ELECTRICAL COMMUNICATION

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

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MANUFACTURE OF MICROSTRIP

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DISTORTION OF A FREQUENCY-MODULATED SIGNAL

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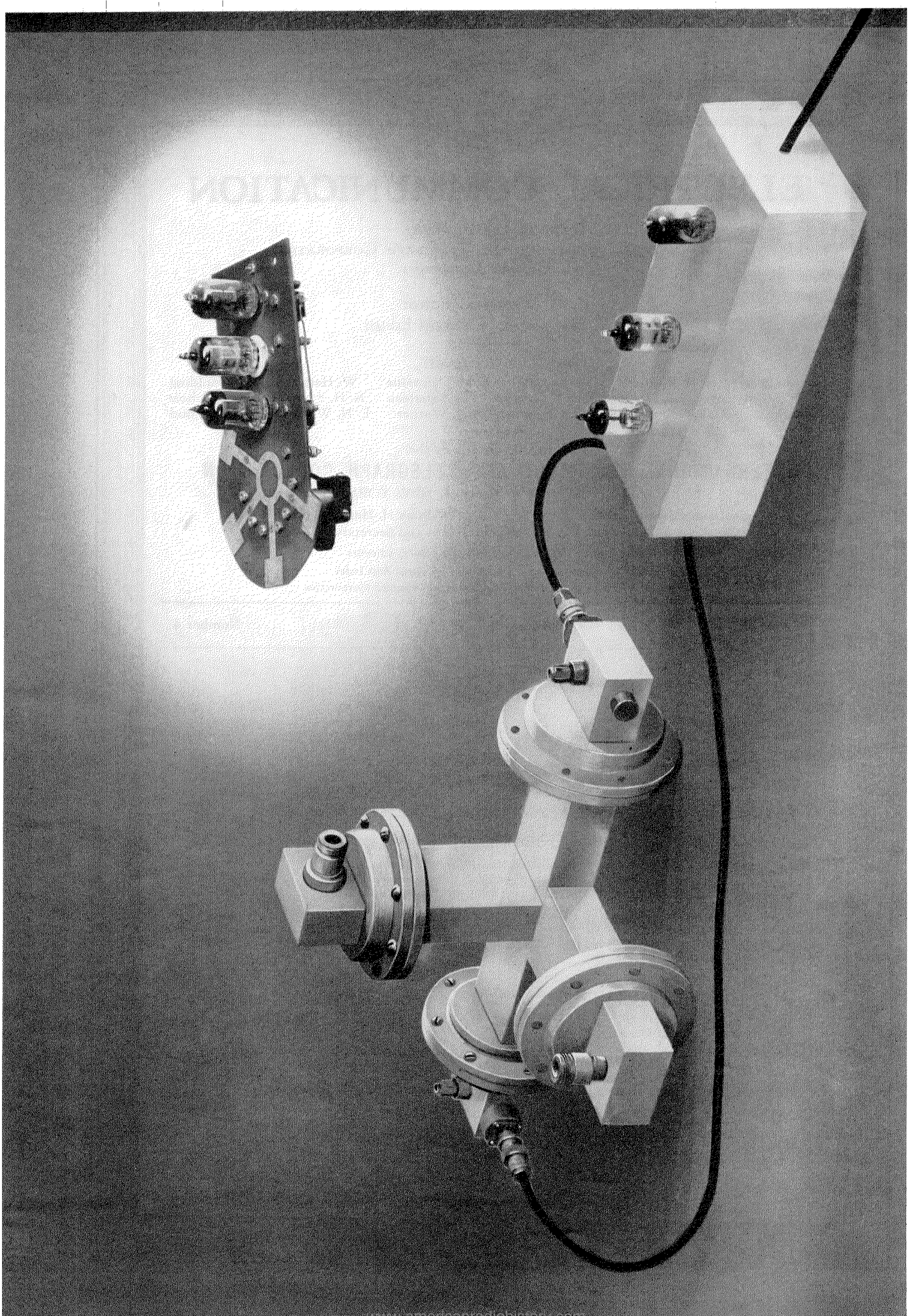
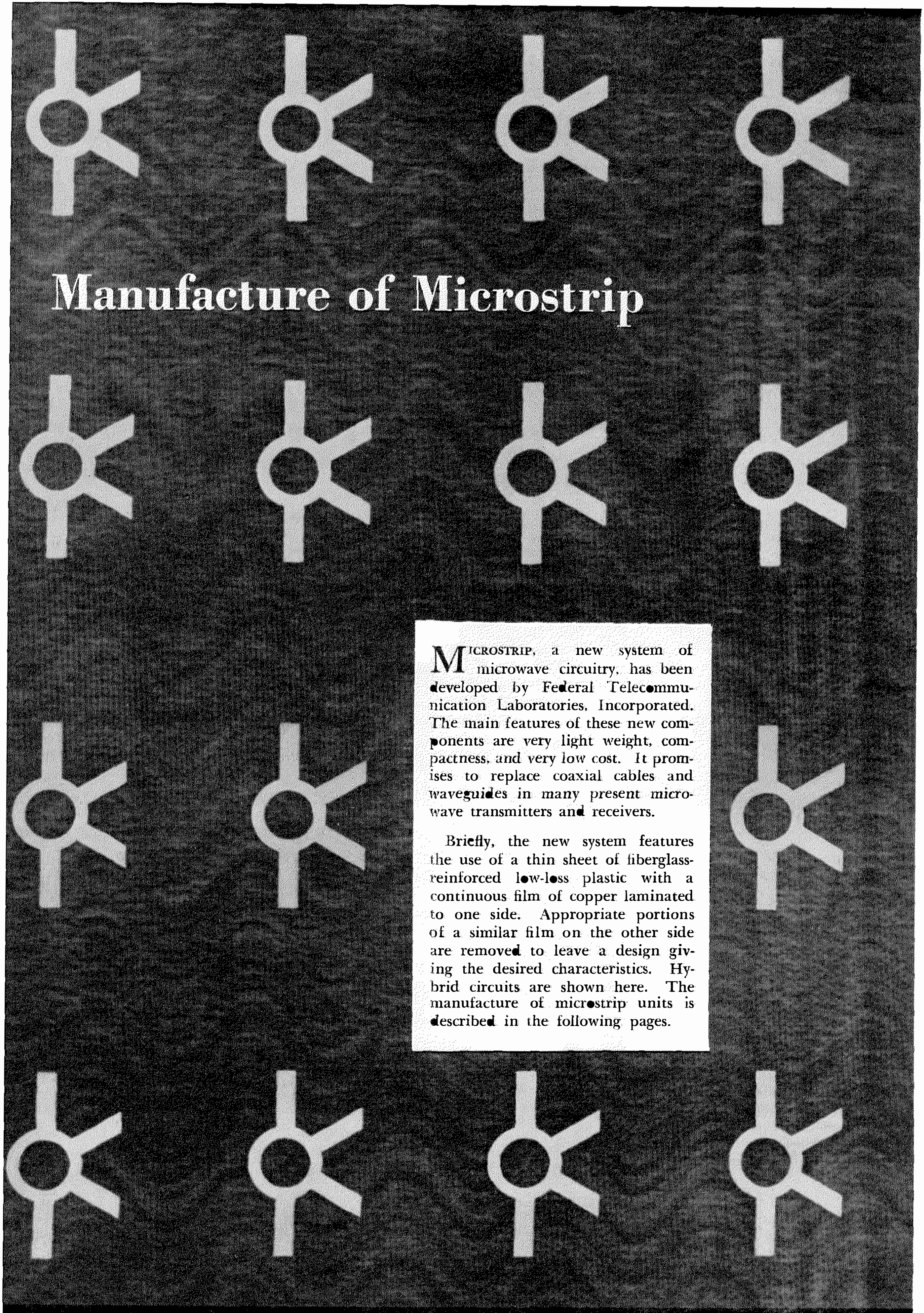
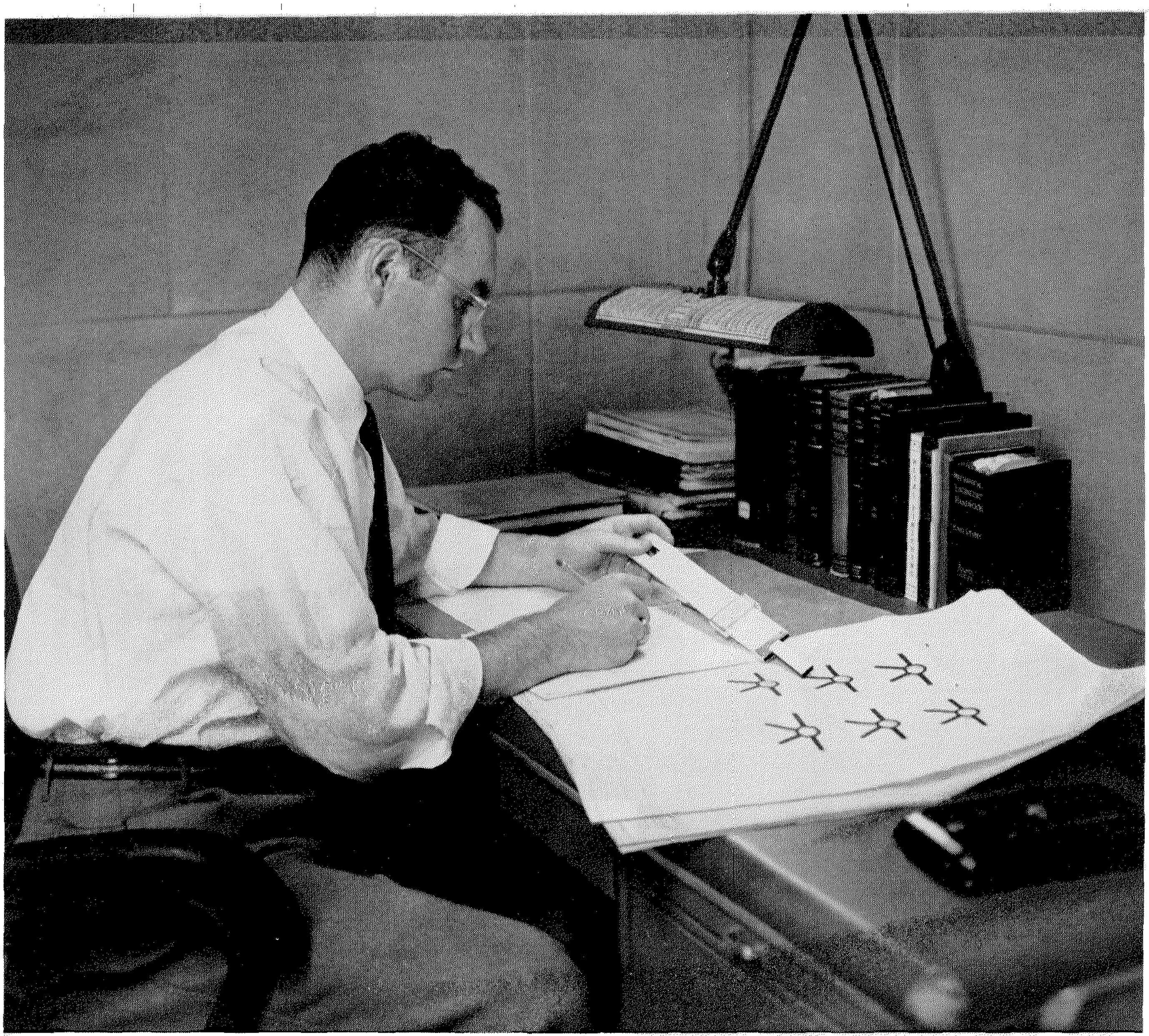


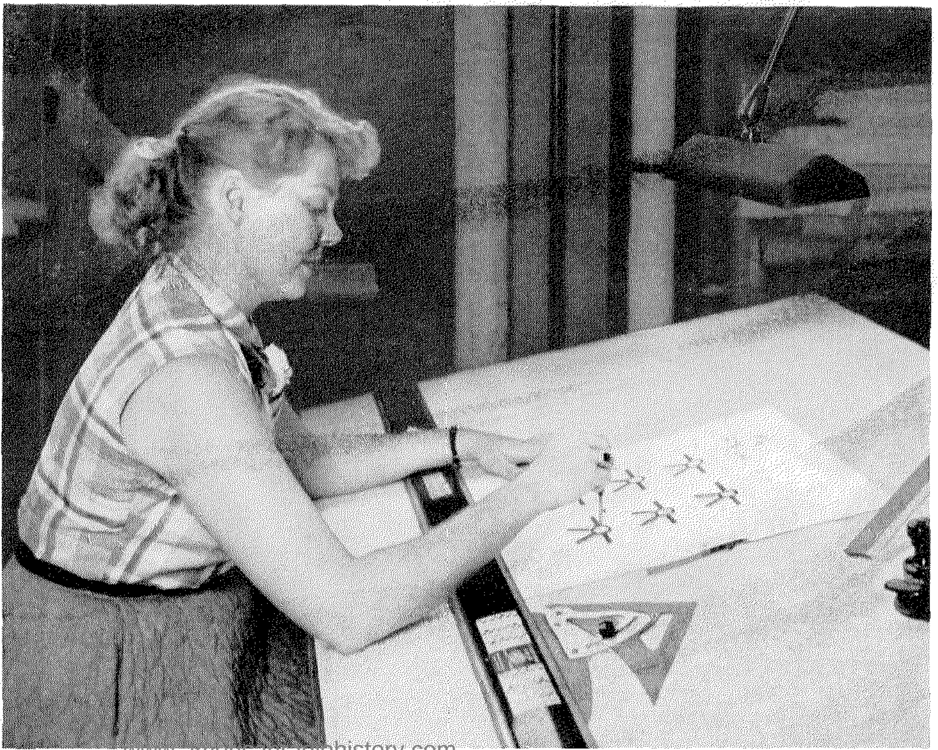
Manufacture of Microstrip



Microstrip, a new system of microwave circuitry, has been developed by Federal Telecommunication Laboratories, Incorporated. The main features of these new components are very light weight, compactness, and very low cost. It promises to replace coaxial cables and waveguides in many present microwave transmitters and receivers.

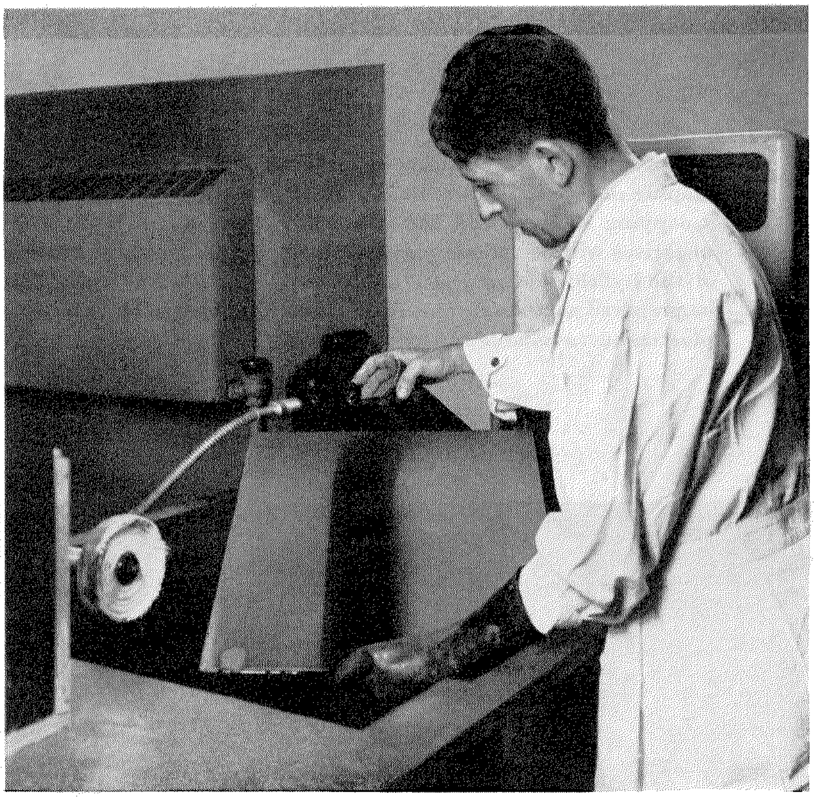
Briefly, the new system features the use of a thin sheet of fiberglass-reinforced low-loss plastic with a continuous film of copper laminated to one side. Appropriate portions of a similar film on the other side are removed to leave a design giving the desired characteristics. Hybrid circuits are shown here. The manufacture of microstrip units is described in the following pages.





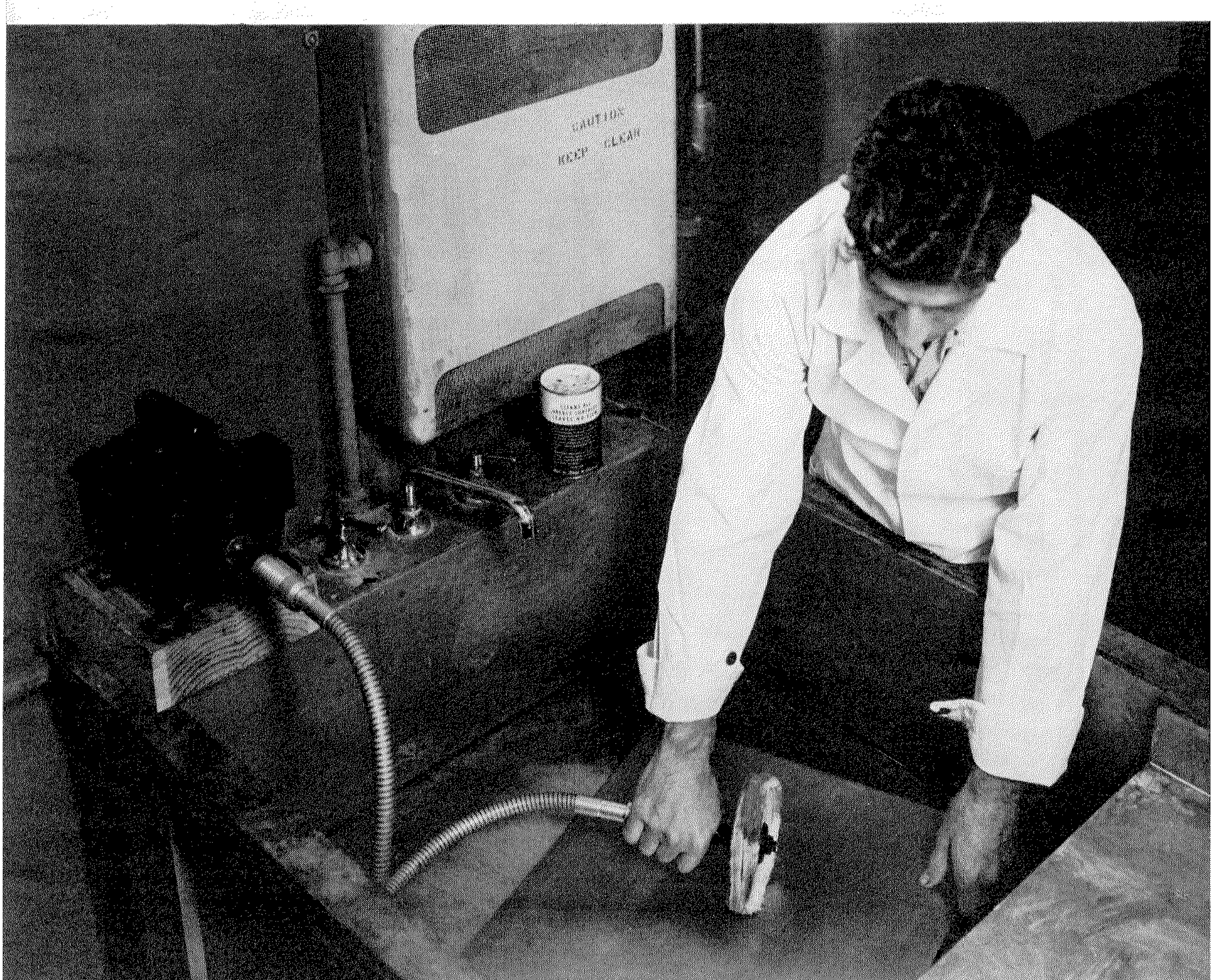
1. One of the simplest methods of producing the design on the copper film involves the use of the photoengraving process. Above, the engineer is making an exact-size design of a hybrid circuit. It is then drawn in ink on tracing cloth (right) to produce a master. The dielectric constant of the plastic, its thickness, and the dimensions of the circle and arms of the hybrid must be carefully chosen for optimum characteristics.

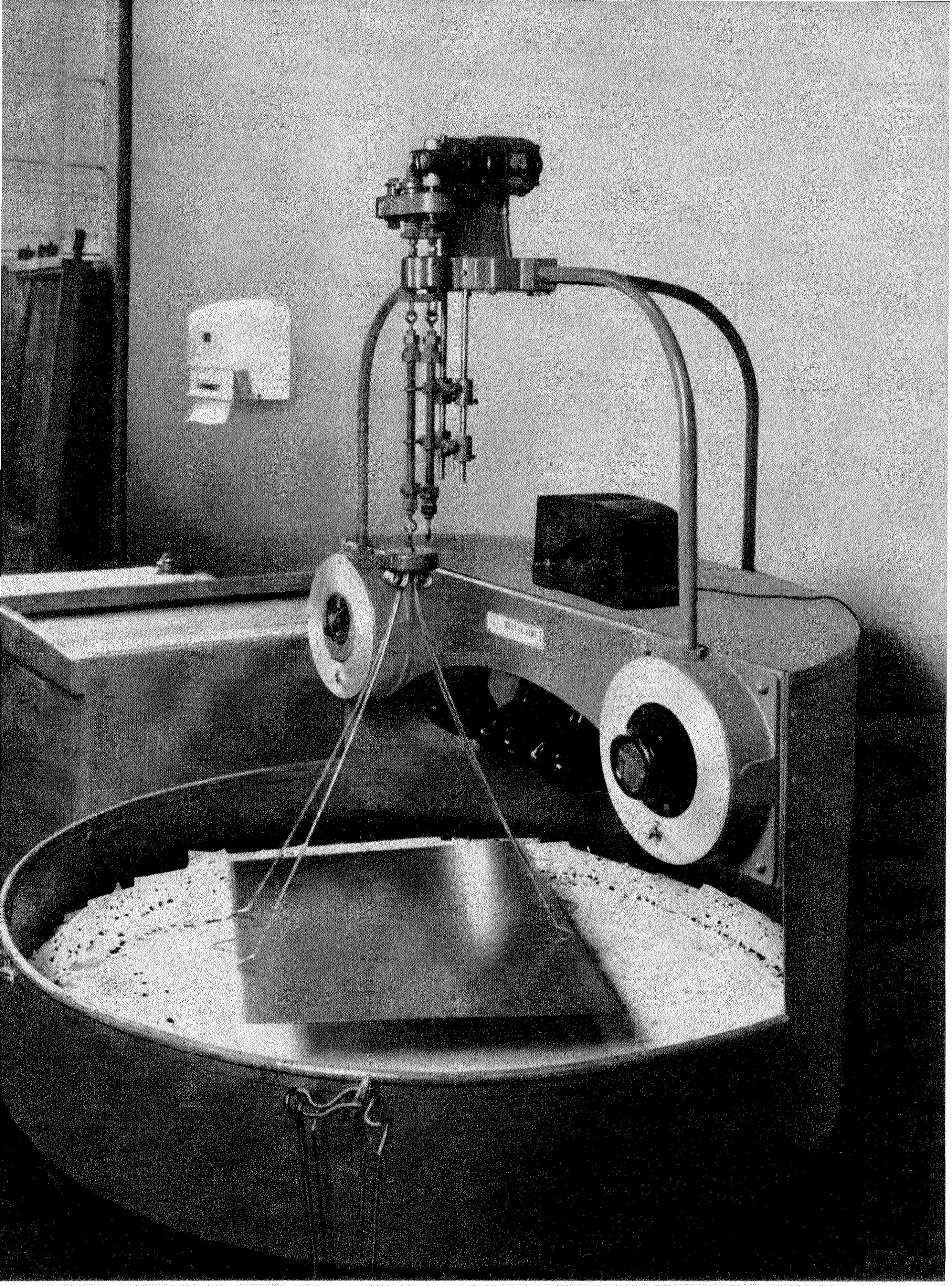
2. Once the master drawing is finished, it is reproduced as a photographic negative. Below, the drawing has been placed in the frame of a copying camera, and five identical negatives will be made. These negatives will be spliced together to form a single sheet of 30 images of the hybrid. For practical purposes, the number of units that may be prepared as a single sheet is limited, in general, by the size of the plastic sheet available and by the capacity of the processing equipment.



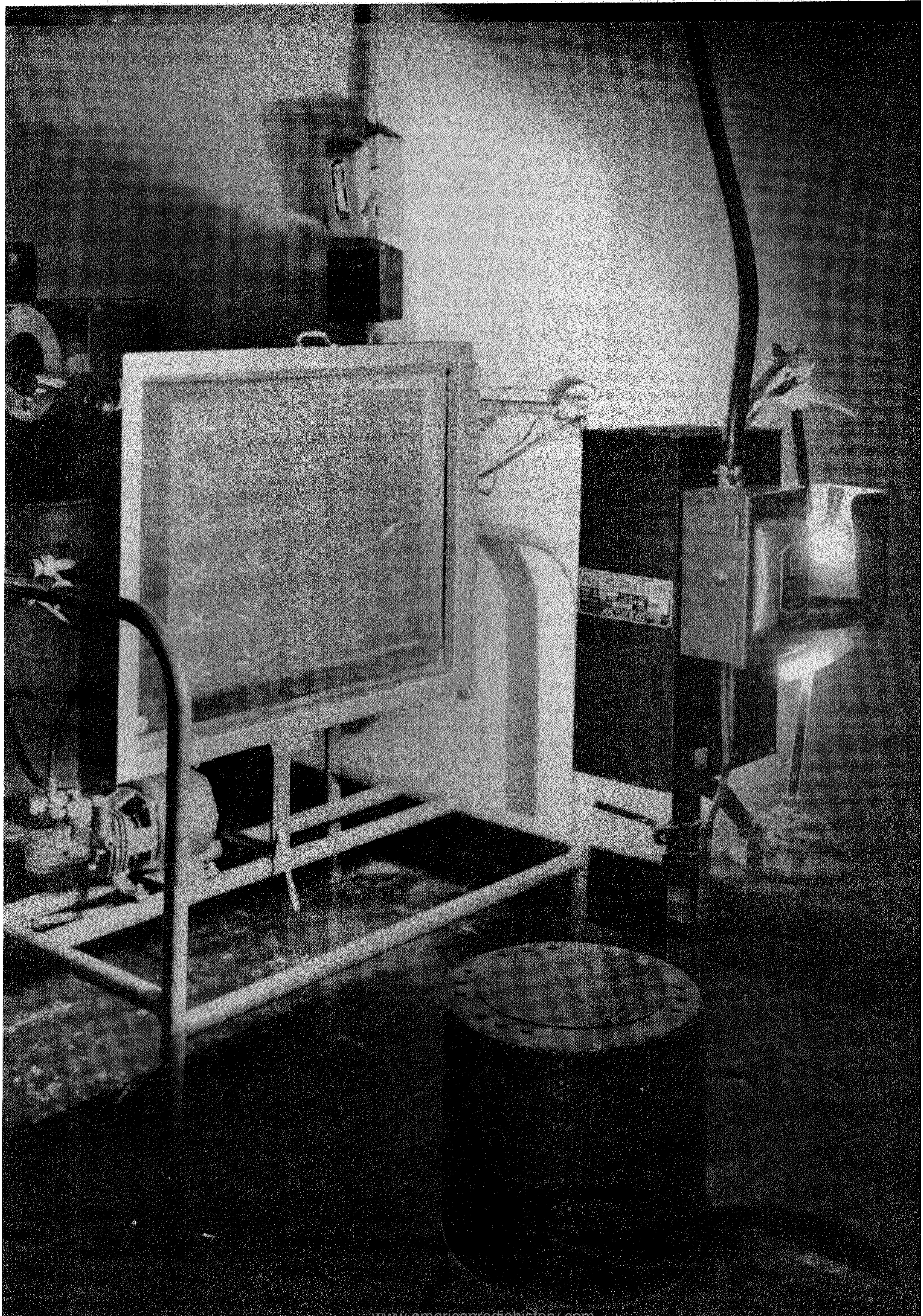
3. The plastic sheet as purchased is already laminated on each side with a continuous film of copper. In the photograph below, the operator is cleaning all dirt and oxides off the copper.

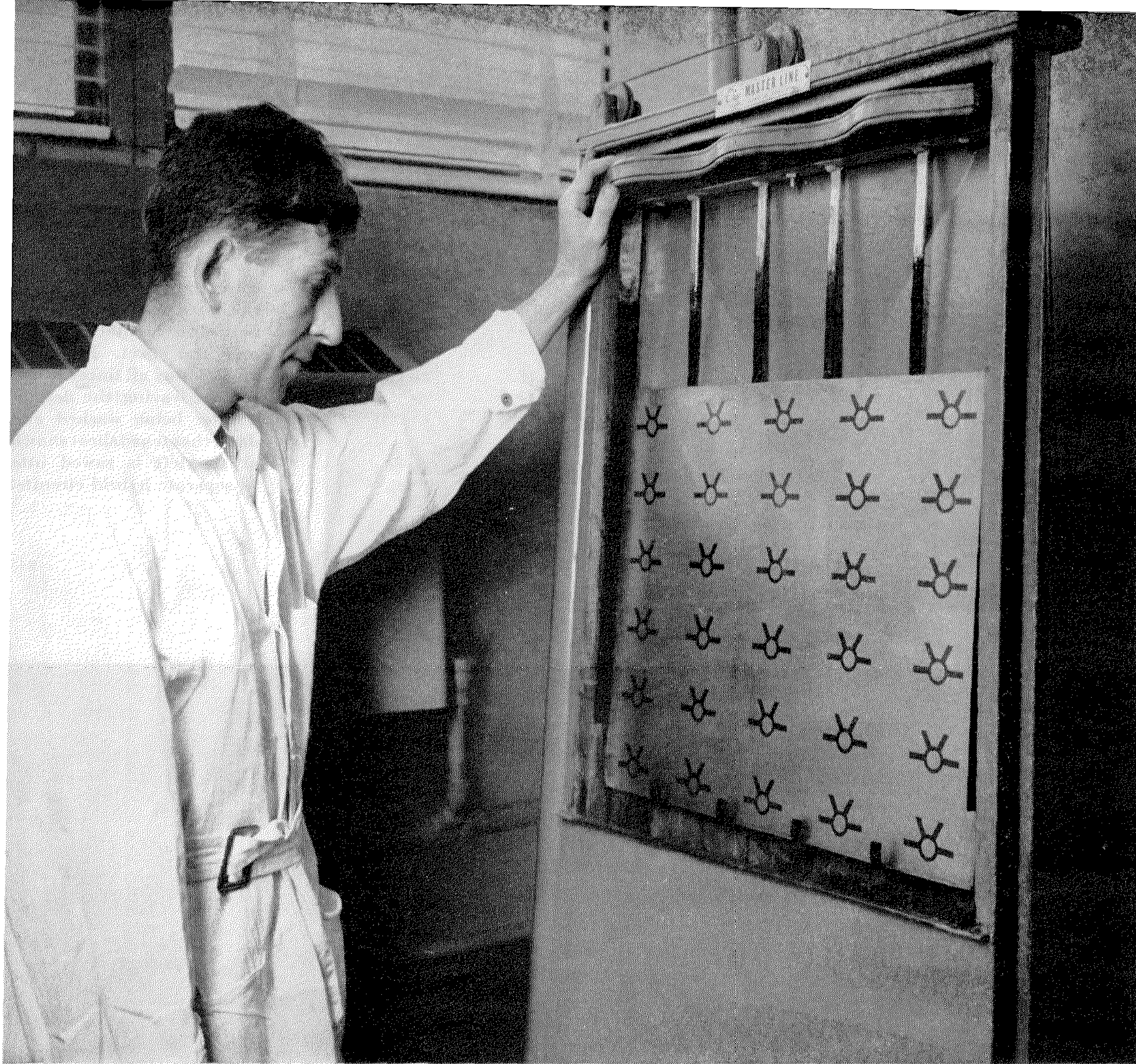
The next step, as shown at the left, is to flow photosensitive compound over one side of the clean wet copper. The operator will tilt the sheet in all directions to form a thin even coat. This photographic emulsion is insensitive to ordinary room illumination.





4. **The sensitized sheet is dried under infrared lamps, being whirled rapidly for a period controlled by an automatic timer. Like most of this equipment, this is a standard drier used by photoengravers. Were this a production rather than a pilot operation, more and larger equipment would be used for these processes.**

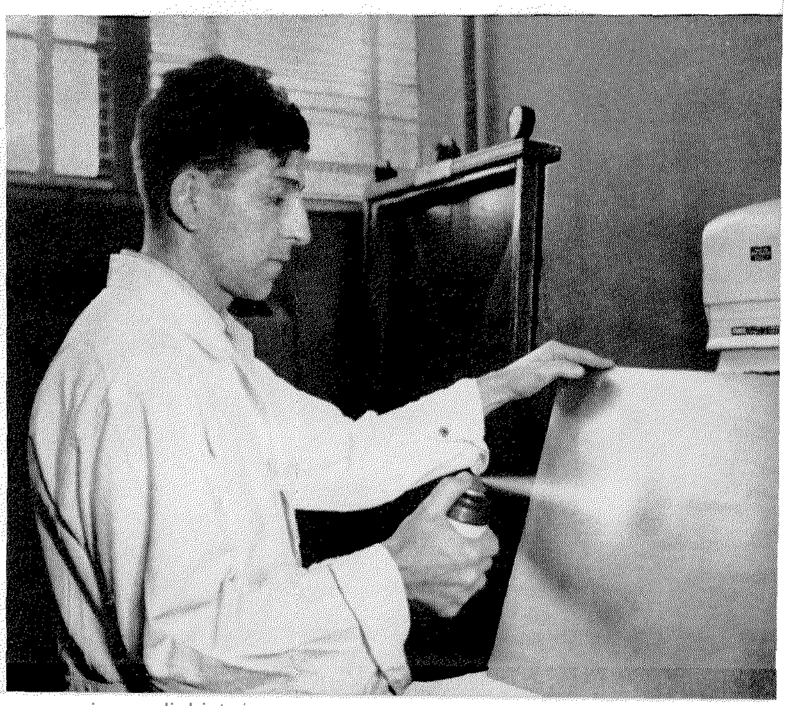


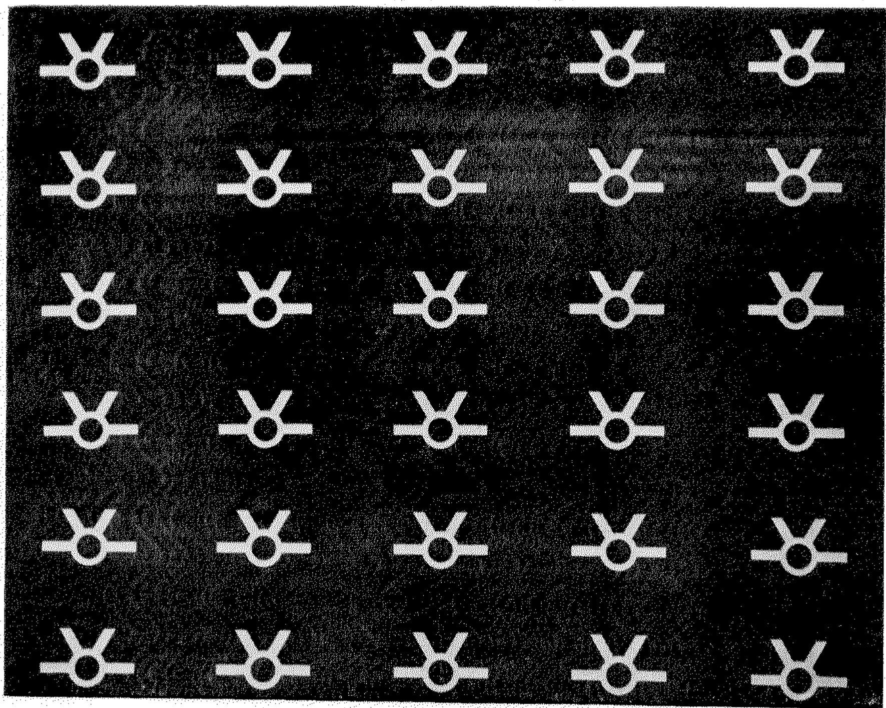


5. **On the opposite page, the negative prepared in step 2 has been placed over the sensitized copper and both are put in a vacuum frame to provide positive contact. The frame is then tilted and exposed to an arc light for some minutes.**

6. **At the top of this page, the design on the exposed emulsion is brought out in a developing bath from which the sheet has just emerged. The developer washes away the sensitized coating wherever the arc light could not reach it through the negative. The desired hybrid designs are left covered with the coating that will protect them against the etching bath.**

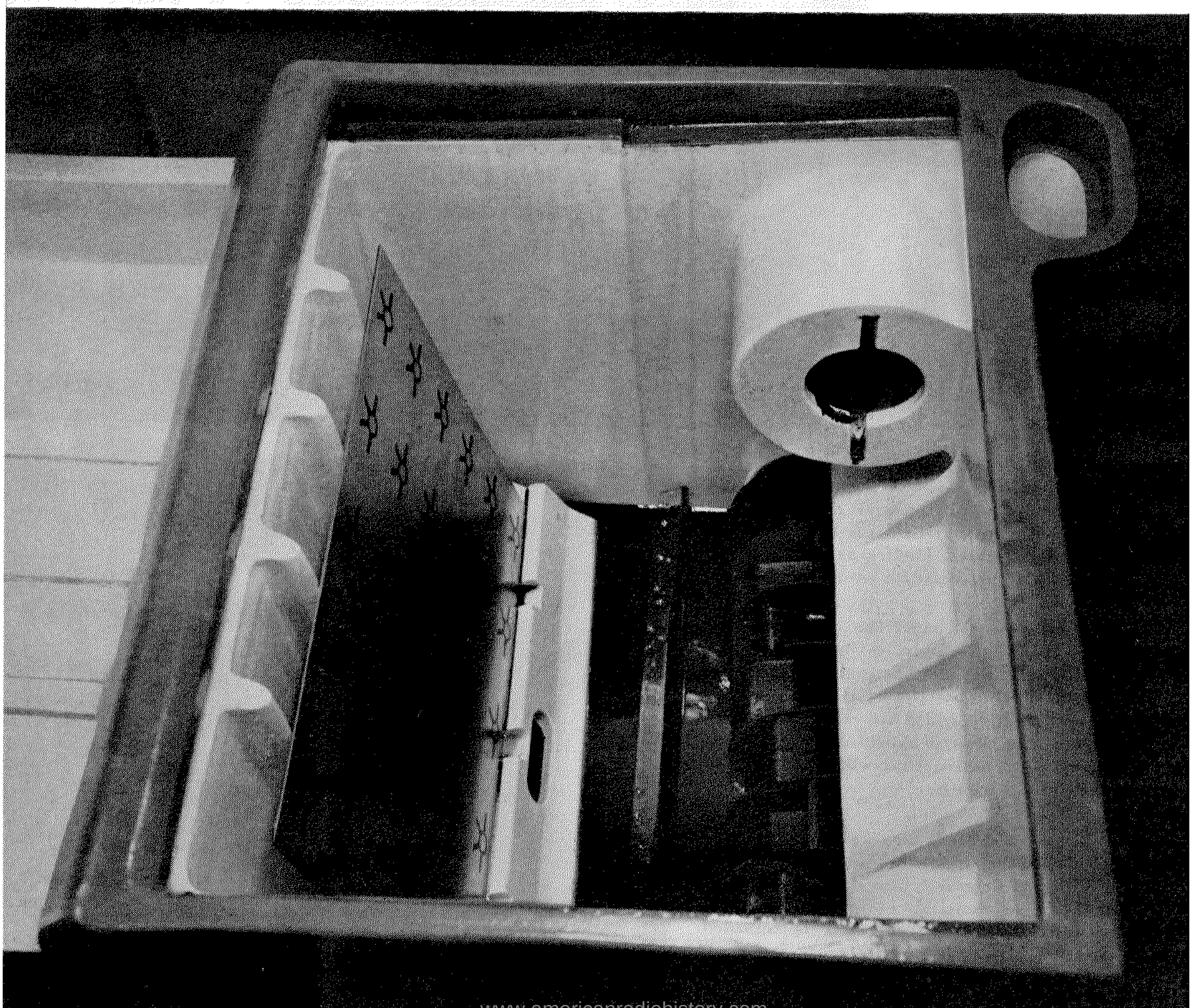
7. **The developed sheet is next washed and dried. Any defects in the design are touched up with acid-resisting paint and at the right, the copper film on the back is entirely covered with a clear acid-resistant plastic coating that is retained permanently.**

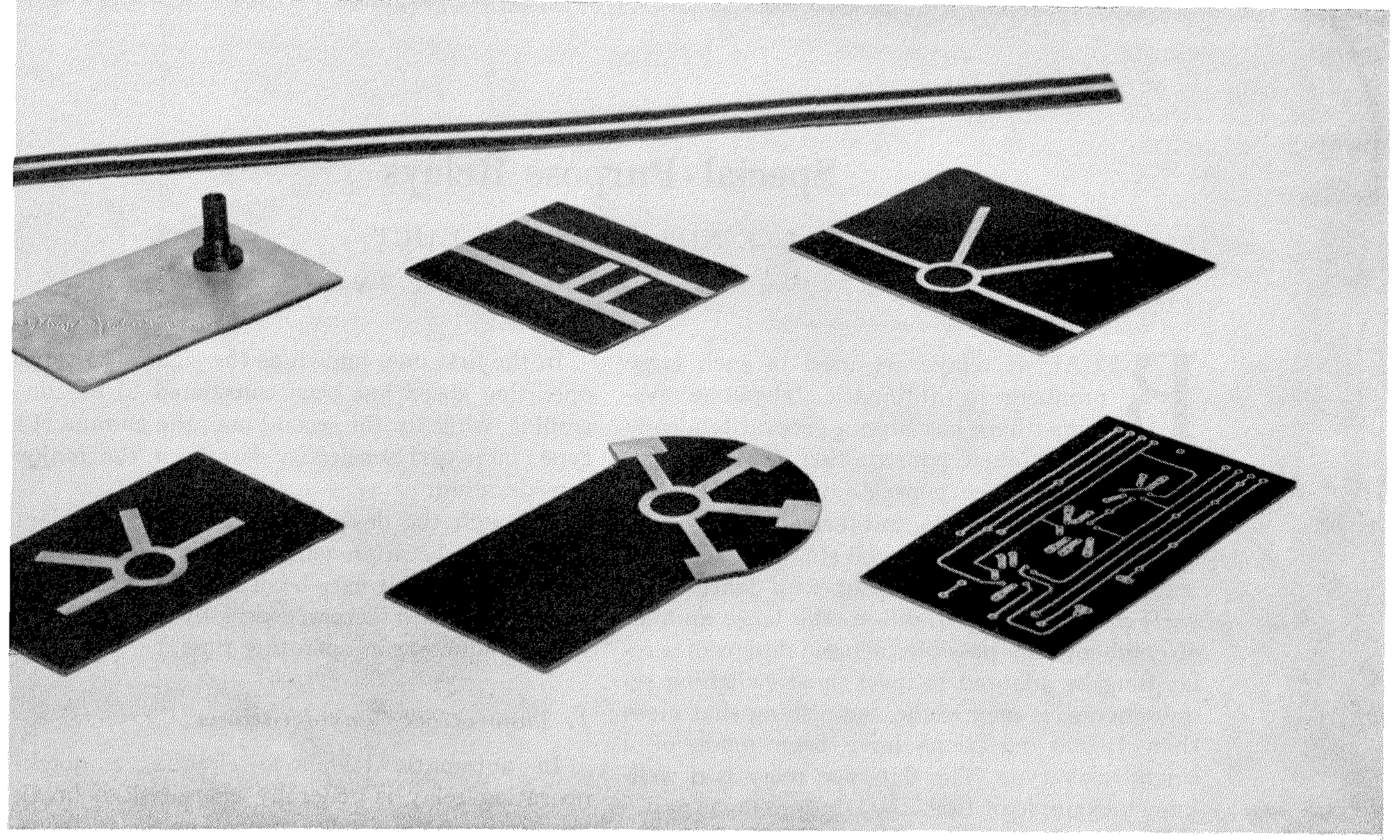




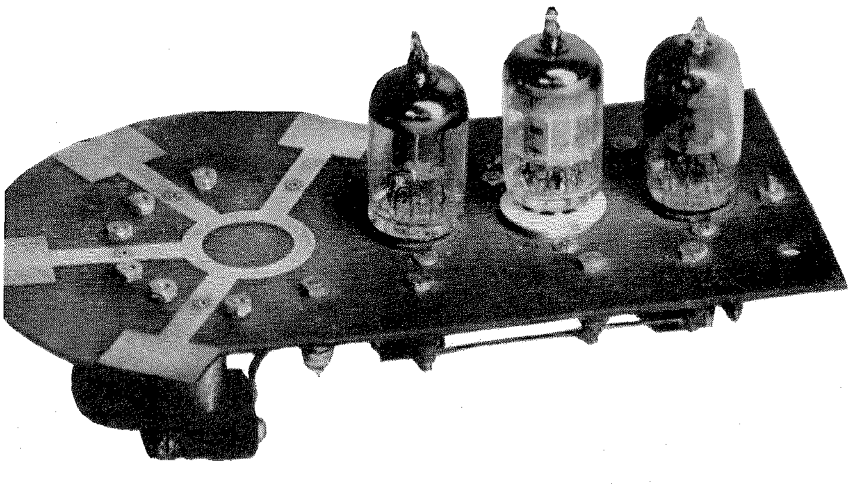
8. The etching machine is shown below and a finished sheet at the left. After step 7, the sheet is placed in the rack of the etching machine. A cover is then placed over the machine, and a motor spins the paddles shown at the bottom; these throw the bath of ferric chloride evenly over the sheet. The bath etches away all unprotected copper, leaving the design.

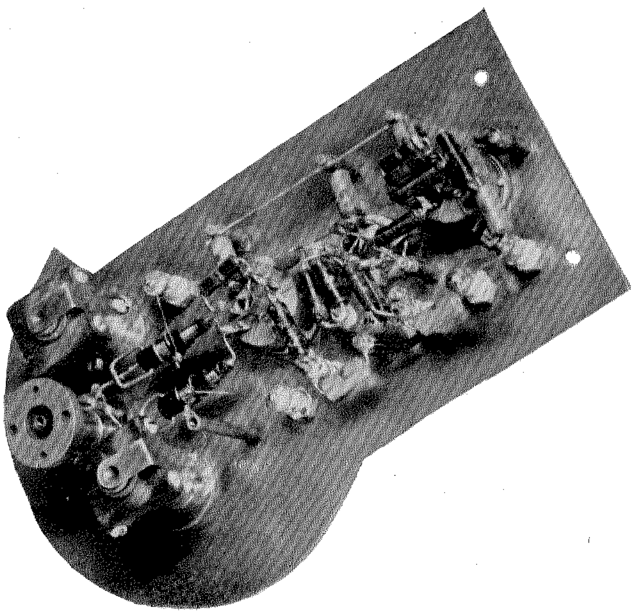
After being washed and dried the etched sheet shown at the left is sawed into 30 separate hybrid circuits.





9. Among the typical microstrip configurations above are a long transmission line at the top and several hybrid circuits. At the left, a hybrid circuit has been turned face down to show a cable connector coupled to one of its arms. Centered below the transmission line is a directional coupler. The printed circuit at the lower right is shown for comparison; unlike it, the operation of the microstrip components is critically related to the shape and dimensions of the conducting areas.





10. Top and bottom views of the balanced crystal mixer and 3-stage preamplifier are shown here. The large squares at the ends of the hybrid arms are terminations used in impedance matching to the connectors on the underside. In the bottom view, standard wiring is used in the preamplifier section, but if this apparatus were placed in production, printed-circuit techniques could economically replace many of the parts.

Special-Purpose Relays

By L. J. NIJS and R. A. H. FAICT

Bell Telephone Manufacturing Company; Antwerp, Belgium

BECAUSE relays are used in such large numbers in automatic telephone systems, there has been a general tendency to standardize their construction. This has led to several types of general-purpose relays for which magnetic circuits, coil forms, springs, contacts, and mountings are well standardized.

Even if only a small number of features or parts may be changed, due to the large number of combinations possible, a basic design of a relay may be adapted to meet most switching requirements. It may sound astonishing that more than 10,000 variations have been made of a single relay type. The flat-type relay is a well-known example of this.

During the last decade, constant effort has been made to improve the performance of existing telephone systems. New electromechanical devices have been developed to increase the operating speed of automatic switching systems, thereby reducing the selection time. The expanding application of automatic telephone service to larger networks has played an important role in making relay-operating time a major factor.

During this development period, the need became evident for general-purpose relays having increasingly greater sensitivity and operating speed in order to satisfy the requirements of improved circuits.

Experience with available contact materials has shown that, if contact trouble is to be avoided, it is not advisable to reduce the contact pressure below 20 grams (0.7 ounce).

Furthermore, there is a limit on how small the armature air gap may be as the contact separation must be large enough to ensure satisfactory operation under all circumstances. A contact clearance of 0.006 inch (0.15 millimeter) has been considered safe based on practical observations made over long periods in existing exchanges.

The above-mentioned limiting conditions and the most severe requirements imposed by the switching circuits have stressed the need for special-purpose relays, two types of which will be described.

In the first one, known as the sigma (Σ) type, operating speed has been considered to be controlling, while for the second one, the gamma (Γ) type, increased sensitivity has been the major consideration.

Although the design of a relay is a problem that has to be approached mainly from the experimental side, it may be of interest to consider a few theoretical factors, especially in connection with a reduction in operating time.

1. Theoretical Considerations

In automatic telephone circuits, a quick-operating relay is generally energized to break the current in the circuits controlling the switches. Accordingly, only the factors influencing the time required to break a contact will be considered, although the relay may be equipped with change-over contacts or other switching facilities.

The relay winding is assumed to be connected directly to the battery with the necessary series resistance to limit the current to a safe value.

The total operating time t of a relay may be divided into two components

$$t = t_1 + t_2, \tag{1}$$

where t_1 extends from the time the winding circuit is closed to the time the contact pressure is reduced to 0, and t_2 is the time required for the armature to move from the 0-contact-pressure position to that in which the contacts just open.

During each of these partial times, the relay armature A in Figure 1 will make corresponding angular motions θ_1 and θ_2.

To insure the shortest-possible operating time, θ_1 and θ_2 will have to be reduced to a minimum. Strictly speaking, only θ_1 is directly dependent on the design of the relay, as θ_2 will be determined principally by contact phenomena and transients caused by the external circuit in which the relay contacts are connected.

It is evident that θ_1 will be small if the relay is equipped with stiff contact springs.

Under these conditions, the velocities reached by the moving parts of the relay during t_1 may be neglected and an approximate value of t_1 will be found by writing

$$h_a \int_0^{t_1} P_1\, dt + h_a' \int_0^{t_1} P_1' dt = h_v \int_0^{t_1} T_v\, dt, \quad (2)$$

the various factors being indicated in Figure 1.

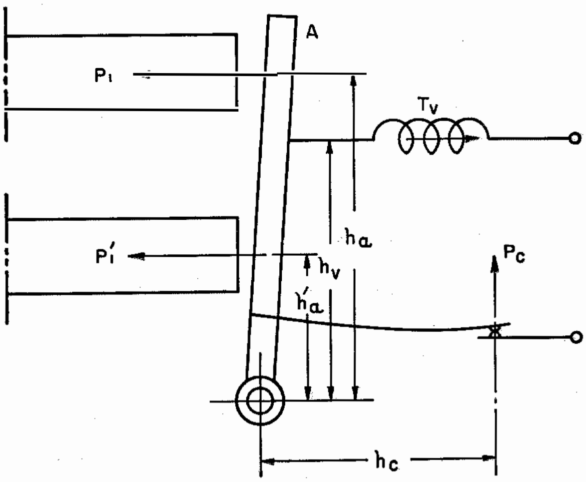


Figure 1—Factors influencing operating time of a relay.

Let $h_a' = m \cdot h_a$, then taking P_1 and P_1' as equal and assuming the relay winding to be connected in a purely resistive external circuit, the following approximate expression may be obtained for t_1

$$t_1 = \frac{1.73n}{Ev}\left[\frac{h_c}{(1+m)h_a} P_c\, 8\pi S\right]^{1/2}, \quad (3)$$

where

E = voltage across the winding

n = number of turns on the winding

S = cross section of the winding core

v = magnetic leakage factor, the ratio of useful flux to total flux

$m = h_a'/h_a$.

It may be seen as a first conclusion that a short operating time will be obtained with a relay winding having a small number of turns, a high voltage applied to the winding, a magnetic circuit with minimum leakage and a small cross section of core, and that the contact should be located near the rotating point of the armature.

The reduction of the core section is evidently limited by the magnetic saturation of the material used. The determination of the optimum value leads to intricate formulas that make a theoretical calculation nearly impossible.

With regard to the number of turns, it must be remembered that the magnetic field is proportional to the ampere-turns ni and a very small coil will require a heavy current to produce the magnetic force necessary for operation. If a value of I_{max} is set, the minimum number of turns to be used would be

$$n_m = \frac{ni}{I_{max}}. \quad (4)$$

In this extreme condition, the influence of the exponential law of current rise in the relay winding becomes predominant and, as a consequence, the operating ni should be reached for a value I_x smaller than I_{max}.

This requires an increased number of turns n_x

$$n_x = \frac{I_{max}}{I_x} n_m. \quad (5)$$

If the number of turns is increased beyond certain limits, the operating time will rise again and the optimum value has been found when

$$\frac{I_x}{I_{max}} = 0.632, \quad (6)$$

corresponding to

$$n_x = 1.58\, n_m. \quad (7)$$

In the determination of the second part t_2 of the operating time, the following equation has been taken as starting point.

$$h_a \int^{t_1+t_2} P_1 dt + h_a' \int_{t_1}^{t_1+t_2} P_1' dt$$
$$= h_v \int_{t_1}^{t_1+t_2} T_v \cdot dt + I_a \cdot \Omega_2, \quad (8)$$

in which I_a is the moment of inertia of the armature relative to the rotating axis and Ω_2 is the angular velocity reached at time $t_1 + t_2$. Variations in the tension and mass of the spring have been assumed to be negligible.

The value of Ω_2 as a function of time is not exactly known, but as in the preceding calculation the acting forces have been taken as quadratic functions of t; Ω_2 will be a 3rd-degree and θ_2 a 4th-degree function.

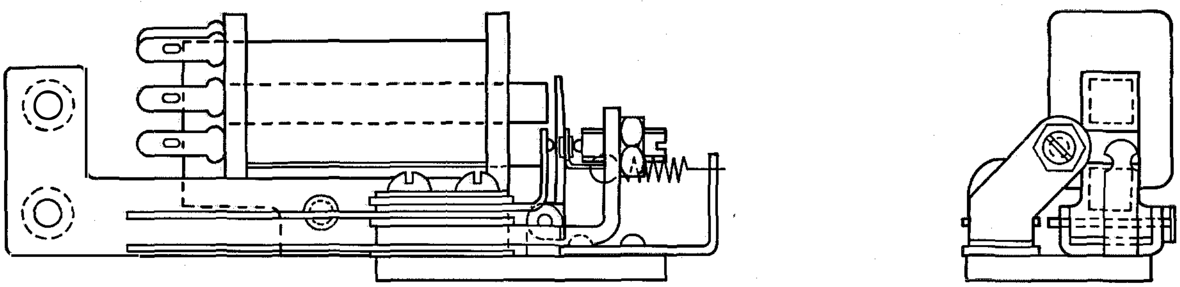


Figure 2—Principal dimensions of the sigma relay. The relay is 6.55 centimeters long, 2.1 wide, and 2.7 high (2.48 by 0.826 by 1.06 inches).

Assuming

$$\theta_2 = a_1t^4 + b_1t^3 + c_1t^2 + d_1t$$

with b_1, c_1, d_1 small compared to a_1, then

$$\Omega_2 = \frac{d\theta_2}{dt} = 4a_1t^3 = \frac{4\theta_2}{t} \qquad (9)$$

may be taken as an approximate value and making the same assumptions for the relay circuit as in the calculation of t_1, the following expression is obtained for t_2:

$$t_2 = \left(\frac{n}{vE}\right)^{1/2}\left[\frac{12\theta_2 I_a}{(1+m)h_a}\, 8\pi S\right]^{1/4}, \qquad (10)$$

showing the influence of two more factors, θ_2 and I_a, on the operating time.

To reduce I_a, the length of the armature and the corresponding distance between the core legs should be small. This distance determines the winding space of the relay and presents a first design limit. Furthermore, as this distance is reduced, the magnetic leakage between core legs will increase. A theoretical calculation of the optimum conditions is practically impossible and here again experimental tests indicate the most advantageous design.

In the reduction of I_a, rectangular, triangular, and trapezoidal shapes of armature have been considered. The smallest value is obtained with a triangular shape, but this has a major disadvantage in that the top part is strongly saturated when the relay is energized. Consequently, in the final design of a quick-operating relay, the trapezoidal shape has been adopted. As for θ_2, its value depends on the contact separation required to break the current in the circuit controlled by the relay. Quite a number of studies have been published on this subject. In the present calculation, the experimental law given by Betteridge and Laird[1] has been used and for

[1] W. Betteridge and J. A. Laird, "The Wear of Electrical Contact Points," *Journal of The Institution of Electrical Engineers*, v. 82, pp. 625–632; June, 1938.

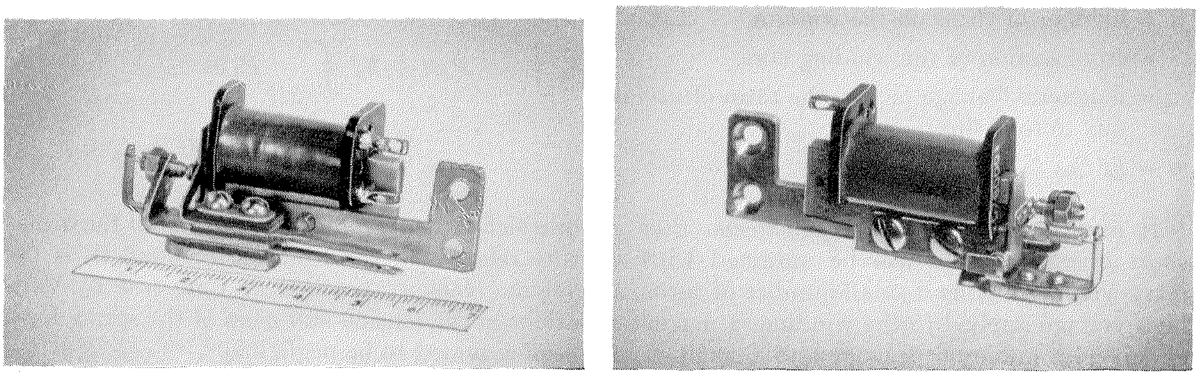


Figure 3—Side views of the sigma relay.

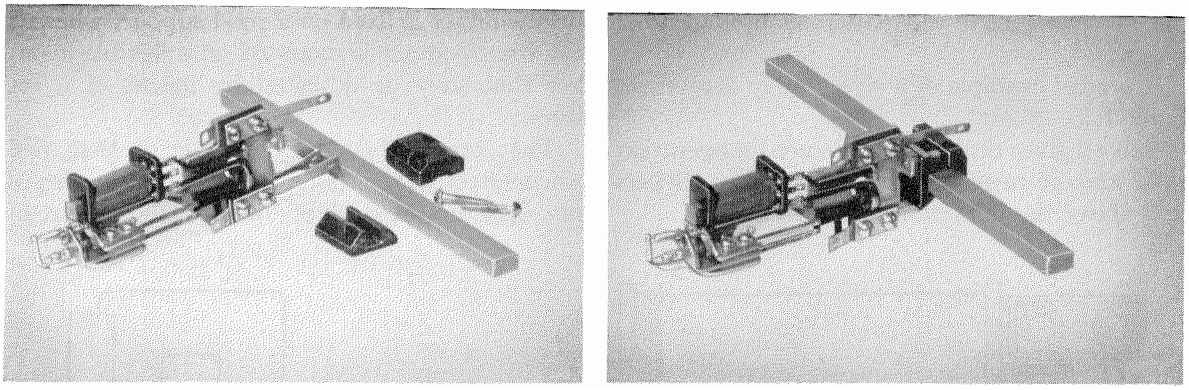


Figure 4—Method of mounting sigma relay on a bar.

normal telephone circuits dictates contact separations in the range from 5 to 10 microns.

With these values, a fairly good conformity has been obtained between calculated and measured operating times on various models of relays constructed during the extensive experimental period that followed the initial theoretical design. Two relays based on the above considerations have been developed.

2. *Sigma Relay*

The sigma relay, shown in Figures 2–5, is a quick-operating and quick-releasing relay with high contact pressure. It is suitable as a testing and stepping relay in switching systems and in other electrical systems where there is a need for quick contact operations. The relays can be equipped for make, break, or change-over contacts.

Two variations of the sigma relay are made: one with and the other without an air gap in the operated position.

In the air-gap unit, the front contact support is very stiff and acts as a stop for the armature travel, avoiding rebound of the armature and consequent vibration of the contacts.

In the second design, the front contact is fixed on a more-flexible support so as to ensure a sufficient follow to guarantee a perfect contact.

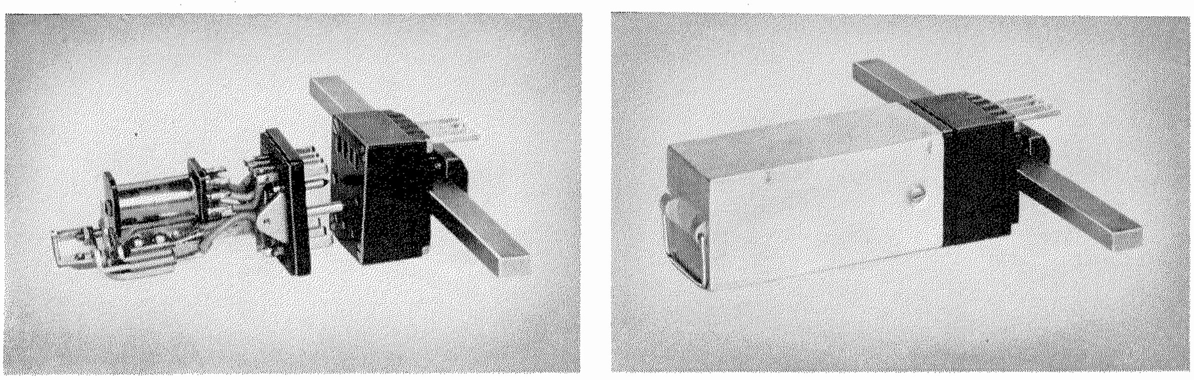
The core of the relay is a pile up of **U**-shaped silicon-steel laminations. The armature is made of magnetic iron with a trapezoidal cross section and pivots on an axle in front of the two legs of the core. The molded bakelite coil is slid over the upper leg of the core. The contacts are of palladium.

2.1 Operating Characteristics

The number of ampere-turns required to operate the relay with a back-contact pressure of 20 grams (0.7 ounce) is of the order of 60. The power necessary to operate the relay with a normal adjustment is 0.08 watt.

Considering a maximum rise in temperature of 55 degrees centigrade (99 degrees fahrenheit),

Figure 5—Plug-in form of sigma relay with bar mounting of sockets.



the allowable heat dissipation is limited to 2 watts.

A typical example of a sigma relay is given in Table 1.

Table 2 gives timing performance for operation at 72 ampere-turns, which corresponds to 20 percent above the minimum operating value.

back contact is fixed on a rigid support whereas the front contact is mounted on a flexible member that may be adjusted by means of a set screw.

The core of the relay is a pile of U-shaped silicon-steel laminations. The armature is of magnetic iron and pivots on an axle in front of

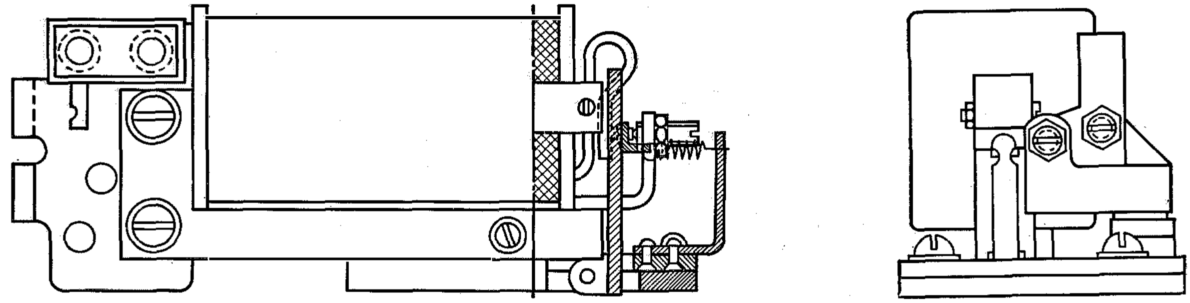


Figure 6—Principal dimensions of the gamma relay. The relay is 9.5 centimeters long, 3.8 wide, and 3.75 high (3.74 by 1.49 by 1.47 inches).

3. *Gamma Relay*

The gamma relay, shown in Figures 6 and 7, is a sensitive relay intended for use in telephone circuits where delta relays have been used.

The gamma relay has been constructed to guarantee a back contact pressure of 20 grams with an operating current of 2 milliamperes, the winding consisting of 20,000 turns.

The construction of the gamma relay is similar to that of the sigma; it may be considered to be an enlarged form of the sigma relay.

The greater volume of the relay made it possible to provide at the front the screw adjustments for both the back and front contacts. The the two legs of the core. The bakelite molded coil is slid over the upper leg of the core.

3.1 Operating Characteristics

The number of ampere-turns required to operate the relay with 20 grams of back-contact pressure is of the order of 40. The power necessary to operate the relay with a normal adjustment is 0.012 watt.

Considering a maximum temperature rise of 55 degrees centigrade (99 degrees fahrenheit), the allowable heat dissipation is limited to 4.5 watts.

A typical example of a gamma relay is given in Tables 3 and 4.

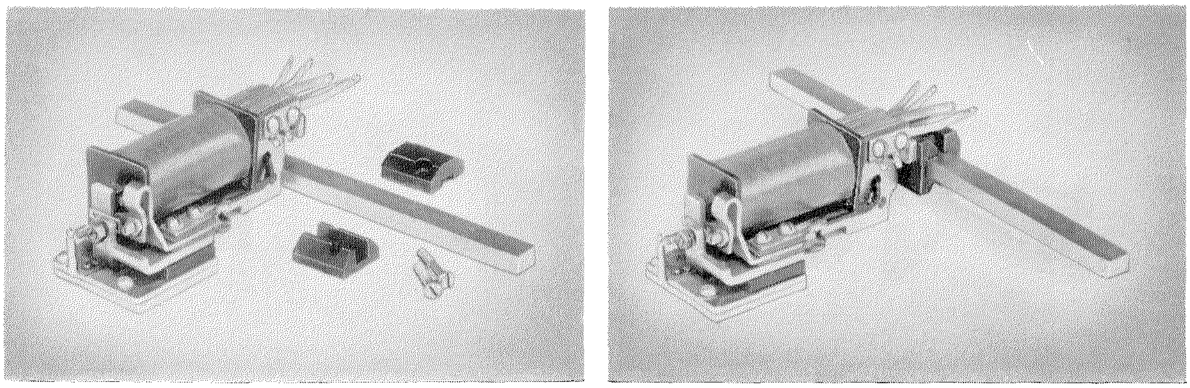


Figure 7—Bar mounting of gamma relay.

TABLE 1

SIGMA RELAY

Coil Winding	3000 Turns
Operating, Average	60 Ampere-Turns
Nonoperating	48 Ampere-Turns
Releasing	32 Ampere-Turns
Holding	35 Ampere-Turns
Back-Contact Pressure	20 Grams (0.7 Ounce)
Air Gaps	
Between Contacts	0.006 Inch (0.15 Millimeter)
Upper Core to Armature	
Nonoperated	0.014 Inch (0.35 Millimeter)
Operated	0.003 Inch (0.08 Millimeter)

TABLE 2

SIGMA RELAY OPERATING SPEED

Operation	Time in Milliseconds
Leave Back Contact	0.8
Make Front Contact	1.8
Leave Front Contact	1.0
Make Back Contact	3.0
Leave Back Contact	
2000 Turns	0.65
1000 Turns	0.58

TABLE 3

GAMMA RELAY

Coil Winding	18,000 Turns
Operating, Average	40 Ampere-Turns
Nonoperating	35 Ampere-Turns
Releasing	8 Ampere-Turns
Holding	13 Ampere-Turns
Back-Contact Pressure	20 Grams (0.7 ounce)
Air Gaps	
Between Contacts	0.006 Inch (0.15 Millimeter)
Upper Core to Armature	
Nonoperated	0.010 Inch (0.25 Millimeter)
Operated	0.004 Inch (0.10 Millimeter)

TABLE 4

GAMMA RELAY OPERATING SPEED

Operation	Time in Milliseconds	
	40 Ampere-Turns	60 Ampere-Turns
Leave Back Contact	10	6
Make Front Contact	12	8
Leave Front Contact	1.5	2.4
Make Back Contact	5.7	6.2

Telecommunications for the 1952 Olympic Games

A FAR-SIGHTED extension of telecommunication facilities within the Swedish–Finnish sector of the European network was prompted by the 1952 Olympic Games in Finland.

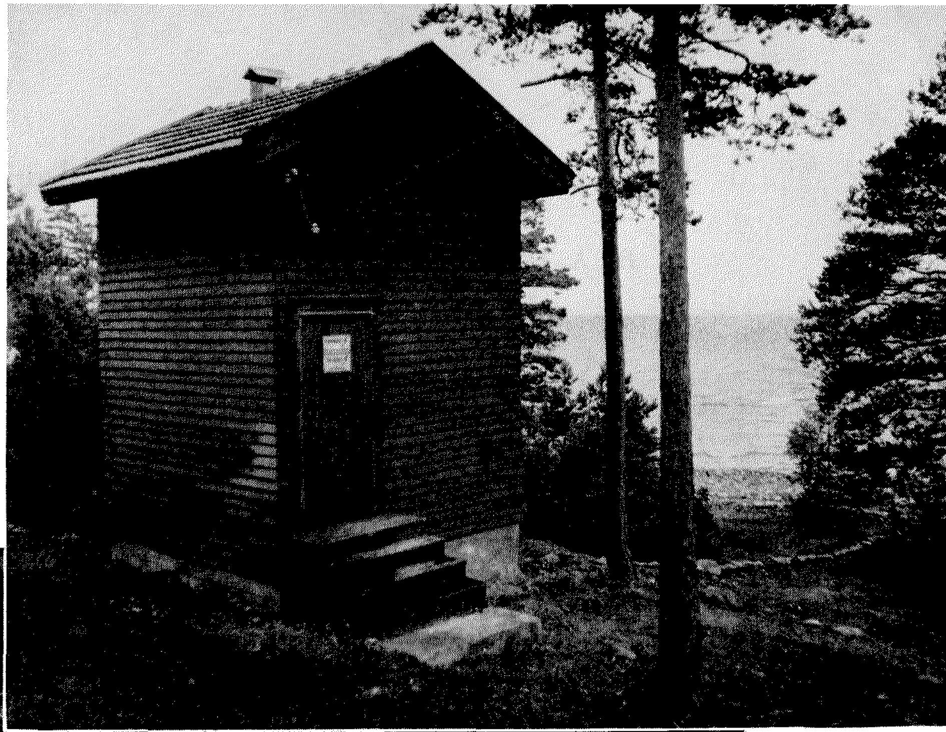
The Stockholm–Helsinki circuits over which this traffic flowed include a short sea crossing from Simpnas, Sweden, to Hammarudda in the Finnish Aland Islands, an island-to-island route to Turku on the mainland, and land cable to Helsinki. Hammarudda is 335 kilometers (208 miles) from Helsinki by this route.

By increasing the number of repeaters and using latest carrier telephone techniques, the capacity of the existing cable network has been materially expanded. Two new 36-channel systems were installed and further extensions can be made when needed. A both-way 10-kilocycle program service for broadcasting may be substituted for three speech channels and provided the only broadcast outlet to the European network.

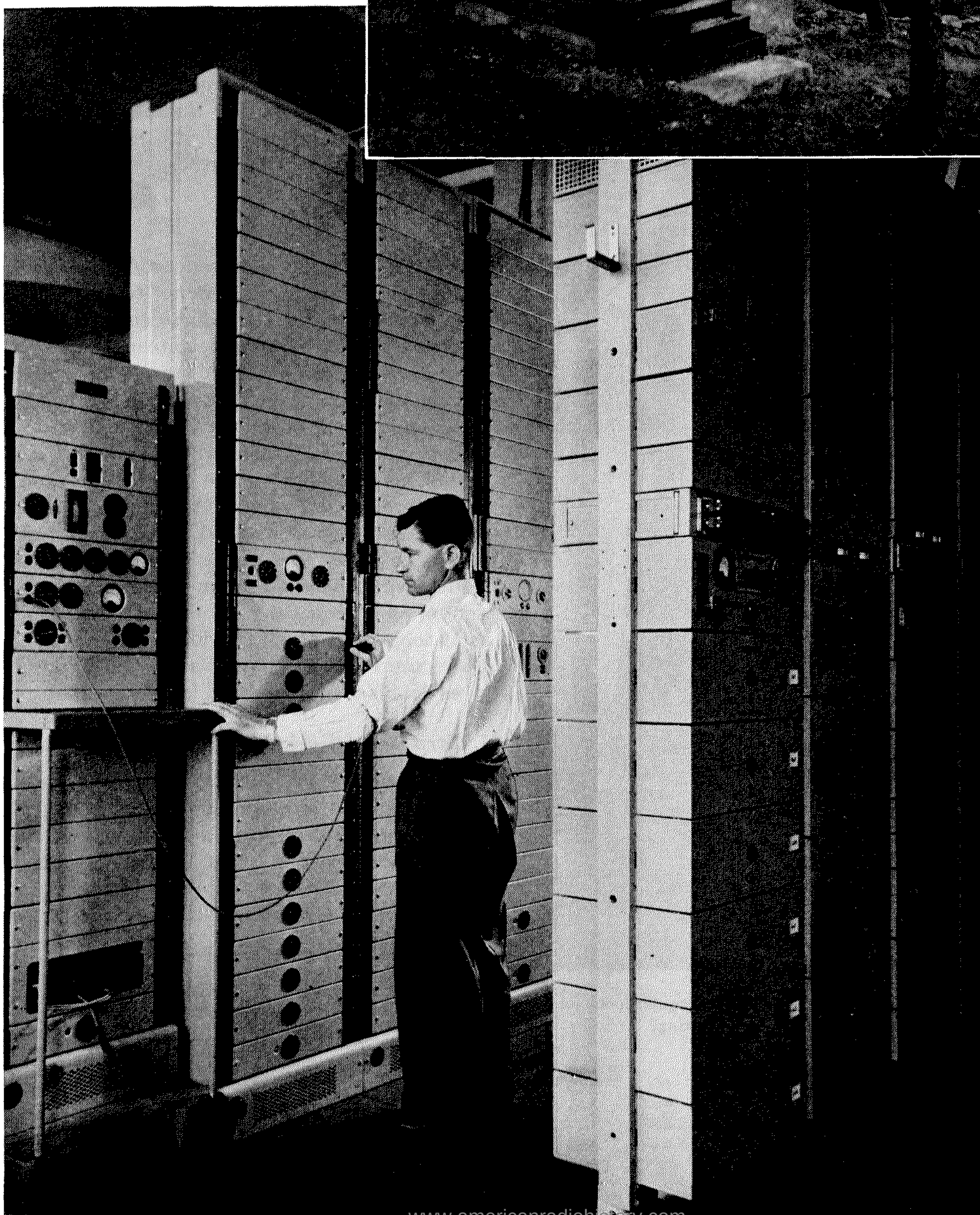
Within Finnish territory, the expansion was entrusted by the Posts and Telegraphs Administrations to Standard Telephones and Cables, Limited, through its associate Oy Stromberg Ab of Helsinki. These circuits are permanent additions to the previously existing international traffic facilities.

Main post office and telephone exchange in Helsinki. This postwar building houses the terminal equipment and switchboard for all international carrier telephone circuits to Finland.

At the right is a typical unattended repeater station on one of the islands on the route to Sweden. The installation of new intermediate repeaters permitted a substantial increase in the number of carrier channels over existing cables.



The latest type of transmission test trolley is used in checking the new terminal equipment at Helsinki.



High-Gain Loop Antenna for Television Broadcasting*

By A. G. KANDOIAN, R. A. FELSENHELD, and WILLIAM SICHAK

Federal Telecommunication Laboratories, Incorporated; Nutley, New Jersey

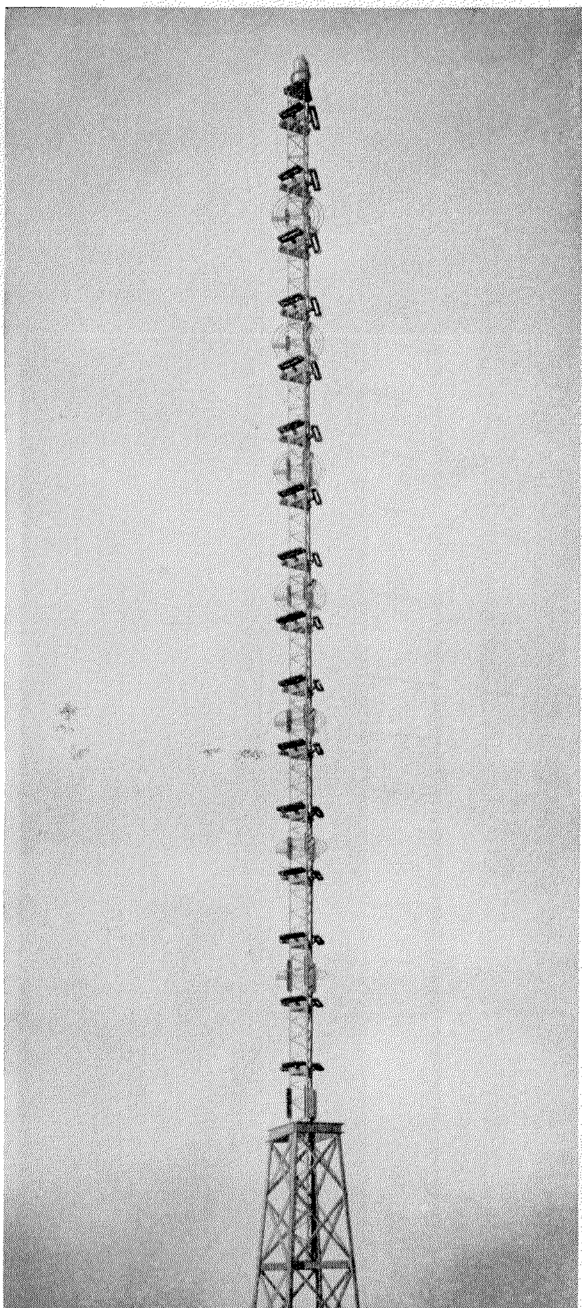


Figure 1—A stacked array of 16 triangular loops for use in television broadcasting.

TRIANGULAR loop antennas for television broadcasting have been described in installations limited to a maximum of 8 loops. By solving certain electrical and structural problems, the design has been extended to stacks of as many as 16 loops, providing a power gain of 17. Various important characteristics of the antenna and of the notch-filter type of diplexer are discussed. Close-in coverage in crowded areas is treated briefly as well as an installation in Buenos Aires.

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The trend in television broadcasting is towards higher effective radiated powers. It is generally more economical to obtain large effective radiated powers by increasing the antenna gain than by raising the transmitter power provided the required antenna gain is less than about 20. This procedure is particularly attractive in the television band from 174 to 216 megacycles per second, corresponding to the 6-megacycle channels *7* through *13* in the United States, in view of the great expense involved in generating high powers at these frequencies. This situation has made desirable the extension of a previous design[1] of an antenna to allow the use of as many as 16 loops, which will provide a power gain of 17. Figure 1 shows a 16-loop array and Figure 2 gives details of an individual loop.

1. Structural Design

The structural design of the antenna system was worked out in cooperation with the Blaw-Knox Company. The loops are mounted on triangular steel lattice structures to whatever height is necessary to achieve the desired power gain. The loop spacing is a constant 5 feet for

* Presented before Radio and Television Manufacturers Association in Chicago, Illinois, on April 2, 1952.

[1] A. G. Kandoian and R. A. Felsenheld, "Triangular High Band TV Loop Antenna System," *Communications*, v. 29, pp. 16–18; August, 1949.

channels *7* through *13*. For the 8-loop array originally designed, the maximum height was 40 feet, and a triangular steel lattice structure 14 inches on a side was sufficient. To accommodate as many as 16 loops—a total height of 80 feet—it is necessary to go to a larger lattice that is 17 inches on a side. Figure 3 and Table 1 give structural data for antennas with 2, 4, 8, 12, and 16 loops. There are actually 4 sizes of tower sections that differ in structural strength and weight. They are designated as types *D*, *E*, *F*, and *K*. Two- and four-loop arrays use type *D* sections, 8-loop arrays use *D* and *E* sections, 12-loop arrays use *D*, *E*, and *F* sections, while the 16-loop arrays use all four types. Each section is 10 feet (3 meters) long with a loop 2.5 feet (0.76 meter) from each end. This provides a 5-foot (1.5-meter) spacing between adjacent loops. The antenna meets all the specifications of the Radio and Television Manufacturers Association.

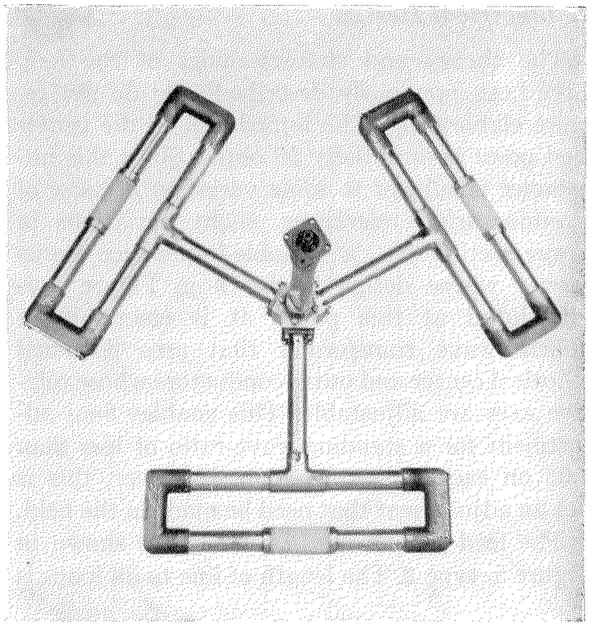


Figure 2—One of the triangular-loop elements.

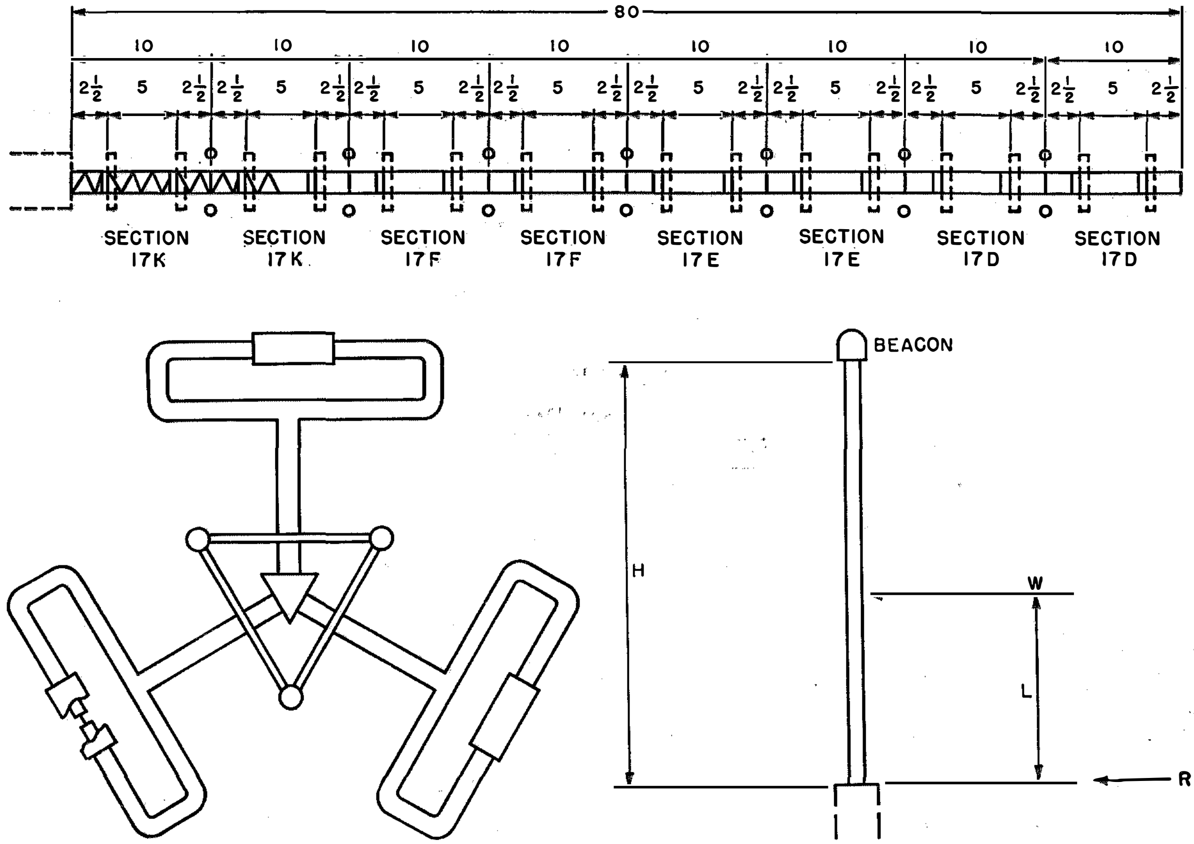
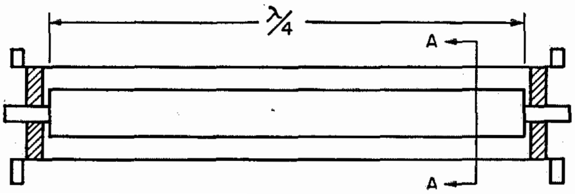


Figure 3—Below, cross section of loops and the triangular supporting structure, which has 17-inch (43-centimeter) sides. The symbols at the right are referred to in Table 1. All the dimensions in the detailed drawing are in feet

2. Electrical Design

The theory and characteristics of the loop have been previously described[1] and do not require elaboration. The impedance at the center feed point is essentially 50 ohms. Since this impedance is subject to some variation because of manufacturing tolerances, slight variations in tower section etc., a variable-impedance transformer whose design is shown in Figure 4 is introduced at this point. It is essentially a quarter-wave transformer that uses flattened elliptical center and outer conductors whose relative axes are adjustable. This enables final adjustment for a standing-wave-ratio of less than 1.05 on each individual loop. However, this is not an adjustment that need be made in the field.

The feed system used previously is shown in Figure 5, type *2*. The length of line to all loops is



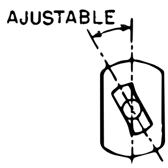


Figure 4—Variable-impedance transformer for adjusting a loop to the line impedance.

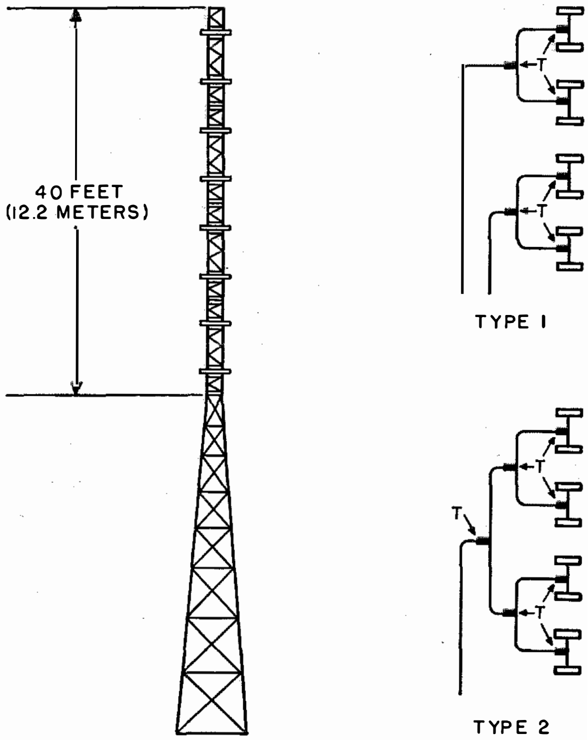


Figure 5—Two of the previously used transmission-line systems for an 8-loop array. The triangular lattice tower has 14-inch (36-centimeter) sides. Each of the four 10-foot (3-meter) sections carries two loops and adjacent loops are at 5-foot (1.5-meter) intervals. *T* is a quarter-wave matching transformer. Rigid $1\frac{5}{8}$-inch (4.1-centimeter) air-dielectric transmission lines are used except for the main line in type *2*, which is $3\frac{1}{8}$ inches (7.9 centimeters) in outside diameter.

TABLE 1

STRUCTURAL DATA

Symbols Are Defined in Figure 3

Number of Loops	Sections		Height *H* in Feet	Load *W* in Pounds	Distance *L* in Feet	Overturning Moment at *R* in Foot-Pounds	Shear at *R* in Pounds	Weight of Steel in Pounds	Weight of Tower and Array in Pounds
	Number	Type							
2	1	*D*	10	298	6.0	1,797	298	240	430
4	2	*D*	20	600	10.8	6,471	600	480	835
8	2 2	*D* *E*	40	1291	18.6	23,984	1291	1120	1885
12	2 2 2	*D* *E* *F*	60	2087	28.1	58,582	2087	2340	3615
16	2 2 2 2	*D* *E* *F* *K*	80	3151	35.9	113,129	3151	4700	6400

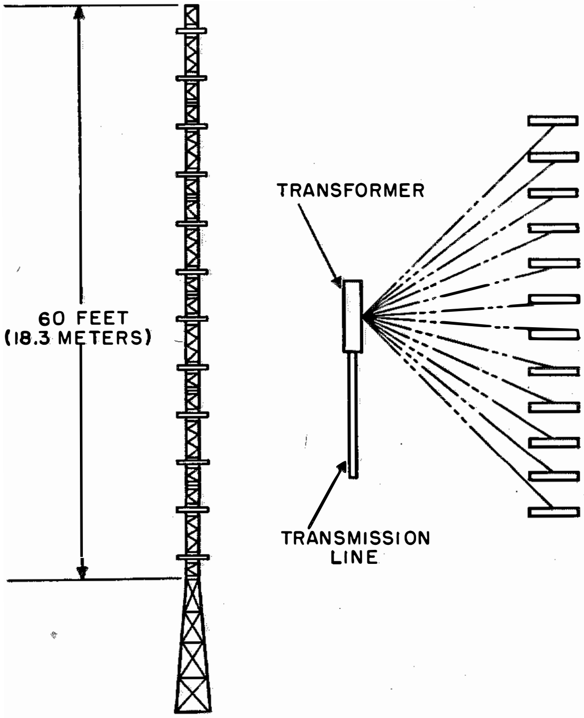


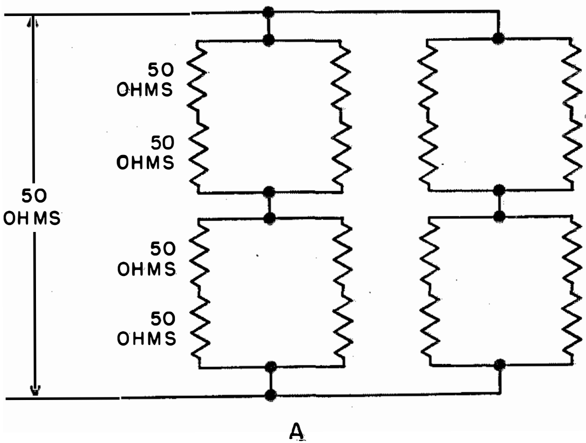
Figure 6—Use of transformer and equal lengths of *RG-17/U* solid-dielectric cables to feed 12 loops.

the same. Each loop is matched to a $1\frac{5}{8}$-inch (4.1-centimeter), 50-ohm air-dielectric line. At each junction, a quarter-wave transformer T is used to match to 50 ohms. Thus, all interconnecting lines are matched and their lengths are determined by mechanical considerations. Electrically, this design is straightforward and can be applied to feed a very large number of radiators. Mechanically the design becomes difficult if more than 8 loops are used because there is not enough room within the steel lattice structure for all the rigid lines and right-angle bends. All the lines being rigid also represents a difficult mechanical alignment problem during the assembly of the loops on the steel structure.

These difficulties may be eliminated if solid-dielectric cables are used to feed the individual loops. Such a design is shown schematically in Figure 6. From a common transformer assembly, equal lengths of *RG-17/U* cables go to each loop.

If all of the cables of a 16-loop array were tied in parallel at the junction point, the resulting impedance would be 50/16 or approximately 3 ohms, which is too low to transform conveniently back to 50 ohms over the complete video spectrum.

The matching problem would be greatly simplified if it were possible to connect the cables in series-parallel combinations as is often done in lumped-circuit work. Figure 7A shows one of the ways 16 loads of 50 ohms each can be connected together to produce an input impedance of 50 ohms. This circuit cannot be obtained in a simple system using transmission lines but, as may be seen in Figure 7B, 16 transmission lines can be connected together so that the input impedance is 50/4 ohms instead of 50/16 ohms. This is done by using a balun, which is normally used to connect a coaxial line to a balanced antenna. In a simple balun, Figure 8A, the two 50-ohm output lines are in series so that the input impedance is 100 ohms. If two more lines are connected to the output, Figure 8B, the input impedance becomes 50 ohms. If N 50-ohm lines are connected to the output, the input impedance becomes $200/N$. The number of output lines must be a multiple of 2. Figure 8C is a sketch of the balun transformer. The shield is a half-wavelength long,



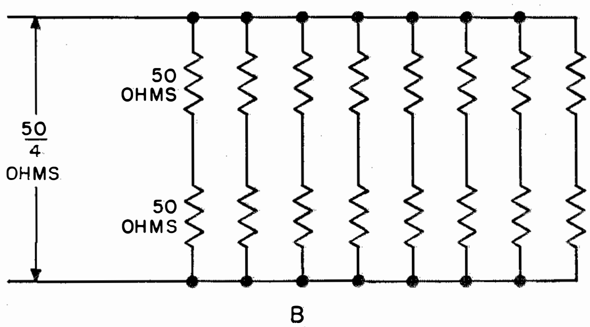


Figure 7—Two methods of connecting 16 loops in series-parallel to obtain practical values of input impedance.

shorted at both ends, so that it presents a high impedance at the center. The inner conductors of the output lines are connected to the two sides of the gap in the input line. The lines connected to one side of the gap are all in phase, but are 180 degrees out of phase (at all frequencies) with the lines connected to the other side of the gap. The loops connected to one side of the balun are reversed so that all loops radiate in phase. Two transformers are used to match to 50 ohms. Only these transformers are changed to accommodate any even number of output lines from 4 to 16 at any 6-megacycle television channel between 174 and 216 megacycles; all other parts of the balun remain the same.

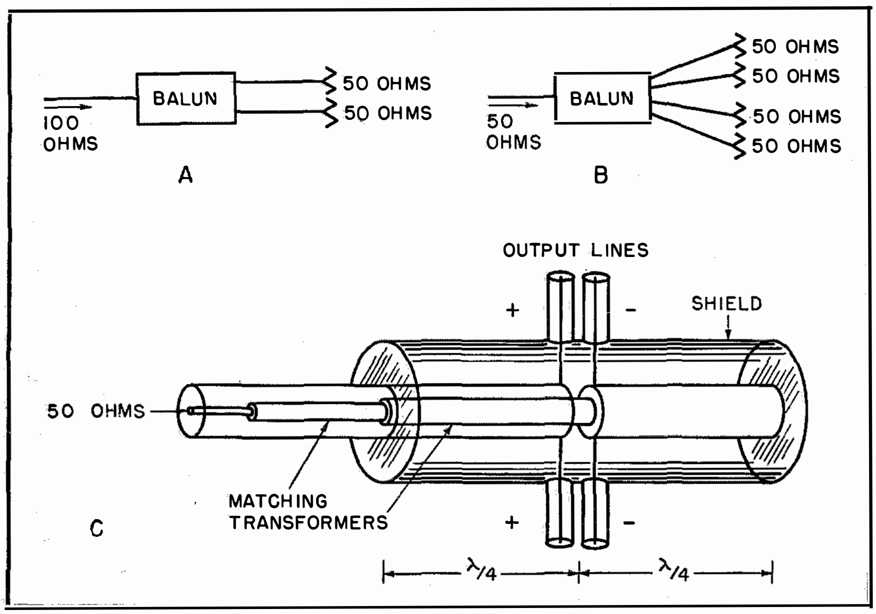


Figure 8—Balun for transforming impedances.

A problem, not fully foreseen in the original design of the stacked-loop array for television applications, is the effect of the very slight coupling between successive pairs of loops on the input impedance of each loop (the standing-wave ratio looking into each loop). Even though this coupling is very low, it introduces a small but nevertheless noticeable variation in impedance over the video bandwidth.

It turns out that it is not possible to compensate for this effect electrically in a simple manner because of the long path length between successive pairs of loops. A practical way out, however, is to place simple untuned isolation rings between pairs of loops as is shown later in Figure 13.

3. Diplexer

A schematic of the diplexer is shown in Figure 9. The two cavities are tuned to the sound-carrier frequency. Cavity *1* acts as a band-pass filter for the sound transmission line while cavity *2* acts as band-reject filter for the sound signals in the picture line. A small amount of the sound transmitter power (less than 0.3 decibel) is absorbed in each cavity. Because of their high selectivity, these cavities have a negligible effect on the picture transmission from the transmitter to the antenna.

An additional quarter-wave tuned circuit is coupled at the input end of the picture line to load it at the sound frequency. This is required to suppress possible oscillation of the output stage of the picture transmitter at that frequency due to the highly reactive load that the diplexer would otherwise present.

The cavities are formed of $6\frac{1}{8}$-inch (15.6-centimeter) coaxial transmission line. Connecting sections are of $1\frac{5}{8}$-inch (4.1-centimeter) coaxial line. The line elements are cut to quarter wavelength for the sound carrier of the band for which the diplexer is to be used. Fine adjustment of the tuning of each cavity is provided by a capacitance plate and screw with locking nut on the outside of the cavity. This has been found to be more satisfactory than vernier adjustment of the length of the inner conductor.

Typical performance data measured on a diplexer tuned to channel *7* are given in Table 2.

The above data were taken with matched loads. A photograph of the unit is shown in Figure 10. A blower is used to supply cooling air to the cavities. The cavity inner conductors are made of silver-plated invar to minimize the shift in resonant frequency due to heating, but a small amount of air (40 cubic feet per minute per cavity) is used so that the cavities, tuned with a signal generator, do not have to be retuned when the full transmitter power is applied.

TABLE 2

PERFORMANCE DATA OF DIPLEXER

Standing-Wave Ratio at Picture-Carrier Frequency	Less Than 1.05
Standing-Wave Ratio at Sound-Carrier Frequency	Less Than 1.20
Insertion Loss—Picture Carrier to Antenna Line	Negligible
Insertion Loss—Sound Carrier to Antenna Line	Less Than 0.5 Decibel
Rejection of Sound Carrier into Picture Line	More Than 26 Decibels
Rejection of Picture Carrier into Sound Line	More Than 23 Decibels

4. Antenna System

The complete antenna system consists of the diplexer, transmission line, and the antenna proper. The diplexer is installed near the transmitter and connected to the antenna through

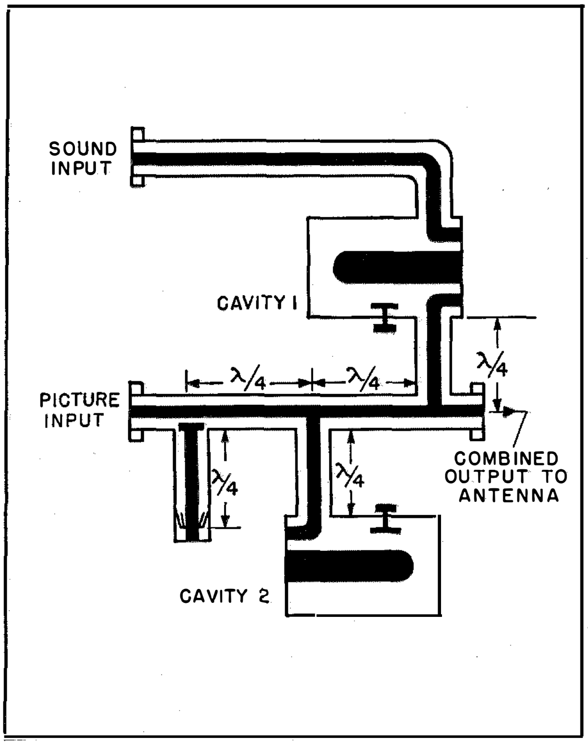


Figure 9—Diplexer for combining sound and picture signals before transmitting them to the antenna.

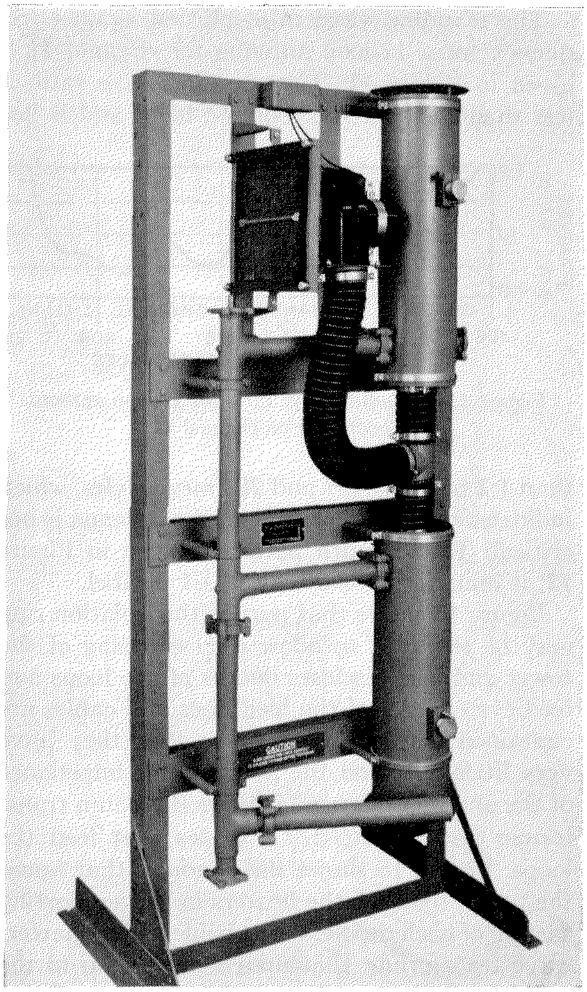


Figure 10—Transmitter diplexer.

50-ohm coaxial air-dielectric line. The size of the transmission line depends on the average power level and how much loss can be tolerated. Generally $3\frac{1}{8}$-inch (7.9-centimeter) or $6\frac{1}{8}$-inch (15.6-centimeter) line is used. Only one coaxial line is required with this antenna.

The gain over a half-wave dipole is given in Table 3 for all channels from *7* through *13*.

TABLE 3

POWER GAIN OVER HALF-WAVE DIPOLE

Number of Loops	Power Gain
2	2.0
4	4.0
8	8.4
12	13
16	17

The standing-wave ratio plotted against frequency for a 12-loop antenna for channel *11* is given in Figure 11. The standing-wave ratio is less than 1.1 over the required band and is less

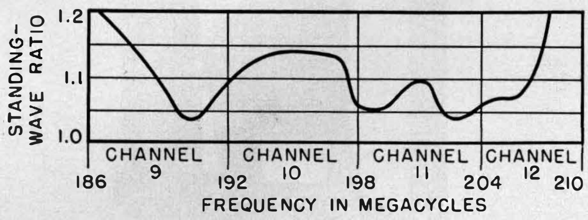


Figure 11—Standing-wave ratio for 12-loop antenna for operation on channel *11*.

than 1.2 between 187 and 208 megacycles, which indicates that the matching of the antenna is not critical. The azimuth pattern, shown in Figure 12, is omnidirectional within ±1 decibel.

Figure 13 shows that part of the isolation ring may be removed to allow easy climbing of the tower and also discloses details of the loops and feed system. All of the feed lines and cables are contained within the tower so that they have very little effect on the pattern and impedance of the antenna. Figure 14 shows the balun transformer and the *RG-17/U* cables that feed the loops. Figure 15 shows the conduits that house the power lines for the heaters in the supporting casting of each dipole. Also visible is the quarter-wave transformer that matches the loop to the cable. Each loop is pressure tight and is supplied with dry air through a tube that connects to the common source.

The 16-loop antenna will safely handle the transmitter powers required to produce an effective radiated power up to 316 kilowatts. The only change required in the 12-loop antenna is to substitute *RG-19/U* cable for the *RG-17/U* cable or to use teflon-insulated *RG-17/U* cable.

5. *Close-In Coverage*

It is sometimes stated that most of the difficulties encountered in receiving a satisfactory signal within a mile or so of the transmitting antenna are due to the fact that this region receives power from the side lobes of a high-gain antenna. In an urban area, it is difficult to separate the effect of reflections from many

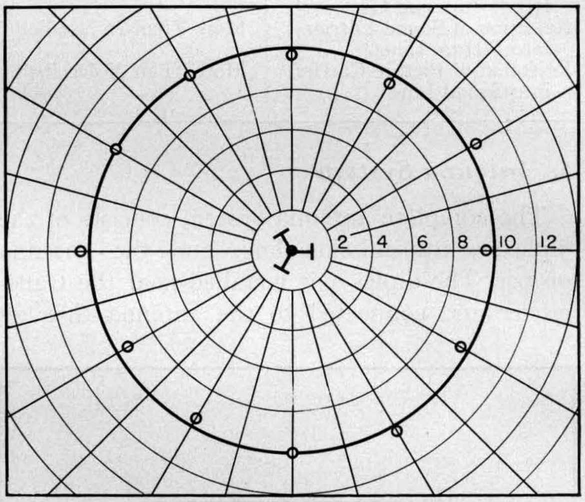


Figure 12—Horizontal radiation pattern of the 12-loop antenna for channel *11*. The circles are for the measured points.

buildings from the effect, if any, of the pattern of the antenna. Figure 16A shows calculated close-in coverage for 18.5 kilowatts of transmitted power into a half-wave dipole and into a 16-loop array located 500 feet above average terrain. It can be seen that there is a very high field strength in the immediate vicinity of the theoretical null of the 16-loop antenna pattern. Hiehle[2] has shown that for a 12-bay antenna 500 feet above ground the field strength is high at distances as close as 200 feet from the antenna base. For very high (a mile or more)

[2] M. E. Hiehle, "Engineering a Super-Gain TV Antenna," *Television Engineering*, v. 2, pp. 16–18, 27–28; May, 1951.

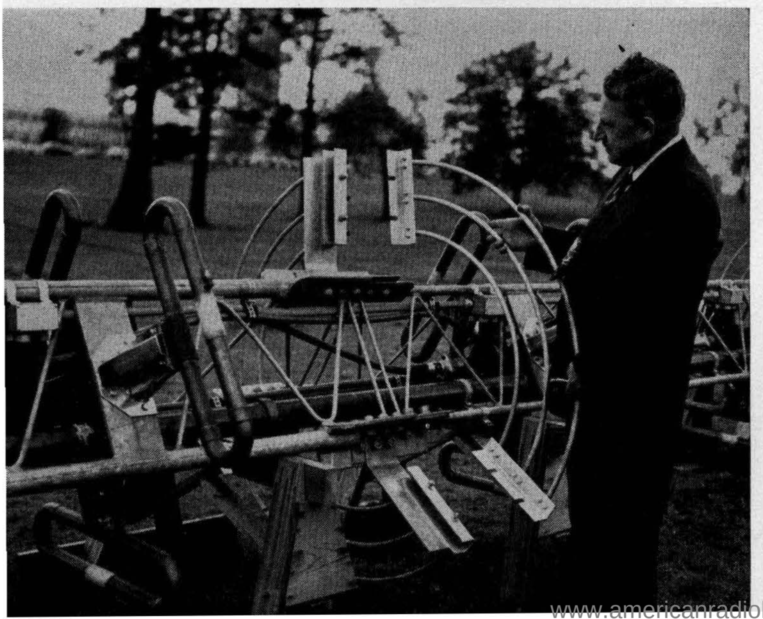


Figure 13—Part of each isolation ring may be removed as shown at the left to permit workmen to climb the tower.

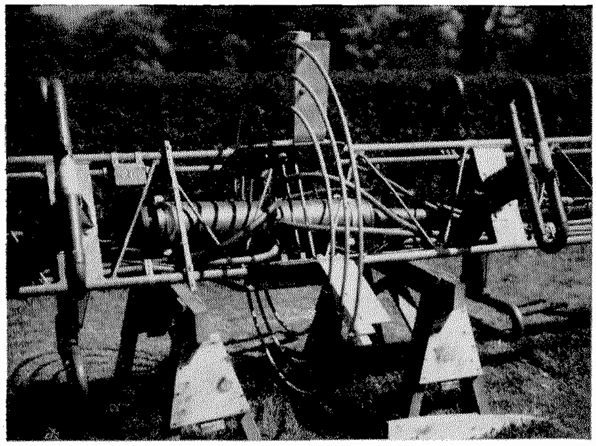


Figure 14—Balun transformer mounted within the tower.

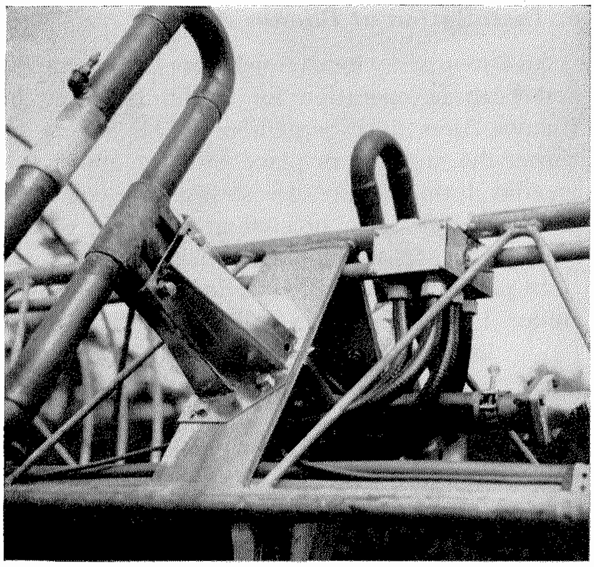


Figure 15—Heaters mounted in the castings that support each dipole are supplied with power through the flexible conduits. The quarter-wave impedance-matching transformer terminates at the junction of the three loops.

antennas, the antenna can be phased to tilt the beam and provide adequate close-in coverage. This may easily be accomplished, as shown in a previous paper[3] by successively advancing the phase of loops with height. This is convenient to do for the feeder to each loop in the array is a matched 50-ohm line.

The minima can be filled by changing the phase of one loop. If the antenna has an odd

[3] A. G. Kandoian, W. Sichak, and R. A. Felsenheld, "High Grain with Discone Antennas," *Electrical Communication*, v. 25, pp. 139–147; June, 1948: also *Proceedings of the National Electronics Conference*, v. 3, pp. 336–346; 1947.

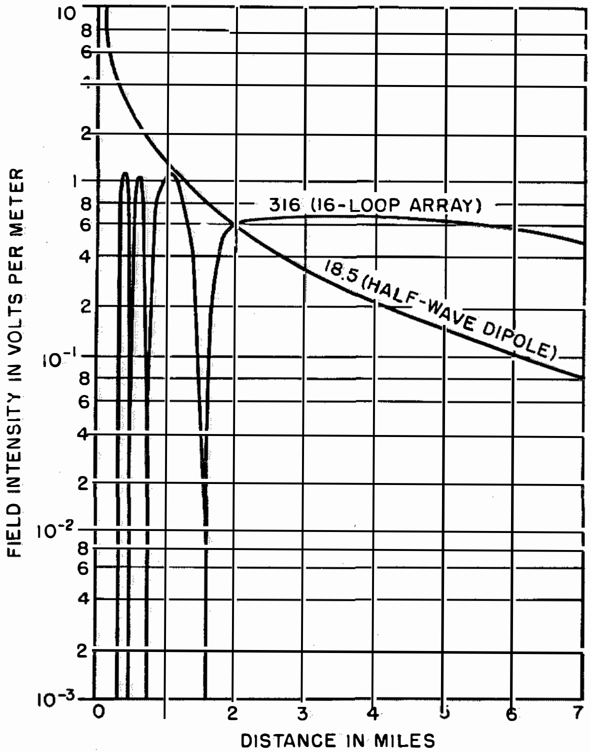


Figure 16A—Calculated field intensity plotted against distance from the base of a 16-loop transmitting antenna and a half-wave dipole 500 feet above ground to a receiving antenna 30 feet above ground for effective radiated powers of 316 and 18.5 kilowatts.

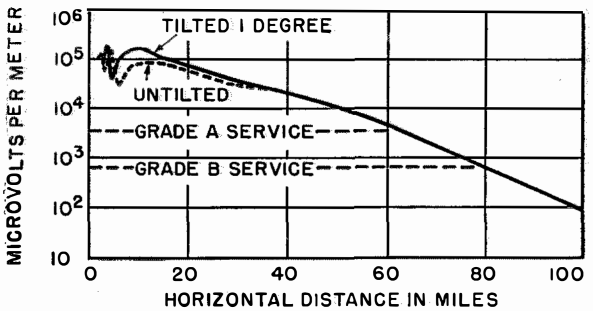


Figure 16B—Calculated field strength for a 16-bay antenna 2000 feet above ground level with the beam tilted down one degree and with the ninth loop from the bottom fed at +90 degrees relative to the other loops.

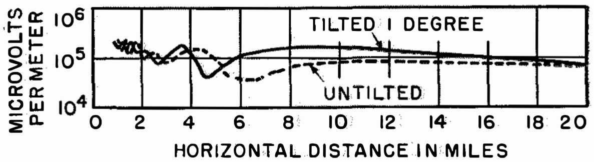


Figure 16C—Enlargement of Figure 16B showing the field strength at distances between 1 and 20 miles.

number of radiators, changing the phase of the center radiator by plus or minus 90 degrees eliminates all nulls because the field from this radiator is always in quadrature with the field from the other radiators. If the antenna has an even number of radiators, changing the phase of one radiator near the center by plus or minus 90 degrees also fills in the nulls, but less completely than with an odd number of radiators. For all practical purposes the results are the same. Figure 16B shows the calculated[4] field strength for a 16-bay antenna 2000 feet above ground with the beam tilted down one degree and with the ninth loop from the bottom fed at +90 degrees relative to the other loops. Grade *A* service (by definition of the Federal Communications Commission, 71 decibels above one microvolt per meter or 3.5 millivolts per meter) extends beyond 60 miles. Grade *B* service (by definition, 56 decibels above one microvolt per meter or 0.6 millivolt per meter) extends out to 80 miles. Figure 16C is an enlargement of Figure 16B and shows the field strength at distances between 1 and 20 miles. Also shown on these figures are the field strengths when the beam is horizontal. By varying the angle of tilt it is possible to favor some distances over others. On the above example the region between $5\frac{1}{2}$ and 20 miles receives more signal than if the beam were not tilted.

With this feeding arrangement, the pattern is roughly "cosecant" (field strength independent of distance) out to about 20 miles. The gain is decreased only a few percent so that high gain is retained for outlying areas where it is needed the most.

[4] "Estimated Field Strength exceeded at 50 percent of the potential receiver locations for at least 50 percent of the time at a receiving antenna height of 30 feet," Appendix 2, Figure 6, Sixth Report and Order of the Federal Communications Commission, FCC52-294; April 14, 1952: Reproduced, for example, in *Television Digest*, Supplement, p. 201; April 14, 1952.

6. *Installation at Buenos Aires*

An 8-loop array for channel 7 has been installed and been in operation for Radio Belgrano in Buenos Aires since September, 1951. Figure 17 shows the antenna in place 450 feet above the ground level. Figure 18 shows the complete antenna unit being hoisted up the side of the steel tower atop the building.

In place, the over-all standing-wave ratio was under 1.1 from 174 to 180 megacycles, being 1.05 at video-carrier and 1.07 at sound-carrier frequencies. No electrical adjustments were necessary during installation for antenna, transmission lines, or diplexer.

Actual field-intensity data are not available for this installation but good reception has been reported in many locations—including several good reports from Montevideo, Uruguay, at a distance of 140 miles (225 kilometers).

7. *Acknowledgments*

Valuable contributions to the mechanical design, construction, and electrical tests of the antennas, balun, and diplexer from Meade J. Maynard and Clement J. Tionaytis, both of Federal Telecommunication Laboratories, is gratefully acknowledged.

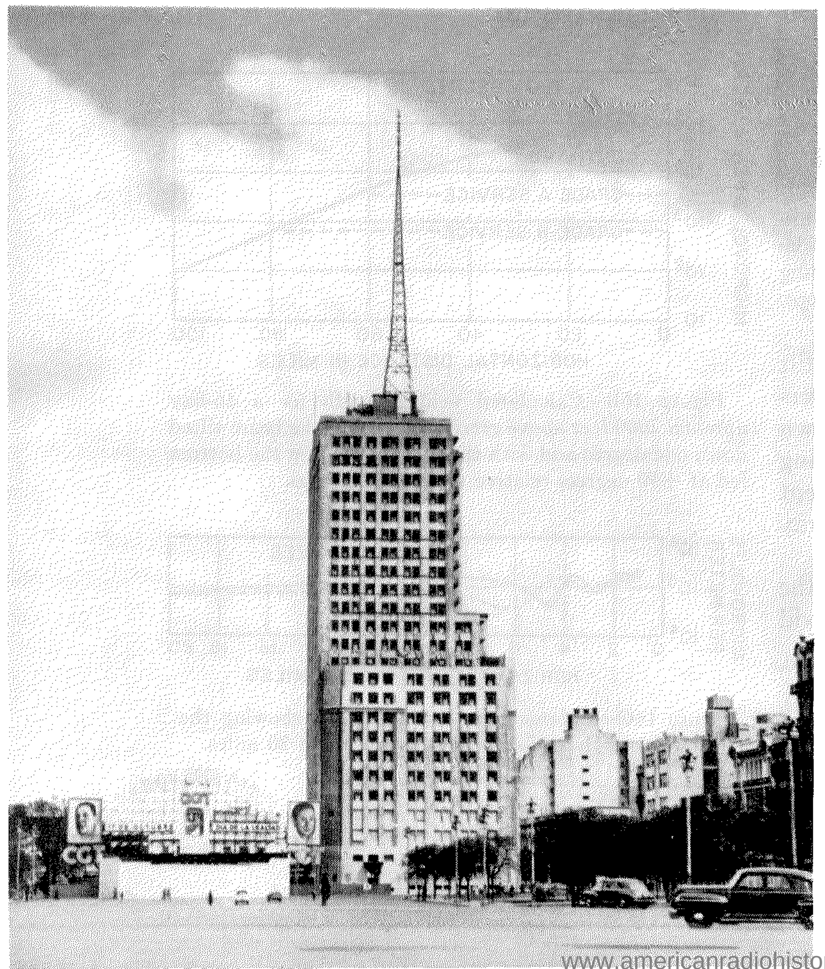
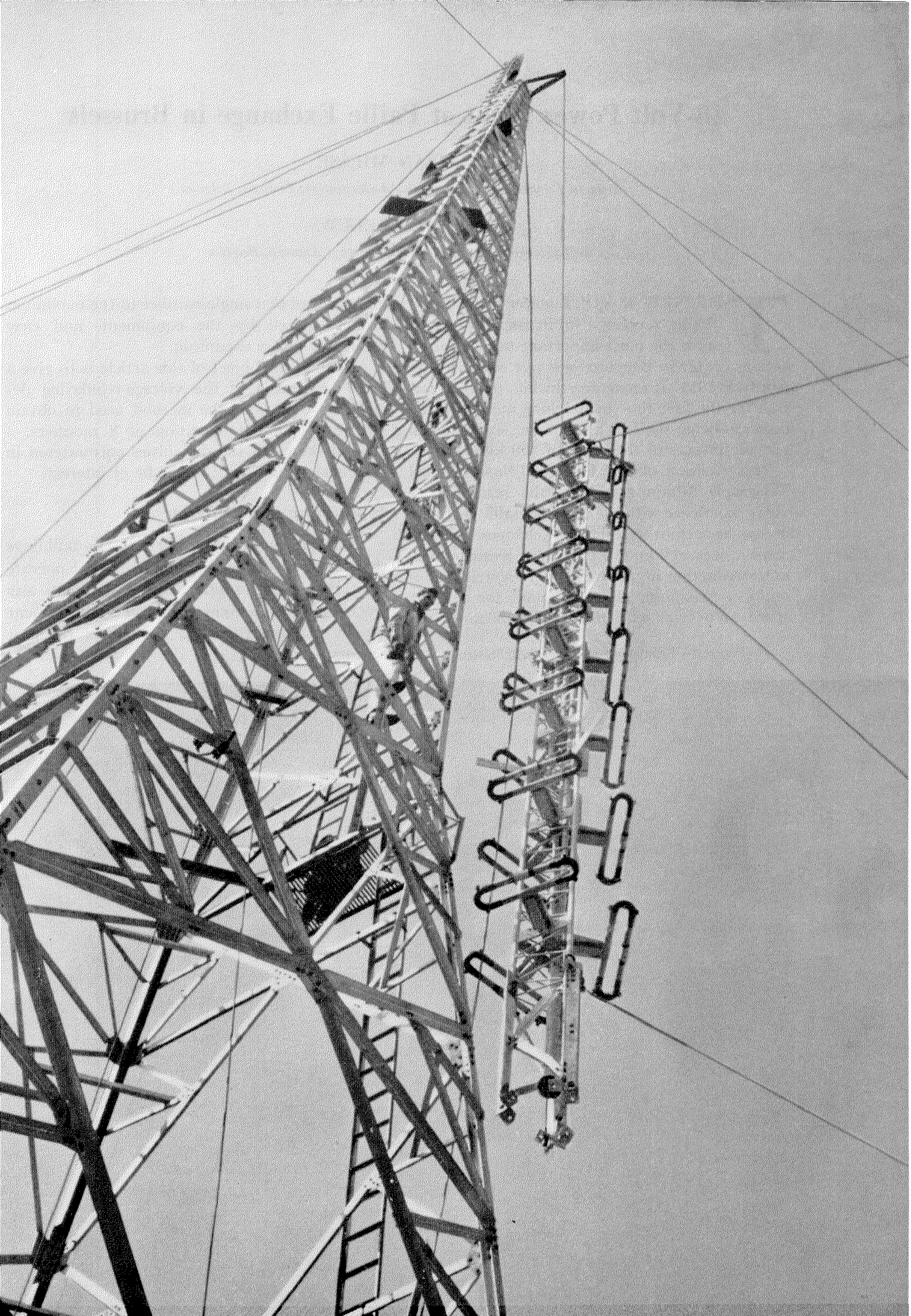


Figure 17—Radio Belgrano antenna in Buenos Aires, Argentina is shown at the left.

Figure 18—On the opposite page, the complete antenna being hoisted to the top of the tower for final installation.



48-Volt Power Plant at Paille Exchange in Brussels

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THE NEW 48-VOLT power plant of the Paille exchange in Brussels, which is now the most-important telecommunications center in Belgium, was put in service on April 15, 1951. It seems worthwhile to point out that for the first time in Belgium, metallic rectifiers are being used in a telephone exchange to provide powers of the order of 100 kilowatts.

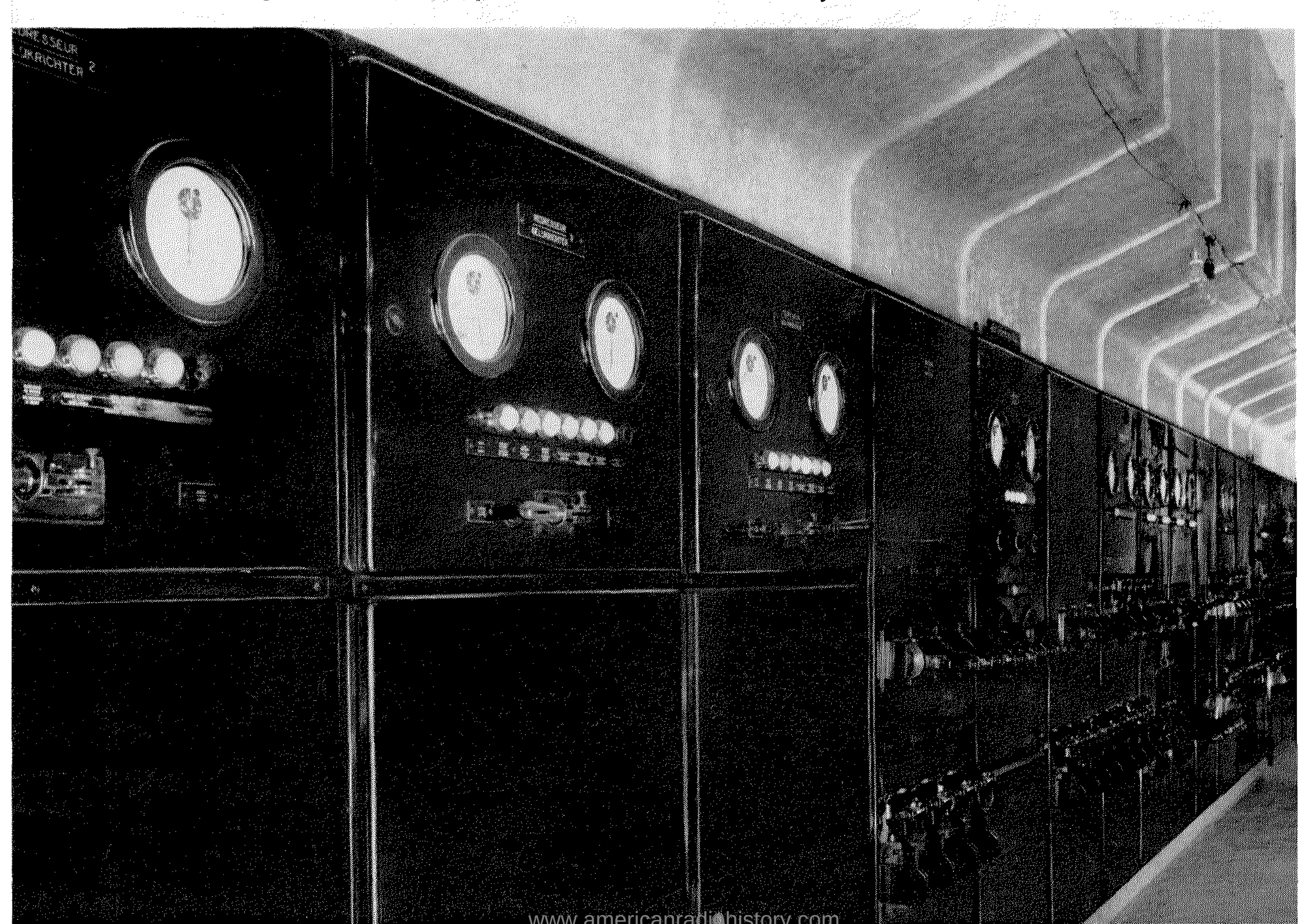
This decision of the Belgian Telephone and Telegraph Administration is the result of 15 years experience with the use of metallic rectifiers in less-important telephone exchanges. In this respect, it is well known that these rectifiers permit a reduction in maintenance to a strict minimum, a maximum of power plant for a given space, an over-all efficiency nearly constant from quarter-load of a single rectifier to the maximum drain required by the equipment, and easy means for future expansion.

Although the object of this article is to give a brief description of the voltage-regulating devices, as well as of the method used to obtain automatic parallel operation of 8 rectifiers, a general sketch of the difficulties encountered in the construction work might be of interest.

1. Building Construction

There are two distinct parts to the buildings that house the various equipments that operate from the 48-volt supply. A new building was erected after the second world war to supplement an old one constructed at the end of the past century.

Figure 1—Front view of power switchboard.



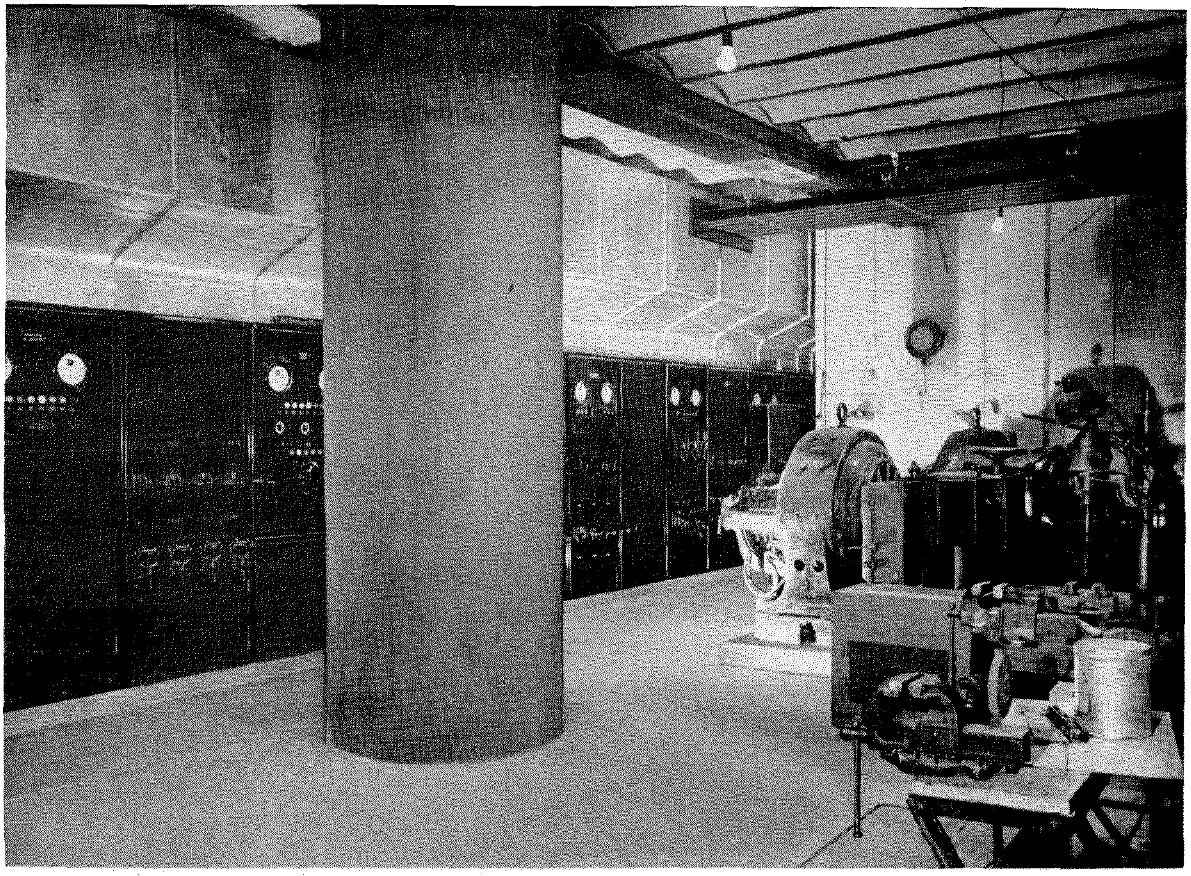


Figure 2—Power room partially completed, showing one of the columns that had to be increased in diameter.

The original power equipment was installed in the lower part of the old building, and the new plant, which required a larger area, had to be installed in part at the same place.

Only a careful program of work made it possible to carry out the changes without a single interruption of power to the exchange, notwithstanding the fact that the operations were very much hindered by the work required for the reinforcement of the building and the entire reconditioning of the power room.

As an example of these modifications, after the new 48-volt power board was cut in service, the columns supporting the floors above the power room had to be enlarged from 0.35 square meter to 1.35 square meters (3.8 to 14.5 square feet). The additional floor space allotted to the new power plant required knocking down a supporting wall and its replacement by beams resting on pillars and on the front and rear walls of the building. A new concrete floor had to be poured.

Figures 1 and 2 show front views of the switchboard and the power room. It will be noted that the board is still partly hidden behind a temporary screening and that all the plastering is still to be done. A false ceiling, which will cover the feeders, is to be made and tiles must be laid on the floor. The space above the power board is occupied by a ventilating duct made of sheet iron to carry off hot air. It is still to be masked by a false wall matching the other walls of the room. This false wall will be about 0.8 meter (2 feet 8 inches) in front of the power panels and its lower edge will conceal the lamps that light the board.

The ventilating duct is necessary because the whole building, the power room included, is air conditioned. It was judged most economical to exhaust directly out of the building the heat produced in converting relatively large amounts of electric energy into direct current. The fresh-air inlet is taken from the cable space under the power room and is about 1.6 meters (5 feet 3 inches) high. Figure 3 is a rear view of the board in its present state.

It is obvious that when activities of this kind are carried out, the amount of dust and moisture in the air depart greatly from normal. Even with the use of cardboard screens, dust infiltrates into the best-protected apparatus and metal parts not perfectly protected become oxidized. It is, therefore, noteworthy that during the 9 months the new power plant has been in service, practically no trouble has been experienced with it and the appearance and finish of the board and its associated apparatus did not suffer from the abnormal atmosphere to which they were exposed.

2. *Importance of the Installation*

The Paille exchange is the most important center for telecommunications in both Brussels and Belgium. The exchange is situated in the busiest part of the city, and it accommodates equipment for a number of important functions.

A. 22,000 fully automatic subscriber lines with provision for 40,000 lines.

B. It is the pivotal center for 15 rural offices, with provision for 17 such offices, of the Brussels telephone district, having at present 25,000 lines connected and a numbering capacity of 90,000 lines. This rural center exchange not only links the tandem connections among the different rural offices, among the rural offices and the Paille subscribers, but also the calls between the rural offices and the 200,000 subscribers connected to the eleven 7-A rotary exchanges of the city

C. The automatic toll center for the subscribers of the 12 city and 15 rural exchanges of the Brussels telephone district.

D. A manual toll board for incoming and outgoing traffic emanating from manual exchanges.

E. The automatic toll transit center for Belgium.

F. The manual international toll board for most Belgian subscribers

G. An international manual transit board.

Practically all the above equipments operate at 50 volts and, although the present current drain does not normally exceed 2000 amperes, a normal busy-hour drain of 2500 amperes is expected in the near future with a peak of about 2800 amperes. This high drain is the result of several factors.

Figure 3—Rear view of power switchboard.

A. The high traffic per line connected to the local exchange.

B. The large amount of automatic incoming, outgoing, and tandem rural and toll traffic.

C. The introduction of subscriber-to-subscriber dialing over long-distance lines with automatic apparatus to compute charges for such calls.

3. *Chief Technical Requirements*

The power plant must be able to deliver a maximum current of 4000 amperes at 48 volts. The current distribution is over two groups of common busbars or sectors, each composed of 6 main discharge feeders. Each of the common busbars is to be supplied from:

A. Four selenium rectifiers incorporated in the power board, each delivering 250 amperes at 48 volts.

B. Two lead storage batteries, each having 26 cells, a plate capacity of 2500 ampere-hours, and a tank capacity of 3000 ampere-hours.

C. Two motor-generator sets, each consisting of a 900-ampere 48-volt shunt-wound dynamo driven by a synchronous motor. These units were already in service in the old installation.

The power board must incorporate a reserve bay to permit the addition of a third motor-generator of 1000-ampere capacity. The connections are to be so arranged that any one of the three motor-generators can be connected to either sector.

Each of the two sectors must be so arranged that either or both batteries can be floated, charged, or discharged as required. Floating is to be performed on 23 cells between 49.5 and 50.6 volts.

It must be possible to charge 24, 25, or 26 cells up to 2.7 volts per cell. While one battery is being charged, the other should remain connected to the load and floated between the specified limits.

Discharge is to be obtained from 24, 25, or 26 cells without dropping below 48 volts, and the introduction of the additional cells to maintain that minimum voltage must be automatic.

When, during heavy-traffic hours, a motor-generator is connected in parallel with the rectifiers and the output is adjusted to a fixed value, the current delivered by the rectifiers should adjust automatically to the reduced requirement. The generator must deliver this fixed output and any variation in the current required by the telephone equipment is to be provided by the rectifiers. The voltage at the battery busbars must remain between the floating limits of 49.5 and 50.6 volts.

When the output of a motor-generator rises beyond its rated capacity, this is to be indicated by visible and audible alarms. When the output of a motor-generator drops below a predetermined but adjustable minimum, visible and audible alarms are also required.

While cells 1 to 23 of the batteries are being floated, sufficient current must be delivered to cells 24, 25, and 26 by an adequate rectifier to keep them in a 100-percent-charged condition.

In addition to the above requirements, the administration requested the possibility of operating both sectors temporarily in parallel. This splitting of the discharge into two independent sectors could not be done at the time the board was first installed.

To satisfy this requirement, the busbars of both sectors have been connected in parallel. The battery cell switches have been mechanically coupled and both switches are driven by a common servo motor under the control of a voltage relay. The 4 batteries are normally operated in parallel. The interconnection of the rectifiers has been changed in such a manner that all 8 rectifiers are automatically inserted one after the other as required by the load.

The 2-sector arrangement can be restored without any difficulty when the situation makes it necessary.

4. *Rectifier Requirements*

In floating position, the rectifier must keep the voltage between the floating limits of 2.15 and 2.2 volts per cell for any output up to 250 amperes, even if the mains supply varies by ±10 percent in voltage and ±2 percent in frequency.

When the nominal output of a rectifier is reached, its voltage must drop so that it cannot for practical purposes be overloaded, even when short circuited. The control of the voltage must be effected by fully static means, excluding the use of servo motors, contact voltmeters, and electronic valves.

The psophometric voltage of the superimposed alternating currents measured at the terminals of the battery should not exceed 0.002 volt.

In charging position, the output of each rectifier is to be easily adjustable and the minimum output at 70 volts must be 200 amperes.

5. *Description of Equipment*

5.1 Circuit and Equipment Arrangement

Figure 4 shows a simplified circuit used for the 48-volt plant, and Figure 5 shows the arrangement of the panels comprising the board. They indicate clearly how the equipment was designed to comply with the requirements to operate the

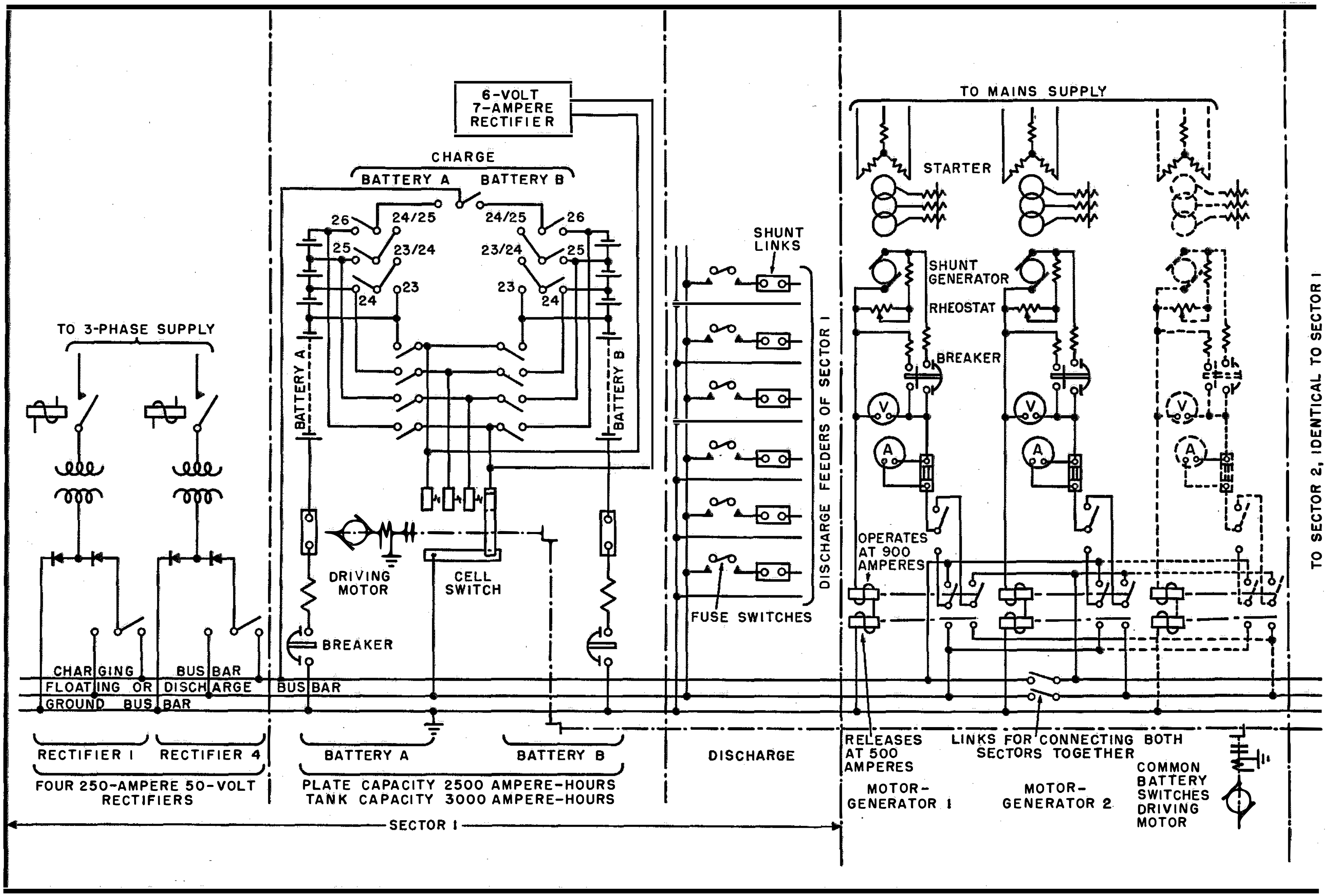
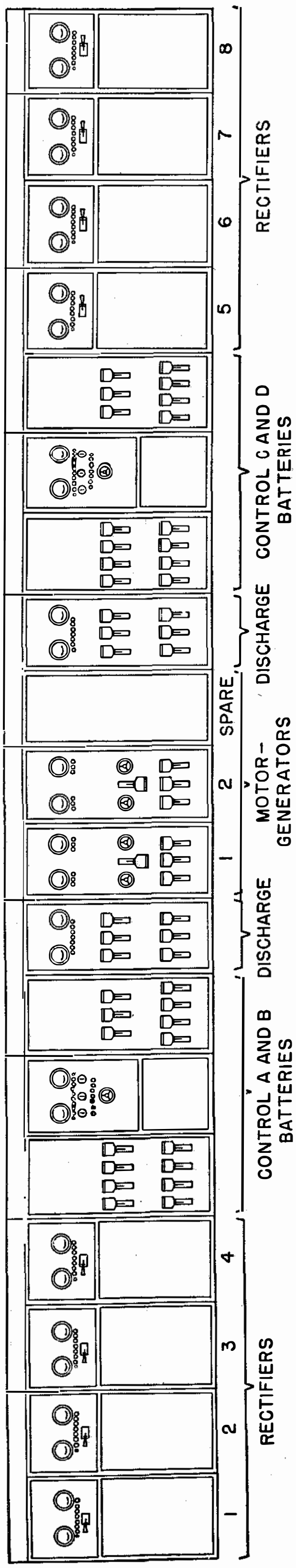


Figure 4—Simplified circuit of the power plant is shown above.

Figure 5—Arrangement of the panels making up the switchboard is shown below. The equipment is 17.4 meters (57 feet) long.



power plant as a single unit or split into two sectors.

The two 2000-ampere battery-cell switches are shown mechanically coupled together; they add emergency cells automatically when the batteries go on discharge. These cells could also be automatically disconnected by the voltage relay that switches them in, but the connection to permit this has been omitted as the Administration prefers that this action be taken by the maintenance man. The position of the cell switches is indicated by signaling lamps.

When manual control is required, either for adding or for subtracting cells, the switching motor can be started in the corresponding direction by pushing a BATTERY VOLTAGE INCREASE or a BATTERY VOLTAGE REDUCTION key. To care for possible motor or circuit trouble, the cell switches are designed so that they can be driven to any desired position by operating a handwheel on the front of the board.

The circuit is arranged so that an accidental opening of the mechanical coupling between the two battery-cell switches stops the common driving motor.

When the power plant is operated in two sectors, batteries *1* and *2* can only be charged by rectifiers *1* to *4* and batteries *3* and *4* by rectifiers *5* to *8*. But each of the four batteries can be charged by the two or three generators. When operated as a single unit, the batteries can also be charged by each of the 8 rectifiers.

The four batteries, when connected for discharge, are floated by all the rectifiers and generators in parallel when this is necessary. The splitting of the power plant into two sectors, or its operation as a single unit, does not affect the floating.

In all principal leads as well as in the discharge feeders, "shunt links" are shown. These shunt links consist of two terminals for connecting a recording ammeter. The terminals are normally bridged by a suitable link, which can be removed after the ammeter shunt has been connected. This arrangement is based on the idea that ammeter indications should be supplemented by a continuous record to obtain a true picture of the load carried over the entire day.

All switches are mounted at the back of the board, but are operated from the front. The fuses as well as the circuit breakers protecting the batteries are located at the rear of the board. The circuit breakers protecting the generators are also mounted at the rear, but can be operated from the front. The circuit breakers are shock mounted so that, when they open, no troublesome mechanical vibrations are transmitted to the equipment.

5.2 Main Parts of the Rectifier Equipment

Each rectifier unit is composed of a main rectifier for floating and a booster rectifier. This booster rectifier is switched in series with the floating rectifier when the voltage is to be increased for charging the batteries.

5.3 Rectifiers

To provide fully static means of controlling the output of the rectifiers, extensive use is made of saturated reactors. For the convenience of the reader, a brief statement of the operation of these extremely useful devices will be given.

5.3.1. *Saturated Reactors*

As is well known, the inductance and the corresponding reactance and impedance of a winding on a ferromagnetic core is reduced if a unidirectional magnetic field is set up in the core. The inductance will drop as the magnetic field is increased until the core cannot carry additional lines of magnetic force. This is the saturation point.

For control purposes, the inductance (impedance) is connected in series with the alternating-current-operated device to be controlled. The unidirectional magnetic field is set up by a direct current flowing in one or more auxiliary windings. The electric and magnetic circuits are proportioned to produce the required changes in impedance over the operating range of the equipment and to prevent harmful effects from alternating voltages induced in the direct-current windings by transformer action from the winding carrying the alternating current.

5.3.2 Main Rectifier

Figure 6 shows the manner in which the rectifiers are controlled. The main as well as the booster rectifier, the latter not shown in Figure 6, are both full-wave 3-phase systems. For simplification, the main rectifier is shown as if it were a single-phase full-wave system. Similarly, the saturated reactors will be shown in simplified form.

The main rectifier *RE1* is supplied with power through *T1* from the 50-cycle mains and delivers power to the load circuit through the parallel connection of *R2* and winding *B* of the saturated reactor *SR1*. The current through *B* is proportional to the output of the rectifier and will develop a flux in *SR1* that reduces the impedance in series with the primary of *T1*.

The current through winding *C* develops a flux in the same direction as that from *B*. This current is obtained from the auxiliary rectifier *RE2* and may be considered to be the voltage-stabilizing means.

Winding *D* gets current only when the output of the rectifier increases above its rated or some other preset value. The flux developed by this current is in opposition to that generated by windings *B* and *C*. The purpose of this current is to reduce the voltage of the floating rectifier to prevent overloading and to limit its output.

5.3.3 Auxiliary Rectifier

The auxilary rectifier *RE2* supplies the voltage-stabilizing current to winding *C* of *SR1* and the accuracy of its voltage determines the voltage limits between which the main rectifier will float

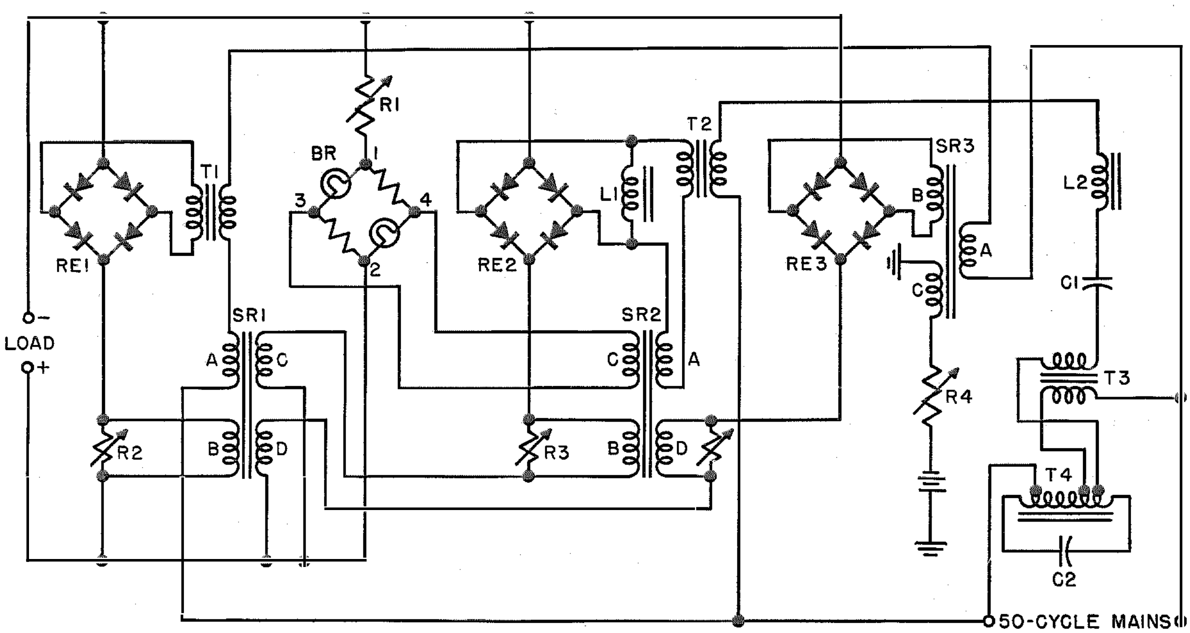


Figure 6—Rectifier circuit.

the load. The output voltage of the auxiliary rectifier is regulated by two different means.

The voltage of the alternating current supplied to transformer *T2* of rectifier *RE2* is stabilized through the action of *T3* and *T4*, which will be treated later. In addition, a saturated reactor *SR2* has its impedance winding *A* in series with *L1* from across which the rectifier *RE2* obtains its power. Winding *B* produces a flux proportional to the intensity of the output current and compensates for the voltage drop in the rectifier disks and in the various windings. Its value is set by *R3*.

Winding *C* corrects for any variation of input alternating voltage that may occur despite the stabilized alternating-current supply and the effect of winding *B*. It is sensitive to the value of current supplied by the reference-voltage source described in Section 5.3.5.

Winding *D*, as in the case of *SR1*, prevents overloading and limits the output.

5.3.4 *Magnetic Stabilizer for Alternating Current*

The alternating current supplied to the auxiliary rectifier through *T2* is stabilized by means of a saturated autotransformer *T4* in series with a nonsaturating transformer *T3* (Figure 6). The iron core of the autotransformer being of small area, saturation occurs, and the current flow in the winding changes rapidly even for small variations of input voltage. However, very little voltage variation occurs across the output terminals of *T4*. In contrast, practically all of the voltage variations of the mains supply are transferred proportionately, according to the transformer turns ratio, to the secondary of *T3*. The voltage variations across this secondary are equal to and in opposition to the variations of the mains supply; the voltage appearing across the primary of *T2* thus remains constant.

A tuned filter, composed of capacitor *C1* and inductor *L2* is incorporated to avoid voltage changes due to changes in mains frequency. The impedance of the filter varies with frequency over a sufficiently wide range; the voltage adjustment is especially sharp between 49 and 51 cycles.

5.3.5 *Reference Voltage*

This part of the circuit consists of a bridge *BR* with two opposite arms formed by linear resistors and the other two arms by constant-current lamps of the iron–hydrogen type. The output voltage of the main rectifier is applied through a series resistance *R1* to the bridge terminals *1* and *2*. The current is adjusted by means of *R1* so that the potential between *3* and *4* is zero when the main rectifier voltage is at its normal value of 50 volts. When there is no voltage between *3* and *4*, no current is sent through the winding *C* of *SR2*. An increase or a reduction in the rectifier voltage disturbs the balance of the bridge and as the current variation is taken up by the lamps, a potential difference is created between terminals *3* and *4*, sending a current through winding *C* of *SR2*, thus changing the impedance of winding *A*.

5.3.6 *Current-Limiting Device*

The current required by windings *D* of *SR1* and *SR2*, when the output of the floating rectifier may not be increased further, is obtained from winding *B* of the saturated reactor *SR3* and rectifier *RE3*. The core of *SR3* is so saturated by direct current passing through winding *C* that the flux generated by the alternating current through winding *A* has so little effect on the magnetization of the cores that the voltage induced in winding *B* is normally too low to obtain at the terminals of rectifier *RE3* a direct voltage higher than the voltage of the main rectifier. When the flux generated by the alternating current in winding *A* rises to such a value that at each half period the direct-current flux value is reduced below the knee in the magnetization curve, the voltage at the terminals of rectifier *RE3* will rise suddenly and the voltage of the limiting device will go above the voltage of the main rectifier and send direct current to the windings *D* of *SR1* and *SR2*, reducing the output voltage of the main rectifier.

5.3.7 *Output-Current Relays*

Current-controlled relays are provided to operate when the rectifier output reaches 90 percent of full load and when it drops to 20 percent of full load. These relays are energized from saturated-reactor-type power supplies similar to those used for the current-limiting system, and their operation will be discussed in Section 6.2.2.

5.3.8 Power-Factor Correction

Capacitors are provided to improve the power factor of the equipment. These capacitors are connected between the phases of the supply and are protected by a circuit breaker.

6. Circuit Operation

6.1 Control of the Main Rectifier

To illustrate how the auxiliary rectifier with its reference-voltage bridge and current-limiting device stabilizes the voltage of the main rectifier, reference is made again to Figure 6. It will be evident that the three rectifiers are connected in parallel to the same load, the outputs of *RE2* and *RE3* also flowing through windings of *SR1* and *SR2*.

The auxiliary rectifier *RE2* is adjusted so that the voltage between its terminals to the load remains at 50 volts. An increasing direct current from it passing through winding *B* of *SR2* will reduce the impedance of winding *A*. The current through *B* is adjusted by *R3* and will be set for the condition of the voltage drop in rectifier *RE2*, in winding *B* itself, and in winding *D* of *SR1*. Any potential difference appearing between *3* and *4* of the lamp bridge will send a current through winding *C* of *SR2* and the flux generated by this current will aid or reduce the flux created by the winding *B*.

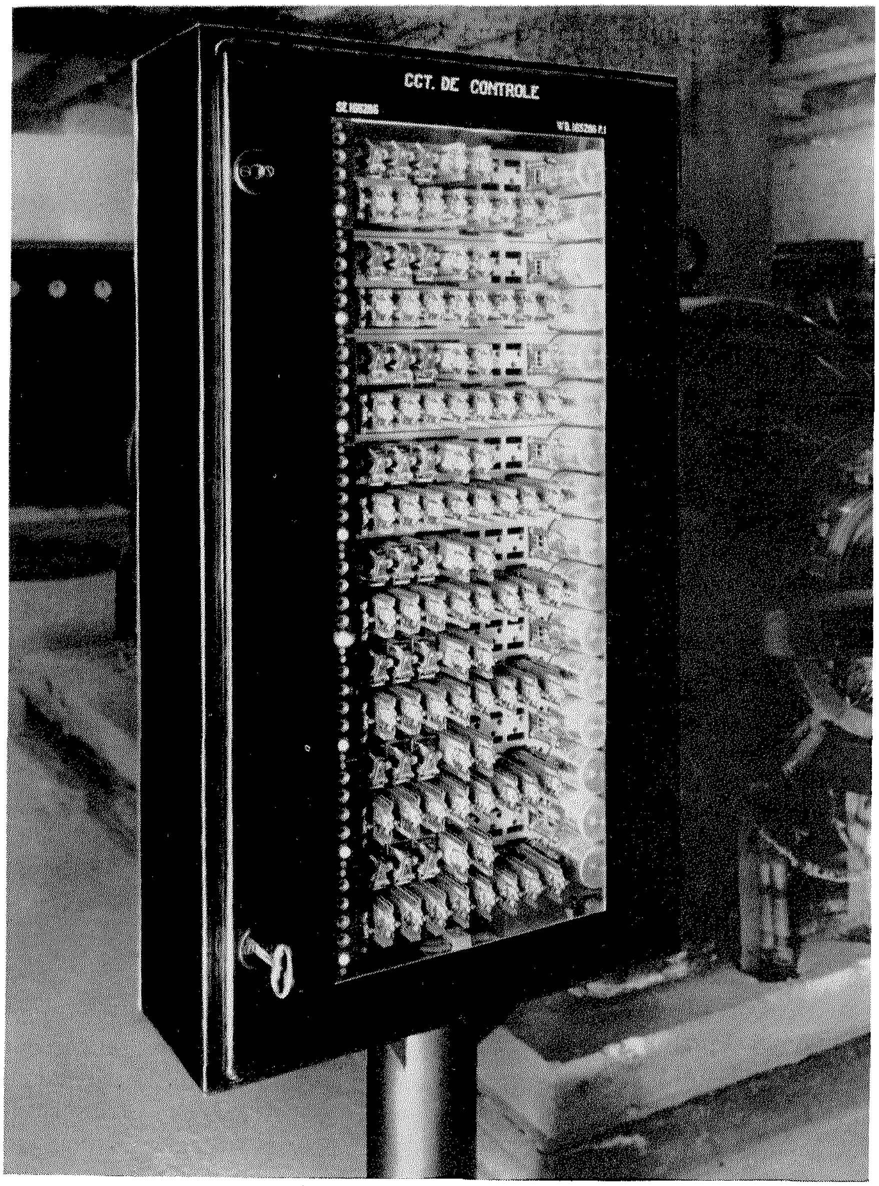


Figure 7—The protective and controlling relays are mounted in an airtight box.

The alternating voltage impressed on the main-rectifier elements *RE1* has such a value that at no load and maximum mains-supply voltage the voltage between the main-rectifier load terminals does not rise above the specified maximum voltage limit of 50.6 volts. When the reactance of *A* is reduced to its minimum by saturation of the core, there must be sufficient alternating voltage at the terminals of the transformer *T1* to keep the direct voltage between the load terminals above the specified minimum value of 49.5 volts, when the mains voltage is at its specified minimum and the nominal full output current passes through the rectifier *RE1*.

If, due to low mains voltage or incomplete compensation for rectifier and other losses, the voltage at the load terminals of the main rectifier drops below 50 volts, the auxiliary rectifier, whose output voltage does not vary, will start feeding the load as soon as its voltage is higher than that of the main rectifier. The current it delivers passes through winding *C* of *SR1*, reinforcing the flux of the winding *B*. The voltage between the load terminals is thereby raised sufficiently to keep it well above the minimum voltage limit.

When the alternating current drawn by the main rectifier goes over the rated value, the voltage across the load terminals of the current-limiting device *RE3*, will rise above the voltage of both the main and auxiliary rectifiers and it will, therefore, deliver current to the load. This current in passing through windings *D* of *SR1* and *SR2* reduces the flux in these reactors, increases the impedance of their windings *A*, and the voltage impressed on both rectifiers *RE1* and *RE2* is reduced. This reduction is so great that the current does not increase above the specified nominal value.

6.2 Automatic Rectifier Switching

Originally, it was intended to mount the control relays of each rectifier on a plate in the rectifier cabinet. The large amount of dust floating in the air after the installation of the power board and the necessity that the plant operate in these dusty conditions for months, induced both the Telephone Administration and the manufacturer to remove the relays from the rectifiers and to mount them in an airtight box in front of the power board. Figure 7 shows this control unit. The arrangement has proved very practical.

Figure 8 shows the relay circuit of one of the rectifiers. When the rectifier is disabled, switch *S2*, which is part of the switch connecting the rectifier output to either the floating or charging busbar, is left in an intermediate position. Switch *S1* is thrown to the position where the impulsing circuits (right of diagram) are connected straight through the rectifier without possibility of interference by the relay circuit of the disabled rectifier. Since operation of the power plant requires a rectifier in priority condition, *S3* must be in the right-hand position before *S1* is operated. Then, unless the main switch (not shown) connecting the primaries of *T5* and *T6* to the mains supply is opened, relays *RY1*, *RY2*, and *RY3* will be operated, or closed, but all other relays will be unenergized. Relays *RY1*, *RY2*, and *RY3* merely indicate that the proper mains supply is present.

6.2.1 Priority

Of the 8 rectifiers that float the batteries during the busy hour, any one can be designated to control the outputs of the others.

The rectifier performing the control operation is called the priority rectifier. All 8 rectifiers being alike, they can all be used as priority rectifiers. The rectifier chosen for controlling the others is given the required characteristics by operating its relays *RY10* and *RY11*. These relays close when *S3* is thrown to the priority position. A lamp mounted on that rectifier and another near the control relays will then indicate which rectifier has the priority function.

When by inadvertance more than one priority key is pushed, only the lowest-numbered rectifier will switch to the priority condition.

In the Paille exchange, all rectifiers successively operate for a week as priority rectifier. The Administration thereby has the practical guarantee that all rectifiers are in good condition and able not only to float the battery but also to control the 48-volt power plant.

6.2.2 Floating

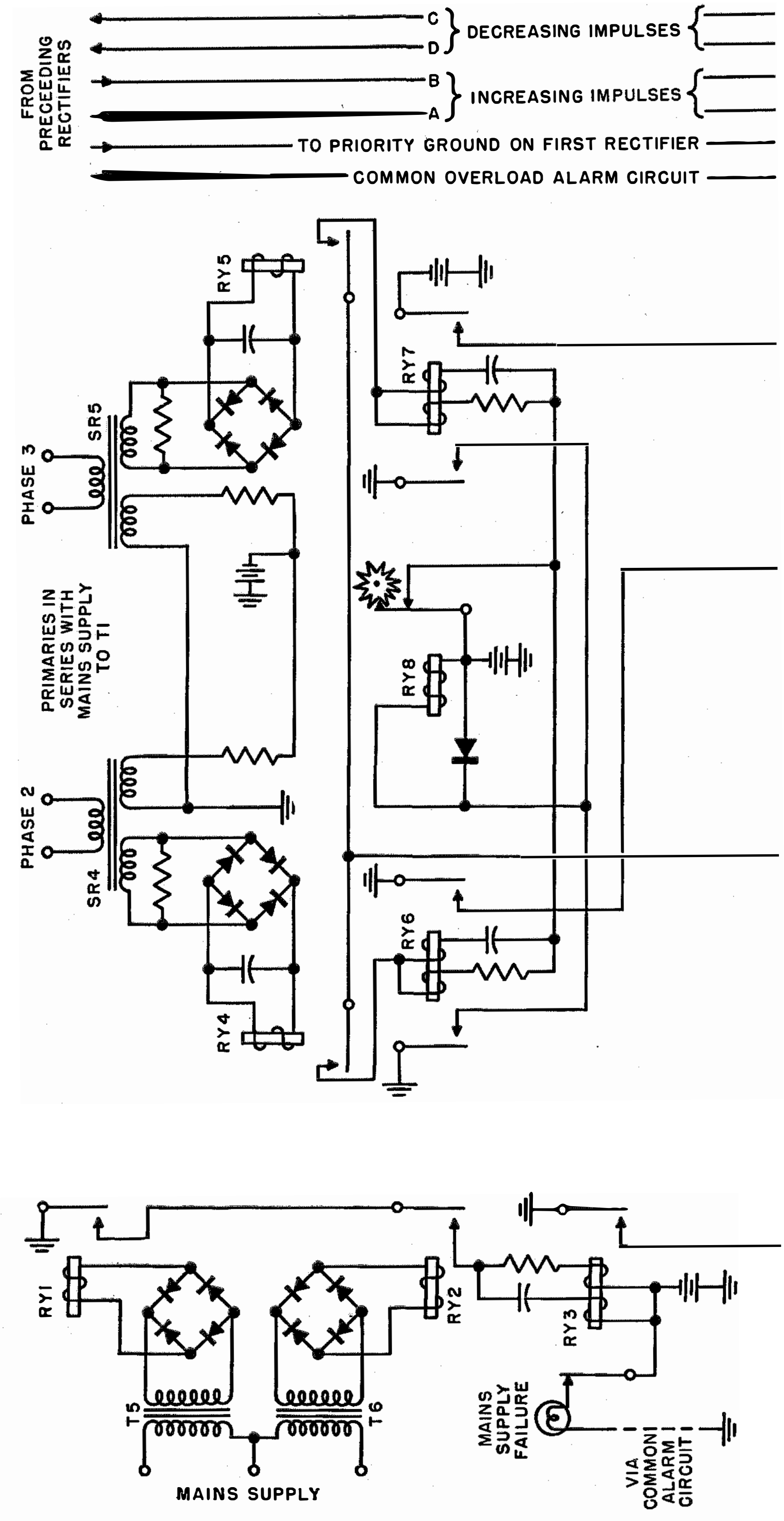
All rectifiers able to float the load have their switches *S1* and *S2* in the position shown in Figure 8. Only the rectifier that has been given priority has its switch *S3* in the left-hand position; for the others, *S3* is thrown to the right. Through contacts not shown on *S2*, the outputs of *RE1*, *RE2*, and *RE3* will be applied to the telephone exchange floating busbar.

The relays that are energized under these conditions are, for all rectifiers, *RY1*, *RY2*, *RY3*, and *RY9*; and, in addition, the priority rectifier has its relays *RY10*, *RY11*, *RY14*, and *RY17* also energized.

Saturable reactors *SR4* and *SR5* operate in the nature of current transformers. The current drawn by the primaries of *T1* (Figure 6) also flows through the primaries of *SR4* and *SR5*. The constants of the circuit incorporating *SR4* and *RY4*, and the saturating current in the control windings of the reactor, are so adjusted that when the output current drawn from the rectifier, and hence the current flowing through the primaries of *T1* and *SR4* reaches 90 percent of the nominal output, or 225 amperes, relay *RY4* will operate. Similarly, if the current drawn from the rectifier drops below 20 percent of the nominal output, or 50 amperes, *RY5* will open.

6.2.2.1 Increasing Load

Now, in periods of light traffic in the exchange, only the priority rectifier will be floating the load. Let us then assume that the traffic starts to increase until the current drawn from this rectifier reaches 90 percent of its capabilities, or 225 amperes. Relay *RY4* will than close. This will close the circuit of *RY6* which will send an impulse through closed contacts of *RY11*, through impulsing line *A*, to *RY14* of the following rectifier in which only *RY1*, *RY2*, *RY3*, and *RY9* are energized. In this second rectifier, *RY14* will operate and will lock in the energized position through its front contacts and the coil of *RY13* and contacts of *RY9* and *RY17*. Then, *RY13* and *RY14* in the second rectifier are energized, and its output is applied to the busbar.



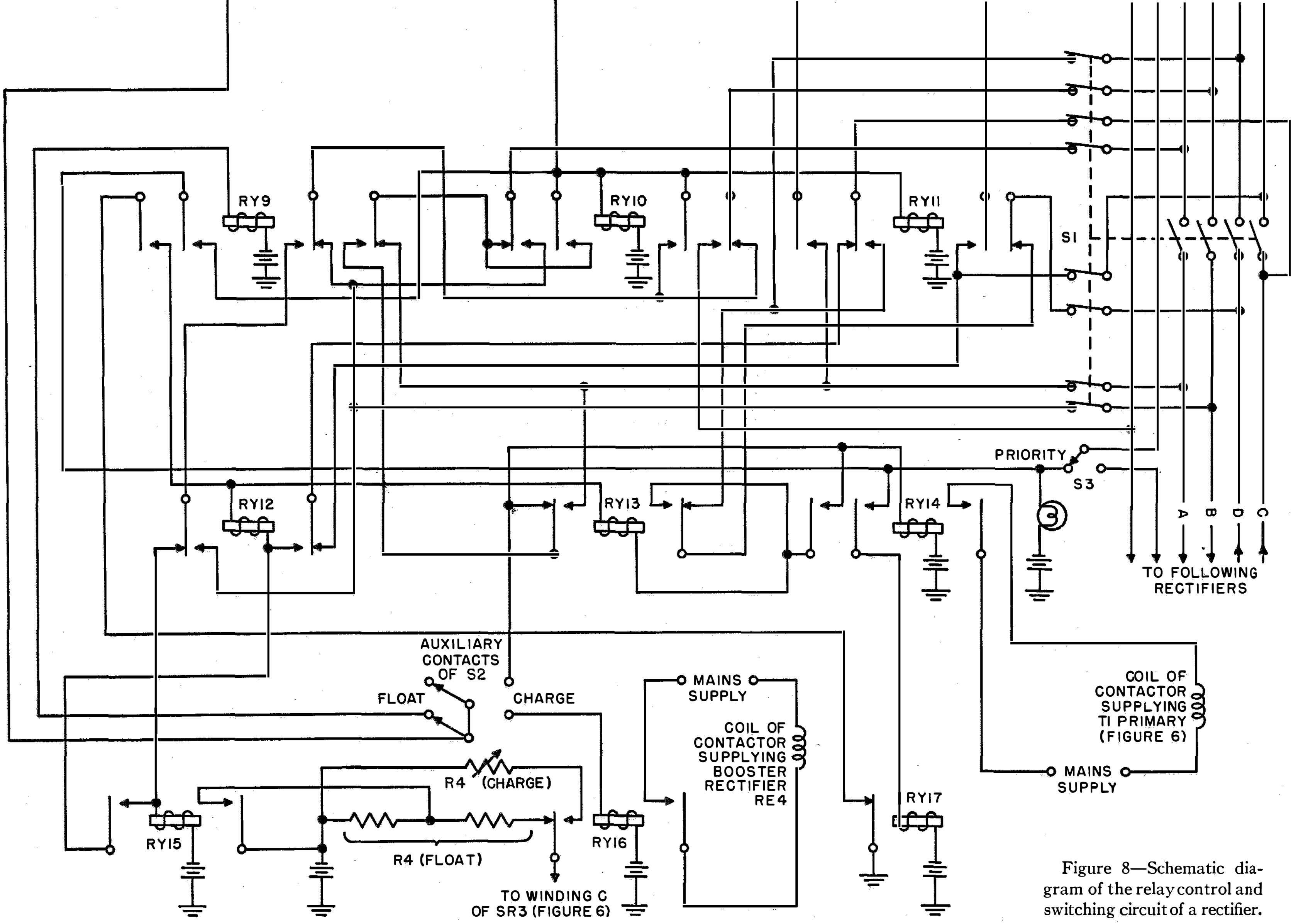


Figure 8—Schematic diagram of the relay control and switching circuit of a rectifier.

Note that if $S2$ of the second rectifier should be in the charging position, *RY9* will be on its back, and the increasing impulse will be shunted directly through to the third rectifier via line *A*.

In order to give the saturated-reactor circuits of the rectifiers time to adjust the output, *RY6* of the priority rectifier can give only one impulse before its operating battery is cut off by operation of the timing relay *RY8*.

When a rectifier is put into service by receipt of the first impulse, its output is limited to 66 percent of normal, or 150 amperes. The output of the priority rectifier is thereby reduced to 75 amperes, and relay *RY4* of the latter releases.

When the output of the priority rectifier reaches 225 amperes for the second time, its *RY4* again operates and an impulse is sent via line *A* through the second rectifier to the *RY14* relay of the next idle rectifier. This impulse passes through the circuits of the rectifiers already in service at 66-percent load through contacts of *RY10* (unoperated), *RY9* (operated), and *RY13* (operated).

The number of rectifiers that can be put in service in this way is practically unlimited.

When all of the rectifiers that are not disabled or charging batteries are in service at 66 percent of full load, the next demand for current causes the priority rectifier's following impulse to be switched in the above manner through the entire ring of rectifiers and back to the priority rectifier where it is switched over contacts of the energized *RY10* from impulsing line *A* to line *B* and thence to the second rectifier. Arriving on line *B* at this rectifier, the impulse passes through contacts of *RY10* (unoperated), *RY9* (operated) and thence to *RY12* and *RY15*, which then operate and lock in that position.

RY15 increases the current in winding *C* of *SR3* (Figure 6), thereby delaying the operation of the limiting device until the rectifier reaches its full load of 250 amperes. The additional 100 amperes supplied by this second rectifier reduces the current drawn from the priority rectifier by a like amount, and *RY4* of the latter rectifier releases. With the next operation of *RY4*, the impulse will travel completely around line *A*, be switched to line *B*, and then be directed through *RY12* (operated) of the second rectifier to *RY12* and *RY15* of the third and so on until all rectifiers are operating at full load.

When all available rectifiers are at full load and *RY4* again gives an impulse, this is directed to an alarm circuit indicating to the maintenance people in the Paille exchange that the rectifier equipment will soon be overloaded and that a generator should be started.

Automatic starting of the motor-generator was considered unnecessary; manual starting made it possible to use the available generators without any change.

6.2.2.2 Decreasing Load

When a generator is connected to the busbar, or if the telephone traffic decreases so that the current drawn from the rectifiers drops, the output of the priority rectifier will also decrease, and when it drops below 20 percent of its nominal output, i.e., below 50 amperes, relay *RY5* releases. An impulse generated by *RY7* is sent over contacts of *RY11* (operated) through decreasing-impulse line *C* to the rectifier whose output was last increased to maximum. In this rectifier, it passes through contacts of *RY11* (unoperated) to the coil circuit of *RY15*, which is thereby short-circuited. *RY15* and *RY12* are released, and the output of the rectifier will drop back to 66 percent of nominal output. *RY5* of the priority rectifier will be re-energized since the priority rectifier must furnish the difference in current. When *RY5* releases again, the impulse will be directed through line *C* to the next rectifier whose output is to be reduced.

When the output of all rectifiers is reduced to 66 percent, the reducing impulses make a complete circle of line *C* coming back into the priority rectifier, where they are directed over a contact of *RY11* (operated) into the *D* line. The impulses arrive at the *RY14* relays of the rectifiers that are still in service, and these relays are thereby short-circuited one after another until the priority rectifier alone floats the load.

The advantage of having all rectifiers in service at 66 percent of their nominal output before switching them to maximum load is obvious, since not only is their efficiency at maximum, but the rectifiers operate every day with a minimum of time at full load, and the ageing, if there is any, will thereby be reduced to a minimum.

6.2.3 Charging

Let us assume that *S2* is thrown to the charging position. Relays *RY14* and *RY16* will then operate, and mains current will be supplied to the primary of *T1* (Figure 6). Relay *RY16* will cause the booster rectifier to be energized (the booster rectifier *RE4* is used in series with *RE1* only when batteries are being charged). Relay *RY16* will also replace the fixed resistors *R4* by an adjustable one in the control circuit of *SR3* (see also Figure 6), and by means of *R4*, the charging current for the batteries may then be adjusted.

With *S2* in the charging position, the outputs of *RE1*, *RE2*, *RE3*, and *RE4* are all applied to the charging busbar, and in the control circuit, only relays *RY1*, *RY2*, *RY3*, *RY14*, and *RY16* are energized.

7. Electrical Characteristics of Rectifiers

The rectifiers were submitted by the Telephone Administration to severe tests. These tests included:

A. The control of the floating and charging voltage outputs at different mains supply voltages and frequencies.

B. Efficiency and power-factor measurements.

C. Insulation tests.

D. Temperature rise of the different pieces of apparatus.

E. Noise voltage of the rectifiers operating individually and in parallel.

As far as output voltage, efficiency, and power factor are concerned, the measurements obtained are illustrated in Figure 9. The curves may be considered as the average of the different rectifiers.

It may be seen from the curve that the efficiency of the converting equipment is above 75 percent day and night, since only the priority rectifier supplies currents of less than 150 amperes at any time. A minimum efficiency of 70 percent and minimum power factor of 0.8 had been guaranteed.

The temperature rise of the apparatus is well below that permitted by the Belgian Electrotechnic Committee, which allows for such transformers a rise of 55 degrees centigrade (99 degrees fahrenheit) when measured by the resistance method. The average temperature rise of the disks is 25 degrees centigrade (45 degrees fahrenheit).

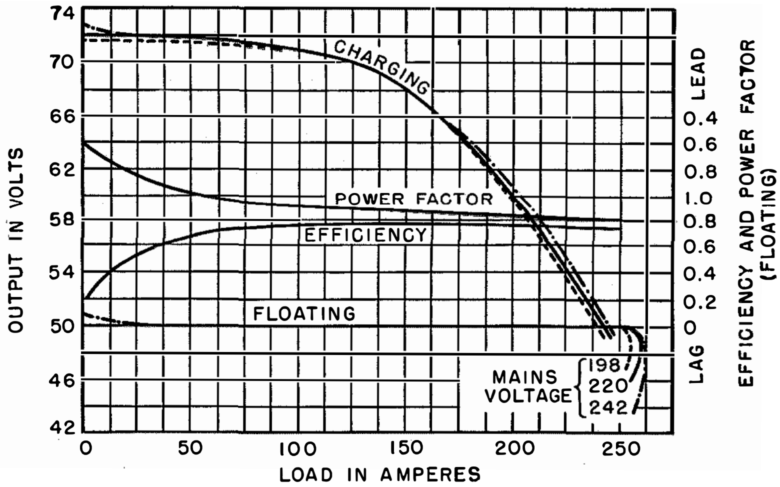


Figure 9—Output voltage, efficiency η, and power factor $\cos\varphi$ plotted against output current for a rectifier.

All insulating spools were tested against breakdown with twice the operating voltage plus 1000 volts.

The total voltage drop in the power board when measured between the battery terminals and the discharge feeders to the telephone equipment is 0.3 volt at 2000 amperes per sector.

The noise voltage measured at the battery busbars with the 4 batteries connected in parallel is below the prescribed limit of 0.002 volt with either one or more rectifiers floating.

Rectifiers regulated by means of presaturated reactors and connected to a fully charged battery sometimes have a tendency to pump, i.e., the current taken by the battery changes constantly between rather large limits. The adjustment of the rectifiers installed in the Paille exchange is such that their operation is perfectly stable under all conditions.

8. Conclusion

The static-regulated-rectifier equipment is not only a technical success, but its performance indicates that it provides a very interesting solution to many problems arising when large power plants are required for telephone exchanges.

Among other advantages, the equipment adopted by the Belgian Telephone Administration for the Paille exchange does the following.

It obviates the inconvenience resulting from the highly variable traffic over a 24-hour period. Whatever the current required by the exchange may be, each of the converters in service works at its maximum efficiency.

It reduces to a minimum the number of manual operations required. In fact, these are limited to starting and stopping the motor-generators when current drain rises over or is well below 2000 amperes.

The number of rectifiers can be increased as may be necessary at any future date to accommodate unforseen increases in telephone traffic.

It easily keeps the voltage at the battery cell terminals between 2.15 and 2.2 volts, avoiding any tendency of the plates to sulphate or otherwise to lose their capacity, and keeps the cells fully charged without overloading them. The life of the batteries is thereby increased while the topping up of the cells is reduced.

In conclusion, it may be interesting to mention that the whole equipment, with the exception of the instruments and the circuit breakers, was designed and manufactured by the Bell Telephone Manufacturing Company at Antwerp.

Alignment and Adjustment of Synchronously Tuned Multiple-Resonant-Circuit Filters

By MILTON DISHAL

ADDENDUM TO VOLUME 29, PAGES 154–164; JUNE, 1952

THE FOLLOWING paragraph should be added at the end of the paper.

The asymptotic values shown on the right-hand side of Figures 8 and 9 are, of course, the values called for by (7A) and (7B); it should be noted, however, that in the graphs, the end resonator that is loaded is numbered resonator n, whereas in (7A) and (7B) this loaded resonator is numbered *1*.

Netherlands Telephone Network and the Arnhem District Exchange*

By J. C. SCHOONEMAN

Bell Telephone Manufacturing Company; Antwerp, Belgium

A DESCRIPTION is given of the telephone network of the Netherlands and, in particular, of the new automatic toll main exchange at Arnhem that replaces the central office destroyed during the war. Provision has been made in the new exchange for long-distance dialing by subscribers and operators. Information is given on the following subjects. Subdivision of the country into main areas with a main tandem exchange and subdivision of the areas into sectors, each with a tandem center and surrounding end exchanges. Prefix and numbering scheme adopted. Construction of the cable network. Type of exchanges, interconnections, and interworking with other systems. Routing of regular traffic over direct junctions with overflow via one or more main routes and tandem main exchanges. Operation and signaling over junctions with direct current, 50-cycle alternating current, and with carrier 4-wire multichannel circuits. Switching between 2-wire and 4-wire circuits, and 4-wire through tandem switching in main toll exchanges. Impedance matching, termination of junctions, transmission levels and losses, and the insertion of amplifying repeaters and attenuation pads. New tariff scheme based on time units and varying in accordance with the distance between stations. Automatic systems used and a description of the *7-D* system of Holland. Equipment and power plant of the Arnhem exchange. Various features and facilities.

• • •

Before the war, telephone service in Arnhem was given by an automatic exchange of 7000 lines. This exchange also contained apparatus for the rural network of Arnhem and the toll exchange for long-distance dialing. The rural district included 48 automatic exchanges; all of the Strowger system. The exchange was an important switching point for this district and for incoming and outgoing traffic with the remaining districts of Holland.

The building of the district exchange was totally destroyed during the war and several of the smaller surrounding exchanges within the district were also destroyed or removed by the occupying forces.

At the end of 1945, an order was placed with Bell Telephone Manufacturing Company for a 7000-line exchange to replace the emergency manual exchange of 2000 lines that had been installed by the Dutch Post, Telegraph, and Telephone Administration. The automatic exchange was delivered within five months and installed by the Nederlandsche Standard Electric Maatschappij. In 1947, the exchange was placed in service and some months later a new toll board of 22 positions was added.

At present, the automatic toll exchange is installed and partly in service for switching automatically tandem, incoming, and outgoing traffic with the remaining districts of Holland. Also 5 new *7-D* automatic exchanges have been installed in the Arnhem sector.

Of the *7-D* system, more than 610,000 lines in some 960 exchanges are in service or on order in different countries all over the world. The Netherlands is in fifth place with 75 exchanges and 76,500 lines.

New circuits were found to be necessary for the *7-D* system in Holland to conform with the special requirements of the telephone administration and to permit interworking with other systems.

Section 1 gives a general description of the telephone network of the Netherlands, both projected and in service. In Section 2, the district exchange of Arnhem is described, and Section 3 deals with the various facilities, equipment, and power plant of this exchange.

* Originally published in Dutch under the title "Het Nederlandse telefoonnet en de Districtscentrale Arnhem" in *Electro-Techniek*, v. 1, pp. 8–12, and v. 2, pp. 19–22; January 4 and 18, 1951.

1. Telephone Network of the Netherlands

1.1 Districts and Sectors

The Netherlands is divided into 20 districts, each district is subdivided into not more than 10 sectors, and each sector includes a number of local networks not exceeding 10 exchanges.

A prefix is allocated to each exchange and consists of 4 digits, known as *S*, *A*, *B*, and *C* figures. For large cities, several exchanges will have only one prefix, and some of the cities like Amsterdam, Rotterdam, The Hague, and Utrecht, will use 2-digit prefixes. Subscribers are numbered by 3 to 6 digits, depending on the capacity of the local network. For local traffic, only the subscriber's number is dialed.

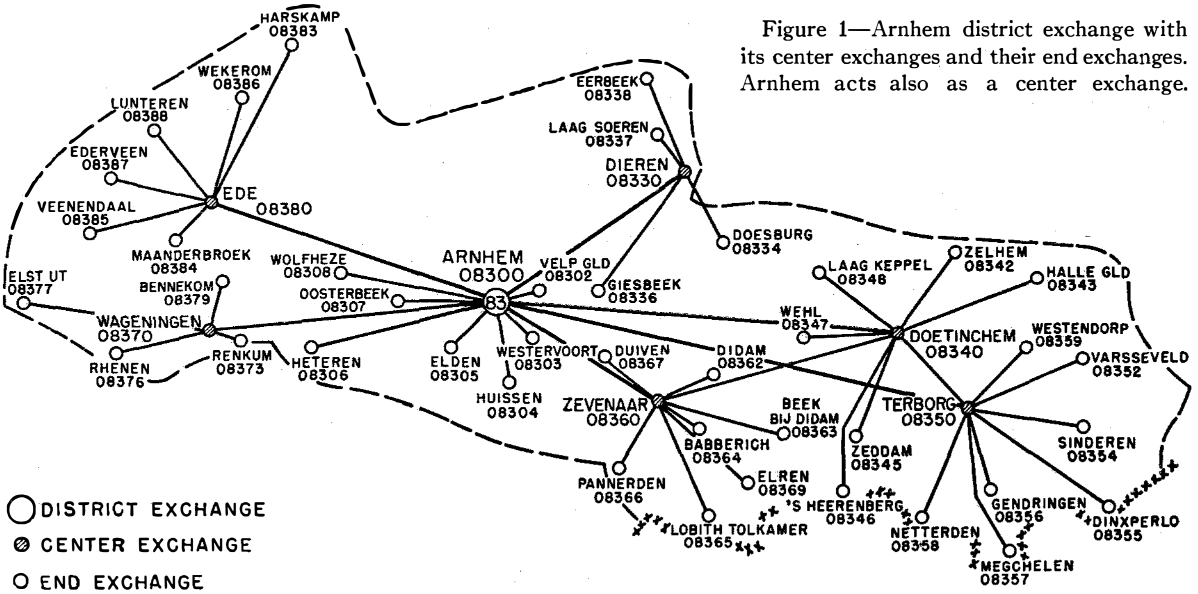


Figure 1—Arnhem district exchange with its center exchanges and their end exchanges. Arnhem acts also as a center exchange.

Each district has a district exchange, preferably located in a large city in the middle of the district, and each sector has a center exchange generally near the center of the sector. The remaining exchanges are called end exchanges. A district exchange will also serve as the center exchange of its own sector.

Figure 1 shows the Arnhem district with its surrounding sectors and associated end exchanges and with the junctions and exchange prefixes. Figure 2 shows a part of the Arnhem district with its numbering and trunk groups between some exchanges of this district and with the district exchanges of Amsterdam, 's-Gravenhage, and Alkmaar.

1.2 Numbering System

With the introduction of automatic toll traffic, the so-called "open-numbering" system was adopted to meet the operational requirements of the Strowger system, which does not make use of registers to increase or decrease the number of selections by certain prefixes.

For outgoing traffic, figure *0* followed by the exchange prefix (the *S*, *A*, *B*, and *C* figures) is first dialed. The *0* indicates an outgoing call, figures *S* and *A* the wanted district, *B* the sector of this district, and *C* the wanted exchange in the sector. When the connection is established to the wanted exchange, a second dial tone of a higher frequency is heard and the number of the wanted subscriber is dialed. For special-service calls, 3 or 4 digits are dialed commencing with the figures *00*.

TABLE 1

S and *A* Figures for the 20 Districts

11	Goes	*44*	Maastricht
16	Breda	*47*	Venlo
17	's-Gravenhage	*49*	Eindhoven
18	Rotterdam	*51*	Leeuwarden
22	Alkmaar	*52*	Zwolle
25	Haarlem	*54*	Hengelo
29	Amsterdam	*59*	Groningen
34	Utrecht	*67*	Deventer
41	's-Hertogenbosch	*83*	Arnhem
42	Tilburg	*88*	Nijmegen

The S and A figures of the 20 districts are given in Table 1. The plan permits other districts to be formed by splitting existing districts.

1.3 Junctions Between Exchanges and Routing of Traffic

Each district exchange is connected with all or nearly all other district exchanges via groups of direct junctions. These are called B directions, as they are connected to B group selectors at the other district exchanges, and all exchanges of these districts can be reached through these junctions. Each district exchange is also connected with all center exchanges in the sectors of its own district. Each center exchange is in turn connected with all end exchanges in its own sector. The direct traffic is routed over this mesh and the star-form cable network between districts and within each district, as may be seen in Figure 2.

The Amsterdam and Rotterdam district exchanges (and Utrecht for the time being) are also tandem and overflow exchanges for inter-district traffic. The traffic between district exchanges not having direct junctions between them is routed via these exchanges, e.g. between Arnhem and Alkmaar (see Figure 2) and also the overflow traffic in case all direct junctions between the two district exchanges are engaged or out of service. The groups of direct junctions between the district exchanges are calculated with a high loss resulting in a high efficiency of these junctions.

For the tandem and overflow traffic, each district exchange is connected with a separate group of junctions to Amsterdam or Rotterdam or both. These are called S directions, being connected to S group selectors in Amsterdam and Rotterdam, via which all districts can be reached.

For districts for which both S directions are provided, overflow can be handled through Amsterdam or Rotterdam as conditions dictate and a second overflow can then take place via

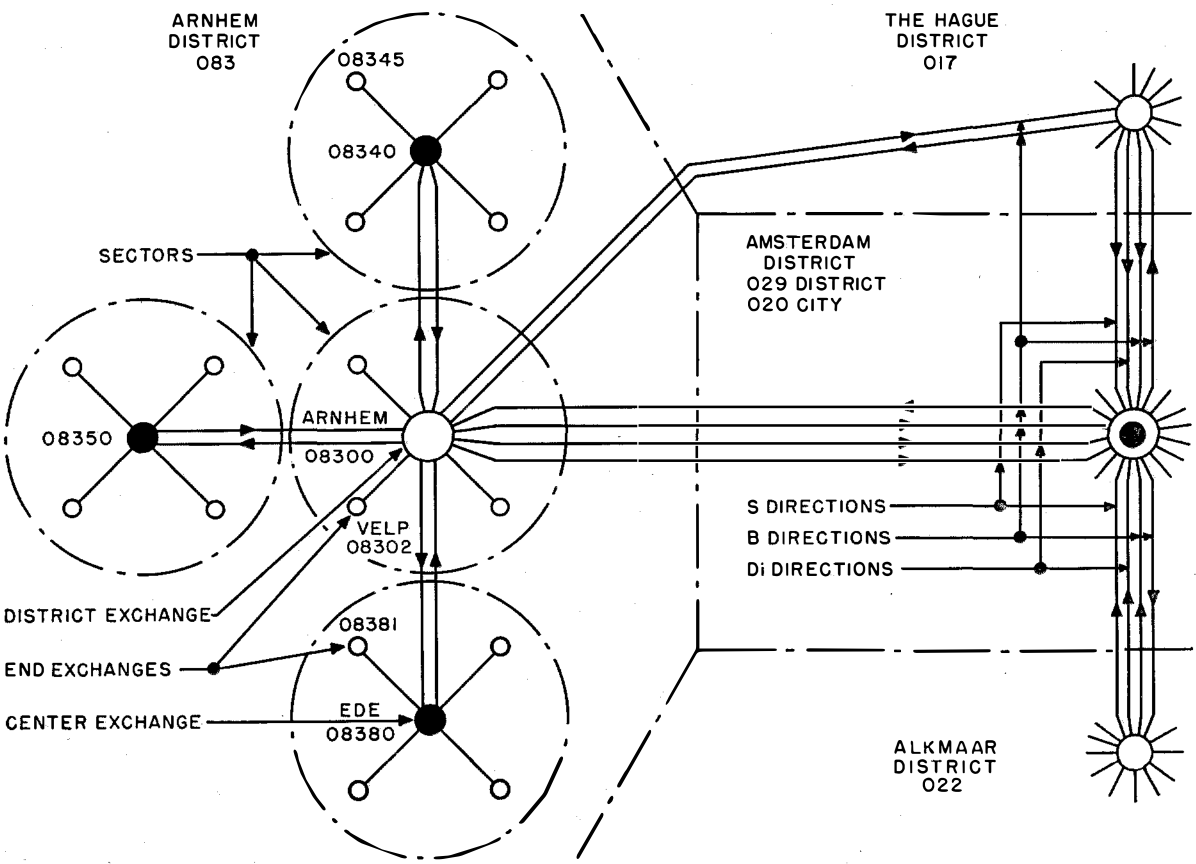


Figure 2—Districts and sectors with prefixes and junctions.

the other S direction. In the event that no free junction is available in the first-overflow direction, the connection may be completed via the second-overflow direction. The overflow junctions are calculated with a low loss. Should no overflow junctions be available in the second direction, busy tone is given to the subscriber.

For district exchanges for which a 2-digit prefix is dialed for the local network, a third group of junctions is provided incoming from a number of other districts, over which exclusively the incoming traffic to the local city network is routed. These are called *Di* directions, being connected to the so-called *Di* group selectors (see Figure 2) to which the city exchanges are connected. With the separation of this traffic, which is an important part of the total traffic to these districts, a reduction in selection time and economy in the number of B and C group selectors in the district exchange is attained. After the zero, the subscriber dials only the S and A figures, and the second dial tone is given from the concerned local network.

1.4 Systems in Use

The automatic telephone systems in use in the Netherlands include *7-A* and *7-D* rotary, various Strowger designs, the Ericsson *500* system, and in the future Ericsson crossbar.

The use of registers insures that toll lines are not unnecessarily engaged. Since the rotary and Ericsson systems employ registers, they can handle automatic toll traffic in a more profitable manner than nonregister systems. It is planned, therefore, to install registers or their equivalents in the Strowger exchanges to facilitate the handling of automatic toll traffic.

1.5 Types of Junctions; Signaling and Interworking with Other Systems

The nonrepeatered traffic within the district is carried over 2-wire junctions. Direct current is usually employed for dial impulses, answering, clearing, release, and other signals. In some cases for long distances, 50-cycle alternating-current signaling is used.

One-way junctions are usually operated within a district. For small exchanges, both-way junctions are also employed. To save switching apparatus, the junctions are usually split into three groups, one for outgoing, one for incoming, and one for both-way traffic, the latter being engaged only if no single-way junction is available in one or both directions.

In the *7-D* system, the maximum distance for 2-wire direct-current signaling is chiefly determined by the ohmic resistance of the cable pairs;

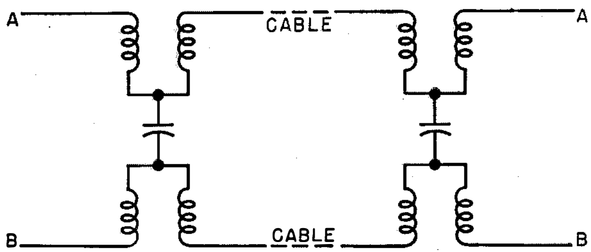


Figure 3—Terminating or matching network.

the total resistance including that of the induction coils in the cable and the terminating transformers or matching coils at each end of the junction must not exceed 1600 ohms. The terminating or matching structure is shown in Figure 3. For shorter distances, when nonloaded or lightly loaded cables are used between the center and end exchanges, usually no terminating or matching coils are provided.

For interworking between *7-D* and Strowger exchanges within a district, which is the case in Arnhem, direct-current signaling, such as is used for the *7-D* exchanges, is employed, and the necessary adaption equipment is located partly in each exchange.

The junctions between the districts operate in one direction and are almost all 4-wire lines with repeaters and voice-frequency signaling. In the "go" direction of the 4-wire lines, signaling is done with 2500-cycle current (forward impulses) and in the "return" direction with 2400 cycles (backward impulses). The direct-current for signaling is converted at the outgoing end into voice-frequency current and at the incoming end from voice-frequency current into direct current. For tandem traffic, it is planned to apply 4-wire through switching and to transmit voice-frequency signals directly through the tandem exchange over the speech path. Some 2-wire junctions are still used for interdistrict traffic with 50-cycle signaling.

Signal	Symbol
Dial Impulses, 45–55 Milliseconds	→ → →
Answering Impulses, 90 Milliseconds	← ←–
Clearance Signal, 90–120 Milliseconds, Continuing while Telephone Is On Hook	← ← ←
Release signal (Alternating-Current Lines), 350 Milliseconds	⟶
Release Signal (Voice-Frequency Lines), Continuous Signal Via "Go" Path in 4-Wire Line Until Revertive Impulse Is Received Over "Return" Path	⟶ ↑⟵
Blocking Signal, Continuous to Place Junction Out of Service	⟵

Figure 4—Power-frequency alternating-current and voice-frequency signals.

Signaling via the 4-wire lines for 4-wire traffic between districts and the 50-cycle signaling over 2-wire lines adopted in Holland are based on the requirements of the Strowger system, which provides no engagement signal in the forward direction or backward signals such as "ready to receive" or "end of selection." Although these signals are useful to engage and disconnect registers, their insertion in the various systems was not considered essential to interworking between these systems.

In the *7-D* district exchanges, the engagement of a register at a line incoming from other districts or from a Strowger exchange is initiated by the first impulse of the digit operating a relay link circuit. By means of revertive signaling, an impulse is sent to the register immediately after each pulse is received from the line, the engagement of the register taking place during the reception of the first impulse.

The signals used over the 50-cycle alternating-current junctions and the voice-frequency 4-wire lines and their timing are shown in Figure 4. Additional signals for operators when offering a toll connection to an already-engaged subscriber are described in Section 2.8.

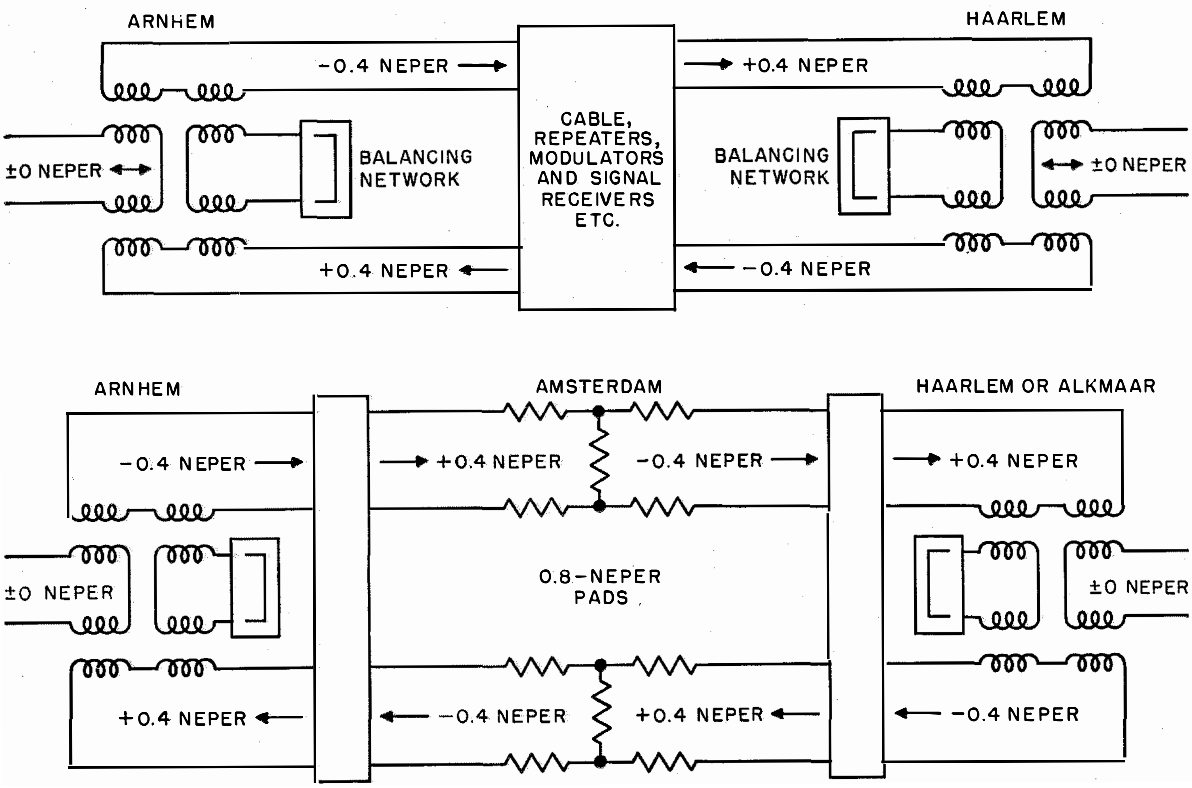


Figure 5—Connections and transmission levels for direct connections (upper) and for overflow or tandem connections (lower) of 4-wire circuits.

1.6 Toll Lines, Repeaters, and Transmission Levels

Each 4-wire toll line is provided with a terminating repeater on the incoming side. For long distances, intermediate repeaters are also installed. The repeaters are so adjusted that the over-all circuit is operated at zero loss as measured on the 2-wire side of the hybrid coils. (See Figure 5.)

These toll lines may be arranged for low-frequency operation only or as one of the multiple channels of a carrier system. Since the signaling frequencies are within the voice-frequency band, it does not make any difference whether the line belongs to the first or the last category.

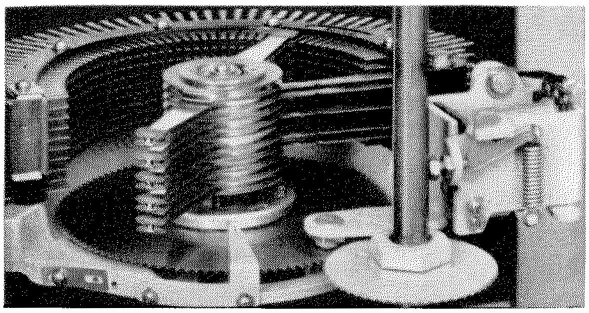


Figure 6—Basic switch used as a line finder or as a selector in the *7-D* rotary system. It carries 100 outlets of 5 contacts each.

In going from 2- to 4-wire toll lines, and vice versa, the hybrid coils and balancing networks are located in the automatic exchange from where the voice-frequency signals are sent over the line. The receivers for the voice-frequency signals are located in the repeater station. The signals from the repeater station to the automatic exchange are transmitted over a separate wire.

For tandem and overflow traffic via *S* directions, both 4-wire lines are interconnected directly without inserting hybrid coils and balancing networks. The 0.8-neper loss that would have been associated with the hybrid circuits is substituted for by pads placed in each branch of the 4-wire circuit in the tandem exchange.

In Figure 5, the transmission levels are shown for a direct 4-wire connection between Arnhem and Haarlem district exchanges (*B* direction) and for an overflow connection to Haarlem or a tandem connection to Alkmaar via the *S* direction in Arnhem with 4-wire through switching in Amsterdam. The switches over which the lines are selected are not shown.

No repeaters are provided for traffic within the district. The grouping of the exchanges and the cable plant within the district is planned so that the transmission loss from subscriber to subscriber never exceeds 3.3 nepers. Since the transmission loss between the districts is zero, this means that the total loss of a connection from the district exchange to a subscriber in its district may be a maximum of 1.65 nepers. For interdistrict traffic from or to subscribers of the local exchange in the district center itself, an artificial loss of, say, 0.3 neper is inserted if the loss in the local network is not more than about 0.6 neper. This is done to reduce the speech volume somewhat and thereby equalize the difference between a direct connection from a subscriber to the district exchange and from a subscriber to a more-distant center or end exchange in this district. For connections without repeaters within the district, this artificial loss is not introduced.

1.7 Tariffs

For local calls and special service calls such as the talking clock, one unit is registered on the

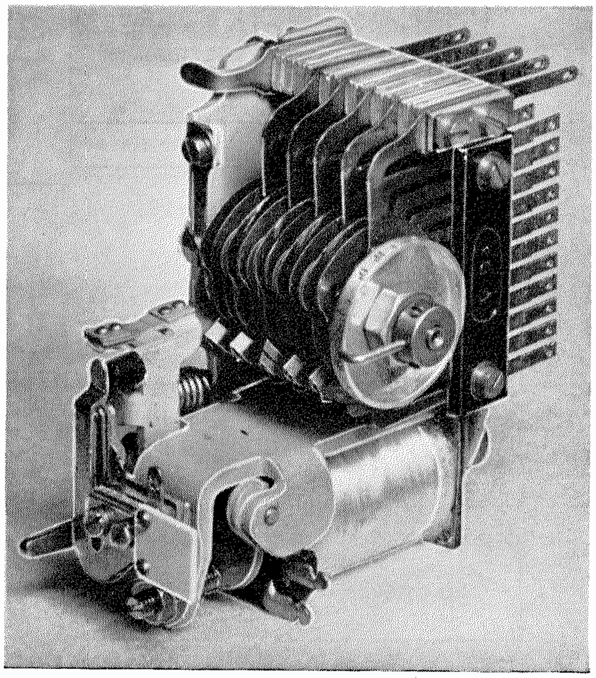


Figure 7—Marker switch for *7-D* system has 11 outlets of 4 contacts each.

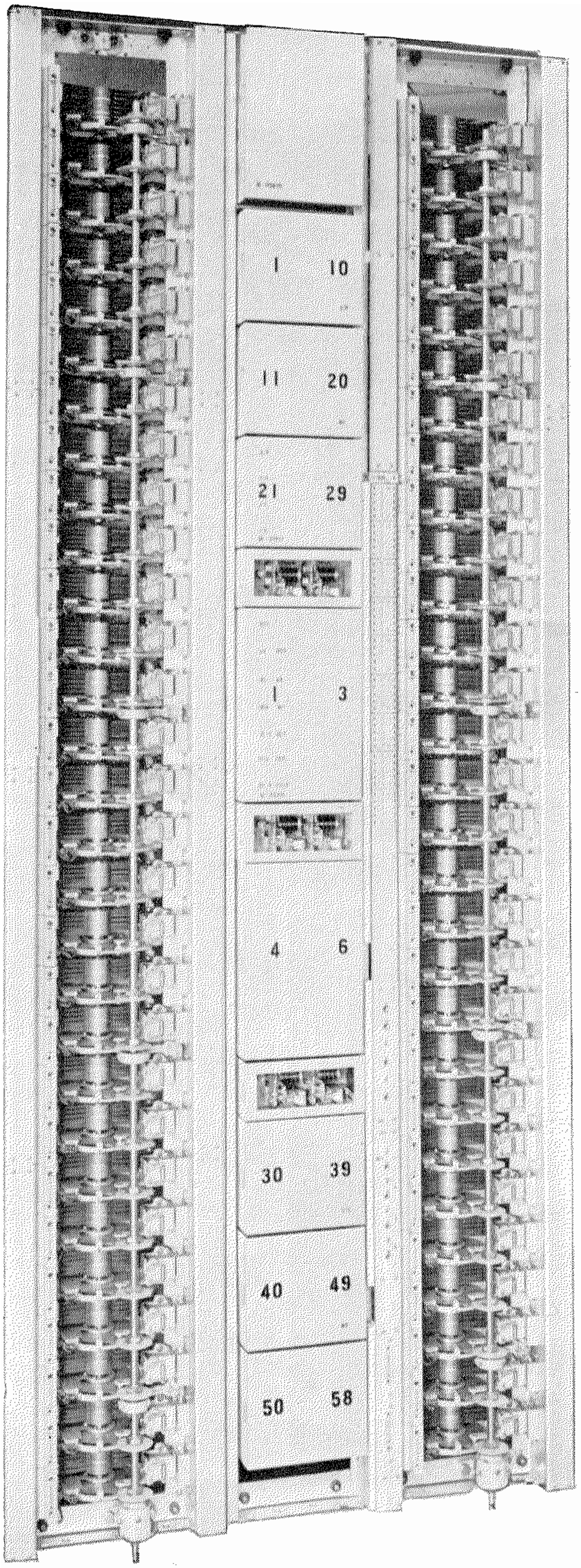


Figure 8—Group-selector bay with 58 selectors and 6 control circuits.

subscriber's meter. For time-and-zone meterings, there are three different tariffs for the whole country. Tariff *A* is applied for connections between exchanges within the sector, tariff *B* for connections between one sector and the immediate surrounding sectors of its own district or other districts, and tariff *C* for connections from a sector to the remaining part of Holland. The tariff to be applied is determined by the prefix only and is in accordance with the distance to the called station.

For outgoing calls, one unit is registered on the meter immediately on completing the connection, then follows a free time from 5 to 10 seconds to enable the subscriber to release his connection before further metering takes place in case he has dialed a wrong number. Following this free period, one or more impulses are produced to establish the tariff classification: for tariff *A*, 1; for *B*, 4; and for *C*, 8 impulses. Further metering is based entirely on time intervals; for *A* every 60 seconds, *B* every 30 seconds, and *C* every 10 seconds. No night tariffs are applied.

By a strap connection in each exchange, conversations may be limited to from 6 to 12 minutes should a shortage of junctions exist. Subscribers are warned by a tone signal 10 seconds before the connection is released.

The system is arranged for delayed back release, so that if only the called party restores, the connection is forcibly released after 30 to 60 seconds.

1.8 Principal Features of the *7-D* System

The *7-D* system employs one type of single-motion switch for use as a line finder or as a selector. This switch, which is shown in Figure 6, has 100 outlets of 5 contacts each. Marker switches are used in both common register and control circuits, having 11 by 4 contacts, as may be seen in Figure 7. In addition, several types of relays of simple construction are used in the *7-D* system.

The selectors and finders are power driven through a flexible gear that is meshed magnetically with a driving gear. Several driving gears are mounted on a common rotating shaft driven through reduction gears by a motor that may be operated by either alternating or direct current. In the larger exchanges, the shafts rotate

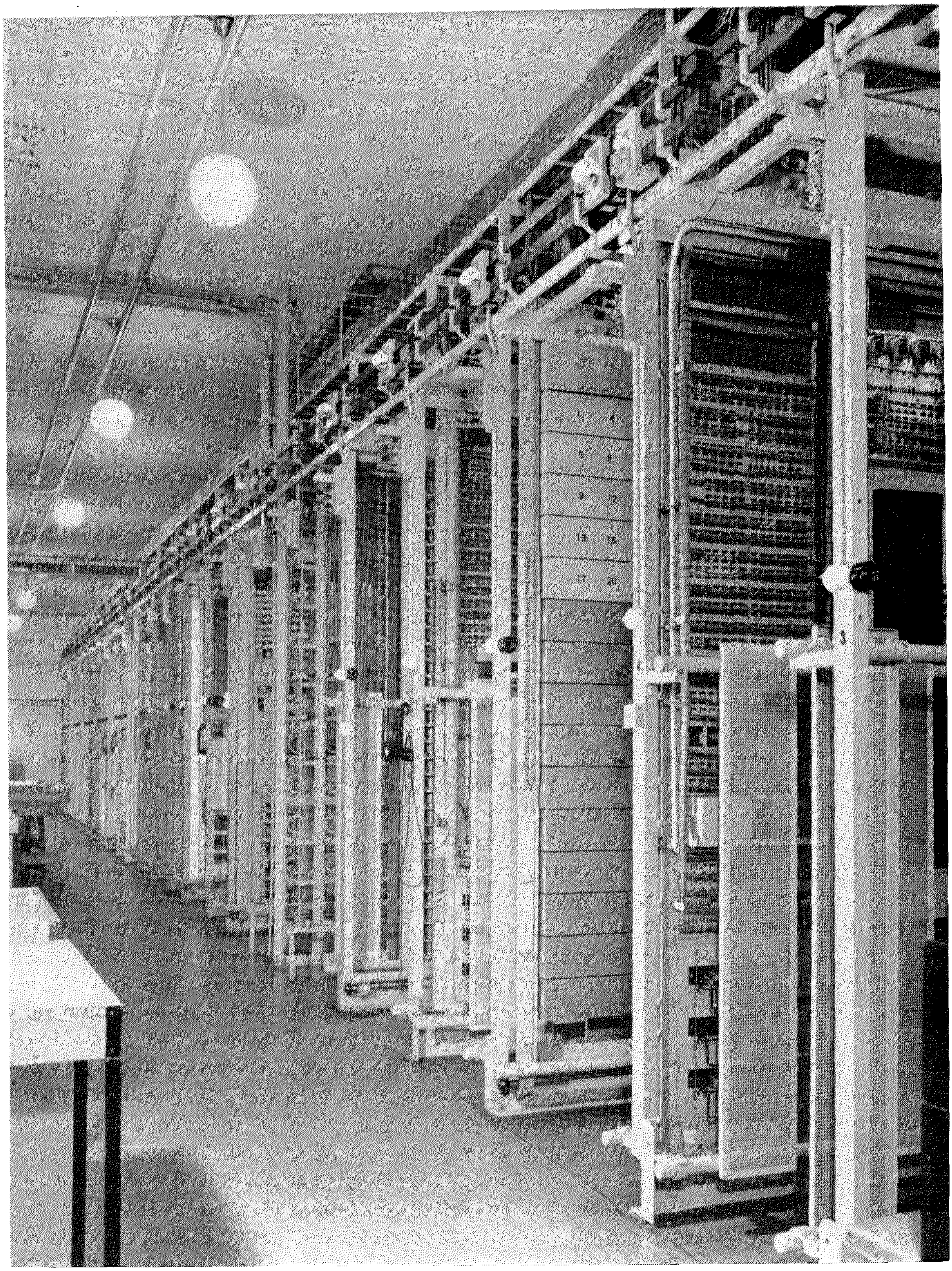


Figure 9—Part of the switch room in the Arnhem exchange.

continuously, but in small exchanges the motor rotates only when a call is made. In the *7-D* system, the dial impulses are received in a register, which under the guidance of control circuits determines the setting of the selectors in accordance with the digits received. The digits are translated by the register, so as to utilize the most economical grouping of selectors and junctions.

Ten selectors, each having two relays, are served by a common control circuit, the components of which include one marker switch and several relays. The control circuit is connected only for such time as is necessary for supervising the operation of a selector. The marker switch hunts for an engaged selector, receives the impulses from the register, and marks the group of outlets in accordance with the figure received. A group-selector bay is shown in Figure 8.

The control circuit opens the test potential to the other selectors so they will not respond, directs the selector to which it is connected to a free outlet in the selected group, the final selector is similarly set to the called subscriber's line, tests this outlet, and connects the *A* and *B* wires through; following these operations, the control circuit disconnects and is prepared to handle another call. Selection time is reduced by the group selector commencing to hunt from a "home" position on receipt of the first impulse, the marking by the marker switch always being in advance of the moving selector. This operation is known as "chasing." Continuous hunting for approximately half a minute is permitted by the register. In the event of all outlets being engaged initially, this arrangement enables the selector to continue hunting until one becomes free.

The division of the 100 outlets of the selector bank over the different levels or groups may be made in accordance with the traffic to be carried in each direction, the more-important groups having preference over the less important. In every case, the distribution may be made to utilize the full capacity of the arc; this is most important on the first group selector if there are but few directions to be reached and if the requirements of the local traffic are limited to one or very few groups of second group selectors. In this manner in some cases, an important saving of group selectors and outgoing junctions can be obtained.

With direct-current signaling between exchanges, the selection impulses are transmitted by interrupting the current in a closed loop that includes the talking conductors and the impulse relay at the distant exchange. By this arrangement, the best possible balancing is obtained to avoid interference to speech over adjacent cable pairs. Loop signaling has a further advantage in that it is not sensitive to inductive interference when a telephone cable lies near high-power transmission lines or electric traction systems. For connections via several exchanges, the pulses are tandemed in each exchange; impulse correctors are employed at each stage.

In some of the registers, the markers for the reception of the dial impulses and the sending of selection impulses are replaced by storing and counting relays, which facilitates maintenance.

2. *Arnhem District*

2.1 Subdivision of Arnhem District

The Arnhem district embraces 7 sectors with a total of 48 exchanges. Each sector has a center exchange and a number of surrounding end exchanges.

The Arnhem sector includes the local exchange of 7000 lines and 7 end exchanges, which have a total of 4000 lines. All these exchanges are of the *7-D* type, a switch room of one being shown in Figure 9. Of the remaining 6 sectors, 3 are of the Strowger system and 3 now under construction will be of the *7-D* type. The total number of subscribers in 1948 was 22,000.

Table 2 shows the prefixes and number of exchanges in the Arnhem district and also the exchange prefixes and number of subscriber lines in the Arnhem sector.

2.2 Local Calls in the Arnhem District Exchange

There have been provided for the 7000 lines of Arnhem: 70 groups of 1st line finders and final switches, 7 groups of 41 link circuits (2nd line finders and 1st group selectors), 348 2nd group selectors, 7 groups of 58 3rd group selectors, and 3 groups of 14 register circuits. A junction diagram is shown in Figure 10, and group and level numbering is given in Table 3. To each group of

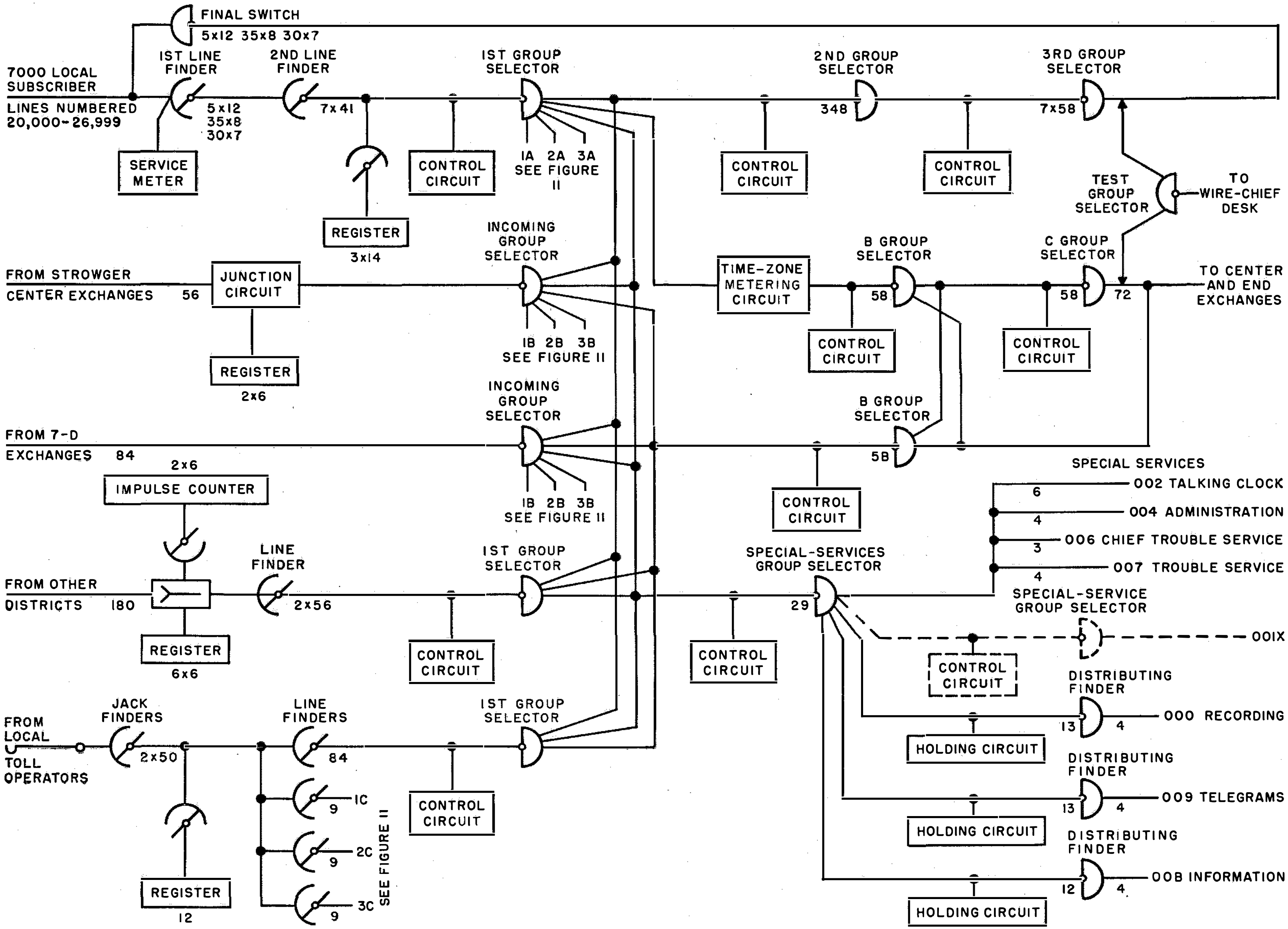


Figure 10—Junction diagram of Arnhem district exchange. Group and level numbering is given in Table 3.

1st line finders and final switches, 100 subscriber lines are connected. Five groups are equipped with 12 line finders and final switches, 35 groups with 8, and 30 with 7 line finders and final switches. Although private branch exchanges are generally connected in the large groups, they may equally well be connected in all groups. In each group, one of the regular final switches is also arranged to be used as a test final switch. This circuit is connected as the last outlet in the 3rd-group-selector arc and also in the arc of the test group selector to permit every subscriber's line to be tested from the wire-chief's desk via the test selectors and final switches.

Local traffic is handled over these circuits. For a local call, only the subscriber's number is dialed after dial tone is received from the register. The number is stored in the register, which directs the group and final selectors to the called line. As soon as the line is tested and is free, ringing current is sent over the line and ringing tone is given to the calling party. When the called party answers, the service meter of the calling party operates.

For calls to a private branch exchange having more than one number, the various lines are tested by the final switch one after another, in case the first line is engaged. Hunting can occur over a maximum of 9 lines; one group of 100 lines is arranged so that private branch exchanges having more than 9 lines may be accommodated.

2.3 Calls from Local Subscribers to Center and End Exchanges

For the outgoing traffic to the center and end exchanges of the Arnhem district, 58 *B* group selectors are provided with time-and-zone metering circuits, 58 *C* group selectors, and 72 outgoing junctions. Arnhem local traffic is handled over these circuits with the other exchanges of the district. The last-connected junction to each

TABLE 2

Arnhem District and Sector Prefixes, Exchanges, and Lines

Arnhem District			Arnhem Sector		
Sectors	Prefixes	Number of Exchanges	End Exchanges	Prefixes	Subscriber Lines
Arnhem	*0–8300–09*	8	Arnhem (local)	*0–8300*	7,000
Dieren	*0–8330–39*	5	Velp	*0–8302*	1,600
Terborg	*0–8340–49*	8	Westervoort	*0–8303*	200
Doetinchem	*0–8350–59*	7	Huisen	*0–8304*	200
Zevenaar	*0–8360–69*	8	Elden	*0–8305*	200
Wageningen	*0–8370–79*	5	Heteren	*0–8306*	200
Ede	*0–8380–89*	7	Oosterbeek	*0–8307*	1,400
			Wolfheze	*0–8308*	200
		48			11,000

TABLE 3

Arnhem District Exchange Group and Level Numbering

1st Group Selector	B Group Selector	C Group Selector
1 *08301–99*, *B* Group Selector, Arnhem District	1 Dead Level	1 Dead Level
2 *20000–29999*, Local, 2nd Group Selector	2 Dead Level	2 *08302*, Velp
3 *01*, *02*, Other Districts, Group 1	3 *08330–39*, Dieren Sector	3 *08303*, Westervoort
4 *03*, *05*, *06*, Other Districts, Group 2	4 *08340–49*, Terborg Sector	4 *08304*, Huisen
5 *04*, *08*, Other Districts, Group 3	5 *08350–59*, Doetinchem Sector	5 *08305*, Elden
6 *00*, Special Services	6 *08360–69*, Zevenaar Sector	6 *08306*, Heteren
7 Dead Level	7 *08370–79*, Wageningen Sector	7 *08307*, Oosterbeek
8 Dead Level	8 *08380–89*, Ede Sector	8 *08308*, Wolfheze
9 Open Metering-Wire Connections	9 Dead level	9 Dead Level
10 False Calls	10 *08301–09*, *C* Group Selector, Arnhem Sector	10 Dead Level

center or end exchange is again arranged for testing of subscriber lines at the distant exchanges, via the test group selector as is evident from Figure 10.

For calls to center and end exchanges, the subscriber first dials *0*, indicating that the call is outgoing, and thereafter the exchange prefix (*S*, *A*, *B*, and *C* figures). As soon as the connection is directed to the wanted exchange by the register in Arnhem, this register gives a second dial tone and receives the called subscriber's number, which consists of 3 or 4 digits. The register establishes the connection, determines the tariff in the time-and-zone metering circuit of the *B* group selector by means of impulses, and when the called party answers, the service meter operates in accordance with the tariff to be applied for the particular connection.

2.4 Calls for Special Services

For special services, 29 group selectors are provided. For three of these services; *000* recording, *009* telegrams, and *008* information, three groups of call-distributing finders and common holding circuits have been used. In the event of all operators being engaged, calls for these services are held in a common field and distributed in rotation as operators become available. Four operating positions are provided for each service, the number of distributing finders being 12 or 13. Should only three positions be occupied, it is possible there might be 9 or 10 waiting calls. By means of lamps, the chief operator is informed of the number of waiting calls and can, accordingly, determine the number of positions to be occupied. Furthermore, the distributing finders ensure an equal distribution of calls among unoccupied operators during slack periods.

The remaining special services have no call-distribution arrangement. For some of the services, metering is required when the call is answered and this is determined by the register. Further services are: *002* talking clock, *003* weather forecast, *004* administration, *006* chief of trouble service, and *007* trouble service.

Calls to the talking clock are held if necessary and switched through just before a complete time announcement; a busy tone is given after three announcements to a subscriber. The talking clock operates from a central point, announcements being given to the subscriber via distributing transformers.

Three calling lamps are provided for services that terminate on desks, one for calls originated by local subscribers, the second for calls from distant exchanges, and the third lamp glows together with either of the others if the call originated from a coin box.

A second group selector (shown in dotted lines in Figure 10) is to be added when the number of services exceeds 9. At that time, the number of services can be increased by 10 by adding a digit to the figure *001*.

An arrangement has been made whereby some of the services may be concentrated on the toll position during the slack evening hours and to transfer them automatically to either Amsterdam or Utrecht when all Arnhem toll operators have left their positions at night.

2.5 Calls from Local Subscribers to Other Districts

Calls from Arnhem subscribers for other districts are handled by three groups of 40 direction-marking circuits with time-and-zone metering. See *1A*, *2A*, and *3A* in Figures 10 and 11. Each group is connected with two common groups of 4 control circuits, which also serve for other groups of direction-marking circuits as shown in Figure 11.

It was found that by subdividing this traffic into three groups, a better distribution resulted coupled with a saving in both material and selection time. Following the setting of the 1st group selector, one figure only is necessary to mark the direction (district), this being determined in the register by the dialed figures *0* and *S* and *A* of the prefix.

Immediately on receipt of the *S* figure in the register (or if the *S* figure is that of the Arnhem district, the *S* and *A* figures), the first group selector (Figure 10) hunts for a free direction-marking circuit in the group marked by the control circuit, the control circuit having received 2, 3, or 4 impulses in accordance with the *S* or *S* and *A* figures. On the direction-marking circuit being found and a control circuit attached, the register transmits only one figure to the control circuit, in accordance with the received *0*, *S*, and A figures for marking the direction. A further reduction in the selection time is gained on the most important directions by the transmission of small figures; e.g. for The Hague, one impulse only is required; Amsterdam, 2 impulses; etc.

Following the reception of the figure in the control circuit, approximately 8 line finders for the selected direction (Figure 11) hunt for the direction-marking circuit. When one of the line finders contacts the direction-marking circuit, the control circuit is disengaged, all line finders are stopped, and the connection is switched to the outgoing line.

The B and C figures are then transmitted by the register to the chosen district and following the transmission of the tariff to the time-and-zone metering circuit in the direction-marking circuit, the register is disconnected. The 2nd dialing tone is then given and the caller dials the wanted number. The dialed impulses are repeated in the direction-marking circuit and transmitted to the outgoing line, where they are transformed into voice-frequency impulses.

Should the chosen district exchange be of the *7-D* type, the B and C figures are received in the register circuit, which is connected to the incoming junctions at the distant exchange as shown for Arnhem in Figure 10, where 6×6 registers are connected to 180 incoming lines. In the incoming lines, the voice-frequency impulses are transformed into direct-current impulses. On the establishment of the connection, the register disengages. In case the chosen district exchange is of the Strowger system, the impulses are received directly in the successive group selectors.

After answering, metering takes place in accordance with the established tariff for the chosen connection. The tariff is received in the time-and-zone metering circuit of the direction-marking circuit by means of impulses from the local register before it disengages.

When calls are made to large multioffice city networks (i.e. Amsterdam), the subscriber dials a 2-digit prefix (*0*, S, and A) and one of the direct lines is engaged as previously described. In this case, however, the local register is disconnected simultaneously with the control circuit of the direction-marking circuit. In Amsterdam, the outgoing lines terminate on *Di* incoming group selectors, to which levels the city exchanges are connected. The 2nd dialing tone is given from the outgoing-line circuit. By the use of a separate group of lines to Amsterdam, no B and C group selectors are required in Amsterdam and selection time is reduced.

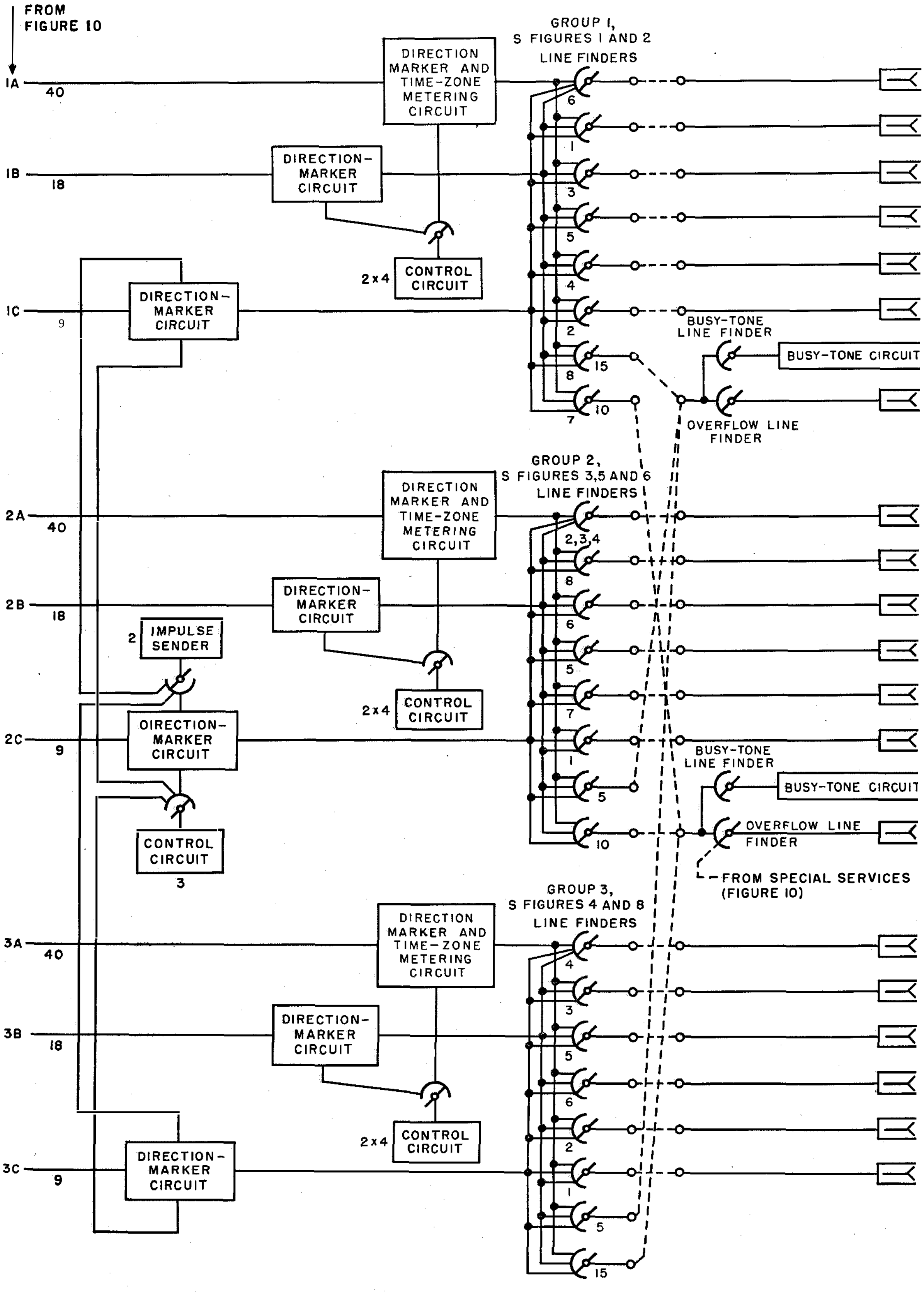
Calls to Utrecht City (*030*), Utrecht Center and end exchanges (*034XX*), and to the headquarters of the Post, Telegraph, and Telephone Administration in The Hague (*033XX*) are directed via the same group of voice-frequency lines to Utrecht, which terminate on A group selectors. The control circuit must, therefore, transmit the A figure (*0*, *4*, or *3*, respectively) before disengaging.

Should all direct lines for the marked direction be engaged or out of service, an indication is given to the control circuit. The control circuit then routes the call via the line finders and overflow finders of either Rotterdam or Utrecht, depending on the direction of the wanted connection. For overflow calls, the control circuit transmits the S and A figures of the wanted district to the S and A selectors in the tandem exchange before disengaging. By these means, a free B direction to the wanted district is engaged in the tandem exchange. The local register then transmits the B and C figures via the tandem exchange to the wanted district, following which the local register is then disconnected. The complete connection is made by the dialing of the subscriber's number.

In the event of all lines being engaged in the selected overflow direction (for example Rotterdam), the call may be routed via the 2nd overflow direction (Utrecht) and should there be no possible means of establishing the connection due e.g. to cable failure, heavy overload, etc., the call is switched to a busy-tone circuit, which transmits a busy signal to the subscriber after the register and control circuit are disengaged.

When direct lines do not exist (i.e. to Alkmaar *022* and Goes *011*), calls are routed via the S directions, Rotterdam and Utrecht. In this case, the control circuit transmits the S and A figures to the tandem exchange before disengaging.

Cross connections on a translator of the control circuit determine the 1st and 2nd overflow directions and the S and A figures to be transmitted. These cross connections may be changed readily to suit traffic requirements.



FROM FIGURE 10
GROUP 1, S FIGURES 1 AND 2 LINE FINDERS
1A
40
DIRECTION MARKER AND TIME-ZONE METERING CIRCUIT
1B
18
DIRECTION-MARKER CIRCUIT
2x4
CONTROL CIRCUIT
1C
9
DIRECTION-MARKER CIRCUIT
BUSY-TONE LINE FINDER
BUSY-TONE CIRCUIT
OVERFLOW LINE FINDER
GROUP 2, S FIGURES 3,5 AND 6 LINE FINDERS
2A
40
DIRECTION MARKER AND TIME-ZONE METERING CIRCUIT
2B
18
DIRECTION-MARKER CIRCUIT
2
IMPULSE SENDER
2x4
CONTROL CIRCUIT
2C
9
DIRECTION-MARKER CIRCUIT
CONTROL CIRCUIT
3
BUSY-TONE LINE FINDER
BUSY-TONE CIRCUIT
OVERFLOW LINE FINDER
FROM SPECIAL SERVICES (FIGURE 10)
GROUP 3, S FIGURES 4 AND 8 LINE FINDERS
3A
40
DIRECTION MARKER AND TIME-ZONE METERING CIRCUIT
3B
18
DIRECTION-MARKER CIRCUIT
2x4
CONTROL CIRCUIT
3C
9
DIRECTION-MARKER CIRCUIT

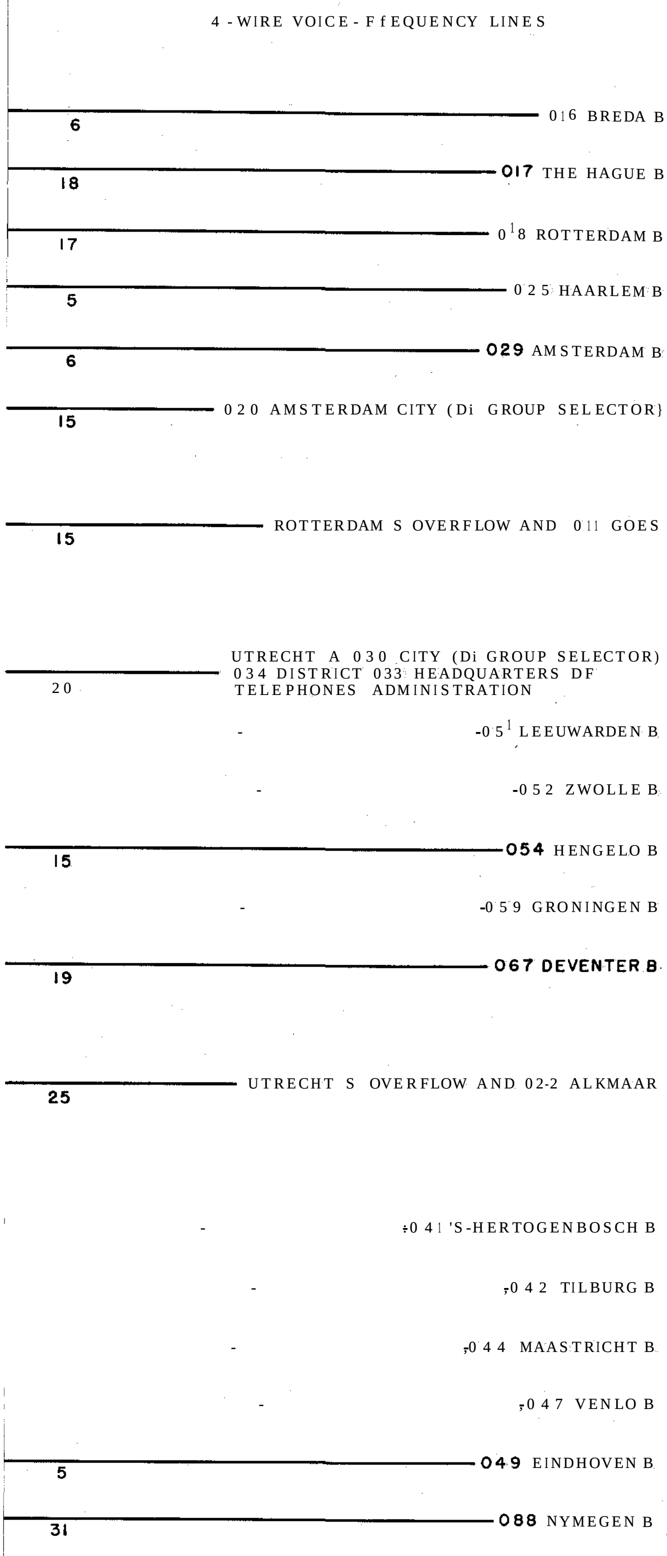


Figure 11—Junction diagram of direction-marking circuits in Arnhem district exchange and outgoing lines to other districts.

2.6 Calls from Center and End Exchanges

To deal with traffic from the surrounding sectors, 56 incoming group selectors are provided for incoming calls from center exchanges.

These selectors are connected to 2 × 6 register circuits (6 registers for each group of 28 incoming group selectors). Immediately the first impulse is received from a center exchange, one register becomes attached to the incoming group selector. This arrangement is necessary because the center exchanges are of the Strowger system and the first dial impulse must be received in the register.

For the 7 end exchanges of the Arnhem sector, 48 incoming group selectors are provided. The end exchanges are of the *7-D* rotary system and contain 1st line finders, link circuits, registers, finals, incoming group selectors, and outgoing junctions with time-and-zone metering circuits.

For calls from center or end exchanges to other exchanges of the district, a separate group of 58 *B* group selectors are installed without time-and-zone metering circuits.

For calls to other districts, three separate groups of 18 direction-marking circuits are provided, also without time-and-zone-metering circuits; see Figure 11, *1B*, *2B*, and *3B*. The time-and-zone-metering circuits for this traffic are located in the outgoing junction in the center or end exchanges, which take care of the charges for the connection.

Calls from center and end exchanges are switched in the same manner as for calls from Arnhem local. Local calls in the center or end exchanges are handled locally.

For calls to subscribers of the Arnhem local exchange, the *0* and prefix *8300* are dialed first and are followed by the subscriber's number, being received by the register in the center or end exchange. The connection is then established via the incoming group selector in Arnhem, the 2nd and 3rd group selectors, and the final switches, which are also used for local traffic in Arnhem.

2.7 Calls from Other Districts

For traffic incoming from the other 19 districts of the Netherlands, 180 incoming voice-frequency lines and 2 × 56 link circuits are provided. The incoming lines are connected with 6 groups of 6 registers (6 for each group of 30 lines). The registers are connected by relay attachment. This arrangement is necessary in connections between Strowger and *7-D* rotary exchanges (as previously explained); the first impulse of the *B* figure from Strowger exchanges must be received in the register.

The incoming lines are also connected to two common groups of 6 impulse counters, the purpose of which will be described later.

The register circuit receives the *B* and *C* figures, transmits the 2nd dialing tone, receives the wanted party's number, and sets up the connection via the circuits previously described, after which it is disconnected.

2.8 Calls from Local Toll Operators to Arnhem and Other Districts

For calls from local toll operators, a group of whom may be seen in Figure 12, to subscribers in the Arnhem and other districts, 22 positions are provided with 120 toll lines for manual service. Ten positions are equipped with 7 cord circuits and 12 with 10 cord circuits (concentration positions). For automatic traffic, each position is provided with key sets (instead of dials) and with 7 jack circuits (see Figure 10). For automatic service, two groups of 50 1st jack finders are provided, 12 registers, 84 links, and 3 groups of direction-marking circuits (see Figures 10 and 11, *1C*, *2C*, and *3C*). To these last groups, a group of two impulse senders and a common group of control circuits are connected.

For all connections previously described, under 2.2 to 2.7 inclusive, the operator depresses the same number of the key set that the subscriber dials and connections are set up via the same junctions and selectors as for traffic from subscribers.

On the called subscriber raising the receiver, the supervisory lamp in the operator's cord circuit extinguishes and on the subscriber replacing the receiver, the lamp lights. Agitation of the subscriber's switchhook causes the lamp to flash.

Should a subscriber be engaged, it is possible for an operator to offer a toll call by depressing a button of the positional circuit. On the release of the button, the operator is cut out of the connection. If, however, the subscriber accepts the toll call by releasing the original busying connection, the called-party line is then tested and the call switched through to the subscriber. The operator then depresses the ringing key and the supervisory lamp extinguishes on the subscriber raising the receiver.

The voice-frequency lines between districts are also used for traffic from operators to other districts. By means of special signals, an operator may listen in on an existing conversation and speak to either of the subscribers. A subscriber cannot reproduce these signals by the manipulation of either the dial or the switchhook. Common impulse senders and counters are attached to the connections through which the special signaling impulses are sent and received.

If in this case the operator hears busy tone, she depresses a button and an impulse sender is connected to the direction-marking circuit for operators' traffic. Impulses are transmitted, are received in an impulse counter connected to the incoming line at the distant exchange, and back impulses are transmitted. Further impulses are then transmitted by the impulse sender and the busy tone is disconnected.

On the release of the operator's button, impulses are transmitted to test the subscriber's line and if the line is free, an answering impulse disengages both the impulse sender and counter.

With the depression of the ringing key, voice-frequency impulses are transmitted from the outgoing line to the incoming line at the distant exchange to ring the wanted party.

Should no answering impulse be received because the subscriber has not released an existing connection, the operator again hears the busy tone, no disengagement of the impulse sender and counter is effected, and the operator may again offer the connection to the wanted subscriber.

3. *Arnhem District Exchange*

3.1 Test Arrangements

The wire-chief's desk is located near the main distributing frame and is arranged for testing all subscribers' lines of the Arnhem district by means of automatic equipment.

Each circuit can be checked by a test box. For the larger exchanges, automatic routine testing is also provided. In this case, all circuits are automatically tested in succession by means of finders and marker switches.

3.2 Irregular Dialing

If dialing is incomplete, the connection is automatically broken after 30 to 60 seconds and the dialing tone is heard by the subscriber. Should a wrong prefix or an unused number be dialed, the busy tone is transmitted. If due to a circuit fault, the connection is incompleted by the register, the subscriber again hears dialing tone via other circuits and an alarm is given simultaneously to the maintenance staff. The faulty connection is blocked until cleared.

In case of no dialing, the call is directed to a false-call circuit or in small exchanges locked up in the line circuit. The register disengages and busy tone and an alarm are given.

3.3 Limitations

For outgoing calls, the ringing period is limited and whether or not the caller replaces his receiver, the connection is automatically broken after 1 to 2 minutes. Arrangements are also made whereby the duration of outgoing calls may be limited to any period between 6 and 12 minutes.

3.4 Delayed Back Release

Should the calling subscriber fail to replace, or misplace, the receiver on the switchhook on the completion of a call, the connection is automatically released 30 to 60 seconds after the called party has restored.

3.5 Subscribers' Arrangements

Any subscriber can be isolated on the main distributing frame by use of a plug that causes a special tone to be given in case this line is called.

This special tone, which is somewhat different from the busy tone, indicates to the calling subscriber that this line is not busy but cannot be reached and that particulars of this line can be obtained by calling the information operator.

Malicious-call adapters are provided to which subscribers can be connected and should these

Figure 12—Toll operators in the Arnhem exchange.

Figure 13—Power room of Arnhem exchange.

subscribers move the switchhook momentarily or dial figure *1* during conversation the calling party is blocked.

3.6 Tax Indicators

Tax indicators can be provided at the subscriber's premises on which the tariff for each call is given.

3.7 Coin Boxes

Coin boxes are connected with the line circuit via an adapter circuit whereby only local calls can be set up automatically. Outgoing calls are handled by operators after dialing the special-service operator. For these calls, an extra impulse is sent by the register to light a special lamp on the operator's position.

3.8 Observation and Control Arrangements

An arrangement is provided in most exchanges for direct-reading traffic metering. The principle of this circuit is that each day during a busy hour and under control of clock contacts all circuits are connected via slowly rotating finders to service meters. One wire (usually the *C* wire) is used for this purpose. For each group of circuits, service meters are provided on which the number of traffic hours are registered.

In larger exchanges, service is observed by operators. The figures dialed are displayed on a number indicator. Service meters are provided on which the following information is given.

A. Number of controlled calls.

B. Talking time (in 5-second units).

C. Number of effective calls.

D. Number of meterings.

E. Time the operator controls connections (in 5-second units).

A circuit is provided to which 10 predetermined subscribers can be connected for control by an operator in a manner similar to that for the service observation.

A subscriber can also be connected to a transportable automatic circuit for observation on which all particulars are registered on a paper tape.

3.9 Busy Indication, Jacks, Etc.

The engaged circuits can be determined by the position of the selectors or by means of busy lamps; a busy jack is provided by which the circuit can be isolated and also a small contact strip is available for listening in and for routine testing.

3.10 Alarm, Alarm Transfer, and Identification

To safeguard the regular operation of the exchange, a number of alarm arrangements are provided to inform the maintenance staff of trouble. The most important are for blown fuses, overloads on various groups of circuits, interruptions of current or tone supplies, potentials not within the prescribed limits, failures on various arrangements or interrupters, operation of the malicious-call arrangement, etc.

In case of an alarm in the other exchanges of the Arnhem district, the warning is transmitted to the district exchange with indications of its urgency and from which exchange the alarm was initiated. By calling a special identification circuit that is provided in each exchange, the alarm can be identified at any subscriber's set by means of a Morse tone at the district exchange.

3.11 Equipment of the Arnhem District Exchange

In the district exchange, there are 25 rows of equipment each 13.5 meters (44.6 feet) in length. Each of the first 7 rows is equipped with 1000 line circuits, 1st line finders, finals, and 3rd group selectors.

The following 5 rows from 8 to 12 (8 and 9 are half rows) are equipped with registers, link circuits, and 2nd group selectors. An intermediate cross-connecting rack is located between rows 7 and 10, in addition to rows 8 and 9. In rows 13 and 14, the operators' circuits and circuits for the special services are located; row 15 carries the time-and-zone metering circuits, *B* and *C* group selectors for traffic to center and end exchanges; row 16, the incoming group selectors from end exchanges and outgoing junctions to end exchanges; and row 17, the incoming group selectors and registers for incoming traffic from center exchanges of the Strowger system.

The direction-marking circuits, the control circuits, and the outgoing voice-frequency lines for outgoing interdistrict traffic are located in rows 18 to 21; and on the remaining 4 rows, the incoming voice-frequency lines, registers, and link circuits are located. Bays for miscellaneous and routine test circuits are divided over the various rows where space is available. The routine test circuits are placed as near as possible to the circuits to be tested.

The row height is 2.90 meters (9.5 feet). The finder and selector bays are provided with 29 finders or selectors. The bay height is 2.50 meters (8.2 feet).

The subscribers' and control service meters are located in a separate room and mounted in rows in such a manner that the readings of the meters can be recorded photographically in a simple manner.

3.12 Power Plant

The power-supply equipment for the Arnhem district exchange (Figure 13) was installed by the Nederlandsche Standard Electric Maatschappij. Primarily, it consists of two main rectifiers obtaining power from the public electricity mains and two storage batteries.

Under normal circumstances, the exchange load is carried by only one main rectifier, whereas during the busy hours or heavy traffic, both rectifiers are connected. The batteries are connected in parallel with the rectifiers; they serve only as reserve sources and supply current in case of emergency, e.g. in the event of a failure of the power mains. The batteries are constantly kept in fully charged condition by a small trickle-charge rectifier. This method ensures that the full capacity of the battery is available in an emergency. Under normal load, the battery is not connected directly to the exchange bus bars; a number of counter-electromotive-force cells are interposed so that an unfavourable voltage variation in the mains supply will not require the battery to supply current. If the mains supply fails or for any reason an abnormally low voltage is applied to the exchange bus bars, the counter-electromotive-force cells are immediately removed from the circuit by a spring-operated contactor that is held in the stand-by position by the mains-applied voltage. By connecting the rectifiers across the exchange bus and not in parallel to the battery, current from the power mains does not pass through the counter cells, thus avoiding the loss that would otherwise result.

This method of operation is possible only if the maximum peak current and the average maximum current during the busy hours are not too large and if switching surges do not exceed too greatly the average current being supplied.

The battery is subdivided into two halves of 25 cells each. By means of two rotary switches, both batteries can be connected in parallel or either one can be switched to the charging condition. To permit the batteries to be charged in the shortest possible time after they have functioned in emergency cases, a separate booster rectifier is provided; its voltage and current are continuously adjustable without loss by means of a regulating transformer. The two main rectifiers maintain the bus-bar voltage between 48 and 52 volts under all circumstances. The battery half that is not in service can be charged with up to 70 volts. The switches required to connect each of the batteries to the booster are so interconnected that at least one battery half is available for emergency use and no faulty connections are possible. The switches are of the quick-acting type and intermediate positions are avoided when switching.

The two main rectifiers are also switched on both the alternating- and direct-current sides by means of interlocking switches. Each of the main rectifiers can supply 200 amperes. This output is subdivided into 5 separate groups of 40 amperes, which are fused separately to increase reliability.

The voltage of the rectifiers feeding the ex-

Figure 14—Adjustment of relays at the Antwerp factory of Bell Telephone Manufacturing Company.

change is kept constant by means of saturated reactors. Each rectifier is provided with 6 of these reactors, the saturating direct current being regulated by a quick-acting voltage regulator. The voltage that is to be kept constant is not directly connected to the quick-acting voltage regulator, but is controlled by a voltage obtained from a limiting rectifier. This limiting rectifier also includes saturated reactors that are energized by the output of the main rectifier, so that the voltage of this auxiliary rectifier is proportional to the output of the main rectifier.

By this regulating system, the exchange voltage is kept constant to within 1 or 2 percent until the normal current capacity, 200 amperes, of the main rectifier is reached, after which the load curve turns down sharply. Both quick-acting regulators are coupled in the usual manner by means of an extra current coil. If the regulators are adjusted to somewhat different voltages, the present arrangement permits one rectifier to handle the total load and only when the demand surpasses 200 amperes will the second rectifier come into action.

In such a system, special attention must be given to sudden current and voltage surges that occur as a result of differences between the battery and bus-bar voltages when a battery is switched into or out of service. To avoid these surges, small resistances are automatically inserted or short-circuited in the control circuits of the quick-acting regulators so that unnecessary under- or overvoltage alarms are not given. By connecting a reference voltage from the bus to the quick-acting regulator of a disconnected rectifier, the output voltage of the rectifier is slowly increased to that of the bus-bar and switching surges are avoided.

A schematic diagram of the power plant is displayed. The conductors are interrupted at the switching points and lamps behind small plexiglass windows are lighted when the switches are connected through. A quick glance will inform the attendant of the operating conditions.

As the maximum load is 400 amperes and the average load is between 100 and 200 amperes, it may be assumed that the power plant has a reserve of 100 percent. In case one of the rectifiers has to be taken out of service, it is possible to operate with the other one and if necessary the battery may be charged during slack hours with the booster rectifier.

4. *Acknowledgement*

The Dutch Administration of Post, Telegraph, and Telephone has kindly consented to the publication of this paper. The author expresses appreciation to Mr. Ir. G. J. Kamerbeek, who has read the contents and whose suggestions have been most appreciated.

5. *Restricted Bibliography*

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Distortion of a Frequency-Modulated Signal by Small Loss and Phase Variations*

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GENERAL FORMULAS are developed for harmonic and total distortion in the frequency of the outputs of linear transmission systems with pure frequency-modulated inputs and with amplitude and phase characteristics involving wiggles that can be represented approximately by single sinusoidal functions of small amplitude. The amplitude wiggles represent departure from flatness, and the phase wiggles departure from linearity. This first-order analysis yields a result for total distortion D that varies linearly with the amplitude of either wiggle if the amplitude of the other is made zero. It will be seen that D is periodic in the frequencies of the wiggles and in the audio frequency p and carrier frequency ω_c of the frequency-modulated input. Of course, D is also a function of its index of modulation m. The formulas for D can be applied to amplifiers, filters, and the like in a communication system that satisfies the above assumptions.

General distortion formulas are applied to waveguides loaded by pure resistances. Among other things, the so-called "long-line" effect in distortion is discussed. Graphs show the dependence of distortion on various parameters.

• • •

1. *Sinusoidal Representation of Amplitude and Phase Wiggles*

The analysis starts with the general linear four-terminal network indicated in Figure 1. If E_1 is a constant-voltage generator of frequency ω, then the solution for E_2 in terms of E_1 has the form

$$E_2 = G(j\omega)E_1 = A(\omega)e^{-j\phi(\omega)}E_1, \qquad (1)$$

where $G(j\omega)$ is dimensionless and is written in polar form. As is well known, nonflatness of $A(\omega)$ and nonlinearity of $\phi(\omega)$ will generally produce harmonic distortion in the frequency of E_2 if E_1 is a pure frequency-modulated wave.

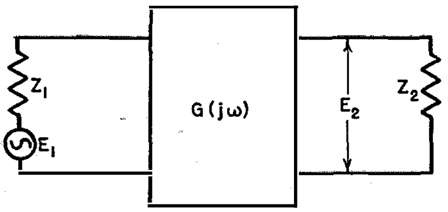

Figure 1—Linear four-terminal network.

It will be assumed now that $A(\omega)$ and $\phi(\omega)$ have the forms indicated in (2).

$$\left.\begin{aligned} A(\omega) &= 1 + \mathcal{E}_1 \cos 2b(\omega - \omega_1), \\ \phi(\omega) &= c(\omega - \omega_0) + \mathcal{E}_2 \sin 2d(\omega - \omega_2). \end{aligned}\right\} \qquad (2)$$

The amplitude and phase characteristics described by (2) are illustrated in Figure 2. It is assumed the $\mathcal{E}_1$ and $\mathcal{E}_2$ are small and that higher powers of $\mathcal{E}_1$ and $\mathcal{E}_2$ can be disregarded in all steps of the subsequent analysis. It should be noted that (2) applies not only to waveguides, but to other types of networks as well.

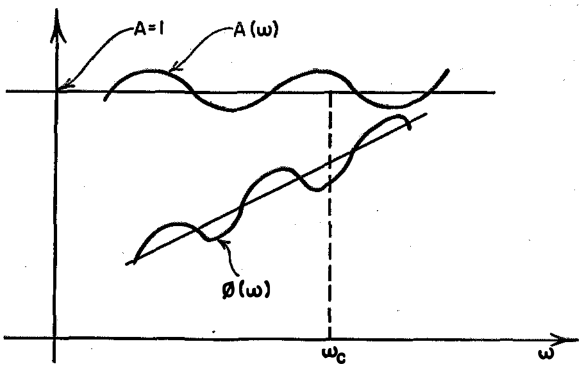

Figure 2—Amplitude and phase characteristics with sinusoidal variation.

* Presented at the National Convention of the Institute of Radio Engineers on March 8, 1950, in New York, New York. Reprinted from *Proceedings of the IRE*, v. 40, pp. 172–176; February, 1952. This work was sponsored by the United States Army Signal Corps Engineering Laboratories.

2. Derivation and Discussion of Distortion Formulas

To obtain the distortion in the frequency of E_2 (see Figure 1) when E_1 is a pure frequency-modulated input, the sideband analysis is followed. E_1 is defined by

$$E_1 = E_0 \sin (\omega_c t + m \sin pt)$$
$$= E_0 \sum_{k=-\infty}^{\infty} J_k(m) \sin (\omega_c + kp)t, \tag{3}$$

where E_0 is constant, ω_c is the carrier frequency, p is the modulating frequency, and m is the index of modulation. The instantaneous frequency Ω in (3) is the derivative of the phase and has the form

$$\Omega = \omega_c + mp \cos pt. \tag{4}$$

Note that mp represents the maximum deviation of the modulating from the carrier frequency.

If each term of the input E_1 is altered suitably with the use of $A(\omega)$ and $\phi(\omega)$ according to the steady-state theory, the output E_2 is given by

$$\frac{E_2}{E_0} = \sum_{-\infty}^{\infty} [1 + \mathcal{E}_1 \cos 2b(\omega_c' + kp)] \\ J_k(m) \sin [(\omega_c + kp)(t-c) \\ - \mathcal{E}_2 \sin 2d(\omega_c'' + kp) + \omega_0 c], \tag{5}$$

where $\omega_c = \omega_c - \omega_1$ and $\omega_c'' = \omega_c - \omega_2$. As expected, the linear term $c\omega$ in the expression for ϕ leads to a delay, but does not produce distortion. It is convenient to replace $t-c$ by τ.

If (5) is expanded and higher powers of $\mathcal{E}_1$ and $\mathcal{E}_2$ are neglected, the result is

$$E_2/E_0 = (A^2 + B^2)^{1/2} \sin (\omega_c \tau + \omega_0 c + \psi), \tag{6}$$

where $\tau = t - c$, and A, B, and ψ are defined by

$$\left.\begin{aligned} A &= \sum_{-\infty}^{\infty} J_k(m)[\cos kp\tau + \mathcal{E}_1 \cos 2b(\omega_c' + kp) \\ &\quad \times \cos kp\tau + \mathcal{E}_2 \sin 2d(\omega_c'' + kp) \sin kp\tau], \\ B &= \sum_{-\infty}^{\infty} J_k(m)[\sin kp\tau + \mathcal{E}_1 \cos 2b(\omega_c' + kp) \\ &\quad \times \sin kp\tau - \mathcal{E}_2 \sin 2d(\omega_c'' + kp) \cos kp\tau], \\ \tan \psi &= B/A. \end{aligned}\right| \tag{7}$$

Equation (6) indicates that the output voltage E_2 is generally no longer a pure frequency-modulated wave. It now has a new instantaneous frequency

$$\Omega = \omega_c + d\psi/d\tau. \tag{8}$$

It turns out that both ψ and $d\psi/d\tau$ are periodic functions of time with fundamental period $2\pi/p$ and can be expanded in Fourier series: $d\psi/d\tau$ can be expressed in the form

$$\left.\begin{aligned} \frac{1}{p}\frac{d\psi}{d\tau} &= m \cos p\tau + \mathcal{E}_1 \sum_{k=-\infty}^{\infty} kJ_k(2m \sin pb) \\ &\quad \times \cos [k(pb + \pi/2) + 2b\omega_c'] \cos kp\tau \\ &\quad + \mathcal{E}_2 \sum_{k=-\infty}^{\infty} kJ_k(2m \sin pd) \\ &\quad \times \sin [k(pd + \pi/2) + 2d\omega_c''] \sin kp\tau. \end{aligned}\right| \tag{9}$$

The last result is basic in distortion calculations. Higher-harmonic terms beyond the first represent distortion in the original modulation. It should be recalled that (9) is a first-order result that is applicable to any network for which $A(\omega)$ and $\phi(\omega)$ have the forms indicated in (2) and Figure 2. Even if $A(\omega)$ and $\phi(\omega)$ are approximately given by (2) for a finite frequency range that includes the essential band of E_1, (9) may still be used.

For distortion calculations, (9) may be written in the form

$$\left.\begin{aligned} \frac{1}{p}\frac{d\psi}{d\tau} &= m \cos \theta + \sum_{k=1}^{\infty} k(\mathcal{E}_1 A_k \cos k\theta \\ &\qquad + \mathcal{E}_2 B_k \sin k\theta), \\ A_k &= J_k(u)[\cos (kb_1 + b_2) \\ &\qquad + (-1)^{k+1} \cos (-kb_1 + b_2)], \\ B_k &= J_k(v)[\sin (kd_1 + d_2) \\ &\qquad + (-1)^k \sin (-kd_1 + d_2)], \end{aligned}\right\} \tag{10}$$

where

$$\begin{aligned} &\theta = p\tau, \\ &u = 2m \sin pb, && v = 2m \sin pd, \\ &b_1 = pb + (\pi/2), && b_2 = 2b(\omega_c - \omega_1), \\ &d_1 = pd + (\pi/2), && d_2 = 2d(\omega_c - \omega_2). \end{aligned}$$

One can put (10) in the final form

$$\left.\begin{aligned} \frac{1}{p}\frac{d\psi}{d\tau} &= m \cos \theta + \sum_{2}^{\infty} kC_k \sin (k\theta + \phi_k), \\ C_k^2 &= \mathcal{E}_1^2 A_k^2 + \mathcal{E}_2^2 B_k^2, \end{aligned}\right\} \tag{11}$$

where the first term of the sum in (10) has been omitted because it leads to higher-order terms in the distortion.

The definitions of distortion used in this report are given by

$$k\text{th-harmonic distortion} = D_k = kC_k/m,$$

$$\text{total distortion } D = \left(\sum_{2}^{\infty} k^2 C_k^2\right)^{1/2} \Big/ m. \quad (12)$$

An expression for harmonic distortion D_k can be obtained from (10) and (11).

If D_A is the total distortion due to amplitude wiggles alone ($\mathcal{E}_2 = 0$) and D_ϕ is the total distortion due to phase wiggles alone ($\mathcal{E}_1 = 0$), then one can write

$$D^2 = D_A^2 + D_\phi^2, \qquad D_k^2 = D_{kA}^2 + D_{k\phi}^2. \quad (13)$$

It is evident from (13) and previous equations that, to a first order, there is no combination of amplitude and phase wiggles that will improve the distortion, harmonic or total, due to either alone.

The summation in (12) leads to

$$\left.\begin{aligned}
4m^2 \frac{D_A^2}{\mathcal{E}_1^2} &= 4m^2 \sin^2 pb \\
&+ 2m \sin pb \cos 4b(\omega_c - \omega_1) \\
&\times \Big[J_1(4m \sin pb) + 4mJ_0(2m \sin 2pb) \\
&\times \sin^3 pb - \frac{J_1(2m \sin 2pb)}{\cos pb} \Big] \\
&- 8m^2 J_0(4m \sin^2 pb) \sin^2 pb \cos^2 pb \\
&+ 2mJ_1(4m \sin^2 pb) \\
&- 16 J_1^2(2m \sin pb) \sin^2 pb \\
&\times \cos^2 2b(\omega_c - \omega_1), \\
4m^2 \frac{D_\phi^2}{\mathcal{E}_2^2} &= 4m^2 \sin^2 pd \\
&+ 2m \sin pd \cos 4d(\omega_c - \omega_2) \\
&\times \Big[J_1(4m \sin pd) - 4mJ_0(2m \sin 2pd) \\
&\times \sin^3 pd + \frac{J_1(2m \sin 2pd)}{\cos pd} \Big] \\
&+ 8m^2 J_0(4m \sin^2 pd) \sin^2 pd \cos^2 pd \\
&- 2mJ_1(4m \sin^2 pd) \\
&- 16 J_1^2(2m \sin pd) \cos^2 pd \\
&\times \cos^2 2d(\omega_c - \omega_2).
\end{aligned}\right\} \quad (14)$$

It can be seen from (14) that D_A has period π in pb and $2b(\omega_c - \omega_1)$, and that D_ϕ has period π in pd and $2d(\omega_c - \omega_2)$. Note that $p = 2\pi f_a$, where f_a is audio frequency, and b or d is related to the number of amplitude or phase wiggles per unit frequency (see Figure 2). Figure 2 can be used to give a crude partial check on the results in (10) and (14), if it is recalled that the amplitude and phase wiggles have period π in pb and pd, respectively. For example, if $pb = \pi$, then ω_c and all the sidebands of the frequency-modulated input fall on a flat line as far as amplitude is concerned. Hence, there should be no distortion D_A due to amplitude alone. From (14), it is seen that $D_A = 0$ for $pb = \pi$. If $pd = \pi$, then ω_c and the sidebands of the frequency-modulated input fall along a line through the phase characteristic, and D_ϕ should be zero. From (14) it is seen that $D_\phi = 0$ for $pd = \pi$.

Figure 2, with the linear term in the phase removed, and (10) yield information about harmonic distortion. If $2b(\omega_c - \omega_1) = n\pi$, n integral, then ω_c is at the peak of an amplitude wiggle, and the sidebands fall at points that are symmetrical with respect to this peak. In this case, (10) shows that $D_{kA} = 0$ for k even. If $2b(\omega_c - \omega_1) = (2n+1)\pi/2$, then ω_c is at a node and the points for the sidebands are odd symmetrical about this node. In this case, $D_{kA} = 0$ for k odd. If $2d(\omega_c - \omega_2) = n\pi$ then ω_c is at a node, and the sideband points are distributed with odd symmetry about this node. For this case, $D_{k\phi} = 0$ for k even. Finally, if $2d(\omega_c - \omega_2) = (2n+1)\pi/2$, then ω_c is at a maximum or minimum, and there is even symmetry for the sideband points. For this case, $D_{k\phi} = 0$ for k odd.

A thorough analytical and numerical discussion of the distortion results in (10) and (14) will not be given in this paper. Since such a discussion is very complicated and probably of no practical value in general form, it will be made later for the special case of the waveguide. However, one interesting statement can be made about D in general.

If neither pb nor pd is close to $n\pi/2$ and m is sufficiently large, then, approximately,

$$\left.\begin{aligned}
D_A &\approx \mathcal{E}_1 \sin pb, \\
D_\phi &\approx \mathcal{E}_2 \sin pd, \\
D^2 &\approx \mathcal{E}_1^2 \sin^2 pb + \mathcal{E}_2^2 \sin^2 pd,
\end{aligned}\right\} \quad (15)$$

for pb and pd unequal to $n\pi/2$ for any integral n and for large m.

It will be seen later in the case of the waveguide that D in (15) is close to its maximum value for a given value of pb ($b=d$ in this special case) and that the over-all maximum value of D is close to its value in (15) for $pb=\pi/2$. It is possible that similar conclusions may apply to the general case. If this is true, then (15) indicates over-all maxima of $D_A=\mathcal{E}_1$, $D_\phi=\mathcal{E}_2$, and $D^2=\mathcal{E}_1^2+\mathcal{E}_2^2$. For example, if $\mathcal{E}_1=\mathcal{E}_2=0.05$, then $D_A=D_\phi=0.05$ and $D=0.07$. It can readily be shown from (14) that, for $pb\neq n\pi/2$ and $pd\neq n\pi/2$, D_A and D_ϕ have maxima and minima with respect to $2b(\omega_c-\omega_1)$ and $2d(\omega_c-\omega_2)$ at $4b(\omega_c-\omega_1)=n\pi$ and $4d(\omega_c-\omega_2)=n\pi$. The two n's need not refer to the same integer.

This concludes the general discussion of the first-order analysis of distortion caused by sinusoidal wiggles in amplitude and phase of transmission systems. If the mathematical description of such wiggles in the essential band of frequencies for the input frequency-modulated wave requires more than one sinusoid, the derivation of distortion results becomes more complicated, but remains possible along the lines of the previous analysis.

3. Derivation of Waveguide Amplitude and Phase Characteristics

We now apply previously obtained distortion results to lossless waveguides. Figure 3 shows their equivalent transmission-line representation.

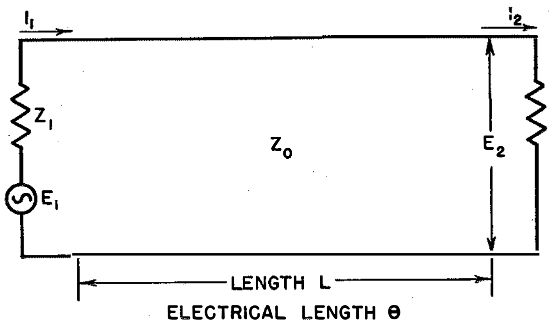

Figure 3—Terminated waveguide.

It is possible to derive the special forms that the distortion expressions take for the waveguide by regarding the output voltage E_2 as being composed of voltages due to the main incident wave and the first re-reflection. The first-order analysis of this report would imply that the remaining re-reflections can be neglected. This point of view can be justified by using the paired-echo method or by superposing the main incident wave and the first re-reflection for each frequency in the input frequency-modulation spectrum. Harmonic-distortion formulas derived from this point of view appear as side products in articles on multipath transmission by Crosby[1] and Corrington.[2]

Now consider the waveguide of Figure 3. To apply previous distortion results to the waveguide, the quantities b, c, d, ω_1, ω_2, $\mathcal{E}_1$, and $\mathcal{E}_2$ have to be expressed in terms of waveguide parameters. From Figure 3 and standard transmission-line equations, one can express E_2 in terms of a constant-voltage generator E_1 by the relation

$$\begin{aligned} E_2 &= \frac{Z_1Z_2}{(Z_1+Z_2)\cos\theta+j(1+Z_1Z_2)\sin\theta}E_1 \\ &= A(\theta)e^{-j\phi(\theta)}E_1. \end{aligned} \tag{16}$$

The impedances Z_1 and Z_2 have been normalized with respect to the characteristic impedance Z_0 of the waveguide.

For real Z_1 and Z_2, one can write

$$\left.\begin{aligned} A(\theta) &= \\ &\frac{Z_1Z_2}{[(Z_1+Z_2)^2+(1-Z_1^2)(1-Z_2^2)\sin^2\theta]^{1/2}}, \\ \tan\phi(\theta) &= \frac{1+Z_1Z_2}{Z_1+Z_2}\tan\theta. \end{aligned}\right\} \tag{17}$$

It is convenient to rewrite (17) in terms of reflection factors r_1 and r_2 defined by

$$\left.\begin{aligned} r_1 &= \frac{1-Z_1}{1+Z_1}, \quad & Z_1<1, \\ r_2 &= \frac{1-Z_2}{1+Z_2}, \quad & Z_2<1. \end{aligned}\right\} \tag{18}$$

If Z_1 or Z_2 is greater than one (or both are), then the numerators in (18) are reversed, but the final results are not affected.

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[1] M. G. Crosby, "Frequency-Modulation Propagation Characteristics," *Proceedings of the IRE*, v. 24, pp. 898–913; June, 1936.

[2] M. S. Corrington, "Frequency-Modulation Distortion Caused by Multipath Transmission," *Proceedings of the IRE*, v. 33, pp. 878–891; December, 1945.

With the use of (18), (17) becomes

$$\left.\begin{aligned} A(\theta) &= \frac{(1-r_1)(1-r_2)}{2[(1-r)^2+4r\sin^2\theta]^{1/2}},\\ \tan\phi(\theta) &= \frac{1+r}{1-r}\tan\theta, \end{aligned}\right\} \tag{19}$$

where $r = r_1 r_2$. Before proceeding, consider the picture of distortion if either load in Figure 3 is matched, i.e., if $r_1 = 0$ or $r_2 = 0$. In either case, $A(\theta)$ reduces to a constant and ϕ becomes θ. Since θ is approximately linear in frequency ω, ϕ becomes linear in ω. In other words, for $r = 0$, the system has a flat amplitude characteristic and linear phase characteristic. Hence, as is well known for this case, the system will not distort the frequency of a frequency-modulated input. If $r \neq 0$, then energy from the generator travels back and forth between Z_1 and Z_2 and undergoes partial reflections at each end. The energy at the load end comes from the main incident wave and re-reflections. It is the latter that cause distortion trouble in the case of a frequency-modulated input.

If now r is assumed to be small, it can be shown that (19) becomes

$$\left.\begin{aligned} A(\theta) &\approx 1 + r\cos 2\theta,\\ \phi(\theta) &\approx \theta + r\sin 2\theta. \end{aligned}\right\} \tag{20}$$

There remains the problem of expressing θ in terms of ω. Waveguide theory yields the formula

$$\theta = \frac{L\omega}{v}\left[1 - \frac{(\omega_1)^2}{(\omega)^2}\right]^{1/2} = a\omega, \tag{21}$$

where L is the physical length of the guide, v is velocity of light in unbounded space of the waveguide medium, and ω_1 is the cutoff frequency of the propagated mode. If ω is restricted to a small band, then the radical can be assumed to have a constant value taken at the center of the band, so that a is essentially constant. The use of (21) in (20) leads to the expressions

$$\left.\begin{aligned} A(\omega) &= 1 + r\cos 2a\omega,\\ \phi(\omega) &= a\omega + r\sin 2a\omega. \end{aligned}\right\} \tag{22}$$

4. *Distortion Formulas for Waveguide*

If (22) is compared to (2), it is seen that $\mathcal{E}_1 = \mathcal{E}_2 = r$, $b = c = d = a$, and $\omega_1 = \omega_2 = 0$. The variable part of the output frequency as given by (11) thus becomes

$$\left.\begin{aligned} \frac{1}{p}\frac{d\psi}{d\tau} &= m\cos p\tau\\ &\quad + 2r\sin 2a\omega_c \sum_{k=2,4,\cdots}^{\infty} kJ_k(2m\sin ap)\\ &\qquad \times \sin k(p\tau - pa - \pi/2)\\ &\quad + 2r\cos 2a\omega_c \sum_{k=3,5,\cdots}^{\infty} kJ_k(2m\sin ap)\\ &\qquad \times \cos k(p\tau - pa - \pi/2). \end{aligned}\right\} \tag{23}$$

The general distortion formulas in (12) now become

$$\left.\begin{aligned} D/2^{1/2}r &= \{\sin^2 ap\{1 + [J_0(4m\sin ap)\\ &\qquad + J_2(4m\sin ap)]\cos 4a\omega_c\}\\ &\qquad - (2/m^2)J_1^2(2m\sin ap)\cos^2 2a\omega_c\}^{1/2},\\ D_2 &= (4r/m)J_2(2m\sin pa)\sin 2a\omega_c,\\ D_3 &= (6r/m)J_3(2m\sin pa)\cos 2a\omega_c \cdots. \end{aligned}\right| \tag{24}$$

In interpreting the distortion results in (24), it is instructive to consider Figure 4. The wiggles in Figure 4 are phased 90 degrees apart,

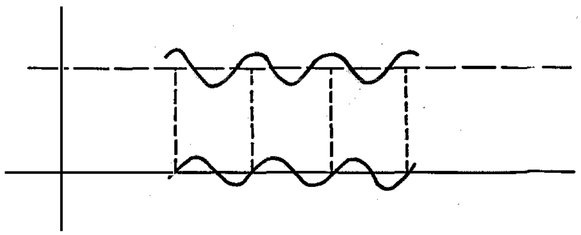


Figure 4—Amplitude and phase characteristics of a terminated waveguide. The upper curve corresponds to $A(\omega) = 1 + r\cos 2a\omega$ and the lower curve to $\phi(\omega) = r\sin 2a\omega$ with the linear term omitted.

have amplitude r, and have period π/a in ω. The discussion following (14) can be applied here. It leads to the conclusions that there is odd-harmonic distortion if $2a\omega_c = n\pi$, even-harmonic distortion if $4a\omega_c = (2n+1)\pi$, and no distortion if $ap = n\pi$.

It is interesting to examine (24) in limiting cases. If $m\sin ap$ is very small, either because of small m or because of small ap, and if $\sin 2a\omega_c \neq 0$, then it can be seen that (24) reduces to

$$D \approx 2rm\sin^2 ap\sin 2a\omega_c \approx D_2. \tag{25}$$

In this case, distortion is chiefly of the second-harmonic type. If $m\sin ap$ is small and $\sin 2a\omega_c$

$=0$, then (24) reduces to

$$D \approx rm^2 \sin^3 ap \approx D_3 \qquad (26)$$

Here, distortion is primarily of the third-harmonic type. Note that, for small $m \sin ap$ and $\sin 2a\omega_c = 0$, distortion drops much more rapidly with $m \sin ap$ than for the case $\sin 2a\omega_c \neq 0$.

If $m \sin ap$ is large, then (24) becomes

$$D \approx 2^{1/2} r \sin ap. \qquad (27)$$

This result is essentially independent of m and $a\omega_c$. It cannot be attributed primarily to any single harmonic.

A brief discussion will now be given of the total distortion D. It depends on the dimensionless parameters r, ap, $a\omega_c$, and m. Since D varies linearly with r, no further discussion of its dependence on r is required. Perhaps the most striking feature about (24) is that D is periodic with fundamental period π in either ap or $2a\omega_c$ for fixed m. In other words, D cannot increase indefinitely with ap or $2a\omega_c$, but passes periodically through zeros and maxima. Since a is linear in waveguide length L, increasing L indefinitely does not produce an indefinitely increasing D.

It appears at first glance from the foregoing that the description of distortion in the waveguide as a long-line effect is inaccurate. However, as will be seen later, the first maximum of D with respect to L for fixed p, ω_c, and m may occur for a large value of L, so that increasing L from zero to this value will produce monotonically increasing D. In this case, increasing distortion can be regarded as a long-line effect so far as physical length L is concerned, but is actually confined to electrical lengths $ap < \pi$.

5. *Construction of Distortion Graphs for Waveguides*

A picture of the distortion introduced by loaded waveguides can be obtained by plotting

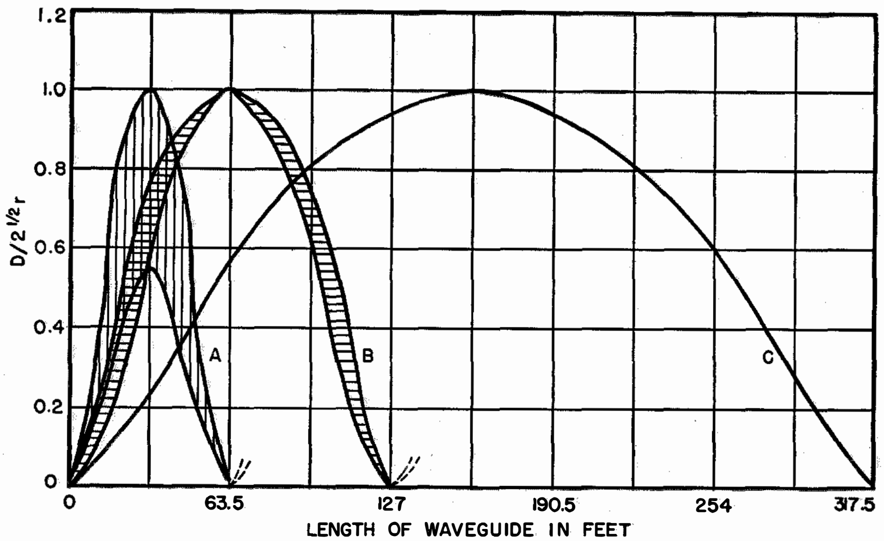


Figure 5—Total distortion D plotted against waveguide length L. Curves A are for $f_a = 10$ megacycles and $m = 1$; B, $f_a = 5$ megacycles and $m = 2$; C, $f_a = 2$ megacycles and $m = 5$.

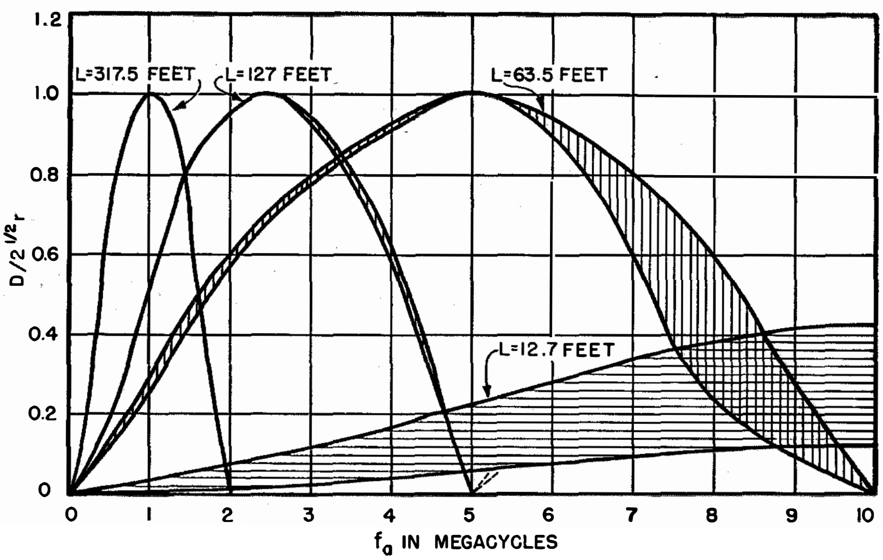


Figure 6—Total distortion D plotted against audio frequency f_a with $m = 10/f_a$.

distortion D against physical length L of waveguide or audio frequency f_a. Assume that the carrier frequency is fixed at 5000 megacycles. Assume also that the maximum instantaneous deviation in the frequency of the frequency-modulated input is fixed. For this case, the index m varies with audio frequency $f_a = p/2\pi$. Assume that $m=1$ when $f_a=10$ megacycles, so that $m=10^7/f_a$ for any other audio frequency f_a.

Now consider the expression given for a in (21). The cutoff frequency ω_1 for the lowest mode in a standard 2-inch by 1-inch waveguide is about $2\pi \times 3.16 \times 10^9$. The value of the radical in (21) is about 0.775 for $\omega=\omega_c$. The value of a is therefore given by $a=7.87\times10^{-10}\ L$ seconds, for L in feet. The expressions for ap, $a\omega_c$, and m to be used in the distortion formulas (24) for the present case become

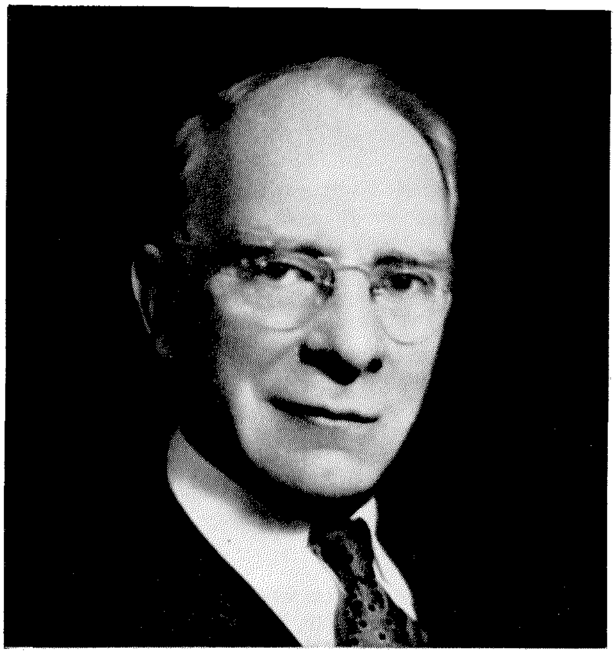
$$\left.\begin{aligned} 2a\omega_c &= 2\pi \times 7.87L, \\ ap &= 2\pi \times 7.87 \times 10^{-10} f_a L, \\ m &= 10^7/f_a. \end{aligned}\right\} \qquad (28)$$

Equation (28) shows that the functions of $2a\omega_c$ and ap in (24) have respective periods of 0.0635 feet and $0.0635\times10^{10}/f_a$ feet in L. In other words, the period of the ap terms is $10^{10}/f_a$ times the period of the $2a\omega_c$ terms. Since $f_a \leqslant 10^7$ in the present application, the terms involving $2a\omega_c$ in (24) have a high frequency compared to those involving ap. Equation (28) also shows that the functions of ap in (24) have period $6.35\times 10^8/L$ cycles in f_a. Note that the functions of $2a\omega_c$ in (24) are independent of f_a.

Graphs are provided in Figures 5 and 6 of $D/2^{1/2}r$ against waveguide length L for different values of audio frequency f_a and against f_a for different values of L. Consider first the plots in Figure 5 of $D/2^{1/2}r$ against L for different values of f_a. For large values of f_a, these graphs show a shaded area bounded by two curves. The actual curve lies in this shaded area and has high-frequency wiggles that have not been indicated. Hence, for large f_a, D changes very rapidly for a slight change in L. As noted above, these high-frequency wiggles have a period of 0.0635 feet in L independently of f_a. In the graph for $f_a=10$ megacycles, for example, there are 1000 wiggles in the shaded area. The amplitude of these wiggles tends to zero as f_a is decreased, and hence m is increased. Only one period of each curve is drawn in Figure 5.

Next consider the plots in Figure 6 of $D/2^{1/2}r$ against f_a for various values of L. For small values of L, these graphs show shaded areas that are interpreted differently from the shaded areas of Figure 5. In the present case, any actual curve again lies within the corresponding shaded area but no longer has any wiggles. A slight change in the parameter L from 0 to 0.0635 feet will yield a distortion curve without wiggles anywhere in a shaded area. Notice that these shaded areas shrink vertically as L is increased. As in Figure 5, only one period of each curve is drawn in Figure 6.

In Memoriam



WOLCOTT H. PITKIN

WOLCOTT H. PITKIN, vice chairman and counsel of the International Telephone and Telegraph Corporation, also served as a director of the corporation since 1925, a few years after its foundation.

Mr. Pitkin was a sound lawyer; beloved, respected, and admired by those with whom he dealt. So many and varied were his contributions to the growth and development of the I.T.&T. System that they cannot well be measured. With exceptional analytical powers and knowledge of the law, his counsel was invariably sought in the solution of the System's major problems. A forthright gentleman who adhered to the highest standards, Mr. Pitkin's loyalty and devotion to the corporation and its interests were a constant inspiration to his many friends and associates.

In his death the corporation has lost one of its ablest counselors and his associates a staunch and loyal friend.

Mr. Pitkin was born in Albany, New York, on December 6, 1881. A graduate of Harvard University, class of 1902, he took his degree in law cum laude from Harvard Law School early in 1906. He was employed by the New York law firm of Simpson, Thatcher, and Bartlett until appointed assistant United States attorney for the southern district of New York in 1909. Named attorney general of Puerto Rico by President Taft in March, 1912, he resigned the post in 1914 to become advisor in foreign affairs to the government of Siam. On returning to the United States, he engaged in the private practice of law until 1925, when he joined the legal department of International Telephone and Telegraph Corporation.

Six months after joining the I.T.&T. System, Mr. Pitkin was elected vice president and general attorney of the corporation, and as such played an important part in every major decision affecting the System during more than a quarter century.

In addition to his duties with the parent company, Mr. Pitkin during his career held numerous offices in various associated companies. He was a director, vice president, and general attorney of International Telephone and Telegraph Corporation, Sud America; a director, vice president, and general counsel of International Standard Electric Corporation; a director and chairman of American Cable and Radio Corporation; and a director and vice chairman of All America Cables and Radio, Incorporated.

He also held the positions of director in Federal Telephone and Radio Corporation, Capehart-Farnsworth Corporation, International Telecommunication Laboratories, Incorporated, and in the Cuban Telephone Company. He was a director and vice president of the Porto Rico Telephone Company, and a director and president of International Telephone Building Corporation.

Because of ill health, Mr. Pitkin had recently retired from active duty in the corporation. He died at his home in Hohokus, New Jersey, on August 18, 1952.

Contributors to This Issue

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FRED ASSADOURIAN was born on April 13, 1915, in Panderma, Turkey. New York University conferred on him the B.S. degree in 1935, the M.S. in 1936, and the Ph.D. degree in mathematics in 1940.

From 1937 to 1942, he instructed in mathematics at New York University and, from 1942 to 1944, he was an associate professor of mathematics at Texas Technological College.

He was a research engineer at the Westinghouse Research Laboratories from 1944 to 1946, working on pulse transformers. Since 1946, he has been a development engineer at Federal Telecommunication Laboratories, where he is doing theoretical work in electronics and communication.

Dr. Assadourian is a member of the American Mathematical Society and of Phi Beta Kappa.

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R. A. H. FAICT

R. A. H. FAICT was born at Boom, Belgium, on June 3, 1910. He was graduated as an electrical engineer from the University of Ghent in 1933.

In 1934, he joined the apparatus division of the Bell Telephone Manufacturing Company and is now assistant to the head of the electrical laboratory.

Mr. Faict served as an officer in the corps of engineers in the Belgian army during 1944 and 1945.

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ROBERT A. FELSENHELD

ROBERT A. FELSENHELD was born on February 15, 1910, in East Orange, New Jersey.

He has been active in the broadcast field since 1927. In 1941, he joined the staff of the Federal Telecommunication Laboratories, where he has been active on a great number of component developments, particularly concerning antennas, transmission lines, and receivers in the very- and ultra-high frequencies. Mr. Felsenheld is a senior project engineer in the radio and radar components division.

He is a Member of the Institute of Radio Engineers.

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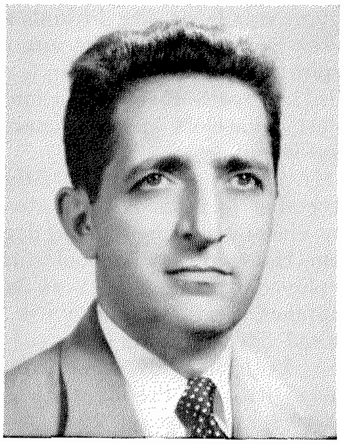

ARMIG G. KANDOIAN

ARMIG G. KANDOIAN received the M.S. degree in electrical engineering from Harvard Graduate School of Engineering in 1935.

He has been associated with the International System since 1935 and has done extensive work on antennas, transmission lines, measurements, and on various problems connected with radar, communications, and navigation. He is head of the radio and radar components division of Federal Telecommunication Laboratories.

Mr. Kandoian received the honorable mention award of Eta Kappa Nu in 1943. He is a Fellow of the Institute of Radio Engineers and a member of the American Institute of Electrical Engineers and Harvard Engineering Society.

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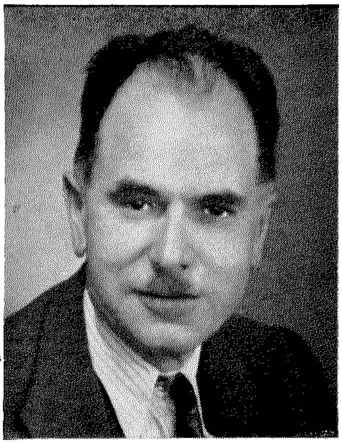
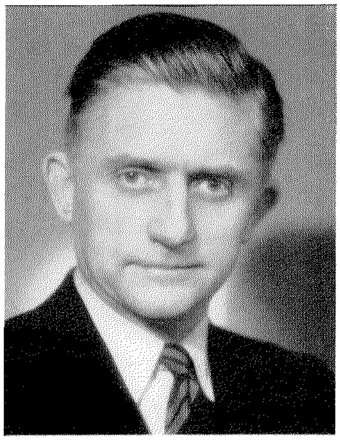
VICTOR CONSTANT MEEUWS was born at Antwerp (Berchem) on August 12, 1891. He was engaged by the Bell Telephone Manufacturing Company in 1913 and worked as a draftsman on the first rotary equipment manufactured by the company. After serving in the army from 1914 to 1919, he was placed in charge of the wiring section. In 1930, he was assigned to equipment design of the 7-D Rotary System. Four years later, he assumed the duties of power engineer.

In 1933, Mr. Meeuws was granted the title of Technical Engineer by a committee set up by law.



Victor C. Meeuws

Jean Miesse was born in Namur, Belgium, on December 2, 1901. He graduated as a mining engineer from the University of Brussels in 1925 and as an electrical engineer from the University of Louvain in 1926.



Jean Miesse

After three years in private industry, he joined the Belgian Telephone and Telegraph Administration in Antwerp. In 1930, he was assigned to Special Apparatus Service becoming director of it in 1949, and has done much work on the development of power stations for telecommunication systems.

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L. J. G. Nijs was born at Perwez, Belgium, on August 4, 1902. He was graduated as a mining engineer from the University of Liege in 1925.

After three years as an engineer in the Belgium coal mines, he joined the Bell Telephone Manufacturing Company in 1928. From 1930 to 1937, he was in charge of raw materials, metallurgical, and chemical studies in the manufacturing division. He was then transferred to the apparatus division, becoming its head in 1950.

Mr. Nijs served as an officer in the corps of engineers of the Belgian army for a year starting in September, 1939.

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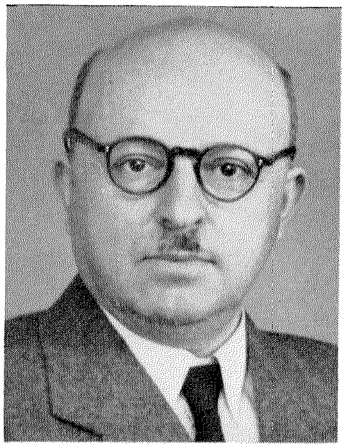
J. C. Schooneman was born in 1896 in Nijmegen, Holland.

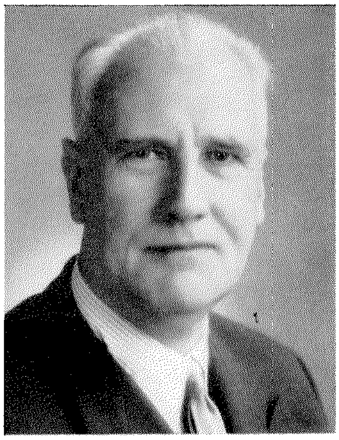
He joined the Bell Telephone Manufacturing Company staff in 1920, working for three years on the construction and testing of automatic telephone exchanges.

In 1923, he became a member of the circuit division in Antwerp and has served since 1930 as a circuit engineer and head of the section on *7-D* systems, rural networks, and interworking with other systems.



L. J. G. Nijs

William Sichak. A photograph and biography of Mr. Sichak will be found on pages 83–84 of the March, 1952, issue.



J. C. Schooneman

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION

Associate Manufacturing and Sales Companies

United States of America

Capehart-Farnsworth Corporation, Fort Wayne, In iana
Flora Cabinet Company, Inc., F ora, Indiana
Thomasville Furniture Corporation, Thomasville, North Carolina
The Coolerator Company, Duluth, Minnesota
Federal Telephone and Radio Corporation, Clifton, New Jersey
Federal Electric Corporation, Clifton, New Jersey
International Standard E ectric Corporation, New York, New York
International Standard Trading Corporation, New York, New York
I. T. & T. Distributing Corporation, New York, New York
Kellogg Switchboard and Supply Company, Chicago, Illinois

British Commonwealth of Nations

Standard Telephones and Cables, Limited, London, England
Creed and Company, Limited, Croydon, England
International Marine Radio Company Limited, Croydon, England
Kolster-Brandes Limited, Sidcup, England
Standard Telephones and Cables Pty. Limited, Sydney, Australia
Silovac Electrical Products Pty. Limited, Sydney, Australia
Austral Standard Cables Pty. Limited, Melbourne, Australia
New Zealand Electric Totalisators Limited, Wellington, New Zealand
Federal Electric Manufacturing Company, Ltd., Montreal, Canada

South America

Compañía Standard Electric Argentina, Sociedad Anónima, Industrial y Comercial, Buenos Aires, Argentina
Standard Electrica, S.A., Rio de Janeiro, Brazil
Compañía Standard Electric, S.A.C., Santiago, Chile

Continental Europe

Vereinigte Telephon- und Telegraphenfabriks Aktiengesellschaft Czeija, Niss & Co., Vienna, Austria
Bell Teleph ne 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
G. Schaub Apparatebau G.m.b.H., Pforzheim, Germany
Süddeutsche Apparatefabrik Gese schaft m.b.H., Nuremberg, Germany
Fabbrica Apparecchiature per Comunicazioni Elettriche, Milan, Italy
Nederlandsche Standard Electric Maatschappij N.V., The Hague, Netherlands
Standard Telefon og Kabelfabrik A/S, Oslo, Norway
Standard Electrica, S.A.R.L., Lis on, 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 Systems

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, H vana, Cuba
Compañía Peruana de Teléfonos Limitada, Lima, Peru
Porto Rico Telephone Company, San Juan, Puerto Rico

Radiotelephone and Radiotelegraph Operating Companies

Compañía Internacional de Radio, Buenos Aires, Argentina
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, Bu nos Aires, Argentina[4]

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

Laboratories

Federal Telecommunication Laboratories, Inc., Nutley, New Jersey
International Teleco munication Laboratories, Inc., New York, New York
Laboratoire Central de Télécommunications, Paris, France
Standard Telecommunication Laboratories, Limited, London, England