(1/S_1)]. \quad (7)$$

Now utilize the results of Section 6.1 and Figure 2, and note that (7) reduces to (9) with an accuracy of one percent when neither $1/S_1$ nor $1/S_2$ exceeds 0.17.

$$1/S_1 = r_1/(1+x_1^2) = g_1/(1+b_1^2), \quad (8)$$
$$1/S_2 = 1/S_1 + (\alpha/\beta)\theta, \quad (9)$$
$$(\alpha/\beta)\theta = \alpha h = 0.115A_0. \quad (10)$$

Finally,

$$\left.\begin{aligned} r_2 &= (1+x_2^2)/S_2, \\ g_2 &= (1+b_2^2)/S_2. \end{aligned}\right\} \quad (11)$$

When (8) to (11) are combined with (4) and (5) for normalized impedance, (1) results. The above equations can be used in a step-by-step method of computing impedance, but usually (1) provides a shorter computation.

Note the remarks under (1) on the sign of the attenuation. When attenuation is greater than 0.01 neper or about 0.1 decibel, it is desirable to take it into account in manipulating the Smith chart. This is done by means of (7) and (9), noting that the radial scale "resistance component" (graduated between 0 and 1.0) is identical with $1/S$. The "1-decibel steps" scale on the chart is too coarse for use in many problems.

5. Power and Efficiency

The net power flowing toward the load at a point on a transmission line (Figure 1) is shown in Section 6.3 to be

$$P = {}_fV^2 G_0[1-|\rho|^2+2|\rho|(B_0/G_0)\sin 2\psi] \quad (12)$$

watts where ${}_fV$ is the root-mean-square amplitude of the voltage of the incident wave. The efficiency of power transfer between point *2* on the generator end and point *1* on the load end of a section of line is

$$\eta = \frac{P_1}{P_2} = \frac{1-|\rho_1|^2+2|\rho_1|(B_0/G_0)\sin 2\psi_1}{1-|\rho_2|^2+2|\rho_2|(B_0/G_0)\sin 2\psi_2} \times \exp(-2\alpha h). \quad (13)$$

This formula can be simplified in many cases according to the conditions of the problem.

5.1 Condition *A*

$$(S_1 - 1/S_1)|B_0/G_0| \ll 1,$$

$$\eta = \frac{1-|\rho_1|^2}{1-|\rho_2|^2}\exp(-2\alpha h)$$
$$= \frac{1/|\rho_1| - |\rho_1|}{1/|\rho_2| - |\rho_2|} = \frac{S_2 - 1/S_2}{S_1 - 1/S_1}, \quad (14)$$

where $|\rho_2|$ and $|\rho_1|$ are related as in (6). The maximum percentage error, due to the combined effects of numerator and denominator, is

$$\pm 100\,(S_1 - 1/S_1)B_0/G_0.$$

This is the usual formula found for the efficiency of a radio-frequency transmission line. When the impedance can be computed accurately on the Smith chart, the voltage standing-wave ratio being less than 10 or 20, equation (14) should ordinarily be used. The values of $|\rho_1|$ and $|\rho_2|$ can be read on the chart, but it is suggested that one be read and the other computed by (6), since they usually differ but little.

5.2 Condition B

$$S_2 \gg 1,$$

$$\eta = \frac{1/S_1 + 0.5(B_0/G_0)\sin 2\psi_1}{1/S_2 + 0.5(B_0/G_0)\sin 2\psi_2}. \qquad (15)$$

The percent error is roughly

$$100/(S_2^2 - 1) - 100/(S_1^2 - 1),$$

which is < 1 percent for $S_2 > 10$ and < 10 percent for $S_2 > 3.3$.

5.3 Condition C

$$S_2 \gg 1 \text{ and } S_1 |B_0/G_0| \ll 1,$$

$$\eta = S_2/S_1 = 1/(1 + S_1 \alpha h)$$

$$= 1/(1 + 0.115\, A_0 S_1). \qquad (16)$$

The error is the algebraic sum of those for conditions A and B. In the expressions involving αh and A_0, this error is increased slightly by an approximation $\tanh x \approx x$ in the use of (7).

5.4 Condition D

$$S \gg 1,\ |B_0/G_0| \ll 1,\ r + jx, \text{ or } g + jb$$

in the "permitted region" of Figure 2.

$$\eta = \frac{R_1}{R_2}\left(\frac{1+x_2^2}{1+x_1^2}\right) = \frac{G_1}{G_2}\left(\frac{1+b_2^2}{1+b_1^2}\right)$$

$$= \frac{R_1}{R_0^2 G_2}\left(\frac{1+b_2^2}{1+x_1^2}\right) = \frac{R_0^2 G_1}{R_2}\left(\frac{1+x_2^2}{1+b_1^2}\right). \qquad (17)$$

The accuracy of (17) is comparable to that of (1) and (2) under the conditions listed for those equations.

R_1 and G_1 are the resistive and conductive components of the ohmic impedance and admittance looking toward the load at point *1*, and similarly for R_2 and G_2. On the other hand, x and b are normalized values. The real part of the characteristic impedance is R_0.

In problems where it is desirable to use (1) and (2) in computing impedance, (17) is generally the simplest one to use for efficiency and the most accurate for numerical computations. The latter equation is identical with the first term on the right-hand side of (1) or (2) divided by R_2 or G_2 as the case may be.

The exponential does not appear explicitly in several of the equations (14) to (17). This is not an approximation for small values of attenuation, but the exponential has been absorbed into the body of the formula.

The stated errors for the formulas are expressed as a percentage of η, obviously not in addition to η. Furthermore, the impedance and line parameters often will be known inaccurately, and can introduce considerable additional error into a numerical computation.

6. Appendix

6.1 Equations for Boundary of Permitted Region

For one-percent or better accuracy in (8) and (11) it is now shown that the impedance point must be in the permitted region of Figure 2, for which

$$|\cot \psi| < 0.1\, S^2/(S^2 - 1)^{1/2}. \qquad (18)$$

For ten-percent accuracy substitute the coefficient 0.32 for 0.1. When working in admittances, use $\tan \psi$ in place of $\cot \psi$. This gives the same boundary line in Figure 2.

Good formulas for checking rapidly the validity of (8) and (11) for one-percent accuracy are

$$\left.\begin{array}{l} r < 0.1\,|x + 1/x|, \\ g < 0.1\,|b + 1/b|, \end{array}\right\} (19)$$

provided $|x| > 0.3$ or $|b| > 0.3$, as the case may be. The accuracy condition can be checked visually on the Smith chart, where the circles of constant x must not deviate from the radial direction by more than about ten degrees at the impedance point in question.

Expression (18) is derived as follows. The complex reflection coefficient can be written

$$\rho = \frac{S-1}{S+1}(\cos 2\psi + j \sin 2\psi).$$

The normalized impedance is given by

$$r + jx = \frac{1+\rho}{1-\rho} = \frac{1 + jS\cot\psi}{S + j\cot\psi}.$$

The expression in S and ψ can be demonstrated most readily by substituting the above value for ρ and equating as a trigonometrical identity. It is an exact formula. Although it corresponds to an impedance formula with attenuation neglected, the fact that attenuation does not appear does not constitute an approximation. The quantities S and ψ are parameters that completely determine the reflection coefficient at the point where the impedance is $r+jx$.

Equation (8) can be derived from the last formula:

$$\frac{r}{1+x^2}=\frac{(1/S)(S^4+S^2\cot^2\psi)}{S^4+\cot^2\psi}=\frac{1+a}{S}.$$

The correction term a is always positive.

$$a=\frac{(S^2-1)\cot^2\psi}{S^4+\cot^2\psi}\approx\frac{S^2-1}{S^4}\cot^2\psi. \quad (18.1)$$

For one-percent error in (8), $a=0.01$ and (18) results.

6.2 Effect of B_0/G_0 Terms in Impedance Formulas

For this discussion, it is convenient to modify (1) by the use of the apparent or approximate standing-wave ratio S' and by a result found in Section 6.4.

$$1/S'=R/R_0(1+x^2)\approx G/G_0(1+b^2),$$
$$\sin 2\psi\approx 2x/(1+x^2)\approx -2b/(1+b^2).$$

Then (1) and (2) become

$$\frac{1}{S_2'}=\frac{1}{S_1'}+\frac{\alpha}{\beta}\theta+\frac{1}{2}\frac{B_0}{G_0}(\sin 2\psi_2-\sin 2\psi_1). \quad (20)$$

The angle of the reflection coefficient 2ψ can be read on the Smith chart. If working with admittances, read the negative of the angle indicated on the periphery for practical purposes in computing $\sin 2\psi$.

The principal point in question is the effect of the B_0/G_0 terms in the over-all computation and whether they can be neglected. The worst case is when $B_0/G_0=\pm\alpha/\beta$. Then we are interested in the relative value of the quantity

$$\tfrac{1}{2}(\sin 2\psi_2-\sin 2\psi_1) \quad (21)$$

compared to the line length θ. If θ is centered about a voltage maximum or minimum, the quantity (21) is greatest with maximum value of unity. The other extreme is for θ centered midway between these points, when (21) is zero. For small values of θ up to about a radian, the quantity can range between almost doubling the effect of θ down to almost annulling it.

Even with a low voltage standing-wave ratio, (21) has the same effect as above on θ. However, when θ is small it does not have appreciable effect on $1/S$ or the impedance relationship in this case. When θ is large enough so attenuation has appreciable effect on impedances at low voltage standing-wave ratio, (21) is negligible in comparison.

Then the B_0/G_0 terms can be neglected when the standing-wave ratio is low. For higher voltage standing-wave ratio, use or omit the B_0/G_0 terms in (1), (2), (4), and (20), depending on a mental comparison of the magnitude of quantity (21) in relation to θ in radians.

6.3 Derivation of Power Equation

The power flowing at a point in an alternating-current circuit is given by

$$P=(\text{Real})\ VI^*. \quad (22)$$

This is the real part of the product of the root-mean-square complex sinusoidal voltage by the conjugate of the corresponding current.

Equation (12) is easily found when the following expressions are substituted in this equation. At a point in a transmission line,

$$V={}_fV(1+\rho),$$
$$I={}_fVY_0(1-\rho),$$
$$I^*={}_fV^*Y_0^*(1-\rho^*),$$
$$Y_0^*=G_0(1-jB_0/G_0),$$
$$\rho=(Z-Z_0)/(Z+Z_0)=|\rho|\exp(j2\psi),$$
$$\rho^*=|\rho|\exp(-j2\psi).$$

The power equation (12) can also be demonstrated by a related method. At a point on a line the power flow is given by $P=V^2G$ where V is the root-mean-square voltage across the line and G is the conductive component of the admittance looking toward the load. When this is expressed in terms of reflection coefficient, etc., (12) results.

The equation can also be demonstrated by integrating the power loss in the series resistance and shunt conductance of the line, between a known load and any other point on the line.

An example and further remarks on the power in a line are given in Section 6.5.4.

6.4 Derivation of Efficiency Formulas

The complete equation (13) follows immediately from (12). In deriving (15) there are used (6) and

$$1-|\rho|^2=4|\rho|/(S-1/S)=(4|\rho|/S)(1+a'), \quad (23)$$
$$a'=1/(S^2-1).$$

The expressions (17) are derived from (13) by way of (15) with the following steps. From (8), (18.1), and (23),

$$\begin{aligned}(1-|\rho|^2)/4|\rho| &= (1+a')/S\\ &= (1+a'-a)r/(1+x^2),\\ a'-a &\approx (1-\cot^2\psi)/S^2.\end{aligned}$$

By a deviation similar to that of Section 6.1,

$$0.5\sin 2\psi = x/(1+x^2)(1-a''),$$
$$a''=\frac{S^2-(S^2-2)\cot^2\psi}{S^4+\cot^2\psi}\approx\frac{1-\cot^2\psi}{S^2}.$$

This is the same as the approximate formula for $a'-a$ found above. Then

$$\begin{aligned}1-|\rho|^2+2|\rho|(B_0/G_0)\sin 2\psi &= (1+a'')4|\rho|\,\frac{r+(B_0/G_0)x}{1+x^2}\\ &= (1+a'')4|\rho|R/R_0(1+x^2).\end{aligned}$$

with (5) used in the last step. A similar formula is found for admittances. The expressions (17) follow readily.

The physical significance of (17) is as follows. Subject to the stated conditions, there holds approximately

$$x=\cot\psi,$$
$$I=I_{\max}\sin\psi,$$

where $I_{\max}$ is the current standing-wave maximum. The power at any point is

$$P=I^2R,$$

where R is the resistive component of the ohmic impedance looking toward the load at the point. The expressions (17) follow, since

$$\begin{aligned}I^2 &= I^2_{\max}\sin^2\psi\\ &= I^2_{\max}/(1+\cot^2\psi)\\ &= I^2_{\max}/(1+x^2).\end{aligned}$$

The value of $I_{\max}$ is constant within practical limits for values of S greater than those listed in the statement of errors, under condition D, Section 5.4.

6.5 Examples and Miscellaneous Remarks

6.5.1 Example of Impedance and Efficiency

A load of $5-j1000$ ohms at 2.0 megacycles per second is fed by a 60-foot (18.3-meter) length of *RG-17/U* cable. What is the input impedance and efficiency?

The attenuation of the cable at 2.0 megacycles is found to be about 0.094 decibel per 100 feet (30.5 meters). The loss angle of the polyethylene dielectric is less than 0.0002, and the dielectric constant is 2.26. The given conditions can be summarized as follows, making use of equations in Section 3.2 on attenuation and line length.

$$\begin{aligned}R_1+jX_1 &= 5-j1000 \text{ ohms},\\ R_0 &= 52 \text{ ohms},\\ \alpha/\beta = B_0/G_0 &= 5.6\times10^{-3},\\ \theta &= 1.15 \text{ radians} = 66 \text{ degrees},\\ h/\lambda &= 0.183.\end{aligned}$$

Then $x_1=-1000/52=-19.2$. By the Smith chart, $x_2=-0.384$, and so $X_2=-20.0$ ohms. The resistance is found by (1), where $1+x_2^2=1.148$ and $1+x_1^2=370$:

$$\begin{aligned}R_2 &= 5\times\frac{1.148}{370}+52\times1.148\times5.6\times10^{-3}\\ &\qquad\times\left(1.15-\frac{0.384}{1.148}+\frac{19.2}{370}\right)\\ &= (15.5+290)\times10^{-3}=0.305 \text{ ohm}.\end{aligned}$$

Efficiency, by (17) is

$$\eta=15.5\times10^{-3}/0.305=0.051=5.1 \text{ percent}.$$

6.5.2 Reflection Coefficient Greater than Unity

Suppose a lossy line with characteristic impedance $Z_0=R_0(1-j0.1)$ is terminated by a lossless load with impedance $Z=jR_0$. Then the normalized load impedance is found to be

$$Z/Z_0=-0.1+j1.0.$$

The negative normalized resistance can be visualized if a phasor diagram of the impedances is drawn. It has no implication of negative ohmic resistance.

The reflection coefficient (see Section 6.3) is

$$\rho=1.11\underline{/90.3^\circ}.$$

Now it is found that there is interchange of power between the incident and reflected waves, but the sum of all the power components is zero at the load.

$$(\text{Real})_f V_f I^* = 1.00,$$
$$(\text{Real})_r V_r I^* = -1.22,$$
$$(\text{Real})_f V_r I^* = 0.11,$$
$$(\text{Real})_r V_f I^* = 0.11.$$

The popular conception that the magnitude of the reflection coefficient cannot exceed unity is correct when either the source or load impedance

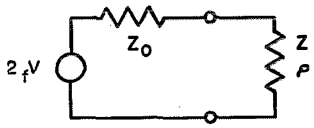

Figure 3—Generator and load.

is a pure resistance. With a transmission line, this is usually justified. In fact, when Z_0 includes an appreciable reactive component, it follows inherently that the attenuation per radian is large. Then even if the reflection coefficient exceeds unity at the load, its magnitude is reduced rapidly along the line and soon is less than unity.

6.5.3 Power in Lumped-Element Network

It may be observed that the derivation in Section 6.3 of (12) shows it to be equally valid for either lumped or distributed networks. For the lumped case shown in Figure 3, Z_0 is the generator impedance, Z the load, and ${}_fV$ is half the open-circuit generator voltage. This equation is not required in most lumped-element network applications since other formulas are usually simpler to apply.

With lumped-element networks, the reflection coefficient can be very large. Take for example a load $Z=R+jX$ connected to a generator impedance $Z_0=Z^*=R-jX$. The reflection coefficient is $\rho=jX/R=\pm jQ$. If the open-circuit generator voltage is E, then the power into the load is $P=E^2/4R$ by inspection. It is interesting to compute the power by (12), which yields the same result.

One use for the idea of reflection coefficient with lumped-element networks is in connection with the application of the principle of superposition. For instance, the load impedance may be replaced by one equal to the source impedance in series with a voltage equal to the actual open-circuit voltage of the source multiplied by the complex reflection coefficient.

6.5.4 Example of Power Flow along Line

A practical interpretation is given of the power equation (12), showing the net power flowing toward the load at various points along a line with high attenuation.

Let ${}_fV_a$ and ρ_a be the values of incident root-mean-square voltage and reflection coefficient at a voltage maximum. Then at any other point

$$ {}_fV = {}_fV_a \exp(-\psi\alpha/\beta),$$
$$|\rho| = |\rho_a| \exp(2\psi\alpha/\beta).$$

Now (12) can be written

$$P = {}_fV_a^2 G_0[\exp(-2\psi\alpha/\beta) - |\rho_a|^2 \times \exp(2\psi\alpha/\beta) + 2|\rho_a|(B_0/G_0)\sin 2\psi].$$

Suppose $\alpha/\beta = B_0/G_0 = 0.0318$ in which case the dielectric loss is negligible. Let $|\rho_a| = 0.9$, and find the power for various values of ψ between 0 and $-\pi$ radians.

The results are plotted in Figure 4, where arbitrarily $P=1.0$ at $\psi=0$, so ${}_fV_a^2G_0 = 5.25$. As a sample computation, let $\psi = -\pi/4$. Then

$$-2\psi\alpha/\beta = 0.050$$
$$P = 5.25[1.051 - (0.810/1.051) - 2\times0.9\times0.0318] = 1.18.$$

The curve of power versus position on line in Figure 4, shows that the slope is almost zero at the current minimum and greatest at the current maximum. This agrees with the assumption of

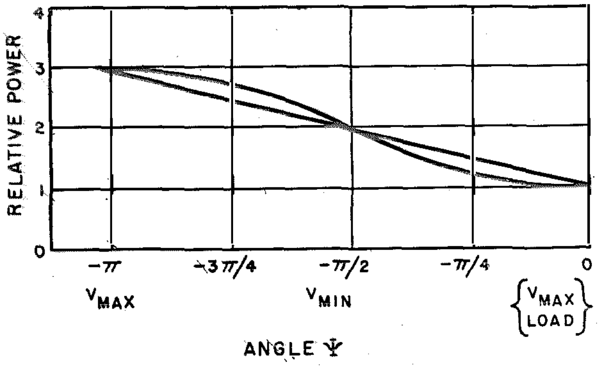

Figure 4—Power flow along line. Straight line is computed power neglecting B_0/G_0 term in (12). Curved line is according to complete formula for case of negligible dielectric loss.

negligible dielectric loss, or $B_0/G_0 = \alpha/\beta$. On the other hand, if the conductor loss had been negligible but the dielectric loss appreciable, there would have resulted $B_0/G_0 = -\alpha/\beta$. Then the lobes of the sinusoidal curve of power would have been on the other side of the average power line (i.e. where the B_0/G_0 term is neglected). The slope would be greatest at the voltage maximum and amost zero at the voltage minimum, which is logical.

The solution of the differential equation of propagation shows uniform voltage and current attenuation of the incident wave and of the reflected wave as they flow in their respective directions. This condition is used in the derivation of (12) and (13). However, as shown in the example, this leads to the power dissipation varying nonuniformly along the line. The discrepancy is resolved by the transfer of power between the incident and reflected waves as shown earlier in this appendix.

7. *Reference*

"Reference Data for Radio Engineers," Third Edition, Federal Telephone and Radio Company, New York, New York; 1949: see chapter 16.

Recent Telecommunication Development

Portable Lifeboat Radio Set

THE NEW TYPE *401-A* portable lifeboat transmitter–receiver, so designed and constructed that even a person without a knowledge of radio can operate it, has been developed by the marine division of Mackay Radio and Telegraph Company. It complies fully with the requirements of the International Convention for Safety of Life at Sea (London–1948), and is the first such unit to be approved for use in this country by the Federal Communications Commission.

The new equipment constitutes a complete lifeboat radio facility in that it includes transmitter, receiver, collapsible antenna mast, ground wire, and necessary rigging accessories. Both receiver and transmitter obtain power from a hand-cranked generator, precluding the possibility of failure that might otherwise occur with battery-operated equipment. The unit operates on international distress frequencies in both the intermediate-frequency (500-kilocycle-per-second) and high-frequency (8364-kilocycle) bands. A special device takes over when the set is placed in automatic operation. This device transmits first a 500-kilocycle auto-alarm signal, intended to alert nearby vessels. It then automatically transmits *SOS* successively on 500 and 8364 kilocycles, after which a long thirty-second dash is transmitted on 8364 kilocycles for use by direction finders. The entire keying sequence is then automatically repeated. Transmissions are crystal-controlled on both frequencies. The equipment may also be operated manually by an experienced radio operator for transmission and reception of messages on either frequency. The unit is completely waterproof and will float if dropped into water.

New Chart for the Solution of Transmission-Line and Polarization Problems*

By G. A. DESCHAMPS

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THE CHART presented in this paper has been described[1] as an orthographic map of the Poincaré sphere. Its application to transmission lines is believed to be new, and since in this respect important properties derive from projective geometry rather than from the relation to the sphere, it is proposed to call it the *projective chart.*

The relations of this chart to nonEuclidean geometry and to relativity[2,3] are interesting and important for understanding its basic properties; but since these theories have a reputation of being difficult, the projective chart will be considered here as a simple modification of the Smith chart. Fundamental properties will be stated without proof and a selection of possible applications will be given to show the versatility of this new graphical representation.

An important aid in these applications is a transparent overlay with convergent lines and graduations, called the ***hyperbolic protractor*** that can be used to measure directly on the chart a special type of distances.

1. Projective Chart

On the Smith chart, a reflection coefficient or reflectance w is represented by a point W just as any complex number is represented on the Argand diagram. The distance OW to the origin is the magnitude r of the reflectance, and all passive loads are represented by points inside the unit circle Γ. If the line OW cuts Γ at points I and J (Figure 1), the ratio

$$\frac{WI}{WJ}=\frac{1+r}{1-r} \tag{1}$$

is the voltage standing-wave ratio corresponding to the reflectance w.

The modification that leads to the projective chart is to represent the reflectance w by the point $\bar{W}$ with the same phase angle as W but at a distance $\bar{r}$ from the origin given by

$$\bar{r}=\frac{2r}{1+r^2}. \tag{2}$$

This makes the ratio $\bar{W}I/\bar{W}J$ equal to the square of the voltage standing-wave ratio.

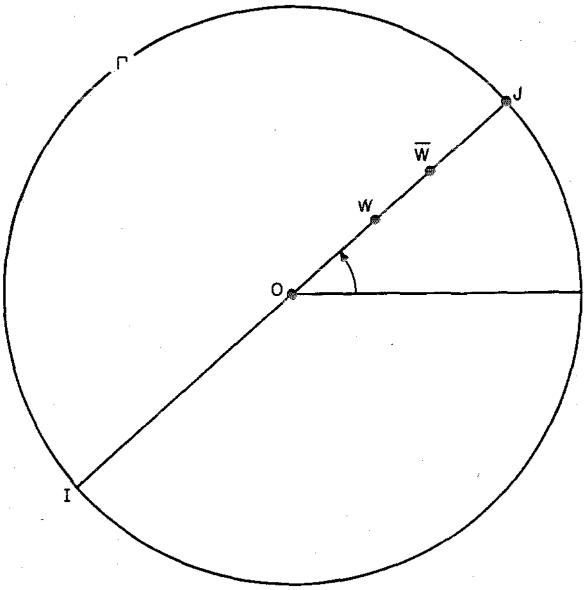

Figure 1—Relation between the representations of a reflection coefficient (or a polarization ratio) on the Smith chart (W) and on the projective chart ($\bar{W}$).

* Reprinted from *Transactions of the IRE Professional Group on Microwave Theory and Techniques*, volume 1, pages 5–13; March, 1953. Presented at the Professional Group Symposium on Microwave Circuitry in New York, New York, on November 7, 1952.

[1] G. A. Deschamps, "Geometrical Representation of the Polarization of a Plane Electromagnetic Wave," *Proceedings of the IRE*, volume 39, pages 540–544; May, 1951.

[2] G. A. Deschamps, "Application of Non-Euclidean Geometry to the Analysis of Waveguide Junctions," presented at the Joint Spring Meeting of the American Section of the International Scientific Radio Union and the Institute of Radio Engineers, Washington, District of Columbia; April 23, 1952: published in part as, "Determination of the Reflection Coefficients and Insertion Loss of a Waveguide Junction," in *Journal of Applied Physics*, volume 24, pages 1046–1050; August, 1953.

[3] G. A. Deschamps, "Geometric Viewpoints in the Representation of Waveguides and Waveguide Junctions," *Proceedings of the Symposium on Modern Network Synthesis*, pages 277–295; September 30, 1952. Presented at the Symposium sponsored by the Polytechnic Institute of Brooklyn and the Office of Naval Research in New York, New York, on April 18, 1952.

If a radial arm carrying a voltage-standing-wave-ratio graduation in decibels is used with the Smith chart, the point $\overline{W}$ will be in front of the graduation $2x$ when W is in front of the graduation x. Plotting points on the projective chart or transforming back and forth to the Smith chart is therefore very simple.

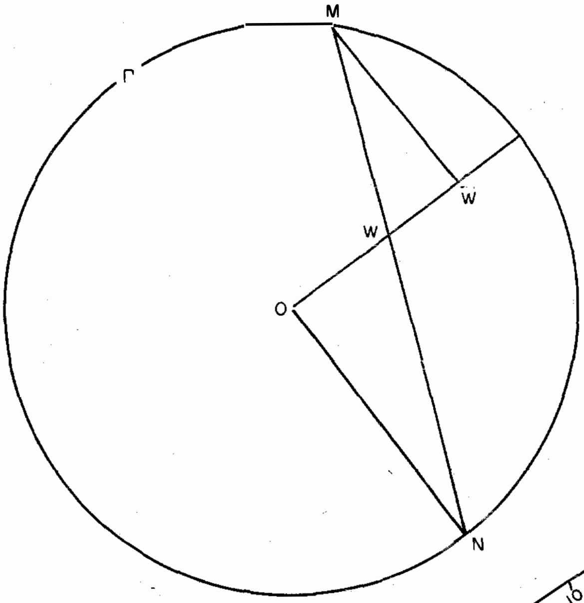

Figure 2—Transformations $\mathcal{B}$ and $\mathcal{B}^{-1}$. Construction of $\overline{W}$ from W or of W from $\overline{W}$.

The transformation $\mathcal{B}$ from W to $\overline{W}$ can also be obtained[1–3] by projecting W on a sphere with equator Γ from one of its poles and then projecting orthogonally from the sphere on the plane of Γ. This justifies the construction shown in Figure 2: $\overline{W}M$ and ON are perpendicular to the radius $O\overline{W}$ and MN goes through W. This can also be used to perform the inverse transformation $\mathcal{B}^{-1}$ from $\overline{W}$ to W.

The circles usually drawn on the Smith chart corresponding to constant resistance or reactance and to constant magnitude or phase of the impedance become on the projective chart straight lines and ellipses as shown in Figure 3. These could be drawn in advance and used as on the Smith and Carter charts to plot impedance measurements taken, for instance, with a bridge.

2. *Distances and Angles on Projective Chart*

Special notions of distance and angle that have useful interpretations can be introduced on the projective chart.

Given two points A,B and the intersections I,J of AB with Γ (Figure 4), the quantity

$$10 \log_{10}\left(\frac{BI}{BJ}:\frac{AI}{AJ}\right) \qquad (3)$$

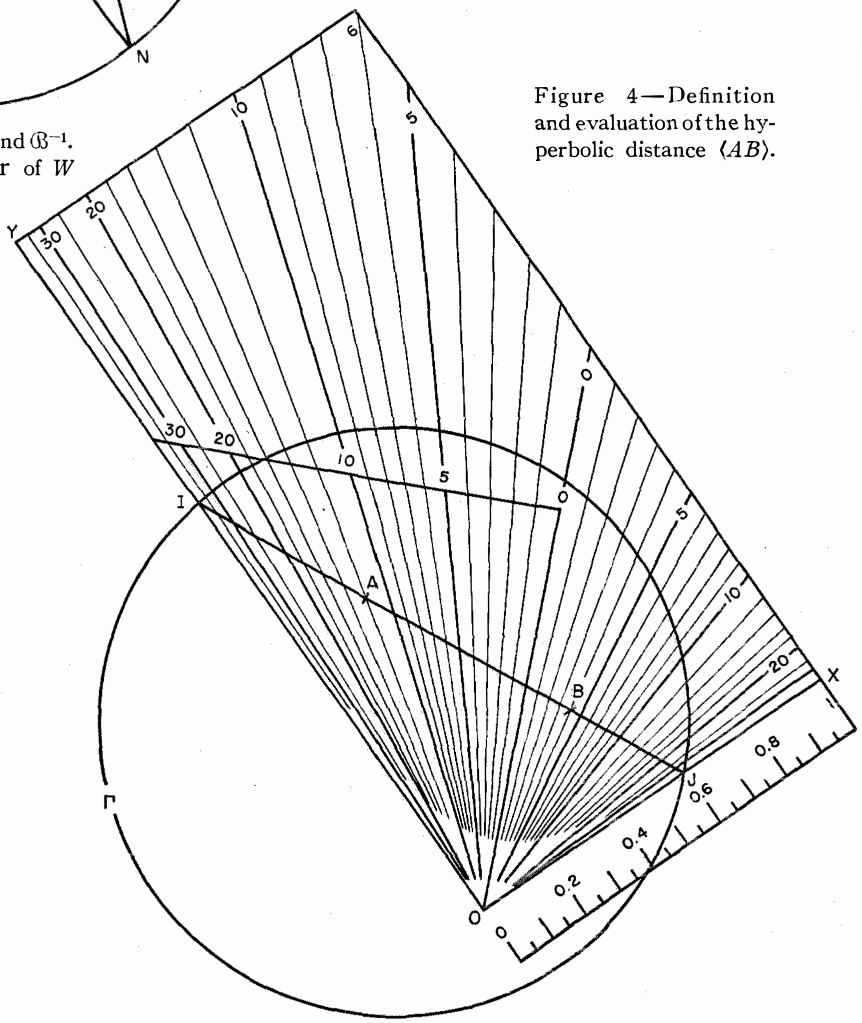

Figure 4—Definition and evaluation of the hyperbolic distance $\langle AB \rangle$.

will be denoted by $\langle AB\rangle$ and called the hyperbolic distance between A and B. It will usually be expressed in decibels as in (3), but can be converted to nepers by substituting $\frac{1}{2}\log_e$ for $10\log_{10}$.

The quantity (3) deserves the name of "distance" because it satisfies the triangular inequality (which shows that straight lines are geodesics for this particular measurement system) and because it is additive; that is, when three points A, B, C are on a straight line in this order:

$$\langle AB\rangle + \langle BC\rangle = \langle AC\rangle. \qquad (4)$$

The hyperbolic distance between the point $\bar{W}$ and the center of the chart is

$$\langle O\bar{W}\rangle = 10\log\frac{1+\bar{r}}{1-\bar{r}} = 20\log\frac{1+r}{1-r}, \qquad (5)$$

and can be interpreted as the voltage standing-wave ratio expressed in decibels.

The expression (3) for the hyperbolic distance does not have to be used in evaluating $\langle AB\rangle$. A scale formed of diverging lines can be traced once for all on a transparent base forming a hyperbolic protractor that is used as follows. The

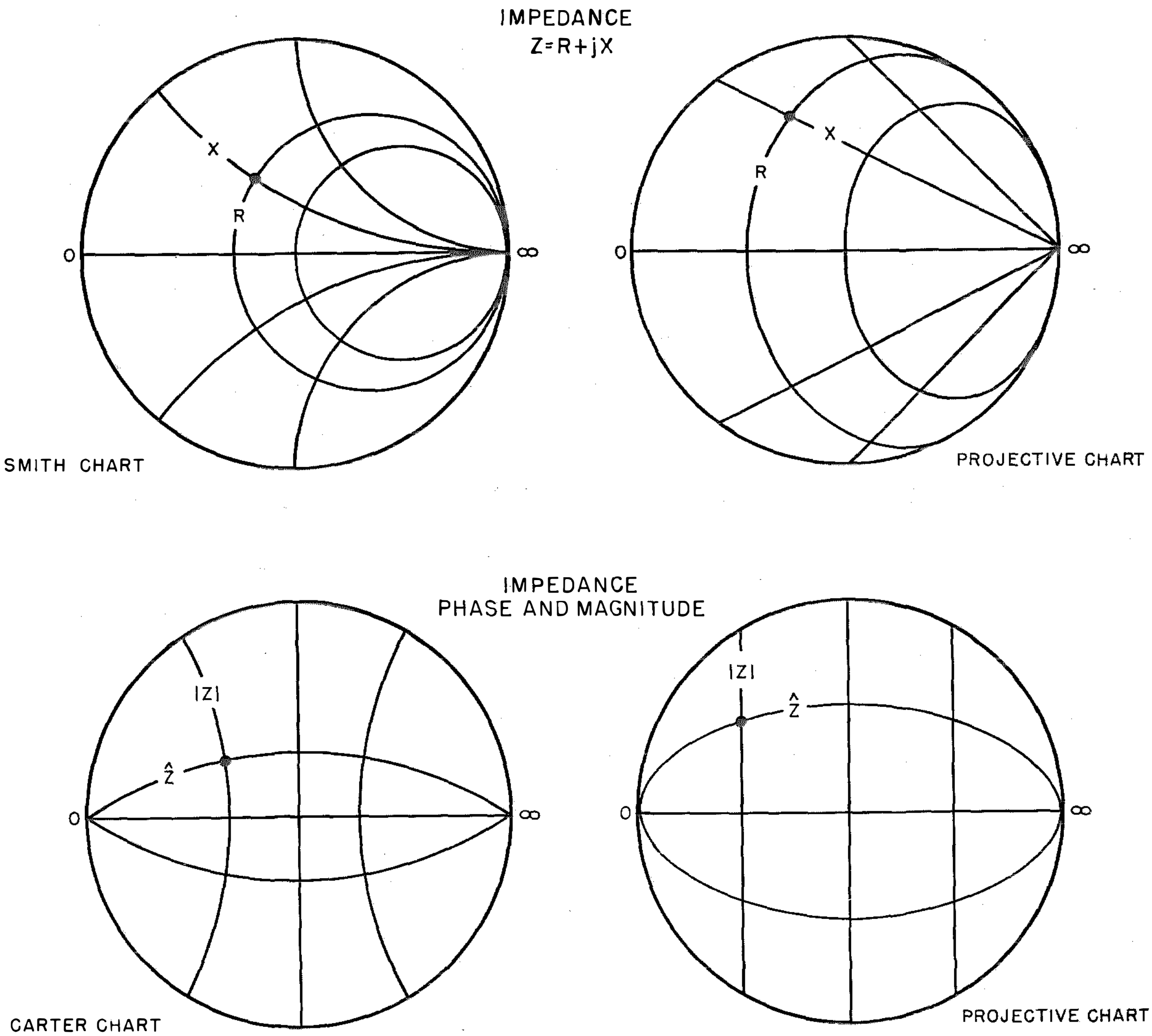

Figure 3—Loci on the projective chart and on the Smith and Carter charts of constant resistance R, reactance X, impedance magnitude $|Z|$, and impedance phase $\hat{Z}$.

protractor is placed on the chart so that the sides OX, OY of the right angle go through points I and J (Figure 4). (This can be done in many ways but does not affect the result.) The numbers read on the radial lines through A and B, respectively, are added if A and B are on opposite sides of the radial line marked O, subtracted otherwise. This result divided by 2 is the distance $\langle AB\rangle$. On Figure 4, for instance, $\langle AB\rangle$ equals $(12+4)/2$ or 8 decibels.

The special type of angle that goes with the hyperbolic metric will be called elliptic. The elliptic angle between the lines $\bar{W}E$ and $\bar{W}F$ is noted by $\langle\bar{W}E,\bar{W}F\rangle$ and can be obtained (Figure 5) by the following construction. Find the point W (if this has not been done), then draw WE and WF to their intersections E' and F' with Γ. The elliptic angle is equal to the ordinary angle (OE', OF'). A special elliptic protractor could also be designed to perform this evaluation directly.

Corresponding notions of distance and angle could be introduced directly on the Smith chart. The geodesics are circles orthogonal to Γ, the angle between two of them is represented by the true angle between their tangents at a point of intersection, and the distance $[AB]$ between two points A and B is most conveniently defined and evaluated by saying that it should be equal to $\langle\bar{A}\bar{B}\rangle$, where $\bar{A}$ and $\bar{B}$ are the images of A and B by the transformation $\mathfrak{B}$.

3. *Representation of Linear Transformers*

A transformation that occurs very often because it expresses the effect of a linear transformer on impedance, reflectance, or polarization ratio is

$$w' = \frac{aw+b}{cw+d}, \tag{6}$$

where a,b,c,d are complex numbers and w is the quantity that is transformed into w'.

This so-called bilinear transformation is represented on the Smith chart by a circular transformation, i.e. one that transforms circles into circles and is conformal (preserves angles). It follows that hyperbolic distances are also preserved in the following sense. If A,B are transformed into A',B' while Γ becomes Γ', the distance $[AB]$ defined above is equal to the distance $[A'B']$ measured as if Γ' were the unit circle:

$$[AB]_\Gamma = [A'B']_{\Gamma'}, \tag{7}$$

the subscript indicating with respect to what circle the distance is measured.

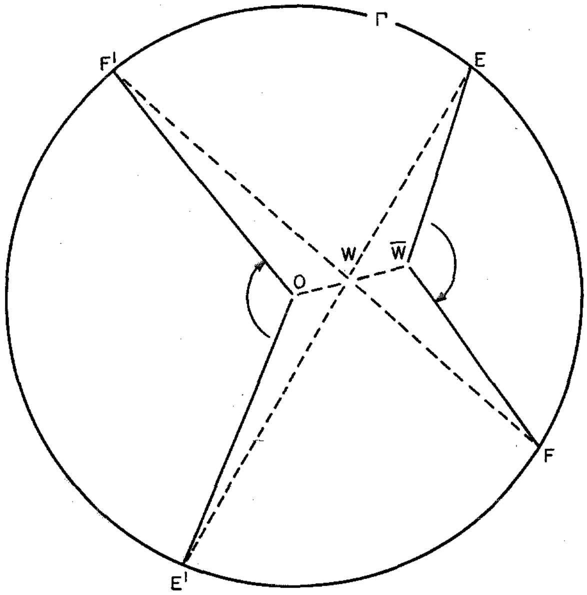

Figure 5—Evaluation of the elliptic angle $\langle\bar{W}E, \bar{W}F\rangle$.

The special transformations (6) that preserve the unit circle (lossless transformations of reflectance for instance) are represented on the projective chart by projective transformations. They transform straight lines into straight lines and as a consequence also leave the hyperbolic distances and elliptic angles invariant. The first applications are based on this property.

4. *Change of Reference Level— Ideal Transformer*

When impedances are plotted on the Smith chart to convert them into reflectances, they must first be divided by the characteristic impedance of the transmission line to which they will be connected. A change in this characteristic-impedance level usually means replotting after a computation (renormalization).

On the projective chart this is unnecessary. If the new characteristic impedance is represented by O' instead of the center O (Figure 6), the new voltage standing-wave ratio in decibels is simply the hyperbolic distance $\langle O'\overline{W}\rangle$, while the new phase angle is the elliptic angle between $O'\overline{W}$ and the positive direction $O'P$.

The effect of a change of reference level on reflectances is the same as that of an ideal transformer. One can also visualize the transformer as producing a change of the reflectance $\overline{W}$ into $\overline{W}'$ and the point $\overline{W}'$ can be constructed (Figure 6) by making

$$\left.\begin{aligned} (OP,O\overline{W}') &= \langle O'P,O'\overline{W}\rangle, \\ \langle O\overline{W}'\rangle &= \langle O'\overline{W}\rangle. \end{aligned}\right\} \quad (8)$$

5. *Reflection Coefficient of a Stratified Medium*

The ease in changing reference levels on the projective chart leads to a simple construction for the input reflectance of a lossless stratified medium.

Take the succession of media $1, 2, \ldots, i, \ldots, n$ each with a characteristic impedance Z_i, a thickness d_i, and a wave number k_i. From this, we deduce a succession of hyperbolic distances

$$u_i = 20 \log_{10}(Z_{i+1}/Z_i) \quad (9)$$

and a succession of angles

$$\alpha_i = k_i d_i. \quad (10)$$

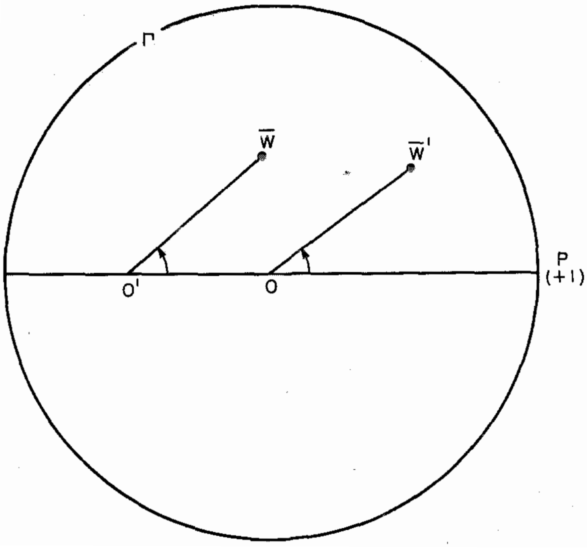

Figure 6—Change of reference level—ideal transformer.

Then, we construct a polygon as follows. We rotate OP clockwise about O through an angle $2\alpha_1$ obtaining OP_1; we find on OP_1 the point O_1 such that $\langle OO_1\rangle = u_1$; next, we rotate O_1P_1 about O_1 clockwise through an elliptic angle $2\alpha_2$; we find on O_1P_2 the point O_2 such that $\langle O_1O_2\rangle = u_2$, and so on. The end point is O_{n-1}, and the last rotation gives $O_{n-1}P_n$. The construction is illustrated in Figure 7.

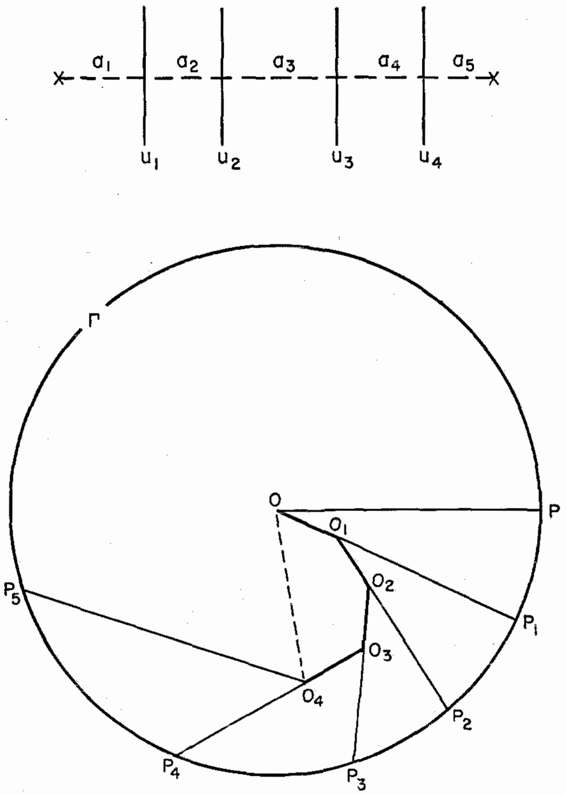

Figure 7—Transformation of reflectance through a stratified medium.

The transformation of reflectance through the stratified medium is represented by the projective transformation that leaves the circle invariant and carries OP onto $O_{n-1}P_n$. All characteristics of this transformation: scattering coefficients, image parameters, and iterative parameters can be read immediately on this picture. For instance, the input reflectance when the last medium is matched is represented by the end point O_{n-1}.

6. *Measurement of Reflectance Through a Lossless Junction*

The transformation of reflectance from one side of the junction to the other is represented on the projective chart by a transformation

$$T: W \rightarrow W', \tag{11}$$

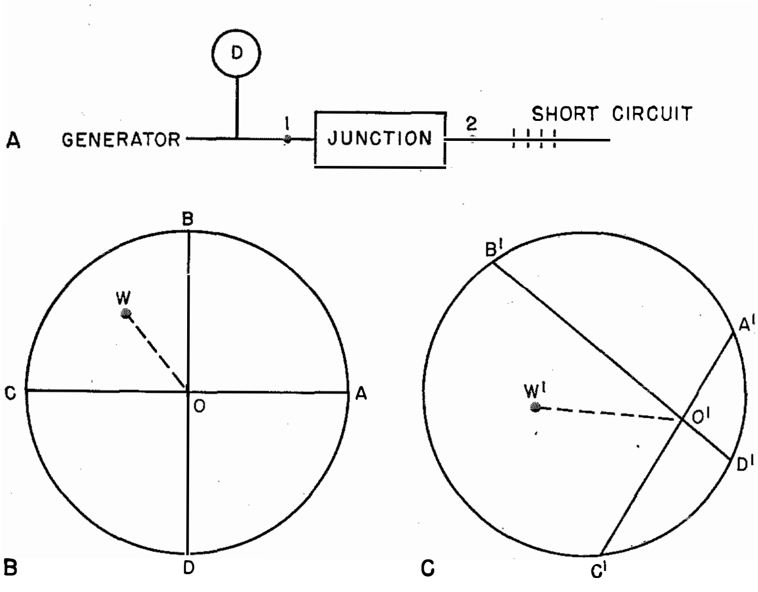

Figure 8—Reflectance measurement through a lossless junction.

which is projective and leaves Γ invariant, and therefore also the hyperbolic distances and elliptic angles.

Referring to Figure 8, we measure on the input side *1* of the junction the reflectances that correspond to four positions of a short circuit taken every eighth of a guide wavelength so as to produce at the reference plane *2* the reflectances A,B,C,D shown in Figure 8B. Measurement at the input gives the images A',B',C',D'. Since the junction is lossless, these also lie on the circle Γ, but are shown on Figure 8C for clarity.

Since the transformation T is projective, the image of O is the intersection O' of $A'C'$ and $B'D'$. This completes the calibration of the junction.

To determine an unknown load W placed in line *2*, its image is measured on side *1* of the junction and represented by W' on the projective chart, Figure 8C. Because of the invariance of the hyperbolic distances, $\langle O'W' \rangle = \langle OW \rangle$ is the corrected voltage standing-wave ratio in decibels and can be evaluated immediately with the protractor, while $\langle O'A', O'W' \rangle = (OA, OW)$ is the corresponding corrected phase angle.

7. *Reflectance Measurement Through a Lossy Junction*

The principle is the same as for the lossless junction: calibration of the junction by measuring the input reflectance for four equispaced positions of a short circuit in the output line; then measurement of the unknown load.

The difference is in the correction procedure (Figure 9), in that it is now simpler to plot the points A',B',C',D' on a Smith chart where they fall on a circle Γ'. The point O' is again the intersection of $A'C'$ and $B'D'$, but instead of using directly the point W', image of the unknown load, we convert it to $\overline{W}$ by applying to W' the transformation $\mathfrak{B}$ as if Γ' were the unit circle.

The corrected voltage standing-wave ratio and phase angle are $\langle O'\overline{W} \rangle$ and $\langle O'A', O'\overline{W} \rangle$, both measured as if Γ' were the unit circle.

These last two applications give the solution to a problem that often occurs in practice. For instance, when experimenting with a new micro-

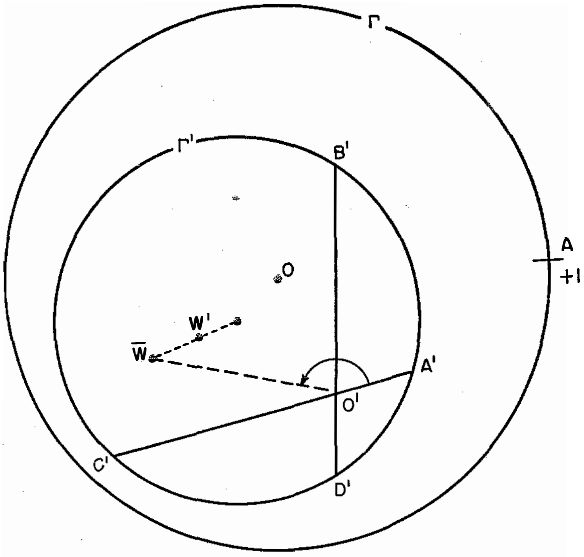

Figure 9—Reflectance measurement through a lossy junction.

wave guide, a standard slotted line can be connected to it by means of some junction that, in general, is not matched on either side, is not symmetrical, and is often lossy. Improving the junction could be a major problem, while correcting for its effect by the usual method would involve finding an equivalent network; this is rather complicated when losses occur. The present method is simple and almost as direct for lossy junctions as for lossless ones.

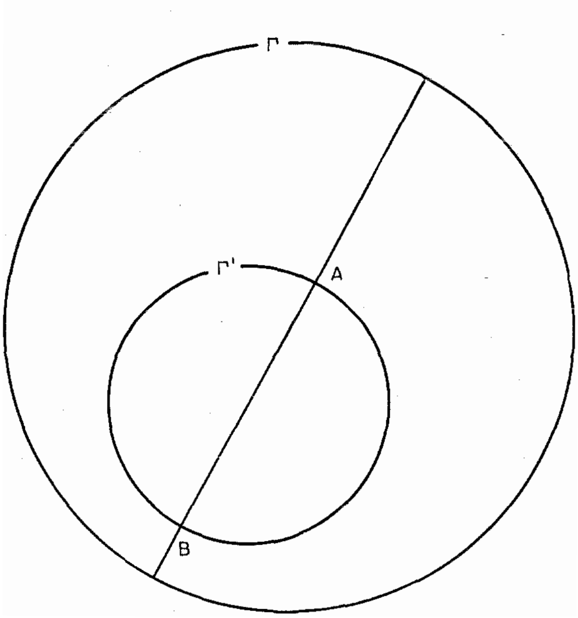

Figure 10—Evaluation of the essential insertion loss.

8. *Essential Insertion Loss of a Junction*

This concept, considered by D. R. Crosby, corresponds to the following problem. Given a lossy junction, find the minimum insertion loss that could be obtained by placing it between two suitable corrective lossless junctions.

Using the image circle Γ' obtained in the preceding problem, we can measure its hyperbolic radius $x=[AB]/2$ (Figure 10). Then the minimum insertion loss y is a simple function of x that can be tabulated

$$y=10\log\frac{1+10^{-x/20}}{1-10^{-x/20}}. \qquad (12)$$

9. *Problems on Power*

Problems that lead to simple graphical solutions on the projective chart are those where the representation of hermitian forms[3] can be used.

Hermitian forms include such physical quantities as power flow in a transmission line or a polarized plane wave, energy density, voltage or current squared, power absorbed by a load, etc. Each is represented, except for a factor, by distances between points on a sphere and planes. By the projection of the sphere on its equatorial plane, which leads to the projective chart, some of these quantities become distances to straight lines.

For instance, the ratio of the powers picked up by two probes in a slotted line varies as the ratio of distances from the point $\overline{W}$ representing the reflectance to the tangents D_1D_2 (Figure 11) to the unit circle Γ at the points that correspond to the probe positions.

Determination of W, or reflectance, by three probe measurements is thus reduced to the intersection of two straight lines.

10. *Problems on Polarization*

Most polarization problems can be deduced from similar problems in transmission lines, the polarization ratio taking the place of the reflectance.

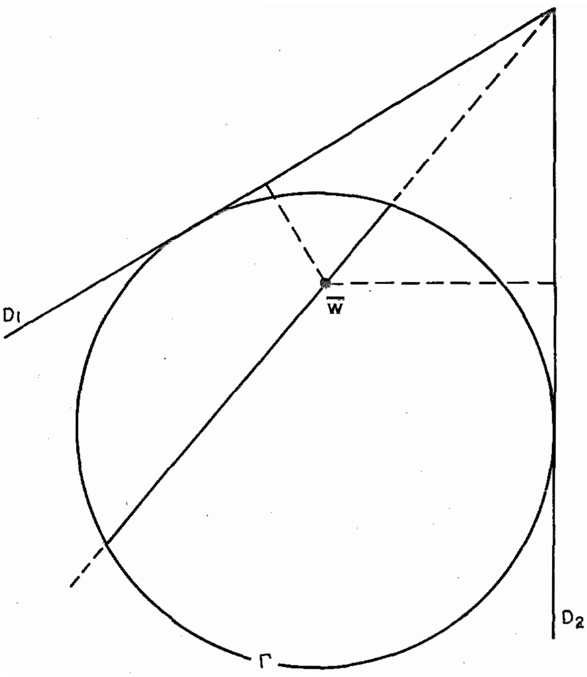

Figure 11—Locus of W for a given ratio of powers picked up by two probes in a slotted line.

Measurement of polarization by comparing the power picked up by several antennas of known polarization is like the determination of reflectance from a few pickup probes. It reduces to the intersection of a number of planes, and in some cases to the intersection of straight lines on the projective chart.

Determination of the polarization of an antenna in the presence of ground or of some other linear transformer of polarization is similar to the measurement of reflectance through a junction and can be solved as above.

Some problems of interference between rays coming from different directions also fall essentially in the same category.

11. Acknowledgment

The hyperbolic protractor was developed under contract with the Air Materiel Command, Wright-Patterson Air Force Base; Dayton, Ohio.

United States Patents Issued to International Telephone and Telegraph System, January–April, 1953

FROM January 1st to April 30th 1953, 47 patents were issued by the United States Patent Office to the International Telephone and Telegraph System companies. These patents are listed below, followed by summaries of several that may be of more than usual interest.

International Telephone and Telegraph Corporation now owns or has licensing rights under some 3000 United States patents, of which approximately 10 percent are in the field of telephony including automatic telephone switching equipment and subscriber apparatus, 50 percent in the field of radio and television including radio navigation, pulse, and other telecommunication systems, the remaining 40 percent being in various fields such as selenium rectifiers, vacuum tubes, and other components, cables, and miscellaneous devices.

R. P. Arthur, see E. L. Earle.

R. S. Bailey, "High-Selectivity Receiver," 2,629,818.

L. C. Baker, see G. H. Hough.

A. H. W. Beck, A. B. Cutting, and A. D. Brisbane, "Electric Rectifier of the Contact Type," 2,631,191.

J. I. Bellamy, "Control and Marking Circuits for Adding-Type Impulse Counters," 2,634,403.

A. D. Brisbane, see A. H. W. Beck.

L. R. Brown, "Conversion from Direct Current to Double Voice-Frequency Impulsing," 2,626,996.

L. A. B. Cabes, "Signal Receiver for Discriminating Signals," 2,633,557.

E. O. Campbell, see H. G. Duhamel.

A. B. Cutting, see A. H. W. Beck.

C. T. Daly, "Method of Calibrating Electric Oscillation Generators," 2,629,829.

G. Deakin, "Alternating Current—Direct Current Pulsing Circuits for Register Senders," 2,636,946.

G. Deakin, "Homing Arrangement for Selector Switches," 2,624,807.

E. M. Deloraine, "Traffic-Control System," Reissue, 23,643.

E. M. Deloraine, "Fixed-Route Vehicular-Location and Communicating System," 2,636,113.

E. M. Deloraine, S. van Mierlo, and B. Derjavitch, "Communication System Utilizing Constant-Amplitude Pulses of Opposite Polarities," 2,629,857.

G. P. de Mengel, "Electric-Wave Generator," 2,627,032.

M. den Hertog, "Device for Indicating Electric Potentials," 2,637,018.

M. den Hertog, "Telephone Trunk Supervision System," 2,636,945.

L. J. Denny, H. G. Duhamel, and R. W. Engsberg, "Telephone Switching System with Selection of Local or Trunk Lines," 2,633,497.

B. Derjavitch, see E. M. Deloraine.

H. G. Duhamel, E. O. Campbell, and R. A. Reed, "Party-Line Telephone System," 2,633,496.

H. G. Duhamel, see L. J. Denny.

E. L. Earle and R. P. Arthur, "Crossbar System Switchboard Construction," 2,627,554.

R. W. Engsberg, see L. J. Denny.

S. F. Essig, "Method of Mounting Vacuum-Tube Electrode," 2,635,391.

R. A. Felsenheld, see A. G. Kandoian.

C. H. Foulkes, "Grid Electrode for Electron-Discharge Devices," 2,624,100.

H. Gallay, "PTM Modulator and Demodulator System," 2,629,856.

W. F. Gould, see E. P. G. Wright.

T. F. S. Hargreaves, see E. P. G. Wright.

P. Hemminger, "Counting and Registering Relay Circuit," 2,624,785.

R. G. Hodgson, see F. C. Wright.

J. D. Holland, see V. J. Terry.

J. F. Houdek, Jr., "Subassembly for Telephone Sets," 2,635,130.

G. H. Hough and L. C. Baker, "Electron-Discharge Glow-Control Electrode," 2,627,-045.

G. H. Hough and T. M. Jackson, "Electric-Discharge Device," 2,631,261.

G. H. Hough and D. S. Ridler, "Electric-Discharge Tube," 2,627,054.

T. M. Jackson, see G. H. Hough.

I. R. J. James, see V. J. Terry.

A. G. Kandoian and R. A. Felsenheld, "High-Altitude Antenna," 2,627,026.

M. A. Kreitchman, "Washing Machine Provided with Resilient Collapsible Inlet," 2,625,031.

G. X. Lens, "Switch Controlled by Bars Actuated in Various Combinations," 2,636,398.

S. E. Mayer, "Production of Metal Oxalates," 2,636,892.

S. Milazzo, see W. Sichak.

A. J. Mullarky, "Gas-Discharge-Tube Counting Arrangement," 2,626,751.

B. Parzen, "Receiver Tuning Device," 2,629,864.

J. Perzel, "Low-Capacitance Cable and Method of Making Same," 2,636,923.

G. J. Rabuteau, "Diversity System," 2,629,816.

R. A. Reed, see H. G. Duhamel.

A. H. Reeves, "Gaseous-Discharge Tube," 2,636,681.

A. H. Reeves, "Gaseous-Discharge Device," 2,624,866.

A. H. Reeves, "Telecommunication System," 2,631,194.

D. S. Ridler, see G. H. Hough.

W. J. Reynolds, see E. P. G. Wright.

A. H. Roche, see F. C. Wright.

E. P. Rudkin, "Radio Receiver Employing Band-Pass-Coupling Circuit Arrangements," 2,624,838.

W. Sichak, "Helically Slotted Cylindrical Antenna," 2,633,532.

W. Sichak and S. Milazzo, "Antenna," 2,631,237.

L. D. Smullin, see G. C. Dewey.

J. V. Terry, J. D. Holland, and I. R. J. James, "Telegraph Receiver," 2,629,776.

S. van Mierlo, see E. M. Deloraine.

H. M. Veaux, "Automatic Switching System for Electrical Telecommunication," 2,626,987.

E. P. G. Wright, "Telecommunication Switching System," 2,633,499.

E. P. G. Wright, "Cordless Switchboard Telecommunication Exchange," 2,633,500.

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E. P. G. Wright, W. F. Gould, T. F. S. Hargreaves, and W. J. Reynolds, "Carrier Telephone System and Supervisory Signaling Arrangement therefor," 2,624,806.

F. C. Wright, R. G. Hodgson, and A. H. Roche, "Control of Carrier Transmission Systems by Pilot Frequencies," 2,626,993.

High-Altitude Antenna

A. G. Kandoian and R. A. Felsenheld

2,627,026 — January 27, 1953.

An ultra-high-frequency antenna with a dielectric housing that forms a pressurized hermetically sealed air chamber about the radiator. This permits high-altitude operation of the antenna without dielectric breakdown that could readily occur due to ionization effects in the rarified atmosphere. The antenna is preferably fed from a conventional coaxial cable provided with a pressurized connector.

Communication System Utilizing Constant-Amplitude Pulses of Opposite Polarities[1]

E. M. Deloraine, S. Van Mierlo, and B. Derjavitch.

2,629,857 — February 24, 1953.

A system for transmitting signals representing a given information wave utilizing pulses. The wave to be transmitted is sampled at fixed intervals and the amplitude of this wave is compared with the preceding amplitude level. If a certain increment of increase has occurred during the interval, pulses of one character are transmitted; whereas if the wave is decreased a comparable amount during this interval pulses of a different character are transmitted. The two types of pulses may, for example, be positive or negative, respectively. The comparison is obtained by storing a given energy level representative of the preceding signal wave amplitude and comparing this stored energy with the succeeding signal amplitude level.

[1] See "Note on Delta Modulation," *Electrical Communication,* volume 30, pages 71–74; March 1953.

Gaseous-Discharge Tube[2]

A. H. Reeves

2,636,681 — April 28, 1953.

A cold-cathode sequential discharge tube is provided with a series of three or more discharge gaps. These gaps are so arranged that upon the discharge being initiated at one of the gaps, ionization from this discharge lowers the striking potential of its neighboring gap so that the gaps may be fired in sequence along the array. The gaps are formed by sets of wires extending from different sides of the tube and in relatively adjacent alignment. Thus the tube may be substantially circular in shape and the array of gaps may be around the circle. Although the tube may be used in any desired mode of operation, this sequential-discharge tube is particularly adapted for use in connection with pulse-operated systems.

Electric-Discharge Device

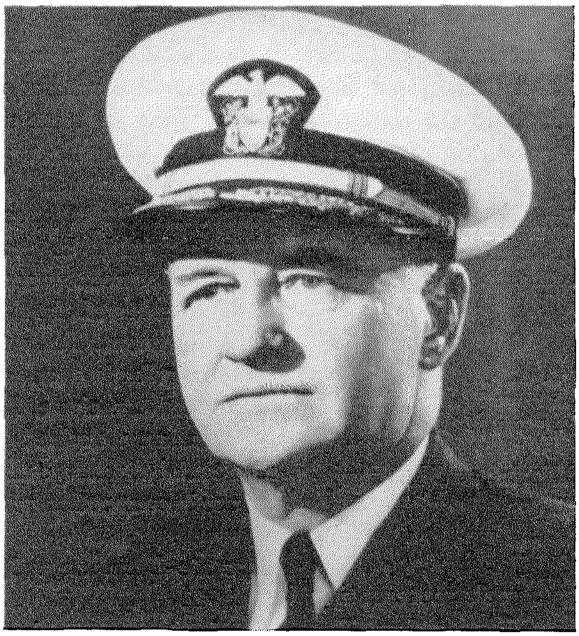
G. H. Hough and T. M. Jackson

2,631,261 — March 10, 1953.

A cold-cathode gas tube provided with one pair of electrodes forming a principal gap and a second pair of electrodes forming a priming gap. A third gap is provided, also forming a trigger gap by reason of one electrode operating in conjunction with the electrodes of one of the previously named gaps. The priming gap is isolated from the main gap but a free path is provided between the priming gap and the trigger gap. By use of the priming gap, the normal statistical delay of firing time when a discharge voltage is applied to the trigger gap is eliminated, but the striking voltage of the main gap is unaffected.

[2] See G. H. Hough and D. S. Ridler, "Multicathode Gas-Tube Counters," *Electrical Communication,* volume 27, pages 214–226; September, 1950.

In Memoriam



CARL F. HOLDEN

A BRILLIANT naval officer who had received many honors; a forceful personality with a gentle, likeable, and friendly nature; the influence and genial presence of Admiral Holden will be sorely missed by his many friends and associates.

Carl F. Holden was born in Bangor, Maine. He graduated from the United States Naval Academy in 1917 and received a master's degree in electrical engineering from Harvard University in 1924.

During the first world war, he saw active duty as an officer aboard destroyers operating from bases in Ireland and France. He was executive officer on the *USS Pennsylvania* when we entered the second world war and after serving as fleet communications officer, he became director of naval communications in 1942.

In 1943, he was placed in command of the newly commissioned *USS New Jersey* and participated in the Marshall Islands campaign, the first two raids on Truk, and in the assault on the Palau Islands. The *New Jersey* played a prominent role in the Hollandia and Marianas campaigns and in the recapture of the Philippines. Later, Admiral Holden commanded a cruiser division that staged a daring midnight raid at the entrance to Tokyo Bay and also participated in the bombardment of the Japanese mainland.

In 1951, he was retired with the rank of Vice Admiral.

In 1952, Admiral Holden was elected president and a member of the board of directors of Federal Telecommunications Laboratories, Incorporated, a research associate of the International Telephone and Telegraph Corporation. A remarkably able and efficient communications officer and executive, Admiral Holden, despite his relatively brief period of service in the International System, contributed greatly to its operations and growth.

Admiral Holden died at the naval hospital in Saint Albans, New York, on May 18th, 1953, in his 58th year.

Contributors to This Issue

Eric Baguley

Eric Baguley was born in Fairfield, Lancashire, England in 1905 and graduated with honours in electrical engineering from Manchester University in 1924.

On graduation, he joined the Western Electric Company in London and transferred the following year to the telephone-cable engineering department. From 1927 to 1932, he was engaged in long-distance telephone-cable studies at the ITT Laboratories in Hendon. He then joined the telephone-line division of Standard Telephones and Cables, Limited, in London, where he has since been concerned with developments of all types of telephone cables. He is now in charge of the telephone-cable development laboratory at North Woolwich. In this issue, he has presented the history of the technical development of coaxial cable in England.

Mr. Baguley is a member of the Institution of Electrical Engineers.

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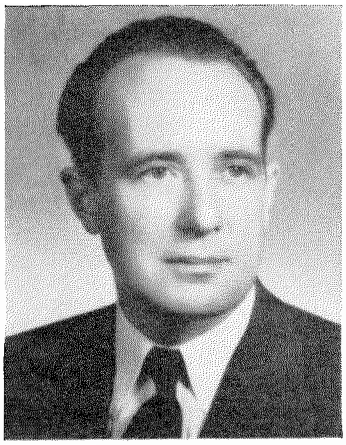

Georges A. Deschamps

Georges A. Deschamps was born in Vendôme, France, on October 18, 1911. He was graduated from the Ecole Normale Supérieure of Paris in 1934, and received the following degrees from the Sorbonne: license in mathematics and physics, diplome d'étude supérieure, and agrégation in mathematics. After two years of research in pure mathematics, one in Paris and one at Princeton University, he joined the Lycée Français de New York as a professor of mathematics and physics. At that time, he also did some work on relativity and the theory of elementary particles.

The outcome of some of Mr. Deschamps' work in mathematics is the hyperbolic protractor used in transmission-line problems, as reported in this issue.

Mr. Deschamps served in the French army during the war, and in 1947, joined Federal Telecommunication Laboratories where he is presently a senior project engineer in the direction-finder and receiver division. He is a member of the American Physical Society.

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Marc Lauvergeon

Marc Lauvergeon was born in Bordeaux, France, on November 24, 1923. He graduated as an engineer from the Ecole Nationale d'Arts et Métiers of Angers in 1943, and as an electrical engineer from the Ecole Supérieure d'Electricité, Paris, in 1946.

Toward the end of 1946, he joined the Compagnie Générale de Constructions Téléphoniques and was assigned to remote-control development and installation. He reports in this issue some of the work done on electricity control systems for railway power networks.

Since 1950, Mr. Lauvergeon has been head of the remote-control and carrier-on-power-line division of the technical department of the company.

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William W. Macalpine was born in Scotland on September 2, 1900. In 1922, he received a B.S. degree in electrical engineering at Carnegie Institute of Technology. He received the M.A. in 1924 and Ph.D. in physics in 1930 from Columbia University, where for three years he was assistant in the

William W. Macalpine

Ernest Kempton Adams Precision Laboratory of Optics and Electricity.

Except for a few months with Wired Radio in 1931, he has been continuously associated with the International System since 1929. Dr. Macalpine served on the engineering staffs of International Communications Laboratories, Federal Telegraph Company, Federal Telephone and Radio Corporation, and, since 1947, in the radio and radar components division of Federal Telecommunication Laboratories. Much of his work has been on communication and marine radio receivers, marine radio direction finders, low-frequency radio range equipment, and applications of transmission-line theory.

Dr. Macalpine's paper in this issue reports some of his work on the characteristics of lines with high standing-wave ratios.

Dr. Macalpine is a Fellow of the American Association for the Advancement of Science, a Senior Member of the Institute of Radio Engineers, and a member of the American Institute of Electrical Engineers and Sigma Xi.

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Federal Telephone and Radio Company, Clifton, New Jersey

Kellogg Switchboard and Supply Company, Chicago, Illinois

Federal Electric Corporation, Clifton, New Jersey

Flora Cabinet Company, Inc., Flora, Indiana

International Standard Electric Corporation, New York, New York

International Standard Trading Corporation, New York, New York

IT&T Distributing Corporation, New York, New York

Telephone Sales and Service Corporation, New York, New York

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Compañía Standard Electric, S.A.C., Santiago, Chile

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Bell Telephone Manufacturing Company, Antwerp, Belgium

Standard Electric Aktieselskab, Copenhagen, Denmark

Compagnie Générale de Constructions Téléphoniques, Paris, France

Le Matériel Téléphonique, Paris, France

Les Téléimprimeurs, Paris, France

C. Lorenz, A.G., Stuttgart, Germany

Mix & Genest Aktiengesellschaft and Subsidiaries, Stuttgart, Germany

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Standard Telefon og Kabelfabrik A/S, Oslo, Norway

Standard Eléctrica, S.A.R.L., Lisbon, Portugal

Compañía Radio Aérea Marítima Española, Madrid, Spain

Standard Eléctrica, S.A., Madrid, Spain

Aktiebolaget Standard Radiofabrik, Stockholm, Sweden

Standard Telephone et Radio S.A., Zurich, Switzerland

Telephone Operating Companies

Companhia Telefônica Nacional, Rio de Janeiro, Brazil

Compañía de Teléfonos de Chile, Santiago, Chile

Cuban American Telephone and Telegraph Company, Havana, Cuba

Cuban Telephone Company, Havana, Cuba

Compañía Peruana de Teléfonos Limitada, Lima, Peru

Porto Rico Telephone Company, San Juan, Puerto Rico

Radiotelephone and Radiotelegraph Operating Companies

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Compañía Internacional de Radio Boliviana, La Paz, Bolivia

Companhia Radio Internacional do Brasil, Rio de Janeiro, Brazil

Compañía Internacional de Radio, S.A., Santiago, Chile

Radio Corporation of Cuba, Havana, Cuba

Radio Corporation of Porto Rico, San Juan, Puerto Rico

Cable and Radiotelegraph Operating Companies

(Controlled by American Cable & Radio Corporation, New York, New York)

The Commercial Cable Company, New York, New York[1]

Mackay Radio and Telegraph Company, New York, New York[2]

All America Cables and Radio, Inc., New York, New York[3]

Sociedad Anónima Radio Argentina, Buenos Aires, Argentina[4]

[1] Cable service. [2] International and marine radiotelegraph services.
[3] Cable and radiotelegraph services. [4] Radiotelegraph service.

Laboratories

Federal Telecommunication Laboratories, a division of International Telephone and Telegraph Corporation, Nutley, New Jersey

International Telecommunication Laboratories, Inc., New York, New York

Laboratoire Central de Télécommunications, Paris, France

Standard Telecommunication Laboratories, Limited, London, England

Associate Licensee, Manufacturing, and Sales Companies in Japan

Nippon Electric Company, Limited, Tokyo

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