ELECTRICAL COMMUNICATION

Technical Journal of the
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
and Associate Companies

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PUBLIC ADDRESS SYSTEMS

THE CURRENT RATING OF PAPER INSULATED POWER CABLES

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MARITIME COMMISSION "M" AWARDED TO FEDERAL TELEPHONE AND RADIO CORPORATION

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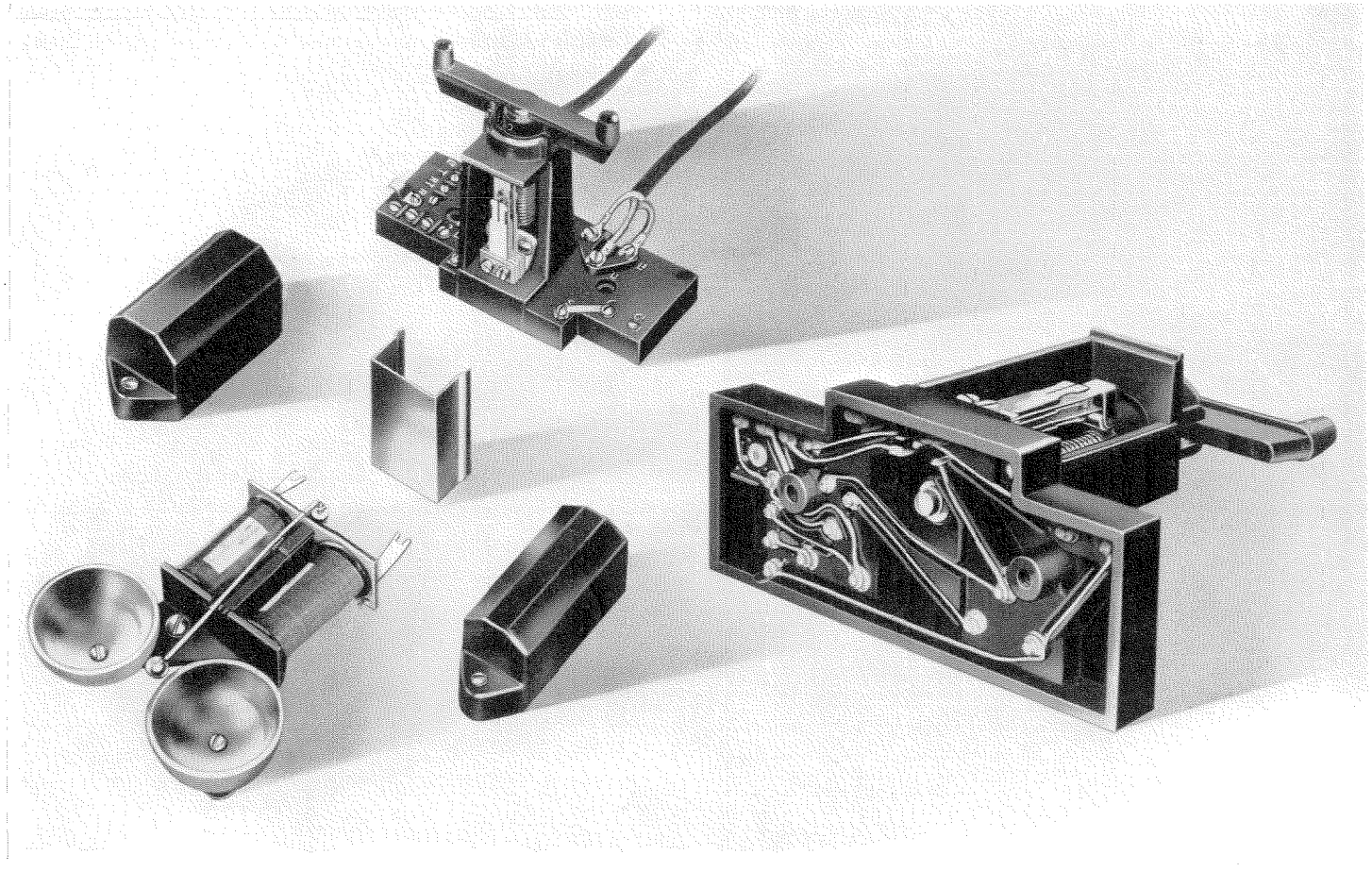
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SHOWING SEPARATE COMPONENTS OF THE SIMPLIFIED SUBSCRIBERS' TELEPHONE SET AND METHOD OF CONNECTING THEM BY MEANS OF BUS-BAR WIRING ON THE UNDER SIDE OF THE CONNECTING BLOCK.

Simplified Subscribers' Telephone Sets

By E. S. McLARN

Assistant General Technical Director, International Standard Electric Corporation, New York, N. Y.

Editor's Note:

The designs described in the following article would appear to represent the first successful attempt at evolving a type of subscriber set in which the components are designed and coordinated logically and comprehensibly with a view to achieving simplified installation together with maximum reliability and economy in maintenance. The improvements embodied in the new sets, in fact, are of such significance as to influence the future general trend of subscriber set design. They resulted from lengthy and intensive study of subscriber set behavior in far-flung I. T. & T. Associate Telephone Companies operating under the most diverse conditions.

Introduction

Telephone set maintenance represents a large item of operating expense. Because of the distance of subscribers' premises from central offices, a considerable time interval necessarily elapses between a subscriber's report of trouble in his telephone and its elimination. Maintenance costs obviously could be lowered by decreasing the number of troubles and the time required to correct them. Further, if repairs were reduced to a simplified error-proof mechanical operation, less skillful help would be required and the training period curtailed.

Causes of Troubles and Their Remedies

To reduce the number of troubles, one must know their cause. An analysis of telephone set troubles under all kinds of climatic conditions, such as obtain in the far-flung I. T. & T. Associate Operating Telephone Companies, shows that the causes are due principally to (*a*) excess moisture, dirt, lint and insects and (*b*) open and high resistance circuits brought about by deteriorated soldered joints, broken conductors and poor contact between conductors and screw-heads.

(*a*) Excess Moisture, Dirt, etc.

Excess moisture holds top rank as a trouble maker. Telephone plants are low potential systems but, nevertheless, the stress imposed on dielectrics is considerable. The central office battery potential, which is usually 48 volts, is applied constantly on the telephone set terminals. Further, the line circuit is highly inductive and circuit interruptions which result from the making and breaking of the gravity switch contacts and the impulse contacts when dialing impose a stress known to reach 600 volts.



Fig. 1—Table Type Subscribers' Set for Automatic Operation.

Excess moisture results from high humidity at high temperature. It lowers insulation resistance between current carrying parts, causing leakage, deterioration of textile, paper and other types of insulating materials and electrolytic corrosion resulting in open windings.

Dirt, lint and insects cause both mechanical and electrical failures. They accentuate the effect of moisture by holding it like a wick. The free movement of ringer armature, switch-plunger, contact springs and contacts is impeded and, in dials, the gears and governor are clogged and the lubrication absorbed.

It would appear logical to exclude these deleterious minutiae from the set. However, limitations in first cost and design possibilities make it difficult to do other than strike a compromise. In other words, make the set reasonably proof

Fig. 2A—Table Type Subscribers' Set for Manual Operation.



Fig. 2A

Fig. 2B—Interior of Table Set with Microtelephone in Place. Illustrates Method of Connecting Circuit Components without Employing Loose Wiring or a Cable Form (See Fig. 8).

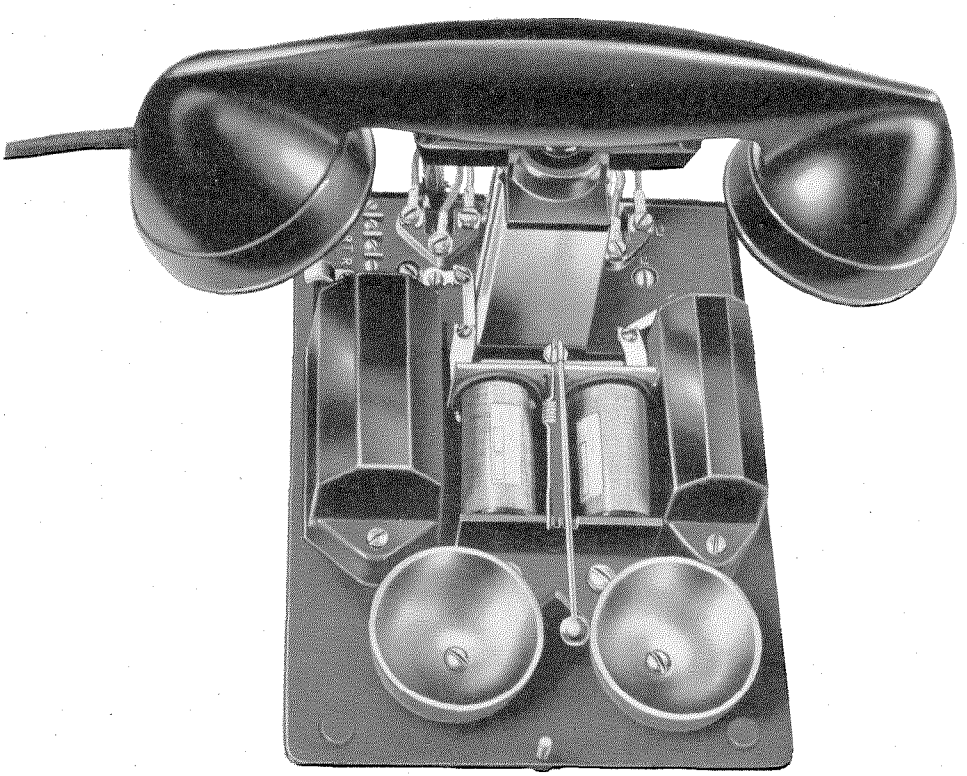


Fig. 2B

against the entrance of dirt, lint and insects and, in addition, design the circuit elements, cording and wiring inside the set to resist the effects of moisture as well as of other unwanted substances that may accumulate.

(*b*) Open Circuits

Wiring, whether run loose in the set or formed into a cable, or whether soldered to terminals or clamped under screw heads, is a source of many cases of trouble. Wires frequently are nicked in skinning, eventually breaking, and soldered joints may become defective. Wires may interfere with moving parts, the insulation becoming defective. Moreover, during damp weather leakage occurs between wires in sewed cable and between wires and metal parts. While complete elimination of wiring and cabling is not feasible, the set components and the wiring can be so arranged as to almost completely remove wiring trouble.

Simplification of Repairs

When repairmen are required to solder and unsolder conductors, follow a color scheme and remove and replace wires under screw heads, they must be trained to know the telephone circuit and must exercise extreme care not to disturb other connections and adjustments when correcting a fault. In short, they must undergo a considerable introductory training period. If, on the other hand, the set components including the cords were made to plug-in, each in its correct position, with no regard to color schemes and with the wiring and cabling eliminated insofar as the repairman is concerned, chances for error would be completely removed, the time of repair would be shortened and the training period would shrink to a minimum. The grade of repairman needed would be lowered with equal or better results and the cost of making repairs would reach a new low.

Objectives Achieved

Companion table and wall telephones embodying a realization of the preceding objectives are pictured in Figs. 1, 2, and 3. The parts of the two telephones are the same except for the molded plastic covers so that stocking and repairs are simplified. Each set is arranged for individual and two-party selective service. In addition, two knock-outs are provided in the covers so that either set can be equipped with a push-button switch for PABX holding and transfer service and with an auxiliary receiver if needed.

General Plan of the New Sets

In all telephones the wiring interconnecting the several circuit components, gravity switch, dial and handset converge into a pair of line wires which run to the Central Office or PABX. They have heretofore been constructed on the plan of placing the various elements more or less haphazardly in the space available and interconnecting them by loose wires or cabling.

In these new telephones a completely reversed plan is followed. The interconnecting medium is a moulded plastic block into which is incorporated the bare copper bus wiring, the gravity switch complete with plunger, and all connecting terminals for the line, handset and dial cords and the several circuit elements. Every element connects directly to this block without the aid of supplementary wiring. The bus bar wiring is completely protected from dust and injury. Leakage paths between buses are great since each bus is placed in its own groove. The buses are short and heavy so that their resistance is almost nil. This combination connecting block and gravity switch is the heart of the new telephones.

The circuit components themselves are fitted with spring brass split (spade) lugs that slip directly under the screw heads of the connecting terminals. The lugs are so located and the method of mounting is such that considerable pressure is maintained between the lugs and their respective terminals in the connecting block even if the screws become loose.

Circuits

The basic circuit is shown in Fig. 4. It is the highly efficient three-winding induction coil, anti-sidetone type with maximum sidetone reduction on 600 ohm loops. Removable links are provided so that the circuit arrangements shown in Figs. 5, 6, and 7 can be obtained. For the arrange-

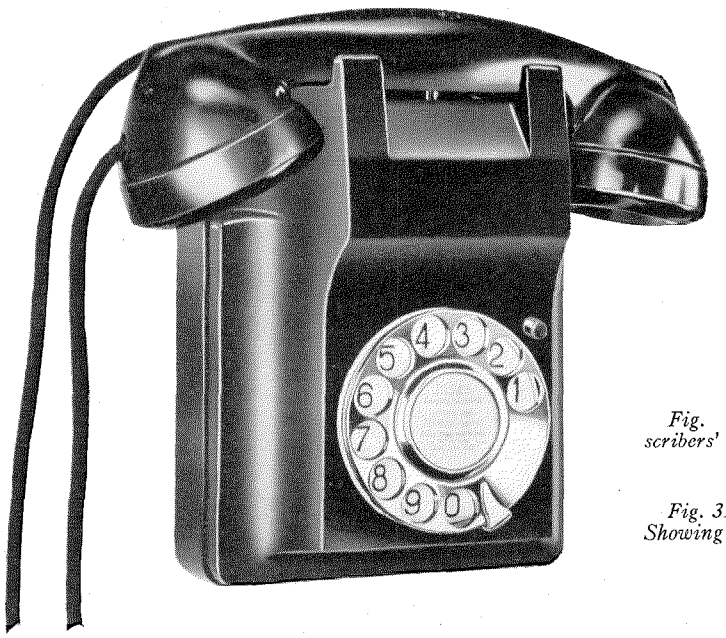
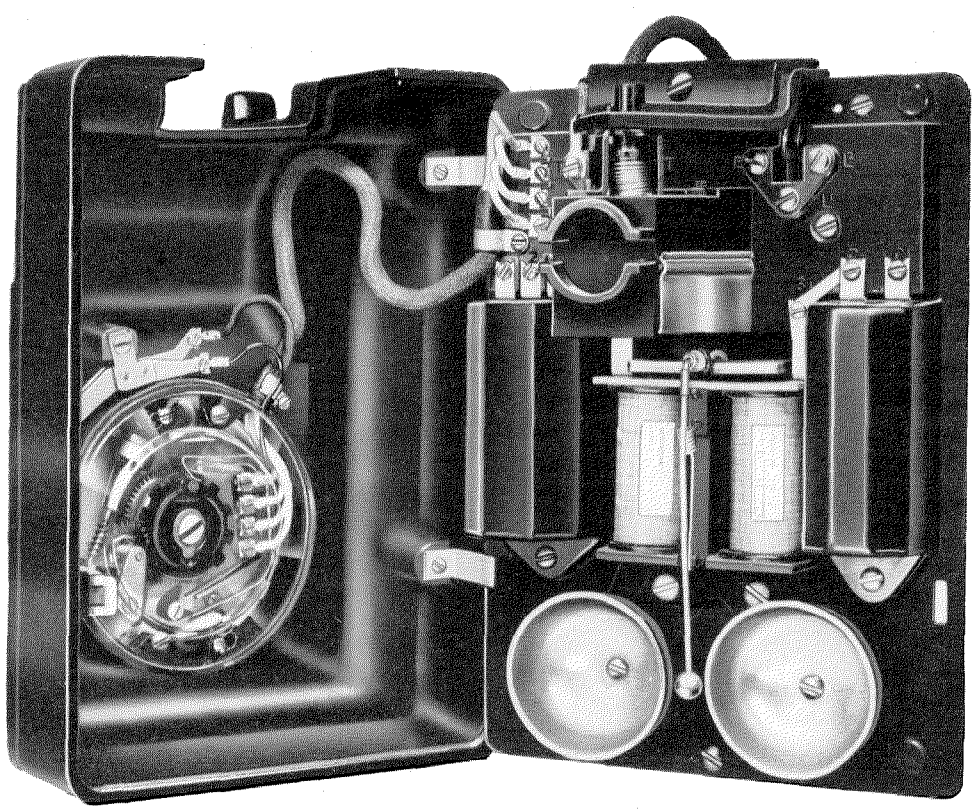


Fig. 3A (left)—Wall Type Subscribers' Set for Automatic Operation.

Fig. 3B (below)—Interior of Wall Set Showing Covered Dial Mechanism.



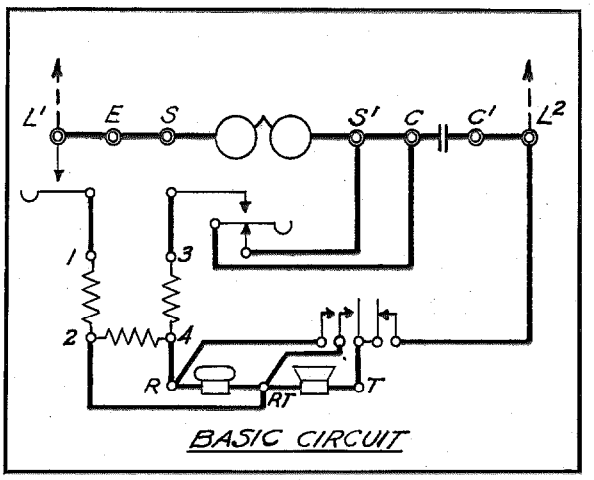


Fig. 4—Basic Circuit of a Modern, Anti-Sidetone Telephone Set as Used in the New Instruments.

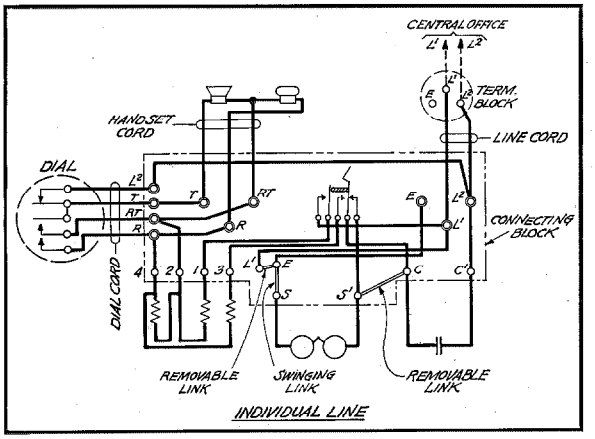


Fig. 5—Wiring Diagram of New Telephone Instrument Connected for Use on an Individual Line.

ment of Fig. 7, a push-button switch is mounted in the cover by means of an insert provided in both wall and desk set covers. The switch is wired in the circuit by using an extra conductor in the dial cord and by a short jumper from the switch to one of the dial terminals (see Fig. 3B).

Unit Components

The unit components are shown in the Frontispiece. These are alike in both table and wall sets with the exception of a difference of 90° in the position of the gravity switch plunger, as is evident by comparing Figs. 2B and 3B. It will be seen that each part fits in its own place and nowhere else, that wrong connections cannot be made except when conventional tipped telephone cords are used. Even this possibility of error has been eliminated by a new type of cordage developed for use with these telephones. A description of the new cordage is given hereinafter.

Detail descriptions of the various units making up the complete assembly follow.

Base Plate

This is a heavy flat steel plate, finished to prevent corrosion, on which all components except the dial are mounted. It is of ample thickness to ensure stability and to prevent the stripping of threads. The four corners are equipped with rubber feet which serve to prevent slipping and marring of highly finished table tops or to insulate the telephone from the wall.

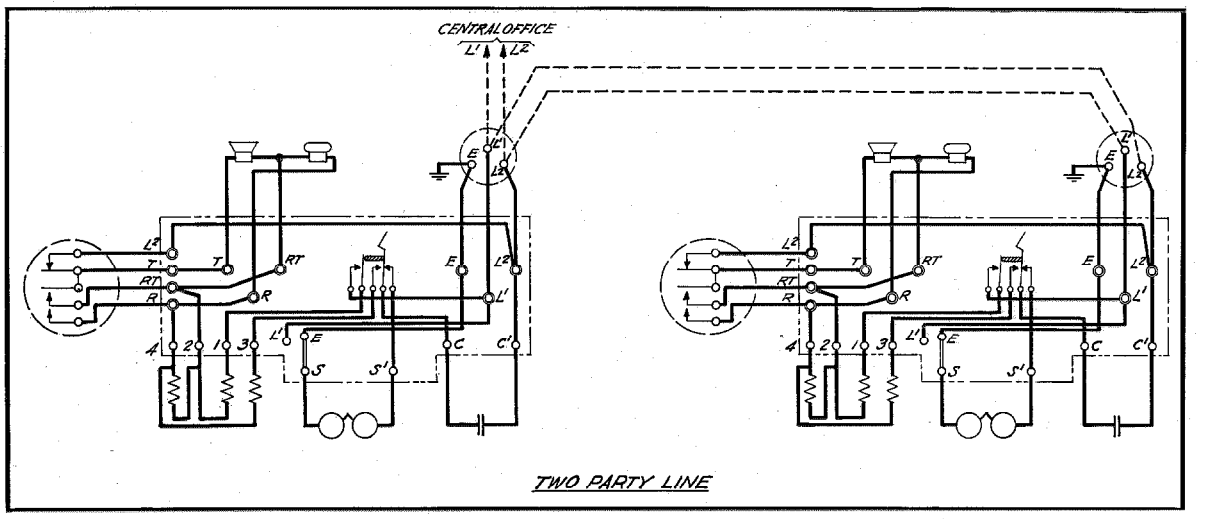


Fig. 6—Wiring Diagram of Two Subscribers' Instruments Connected for Use on a Two-Party Line.

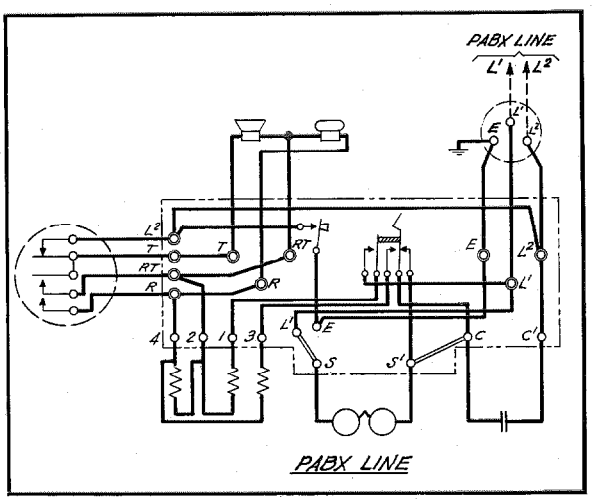


Fig. 7—Wiring Diagram of Connections to a PABX Line. A Knockout is Provided on Each Instrument to Permit Easy Installation of the Push-Button Switch.

Connecting Block

As shown in the Frontispiece, the connecting block is a heavy phenol plastic moulding of ample strength and insulating qualities. Threaded inserts to which the bus wiring is attached underneath are securely moulded into place. The threaded portions of the inserts accommodate the screws by which the circuit elements and cords are attached. The gravity switch housing, which is moulded integrally with the connecting block, is recessed at the front and right to give access to the switch for inspection and adjustment. A snap cover insures the exclusion of dust from the gravity switch housing.

Gravity Switch

The gravity switch springs are long and resilient and each is equipped with two precious metal contacts. Since alternating springs are bifurcated all contacts are made in parallel and, once properly adjusted, they are likely to remain so. (The chance of an open when two contacts are used in parallel is only a fraction of the chance when single contacts are used.) The spring nest is assembled as a unit which can easily be removed, if necessary. The main operating spring of the gravity switch is fitted with a bronze roller which registers with and is moved by the angular surface of the switch plunger of the table set, thus ensuring true rolling action between the two. The wall set plunger acts at right angles to the main

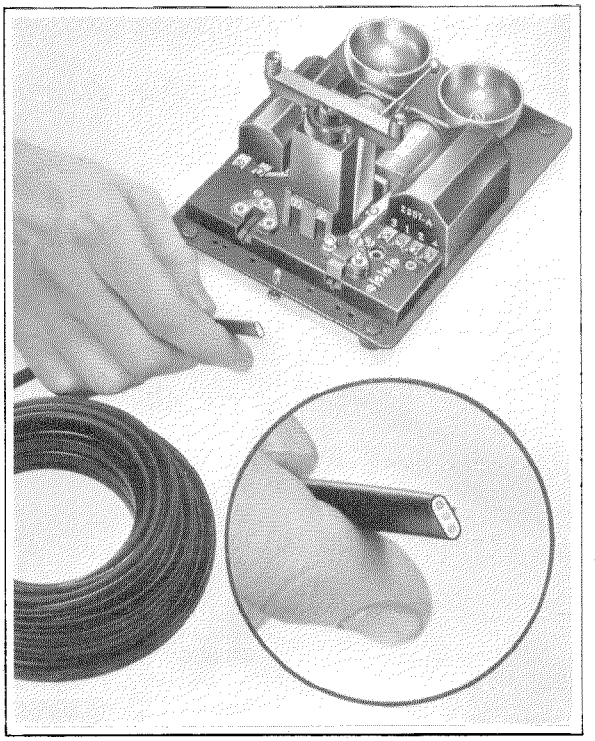


Fig. 8A

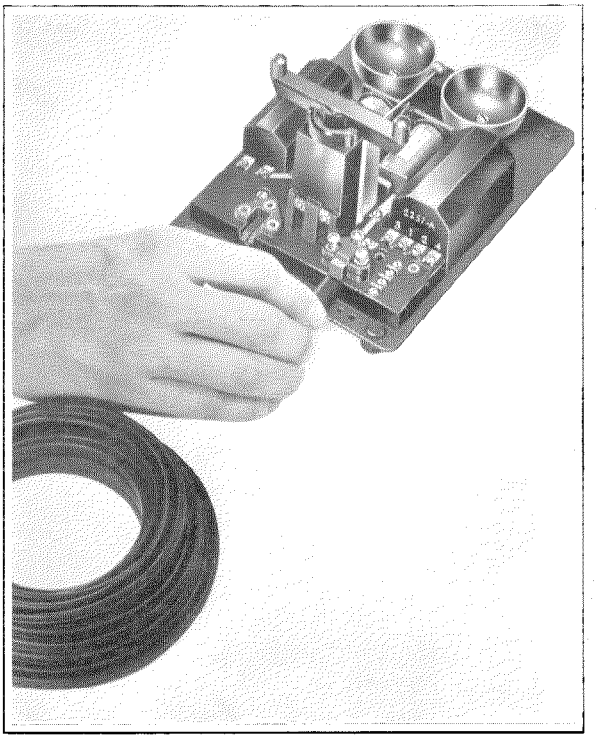


Fig. 8B

operating spring, producing movement of the latter by direct action rather than by camming action.

Plungers for both the table and wall sets are moulded in one piece with two widely separated bearing points; restoration by long resilient coil springs is positive. Further, the projecting knobs which register with the handset pass through holes in the cover which at all times completely clear the knobs, thus entirely avoiding friction with the cover. This construction ensures positive, unchanging adjustment of the gravity switch regardless of whether the set cover is off or on.

Induction Coil

The 3-winding induction coil is potted in a strong bakelite case which is filled with a high melting point compound. The bottom is sealed to prevent leakage at abnormally high temperatures. It is provided with a captive mounting screw at one end and four spade terminals at the other end. The spade terminals are clamped under their respective screws on the connecting block.

In addition to the protection from moisture provided by sealing, the windings are placed on a bakelite spool and the layers are insulated where necessary with cellulose acetate sheet. The use of insulating paper, which usually contains impurities that promote electrolytic corrosion, is avoided. Cellulose acetate sheet, on the other hand, contains no impurities; it is, therefore, much more satisfactory as a core covering and as an insulator between winding layers.

Condenser

The condenser is similar to the induction coil in appearance and sealing construction. The 2-μf condenser unit contained in the bakelite housing is capable of withstanding indefinitely the normal potential stresses to which it is subjected. It terminates in two spade tips which fit only under the proper screw heads in the connecting block.

Ringer

Simplification, as compared with past designs, has been extended to the new ringer. Adjustments are confined to the eccentric gongs and a simple

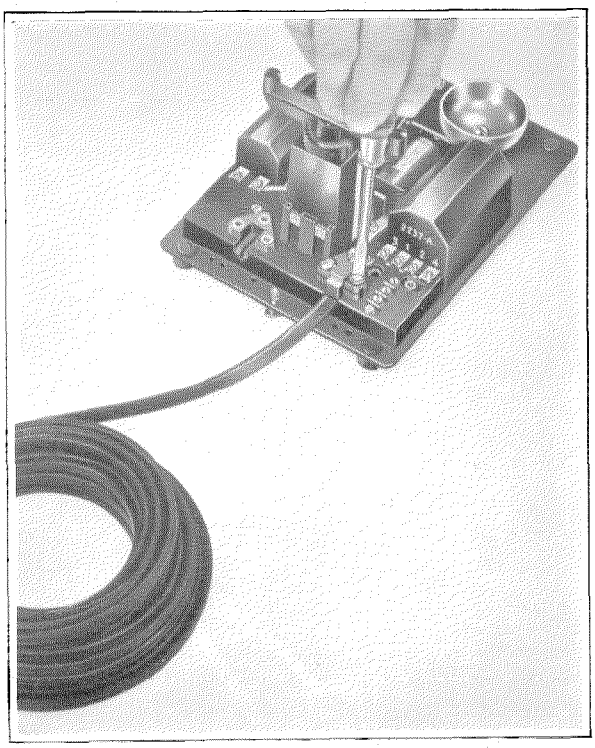


Fig. 8C

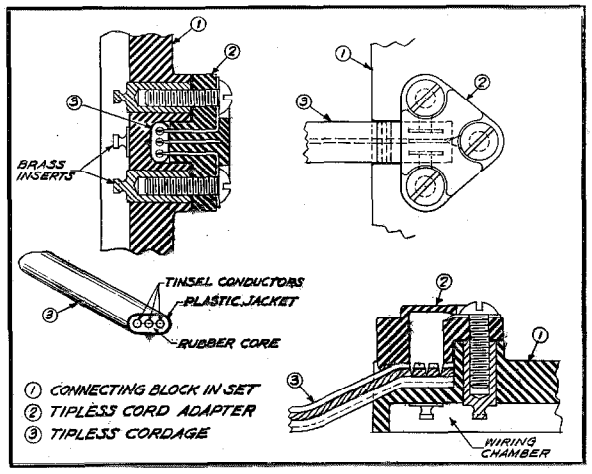


Fig. 8D

Fig. 8—Showing the New Plastic-Covered Tipless Cord and Method of Connection: (A) Cord as Cut from Bulk Stock Ready for Insertion into Special Cord Receptacle; (B) End of Cord Inserted into Receptacle, Rib Down; (C) Tightening Three Screws, thus Connecting and Fastening the Cord. Diagram (D) Illustrates the Mechanics of the Tipless Cord Connection.



Fig. 9A (left)—Showing the Conventional Textile-Covered Telephone Cord Bunched up by Twisting.

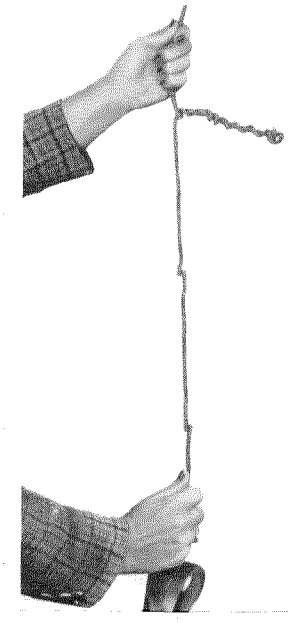


Fig. 9B (right)—Showing the Conventional Cord Pulled to Straighten it Out. Kinks and Knots Remain since Conductors Enclosed by the Outer Braiding Have Stretched Unevenly and Moved with Respect to Each Other.



Fig. 10A—Showing the New Plastic-Covered Tipless Cord Twisted and Bunched Up.

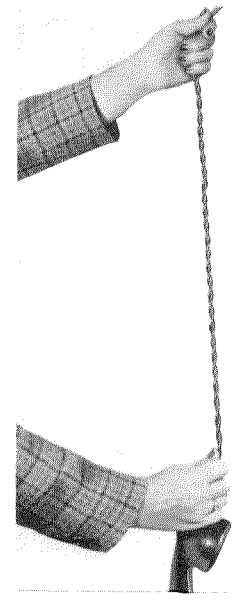


Fig. 10B—Showing the New Plastic-Covered Tipless Cord Drawn Out Straight. Kinks and Knots Do Not Develop.

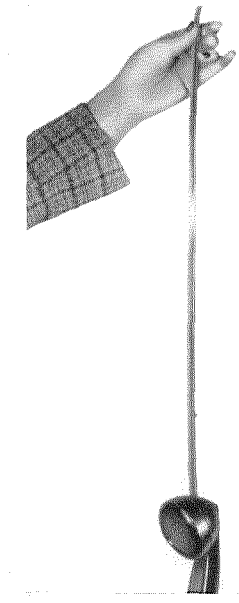


Fig. 10C—When Allowed to Unwind, the New Plastic-Covered Tipless Cord Returns to its Original Shape, Free from Any Kinks or Irregularities.

positive biasing arrangement that is completely dependable. After adjustment in the factory, adjustment in the field is unnecessary although it can be readjusted easily in case of necessity. Spade terminals again are employed for assembly to the connecting block, similar to the other components. The ringer frame is completely insulated from the metal base of the set; its coils are wound on bakelite spools with cellulose acetate insulation between the winding layers and as a covering for the coils. Since the ringer is in series with the condenser, no potential difference is maintained between winding terminals due to the central office battery. Electrolytic corrosion of windings, therefore, is amply guarded against by the precautions taken in insulating the windings, and potting of the coils is not necessary.

Dial

The dial used is basically the same as that used for some years past. It is of rugged construction and proved reliability. It has been improved, however, by the addition of a transparent cover which eliminates mechanical failures caused by dust and lint and causes the dial lubrication to be retained for longer periods. Further, the pulsing and off-normal springs are each fitted with two precious metal parallel contacts which, with alternate springs bifurcated, assure freedom from contact trouble.

Dial Cable

A short, flexible cable connects the dial to the connecting block. This cable is formed by a heavy outside braiding over four color-coded tinsel conductors each encased in rubber. Each separate conductor end is cut to exactly the correct length to fit its respective terminal and equipped with spade tips so that incorrect connection is impossible even if the color code is not known. Tinsel conductors are superior to either stranded or solid conductors for this purpose since the latter break or become noisy.

Handset and Line Cords

Cord maintenance is one of the largest items of telephone maintenance costs. This comes about from several factors such as rotted or discolored outside braiding, knots, twists and loops that make the cord unusable, open or noisy conductors, low insulation or conversely leakage between conductors, and loose cord tips. Moreover, since conventional telephone cords have loose ends equipped with tips, there is always the chance of a wrong connection. Repairmen should have some knowledge of the circuit functions to ensure proper installation of such cords.

An entirely new type of cord that minimizes or completely avoids these objections has been developed for the new telephones. It consists of three tinsel conductors laid in parallel in high grade insulating but low sulphur content rubber. The core so formed is then encased in a black plastic sheathing or jacket which resists sunlight, acids, alkalies and grease far better than either a textile braid or a rubber sheathing. The cordage comes in rolls and is cut to the lengths needed. No other preparation of the cord is required; it is installed in the telephone set, handset and line terminal block by exactly the same simple operation with no possibility of wrong connections. Actually, the cord conductors are poled correctly by providing the cord sheath with a rib fitting into a corresponding groove in the cord receptacle.

Thus, when a cord is inserted into the cord receptacle, its conductors are positioned practically automatically. To complete the connection, it is then only necessary to tighten the screws which cause metallic points to pierce the jacket and rubber insulation of the cord and to enter the tinsel. Inasmuch as the cords are securely snubbed ahead of the connecting points, all possibility of accidental loosening of the cords or of noisy connections is avoided.

Fig. 8 (A, B, C and D) shows a cross-section of the cordage and the simple mechanics of the connection. Cords remain clean and sanitary under all conditions throughout their life; they are truly waterproof and there is no braid to fray, fade and rot. In addition to an exceptionally long life, this type of cord has the virtue of resisting the effects of twisting, kinking and knotting. Figs. 9A and B show a conventional tipped cord which has been badly twisted and then straightened out by pulling. Some kinks and knots have not come out and the cord cannot be completely straightened because the three conductors enclosed by the outer braiding have stretched unevenly and moved with respect to each other. On the other hand, Figs. 10A, B and C show the new tipless cord which has been (*a*) badly

twisted, (*b*) straightened by pulling and (*c*) allowed to unwind by hanging free. It will be noted that the cord has completely recovered its original contour with no signs of uneveness.*

Summary

The improved features of the new telephone sets may be summarized as follows:

1. Complete unit mounting of components
2. No loose wiring.
3. Screw connections throughout—no soldering.
4. Gravity switch a single unit and integral with the base assembly—readily accessible for adjustment.
5. Dial mechanism and gravity switch springs protected from dust, lint, insects, etc.
6. All spring contacts double-connected in parallel.
7. Gravity switch springs operated by a bronze roller.
8. Simplified tamper-proof ringer.
9. Induction coil and condenser sealed in bakelite cases.
10. Cellulose acetate sheet and plastics used instead of paper, fiber and textile insulation.
11. New tipless cord—easier to connect, prevents error, more durable, snarl-resistant, cheaper to use.
12. Components of entire set replaceable with a screwdriver by unskilled repairmen—impossible to assemble incorrectly.
13. Rust-resisting steel base plate of sufficient thickness to prevent thread stripping.

* Restrictions in materials prevent the use of the new tipless cord for the time being. However, these new telephones are arranged to be corded with the conventional tipped cords as well as with tipless cords. The former have been used in some of the illustrations.

Public Address Systems*

By S. HILL, M.Eng.

Standard Telephones and Cables, Limited, London, England

Summary

The amplification and distribution of speech and music by means of microphones, amplifiers and loudspeakers is one of the youngest of the electrical sciences. Only 20 years ago "Public Address," the name by which the system is universally known, was regarded as only a scientific toy by the public. During the ensuing years, however, notable improvements have been made, and this paper traces the history and development of public address systems from their first appearance in this country to the present day.

Although analogous to telephony and broadcasting, public address presents many widely divergent problems, particularly in the design and location of the various elements, which must vary for indoor or outdoor use, also for reinforcing the original sound or for use as a sound-diffusion system.

A description of the various types of microphones, amplifiers and loudspeakers which have been used is given, and their advantages and disadvantages are considered in the light of present-day knowledge.

The acoustic problems in auditoria are discussed, showing the need for co-operation between architect and acoustic engineer in their design, with suggestions for the planning of public address installations to overcome defects in the design of auditoria causing reflection and reverberation. It is also shown how these troubles can be overcome in outside broadcasts by the proper placing of subsidiary loudspeakers.

The problems of "time delay" are discussed at length and proposals made so that the normal result of distance can be produced without an unwanted echo effect. Means are also given for artificially producing "time delay" when desired.

Consideration is given to the intensity necessary to overcome the noises caused by the audience in confined spaces, and wind noise in the open air.

Auditory perspective by "stereoscopic" means, which requires the highest possible fidelity of reproduction, is briefly described, and the paper concludes with descriptions of three installations as typical examples of the employment of the principles advocated.

(1) Introduction.
(2) Classification.
(3) Early History.
(4) Basic Elements.
  (4.1) The microphone.
  (4.2) The amplifier.
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(1) *Introduction*

THE term "public address" is used to denote that branch of the art of communication by which speech or music is made audible by artificial means to large audiences congregated at one place. The art is closely allied both to radio broadcasting and to telephony. Thus the three principal elements of a public address system—the microphone, the loudspeaker and the valve amplifier—are common to broadcasting, and analogous to the transmitter, receiver and repeater of a telephone system. The most distinctive feature of these systems, however, viz., the ether or the wire link, is absent from or merely incidental to a public address system, while the final stage, that of the translation of electrical into acoustic

* Paper presented before The Institution of Electrical Engineers, Wireless Section, March 4, 1942.

energy, is much elaborated. The public address system is in fact concerned not so much with the transmission problem as with that of distribution of sound waves.

Public address systems have a very wide scope of application. Besides their temporary use for public meetings and special functions, there are a great number of permanent installations used in many large halls, in railway stations, in hotels, on race-courses, in large liners, etc. Mobile systems mounted in motor-vans are used for political campaigns or for traffic direction and police work, while systems have also been installed in aeroplanes and used for propaganda purposes.

(2) *Classification*

Various classifications are possible, the basic being:

(*a*) Sound-reinforcement systems,

(*b*) Sound-diffusion systems or public address systems proper.

The former type of system is used to supplement the voice of a speaker or singer when the audience is too large to be reached by the unaided voice. (In the theater, too, a technique has appeared in which a change of quality is actually as essential a feature as enhanced volume.) The diffusion system is used to reach audiences located beyond the range of the speaker's voice. In such systems, also, the speaker is usually not visible to his audience.

Another possible division is into indoor and outdoor systems. The indoor systems are usually small and their problems are allied to those of architectural acoustics. The outdoor systems sometimes cover vast areas and the principal problem is usually how to reach a maximum audience in spite of wind, extraneous noise, etc., with the minimum of overlapping or dead areas.

Systems may be still further divided into concentrated and distributed systems. The former includes systems where loudspeakers are concentrated at one point, giving the effect of a magnified voice; the latter covers systems where a large number of low-intensity loudspeakers are distributed over a given area.

In addition to these, there are various commercial classifications, of which perhaps the most broadly useful is based on the rated output of the amplifier.

(3) *Early History*

Earlier attempts to reach large audiences include musical instruments capable of great penetrative power, e.g. trumpets, drums, etc.; the careful acoustic design (largely empirical) of auditoria; and the use of megaphones. Usually, however, sound was neglected in favor of vision, in which case the problem was much simpler.

A modern solution was not found until the apparently more difficult arts of telephony and radio were well advanced; until, in fact, valves of sufficient power and reliability became commercially available. It is almost impossible to name the first public address installation, as a variety of unrecorded attempts to enable a group of people to hear the novelty of an early radio programme come into this category. Commercial equipments, intended for hire to promoters of public meetings, first made their appearance in this country in 1922. These early systems were by no means insignificant when judged by modern standards; they were well designed and gave outputs up to 40 watts with a degree of fidelity which compared very well with that offered by radio practice. Their convenience was, however, limited by the necessity of battery operation. As the art advanced there was an appreciable increase in the size of such installations and in the fidelity of reproduction attained. Increased power was largely associated with advancing technique in the valves available for high-power amplifiers, while improved fidelity was achieved by better-quality microphones and loudspeakers.

(4) *Basic Elements*

The success of a public address system depends in part on the correct disposition of the microphones and loudspeakers and in part on the technical excellence of the three elements already referred to, i.e., the microphone, the amplifier and the loudspeaker.

(4.1) The Microphone

It was recognized from the beginning that public address operation required a higher fidelity than that required for a telephone circuit, since an audience is concerned with the accurate presentation of the speaker's voice as well as his subject. In very early systems attempts were

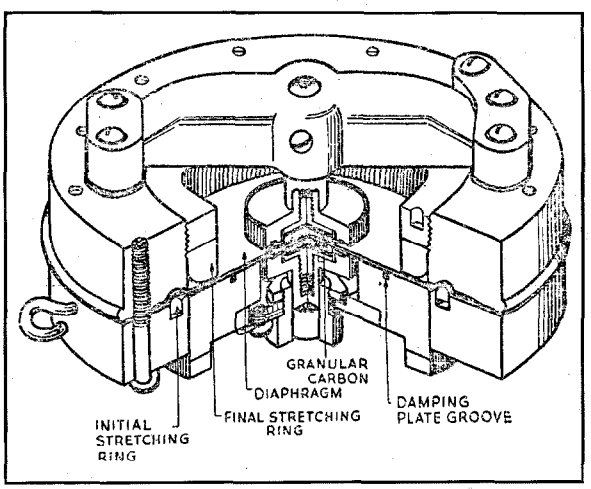
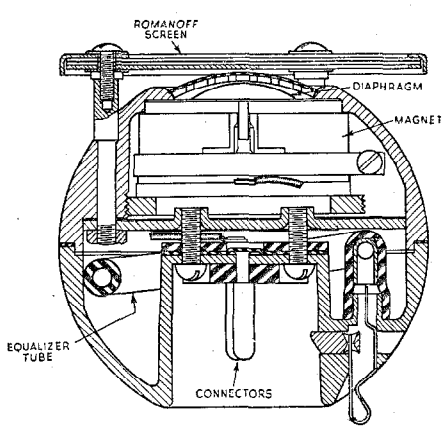


Fig. 1—Double-Button Carbon Microphone.

made to provide a high-fidelity microphone as distinct from a simple telephone transmitter.

For some time the carbon-button principle was the basis of microphone design. An early form of high-quality carbon transmitter is shown in Fig. 1. Two buttons were used in push-pull, an arrangement which increased the linearity of the microphone response and provided a ready means of balancing out the feed current in the balanced primary winding of the input transformer. While resonance in the diaphragms of a telephone transmitter had previously been cultivated as a means of increasing efficiency, it was deliberately reduced in the interests of high quality in this type of microphone by using a thin duralumin diaphragm stretched to resonate at about 6,000 c.p.s., a limit which was then considered to be outside the useful audio range. The resonance was partly damped by the felt surrounds of the buttons or by the air trapped between the leaves of a paper wad attached to the buttons—a process known as "book damping." The efficiency was low by the standards of that time, and some difficulty arose from the packing of the carbon granules and was aggravated by the need to maintain the buttons in balance. Carbon noise was not considered unduly serious but close talking was essential. The microphone was shielded and protected against injury by spring suspension inside a perforated metal cage.

Two other microphones in early use deserve mention here as both were capable of a somewhat higher performance than the carbon microphone, i.e., the Round moving coil and the condenser microphones. Both were essentially studio microphones insufficiently robust and reliable for public address work and it is doubtful if the loudspeakers at that time did justice to the



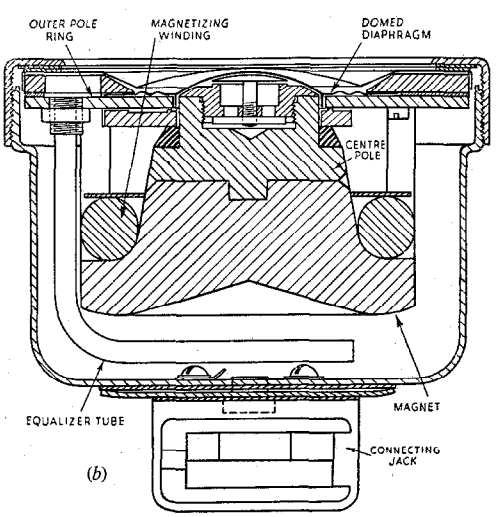


Fig. 2—Moving-Coil Microphones.

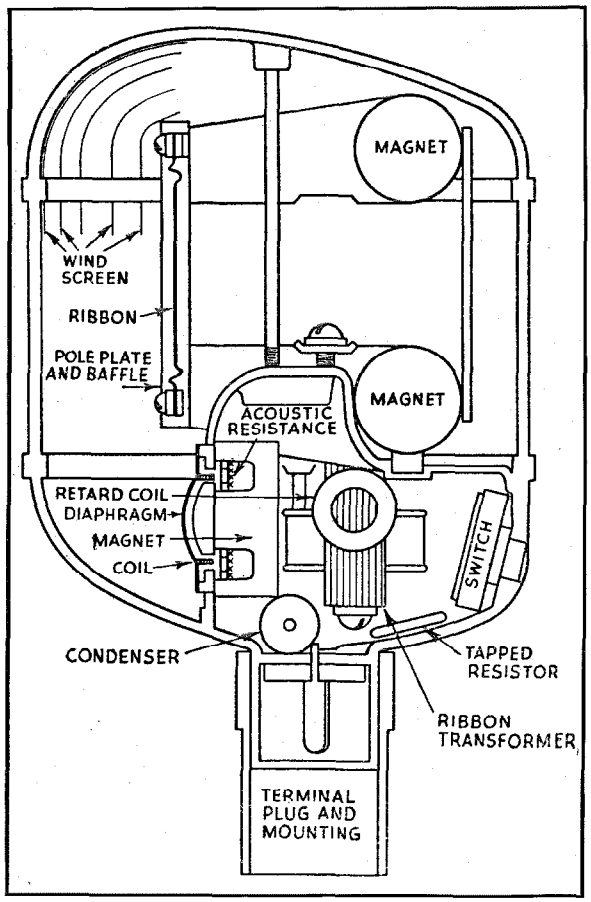


Fig. 3—Cardioid Microphone.

improved microphone fidelity. The Reisz carbon microphone and other applications of the transverse current principle were later used with considerable success but, like the double-button type, suffered from carbon noise and a tendency to "pack." The elimination of any diaphragm other than the thin membrane necessary to keep the granules in place enabled a good performance to be obtained, but the response characteristic was not ideally flat owing to reflections from the back of the granule chamber and also to the selective response of the granules themselves.

Any microphone suitable for broadcasting purposes may be used for public address work, and there has been a tendency to use the type of microphone most widely used in the broadcasting studio. It is to be noted that the requirements which a public address microphone has to meet are not quite those of a studio microphone, but rather of a microphone which a broadcasting organization would use for outside work. In addition to the necessity for high fidelity and moderately low impedance which studio work demands, public address practice emphasizes the need for robustness and freedom from wind noise where microphone and loudspeakers are in the same location. For these reasons, although crystal and ribbon microphones are sometimes used, the moving-coil type has found increasing favor in modern practice. Two varieties of this type are shown in Fig. 2.

A third and more elaborate adaptation of the microphone illustrated in Fig. 3 exists but has not been widely used in this country. This consists of a two-unit microphone, one unit of which is similar to Fig. 2(*a*) while the other is of the ribbon type. The moving-coil element responds to changes in pressure, which is a scalar quantity, and for this reason it does not distinguish between sound waves impinging from different directions except in so far as the sound field may vary in distribution with the direction of the incident sound. The ribbon element responds to the gradient of the pressure, which is a vector quantity. Neglecting secondary effects, the polar characteristic of the two elements will be as shown in Fig. 4. By combining the two elements

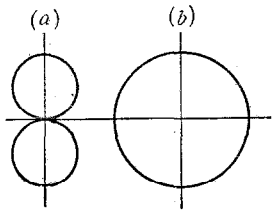


Fig. 4—Polar Characteristics of the Two Units of a Cardioid Microphone.

in suitable proportions polar curves of the various forms shown in Fig. 5 may be obtained. A criterion of the behavior of such microphones in a reverberant room may be assessed by dividing the output of the microphone obtained when the incident sound arrives equally from all directions by the resulting output if this sound is supposed to be concentrated in the direction of maximum response. The figure may be arrived at by integrating the appropriate polar function. For a so-called non-directional (or rather omnidirectional) microphone this figure is clearly

unity. For a typical ribbon characteristic [Fig. 4(*a*)] or a cardioid characteristic [Fig. 5(*c*)] a ratio of 1 : 3 is obtained. A combination microphone of the type described is very useful for special purposes, but robustness and freedom from wind noise have of necessity been sacrificed to some extent.

A method of securing a highly directional response for any type of pressure-operated microphone is to add a system of tubes as shown in Fig. 6. When a sound wave advances from the side, different elements of the wave are delayed to varying extents in passing down tubes of different lengths. The superimposition of these various elements in random phase produces a large measure of cancellation. Since this clearly does not apply to any wave advancing directly towards the mouths of the tubes, a directional effect is obtained. The instrument suffers, however, from liability to excessive wind noise generated by air currents passing across the openings of the tubes.

Another special microphone which has occasionally been used is the "lapel" microphone designed to be worn in the lapel of the speaker's coat. This microphone, although perfectly satisfactory if used by an undemonstrative speaker, is highly undesirable for a speaker who is dynamic in his actions and moves rapidly about the platform. There is also the difficulty of the trailing cable, which is liable to give trouble to those who forget its existence.

(4.2) The Amplifier

Amplifiers for public address work are designed on principles which are already well known. The

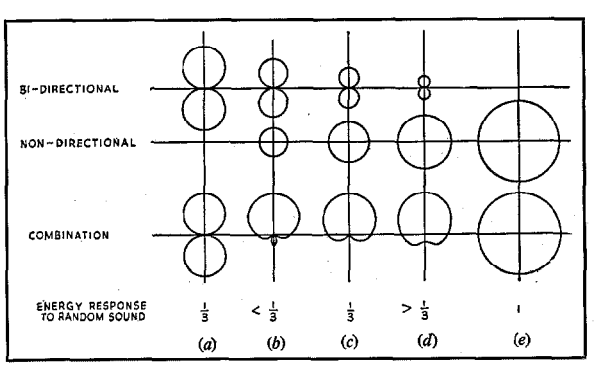


Fig. 5—Polar Characteristics Obtainable by Different Combinations of the Elements of a Cardioid Microphone.

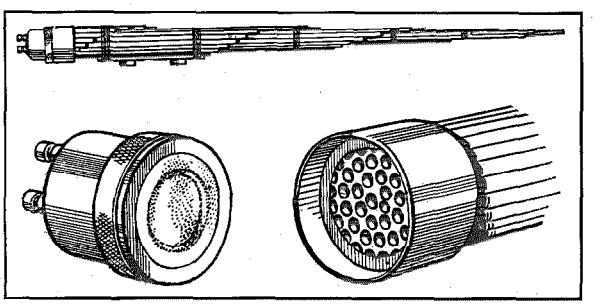


Fig. 6—Tube System for Obtaining Highly Directional Response.

main problem is chiefly economic, i.e., the production of large electrical outputs with the minimum of apparatus. Usually this kind of problem is more acute for commercial reasons in systems rated at from 30 to 100 watts, than in large installations having a rating 1kW or more. The output stages of such medium-power amplifiers are very often operated in push-pull (class AB or class B amplification). Since the high-tension power supply required often falls just outside the range of small rectifiers designed for radio receivers, mercury-vapor rectifiers are frequently employed. Sometimes a designer prefers to keep within the range of the radio receiver valves by using two or more output valves in parallel. These may be high-output pentodes, beam power pentodes, or double triodes of the 6B5 type.

If an economical design of, say, a 60-watt amplifier can be achieved on these lines it may be considered worth while to build up a high-power system by using several such amplifiers in parallel or, better still, by feeding separate sections of the load from the several amplifiers. Other designers prefer to accomplish the same result in a single output stage with appropriate large valves. Since the main differences between public address amplifiers lie in the output stage, this is often treated separately; in other words, a range of output amplifiers is provided from perhaps 10 watts to 1,000 watts, arranged to work from a single microphone amplifier. On the other hand larger power amplifiers may be intended to follow a complete public address system of one of the smaller types.

Microphone amplifiers are usually of a straightforward design, but special attention must be paid to the first stage to achieve a high ratio of signal to noise. Although close talking is more

common in public address practice than in studio work, it is necessary to allow for an input as low as 70 phons. This may give an electrical input of about 75 db below 1mW, or about 53 db above thermal agitation which, for a 10-kc/s band width and a temperature of 15° C., may be taken as −128 db. For high-quality reproduction the hum level should not be less than 50 db below the signal level or more than 3 db above the thermal agitation level. These figures are not difficult to achieve but demand a careful choice of the first valve together with good electrical and magnetic screening of the input elements.

Sometimes the input amplifier incorporates faders or mixers, which are usually resistance attenuators whose purpose is to enable an operator to pass smoothly from one microphone to another or to combine the outputs of two or more microphones of different responses or situated in different locations. It is more usual, however, to mount these on a separate control panel which may be located in a position from which the proceedings can be followed more easily than from the amplifier room. It may also be convenient to mount the main gain control on this panel. The whole programme may then be controlled by an operator at the control panel, who will switch on or fade in the various microphones as required and monitor the programme either by listening to the auditorium loudspeakers or with the aid of a monitoring loudspeaker or head receiver.

A volume control which can be adjusted by an operator during the performance is usually provided. Where an operator cannot be in attendance and where large variations in input are to be expected, e.g., during a lecture when the speaker may turn away to point to a diagram or lantern slide, use may be made of automatic volume compression, a portion of the output being rectified to produce a control voltage. This may then be used to control the bias of one or more variable-μ valves. The time interval between an increase in input level and the consequent decrease in the sensitivity of the amplifier is controlled by the use of suitable delay networks in the control path. This time interval is a factor of considerable importance. If it is too short, undesirable transients are introduced; if it is too long, overloading during the period of adjustment may be apparent. Usually an increase in input level is followed by a decrease of gain after an interval of the order of 10 milliseconds, and this condition is made to persist for a period of 50–250 milliseconds after a fall in input level. A variety of input-output characteristics may be obtained to suit different operating conditions. The simplest arrangement provides only for a limitation of output and prevents overloading, but the following arrangement provides a more complete control. For very low inputs the gain is reduced to prevent singing or undue amplification of noise. Over the expected normal range of input, the output is compressed to cover some chosen fraction of the input range. For excessive inputs a higher degree of compression is applied in order to prevent overloading. Where the only problem arises from the movement of the speaker, a straightforward amplifier may be used with a lapel microphone.

(4.3) The Loudspeaker

Although any loudspeaker suitable for domestic radio reproduction may be used for public address work, systems of the "concentrated" type require horn loudspeakers to obtain the necessary coverage with sufficient directional effect to avoid singing. This to a great extent limits the possibility of high-quality reception. It is well known that the cut-off frequency of an exponential horn and the restriction of harmonics of low frequencies necessitate the use of long horns with wide flares to obtain good quality. Even if very massive horns are used the variation in polar distribution (with frequency) will rob the distant listener of much of the lower register. Fortunately in many installations of the concentrated type, such as those used for open air meetings, the attenuation of the lower register is acceptable for two reasons, (*a*) that intelligibility is usually the chief consideration and this is not seriously impaired by attenuating frequencies below 500 c./s., and (*b*) that, provided the audience can see the speaker, a change in quality with distance is so much expected as to pass unnoticed. For installations of this type, horns of moderate length are often satisfactory. In the case of indoor installations, such as theaters, an admirable solution has been found in the use of a diaphragm type of low-frequency

acoustic radiator operated in conjunction with a horn type unit for the middle and upper frequencies and designed to give a wide angle of distribution. A description of one such combination, although it is one of many, will serve as a typical illustration of public address loudspeakers.

The low-frequency radiator comprises four cone type electrodynamic loudspeakers mounted in a large shallow horn whose flare is a flat baffle approximately 10 ft. square. The structure is made as rigid as possible to minimize resonance effects. The high-frequency radiator consists of two metal diaphragm loudspeakers connected by separate "throats" to a multicellular horn. This horn is an assemblage of 15 smaller horns or "cells" each exponentially tapered from a throat area of 0.4 sq. in. to a flare area of 64 sq. in. The walls of the cells are made of two metal sheets (soldered together at the edges) between which is cemented a sheet of felt. This construction effectively prevents rattles and minimizes horn resonances. Although there is a concentration of high-frequency sound along the axis of each cell, the whole assemblage radiates substantially uniformly in a horizontal plane over an angle of 60°. Two high-frequency radiators placed side by side may be used to radiate over an angle of 120°. The loudspeaker units are of the electrodynamic type. Sound is radiated from the rear of the diaphragm and passed to the horns through narrow passages in the central pole. This construction increases the output at the higher frequencies for, if the diaphragm were to face a chamber whose dimensions were appreciable compared with the wavelength of the emitted sound, random phase cancellation would occur between sound emitted from different parts of the diaphragm. The high-frequency and low-frequency radiators are supplied with power through an electrical dividing network. Frequencies below 300 c./s. are passed to the low-frequency radiator, and frequencies above 300 c./s. are passed to the high-frequency radiator.

This description is typical of a good-quality loudspeaker of moderate power. Where a single unit is required to carry 500 watts special care is necessary in design to meet the very greatly increased stresses. Fig. 7 shows a loudspeaker designed to radiate up to 1,000 watts.

A domed diaphragm about 10 inches in diameter with a surround of beryllium copper is employed. The moving coil is designed to dissipate 500 watts continuously and the connection between the coil and the diaphragm is designed to withstand a disruptive force of 50 lb. Radiation from the rear of the diaphragm is guided through narrow annular passages to a cast metal horn. This horn is of the "folded" type, i.e., the narrower end consists of passages built within the flare. The directional effect of the horn is marked for frequencies above 300 c./s. Frequencies below 300 c./s. are removed by means of a filter, partly to limit the movement of the coil and diaphragm and partly because these frequencies could not be concentrated in a beam sufficiently narrow to produce a useful effect at distances of 2,000 yards. The efficiency of a domestic loudspeaker is of the order of 5–10% and that of an average horn type public address loudspeaker may be taken as about 25%. The efficiency claimed for the loudspeaker described above is 75%. When supplied with a speech power of 1 kW speech is clearly audible at distances exceeding 2,000 yards.

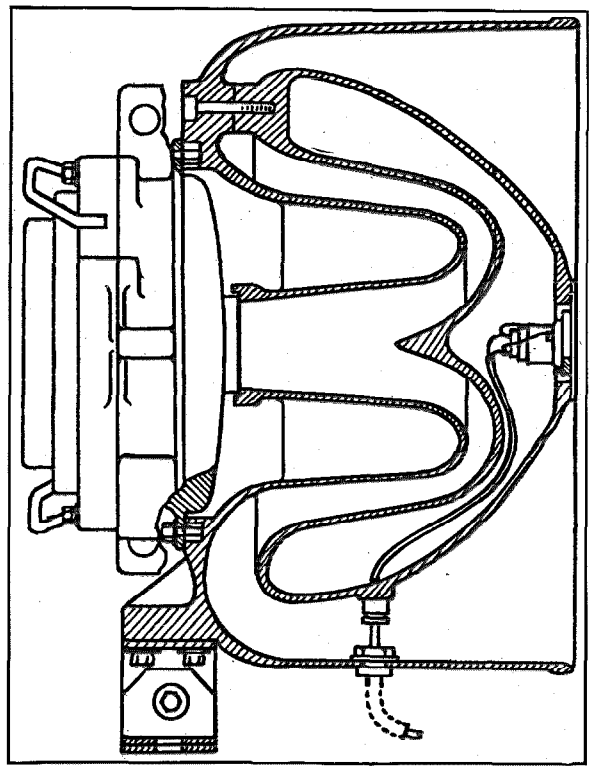


Fig. 7—High-Power Loudspeaker.

(5) *Architectural Acoustics*

Public address technique is bound up with the art of architectural acoustics in that the solution of an acoustic problem in a building often involves the use of a public address system. For this reason an architect should either have some basic knowledge of acoustics and the advantages and assistance given by a public address system or should co-operate with acoustic experts. There has undoubtedly been a considerable trend in this direction during the last few years, but there is still room for a greater appreciation of acoustic problems among designers of auditoria. Far too often a public address system has to be added as an afterthought in order to improve the poor acoustics of a building. In such circumstances it is rarely possible to make a completely successful installation, as the engineer is hampered by the need to preserve the artistic design of the auditorium. There are few halls which may not at some time require a public address system since, even if by reason of their size or acoustic design no reinforcement is needed, they may be used as an overflow for a remote meeting. Provision should therefore be made in the original plans for housing amplifiers and mounting loudspeakers, although the architect should try, by the use of suitable materials and by correct proportioning and disposition of flat surfaces, to minimize the need for sound reinforcement.

Where a public address system has to be installed in a completed building, the engineer is often faced with an artistic as well as a technical problem. Loudspeakers with large exponential horns are very difficult to reconcile with a decorative scheme and it becomes necessary either to hide or disguise them.

(6) *Planning and Installation*

(6.1) General

A temporary installation, usually required at very short notice, can only be planned on a basis of past experience and modified by trial and error. Permanent installations may be planned in a similar way, and indeed in practice this is the commonest procedure. Naturally this procedure has all the disadvantages of an empirical method and suffers from the added disadvantage that it is usually impossible to listen to the result in the presence of a representative audience. The engineer must therefore make some allowance for the effect of an audience in reducing volume and reverberation and in increasing noise. An important installation justifies a more theoretical treatment but the problem rarely admits of an exact solution so that the results of a theoretical study need to be checked and modified after installation.

The first requirement of a system is the production of adequate and uniform intensity over a given area. This problem takes its simplest form in the case of an outdoor gathering when the audience is massed around the speaker. The usual plan is to mount a battery of directional loudspeakers above the point where the microphone is to be placed. This plan has the merit of simplicity and helps to preserve the illusion that the speaker's voice is actually being heard. The height and direction of the loudspeakers are determined by two conditions, (*a*) that the microphone should be in the acoustic shadow of the loudspeakers to give sufficient amplification without "singing" caused by acoustical coupling, and (*b*) that those of the audience who can hear the speaker directly are also to some extent in the acoustic shadow. The first condition demands that the loss between the microphone and the loudspeakers, added to the loss occurring in the electro-acoustic transformations in microphone and loudspeaker, should exceed the amplifier gain. Since the loss terms are fixed for any given disposition of the equipment while the amplifier gain is variable, there will always be an adjustment which causes "singing" and it is necessary to ensure that this point is at least 5 db above the normal operating point. In an indoor installation it can usually be assumed that if the condition is met in an empty hall it will also be met when the hall is filled. In an outdoor installation it is important to remember that the "singing" point may be modified by the effect of wind.

In locations where the sound intensity is not appreciably affected by reflected sound, i.e., in the open air or in some large halls when they are well filled, it is possible to predict the resultant intensity at any point due to the original source and the loudspeakers. If E_1 be the measured intensity of the source at a distance d at which the microphone is to be placed, the intensity at any other distance D will be E_1d^2/D^2. Laboratory data on the amplifier and loud-

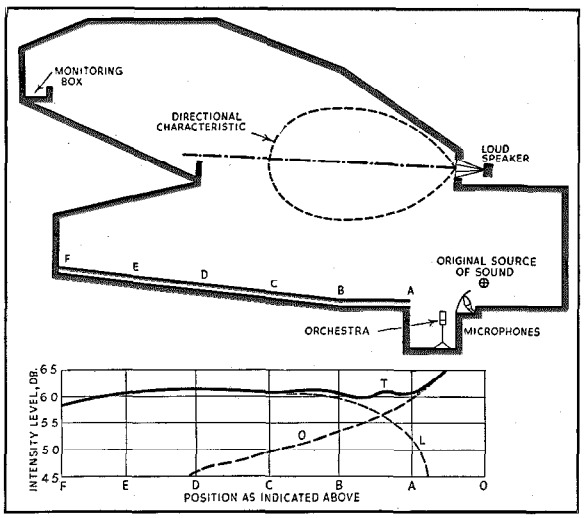


Fig. 8—Resultant Intensity of Direct and Re-radiated Sound.
Curve O—Intensity due to original source of sound.
Curve L—Intensity due to loudspeaker.
Curve T—Resultant intensity.

speaker will give the intensity E_2 at the same point due to the loudspeakers. Ordinarily the axial intensity will be obtained for the appropriate distance and this will be multiplied by a factor taken from the polar distribution curve. Fig. 8, after Olson, shows how uniform the resultant intensity may be made.

(6.2) Time Interval

A second requirement is that where sound is heard independently from two sources the time interval should not exceed about 0.06 sec. if the two sources are comparable in intensity. This is one reason for the concentration of the loudspeakers in a battery near the speaker and, at first sight, seems almost to preclude the use of what has been referred to previously as the distributive system using distributed loudspeakers.

It is, of course, well known that the distributive system may be quite successful in practice, a fact which can be explained by the principle of maximum stimulation. In the theory of hearing, this principle is relied upon to explain the absence of confusion between adjacent frequencies which the resonance theory of the basilar membrane suggests. This principle is usually illustrated from our common experience in the sensation of touch, where it can easily be demonstrated that the pressure of two needle points close together on the skin is appreciated as a single stimulus located at the point of application of the stronger (or midway when the stimuli are equal). If an observer stands between the two sources of the same sound he finds that a very small advance towards either source causes the sound to appear to come entirely from that source, i.e., the more powerful stimulus inhibits appreciation of the weaker; and this will apply even if the sources differ as, for example, in the matter of time delay, provided the difference is small. If one walks down a corridor in the ceiling of which loudspeakers are situated at fairly wide intervals and all are emitting the same sound, one has the impression that the loudspeakers are switched on successively, and that those left behind are switched off. Consequently there is no confusion if an ordered series is maintained. Where all loudspeakers are concentrated at one point confusion due to multiple sources can still occur owing to the echo. In a hall these effects can be minimized by raising the loudspeakers and directing them downwards towards the audience.

With large outdoor installations echoes are often more troublesome than in buildings, due to the reflecting surfaces provided by large natural objects such as hillsides. The best arrangement is sought experimentally, and local areas where this trouble is unavoidable should be covered by local loudspeakers intended to override the echoes.

Installations have been described in which delay is artificially introduced. In the center of a large crowd a group of loudspeakers covers a central area. At a distance where the volume of sound becomes unsatisfactory other groups of loudspeakers are provided and, to prevent confusion, the sound which they emit is delayed by the time appropriate to their distance from the center. This delay may be produced acoustically, by means of underground tubes, or electrically, by means of a steel tape machine. Although systems of this kind are of technical interest, it seems probable that no actual case is likely to arise which cannot be dealt with more economically by relying on small directional loudspeakers to cover any narrow bands of confusion.

(6.3) Reverberation

A third principal requirement is fidelity of reproduction. It is true that in many sound reinforcing installations a system may be accept-

able whose standard of fidelity is not very high. This is because the aim of these systems is generally intelligibility and the creation of illusion. High fidelity, however, is very necessary where the original source of sound is not visible, and is particularly important when music is diffused.

High fidelity in a public address system chiefly depends on the design of its three principal elements and on the success of the planning engineer in obtaining a uniform distribution of sound at all useful frequencies. It also depends on the acoustics of the auditorium. The most important single factor is the reverberation period. Reverberation is due to a succession of reflected sounds following each other too rapidly to be heard as separate echoes. The reverberation time is usually defined as that required for a sound to decay in intensity by 60 db and is calculated from the classical formula

$$t = 0.05 \frac{V}{\sum aS}$$

where V = volume of the auditorium
S = area of any uniform surface
a = an absorption coefficient determined experimentally in advance for each type of surface.

The optimum reverberation time is usually considered to be 0.5 sec. for speech and 1 sec. for music, but this is influenced by other factors such as the type of auditorium. Thus we are accustomed alike to the "deadness" of the domestic living-room and the "liveliness" of a church, and expect the quality of speech or music we hear to reinforce our preconception to some extent. The addition of a loudspeaker introduces an area S' which emits sound, and if to this area a suitable negative absorption coefficient $-a'$ be assigned it may be included in the summation indicated by the formula. The reverberation time is thus increased and becomes infinite at the singing point. The effectiveness of reverberation is also increased because the louder sound produced does not fall so quickly below the threshold of hearing. It would, however, be a mistake to suppose that a public address system could not improve intelligibility in a highly reverberant room. There are two ways of achieving this. One method is to use highly directional loudspeakers directed towards the audience, where the sound is almost completely absorbed without reflection and does not therefore add to the reverberant sound. At the same time the microphone, which should be directional, is placed as near as possible to the speaker so that it receives a high proportion of its input directly from him and a smaller proportion by multiple reflection. In general it is necessary to attenuate the lower frequencies, since horn loudspeakers of practicable size are much less directional for the lower than for the higher frequencies. A second and usually more effective method is to employ a distributive system. As large a number of loudspeakers as possible is used and so arranged that for each member of the audience direct sound predominates over reverberant sound. The loudspeakers need not be as directional as in the first method, although it is still necessary to ensure that most of the output is absorbed by the audience at first incidence. Close talking and a directional microphone are again necessary. It should be noted that if the loudspeakers are placed only around the walls of a large hall the conditions leading to a narrow confusion area do not necessarily apply in the center, where a number of loudspeakers may be heard at comparable levels and at slightly different times. In certain exceptional circumstances it has been noticed that loudspeakers heard in succession produce a false effect of reverberation.

This method of dealing with reverberation is particularly applicable to churches. The usual type of church has come down to us from a time when depreciation of intelligibility due to reverberation was accepted as inevitable, and both the music and speech made within the church were adapted to this fact. The reverberation period often exceeds the 3 seconds generally considered to be the limit consistent with intelligibility, and distributed loudspeakers, together with as much acoustic treatment as can be accomplished by a few additional hassocks and padded pews, provide the only solution. Where the loudspeakers can be attached to pillars they serve the special function of covering the acoustic shadow which the pillars often cause in the higher audio range. They should be mounted high on the pillars and directed downwards to obtain maximum absorption from the congregation and so controlled that any which serve an empty

region may be switched off as these otherwise only increase the reverberation time.

Although excessive reverberation is troublesome, in moderation it is a help to a speaker since it increases the volume of useful sound. The intensity level L referred to 10^{-16} watt per cm^2 is given by the formula

$$L = W - 10 \log \frac{V}{T} + 73.8$$

for both high and moderate values of reverberation time. Here W is the level of the sound source in decibels above $1\mu W$, V is the volume of the auditorium in cubic meters, and T the reverberation time in seconds. For a source level of +10 db, corresponding to conversational speech, and a medium-sized hall of, say, 3,000 m^3, the intensity level, if the auditorium were fairly "dead" (say 0.5 sec. reverberation time), would be about 46 db. For a very "lively" but still intelligible room having a reverberation period of $2\frac{1}{2}$ sec. it would be about 53 db. As the noise level might well be about 40 phons, the first condition would not be met without some strain to an average speaker, while the second condition would give complete intelligibility if the speaker's enunciation were slow. On the basis of the same formula, it would be possible to calculate the output of a public address system required to give a comfortable listening level of 75 db, but the calculation is of little practical value as it leads to a result many times smaller than that given by experience. This is in part due to the over-simplification implicit in the assumptions on which the reverberation formula is built. Thus the reverberation time is not, as the classical theory indicates, independent of the position of the source, since, as we have seen, a loudspeaker directed towards an audience is by no means equivalent to a voice speaking from a platform. The theory only gives satisfactory results if it is used with some caution. It is better to assume that all the output of the loudspeakers is absorbed and to calculate, as if open-air conditions applied, the power needed to give 75 db at the back of the auditorium. A margin of about 15 db should be allowed on the power so calculated to provide for exceptional peaks and the increased noise which an audience will make when relieved of the strain of listening to an inadequate level. A ready method of estimating the power is to use an empirical curve such as that shown in Fig. 9, due to J. P. Taylor and based on a number of actual installations.

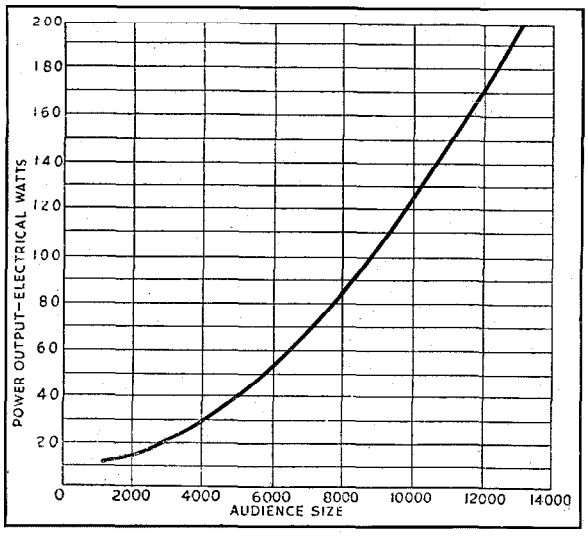


Fig. 9—Empirical Curve for Estimating Power.

(7) *Noise*

Reference has been made to the disturbing effect of noise, which plays as important a role as reverberation in limiting intelligibility. Two kinds of noise may be distinguished, (*a*) that which is independent of the electrical system, such as auditorium noise, and (*b*) that which is introduced by the system, such as microphone noise. The chief effect of auditorium noise is to require a higher level of signal. A level of 15 db above basic noise may be taken as the minimum, but a satisfactory system should aim at 30 db. In making an estimate of the noise it must be remembered that it will generally increase with increase of signal strength for the psychological reasons already mentioned.

When carbon microphones are used the microphone itself generally makes a substantial contribution to the total noise, but with the use of ribbon or electrodynamic microphones this noise is greatly reduced. Microphone noise has not, however, wholly disappeared as there still remains the noise of thermal agitation in the operating winding of the microphone, and since most high-quality instruments sacrifice efficiency to fidelity this noise may be audible under quiet conditions as a hiss not unlike carbon noise. For

satisfactory operation under quiet conditions the thermal noise should be at least 50 db below normal signal level, and this can usually be achieved by talking normally at a distance of 3 ft. or less from the microphone.

In outdoor installations wind noise may be a troublesome factor. The wind noise referred to is not the noise which a person standing near the microphone might hear, but the added noise associated with the microphone design. It is of two kinds, (*a*) that due to the fluttering of the electrodynamic element or similar causes, and (*b*) that arising from the turbulent disturbances of the air caused by the microphone, particularly if this has sharp edges which can produce irregular edge tones. Wind shields have been designed which reduce these effects, but it is better to choose a microphone which, by reason of its shape and construction, is known to be but little prone to wind noise. At the output end of the system, the chief effect of the wind, apart from adding to the general noise background, is to diffract the sound. This diffraction is upwards when the wind is blowing towards the source. At the microphone end of the system close talking is a cure for noise whether caused by wind, thermal agitation or extraneous disturbance, since the input is thus made large enough to dominate true noise. With certain microphones, such as the ribbon type, too close talking will produce an emphasis of the lower frequencies owing to the different properties of plane and spherical waves. This effect can be allowed for, but it is better not to use a pressure-gradient microphone if the talking distance is likely to vary to any great extent.

(8) *Auditory Perspective*

Auditory perspective enhances listening in much the same way as stereoscopic representation enhances vision, but fortunately we have accustomed ourselves to do without both in large-scale reproduction. There are occasions, however, whose importance justifies the complexity necessary to secure auditory perspective. Complete illusion in reproducing orchestral music cannot be secured without this perspective. A very famous experiment on auditory perspective was described by Harvey Fletcher of the Bell Telephone Laboratories at the Winter Convention of the A.I.E.E. in January, 1934.[7] Three separate channels were set up, each with its own microphone, amplifier and loudspeaker array, and a very high degree of sound localization was achieved. The occasion was also notable for the great pains taken to achieve the highest possible fidelity without which perspective obviously is of no great value. It is of interest here to compare the very different approach to the problem made by the engineers responsible for the system used in the Hollywood Bowl on the occasion of the great pageant in 1933. Here the perspective was obtained by an elaborate system of manual control of the relative intensities of the many loudspeakers used. The actors mimed their parts, their words being spoken for them into microphones off-stage. As the players moved about the great stage the distribution of sound was so controlled that the virtual source followed their movements so that the audience was generally unaware that the players were acting only in dumb-show.

Controlled reverberation has been used to enhance illusion and, although falling far short of auditory perspective, remarkable effects can be achieved with relatively simple means. A portion of the energy is passed into an echo room or reverberant chamber and is later recombined with the direct energy in varying proportions. To obtain the full range of effects, the frequency responses of both channels as well as their relative magnitudes must be made adjustable.

(9) *Typical Installations*

The following descriptions of a few installations will serve to indicate how the foregoing principles may be applied to the solution of some typical public address problems.

(9.1) Le Vray Mistère de la Passion

This religious pageant was performed in 1935 and 1936 in the great square before the Cathedral of Nôtre Dame in Paris before an audience of 10,000 people and was a good example of a large-scale outdoor installation. The nature of the material diffused made it of first importance to secure a high degree of illusion, and since over 50 microphones and several groups of loudspeakers were used an elaborate switching, mixing and fading system was required. Electrodynamic

microphones were used, some of which were of the directional and others of the non-directional type. For the transmission of the organ and choral items both types were used together and their outputs suitably mixed. For the stage scenes and "apparitions" a large number of distributed microphones were used and these were switched in and out by means of relays controlled from a central switchboard. A single control lever was used for this purpose, capable of two motions at right angles, each position of the lever corresponding to a particular point on the stage. For the musical items a large loudspeaker was used the exponential horn of which had a length of 6.80 m and a cross-section of 8 m^2. This loudspeaker had a multiple throat fitted with 12 electrodynamic units. It was mounted at a height of 50 m and supplied with a peak power of about 90 watts. The estimated power efficiency was 25%. For certain special effects this loudspeaker was supplemented with a number of smaller single-unit loudspeakers mounted on the façade and the two towers of the cathedral.

For the stage scenes, six banks of loudspeakers were mounted at various distances from the stage on each side of the public auditorium. It was found that for the majority of the audience the sound appeared to proceed from the stage.

(9.2) Westminster Abbey

The public address system installed for the coronation of Their Majesties King George VI and Queen Elizabeth in 1937 was an example of an indoor system designed to meet the requirements of a special occasion. About 120 loudspeakers, each supplied with a peak power of about 1 watt, were employed. These were of the small cone permanent-magnet moving-coil type housed in closed cabinets 20 in. square by 9 in. deep. These cabinets were mounted about 6 ft. above the heads of the congregation, facing downwards and concealed by drapery. They were spaced at intervals of about 20 ft. and the resulting sound field was very uniform with negligible confusion. In order to secure maximum reliability, the loudspeakers were arranged in groups of about 15 and each group was supplied by a separate mains-operated power amplifier with an output power of 30 watts. The input and output circuits of these amplifiers were brought out to jacks so that if any amplifier developed a fault a spare amplifier could rapidly be brought into service by means of patching cords, or the load of one amplifier could be transferred to the output circuit of any other amplifier. A number of concealed electrodynamic microphones were employed and, as the ceremony was broadcast, their outputs were connected to the normal amplifying and control circuits of the British Broadcasting Corporation. One output line from the equipment was brought to the input terminals of a 3-stage pre-amplifier located in the public address amplifier room.

(9.3) Argentine Chamber of Deputies

The public address system installed in this auditorium in 1939–1940 is an example of a system used as a means of overcoming acoustic difficulties inherent in the design of the chamber. These difficulties were due to the absence of reverberation brought about by the great relative height of the ceiling and the use of much damping material, i.e., soft carpet on the floor, cushions on the chairs, curtained alcoves in the walls, etc. Two independent transmission channels were used, one for the President and his ministers who sat at a table facing the deputies, and one for the use of the deputies, each of whom was provided with a separate microphone and a switching panel. The microphones were of the moving-coil type and the switching was so arranged that only one deputy at a time had access to the deputies' channel. There were four loudspeakers, of which each channel employed three. These were of the dual type, i.e., the frequencies up to 400 c./s. were radiated by cone type loudspeakers and the frequencies between 400 and 10,000 c./s. were radiated by high-frequency units of the horn type. The loudspeakers were supplied through attenuators adjusted to give appropriate operating levels for each of the two channels. They were located about 5 m above floor level and concealed by drapery matching the curtains of the alcoves. A control cabinet was provided within reach of the executive secretary and carried a master power switch and a master microphone switch for each channel, together with the necessary indicating lamps. It is to be noted that the provision of one microphone for each speaker, a feature of great value in a

debating chamber, was only made possible by the lack of reverberation. In a chamber suffering from excessive reverberation it would be necessary for each speaker to come forward to a selected speaking position to address the audience.

(10) *Conclusion*

The public address system is today finding an increasing field of application and is widely accepted as a necessary public service. The existence of such a service is increasingly taken into account in the organization of all kinds of public gatherings and in the design of public halls. Although individual manufacturers have necessarily achieved a large measure of standardization of equipment, there has been but little in the industry as a whole. One reason for this is the wide variety of problems which have to be solved. Many installations are planned for but a single outstanding occasion where difficulties are peculiar to the particular site, the material to be diffused or the size of the audience. The basic principles are fixed, but in the present state of the art it is not possible except in a few simple cases to determine a unique solution of each problem: different engineers may arrive at widely varied but equally acceptable solutions. It may be expected, however, that increasing use of public address systems may lead to a generally acceptable standard of practice among engineers, and to an even higher standard of performance.

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The Current Rating of Paper Insulated Power Cables

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Editor's Note:

In publishing this summarization and clarification of cable rating methods, particular attention is directed to the author's comment that American practice is to load conductors for higher operating temperatures than is customary in Europe. This difference should be kept in mind in comparing ratings derived from the formulas given below with ratings published by American manufacturers and the Insulated Power Cable Engineers Association who, during recent years, have been cooperating towards establishing a common basis for the rating of cables.

Synopsis

The first part of this paper outlines briefly the method adopted for computing the permissible continuous rating of power cables. This is followed by detailed examples for cables installed under specified conditions and, finally, the results obtained are summarized and compared.

For convenience the data given is divided into sections as follows:

Section

1. *General outline.*
2. *Temperature Limits.*
3. *Methods of Installing Cables.*
4. *Fundamental Laws of Heat Flow.*
5. *Heat Flow Problems of a Cable.*
6. *Determination of the Thermal Resistance of a Cable.*

6.1 *Thermal Resistivity of Cable Materials.*

6.2 *The Geometric Factor.*

6.3 *Internal Thermal Resistance of Single Core Cable and S.L. Type Cables.*

6.4 *Internal Thermal Resistance of 'Belted' Multiconductor Cables.*

6.5 *Internal Thermal Resistance of 'H' type Cables.*

6.6 *Thermal Resistance of Bedding and Serving.*

7. *Thermal Resistance of the Soil.*
8. *Conductor Resistance.*
9. *Cable Design.*
10. *Cables Laid Direct: Calculations for.*

Section

10.1 *L.T. 3 Core Belted Type Lead Covered and Armoured 1 kV.*

10.2 *Sector Shaped Conductors.*

10.3 *H.T. 3 Core 'H' Type Lead Covered and Armoured 20 kV.*

11. *Cables in Air: Calculations for.*

11.1 *Cables (as in Section 10.1) but erected in free air.*

12. *Cables in Ducts.*

12.1 *Heat Flow Considerations.*

12.2 *Current Rating Calculations for L.T. 3 Core Cable in a Single Way Duct.*

12.3 *Current Rating Calculations for L.T. 3 Core Cable in a Multiway Duct.*

13. *Comparison of Results.*
14. *Additional A.C. Losses.*

14.1 *Dielectric Losses.*

14.2 *Sheath and Armour Losses.*

15. *Grouping of Cables.*
16. *Bibliography.*

Appendix 1. Cables in Ducts.

1. *General Outline*

WHEN electrical engineering was in its early stages, the rating of power cables was very approximate, a general rule being one thousand amps. per square inch of conductor section, but the increasing necessity of economy of materials and costs led to more detailed studies of the factors involved.

On low pressure systems, in which each consumer is connected to service mains supplied by distributors, the selection of a suitable cable is, in general, determined by the permissible volt drop.

The distributors in turn are supplied by H.V. feeders whose cross-section is usually large and, for this case, the conductor sections are deter-

mined by the maximum permissible temperature rise due to the currents circulating through them.

Such heating effects are considered in the following discussion.

2. *Temperature Limits*

Early tables published giving current ratings for cables fixed the maximum temperature of the copper conductor by practical experience, the maximum temperature being the ambient (or surrounding) temperature of the cable, plus the temperature rise due to load conditions.

Numerous investigations have been made in this country of the various limiting factors, such as expansion and contraction effects caused by the different co-efficients of expansion of the insulating paper, impregnating oil, lead sheath, troubles occurring from the thermal elongation of hot cables and the movements of cables when installed in ducts, etc.

Table I gives safe temperature limits which have been standardized in Great Britain.

It is interesting to note that most European countries use an empirical temperature basis—25° C. ambient and 25° C. or 35° C. temperature rise, depending on the rated voltage, which results, in general, in a lower current loading for a given size of conductor than would be obtained by the limits quoted in Table I.

Conversely American practice permits, in general, a higher temperature limit.

3. *Methods of Installing Cables*

For current rating calculations, paper cables are classified broadly into three groups according to the conditions of installation:

3.1. Laid direct (buried) in the ground (normal soil temperature assumed 15° C. = 59° F.).

3.2. Pulled into ducts which are buried in the ground (normal soil temperature assumed 15° C. = 59° F.).

3.3. Installed indoors, or outdoors, in free air, but protected from direct rays of the sun (normal ambient air temperature assumed 25° C. = 77° F.).

For the exceptional cases (under 3.3) where it is not possible to provide suitable screening, the ambient temperature assumed is 40° C. (104° F.) for cables less than $1\frac{1}{2}''$ overall diameter, and 45° C. (113° F.) for cables of greater overall diameter.

4. *Fundamental Laws of Heat Flow*

When the conductors in a cable are carrying current, the heat generated (in accordance with Joule's Law) flows outwards from the conductors, passing through the insulating medium, lead sheath, cable servings and finally into the surrounding earth or air.

This heat flow is due to the temperature difference between the conductor and its surround-

TABLE I

TEMPERATURE LIMITS

Type of Cable and Method of Installation	Voltage	Cable Specification	Max. Permissible Core Temperature
			°C.
Paper Insulated, Lead Covered and/or Wire Armoured, in Air, or in the Ground	Up to 10 KV.	All types Twin and Multi-Core Belted Cables Excluding 10 KV.	70
	10 KV and Up to 20 KV.	All types Excluding 20 KV. multicore Belted	65
	20 KV.	Multicore Belted	55
Paper Insulated, Lead Covered Cables in Ducts	All Voltages	All Types	50
Screened ('H' Type) Paper Insulated, Lead Covered and/or Wire Armoured in Air or in the Ground	30 KV. Round Conductors	Single Core and Multicore Screened ('H' Type) Cables	60
	30 KV Oval Conductors	Single Core and Multicore Screened ('H' Type) Cables	65
Screened ('H' type) Paper Insulated, Lead Covered and/or Wire Armoured in Air or in the Ground	60 KV. Round Conductors	Single Core	60
	60 KV. Oval Conductors	Single Core	65

TABLE II

Electric Circuit	Current (Amps.)	Voltage Drop (Volts)	Specific Resistance (Ohms/unit Cube)	Resistance (Ohms)	Equipotential	Lines of Current Flow
Thermal Circuit	Heat Flow (Watts)	Temperature Drop (°C.)	Thermal Resistivity °C./Watt/cm.³	Thermal Resistance (Thermal Ohms)	Isothermal	Lines of Heat Flow

ing medium and in the majority of cases is controlled by exactly the same laws as electric currents, caused by a difference of potential.

For any conductor of unit length and cross section we have by Ohm's Law

$$\text{Current } I=\frac{dV\times A}{C\times dl}$$
$$=\frac{\text{Voltage drop}\times\text{Cross Section}}{C\times\text{length}} \quad \text{(I)}$$

and for the corresponding thermal circuit

$$\text{Heat flow } H=\frac{d\theta\times A}{C^1\times dl}$$
$$=\frac{\text{Temperature drop}\times\text{Cross Section}}{C^1\times\text{length}}, \quad \text{(II)}$$

where C^1 = thermal resistivity of that body. This fundamental relation is known as "Ohm's Law for Heat Flow."

Thermal resistivity is defined as "the difference in degrees centigrade between opposite faces of a centimetre cube caused by the transference of one watt of heat (°C./Watt/cm.³)" and is expressed in thermal ohms.

From this fundamental basis heat flow problems, in general, can be translated into problems of electric currents, and vice versa, by substituting the analogous terms in Table II.

Thus current rating calculations which depend entirely on thermal phenomena offer an exact solution in the form of electrical problems.

5. *Heat Flow Problems of a Cable*

Example: Armoured Cable Buried in the Ground (see Figs. 1 and 2).

Fig. 1 shows the cross section of a 3 core (phase) cable which is heated by the load current passing along the conductors. The heat generated in the three conductors flows outwards from the copper strands and Fig. 2 illustrates the path taken by the heat flow.

After the heat generated has passed through the cable insulation, as indicated by the heat

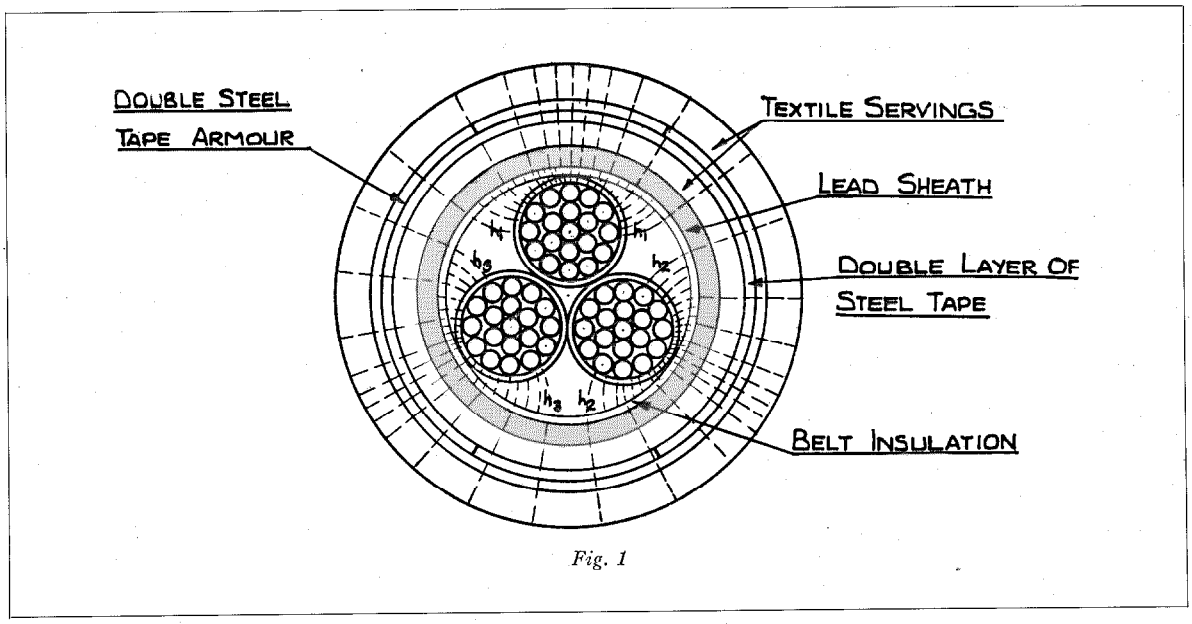


Fig. 1

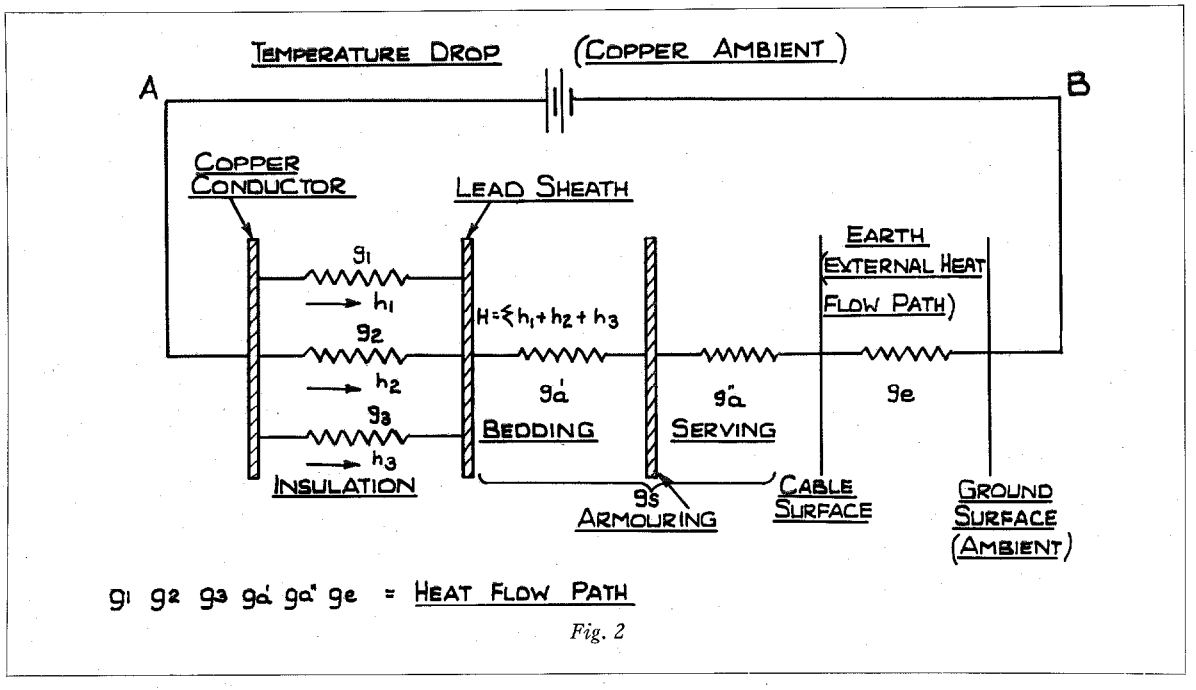


Fig. 2

flow lines, h_1, h_2 and h_3 of Fig. 1, it passes through the belt insulation and the lead sheath (which does not offer any appreciable resistance due to the relatively high thermal conductivity of lead).

The (dotted) heat flow lines then indicate the path taken through the (textile) bedding and metallic armouring (which also offers negligible resistance to heat flow) and the overall serving of the cable, after which the heat passes into the soil, where it flows towards the surface of the soil, which is assumed to be at constant temperature, i.e., the so-called ambient temperature.

When all three conductors are of equal cross section and carrying a balanced load, the heat flow in the cable will be symmetrical for all conductors and the three conductors will be at the same temperature.

The mechanism of heat flow can be clearly seen from Fig. 2.

The three copper conductors, at the same temperature, may be likened to one pole and the soil surface represents the other pole, so that the total temperature difference (analogous to E.M.F. in the electric circuit) is given by the conductor-ambient temperature drop.

From the conductor the heat flows outwards through three parallel paths (or resistances) g_1, g_2 and g_3 to the lead sheath and then through the resistance g_a' of the bedding, the relatively small resistance due to the metallic armouring, and then the resistance of the serving, as shown by g_a'', and finally from the cable exterior through the soil path to the ground surface, i.e., into the ambient.

Thus the heat flow problem is equivalent to the conventional electrical circuit, the thermal resistance of the textile bedding and servings being in series with that of the earth path (g_e).

Therefore, tackling the problem in accordance with Fig. 2 and letting the temperature drop A to B, copper conductors—ambient $=\theta$, and the total heat generated in the conductors $=H$, then

$$\text{Heat flow } H=\frac{\theta}{\Sigma R_T}$$

$$=\frac{\text{Total Temperature Drop}}{\text{Total Thermal Resistance}}. \quad \text{(III)}$$

In this equation the maximum permissible temperature drop θ is fixed by the regulations in force in the various countries. Thus the maximum permissible core temperature (see Table I) minus the initial temperature (ground temperature or air temperature), which is taken to be 15° C. or 25° C., respectively, for normal conditions equals the temperature drop θ.

Heat generated (H) in a cable having

$$\text{“}n\text{”} \text{ conductors} = nI^2R_\theta, \quad \text{(IV)}$$

where R_θ is the ohmic resistance of one centimetre length of copper conductor at the maximum operating temperature $=(15+\theta)$°C. or $(25+\theta)$°C.—(see also section 8).

Substituting equation (IV) in equation (III), we get, after transformation,

$$I=\sqrt{\frac{\theta}{nR_\theta \times \Sigma R_T}}, \qquad \text{(V)}$$

where I = safe current carrying capacity and the other factors in the equation are as detailed above.

The problem of calculating the total temperature of the hottest part of the insulation resolves itself into the question of determining the total thermal resistance of the path taken by the heat flow (ΣR_T) which is obtained by calculating the value of components g_1, g_2, g_3, g_a', g_a'', g_e, the individual thermal resistances shown in Fig. 2.

6. *Determination of the Thermal Resistance of a Cable*

From Fig. 2 we see the thermal resistance ΣR_T consists of resistances partly in series and partly in parallel, so it is necessary to compute the values of these so-called "partial thermal resistances."

Each partial resistance can be split up into two factors, one being essentially the thermal resistivity of the material (K) and the other a function of the shape of the material through which the heat passes. The latter factor is called the Geometric Factor (D. M. Simmons).

The thermal resistance (G) is given by:

$G=K/2\pi \times$G.F. thermal ohms per cm. length of cable. (VI)

6.1 *Thermal Resistivity of Cable Material*

The following values are used (in this country) for the thermal resistivity of each part of the cable through which the generated heat flows:

Dielectric (Impregnated Paper).

$K=750$° C./Watt per cm.[3] for voltages up to and including 1.5 kV.

$K=550$° C./Watt per cm.[3] for higher voltages.

Textile Protective Covering.

$K=500$° C./Watt per cm.[3]

The thermal resistivity of the lead sheath and metallic armouring is taken as zero (owing to their relatively high thermal conductivity).

Soil thermal resistivity, $g=120$° C./Watt per cm.[3]

The value quoted above for the soil resistivity is the accepted standard value, but it may vary widely with the nature of the soil and its moisture content.

6.2 *Geometric Factor*

For certain problems the G.F. may be calculated, but there are some cases for which such a calculation would be very complicated, or even impossible, so that under certain conditions it is necessary to resort again to the analogy between the law governing the flow of electricity (Ohm's law) and that of heat (Ohm's Law for Heat Flow)—vide section 4—and solve the analogous electrical problem by the measurement of the electrical resistance of models comprising electrodes immersed in an electrolyte. These models are so constructed that an electrolyte fills the space between the parallel cylindrical conductors and the lead sheath, so that measurements can be conveniently taken.

The first step in calculating the current rating of a cable is to determine the thermal resistance from conductor to lead sheath, i.e., the so-called internal thermal resistance of a cable for unit length.

6.3 *Internal Thermal Resistance of Single Conductor and S.L. (Separate Lead Sheathed) Type Cable*

The G.F. for a unit length single conductor cable consisting of a solid conductor of diameter r and a dielectric (insulation) radial thickness E can be calculated from

$$\text{G.F.}=\log_e(1+E/r). \qquad \text{(VII)}$$

The problem for the normal case of a stranded conductor has been solved by rather complicated calculations (Levi-Civita) in addition to the analogous method outlined under 6.2.

The result is very nearly the same as given by equation (VII). Hence the expression is used for both solid and stranded conductors, the internal

thermal resistance being

$$G=\frac{K}{2\pi}\log_e\frac{r_1}{r}\ \text{thermal ohms per cm. length of Core,} \qquad \text{(VIII)}$$

where r_1=radius over dielectric, r=conductor radius.

In the case of an S.L. type cable, which consists of three separate lead covered cores twisted together, the internal thermal resistance is given by

$$G=\frac{K}{6\pi}\log_e\frac{r_1}{r}\ \text{thermal ohms per cm. length of cable.} \qquad \text{(IX)}$$

6.4 *Internal Thermal Resistance of Multiconductor Belted Type Cables*

For multicore cables and particularly for the case of a three core cable consisting of three solid conductors with equal radii and insulated with a radial dielectric of thickness E, the cores being twisted together and made into a circular section (with wormings of jute or paper), the assembly then being lapped with a belt of paper of thickness E (for the case of an earthed type cable the belt insulation will be less than E), the G.F. can be obtained mathematically (Mie, Russell). These calculations, however, are very complicated.

This problem and allied problems have been solved by the electrolytic method mentioned under 6.2. Fig. 3 gives results obtained in the form of thermal resistance values per core for twin and four core Belted cables and also for three core (phase) cables with full belt insulation E (suitable for unearthed systems), with reduced belt insulation (earthed systems) and without belt insulation (confined to 460 volt cables only).

The left hand scale applies to paper insulated cables up to 1.5 kV. and to Varnished Cambric cables of all types and voltages up to 20 kV. while the right hand scale is applicable to paper impregnated cables for voltages above 1.5 kV.

For practical purposes these results apply to both solid conductors and circular stranded conductors. For shaped conductors refer to Section 10.2 and Table V.

6.5. *Internal Thermal Resistance of Screened (Hochstadter type) Cables*

From experience it was found that the "belted" or "solid" type cables were relatively

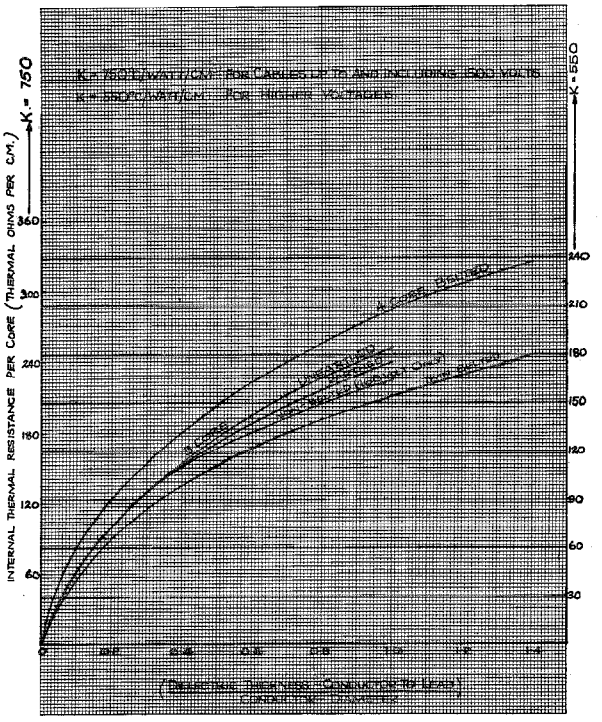


Fig. 3

unsuitable at voltages in excess of 20 kV. so that the screened (shielded) 'H' type cable was developed. It is often used on 20 kV. but its principal field of application is at 30 kV. and higher voltages.

Screening the individual cores (by means of the perforated aluminium foil generally used in Europe, or the American practice of using 3 mil copper tapes) reduces the internal thermal resistance of a cable by providing additional heat paths of high thermal conductivity in parallel with the path through the dielectric.

Attempts have been made to calculate the internal thermal resistance of an 'H' type cable or, at least, to obtain an approximate result (C. Feldman-D. M. Simmons) but no reliable values have been obtained for the type used in Europe.

Further developments (Konstantinowsky) of the electrolytic method yielded satisfactory results. This method was later adopted by others (Waddicor, E. R. A.) and it has also been used for solving other electrical problems.

The internal thermal resistance of a screened cable per cm. length, of cable, i.e., the resistance offered to the flow of heat from the three conductors of a three core 'H' type cable to the

surrounding lead sheath, is a function of the ratio of diameter over screen and diameter ($2r$) over conductor and of $P=tK/3(2rK_s)$ where t=thickness of screening foil (5×10^{-4} inch) or copper tapes (3×10^{-3} inch).

r=Radius of conductor (inches).
K=Thermal resistivity of dielectric.
K_s=Thermal resistivity of the screening foil material (0.26° C./Watt per cm.^{3} for copper or 0.5° C./Watt per cm.^{3} for aluminium).

Fig. 4 gives the appropriate value of the internal thermal resistance per cm. length for a three core 'H' type cable (circular conductors).

At 60 kV. and higher voltages 'H' type cables are used as single core cables only, since the weight for a multiconductor cable becomes excessive. Consequently, the current rating for a 60 kV. cable is obtained by a similar method to that adopted for single core low tension cables; however, the correct value of K to use is 550° C./Watt per cm.^{3} (refer to formula XXIII for dielectric losses).

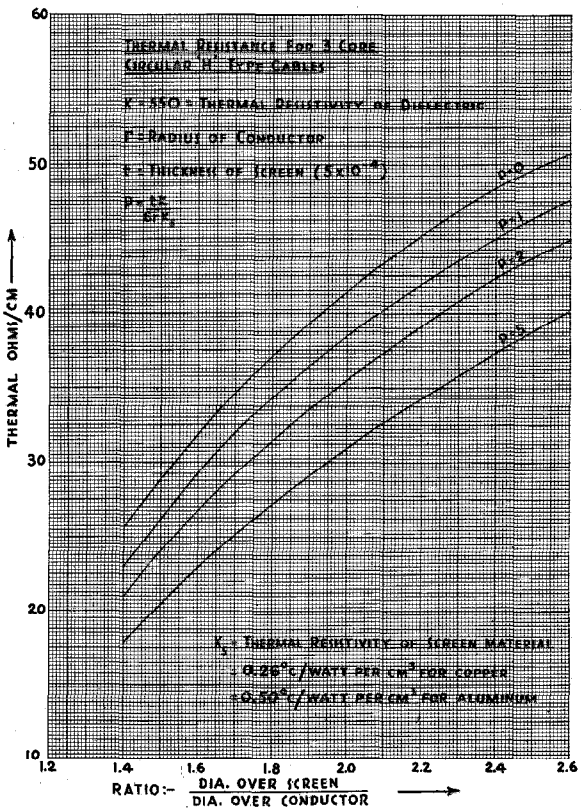


Fig. 4

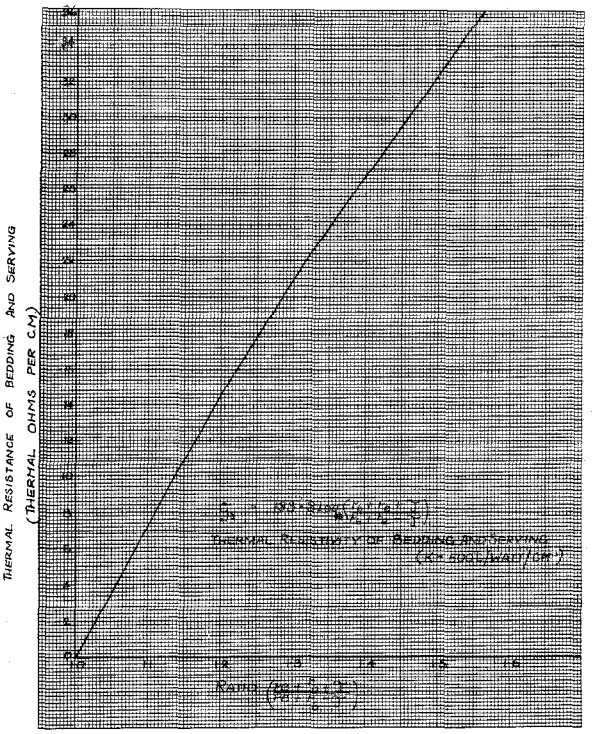


Fig. 5

6.6 *Thermal Resistance of Bedding and Serving*

The thermal resistance of the protective coverings, i.e., the textile bedding and servings ($g_s=g_a'+g_a''$—see Fig. 2) is obtained from the following expression:

$$G_s=\frac{K}{2\pi}\log_e\frac{(r_6+r_e+\tau)}{(r_6+r_e-\tau)}\ \text{thermal ohms per cm. length of cable,} \qquad (X)$$

where r_6 is the external radius of the lead sheath, r_e is the external radius of the finished cable and τ is the total radial thickness of the servings (see examples Section 10).

The thermal resistance of the protective coverings may be quickly obtained from Fig. 5.

If there is only one layer of protective textile material, the thermal resistance per cm. length of cable is given with sufficient accuracy by

$$G_s=\frac{K}{2\pi}\times\frac{\tau}{r_6}, \qquad (XI)$$

where τ is the thickness of the protective layer and r_6 the external radius of the lead sheath.

7. *Thermal Resistance of the Soil*

For cables laid in the ground the heat transmitted through the cables passes into the surrounding soil.

No conclusive evidence is available regarding the nature of heat flow in the soil, but the basis used for calculation in Great Britain accepts the theory (advanced by A. E. Kennelly) that the ground surface above the cable is a plain isothermal of the ambient temperature so that all heat generated is ultimately transmitted to the ground surface which remains at a constant temperature.

The thermal resistance g_e (see Fig. 2) between the outer covering of a cable and the surface of the earth is given by

$$g_e=\frac{g}{2\pi}\log_e\frac{(2h-r_e)}{r_e}\ \text{thermal ohms per cm. length,} \qquad \text{(XII)}$$

where "h" and "r_e" are expressed in the same units of length.

To minimize calculations, values of g_e have been computed from the above formula and are given in Fig. 6.

The soil thermal resistivity (g) depends largely upon the amount of moisture present and upon the type of soil, but for all normal conditions "g" is taken as 120° C./Watt per cm.[3]

Standard depths of laying "h" are 18" plus radius (r_e) of completed cable for voltages up to and including 1.5 kV., 36" plus radius of completed cable for voltages from 3 kV. to 20 kV. inclusive, and 42" for voltages above 20 kV.

The thermal problem for cables in air and ducts are detailed later in Sections 11 and 12.

It is now necessary to deal with the next part of formula (V).

8. *Conductor Resistance*

The ohmic resistance for the range of standard copper conductors is given by

$$R=\frac{(0.24)}{\text{Area in sq. inch}}\ \text{ohms per 1000 yards, annealed copper at 15.6°C. (60°F.), 100% conductivity (I.A.C.S.)} \qquad \text{(XIII)}$$

The resistance value obtained must now be increased by 2% to allow for the stranding of the wires, then a further 2% increase in the case of multicore cables is allowed for the extra core length necessary when the insulated cores are twisted together into cable form. Thus

$$R_S=\frac{(0.2678)}{(\text{Area in sq. inches})}\times 10^{-6}\ \text{ohms per cm. length} \qquad \text{(XIV)}$$

for single core cables; also

$$R_m=\frac{(0.2732)}{(\text{Area in sq. inches})}\times 10^{-6}\ \text{ohms per cm. length of cable} \qquad \text{(XV)}$$

for multicore cables.

The ohmic resistance of a conductor at maximum working temperature is obtained from the expression $R_\theta=R(1+\alpha\theta)$. (XVI)

R = resistance (single or multicore) in ohms per cm. at 15.6° C. (60° F.).

α = temperature coefficient of copper for the temperature range 0° to 100° C. = 0.00428.

θ = temperature rise (i.e., above the ambient temperature of 15° C. or 25° C.).

If cables with large copper sections (0.2 sq. inch or larger) are used on an A.C. supply, the D.C. resistance (R) value is subject to a small increase for "skin effect" (y) and "proximity effect" (y_1), due to other current carrying conductors in the immediate vicinity, so that the total conductor resistance $R_T=R(1+y+y_1)$.

All the factors in formula (V) have now been considered for a cable laid direct and practical examples can now be considered.

9. *Cable Design*

Thickness of insulation, lead sheath and steel tapes, or wire armour, are obtained from B.S.I. 480—1933 specification (this specification supercedes the well-known B.E.S.A. No. 7—1926 report) and full design data is included for paper insulated cables rated at voltages from 460 volts up to and including 20 kV.

Paper cables used in mines are provided for by B.S.I. 760—1938 specification.

In order to compute the thermal resistance of the different heat paths, it is necessary to obtain the dimensions of the cable, as follows:

Circular strand diameters are obtained from either of the specifications referred to; twice the radial thickness of insulation is added; then the diameter over the "laid up" cores (i.e. when

twisted together helically) is obtained by multiplying the core diameter by the appropriate constant from Table III.

TABLE III
"LAY UP" CONSTANTS

No. of Cores	Multiplying Constant
Two	2.0
Three	2.16
Four	2.414

Now add twice the radial thickness of belt insulation (except for non-belted type 460 volt cables) in order to get the diameter under the lead sheath; also add twice the thickness of lead sheath, bedding, S.T.A., or Wire Armour, and overall serving, to obtain the external diameter of cable.

10. *Cables Laid Direct (Examples)*

To show the method of calculation, the rating is computed below for (*a*) 0.1 sq. in. 1 kV. 3-core Belted Type cable, and (*b*) 0.1 sq. in. H.T. 3-core Screened Cable (Section 10.3).

10.1 *L.T. Cable "Belted" type—Round Conductors* (Table IV)

Specification: 0.1 sq. in. (19/0.083) Low Tension, 3 Core, Paper Insulated, Lead Sheathed, served with a layer of jute, compounded, armoured with a double layer of steel tape, jute served and compounded overall (B.S.I. 480—1933, Table IV—1 kV.).

METHOD OF LAYING: Direct in the ground at a depth of 18" (Vide Section 7).

SOIL TEMPERATURE: 15° C. (59° F.).

PERMISSIBLE TEMP. RISE OF CONDUCTOR: 55° C. (99° F.).

FINAL CONDUCTOR TEMPERATURE: 70° C. (158° F.). (Refer to Table I).

Internal Thermal Resistance

$$\text{Ratio}\left[\frac{\text{Dielectric thickness (Conductor to sheath)}}{\text{Conductor dia.}}\right]=\frac{0.070}{0.415}=0.169.$$

From Fig. 3 internal thermal resistance = 91 thermal ohms per loaded core/cm. length of cable (a 1 kV. cable has the same thickness of dielectric between conductors and between conductors and lead and is, therefore, considered as an Unearthed Cable). Internal thermal resistance of cable = 91/3 = *30.4 thermal ohms per cm. length of cable* (since the three cores are in parallel—see Fig. 2).

Thermal resistance of Bedding and Serving

$$\text{Ratio}\left(\frac{r_6+r_e+\tau}{r_6+r_e-\tau}\right)=\left(\frac{0.937+0.647+0.200}{0.937+0.647-0.200}\right)=1.29.$$

Referring to Fig. 5, the required thermal resistance for a cable having overall diameter of 1.875, $G_s = 20.6$ *thermal ohms per cm. length of cable.*

Thermal Resistance of Earth Path

The value of the thermal resistance for this part of the heat flow path is calculated by formula (XII), or obtained from Fig. 6 for a depth of laying of 18 inches. $G_e = 70$ *thermal ohms per cm. of cable.*

TABLE IV.

Design		Diameter (Inches)	
CONDUCTOR 0.1 sq. in.	19/0.083 Circular	0.415	
INSULATION	0.035" Radial Thickness*	0.485	
LAY UP	3 Cores (0.485×2.16)	1.050	
BELT INSULATION	0.035 Radial Thickness	1.120	
LEAD SHEATH	0.080" Radial Thickness	1.295	Tolerance on Minimum Sheath Thickness Allowed
BEDDING	Jute 0.1" Radial Thickness	1.495	
ARMOUR	Two Steel Tapes Each 0.040" Radial Thickness	1.675	Small Allowance Made for Armouring Compounds
OVERALL SERVING	Jute 0.1" Radial Thickness	1.875	

* It will be noted that the specified thickness of insulation given in the B.S.I. specification is obtained by having half this value on each core.

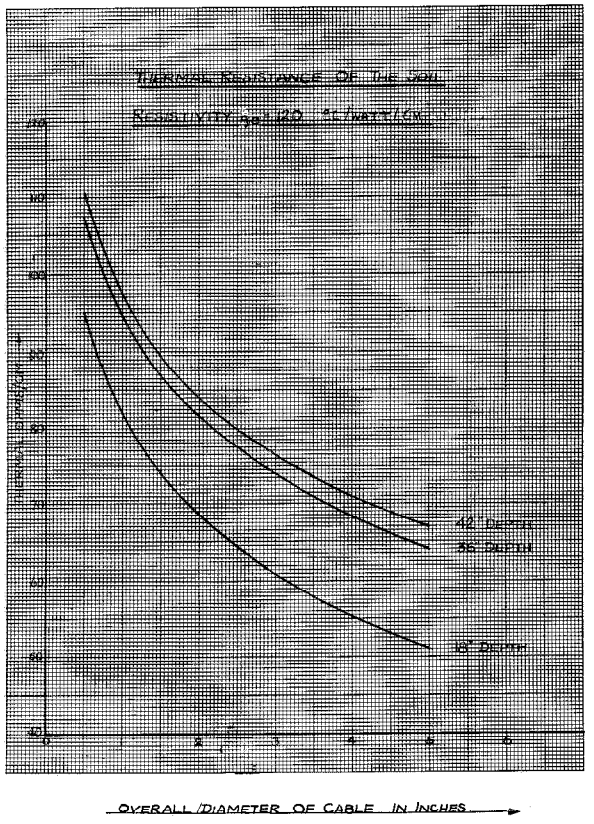


Fig. 6

Total thermal resistance (see Fig. 2) $=\Sigma R_T = g_i+(g_a'+g_a'')+g_e=30.4+20.6+70=121$ *thermal ohms per cm. of cable.* Conductor resistance $R_\theta=3.305\times10^{-6}$ ohms per cm. for conductor at 70° C. (see section 8). Temperature rise = maximum temperature (Section 2, Table I)—initial temperature = (70 − 15) = 55° C.

Thus permissible current rating according to formula (V),

$$I=\sqrt{\frac{55}{3\times3.305\times10^{-6}\times121}}=210 \text{ Amps.}$$

10.2. *Sector Shaped Conductors*

The current loading obtained applies to cables with circular conductors, but the majority of power cables are manufactured with sector shaped conductors thereby reducing the overall diameter of the cable and minimizing the materials required for the lead sheath, armouring and serving of the cable.

Therefore, the rating for BELTED type circular conductor cables (laid direct) must be modified by the correction factor given in Table V.

For Belted type cables in air, or pulled into ducts, there is no correction for shaped conductors over the voltage range 460 volts—20,000 volts.

20 kV. 'H' Type Cables: When laid direct sector shaped cores for this type of cable are rated at approximately 1% higher than round conductors, and again there is no correction necessary when run in air or pulled into ducts.

30 kV. 'H' Type Cables: Ratings for cables with oval conductors when laid direct are about 2% higher, and 3% higher than circular conductors when run in air.

For 30 kV. and over, oval conductors are preferable to sector shaped conductors because too pronounced shaping of the conductor tends to accentuate the electrical stresses.

60 kV. Single Core 'H' Type Cables: These cables are usually installed in trefoil formation (i.e., with lead sheaths, or outer servings, touching) and the same rating is used for both circular and oval conductors.

The internal thermal resistance of cables with sector shaped or oval conductors is smaller than that of cables with circular conductors, but the reduction in the overall diameter of the cable gives an increased external thermal resistance which tends to compensate for the reduced internal thermal resistance. Thus, the increased rating for shaped conductors is small.

10.3 *Example: H.T. "Screened" Cable* (Table VI)

Specification: 0.1 sq. in. (19/0.083) High Tension, 3 Core, paper insulated, lead sheathed,

TABLE V

CURRENT RATING FOR SECTOR SHAPED CONDUCTORS/CURRENT RATING FOR CIRCULAR CONDUCTORS

Voltage	460 V. and 1000 V.	3000 V.	6000 V.	10,000 V.	20,000 V.
Correction Factor for Current Carrying Capacity	1.03	1.02	1.02	1.02	1.02

served with a layer of jute, compounded, armoured with a double layer of steel tapes, jute served and compounded overall, 'H' type cable, 20 kV. Round conductors. Earthed system. Table 11 of B.S.I. 480—1933.

METHOD OF LAYING: Direct in the ground at a depth of 36" (vide Section 7).

SOIL TEMPERATURE: 15° C. (59° F.).

PERMISSIBLE TEMPERATURE RISE OF CONDUCTOR: 50° C. (90° F.).

FINAL CONDUCTOR TEMPERATURE: 65° C. (149° F.). (Refer to Table I.).

Internal Thermal Resistance

$$\text{Ratio } \frac{\text{Dia. over screen}}{\text{Conductor diameter}}=\frac{0.885}{0.415}=2.13;$$

$$\text{Parameter } P=\frac{tK}{2rK_s}=\frac{5\times10^{-4}\times550}{2\times0.207\times0.5}=1.33;$$

from Fig. 4 thermal resistance for a 3 core cable $=40$ thermal ohms per cm. length.

Thermal Resistance of Bedding and Serving

$$\text{Ratio } \left(\frac{r_e+r_6+\tau}{r_e+r_6-\tau}\right)=\left(\frac{1.38+1.09+0.200}{1.38+1.09-0.200}\right)=1.17$$

and from Fig. 5, $G_s=12.6$ *thermal ohms per cm. of cable.*

Thermal Resistance of Earth Path

From Fig. 6, for cable laid direct at a depth of 36" and having an overall diameter of 2.760", $G_e=75.5$ *thermal ohms per cm. of cable.*

Total thermal resistance (see Fig. 2) $\Sigma R_T=g_1+(g_a'+g_a'')+g_e=40+12.6+75.5=128$ *thermal ohms per cm. of cable.*

Permissible temperature rise $\theta=(65-15)°$ C. $=50°$ C. (Table I). $R_\theta=3.251\times10^{-6}$ ohms per cm. for conductor at 65° C. (see Section 8); hence, from equation (V),

$$I=\sqrt{\frac{50}{3\times3.251\times10^{-6}\times128}}=203 \text{ Amps.}$$

11. *Cables in Air*

When cables are installed in free air the ambient temperature is taken as 25° C. for normal conditions (see 3.3). When, however, the cables are run in buildings, it is necessary to refer to the "I.E.E. Regulations for the Electrical Equipment of Buildings," for the permissible rating; these tables are based on carefully defined conditions of installation, ambient temperature, method of grouping, etc.

With regard to the external thermal resistance, from observations made at the N.P.L. it has been deduced that the total heat flow "H" per cm. of cable from its surface in air may be represented as $(\pi dh\theta_s^{5/4})$, d being the diameter of the cable in centimetres and h a constant representing heat flow by convection (i.e., moving air), conduction (i.e., heat flow through the air) and radiation; θ_s = sheath temperature rise (i.e., above the ambient). Thus the external thermal resistance, i.e., the thermal resistance from cable

TABLE VI

Design		Diameter (inches)	
CONDUCTOR	0.1 sq. in. = 19/0.083 Circular	0.415	
INSULATION	0.23" Radial Thickness	0.875	
	1×5 mil Aluminum Screen Including Backing Paper	0.885	
LAY UP	3 Cores (0.885×2.16)	1.910	See below.*
BELT INSULATION	Linen Binder Interwoven with Copper Threads.	1.940	
LEAD SHEATH	0.110" Radial Thickness	2.180	Tolerance on minimum thickness allowed.
BEDDING	Jute 0.10" Radial Thickness	2.380	
ARMOUR	Two Steel Tapes Each 0.040" Radial Thickness	2.560	Allowance made for compounds over steel tapes
OVERALL SERVING	Jute 0.1" Radial Thickness	2.760	

* Unlike "Belted type" cables, which have several layers of paper applied over the cores after they have been helically twisted together, screened 'H' type cables have only a metallized linen binder (i.e., linen tape interwoven with copper wires), or metallized papers applied over the laid up cores. The purpose of the metallized binder is to ensure sound electrical contact between the screened cores and the lead sheath throughout the whole length of the cable.

TABLE VII

Type of Cable	3 Single Core Cables 1–3 kV A.C.		3 Single Core Cables 20 kV.		3 Core Belted Cable 1–3 kV.		3 Core Belted Cable 20 kV.	
	θ_s(°C.)	$1/\theta_s^{\frac{1}{4}}$	θ_s(°C.)	$1/\theta_s^{\frac{1}{4}}$	θ_s(°C.)	$1/\theta_s^{\frac{1}{4}}$	θ_s(°C.)	$1/\theta_s^{\frac{1}{4}}$
Core Temp. Rise °C. (θ)	45	—	40	—	45	—	30	—
Plain Lead Covered	37.1	0.407	29.2	0.43	34.5	0.415	18.3	0.485
Served Unarmoured Cable	34.1	0.415	26.9	0.44	30.5	0.425	16.7	0.495
Armoured and Served Cable	—	—	—	—	28.5	0.435	15.0	0.510

surface to ambient, is given by

$$G_A=\frac{\theta_s}{H}=\frac{\theta_s}{\pi dh\theta_s^{5/4}}=\frac{1}{\pi dh\theta_s^{1/4}}. \qquad \text{(XVII)}$$

Typical values of θ_s are given in Table VII with the corresponding value for $1/\theta_s^{1/4}$. Values of $1/\pi dh$ have been plotted against the external cable diameter (inches) in Fig. 7.

Thus the external thermal resistance of the air path can be found by multiplying the value $1/(\pi dh)$ obtained from Fig. 7 by the value $1/\theta^{1/4}$ from Table VII corresponding to the case in question.

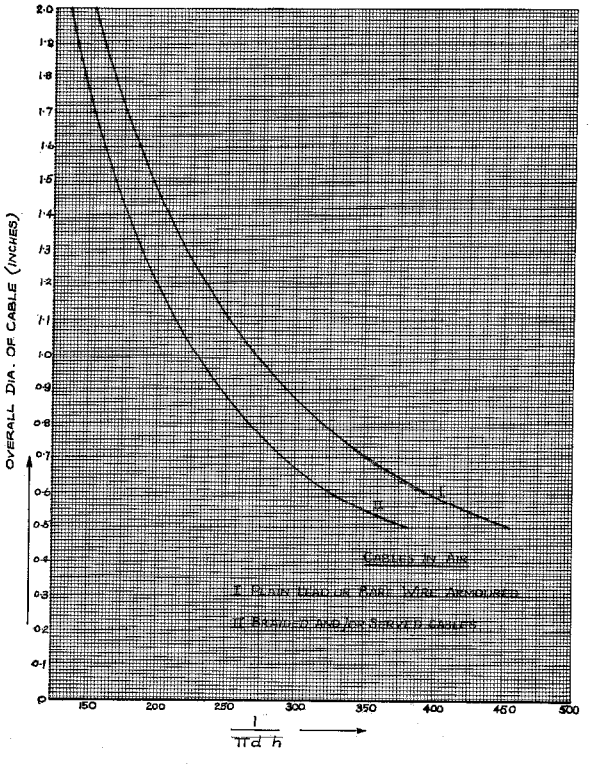


Fig. 7

11.1. *Example: Cable (as in Section 10.1) but erected in free air*

Cables run in air may not need any protection over the lead sheath against mechanical damage but, should suitable protection be deemed advisable, steel wire armouring is used for multi-conductor cable. In this case the design details (see Table IV) over the lead sheath must be modified as in Table VIII.

TABLE VIII

		Diameter
Lead Sheath	0.08″ Radial Thickness	1.295
Bedding	Jute 0.10″ Radial Thickness	1.495
Armour	Single Layer of Galvanized Steel Wires Each 0.104″ Dia.	1.703
Overall Serving	Armour Left Bare	1.703

Method of Installing: In free air.

Ambient Temperature: 25° C. (77° F.).

Permissible Temperature Rise of Conductor: 45° C. (81° F.).

Final Conductor Temperature: 70° C. (158° F.) (refer to Table I).

Internal Thermal Resistance (from Example 10.1): $g_i=30.4$ *thermal ohms per cm. of cable.*

Protective Covering, Ratio $\left(\frac{r_e+r_6+\tau}{r_e+r_6-\tau}\right)=1.155$

and, from Fig. 5, $g_s=(g_a'+g_a'')=11.5$ *thermal ohms per cm. of cable.*

N.B. In obtaining the above ratio the thermal resistance of the armouring is considered negligible so that $r_e=0.747''$.

Thermal Resistance of the Air Path

From Table VII, $1/\theta_s^{1/4}=0.430$ (i.e., mean value between a served unarmoured cable and an armoured and served cable).

Fig. 7—for a wire armoured cable having an overall diameter of 1.703", $(1/\pi dh)=176$ (Curve I); hence $G_e=0.430\times176=75.5$ *thermal ohms per cm. of cable.*

Total thermal resistance (see Fig. 2)

$\Sigma R_T=g_i+(g_a'+g_a'')+g_e=30.4+11.5+75.5$
$=117.4$ *thermal ohms per cm. of cable.*

$R_\theta=3.305\times10^{-6}$ ohms per cm. for conductor temperature of 70° C.

Temperature rise $\theta=(70-25)=45°$ C.; therefore (formula (V))

$$I=\sqrt{\frac{50}{3\times3.305\times10^{-6}\times117.4}}=200 \text{ amps.}$$

12. *Cables in Ducts*

12.1. *Heat Flow Considerations*

When cables are installed in cities and crowded areas they are often pulled into ducts since this method of laying allows for the addition of new cables to a cable route with the minimum of labour. Further, cables when installed in ducts can easily be withdrawn if any modifications in the route are necessary.

By comparison with the two previous methods of installation, cables laid in ducts have a lower rating, due to the higher thermal resistance of the heat flow path. This path of heat flow again comprises a number of thermal resistances in series, as illustrated in Fig. 8.

Reverting to Fig. 2, it is clear that the above condition represents a modification of the problem dealt with there, i.e., we have the thermal resistance of the cable $g_i+(g_a'+g_a'')$ (where g_i represents the resultant thermal resistance of three cores in parallel), as in original problem, to which must be added the thermal resistance of the air space surrounding the cable in the duct (g_{AS}); also, the heat passes through the duct wall (g_D) and finally it flows through the earth path (g_e) so that the total resistance to heat flow comprises the partial resistances $g_i+(g_a'+g_a'')+g_{AS}+g_D+g_e$, all of which are in series.

The method of calculating the thermal resistance of a cable $g_i+(g_a'+g_a'')$, i.e., from copper conductors to cable surface, has already been established (Section 6). The following outlines the calculation for the additional partial resistances from the cable surface through the ductway to the ground surface (g_{AS}, g_D, g_e).

Heat is dissipated through the air space between the cable surface and the duct wall by Conduction, Convection and Radiation (see also Section 11).

RADIATION flow in watts per centimetre length of cable,

$$H_r=\frac{23d}{10^4}\left(\frac{E_1\times E_2}{E_1+E_2-E_1E_2}\right)\theta, \quad \text{(XVIII)}$$

where θ = temperature difference between cable surface and the inner wall of the duct.

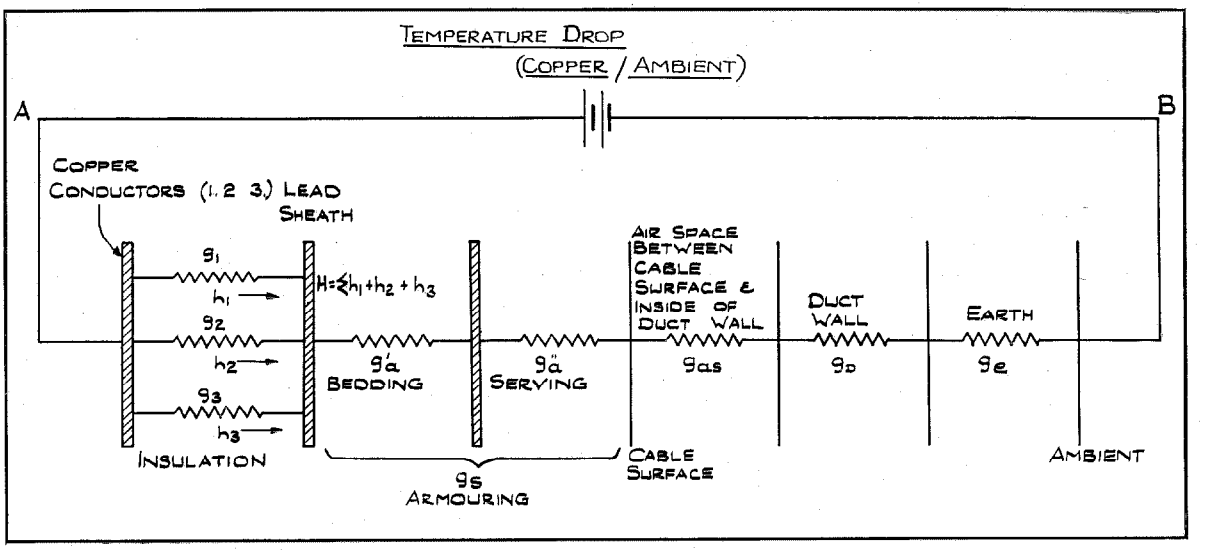


Fig. 8

The following values of θ, having been calculated as a mean for typical cases, may be used:

$\theta = 0.34\theta_c$ for a cable in a Single Way Duct.
$\theta = 0.21\theta_c$ for cables in Four Way Ducts, all cables loaded.
$\theta = 0.11\theta_c$ for cables in Nine Way Ducts, all cables loaded.
θ_c = Maximum permissible core temperature rise, i.e., if ground temperature is taken as 15° C. and maximum core temperature (vide Table I) = 70° C., then $\theta_c = (70-15) = 55°$ C.

The following values are generally assumed:

$E_1 = 0.6$ for unserved cables or bare wire armoured cables.
E_1 = Unity for served cables.
E_2 = Unity for glazed earthenware ducts or concrete ducts.
d = Overall diameter of cable in centimetres.

CONVECTION flow in watts per centimetre length of cable

$$H_c = 0.7(k_c \times d^{3/4} \times \theta^{5/4}), \qquad \text{(XIX)}$$

where k_c = convection constant given in Fig. 9.

CONDUCTION flow in watts per centimetre length of cable is calculated by

$$H_d = 2.04 \times 10^{-3} \sqrt{\frac{r_c r_d}{r_d - r_c}} \times \theta, \qquad \text{(XX)}$$

where r_d = internal radius of duct which is usually 2 inches (5.08 cm.) or 2.5 inches (6.35 cm.) and r_c = overall radius of cable.

Thus the total heat transmitted from the cable surface to the inner duct wall $= H_T = H_r + H_c + H_d$ watts per cm. length, and the thermal resistance between the cable surface and the inner surface of the ductway is according to "Ohm's Law for Heat Flow" (see Section 4) given by:

$$G_{AS} = \left\{ \frac{\text{Temperature Drop}}{\text{Total Heat Transmitted per cm. Length of Cable}} \right\}.$$

12.2 *Current Rating Calculations for L.T. 3 Core Cable in a Single Way Duct*

The cable considered in the example is a 19/0.083 L.T. 3 core Paper Insulated, Lead Covered and Bare Wire Armoured 1 kV. cable having dimensions as detailed in Section 11. The following partial resistances have already been computed:

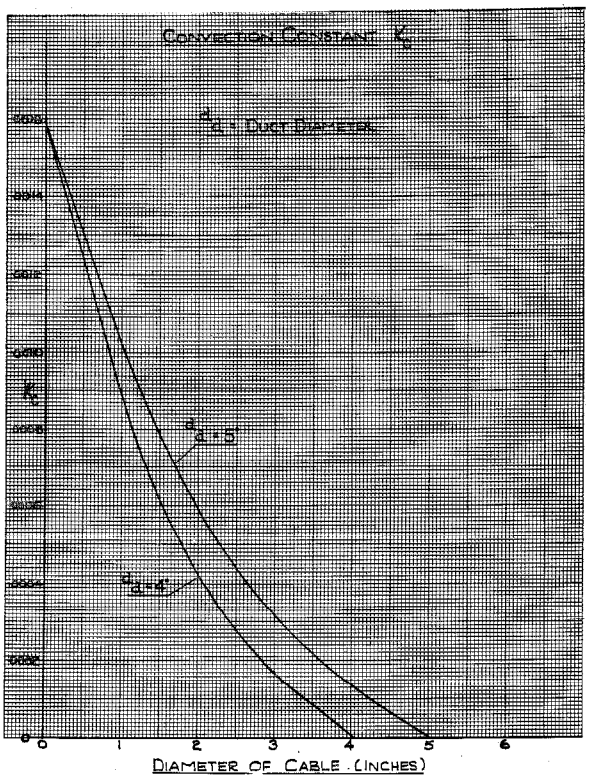


Fig. 9

Internal thermal resistance $(g_1) = 30.4$ *thermal ohms per cm. length of cable.*

Thermal resistance of bedding and serving $(g_a' + g_a'') = 11.5$ *thermal ohms per cm. length of cable.*

Radiation flow $H_r = \frac{23 \times (1.7 \times 2.54)}{10^4} \times \left(\frac{0.6 \times 1}{0.6 + 1 - 0.6 \times 1} \right) \times 0.34 \times \theta_c,$

θ_c = Core temperature rise $(70-15) = 55°$ C.,
$H_r = 0.111$ *watts per cm. length of cable.*

Convection flow $H_c = 0.7(53 \times 10^{-5} \times 4.32^{3/4} \times (0.34 \times 55)^{5/4}),$

where $k_c = 0.7$ = convection constant from Fig. 9 (overall diameter of cable 4.32 cm., and ductway 10.16 cm. (4 inches) internal diameter) $= 53 \times 10^{-5}$; thus $H_c = 0.043$ *watts per cm. of cable.*

Conduction flow $H_d = 2.04 \times 10^{-3} \sqrt{\frac{0.85 \times 2}{2 - 0.85}} \times (0.34 \times 55)$,

where $r_d = 2$ inches; hence

$H_d = 0.046$ *watts per cm. length of cable.*

Total heat transmitted from cable surface to the inner duct wall

$H_T = H_r + H_c + H_d$
$= 0.20$ *watts per cm. length of cable;*

therefore,

$G_{AS} = \frac{0.55 \times 0.34}{0.20} = 93$ *thermal ohms per cm. length of cable.*

The thermal resistance of the duct wall itself, i.e., from the inner to the outer surface of the duct $= G_d = g_d / 2\pi \log_e r_0/r_d$ thermal ohms per cm. of duct, (XXI)

where g_d = thermal resistivity of the duct material
= 120° C. per watt per cm.^{3} for Earthenware Ducts or
= 500 (approximately) for Fibre Ducts.
r_0 = external radius of duct.
r_d = internal radius of duct.

$G_d = \frac{120}{2\pi} \log_e \frac{2.5}{2} = 4.30$ thermal ohms per cm. of ductway for the case of an Earthenware Duct having an internal diameter of 4″ and a wall thickness of 0.5″.

Soil Path (i.e., partial thermal resistance from the outer surface of the duct to the ground surface):

$G_S = \frac{g}{2\pi} \log_e \left(\frac{2h - r_0}{r_0} \right)$ thermal ohms per cm. length. (XXII)

h = depth from ground surface to duct axis,
r_0 = external radius of duct as above noted,
g = soil thermal resistivity.

A depth of laying of 2.5 ft. to the top of the duct may be taken as the standard depth of laying for all types of ducts; therefore

$G_S = \frac{120}{2\pi} \log_e \left(\frac{2 \times 32.5 - 2.5}{2.5} \right) = 61$ *thermal ohms per cm. length.*

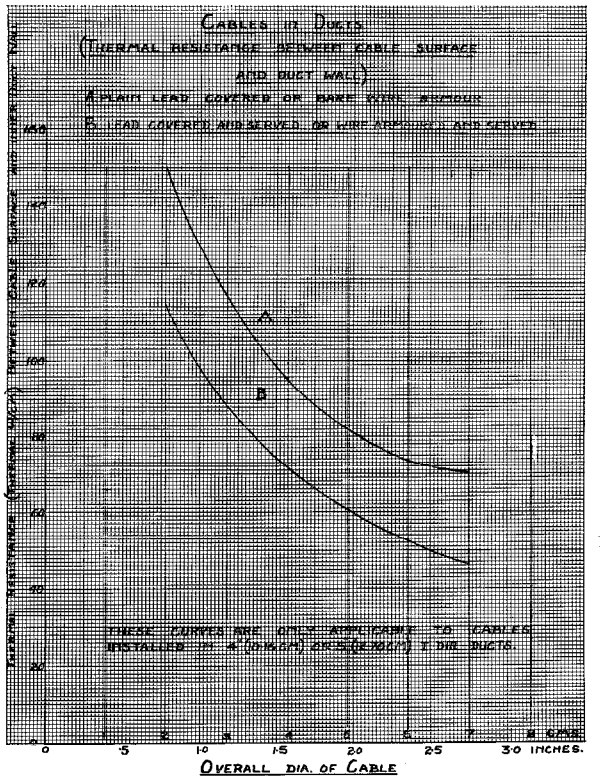


Fig. 10

Hence the total thermal resistance for this particular case

$G_T = 30.4 + 11.5 + 93 + 4.3 + 61$
$= 200$ *thermal ohms per cm. length.*

$R_\theta = 3.305 \times 10^{-6}$ ohms per cm. length of conductor at final temperature of 70° C.

Permissible temperature rise

$\theta = (70 - 15) = 55°$ C.;

therefore, from Formula (V),

$$I = \sqrt{\frac{55}{3 \times 3.305 \times 10^{-6} \times 200}} = 168 \text{ amps.}$$

12.3 *Current Rating Calculations for L.T. 3 Core Cable in a Multiway Duct*

The previous section deals only with Single Way Ducts, but ductways often consist of multiway ducts arranged for three, six or nine cables. The rating for a cable in a single way duct is converted to that for a multiway duct by multiplication by the appropriate rating factor obtained from Fig. 11.

Occasionally a multiway duct may not contain the full number of cables, or the permissible rating with several of the cables idle may be required. This loading is obtained by multiplying the rating for cables in a full duct system by the appropriate factor from Table IX.

TABLE IX

3-Way Duct		6-Way Duct		9-Way Duct	
(Number of Cables in Duct Cluster)					
1	2	4	5	7	8
1.15	1.07	1.10	1.04	1.10	1.05

When three cables only are loaded in a six way duct, the ratings for three cables in a three way duct may be taken. Similarly for six cables in a nine way duct.

Example: From Section 12.2 current rating for a cable in a single way duct = 168 amps. It is now required to find the rating for seven similar cables pulled into a nine way duct.

From Fig. 11 the correction factor for nine cables in a nine way duct = 0.57. For seven loaded cables in a nine way duct the appropriate factor from Table IX = 1.10; therefore, the required rating $= 168 \times 0.57 \times 1.10 = 105$ *amps.*

13. *Comparison of Results*

Of necessity the protective servings and armouring must be designed to suit widely varying conditions of installation and service. The maximum permissible temperature rise also must be modified for these reasons so that a direct comparison is difficult without entering into great detail. Nevertheless, the estimated ratings calculated show a very interesting comparison (Table X).

Referring to Table X, Rows 1 and 3 to 7, consider the particular case of a 19/0.083 3-core (Belted type) Paper Insulated, Lead Covered and Armoured 1 kV. cable.

It is shown that the same cable will carry

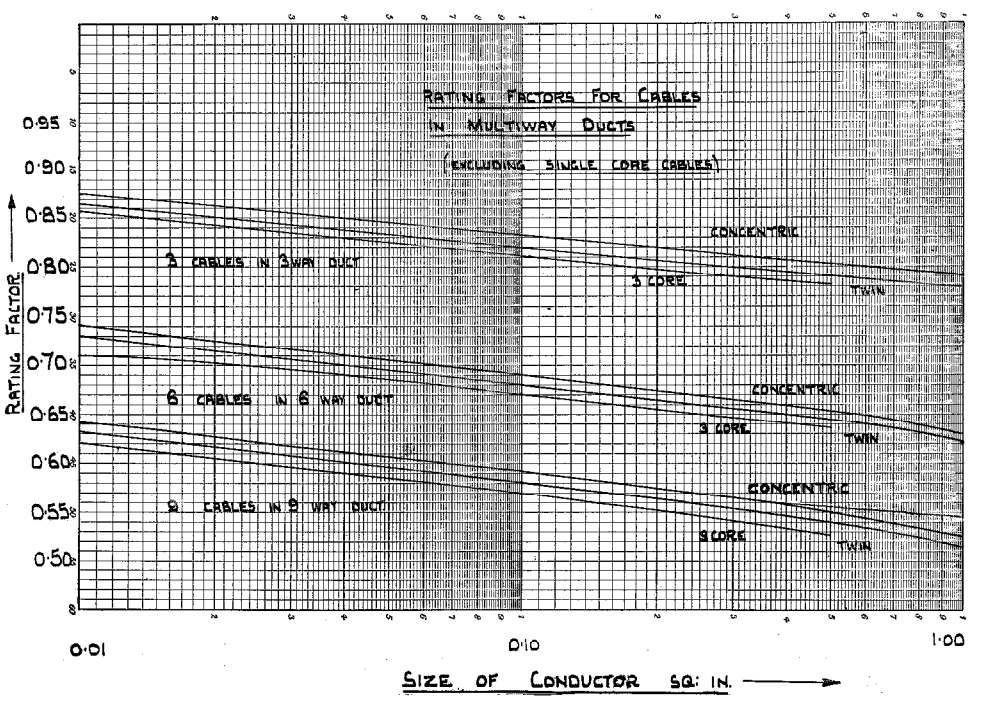


Fig. 11

TABLE X

COMPARATIVE RESULTS

No.	Cable	Voltage	Finish over Lead Sheath	Method of Installation	Thermal Resistance of Cable	External Thermal Resistance	Total Thermal Resistance	Permissible Temperature Rise °C.	Current Rating Amps.	Current Rating as % of that for a L.T. Cable Laid Direct
					Thermal ohms per cm. length					
1.	19/0.083 3-core Belted Type	1 kV.	Jute Bedding. 2 Steel Tapes. Jute Serving	Laid Direct in the Ground at a Depth of 18"	51	70	121	55	210	100%
2.	19/0.083 3-core H Type Screened	20 kV.	As 1 Above	Laid Direct in the Ground at a Depth of 36"	52	75	127	50	203	96.8%
3.	19/0.083 3-core Belted Type	1 kV.	Jute Bedding S.W.A. Left Bright	Run in Free Air	42	75	117	45	200	95.4%
4.	19/0.083 3-core Belted Type	1 kV.	As 3 Above	Run in Free Air	42	75	117	55	221	105%
5.	19/0.083 3-core Belted Type	1 kV.	As 3 Above	Pulled into Single Way Duct Laid Direct in the Ground	42	158	200	55	168	80%
6.	19/0.083 3-core Belted Type	1 kV.	As 3 Above	Pulled into 9 Way Duct Laid Direct in the Ground. (Seven Loaded Cables Only.)	42	—	—	55	105	50%
7.	19/0.083 3-core Belted Type	1 kV.	Based on Approximate Rule of 1000 Amps. per sq. inch						100	47.6%

* Note: For a comparative basis it has been assumed that the permissible temperature rise of a cable installed as detailed in Row 4 is 55° C. so that the revised rating $= 200 \times \sqrt{\frac{55}{45}} = 221$ amps.

currents in descending order of magnitude if:

1. Laid underground.
2. In free air.
3. In single way ducts.
4. In multiway ducts.
5. Based on 1000 amps. per sq. inch rule.

When L.T. cables laid direct and in air are compared on the basis of the same initial temperature, the additional 10° C. temperature drop assumed for the cable in air (Row 4) gives it a more favourable rating. According to the latest German rules, however (VDE. 0255/1937 Valid Nov. 1934), it is considered advisable that a cable in air should not be loaded to more than 75% of the estimated rating laid direct. This ruling in the German tables is applicable to cables for the range 1 to 60 kV. (inclusive).

American rating tables show many differences from the practice recognised in Great Britain.

The majority of cables installed in the U.S.A. are pulled into ducts which are buried in the

ground and the current loading is based on an ambient earth temperature of 20° C. for ductways or 40° C. ambient air temperature.

Again in the U.S.A. the thermal resistivity of solid paper insulation is taken as 700° C./Watt/cm. (see Section 6.1) and the rating tables are based on 50%, 75%, and 100% Load Factor compared with the continuous rating used in this country.

In general American rules permit higher conductor temperatures than are allowed in this country (i.e., maximum copper temperature 85° C. on voltages up to 4.5 kV. (phase to phase) and a maximum temperature of 60° C. for the highest voltage). See Table I, for limits used in Great Britain.

Table XI gives loadings which show the wide variation resulting from these different rules. Owing to the many differences it is not possible to make any generalizations from Table XI which is confined to one size and type of cable.

Reverting to Table X and comparing rows 1 and 2, there is only a small difference between the two ratings although the thickness of dielectric, conductor to lead sheath, is 0.070″ for the 1 kV. cable compared with 0.230″ for the 20 kV. 'H' type cable, which shows that for a given conductor size the variation in internal thermal resistance, total thermal resistance and current rating is small for the comparatively wide voltage range 1 kV.–20 kV.

If these two cables are compared on the basis of the same maximum temperature (70°) this difference in current loading is negligible.

Comparing Row 7 of Table X with the other results, it is obvious that the approximate rule of 1000 amperes per square inch of conductor section is no basis for the accurate or economic current rating of paper insulated cables.

This table also indicates clearly the impossibility of establishing a simple rule from which the permissible rating can be computed for the many different installation conditions which occur in practice.

14. *Additional A.C. Losses*

14.1 *Dielectric Losses*

In the case of modern cables the dielectric losses are negligible for cables up to 30 kV. and for higher voltages they may be calculated from*

$$(W) = 2\pi \times \text{frequency} \times \text{capacity (farads/cm. length)} \times (\text{voltage})^2 \times \text{power factor.} \quad \text{(XXIII)}$$

For a 132 kV. cable, these losses are quite considerable and must be allowed for (see Bibliography).

14.2 *Sheath and Armour Losses*

For multicore cables and an A.C. frequency of 50 cycles per second, these losses do not become appreciable for conductor sections of 0.5 sq. in. or less which covers all normal multicore power cable requirements.

For special cases in power stations where very large sections are essential, it is usual under these conditions to run single core cable in parallel, but for these special cases the problem of sheath and armour losses requires special consideration for each particular case in order to minimise the losses. (See Bibliography.)

15. *Grouping of Cables*

In previous examples the rating has been calculated only for individual cables. Where a number of cables are grouped in close proximity,

* The loss in watts/cm. length of cable.

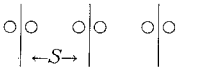
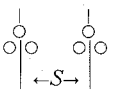
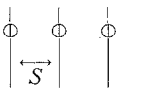
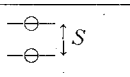
TABLE XI

(0.1 SQ. IN. 3-CORE P.I.L.C. AND ARMOURED 1 KV.—100% LOADING)

Method of Installation	Great Britain	VDE. (German)	U.S.A.
Laid direct	210 amps.	245 amps.	——
In Ducts (3 way all cables loaded)	136 amps.	141 amps.	170 amps.
In Air	200 amps.	184 amps.	185 amps.
Section	0.10 sq. in. =	70 sq. m.m. =	133.100 Circular mils. (2/0 A.W.G.)

TABLE XII

GROUPING FACTORS

Type of Cable and Method of Installation	No. of Cables or Groups of Cables Run Together	Rating Factor for Axial Spacing of—(inches)					Remarks
		Touching	6″	12″	18″	24″	
Single Core Unarmoured Cables in Pairs (up to 1.5 kV.).	2 pairs 3 pairs 4 pairs 6 pairs	0.80 0.70 0.64 0.56	0.83 0.74 0.69 0.62	0.88 0.81 0.77 0.72	0.91 0.85 0.82 0.79	0.94 0.89 0.86 0.84	 S=Spacing
Single Core Unarmoured Cables in Trefoil Formation and Touching (up to 20 kV.).	2 groups 3 groups 4 groups 6 groups	0.75 0.63 0.56 0.48	0.78 0.66 0.60 0.52	0.83 0.73 0.67 0.60	0.87 0.78 0.73 0.68	0.90 0.82 0.78 0.74	 S=Spacing
Twin and Multicore Cables in Horizontal Formation (up to 20 kV.).	2 cables 3 cables 4 cables 6 cables	0.81 0.71 0.65 0.58	0.86 0.76 0.70 0.64	0.89 0.81 0.77 0.70	0.91 0.84 0.79 0.75	0.93 0.86 0.82 0.79	 S=Spacing
Twin and Multicore Cables in Tier Formation.	2 cables 3 cables 4 cables 6 cables	0.81 0.71 0.62 0.51	0.86 0.76 0.69 0.59	0.89 0.81 0.74 0.65	0.91 0.84 0.77 0.68	0.93 0.86 0.80 0.71	 S=Spacing

the rating must be reduced by the appropriate factor from Table XII.

The correction factors in Table XII have been interpolated from curves in E.R.A. Report F/T 128, but it must be noted that the report allows for spacing between EXTERNAL SURFACES OF CABLES while these factors have been corrected to ALLOW for SPACING BETWEEN CENTRES of cables, or trefoil groups, since this is the spacing usually referred to in practice.

On p. 161, *I.E.E. Journal*, May 1923, a mathematical solution is given. The table of correction factors may be used for all normal methods of grouping.

Of necessity, certain sections of this article, such as those on sheath losses and the grouping of cables, are very brief. A bibliography is, therefore, included giving reference to papers which provide very detailed information on these points.

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17. *Acknowledgment*

The author wishes to take this opportunity of expressing his indebtedness to Dr. K. Konstantinowsky for his very helpful criticisms and advice.

Appendix 1

Cables in Ducts

Section 12.2 outlines the calculations necessary to compute the rating for a cable pulled into a single way duct, and in particular formulae are quoted to enable the Radiation, Conduction and Convection losses to be obtained, so that the thermal resistance between the cable surface and the inside of the duct wall may be evaluated.

Fig. 10 has been constructed so that this value may be obtained quickly, thus obviating the possibility of an arithmetical error when using the formulae quoted.

The Standard D.C. Bias System as Applied to the Control of Water Heater Loads in New Zealand

By G. H. J. UNDERWOOD

Standard Telephones and Cables Pty. Limited, Wellington, New Zealand

Introduction

IN an article published in October, 1938,* the D.C. Bias System for effecting control of a number of services over low tension alternating current networks, then newly developed by Standard Telephones and Cables, Ltd., London, was described together with some details of a few of the early installations. Since that date and up to the outbreak of war, many successful installations, mainly for the control of street lighting were completed in Great Britain, including the control of the first trunk road lighting system (Bath Road), installed in October, 1938, under the scheme of Government assistance. Certain of these pre-war installations, somewhat modified, and many effected thereafter have proved useful in the towns, factories, shipyards and steelworks of Great Britain for giving air-raid signals, last minute warnings and control of permitted lighting, thus enabling essential war work to be continued with the least possible interruption.

Standard Telephones and Cables Pty. Limited, Wellington, in collaboration with engineers of supply authorities, have developed and supplied equipment utilizing exactly the same principles for the control of almost ten percent of the domestic water heating appliances in the Dominion.

The equipment used for introducing the direct current from a six-volt car battery into the alternating current network, as designed by Standard Telephones and Cables, London, essentially for its home market (where substation capacities are rarely lower than 250 kva and often as high as 4,000 kva), was not suited economically to conditions prevailing in the rural districts of New Zealand. Accordingly, it was necessary to produce equipment designs more appropriate to the lower capacity substations.

For the receiving unit in the consumer's premises the original London design for street-lighting control was found suitable with minor changes. The modified design has been adopted by S. T. & C., London, for post-war application to the control of domestic water heating loads.

The application in New Zealand of the D.C. Bias System to the control of water heating loads, effected in a relatively short time, has been surprisingly encouraging. In order that the reasons for this development may be better appreciated, a few notes are given on the use of electricity in the Dominion.

Electricity in New Zealand

The Dominion of New Zealand is par excellence a country where the consumer of electricity obtains a first-class all round service at a very low charge. Explanation would involve a complicated dissertation extraneous to the purpose of this article.

The Dominion is generously endowed with water power resources and hydro-electric generation thus is the chief means of supply. The rivers are fed mainly from the snow level in the numerous mountain ranges so that in summer, when the snow melts, there is an abundance of running water from the high altitudes and conservation areas are replenished.

In New Zealand it is the rule rather than the exception for the most modest home to be "all electric," including the heating of water in storage tanks for domestic purposes. In the early days, when the technique of hot water storage was not appreciated as it is today, many supply authorities provided a 24-hour unrestricted service which admirably suited their local load factor. Today, however, with expansion of secondary industry and the greatly increased number of consumers, the water heating load is an embarrassment and most of the electricity undertakings restrict the service rather than alter the tariff charges.

* "The Remote Control Over Power Mains of Street Lighting, Water Heating and Other Services," by E. M. S. McWhirter, *El. Com.*, Vol. 17, No. 2, 1938.

Generation

Generally speaking, the electrical supply industry has two main branches—generation and distribution. Generation is almost entirely the function of the Government acting through the Public Works Department which furnishes a bulk supply to the distributing stations. There are also certain selected distributing authorities who are under agreement with the Government to generate power should the Public Works Department consider this necessary.

Since two islands, the North Island and the South Island, constitute the Dominion of New Zealand, there are two separate electric power systems. Each system contains large interconnected hydro-electric stations. Below are shown summarized capacities of the main and standby plants, together with the maximum load for the year 1940.

Main Plant

No.	Type	kw
34	Water	298,129
1	Steam	750
6	Oil	537
41		299,416

Standby

No.	Type	kw
15	Water	3,688
10	Steam	77,150
3	Gas	1,101
23	Oil	18,600
51		100,539

The maximum load was:

North Island System	218,300 kw
South Island System	76,100 kw
Total	294,400 kw

Distribution

The total population at 31st March, 1939, within the licensed area of the local authorities, the retailers of electrical energy, was 1,466,370 or ninety percent of the total population of the Dominion; the consumers were 390,505. The connected load, excluding bulk supply, aggregated 1,774,438 kilowatts. Approximately 88 percent of the population concerned is served by distributing authorities, the balance being in districts supplied directly from generating stations. Distributing authorities serve 87 percent of the total consumers with a connected load representing ninety percent of the total.

The total number of water heaters in New Zealand at the 31st March, 1939, was 90,296, the consumption being 73,760 kw and representing a percentage consumption of 23.12. The lowest ratio curiously enough is at Invercargill, the most southerly point of the South Island and the coldest point in the Dominion, with 0.89 percent. The highest occurs in the Bay of Plenty, northwest of the North Island, where the ratio is 61.63 percent. Considering the number of other alternatives for water heating such as gas, coal, chip fires, etc., the number of electric water heaters per capita is extremely high.*

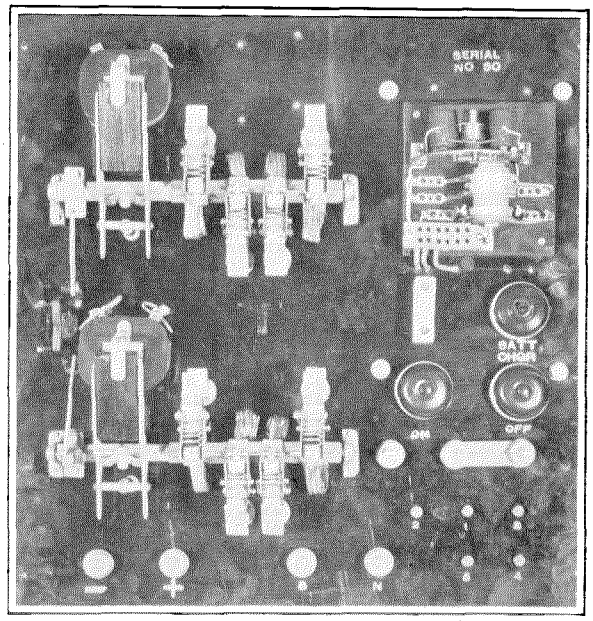


Fig. 1—Larger Type of Biasing Panel.

There is a very marked population difference in the areas served by the 82 electric generating stations owned by the Electric Power Boards, Borough Councils, Town Boards, City Councils, or County Councils. On the basis of population per area supplied, two distribute to under 1,000; nine to 1,000–2,500; seven to 2,500–5,000; six to 5,000–10,000; eighteen to 10,000–20,000; ten to 20,000–30,000; four to 30,000–50,000 and five to 50,000 and over. Here the difference in the composition of the population must be considered inasmuch as New Zealand is largely agricultural and pastoral. In the primary producing districts the consumer density per transformer is sometimes as low as three; but, according to law, these consumers, especially in the dairy produce industry, must be provided with water heating

* According to a recently published statement the units sold by many of the larger undertakings for water heating are over fifty percent of the total sold, a fact which is causing some anxiety among New Zealand Power Board engineers.

service of some kind for milking plant cleansing purposes.

Tariffs, of course, vary throughout the several supply areas. In general the water heating service is switched on for a predetermined number of hours per diem and an annual or monthly flat charge is made based on the wattage. Some idea of the low cost of electricity to the domestic consumer can be gained by quoting the tariffs for the capital of the Dominion, Wellington. Domestic lighting, including heating and cooking, costs 3d per unit on a scale of units from 8 to 42 depending on the number of lighting points per dwelling. The balance is at ½d per unit. Water heating is restricted to nine hours per diem at 6d per 100 watts per month. The average total cost of electricity for a household of four persons using neither gas, coal, nor wood, living in a three bedroomed house, is approximately 5/6d (five shillings and sixpence) per week.

Some supply authorities give continuous water heating service without any means of control, but the majority switch off the water heaters for some period or periods during the 24 hours. Such control as existed before the advent in New Zealand of the "Standard" D.C. Bias System was by pilot wire or time switch. The former necessitates a considerable wire mileage involving high capital cost, although the control relay is comparatively low in price. Time switches are high in initial cost and involve a maintenance charge of the order of £1 per clock per annum.

General

The problem of control of "off peak" loads is by no means an easy one to solve; the governing

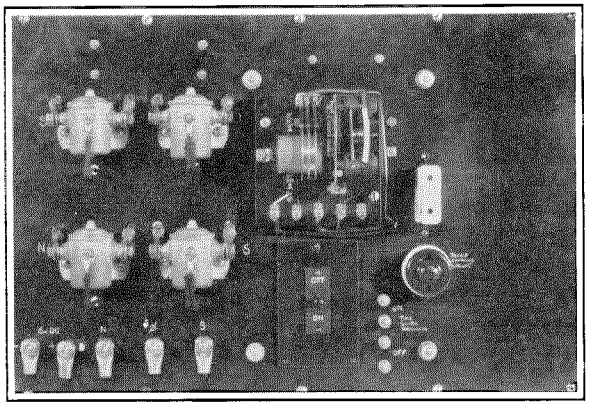


Fig. 2—Smaller Type of Biasing Panel.

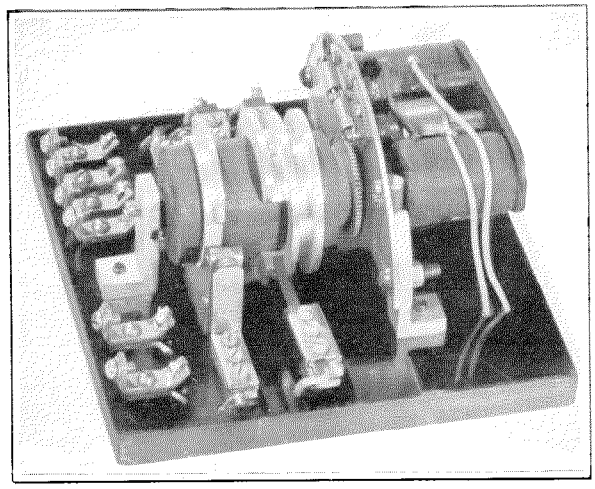


Fig. 3—Impulse Sending Device.

factor is largely economic. In the large cities, where the consumer density per L.T. transformer is high, the capital cost to the consumer of D.C. Bias control is low, whereas in the country areas the reverse is the case.

Admittedly, the ideal method of control is by means of a signal or series of signals superimposed on the H.T. network and such a system has more attraction for the small country authorities than for the densely populated main centers. A rural supply authority may cover a vast territory of several 1,000 square miles with only two or three small towns within its boundaries. While the load in the towns is comparatively simple to control, the control of the load in the outer districts (by far the greater and more important) presents a very difficult problem.

The pilot wire system is not attractive because of the high cost of wire. Time switches are out of the question because of the large amount of traveling time involved in maintenance. Hence there remains the superimposed method. Ripple control and the like represent the ideal from a theoretical point of view, but few country supply authorities can afford the initial cost, while the technical problems of such systems will often be peculiar to a single installation. The D.C. Bias System offers better prospects even though a biasing panel per L.T. transformer is essential. Most of the L.T. transformers in such scattered districts are fed through small distribution transformers up to 30 kva capacity, and to meet such cases Standard Telephones and Cables Proprie-

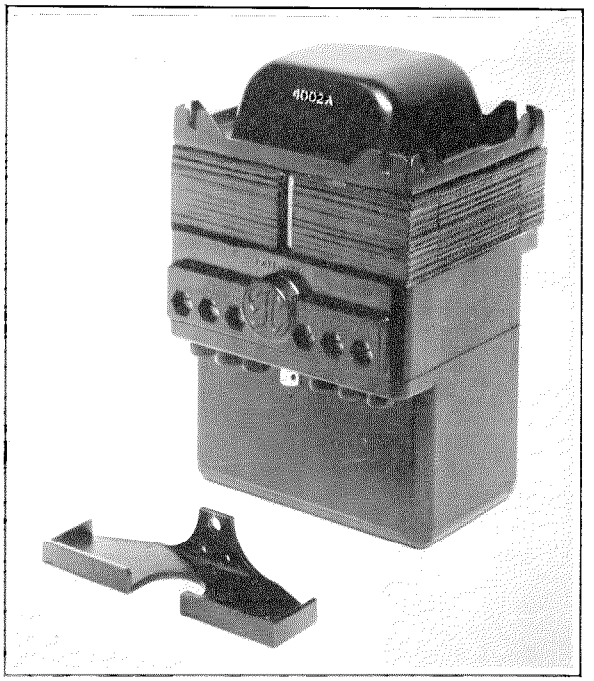


Fig. 4—4002-A Control Unit.

tary Limited, New Zealand, with the assistance of the Bay of Plenty Electric Power Board, designed a miniature type of biasing panel similar in principle to the standard type. The 30 kva biasing panel uses suitably modified automobile starting solenoids as contactors and the cost is thus reduced to about £5.0.0 per consumer where the number of consumers per L.T. transformer is as low as seven.

In the present stage of progress towards the ideal, that is, to full control of load from the main sub-station, a time switch is associated with each biasing panel to eliminate the known uneconomic load peaks. The ultimate goal will be the addition of the D.C. Biasing System over the H.T. Network; in the interim the simple two-signal system to be described is but a compromise.

In the towns and cities where the water-heating consumer density is as high as 200 per L.T. transformer, the larger, standard type of biasing panel is used and in such cases the capital cost

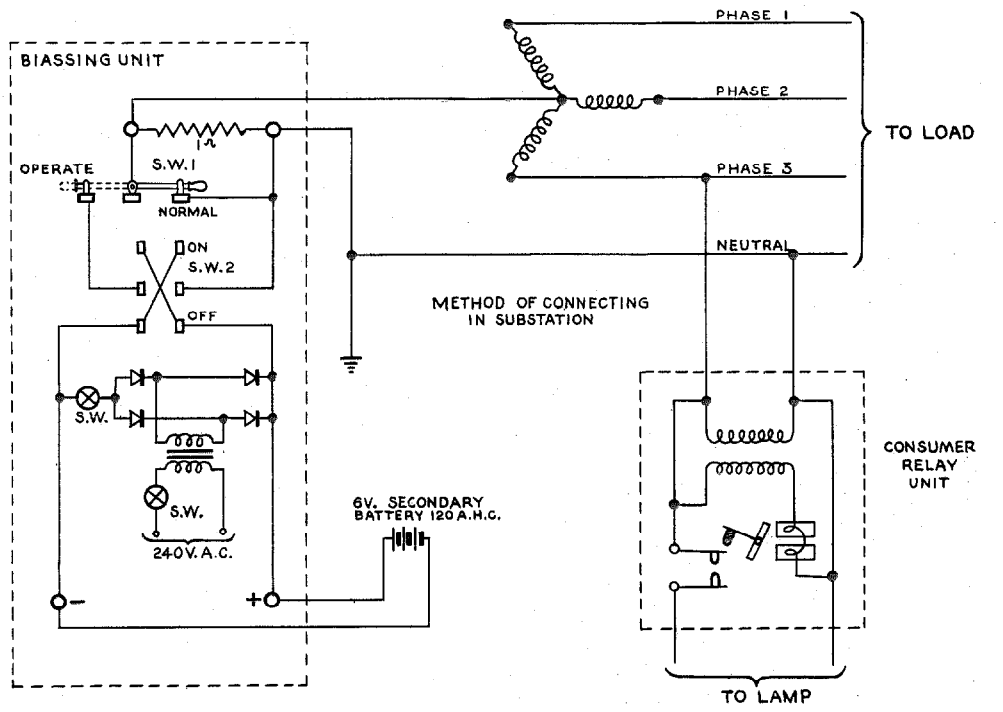


Fig. 5—Simple Diagram of Biasing Panel Principle.

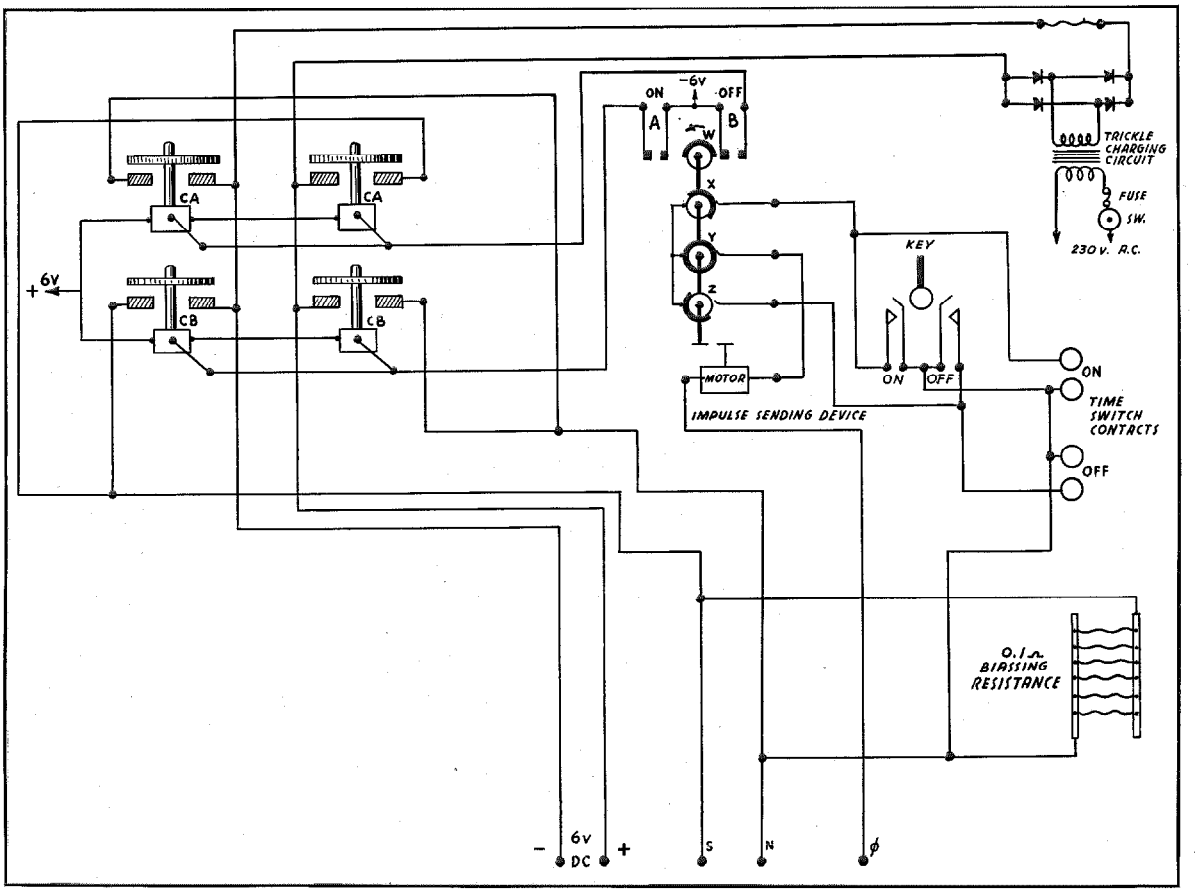


Fig. 6—Schematic for 30 kva Biasing Panel and Impulse Sending Device.

per consumer is as low as £3.0.0. As in the case of the 30 kva panel, a time switch is sometimes associated with each biasing panel until such time as the H.T. Biasing System is installed. Some supply authorities link their substation biasing panel to a main control point by pilot wire and are thereby able to control the "off" peak load at any time during the 24 hours.

Equipment

(*A*) Biasing Panels

(1) *Large Type for Substations 150 kva and Larger*

Two types are in use in the Dominion: one designed and produced by Standard Telephones and Cables Limited, London (see Fig. 1 of article previously cited); the other designed by Standard Telephones and Cables Proprietary Limited, Sydney, Australia, and produced by Standard Telephones and Cables Proprietary Limited, Wellington, New Zealand (Fig. 1). The latter, because of its simplification in that the interlocking is solely mechanical, is lower in cost and thus more widely used.

(2) *Small Type for Transformers up to 30 kva*

This unit (Fig. 2) mounts on a panel 20″×15″. The contactors are automobile starting solenoids.

In Fig. 2 the manual control key is shown as a lever type telephone key. This has now been replaced by push button switches.

(*B*) Impulse Sending Device

This device, designed by the Wellington City Council Electricity Department, is produced by Standard Telephones and Cables Proprietary Limited, New Zealand, for the purpose of maintaining the closure of the biasing signal contactors for two or three seconds. It is used with both types of biasing panel, in connection with time switches, whose contacts on closing do not

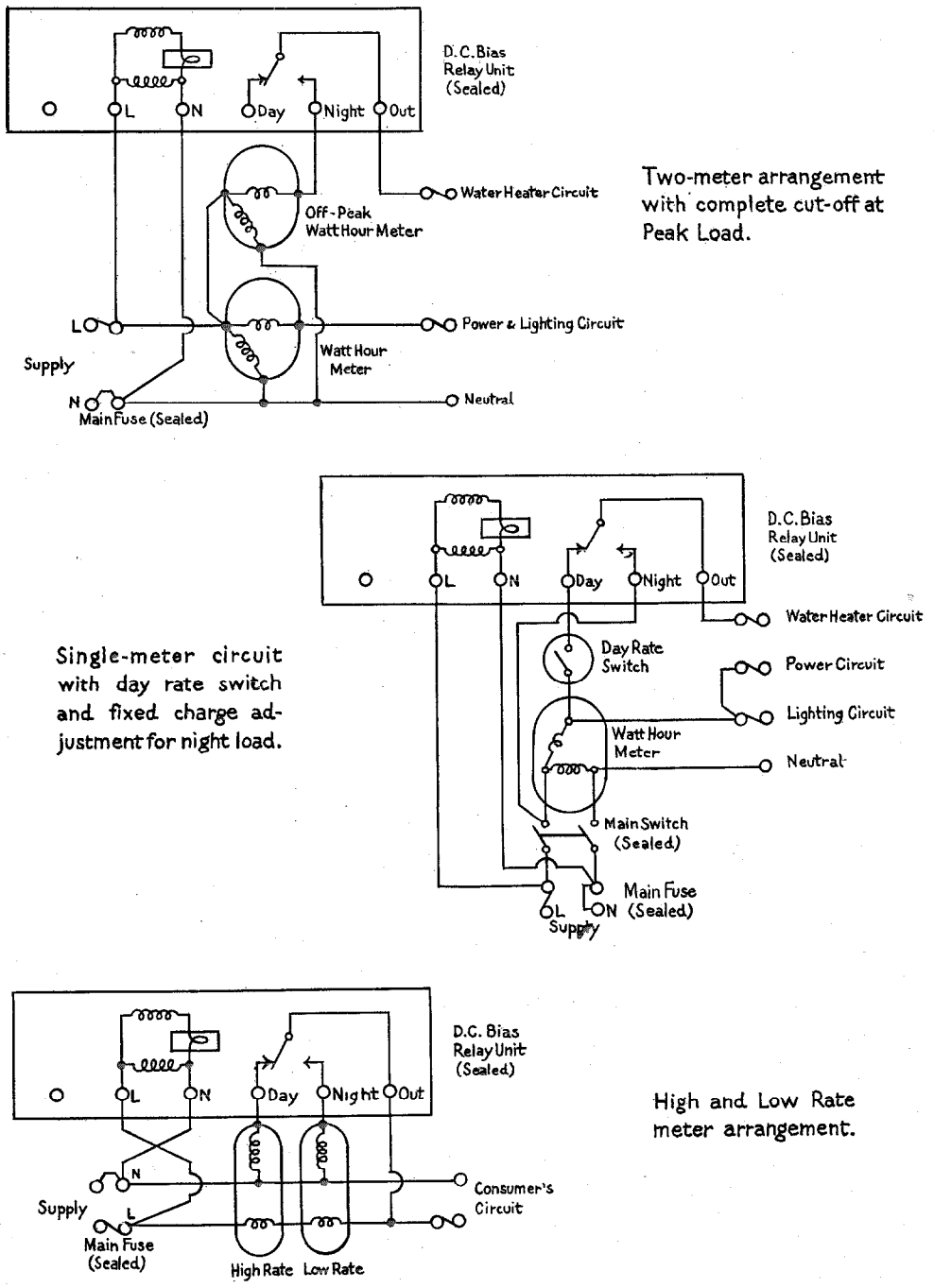


Fig. 7—Typical Switching Circuits for Off-Peak Load Control.

open for several minutes, or by direct pilot wire. A vibrating clockmotor is coupled through suitable gearing to a drum on which are mounted the control cams for the motor circuit and a cam for closing the "On" or "Off" contactor circuit. The impulse sending device is illustrated in Fig. 3.

(*C*) Relay or Consumer Unit

The 4001-C lighting unit, with minor additions, was used in New Zealand on the introduction of the D.C. Bias System in 1939 for the control of water heaters.

In the case of a large customer it was necessary to provide for a water heating service in which the consumer could obtain supply during the restricted hours. Such service was switched on by the consumer and was metered through the "Off" contacts of the relay. The 4002-A unit was designed for this purpose; it has six terminal outlets as against the four in 4001-C unit. The 4002-A unit, now standard for New Zealand, is shown in Fig. 4.

Circuit Operation

(*A*) Larger Type of Biasing Panels

The circuit arrangement of the larger type of biasing panel for substations up to 150 kva capacity is the same as that used in the London design, shown in Fig. 8 of the article previously mentioned. For clearness a simplified circuit diagram is shown here in Fig. 5.

Normally, the 0.1-ohm resistance is short circuited. The "On" signal, whether from an impulse sending device, time switch, pilot wire control, or manual control, connects the biasing battery (6 v) with the appropriate polarity between the star point of the L.T. transformer and the neutral. At the moment of such connection, and for a period of two to three seconds afterwards, the short circuit is removed from the 0.1-ohm resistance. The biasing voltage is thus superimposed on the L.T. mains between phase and neutral, but this has no effect on any phase-to-phase load or upon any equipment connected between phase and neutral.

For the "Off" signal, reversal of polarity is obtained by using another set of contactors. Provision is made for an interlock so that only one set of signaling contactors can be operated at a time.

(*B*) Smaller Type of Biasing Panel (Up to 30 kva)

As with the larger type of panel the principle of operation is the same except that the signaling contactors are operated from the 6-v battery. The safeguarding interlock is obtained by the utilization of cams "A" or "B" of the impulse sending device.

Fig. 6 shows the schematic for both the 30-kva panel and the impulse sending device.

Consumer Relay Units

The circuit arrangement of the 4002-A unit with typical switching circuits is shown in Fig. 7. The middle diagram gives the particular arrangement responsible for the redesign of the 4001-C unit. The simple two-signal system (positive to switch "On" and negative to switch "Off") is received on a polarized relay with which is associated an A.C. choke to prevent the alternating current affecting the D.C. relay. The contacts of the relay are designed to carry 15 amperes.

Conclusion

The D.C. Bias System has provided a means of control of the water heating load to the entire satisfaction of some twelve supply authorities in New Zealand where nearly 100 biasing panels and 9,500 consumer units of the types described are in operation. This development has taken place in the short space of two years.

The author desires to express his thanks to Mr. R. S. Maunder, of the Wellington City Council, for his assistance and to state that the statistical information is taken from the official Year Book of the Government of New Zealand (1940) and the Local Authorities Handbook (1938–1939).

Conversion of Brazilian Capital to Full Rotary Automatic Operation

By W. HIRSCH
Chief Engineer, Brazilian Telephone Company
and
E. A. BRANDER
Technical Telephone Superintendent, Standard Electrica S. A., Rio de Janeiro, Brazil

OCTOBER 19, 1940, marked an important consummation in the telephone history of the Capital of Brazil, the conversion of the Rio de Janeiro telephone system to full automatic service as a result of the replacement of the last manual exchange "25" by 7A.2 Rotary automatic equipment without change of prefix. With 100 percent full automatic operation, cumbersome call indicators and other temporary equipment, necessary for automatic-manual interworking, were eliminated. This final step represents the completion of a conversion period initiated on January 1, 1930, when the first automatic central office, unit "3" with 6,000 lines of 7A.1 Rotary equipment, was opened to traffic.

Simultaneously with the engineering of the conversion program, a substantial expansion of telephone facilities was necessary. Consequently, the program, involving both central office and outside plant facilities, required continuous enlargement. As a result, the present automatic plant in Rio de Janeiro probably is one of the most modern in existence.

The greater part of the central office equipment is of the 7A.2 Rotary type, the remainder being of the 7A.1 type. Growth of subscriber lines during the conversion period is shown in Fig. 1.

Since 1931 and up to 1940, facilities adequate for meeting subscribers' demands have been available and no delay has been experienced in executing new service orders. On occasion, however, new central office installations barely kept pace with demand, and one or more of the existing exchanges were filled to capacity. Fig. 2 indicates the combined terminal capacity of all exchanges together with types of equipment for the years 1929 to 1941.

Service offered to the public showed continuous improvement during this period inasmuch as the development of service and traffic observation facilities permitted increasingly exact studies of the local (City) requirements. Direct reading traffic recorders of the Rotary type have been installed in almost all the exchanges. These permit the direct recording of traffic intensities in Equated Busy Hour Calls (EBHC) on a small number of meters. Involved calculations consequently are avoided. Plans thus could be formulated for central office layouts and facilities to meet these requirements. The existing plant, in fact, admirably satisfies the local conditions as regards calling rates, switch and register quantities, and special service facilities.

For interworking between units located in the same building, the 3-wire method is employed. Trunks between distant exchanges comprise 2-wire circuits.

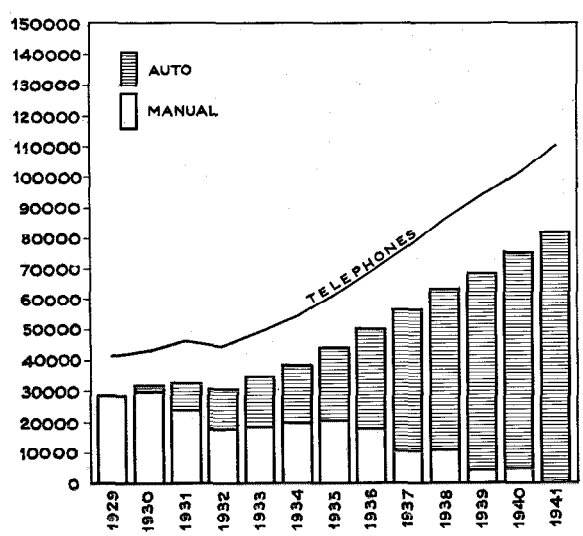


Fig. 1—Growth of Subscriber Lines During the Conversion Period.

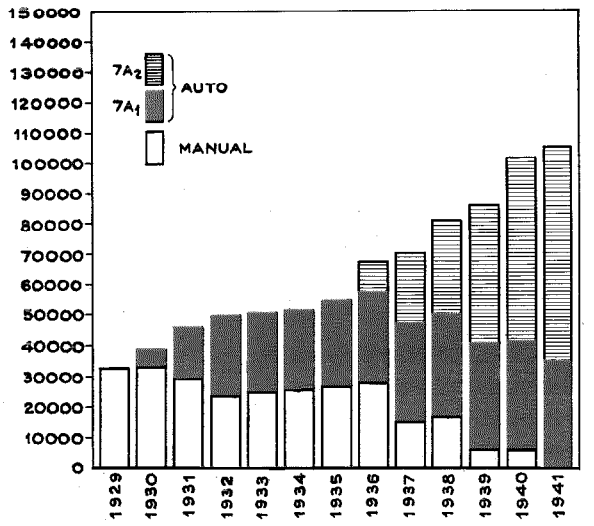


Fig. 2—Combined Terminal Capacity of All Exchanges.

Trunk cables between the automatic exchanges located in remote districts of the city, the loop resistance of which is greater than 800 ohms, are loaded. The H-135 loading system (1830 meters spacing) is, in general, utilized.

The general trunking plan of the Rio de Janeiro city network is shown in Fig. 3. Table I, complementary to this trunking plan, indicates the trunking routes, distances in kilometers, loop resistances and whether trunk cables are loaded or non-loaded.

The rural zones are directly connected to the city network by trunks (refer to directions "A" to "G" of trunking Table I).

For the present, the rural zones are served by magneto switchboards. Projects for automatization have been under consideration since 1939, but their execution has been delayed due to the situation created by the World War.

The rural zones are divided into two groups:

(*A*) Those in the upward district: Jacarepaguá, Marechal Hermes, Bangú, Campo Grande and Santa Cruz. These rural zones are connected by the same main trunk route to Satellite "29-8."

(*B*) The two rural zones in the Bay of Guanabara: Ilha do Governador and Ilha de Paquetá. The trunks for these two zones pass through submarine cables to exchange "30."

A city subscriber wishing to call one of the rural districts dials "00" and requests the Assistance operator to establish the connection to the wanted zone. Normally, this is accomplished without delay by the operator who, by means of the Assistance A-board keyset, sets up a connection involving the jacks to the toll switching trunks. This is easily accomplished inasmuch as the Toll Board and Assistance A-board are located in the same building. The connection is then established up to the final selector in Satellite "29-8" or exchange "30," whereupon one of the trunks to the zone dialed is called automatically. It is interesting in this connection to note that only number-to-number calls are accepted to the rural zones; the "00" operator writes out a ticket for each call, using a ticket form which is simpler than the ordinary toll ticket.

Distances between the city network and the rural zones are considerable and this is one of the reasons for using toll switching trunks to complete calls.

These trunks are of No. 19 gauge and loaded H-135. Beyond Satellite "29-8," the cables are of the same gauge and have the same loading. Actually the cable plant is extended up to Bangú, and beyond it is continued by means of open-wire construction having lower transmission losses than cables. The traffic to and from these rural zones is increasing from year to year and within a short time it will become necessary to extend cable routes from Bangú to Campo Grande and Santa Cruz. This will necessitate the installation of voice repeaters in Bangú with facilities for through dialing and signaling.

Calls originating from rural districts and directed to the city network are handled by the operator dialing directly from the magneto boards into the city network over rural line circuits in Satellite "29-8" and exchange "30."

Great relief was felt after the cut-over, on October 19, 1940, of the 8,000-line 7A.2 exchange "25," when subscribers benefited from the full automatic service doing away with the long delays resulting from the call-indicator operation in the manual exchanges. The full automatic service assures an unimpeded traffic flow in all directions.

During the conversion period, two significant service changes were introduced. In 1934, 6-digit dialing replaced 5-digit dialing and, in 1940, shortly before the inauguration of office "25," measured rates were applied to business lines.

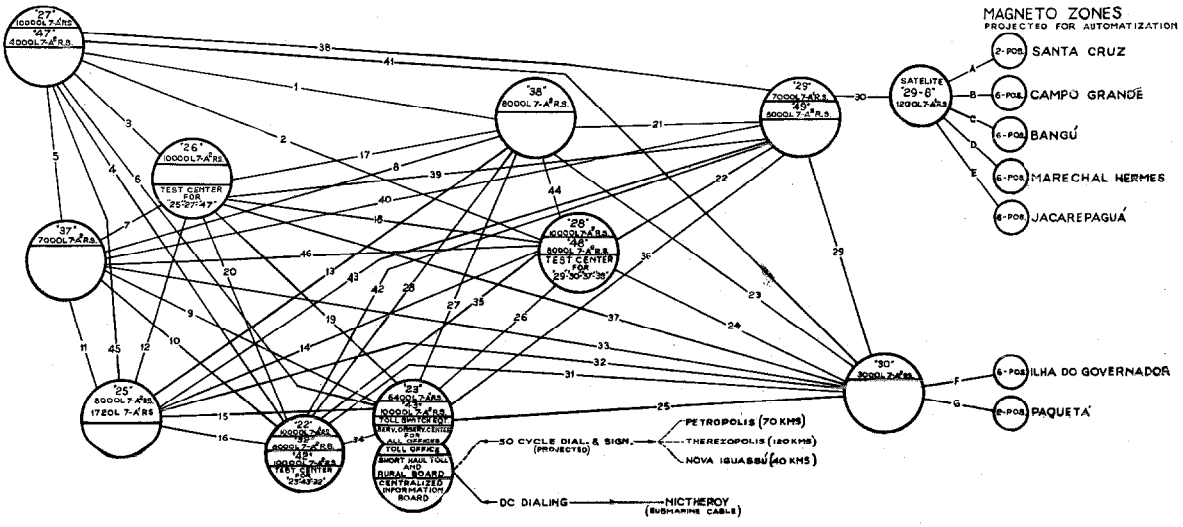


Fig. 3—General Trunking Plan of the Rio de Janeiro City Network.

Thanks to the careful advance preparation, including the provision of equipment such as message registers, photographic paraphernalia, etc., this change in rate structure was effected smoothly.

Prior to the application of the measured service to business lines, the average originating traffic per line per busy hour for the whole area was 2.8 calls with a holding time of 82 seconds. After the introduction of the measured service for business lines, which represent 50 percent of the total lines, the average originating traffic per line (business and commercial combined) per busy hour dropped from 2.8 to 2.5 calls and the holding time from 82 to 80 seconds.

Expressed in EBHC (Equated Busy Hour Calls), the average originating traffic figure of 1.91 EBHC, recorded before the abolition of the flat rate service, decreased to 1.67 EBHC after measured rate service was applied to business lines.

The lower traffic figure permits a substantial saving in switching equipment. It especially applies to exchanges located in business centers, such as office "23/43," where 84 percent of the lines connected are business subscribers.

Prior to the change to 6-digit dialing, numerous studies pertaining to the merits of straight 6-digit working, as compared with an office prefix followed by 4 digits, were made. Experience seems to justify the 6-digit choice; it is simple and was introduced without interference with the normal exchange service. At the time (1934), only register modifications were necessary to provide for the functioning of a maximum of eight 20,000-line central offices; no additional selector stages were required. In 1938, however, auxiliary selectors were introduced to provide facilities for the interworking of sixteen central offices of 20,000 lines each. The numbering capacity of the area will thus total 320,000 lines.

The area at present consists of eight central offices of 20,000 lines capacity and one satellite. Three new central offices will be installed during 1943. Table II shows the prefixes assigned to the various exchanges, the number of lines installed and ordered and the type of equipment supplied.

In the course of the development a satisfactory degree of standardization was achieved in automatic equipment and buildings. The "25" central office building is shown in Fig. 4; Figs. 5, 6 and 7 illustrate the Rotary automatic equipment installed in this exchange.

The "25" central office building is typical of the design adopted for 20,000-line automatic installations. It is of re-enforced concrete with brick walls and steel-frame windows affording protection against fire. The ground floor has ample ceiling height for the Main Distributing Frame, common to two 10,000-line units and consisting of 50 verticals, each with 404 pro-

tectors. This floor also accommodates Message Register Racks equipped with the plug-in type message registers for commercial subscribers or with equivalent plug-in type resistances for residential subscribers. The Miscellaneous Relay Racks and one No. 2012 Local Wire Chief Desk are also located on this floor.

Adjacent to this is the battery room with two 26-cell Chloride Rosette-type batteries, each with an initial capacity of 1,500 A.H. and an ultimate of 3,400 A.H. at a 10-hour discharge rate. Located directly above, on a Mezzanine floor which divides the ceiling height in two, is the machine room accommodating the 220-volt, 50-cycle a.c. mains supply control board, and the 48-volt d.c. power control board for manual operation, including automatic voltage regulators consisting of a Solenoid-type voltage relay, motor-driven field rheostat and a Telechron motor interrupter to maintain the voltage on the busbars within the prescribed limits of 49.5 $\pm$ 0.25 volts. One 60-amp, Selenium-type rectifier is also lined

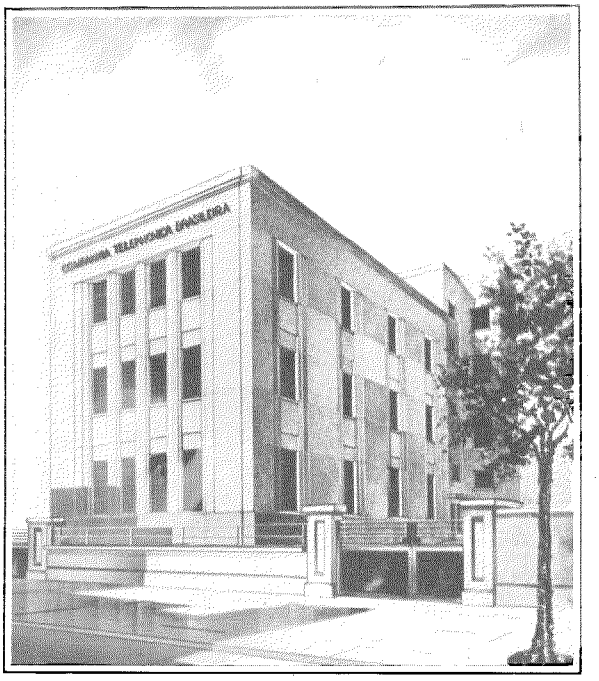


Fig. 4—The "25" Central Office Building.

TABLE I

Direction	Exchange to Exchange	Distance in Kilometers	Loop Resistance	Trunk Cables Loaded and Non-loaded	Direction	Exchange to Exchange	Distance in Kilometers	Loop Resistance	Trunk Cables Loaded and Non-loaded
1	27/47–38	20.2	1160	L	31	22/42–30	11.6	680	L
2	27/47–28/48	17.0	1000	L	32	25–30	19.2	1120	L
3	27/47–26	4.2	240	NL	33	37–30	26.0	1500	L
4	27/47–22/42	12.0	710	NL	34	22/42–23/43	1.0	60	NL
5	27/47–37	6.0	340	NL	35	22/42–28/48	5.0	290	NL
6	27/47–23/43	13.0	770	NL	36	23/43–29	14.0	830	L
7	37–26	5.1	300	NL	37	26–30	23.0	1340	L
8	37–38	16.0	950	L	38	27/47–29	25.3	1460	L
9	37–23/43	11.8	700	NL	39	26–29	19.4	1150	L
10	37–22/42	9.5	550	NL	40	37–29	22.4	1280	L
11	37–25	7.0	410	NL	41	27/47–30	28.3	1475	L
12	26–25	4.2	240	NL	42	22/42–29	13.0	770	NL
13	25–35	11.3	660	NL	43	25–29	15.4	910	L
14	25–28/48	9.2	540	NL	44	38–28/48	2.7	160	NL
15	25–23/43	5.1	300	NL	45	27/47–25	8.4	490	NL
16	25–22/42	3.7	220	NL	46	37–28/48	14.3	840	L
17	26–38	16.7	980	L					
18	26–28/48	11.1	650	NL					
19	26–23/43	7.1	430	NL					
20	26–22/42	5.1	350	NL					
21	38–29	11.5	680	NL					
22	28/48–29	8.3	490	NL	"A"	29-8–STC	39.7	1120	Partly
23	38–30	11.7	690	NL	"B"	29-8–CG	26.5	900	bare
24	28/48–30	9.1	540	NL	"C"	29-8–BNG	12.3	650	copper
25	23/43–30	14.2	840	L	"D"	29-8–MHS	5.7	362	overhead
26	23/43–28/48	6.0	350	NL	"E"	29-8–JPA	5.8	306	lines and
27	23/43–38	8.0	465	NL	"F"	30–GOV	13.0	675	submarine
28	22/42–38	8.3	480	NL	"G"	30–PE	18.7	980	cables
29	29–30	7.0	410	NL					
30	29–29-8	5.1	300	NL					

up with the Power Board for "night-floating" purposes.

Two shunt-type 350-amp charging generator sets and two ringing machines, one a.c.-driven and the other d.c.-driven, and arranged for automatic change-over in case of mains failure, are also located on this floor.

The two upper floors are reserved for two 10,000-line 7A.2 units and common interworking equipment, forming a combined unit of 20,000 lines from a trunking point of view. The common equipment includes auxiliary group selectors, the 10 levels of which provide access to 10 20,000-line central office units.

Ventilating equipment with air inlets and dust filters is provided on the roof of the building. Air is distributed by means of galvanized iron ducts through the full length of the switch and terminal rooms for the dual purpose of minimizing dust deposits and giving some relief

TABLE II

Prefix	Regular Lines		Coin Box Lines	PBX Lines		Remarks
	7A.1 Rotary System	7A.2 Rotary System		Numbered	Unnumbered	
Twin Unit "22"	9000	—	—	1000	—	In service
Twin Unit "42"	—	9000	400	600	—	" "
" " "23"	5600	—	—	800	300	" "
" " "43"	—	9000	400	600	—	" "
" " "25"	1720	7600	200	200	—	" "
" " "45"	—	—	—	—	—	Future
" " "26"	—	9800	200	—	—	In service
" " "46"	—	—	—	—	—	Future
" " "27"	9800	—	—	200	—	In service
" " "47"	—	3600	200	—	—	" "
" " "28"	—	9600	200	200	—	" "
" " "48"	—	7600	400	—	—	" "
" " "29"	6400	—	—	200	—	" "
" " "49"	—	5000	400	—	—	Cut-over 1943
" " "30"	—	2800	400	—	—	In service
" " "50"	—	—	—	—	—	Future
" " "32"	—	7800	—	200	—	Cut-over 1943
" " "52"	—	—	—	—	—	Future
" " "33"	—	—	—	—	—	"
" " "53"	—	—	—	—	—	"
" " "34"	—	—	—	—	—	"
" " "54"	—	—	—	—	—	"
" " "35"	—	—	—	—	—	"
" " "55"	—	—	—	—	—	"
" " "36"	—	—	—	—	—	"
" " "56"	—	—	—	—	—	"
" " "37"	—	7000	—	—	—	Cut-over 1943
" " "57"	—	—	—	—		Future
" " "38"	—	8000	—	—	—	In service
" " "58"	—	—	—	—	—	Future
" " "39"	—	—	—	—	—	"
" " "59"	—	—	—	—	—	"
Satellite "29-8"	1000	—	—	—	—	In service

Summary

Automatic lines equipped end 1941	106,520
" " ordered	20,000

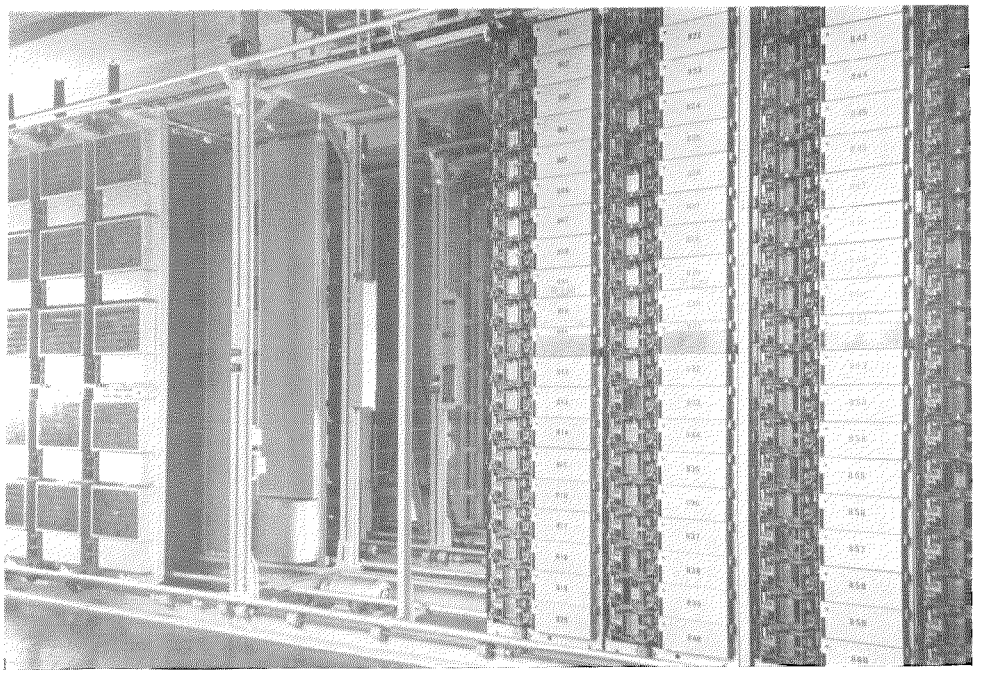


Fig. 5—Illustrating Bays of Local Registers and 1st Group Selectors and Location of Driving Motor.

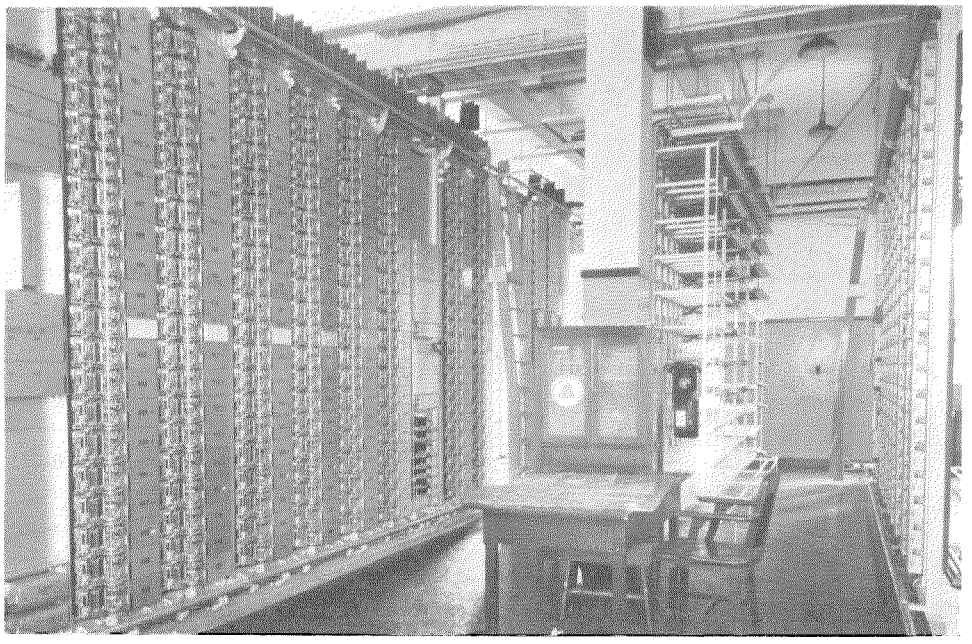


Fig. 6—Bays of 3rd Group Selectors and Circuit Distributing Frame.



Fig. 7—An End Alley, Illustrating Cable Supports, Alarm Lamp Panels and Bay Dust-Shielding.

during hot weather when heat radiated by the automatic equipment tends to elevate the room temperature. Since the air in the building is under pressure, it leaks out through the screened windows. In order to maintain the indoor relative humidity below 70 percent on rainy days, automatic controls are provided to cut off the power supply to the ventilating fan.

The growth of the city network continues. It is true that war conditions have hampered normal development during the last two years, inasmuch as the necessary telephone apparatus and equipment cannot be obtained as quickly as is desired to balance the growth of a multi-office telephone network of the importance of Rio de Janeiro. Nevertheless, the manufacture of 20,000 lines of 7A.2 Rotary System equipment for the three new exchanges, "32," "37" and "49," is in an advanced stage and it is hoped that the installations and cut-overs can be effected in the course of the coming year, 1943. In addition to these 20,000 lines under manufacture, a new 4,000-line 7A.2 exchange "45," forming the twin unit with exchange "25," and 2,000-line extensions to each of exchanges "30," "38" and "48," will be required shortly.

Addendum: For more detailed technical information on the Rio de Janeiro Local and Toll Telephone system, the reader is referred to articles previously published in *Electrical Communication*.*

* "The Development of the Rio de Janeiro Automatic Telephone Network," by W. Hirsch and E. A. Brander, *El. Com.*, Vol. 16, No. 3, 1938. "The Toll Board Installation, City of Rio de Janeiro, Federal District, Brazil," by W. Hirsch and E. A. Brander, *El. Com.*, Vol. 18, No. 2, 1939.

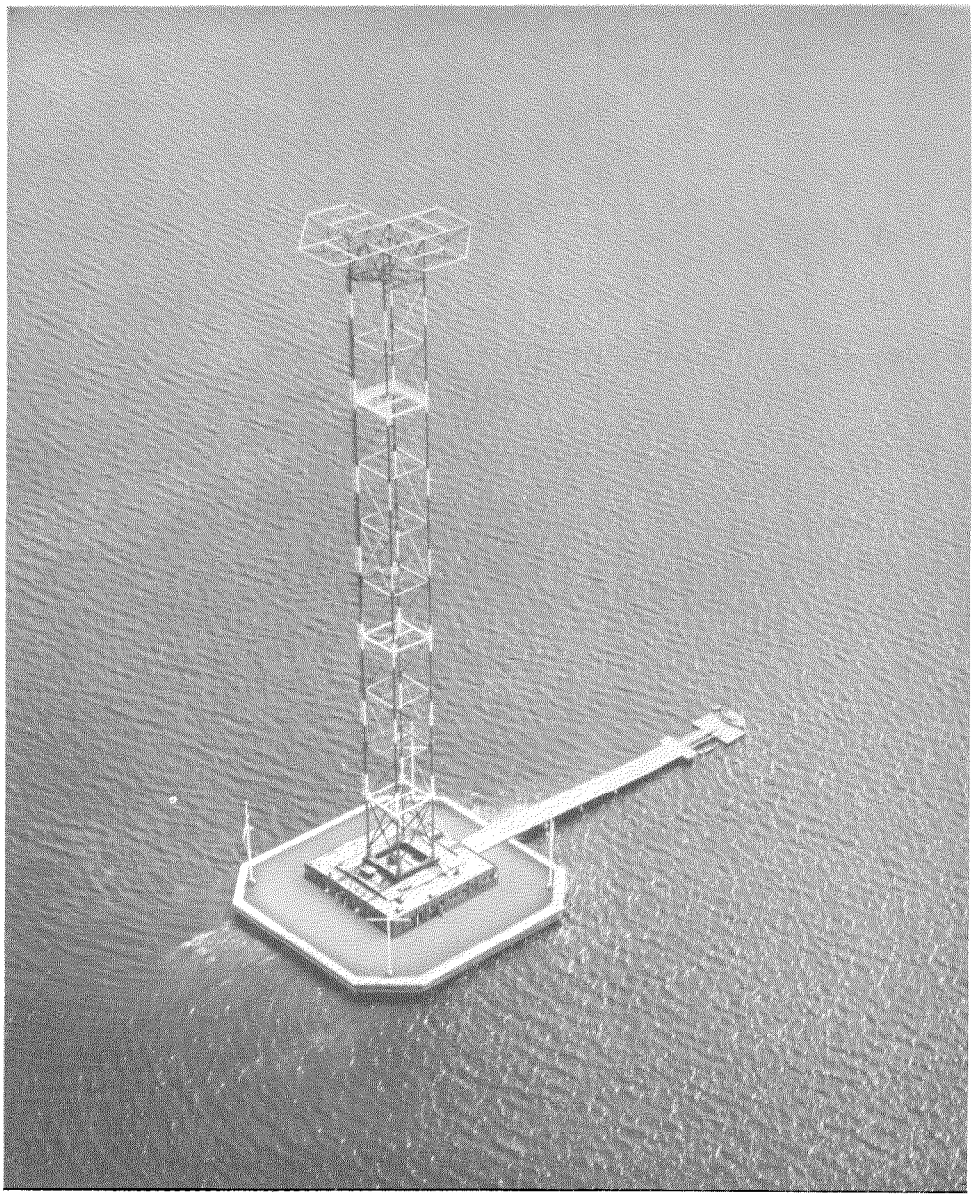


Fig. 1—WABC—Key Radio Station of the Columbia Broadcasting System as Viewed from the Air, Showing How Its Tiny Man-Made Island Is Completely Surrounded by Water and Illustrating the Unusual Top Hat Design of the Antenna.

WABC—Key Station of the Columbia Broadcasting System

A Radio Station on its Own Island

By E. M. OSTLUND

Federal Telephone and Radio Corporation, Newark, New Jersey

WHEN operation of the Columbia Broadcasting System's new 50-kilowatt key radio station for its WABC channel was inaugurated October 18, 1941, 15,000,000 listeners were provided with as clear and as loud a radio voice as they had ever heard. To assure a great increase in signal strength with no greater power, the location for WABC was moved from Wayne, New Jersey, to a small island on Long Island Sound, near New Rochelle, New York, constructed especially for the station over a few rocks that jutted out of the water at high tide. Initial transmission now occurs over salt water for at least a mile in all directions, a close approach to an engineering ideal. The old 50-kilowatt Wayne transmitter, which gave ten years of service, was discarded and an entirely new transmitter was designed and built. To meet the special problem of providing a transmitter for uninterrupted, high quality, and efficient service in a highly competitive broadcasting area, CBS chose the Federal Telegraph Company* to design and build the new equipment.

Less than two months after operation at the new location was begun, war was declared and WABC went on a 24-hour-a-day basis. Until December 7, 1941, WABC had been operating 19½ hours a day, providing a short daily period for readjustment and repairs with the station off the air. However, such layup periods are not possible now, and, barring actual breakdown, the station has been enlisted for continuous duty for the duration. Complete breakdown, which would necessitate shutting down operation for any period of time, is not anticipated since numerous safeguards, duplicate circuits, and duplicate equipment have been provided in the station. In fact, there are two complete transmitters, the main 50-kilowatt transmitter and a 5-kilowatt auxiliary transmitter. After more than a year of uninterrupted operation, the new WABC has given ample proof that CBS's and Federal's engineers have designed a station that can meet the emergency.

Improved Signal and Quality

Not only has the new station demonstrated that it can provide continuous operation under the severest conditions, but tests show that it is also radiating a clear and strong signal efficiently. Signal strength in the primary service area, estimated to have a population of 15,000,000, is two to ten times as great as it was in the same area with the old Wayne transmitter. Frequency response is essentially flat from 30 to 10,000 cycles with an overall harmonic distortion at 1,000 cycles of less than 1.5 per cent, at 7,500 cycles less than five per cent, using 95 per cent modulation. Hum level is exceedingly low, more than 60 db below 100 per cent modulation.

Efficiency of the final amplifier stage is 75 per cent, which is excellent for a transmitter of such conservative design and high fidelity. Such efficient operation may be attributed to the carefully drawn up specifications of the Columbia Broadcasting System and to Federal's long experience with high power radio equipment, as well as to the modern approach of both groups of engineers in formulating the new and specialized design of WABC. A simplified, functional layout was substituted for the recent trend of building mostly for appearance and for the now too common practice of putting into a station so many complicated and automatic devices that they defeat their purpose by becoming an operator's nightmare of servicing and maintenance. The result is a station simple to operate with very little to service.

Station Features

Efficiency and reliability in a radio station are functions of careful design and good construction. But a number of outstanding and unusual features in the new station have contributed to the

* Now the Federal Telephone and Radio Corporation.

excellent results obtained and make WABC an interesting example of modern radio station design. These features may be summarized as follows:

A. Two transmitters are provided. As stated, the main transmitter has an output of 50 kilowatts, the auxiliary transmitter 5 kilowatts. Either transmitter may be operated separately using the regular antenna system. Change-over may be made instantaneously without interruption to service. Further, the 5-kilowatt transmitter may be used to energize the final amplifier of the 50-kilowatt transmitter if its low power RF stages should become inoperative.

B. Functional, unified design is used throughout with electrical circuits simply arranged for greatest electrical efficiency instead of mechanical symmetry. No sacrifice in appearance has resulted since controls have been provided with mechanical linkages and extensions wherever the electrical and mechanical layout makes them desirable. Clean, open arrangement behind panels permits easy accessibility for maintenance.

C. Unusual "top hat" design of the antenna permits efficient radiation and proper loading without great height which would be a hazard to aircraft operating in the vicinity.

D. All audio amplifier stages are push-pull for improved quality and minimization of noise.

E. Both transmitters may be completely operated from the control console in the center of the operating room or from control panels located in front of each unit of the transmitter enclosure.

F. Two separate systems of protection are provided on enclosure doors to safeguard operators from accident. Operators can actuate electric door latches and open doors only when the high voltage is turned off and a switch shorting the high voltage supply is closed. Moreover, interlock switches attached to each door open power circuits when the doors are opened. Numerous safety devices are also employed to safeguard the equipment from failure of the cooling systems, from current surges, lightning, etc.

G. Quick acting circuit breakers are used throughout. The plate power circuit breaker is equipped with a recycling mechanism that reapplies plate power after a predetermined period has elapsed so that, if the cause of the overload has been cleared, the station may continue operating without further interruption. Only the oscillator-buffer and pre-amplifier units are fused.

H. The oscillator and RF buffer stages and the first two audio stages of both transmitters are duplicated in each case with means for quick change-over. Each is a separate unit with its own power supply.

I. The final RF stage and modulator tubes of the 50-kilowatt transmitter are water-cooled with the cooling system in duplicate and arranged for fast change-over.

J. All tubes in the 5-kilowatt transmitter are air-cooled to permit complete emergency operation without dependence upon the water cooling system.

K. All circuit elements are operated from regulated a-c supplies.

L. A spare rectifier tube is provided with the high-voltage, three-phase rectifier supplying d-c plate potential to each transmitter. Rectifiers are so arranged that the spare may be quickly inserted into the proper circuit in case of tube failure.

M. Rotating machinery is regularly used only to operate water pumps, blowers, and circuit breakers.

N. A water-cooled dummy antenna of compact design connects to either transmitter, permitting full-power operation without radiation.

O. A gasoline-driven motor generator supplies 92 kva at 460 volts to operate all equipment if the two regular power lines to the transmitters should fail. The motor generator may be operated continuously.

P. A 335-megacycle, frequency-modulated radio link is provided between the studio and transmitter station to permit operation even if two separated land and underwater telephone cable links should be interrupted.

Description of Transmitters

Fundamentally, the 50-kilowatt transmitter consists of a crystal-controlled oscillator followed by four stages of radio frequency amplification (Fig. 2). The last stage is plate-modulated by a high level, class AB_1 modulator which is driven by three push-pull audio stages. Two federal F-124-A water-cooled triodes are connected in parallel in the final amplifier. Each tube has a plate dissipation rating of 40 kilowatts and to-

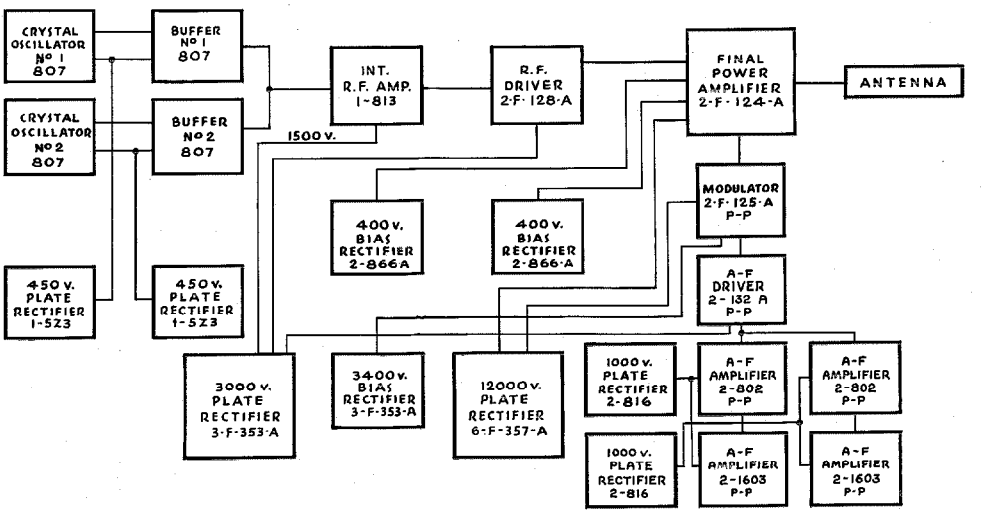


Fig. 2—Block Diagram of Circuit Elements of 50-Kilowatt Radio Broadcast Transmitter.

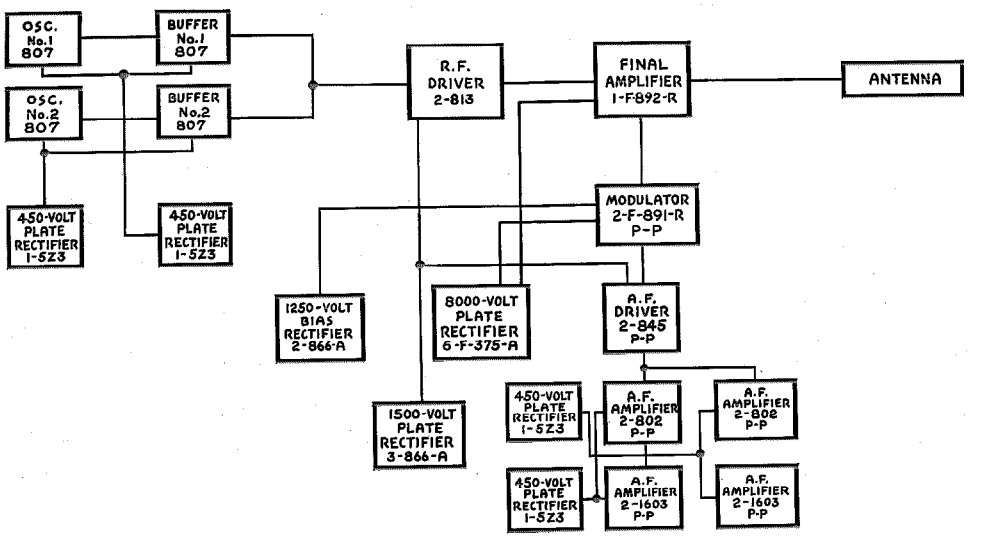


Fig. 3—Block Diagram of Circuit Elements of 5-Kilowatt Radio Broadcast Transmitter.

gether they conservatively supply a 50-kilowatt carrier signal and are capable of delivering a peak power of 200 kilowatts at 100 per cent modulation. The two Federal F-125-A modulator tubes, also water-cooled, are the same size as the final amplifier tubes but were designed specifically for audio frequency operation. The tube filaments are operated from 460-volt, three-phase alternating current which also provides power for the 12,000-volt rectified anode supply. A separate voltage regulator is provided for each tube filament and it also acts as a reactor to limit initial current when the filaments are turned on. This method of applying power to the filaments prolongs the life of the tubes. (The nominal life of the water-cooled tubes is 10,000 hours.) Six Federal F-357-A hot-cathode, mercury-vapor rectifier tubes are used in the rectifier circuit. The plate transformers for the rectifier are supplied through an induction regulator which provides either automatic or manual control of d-c plate voltage through a range of 10 per cent above to 30 per cent below the normal 12,000-volt value.

The 5-kilowatt transmitter has one stage of RF amplification less than the 50-kilowatt transmitter, but its other circuit elements are similar as will be noted from Fig. 3. One F-892-R triode is used in the final amplifier and two F-891-R tubes are employed in the modulator, all forced-air cooled. Regulated alternating current is supplied for the tube filaments and for the 8,000-volt anode supply rectifier.

Details of the 50-kilowatt exciter and final amplifier, and the 5-kilowatt modulator, are given in Figs. 4, 5, and 6.

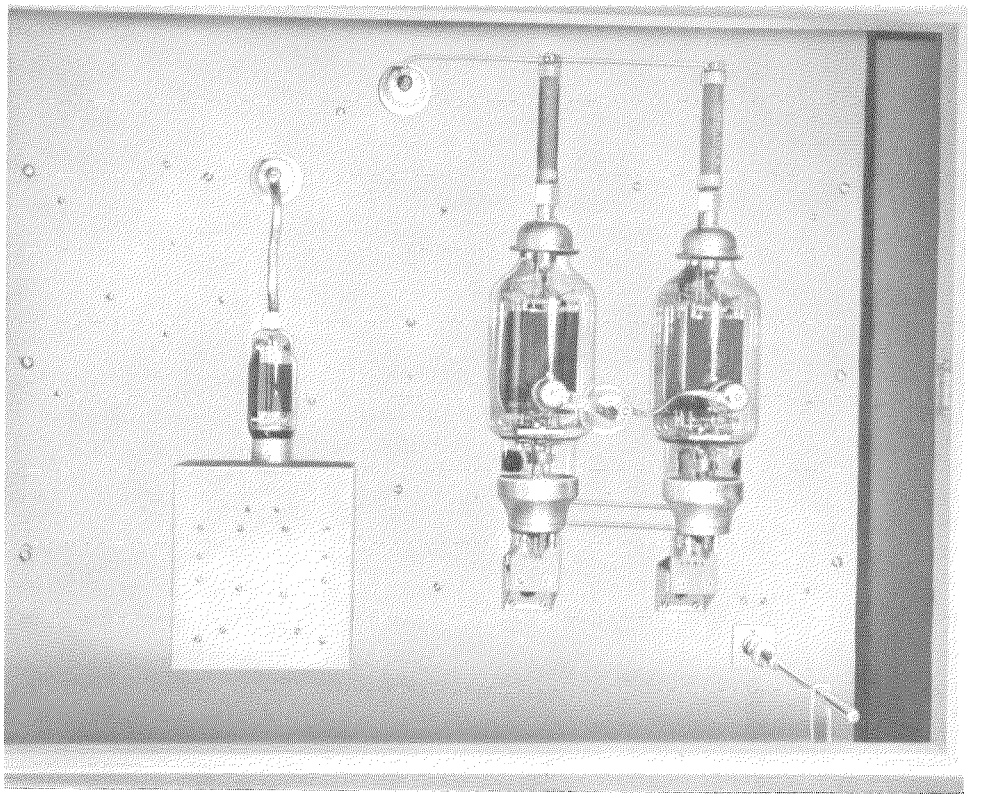


Fig. 4—RF Exciter Panel for 50-Kilowatt Transmitter.

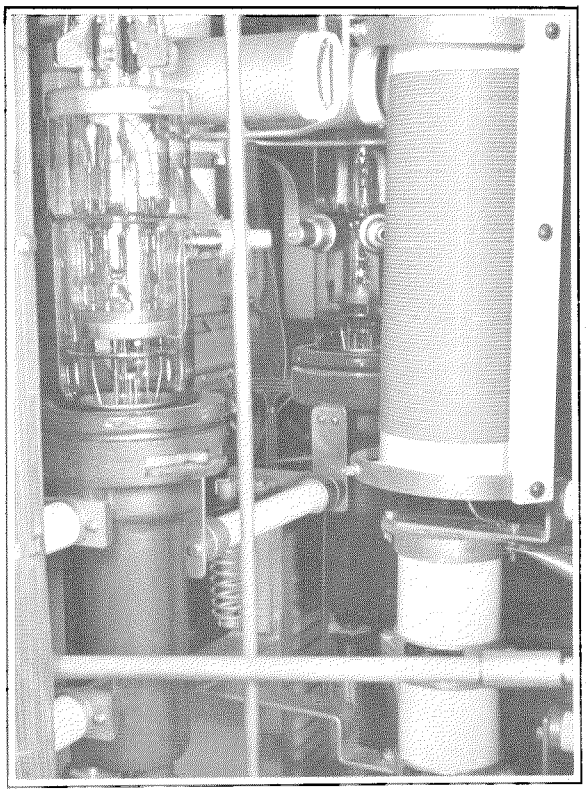


Fig. 5—High-Powered RF Stage of the 50-Kilowatt Transmitter Showing the Two Federal F-124 Tubes Capable of Delivering a Peak Power of 200 Kilowatts.

Station Layout

As shown in the floor plan of the station, Fig. 7, the transmitter panels are arranged in a "U" around one end of the operating room. The left wing houses the station measuring apparatus, oscillator-buffer, RF exciter, and audio pre-amplifier equipment. Directly in front of the control desk are the 50-kilowatt modulator at the left and the 50-kilowatt final amplifier on the right with the station control and indicating apparatus behind the center panel. The antenna coupler is mounted above the final 50-kilowatt amplifier and is conveniently located for connection to the output of either the 50-kilowatt transmitter or the 5-kilowatt transmitter in the right wing.

It will be noted from Figs. 8 and 9 that large meters are placed on sloping panels at the correct height for the operator to read them without difficulty while seated at the desk. Sloping the meters causes the light to strike them at an angle that prevents glare.

The sloping doors in the same plane as the meters may be dropped to expose controls and additional meters for station adjustment. Push buttons are provided on the sloping instrument panels to operate electric latches on the lower doors. In the left and right wings, these doors cover the oscillator and amplifier units for each transmitter. Since each oscillator-buffer and two-stage, push-pull pre-amplifier unit is complete with its own power supply, it may be removed without disturbing the other units. An amplifier or oscillator-buffer slides into place on rollers like a drawer as shown in Fig. 9. The unit automatically makes all connections through plugs at the rear of the chassis. However, an electric latch fastens each drawer into place and releases only if the unit is not being used, so that it may not be removed while in operation. Since each unit is supplied in duplicate, with switches for quick change-over, one unit may be removed and repaired while the other is operating.

The station wiring channel is also illustrated in Fig. 9. This is a U-shaped duct located just above the floor and extending around the three wings of the transmitter. All wiring is run to terminal blocks immediately above the channel so that it is possible to change connections from the front of the transmitter.

Electric latches fasten all doors at the rear of the transmitter. These operate only when the section of the transmitter to which they permit access is turned off and is inoperative. They will not work, though, even after the power supply switch is opened, unless the shorting switch is closed, short circuiting the high voltage supply. An operator, therefore, cannot enter the area until all dangerous high voltages are disconnected and high voltage condensers are discharged. This is a simpler and more foolproof method of protection than the grounding stick and chain usually provided to short circuit capacitors.

Fig. 10 illustrates the general arrangement behind the transmitter panels. Two areas are provided—one for each transmitter. Each area is closed off by heavy wire doors and partitions like the one shown at the rear of Fig. 10. The areas are indicated in the floor plan. It is possible to replace the exciter tubes for the 50-kilowatt transmitter while the power amplifier is being excited by the 5-kilowatt transmitter. Tubes are replaced from the front of the transmitter so that it is not neces-

sary to enter the enclosure for this purpose. As shown, all components of the transmitters are easily accessible for repair.

The brick wall behind the 12-kilovolt plate rectifier is part of the transformer vault located in the rear of the building. This vault houses the duplicate banks of power transformers for the two three-phase power lines which enter the building through the basement at this point. All oil-immersed equipment, including the regulator for the 50-kilowatt plate supply, the high-voltage power transformers, modulation transformers and reactors, and protective apparatus are located in this vault. The high voltage equipment associated with each transmitter is separately enclosed; the protective system employed to prevent entrance when high voltage is turned on is the same as for the transmitter enclosures. Filament voltage regulators are located on a rack in the 50-kilowatt transmitter enclosure, while the 5-kilowatt, air-cooled plate supply regulators are in the basement.

Description of the 12-Kilovolt Rectifier

In the closeup of the 12-kilovolt plate rectifier for the 50-kilowatt transmitter, Fig. 11, it will be noted that the components are arranged for efficient operation and easy accessibility. The symmetrical open design of the rectifier is typical of all the units in the transmitter. Seven tubes are provided although only six are used when the rectifier is operating. The last tube on the right is a spare whose filament is kept heated to half operating temperature to keep the tube warm and ready for instant operation should one of the other tubes become inoperative. The spare tube may be placed into service in place of a defective tube by changing the position of a connecting

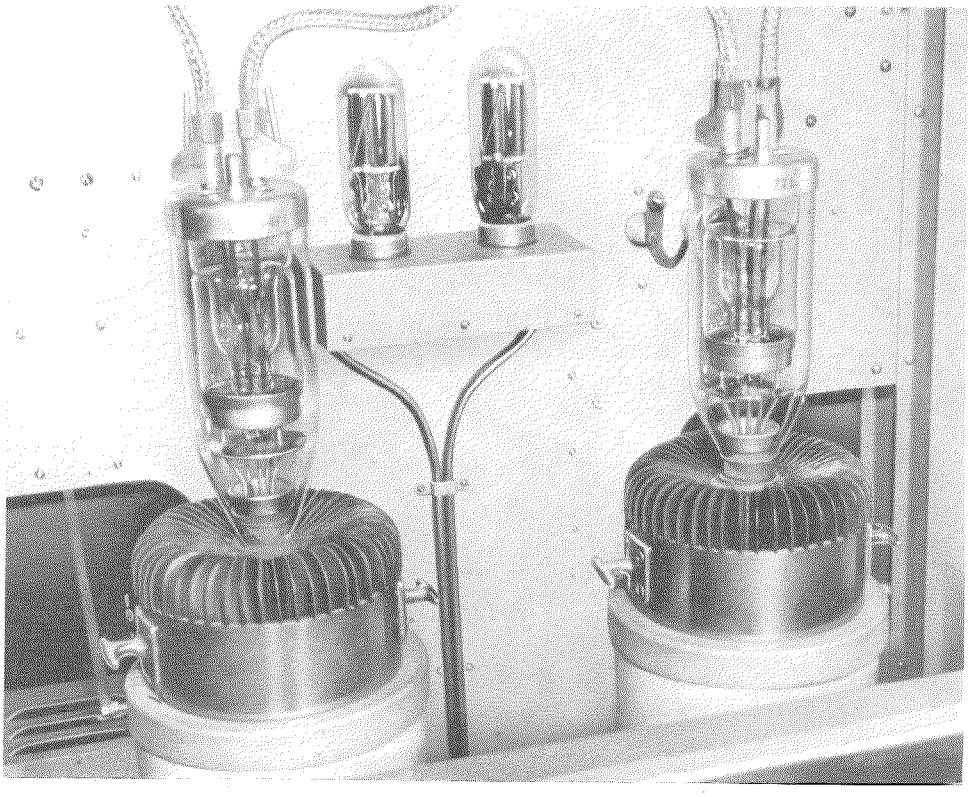


Fig. 6—Air-Cooled Modulator Tubes of the 5-Kilowatt Auxiliary Transmitter.

bar on top of the rectifier unit and switching the filament transformer to full voltage. A thermostatically-controlled blower to provide forced air to cool the tube stems is located on the rack. The hollow porcelain cones behind the tube bases direct a jet of air to the lower portion of each tube. A similar rectifier rack using smaller tubes supplies 8-kilovolt anode power for the 5-kilowatt transmitter.

Two condenser banks are located at the bottom of the rectifier, one bank for the filter supply and one connected in the modulation transformer and audio reactor circuit. Each condenser has a horn gap over it shorted with fuse wire; the horn gaps are connected in series with each section. If a single section of condenser should break down, the fuse wire will melt and the resulting arc when the circuit opens will be extinguished by the horn gap and the defective section will be taken out of the circuit and grounded automatically without interruption of operation. The station can then remain in operation, less one condenser section.

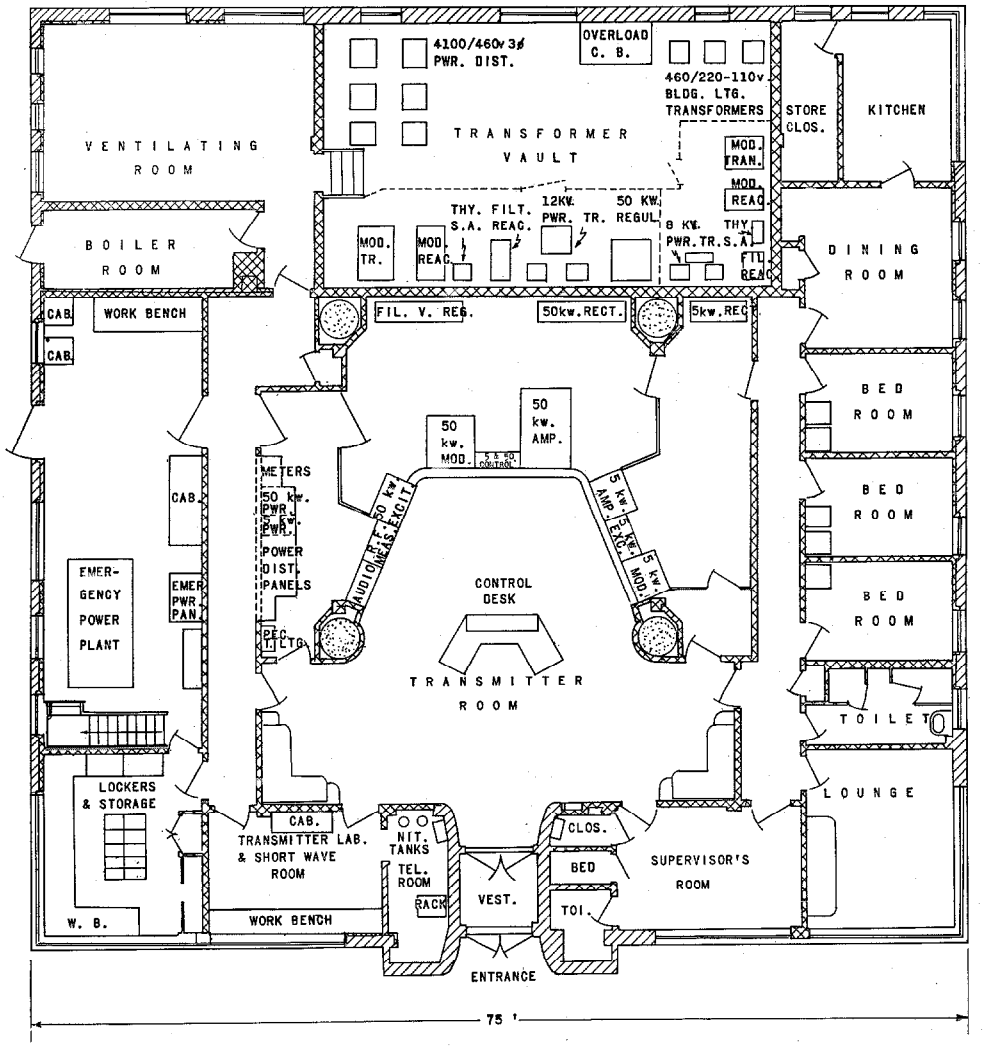


Fig. 7—Main Floor Plan of Station WABC.

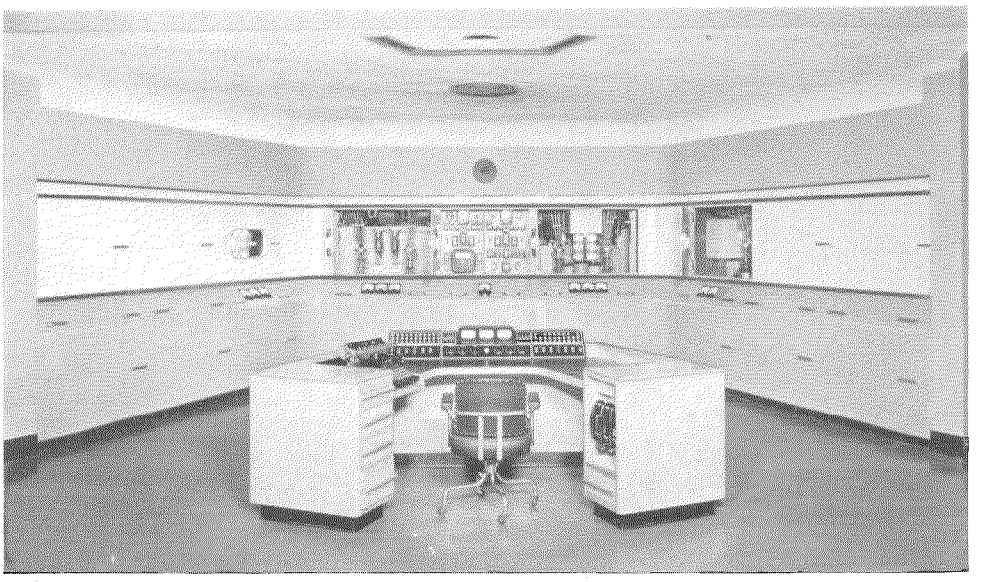


Fig. 8—Operating Room of Station WABC Showing the Operator's Desk and the Control Console. Some of the Upper Panel Doors Have Been Opened to Show Relative Positions of the 50-Kilowatt RF Amplifier and Modulator. The RF Exciter Shown in Fig. 4 May Be Seen Behind the Window of the Closed Door at the Left. The 5-Kilowatt Final Amplifier Tube is Visible at the Right.

Sufficient capacitance is included in the bank so that reduction by one section will not seriously increase hum or impair quality of transmission.

Complete Air Conditioning

Two air conditioning systems cool, filter, and dry the air in the station. One system controls the temperature and air in front of the transmitter panels and the other system conditions the air going to the components at the rear of the panels. The transmitter panels, therefore, divide the two areas and the separate systems permit different temperatures in the two sections. Since the station is completely surrounded by salt water, all air is dried upon entering the station and filtered to safeguard components against corrosion and the establishment of conducting paths between high potential terminals due to salt or moisture.

Distilled water for cooling the large final amplifier and modulator tubes is conducted through porcelain pipes to the tube anodes from the basement where the cooling and circulating system is located under the ventilating room. The water-cooling equipment is in duplicate and changeover may be made quickly if trouble develops in the system being used. Two large, cylindrical tanks are provided to store the distilled water of the closed system. A separate rotary pump and evaporative cooler is included with each. D-C leakage through the distilled water due to conducting salts or chemicals that become dissolved in it is checked on a meter located on the control panel. Whenever the distilled water begins to be-

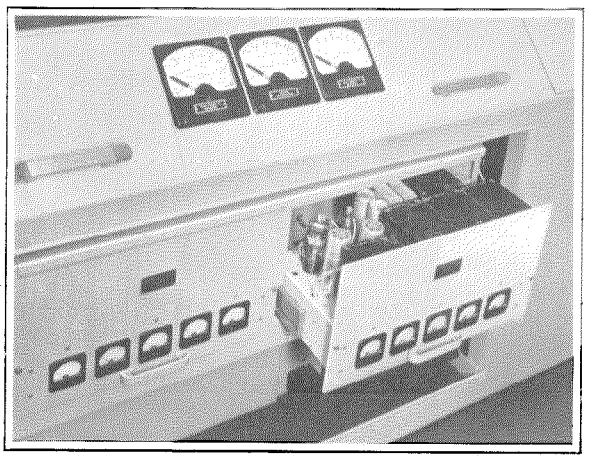


Fig. 9—View of the First and Second Stage Audio Amplifiers for the 50-Kilowatt Transmitter Showing How Each Unit Slides Out in Drawer Fashion.

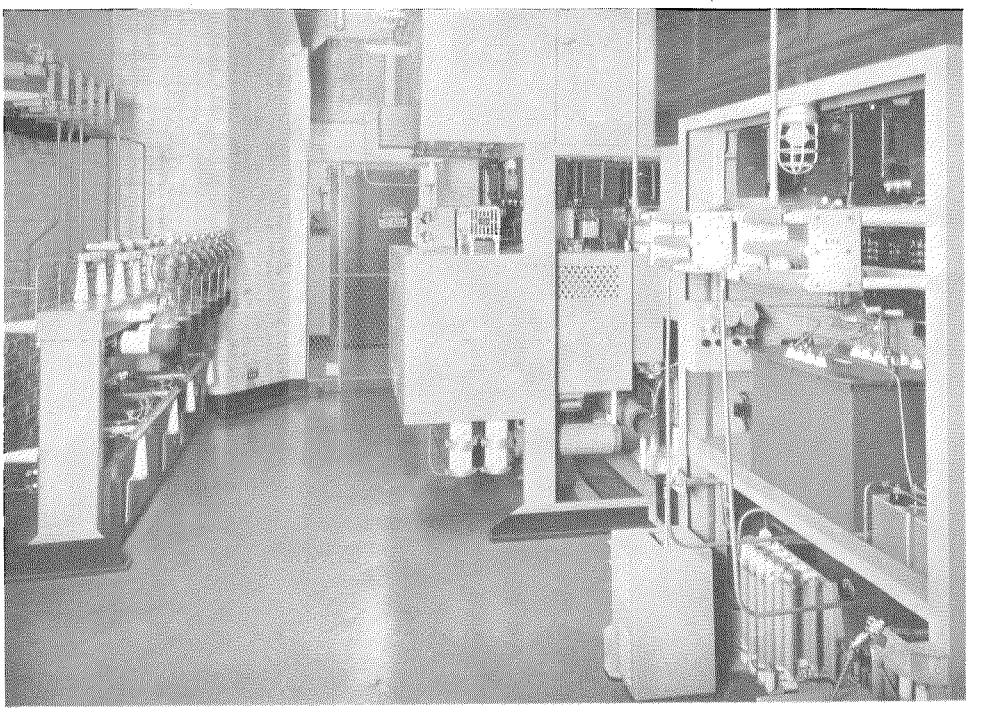


Fig. 10—Interior of the 50-Kilowatt High Power Area. The 12-Kilovolt Rectifier Is Located at the Left with the High Voltage Shorting Switch Above. The Modulator and RF Components Are at the Right.

come conductive in one system, the other system is placed in operation and the first cooling system is drained. The tank is then filled with fresh distilled water. Flow meters and thermometers are provided to check flow and temperature before and after passing over the triode anodes. If temperature rises to the danger point, an alarm bell rings. If it rises beyond the danger point, a relay turns off plate and filament supplies to the water-cooled tubes.

The spare water pump and cooler may be operated with the water-cooled dummy antenna on either the 50-kilowatt or 5-kilowatt transmitters. WABC's dummy antenna is small enough to be mounted in a 3-inch diameter porcelain pipe approximately 28 inches long. Complete shielding was, therefore, a simple matter. In spite of its small size, this unit permits the entire 75 kilowatts or more output at full modulation to be dissipated through the cooling system. Conventional dummy antennas for 50-kilowatt stations are usually air cooled and may occupy a space as large as a small living room. The small size of the WABC dummy antenna permits its location behind the antenna tuning panel and connection to the antenna change-over switch with a short section of concentric line.

Individual blowers are placed wherever air cooling is required. Blowers are equipped with velocity type cutoffs to remove plate and filament power if the flow of air should drop or be cut off.

Antenna System

A 75-ohm pi network connects either transmitter to the antenna through a concentric line. The network was designed to accommodate wide limits of output impedance so that the transmitters may be coupled to various antenna loads.

Harmonic suppression is accomplished with a folded, gas-filled concentric line fastened to the basement ceiling.

The antenna is of unconventional design. Instead of the usual quarter-wave vertical antenna, a top loaded radiator, as shown in Fig. 1, is used. An extended flat section is built at the top and insulated from the rest of the mast. The antenna is terminated in this section. This design for the antenna permits a shorter tower than usual and was a requirement of the locality since several airports are in the vicinity. It also has the advantage of suppressing radiation in the vertical direction and intensifying radiation in the horizontal direction.

The tower is 410 feet high and is located directly over the transmitter building. The four tower legs go through the building and are supported by four concrete blocks, each 22 feet square, weighing 2,500 tons and resting on the rock of the island foundation. The tower legs are constructed separately from the building; large rubber gaskets between them and the building seal the latter from weather without transmitting tower vibration to it. This vertical type of construction was necessitated by the small size of the island which extends less than fifty feet from the sides of the building.

The modern operating building is a huge electrical shield for the transmitter since it is completely sheathed in metal and connected to a large radial ground system composed of many cables running several hundred feet out into the water around the island and anchored to the sea bottom. Besides the facilities for keeping the station in operation and repair, the building is also equipped to provide for the comfort of the operating staff. When weather permits, the operators commute from the mainland in a large motor launch. However, bedrooms and comfortable beds are provided for as many as eight of the staff to sleep on the island in case of stormy weather. A completely equipped kitchen and dining room permit the preparation and serving of meals.

Complete Test and Control Equipment

The test equipment located in the left wing of the station is permanently installed as an integral part of the transmitter equipment. Tests of frequency stability, distortion, percentage modulation, hum level, etc., may be made by simply throwing switches and patching in circuits on special patch boards located under the test panels. Standardized tests of station operation may, therefore, be made as easily as actual station adjustment. Monitoring equipment is also provided on the test panel and remotely connected to the control console on the operator's desk. There lamps and meters indicate over-modulation and deviation from carrier stability which is kept within plus or minus two cycles of the regular operating frequency of 880 kilocycles.

As will be noted from Fig. 8, the control console is divided into three sections. The left-hand section contains indicating lamps and switches associated with the control of the 50-kilowatt transmitter. The right-hand section contains indicating lamps and switches associated with the control of the 5-kilowatt transmitter and with the transfer of the smaller transmitter to the antenna in place of the regular transmitter. Switches are also provided on this side of the console to connect the 5-kilowatt transmitter as an exciter for the 50-kilowatt power amplifier in place of the regular 50-kilowatt exciter. The center of the console is equipped with the usual audio level



Fig. 11—Closeup of the 12-Kilovolt Rectifier Showing the Simplified, Clean-Cut Design Typical of the Entire Station.

controls and overmodulation lamp as well as the modulation and frequency deviation meters.

As each circuit of a transmitter is switched in on the console, the progression is indicated by a series of lamps. When all the switches necessary to operate the transmitter are thrown, a green lamp lights, indicating that the transmitter is available for broadcasting. A series of lamps also shows the condition of the safety interlock system. These lamps are normally lighted if none of the transmitter enclosure doors is open and the shorting switch is in its normal operating position. A third row of lamps provides a means of indicating overloads in the various supply circuits of the transmitters when they are in operation. Lamps at the right of the console also indicate when the tower lights are turned on and if trouble develops in the telephone cables.

Station Ideally Equipped for Continuous Operation

Although the new station was planned more than two years before the present emergency began, it could not have been better equipped for the full-time job it is now doing. Emphasis of design was upon giving reliable, uninterrupted service, and so many duplications of equipment and services were provided that the station is virtually breakdown-proof. Not only are there two complete transmitters, but almost everything else is duplicated and even triplicated.

The duplicate water cooling systems, control positions, and pre-amplifier and oscillator units of the two transmitters have been described. To provide uninterrupted power, two power lines run from the mainland to the island. The lines reach the island from different directions so that a disturbance to one line need not affect the other. But if power from the mainland should be completely cut off for any reason, the station may still be operated almost at full output from the gasoline-driven motor generator on the island.

The 342-ton tower has been built to withstand wind velocities exceeding 120 miles an hour. Such pressure is far in excess of any storm winds experienced in the locality. The tower is so substantial that it would stand on three legs, but provisions have been made to permit operation of the station even if the tower should topple over. The four flag poles, which add a decorative and nautical note to the island, have coaxial cables running to their bases from the transmitters. An emergency antenna system may be strung up on the poles and fed through these coaxial lines.

Even the fresh water supply, used with the transmitter cooling units and the station air conditioning system, is provided in duplicate. Water is obtained from a well dug 910 feet into the island foundation, and this is supplemented by water from the city of New York water system.

An elaborate system of assuring the maintenance of program service from WABC has been set up. Two high fidelity telephone cables connect the mainland to the island over separate routes and are used to convey the programs originating in the CBS studios in New York to the transmitting station. These telephone lines are protected by gas kept under pressure in each cable so that if a leak in the cable wall should develop, the gas would force itself out and prevent the water from entering. A reduction in gas pressure would also indicate that a leak had developed. Even if disaster should strike twice at the same time and both telephone lines be put out of service, program transmission may still be maintained at full fidelity over the 335-megacycle, frequency modulated radio link between the studio building and the transmitter. A short-wave antenna has been installed on top of the WABC tower and a separate coaxial line connects the antenna to two frequency modulation receivers in the building. The antenna is high enough to be visible from the FM transmitter atop the studio building in Manhattan, so that line-of-sight transmission is practicable.

Since it is entirely possible that conditions that might cause breakdown of the communication system between the island and the mainland, such as extremely stormy weather, would conceivably completely isolate the operators on the island, the station may still be kept on the air in an emergency by using transcriptions. A turntable and pickup have been placed beside the operator's desk for this purpose.

In addition to all the facilities for keeping program material on the air, one of the rooms in the transmitter building has been equipped to permit its use as a studio. This is the lounge in one corner of the building. The walls of this room have been covered with acoustic material. Early tests of the station were made from this studio and it

is now ready for use at any time for emergency programs or announcements.

Conclusion

In the design of the new transmitter, emphasis was placed on efficient carrier radiation, reliability of operation, and high audio fidelity. With carrier power limited to 50 kilowatts in the U. S. A., efficient radiation was considered sufficiently important to merit the added difficulty and expense of placing the station at its island location. The many safeguards and duplications of equipment for keeping the station on the air show that reliability of service has become as important to the radio broadcasting station as it is to the electric generating plant or the telephone system. Further, the high fidelity capabilities of the new station indicate the stress being placed more and more on the audio quality the listener may receive. This last feature, involving as it does high fidelity telephone lines as well as transmitters of very low overall distortion, may be considered unnecessary since the average radio receiver has an upper audio limit of less than 5,000 cycles with at least 10 per cent harmonic distortion. But it probably marks a trend that was apparent when specifications for WABC were drawn up—the desire of the listener for better program quality. Although manufacture of both broadcast transmitters and receivers has been halted by the government for the present, these features of WABC should indicate to engineers the basis for development when new construction is resumed.

Maritime "M" Awarded to Federal Telephone and Radio

THE UNITED STATES MARITIME COMMISSION "M" Pennant and Victory Fleet Flag for outstanding performance in the development and production of radio equipment was officially presented to Federal Telephone and Radio Corporation, manufacturing subsidiary of International Telephone and Telegraph Corporation, at a special ceremony held at Newark, New Jersey, December 21, 1942. F. E. Hickey, Director of the Maritime Commission's Division of Purchase and Supply, made the awards which were received in behalf of the Corporation by its President, Colonel Sosthenes Behn. Mr. Hickey also presented Maritime Merit Badges to employees.

Announcement of the award was made to Colonel Behn December 14 in a telegram sent him by Admiral H. L. Vickery, Commissioner, U. S. Maritime Commission. The telegram read in part:

"As Chairman of the United States Maritime Commission Board of Awards, I take pleasure in advising you that the Board, in recognition of outstanding performance in the development and production of radio equipment for the United States Maritime Commission, has awarded your plant at 200 Mount Pleasant Avenue, Newark, New Jersey, the Maritime "M" Pennant, the Victory Fleet Flag and Maritime Merit Badges for all plant employees."

While the Federal Telephone and Radio Corporation is a large producer of war matériel, both radio and telephone, the Maritime award represents special recognition for its Marine Radio Unit, which has been a major contribution in speeding delivery of the Maritime Commission's Liberty Fleet. This unit was developed by Federal when the emergency cargo vessel building program, formulated by the Maritime Commission as part of the National Defense Program, was inaugurated. Describing Federal's part in providing the Marine Radio Unit, Mr. Hickey, in his speech of presentation, stated in part: "Specifically, your company initiated, proposed and developed the idea of a single unit for the radio room on the Liberty type vessels which contained all the radio equipment required by law."

Installation of the combination unit equipment on shipboard consists chiefly in securing the unit in place in the radio room and connecting the antenna and power leads. These operations can be completed in a fraction of the time necessary for an equivalent installation of the ordinary type comprising separately placed transmitters, receivers, motor generator sets, etc. The wiring problem, obviously, is also greatly simplified. Installation of the ordinary type, moreover, tends to interfere with concurrent construction work on the ship itself. With the new Marine Radio Unit, on the other hand, practically all work on the ship can be completed prior to the time the radio unit is placed into position. Its installation on Liberty ships has resulted not only in a great saving of time, but also has released many hours of skilled labor for other war work.

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