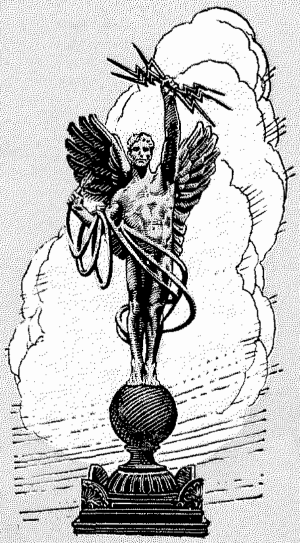
ELECTRICAL COMMUNICATION



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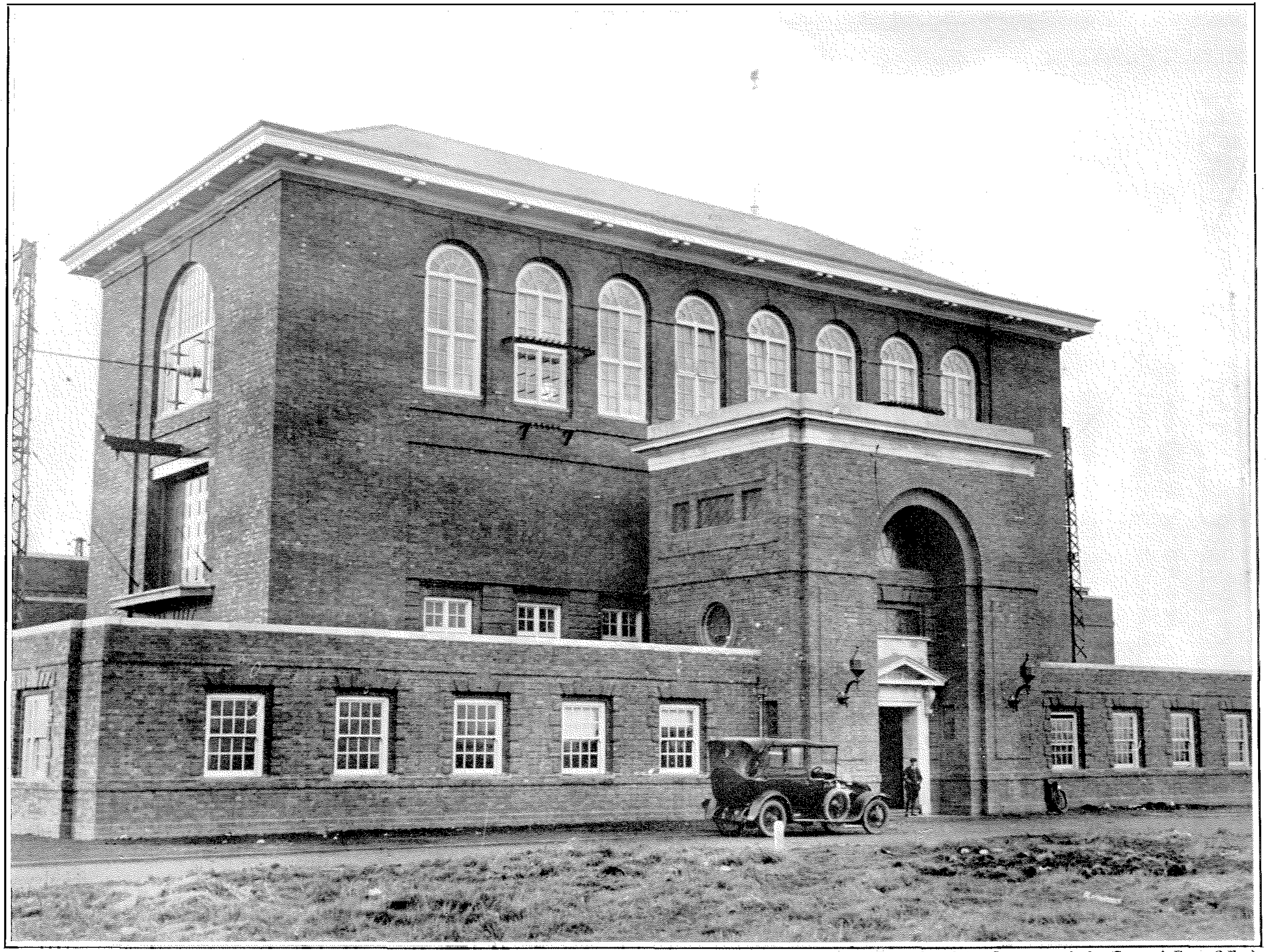
CONTENTS



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Rugby Radio Station—Main Building

Transatlantic Radio Telephony

Radio Station of the British Post Office at Rugby

By **E. M. DELORAINE**

European Engineering Department, International Standard Electric Corporation

THE interest which has been engendered by the recent experiments in talking two ways across the Atlantic between England and America focuses at the British end upon the powerful transmitting station of the British General Post Office at Rugby. This newly completed station, which has many novel and interesting features has been described [1] from various standpoints. There has, as yet, appeared no detailed description of the modulating and amplifying apparatus used in the high-power radio telephone experiments. It is the purpose of this paper to describe that portion of the Rugby installation and to discuss, in some detail, its more interesting features.

Essentially the equipment consists of the single side-band input equipment, the high-power radio amplifier, together with the necessary system of controls and protections. The single side-band input apparatus and the high-power amplifier are both generally similar to the corresponding equipment employed on the American side in the Rocky Point transmitting station. The Rugby equipment was provided, installed, and tested by the Standard Telephones and Cables, Ltd., working in cooperation with the General Post Office Engineering Department and with the consulting advice of the Bell Telephone Laboratories, Inc.

Method of Transmission

The Rugby station is of special interest not only because of its size but also on account of outstanding features arising from the method of transmission employed. Inasmuch as the principles involved and the types of circuits used in the single side-band eliminated-carrier method of transmission have already been described,[2] only the fundamental features will be reviewed and the more important advantages stated.

It is well known that the result of amplitude modulation of a carrier wave by a voice-frequency wave is the production of two bands of waves, one band having frequencies greater than that of the carrier and the other having frequencies less than that of the carrier. The carrier wave itself is not altered in any way by modulation, and consequently contains no part of the message and need not be transmitted. The upper band of waves is an exact copy of the speech waves, with each frequency increased by a fixed amount equal to the carrier frequency. The lower band takes a reversed position; that is, its component frequencies are equal to the carrier frequency minus the voice frequencies.

These relationahips are plotted in Figure 1-A as a spectrum. If the line S_1 is taken as the lowest speech frequency and S_2 as the highest,

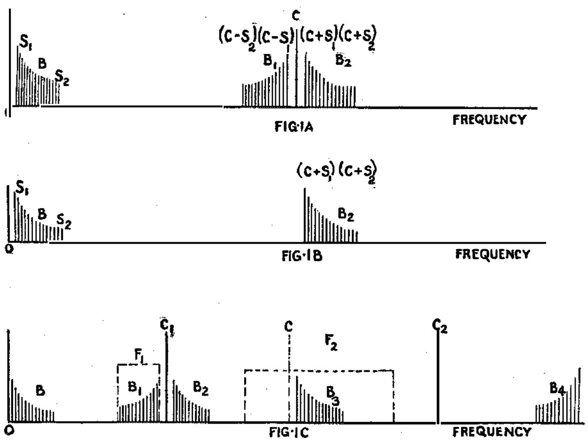


Figure 1—Spectra of Speech Bands

all the frequencies in speech may be represented by lines in the band B. The lengths of these lines have no significance, but they have been made unequal in order that the frequency relations in the subsequent transformations may be more easily followed. The line C represents the carrier frequency; and the result of modulation is to produce the bands B_1 and B_2, which are spread over a frequency range equal to twice S_2. B_1 and B_2 are usually referred to as the

[1] The Rugby Radio Station, E. H. Shaughnessy, O.B.E., M.I.E.E., *Electrical Review*, Vol. XCVIII, No. 2527, April 30, 1926.

[2] Colpitts and Blackwell, *Journal of the American Institute of Electrical Engineers*, April, 1921. R. A. Heising, Proceedings I. R. E., June, 1925. Trans-Oceanic Wireless Telephony, H. W. Nichols, read before the British Institute of Electrical Engineers, February, 1923. Transatlantic Radio Telephony, H. D. Arnold and Lloyd Espenschied, *Journal of the American Institute of Electrical Engineers*, August, 1923.

lower and upper side-bands, respectively. Each of the bands B_1 and B_2 contains in itself all the elements necessary to reproduce the original speech. Only one side-band is necessary for reception, and nothing would be gained in the case of transatlantic radio telephony by transmitting two rather than one. On the contrary, several advantages accrue from the exclusion of one side-band. In the ordinary method of radio transmission both the carrier and the two side-bands are impressed on the antenna circuit and radiated. Since the carrier contains not less than two-thirds of the total energy and the products of modulation occupy more than twice the necessary frequency range, it is clear that the ordinary method of transmission does not lead to maximum efficiency either with respect to power consumption or the economical use of the ether. In the single side-band eliminated-carrier system only one of the side-bands, such as B_2, is selected from the components of modulation and amplified to the power level necessary for transmission. In this case the overall result of modulation is a simple frequency transformation upward, as shown in the spectrum of Figure 1-B, where the band B represents the speech frequencies and the band B_2 represents the frequencies radiated from the transmitting antenna. Obviously, the process of receptiom involves the selection of the band B_2 and the transformation of all the frequencies back of their original positions with respect to zero frequency, in order to reproduce the original speech-frequency spectrum. This frequency conversion is brought about by re-introducing the carrier frequency C at the grid of the receiving detector,—or, in other words, by employing a heterodyne frequency corresponding to the carrier eliminated at the transmitting station. This is quite easily effected, but the heterodyne frequency must be adjusted accurately; otherwise the reproduced frequencies will not bear the proper relation to zero frequency and the quality of the reproduced speech will be impaired.

As already stated, the elimination of the carrier alone establishes a power-saving of at least two-thirds, in addition, the suppression of one side-band reduces the transmitting band width to slightly less than one-half, thereby conserving the available wave-length range for other radio transmissions. The narrow frequency band permits the use of more selective receiving end circuits which help considerably in reducing the exposure to radio noise and improve the signal-to-noise ratio. Provided all other conditions remain unchanged, this improvement allows a further reduction in power at the transmitting station. Another important advantage arising from the reduction in band width is the simplification of the circuit problems at the transmitting station; for example, at the wave-lengths employed for transatlantic telephony, it is very difficult to design a reasonably efficient antenna which will pass even one side-band.

The single side-band eliminated-carrier method of transmission has another very important advantage; namely, the reduction of signal fluctuations caused by changes in the transmitting medium. The amplitude of the signal produced at the output of a receiver is proportional to the product of the side-band amplitude and the carrier amplitude. In the ordinary system of transmission, the amplitudes of both the carrier and side-band are affected by the transmitting medium, so that the changes in the amplitude of the detected signal are proportional to the product of the changes in carrier and side-band. In the single side-band receiver the locally supplied carrier is constant in amplitude, and consequently the variations in strength of the detected signal are much smaller than in the ordinary method of transmission.

In a transatlantic telephone system it is necessary to strive for improved efficiency and it is extremely important that the frequency range occupied in the ether be as small as possible since the range available for all classes of communication is very limited. It will be seen from the preceding that the advantages of the single side-band system all tend toward meeting these requirements. The employment of this system is, therefore, highly desirable.

In the choice of the wave-length range over which the telephone transmitter should be capable of being operated, the controlling factors were the economics of transmitter design and the characteristics of the transmitting medium. An extended study of the transmission across the Atlantic of radio signals at wave-lengths between 5,000 and 17,000 meters showed that in general the longer waves are steadier in strength at any given time and less exposed to extreme of diurnal and annual variation than the shorter waves. It showed, on the other hand, that the interference produced by atmospheric disturbances is less in the case of the shorter waves. Longer waves involve increased expenditure on the sending station. After consideration of the various factors involved, including the relative importance of long and medium wave-lengths to telegraph traffic, it was decided that the value of mid-band frequency used for the transatlantic telephone experiments should be taken between 50 and 65 kilocycles.

The use of the single side-band method of transmission involves the modulation and filtration of the high-frequency wave at low power. The transmitter consequently includes a low-power input equipment and a high-frequency power amplifier. The equipment is of an experimental nature and provision has, therefore, been made for a maximum of flexibility. In order to facilitate the operation and supervision of the transmitter, it was considered desirable to concentrate most of the controls and measuring instruments at a centre control position. Another feature incorporated in the equipment is a comprehensive scheme of protections and the provision of apparatus for the automatic detection of a number of abnormal operating conditions.

Production of Side-Band Signal

It is desirable to consider in more detail the actual method employed at Rugby to generate and to select the single side-band signal. The overall result at the transmitting station has been shown to be a simple frequency transformation upward, in which a fixed frequency is added to each frequency in the voice wave. This frequency conversion involves modulation and filtration. A large portion of the carrier may be eliminated by the use of a balanced modulator circuit, but the filter must suppress the remainder of the carrier as well as the opposite side-band. The filters for this purpose must be capable of a very high degree of discrimination. The lowest frequency considered, S_1 (Figure 1-A), is 300 cycles. The difference between the carrier frequency C and the nearest frequency in the side-bands is thus 300 cycles; the filter must, therefore, discriminate sharply between two frequencies 300 cycles apart. Consequently at the upper limit of the frequency range, 50 to 65 kilocycles, the smallest percentage difference between the frequencies which are to be passed and those which are to be suppressed is approximately four-tenths of one per cent. Furthermore, in order to provide for the possibility of changing wave-lengths in the transatlantic system, it is necessary to be able to produce the side-band signal for any channel, within the range of 50 to 65 kilocycles, which may be assigned to the station, and which will be decided on finally with due regard to a number of factors, one of which is the antenna characteristic. These requirements lead to the conclusion that a band filter is necessary which has extremely sharp and also widely variable cut-offs. In the present state of the radio art this would be a difficult and expensive proposition. It is far more satisfactory to resort to a system of double modulation with fixed filters. These fixed filters cannot be designed economically to handle any considerable amount of power. It is found preferable to perform the modulation on very small currents and to amplify the high-frequency wave in its final form to the required level. Such a system is employed at Rugby and will now be described.

The first operation comprises modulation of an intermediate carrier having a fixed frequency C_1 (Figure 1-C) much lower than the frequencies used for transmission. The carrier C_1 is modulated by speech currents the frequencies of which lie within the band B; and the modulator output circuit contains currents of frequencies which form the spectrum $B_1\,C_1\,B_2$. These currents are passed through a fixed band filter having limits designated by F_1. It will be noted that F_1 selects the lower side-band B_1. The entire process is then repeated by setting the currents from the output of filter F_1 to modulate a second carrier of frequency C_2, which is so adjusted that

$$C_2 - C_1 = C,$$

where C corresponds to the carrier frequency which would have been employed, if the signal had been produced in a single step. The second modulation produces a second combination of carrier and two side-bands, viz., C_2, B_3 and B_4; but in this case the bands B_3 and B_4 are well separated from C_2. Discrimination in this case is not a difficult matter and B_3 can be selected by means of a comparatively broad band filter F_2. The position of the band B_3 inside the filter limits may be shifted by changing the frequency of the oscillator, which supplies the carrier C_2. A very simple means is thus provided for changing the frequency of the wave delivered by the modulation apparatus.

After the first band filter has selected the lower side-band from the first modulator, and the second band filter has selected the lower side-band from the second modulator, the frequencies of the final band are restored to their relative positions in the original speech-frequency band. In other words, selecting the lower side-band twice is equivalent to selecting the upper side-band in a single step of modulation with a carrier equal to the difference in frequency between the first and second carrier oscillators of the double modulation process. The overall result is a simple frequency transformation, in which this fixed difference frequency has been added to each frequency in the original speech band. A flexible system, which eliminates one side-band and the carrier, is thus obtained by means of fixed filters.

Speech and Radio Input Equipment

The apparatus which receives the speech currents from the telephone line and produces the high-frequency single side-band signal is shown in Figure 2. A standard mounting for

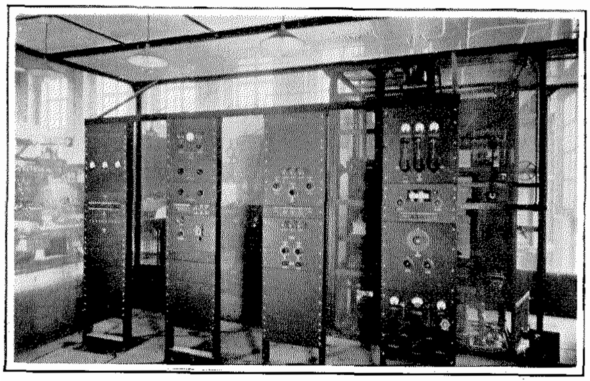


Figure 2—Speech and Radio Input Equipment

telephone apparatus has been used, in which the various units form independent panels, which are installed on the vertical racks or bays. The units of each panel are fitted with metal containers, which are readily removable for inspection purposes and which provide electrical shielding and mechanical protection. The panels have been grouped according to their function as follows: the first bay is the power bay, the second the speech input equipment bay, the third the modulation bay, and the last the intermediate amplifier and radio test oscillator bay. The arrangement of the power bay will be better understood after the other bays have been described. The apparatus in each panel is connected to that in the next through double jacks, which can be used for testing purposes.

Speech Input Equipment Bay

It will be seen from Figure 3, that the bay layout of the speech input equipment apparatus,

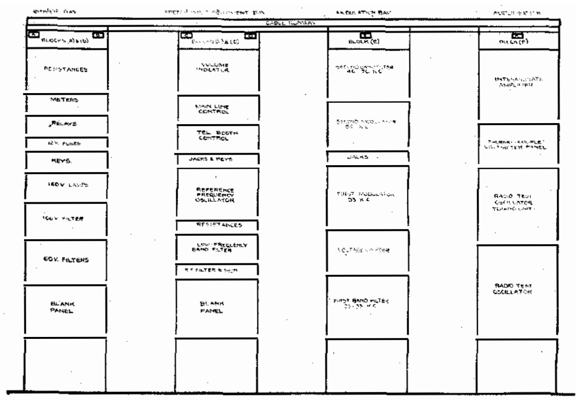


Figure 3—Input Equipment Bay Layout

starting from the top, is as follows: terminal block, volume indicator, main line control, telephone booth control, jacks and keys, reference frequency oscillator, resistances, low-frequency band filter, radio-frequency filter and monitoring coils, and blank panel.

The circuit diagram of the second, third and fourth bays is given in Figure 4. Two trunk lines are provided for connecting the toll line apparatus at London to the speech input equipment at Rugby. Line No. 1 is used normally, and line No. 2 is spare. The speech input equipment has been designed for 900 ohms impedance, and the lines are connected to the equipment through suitable transformers. The incoming signal first encounters a radio-frequency suppression filter, the purpose of which is to elimi-

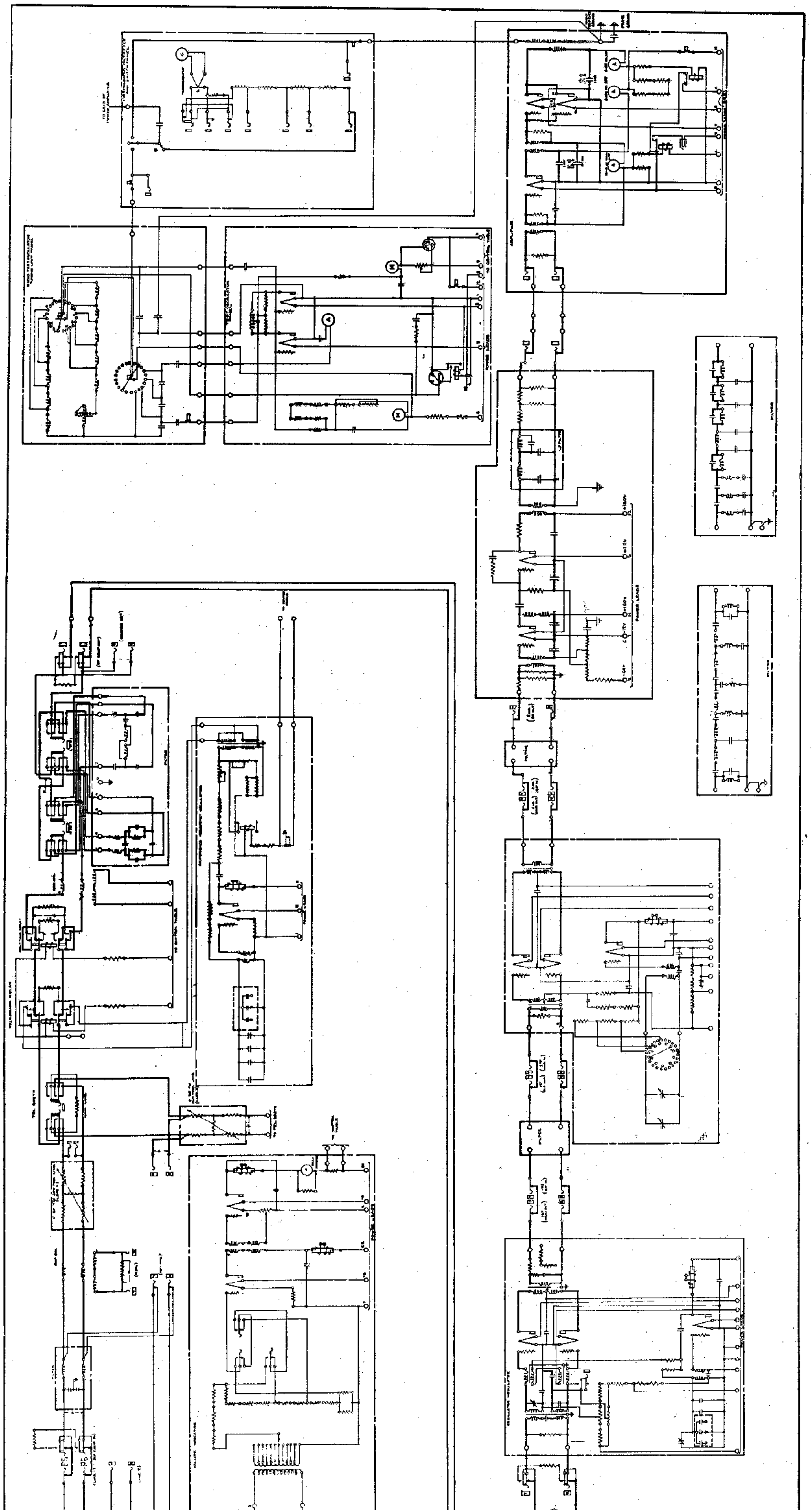


Figure 4—Input Equipment Circuit Diagram

nate radio-frequency currents which may be present in the telephone lines due to their proximity to the transmitting system. This filter is made of two shunt condensers with the mid-point grounded, and two series inductances, one on each side of the line. The attenuation is less than 0.2 T.U. (Transmission Units) up to 5,000 cycles and is 26 T.U. at 50,000 cycles. The next piece of apparatus across the line is a volume indicator, which is used to check the incoming speech volume. The circuit is a modification of that of the standard volume indicator employed in connection with public address systems and broadcasting equipments. In order to obtain a very wide range, an extra stage of amplification has been added so that it is possible to read volumes from −26 to +40 T.U. in steps of 2 T.U. Two meters are placed in series in the plate circuit, one being located on the volume indicator panel and the other on the control table. A monitoring coil is introduced in the circuit immediately after the radio-frequency suppression filter. This enables the attendant to listen to the incoming speech at this point when faults are being located or when special tests are being carried out.

Two artificial lines are used to control the speech input. They consist of "H" type attenuation networks with a total range of 20 T.U. and a constant 900-ohm impedance. The first is connected in the main incoming line and the second in the line from the telephone booth provided for local testing of the station. The adjustments for local test transmissions from the booth are thus made independent of the adjustments for transmission from London, and no changes are required when switching from one line to the other.

After the main line control, the circuit is connected to a number of relays and switching keys, the relays being operated from the control table. The function of the first key is to change over from the London line to the local telephone booth. The first relay changes from telephone to telegraph; that is, it suitably terminates the line and connects to the modulating equipment a single-tone oscillator, by which telegraph signals may be transmitted. The signal current derived from this oscillator is very stable and has a pure tone at 1,500 cycles, which frequency is taken as a reference for adjusting the carrier at the receiving station. The next relay is provided to enable the attendant at the control position to isolate the radio transmitting system from the whole of the speech input circuit in an emergency. When this is done, the telephone-line and the transmitting systems are both suitably terminated. A second monitoring coil, introduced in the circuit immediately after the splitting relay, is connected directly to a telephone headset on the control table.

The circuit of the speech input equipment connects finally to one high-pass and one low-pass filter. The band of frequencies to be transmitted, even when advantage is taken of the single side-band method, is still relatively great, and it is advisable to reduce it as much as possible, so long as the intelligibility of the system is not affected to an intolerable extent. The band which is transmitted through this apparatus lies between approximately 350 and 2,800 cycles. A large proportion of the energy in the speech spectrum is carried by the lower frequencies, and, although these are useful for the natural reproduction of the voice, they are less important to intelligibility. A considerable saving in tube capacity and power can be effected if these frequencies are not fully transmitted. The equipment is provided with a high-pass filter, which introduces a loss less than 1 T.U. for frequencies above 500 cycles, about 10 T.U. at 350 cycles, and more than 30 T.U. at 250 cycles. A low-pass filter is also provided, which introduces a loss less than 1 T.U. for all frequencies up to 2,500 cycles, about 6 T.U. at 3,000 cycles, and 20 T.U. at 3,500 cycles. These two filters can be connected into the circuit independently, or switched out of it by means of two keys. The filters should not be switched out of the circuit when the power amplifier is in operation, unless special precautions have been taken to ensure that no excess voltages will be produced in the amplifier as a result of the increased width of the frequency band.

The 1,500-cycle reference-frequency oscillator at Rugby has been designed to produce extremely constant frequency. The plate of the oscillator tube is fed through a choke coil and connects through resistances to a tuned circuit, which is electro-magnetically coupled to the grid. The load is connected across a resistance, which is a small portion of the output circuit resistance, so that no appreciable variation of output impedance is produced by variations in the load circuit. Two Morse keys are provided for sending telegraph signals. One is located on the oscillator panel and the other is on the control table. They are connected in parallel and control a relay, which short-circuits the primary of the oscillator output transformer. The variation of the reference-frequency oscillator with temperature is 0.0014 per cent. per degree Fahrenheit; that is, a variation of 20° F. will produce a frequency change of approximately 0.4 cycles. The frequency changes due to normal fluctuations of plate or filament supply are quite negligible.

Modulation Bay

The layout of the modulation bay can be seen from Figure 3. The arrangement of panels, starting from the top, is as follows: terminal block, 40 to 70-kilocycle second band filter, 90-kilocycle second modulator, jack panel, 33-kilocycle first modulator, voltage limiter, and 28 to 33-kilocycle first band filter.

The circuits for both the first and second modulators are of the balanced type, two modulator tubes being used for each unit. The signal is impressed on the grids in opposition through an input transformer, the secondary of which is divided into two windings. The carrier is impressed on the two grids in parallel through transformers placed on the grid side of the input transformer. The carrier oscillators are of a similar design to the 1,500-cycle oscillator. The negative grid voltage is supplied from two independent potentiometers, one of which is fixed and the other of which has both a coarse and a fine adjustment. Balancing condensers are connected across each secondary coil of the input transformer, one of them being variable. The output of the balanced modulator contains the two side-bands and an amount of carrier, which corresponds to the unbalance in the two tubes. A very satisfactory balance of the first modulator can be obtained by a proper setting of the potentiometers and of the variable balancing condenser; the amount of carrier which does get through is still further reduced in the band filter.

For transmission of the type here considered, the difference between the suppressed carrier frequency and the re-introduced carrier at the receiving end should be maintained within approximately 20 cycles. This frequency difference includes the combined total variation of the oscillators at the transmitting and receiving points of one channel. The absolute variation of frequency of the 1,500-cycle oscillator is negligible compared with that of the carrier oscillators. The lower side-band is selected at the output of the first modulator and the lower side-band is again selected at the output of the second modulator, so that the final frequency depends upon the frequency difference between the first and second carrier oscillators. Any change which causes one oscillator to vary its frequency will cause the other oscillator to vary in the same direction. Hence the overall variation of the radio-frequency signal corresponding to a steady low-frequency signal impressed on the input of the modulator system will be the difference of the variations in frequency of the two carrier oscillators. It is thus desirable to design the two oscillators in such a way that they have as nearly as possible the same absolute variation of frequency. Consequently, the second oscillator should be made as stable as possible, and the first oscillator should be designed to offset the variations of the second. The predominant source of frequency variation in the oscillators described is temperature change. A variation in temperature of 25° F. produces a change of frequency of the first carrier oscillator of about 40 cycles, and when the two oscillators are used together the frequency change caused by such a rise of temperature is less than 14 cycles. The frequency changes due to normal fluctuations of plate or filament supply are quite negligible. Changing of tubes produces a change of frequency not exceeding 10 cycles. The first oscillator has a range from 32.7 kilocycles to 33.6 kilocycles. Normally it is set at a frequency of the order of 33 kilocycles. If a higher frequency is used, the carrier will meet with greater attenuation in the filter, but the lower speech frequencies also will be attenuated to a higher degree. The exact frequency to be used depends on a compromise between carrier elimination and the transmission of the lower speech frequencies.

The function of the first band filter is to pass the lower side-band signals produced by the first modulator and to suppress the unbalanced carrier and the upper side-band. The first band filter introduces a loss less than 2 T.U. for frequencies between 27.6 kilocycles and 31.4 kilocycles. It has a very sharp cut-off on the high-frequency side, the attenuation being 32.2 T.U. at 32 kilocycles, and 57 T.U. at 32.8 kilocycles. The filter curve rounds off a little more on the low-frequency side, the attenuation being 3.5 T.U. at 27.4 kilocycles and approximately 13 T.U. at 27 kilocycles. The modulating currents in the second balanced modulator are now the side-band components passed by the first band filter, and the mid-frequency of the band is approximately 31.5 kilocycles. The modulating frequency is supplied from the second carrier oscillator, which has a frequency range of 70 kilocycles to 102 kilocycles.

The type of circuit used for both the balanced modulator and oscillator in this second stage is somewhat similar to the corresponding units in the first stage. There are two differences. On account of the greater spacing between carrier and side-bands, it is not necessary to balance the modulator very carefully, since the second band filter will attenuate the second carrier to a sufficient extent without attenuating any part of the side-band which is being selected. Hence the negative grid voltage supplied to the tubes of the second modulator is not critical and requires no variable elements, but is merely taken at a predetermined fixed value. Likewise, there are no balancing condensers across the secondary windings of the input transformer. The second difference is that the second carrier oscillator has a wide frequency range.

The function of the second band filter is to select and pass the lower side-band produced by the second modulator and to exclude all other frequencies, including that of the second carrier oscillator as well as the upper side-band. The second band filter is a combination of a high-pass and a low-pass filter. It introduces a loss less than 2 T.U. for all frequencies between 42.6 and 60 kilocycles. The attenuation is 5 T.U. for 40 kilocycles and 68 kilocycles, and 70 T.U. for 32 kilocycles and 75 kilocycles.

In order to safeguard the high-frequency power amplifier in the event of the signal currents arriving on the line at a volume higher than normal, a voltage limiter is introduced between the output of the second band filter and the input of the intermediate amplifier. The principle of this limiter is as follows:—

Two paths of unequal gain are provided for the high-frequency currents, one of which overloads for a lower input amplitude than the other. The currents corresponding to each path are in opposition in the output circuit, and the circuit is so adjusted that the larger current arrives through the path which overloads first. For normal amplitudes, the output currents for each path and, therefore, also the difference of the outputs, are proportional to the input. After the overload point is reached for the first path, the gain through that channel is decreased, while the gain through the second path, which subtracts from the first, remains constant. The overall gain consequently decreases for increasing input amplitudes, thus limiting the output voltages to a predetermined maximum value. The overloading effect is obviously accompanied by the production of harmonics, which are prevented from reaching the intermediate power amplifier by the insertion of a low-pass filter, introducing an attenuation of 25 T.U. or more for all frequencies above 90 kilocycles.

The limiter unit includes one stage of amplification, in order to secure zero transmission equivalent at normal amplitudes. This makes it possible to cut out the limiter, if desired, by plugging a patch cord between the output of the second band filter and the input to the intermediate power amplifier. The limiter is provided with input and output resistance "pads", i.e., resistance networks, which are adjusted to give the overload at the proper value. The overload point can be changed at will by removing a "pad" from the input and adding a corresponding "pad" to the output, or vice versa. The change in the overload point will correspond to the number of T.U. thus transferred.

Amplifier and Radio Test Oscillator Bay

The layout of the amplifier and radio test oscillator bay can be seen from Figure 3. The arrangement of panels, starting from the top, is as follows: terminal block, intermediate amplifier, thermocouple and voltmeter panel, radio test oscillator tuning unit, and radio test oscillator.

The amplifier comprises two stages of radio-frequency amplification, the first stage having one tube, and the second two tubes in parallel. These tubes are capable of dissipating 50 watts on the plates. Transformers with cores of magnetic material are used throughout the circuit. Meters are provided for reading the grid and plate currents of the tubes. A negative grid voltage alarm lamp is provided which will light if the plate voltage is applied when there is not a proper negative voltage on the grid.

The output of the intermediate amplifier is taken through a transformer to the input circuit of the first stage of the power amplifier. A radio test oscillator is provided, in order to test the power amplifier independently of the input equipment. It will generate sufficient high-frequency power at any frequency in the range covered by the input equipment to replace the latter for single frequency test purposes. The oscillator is of the Colpitts type and uses two tubes in parallel, each of which is capable of 50 watts dissipation. The plates are connected through an anti-singing circuit to prevent spurious inter-tube oscillations. The maximum power output is 75 watts and the frequency range is 40 to 75 kilocycles. The frequency is regulated by one dial, which controls a variometer, and another which switches in fixed inductances in various combinations. One group of inductances is in series with the variometer, and the other in shunt across the variometer and a series inductance. This arrangement has the advantage of giving a comparatively uniform change of frequency for a given change of variometer setting over the whole frequency range of the oscillator. The output is taken across a condenser on the plate side of the oscillator. The amplitude of the output currents can be changed in steps by means of an output control switch, and fine adjustment is obtained by regulating the D.C. supply to the anode by means of a series rheostat.

The normal negative voltage is established by a grid leak and condenser. During keying a relay controlled by Morse keys, changes the grid voltage from normal to negative, 250 volts approximately, and thereby stops the oscillations. Two Morse keys are in parallel, one being located on the oscillator and the other on the control table. The oscillator panel is provided with meters for reading the plate, the grid, and the oscillatory current.

A thermocouple voltmeter is provided to measure the effective voltage across certain circuits in the equipment. The voltmeter is normally bridged across the line connecting the input equipment to the power amplifier, and measures the effective voltage delivered by either the intermediate power amplifier or the radio test oscillator. For purposes of testing, the voltmeter sensitivity may be changed, a number of jacks being provided for this purpose.

Power Bay

The layout of the power bay is shown on Figure 3, and is as follows: terminal block, meters, relays, 12-volt fuses, keys, 160-volt lamps, 60-volt filter, and 160-volt filter. The power circuits are shown on Figure 5. All power connections, except the D.C. plate supply for the radio test oscillator and intermediate amplifier, are made through the power bay. By means of switching keys, meters may be connected into circuit to measure the filament current of any tube in the equipment, the grid current of the oscillators, and the plate current of any tube, with the exception of the intermediate amplifier and the radio test oscillator tubes.

The protective system includes filament, plate, negative grid voltage and fuse alarm circuits. These four circuits are adequately interlocked to give an alarm if the various supply sources are not switched on in the proper sequence or if the supply to any unit fails. Relays inserted in the common return of both modulator plate circuits will operate if there is a failure of filament or plate supply or if there is a failure of carrier supply. Relays are connected in the filament supply of all tubes with the exception of the two volume indicator tubes and the two test oscillator tubes. The negative grid voltage alarm operates if the plate voltage is switched on before the application of the grid polarizing voltage, or if the latter fails during operation. The fuse alarm will operate if any of the fuses on the 12-volt or 160-volt supply blow out. An additional protection is provided

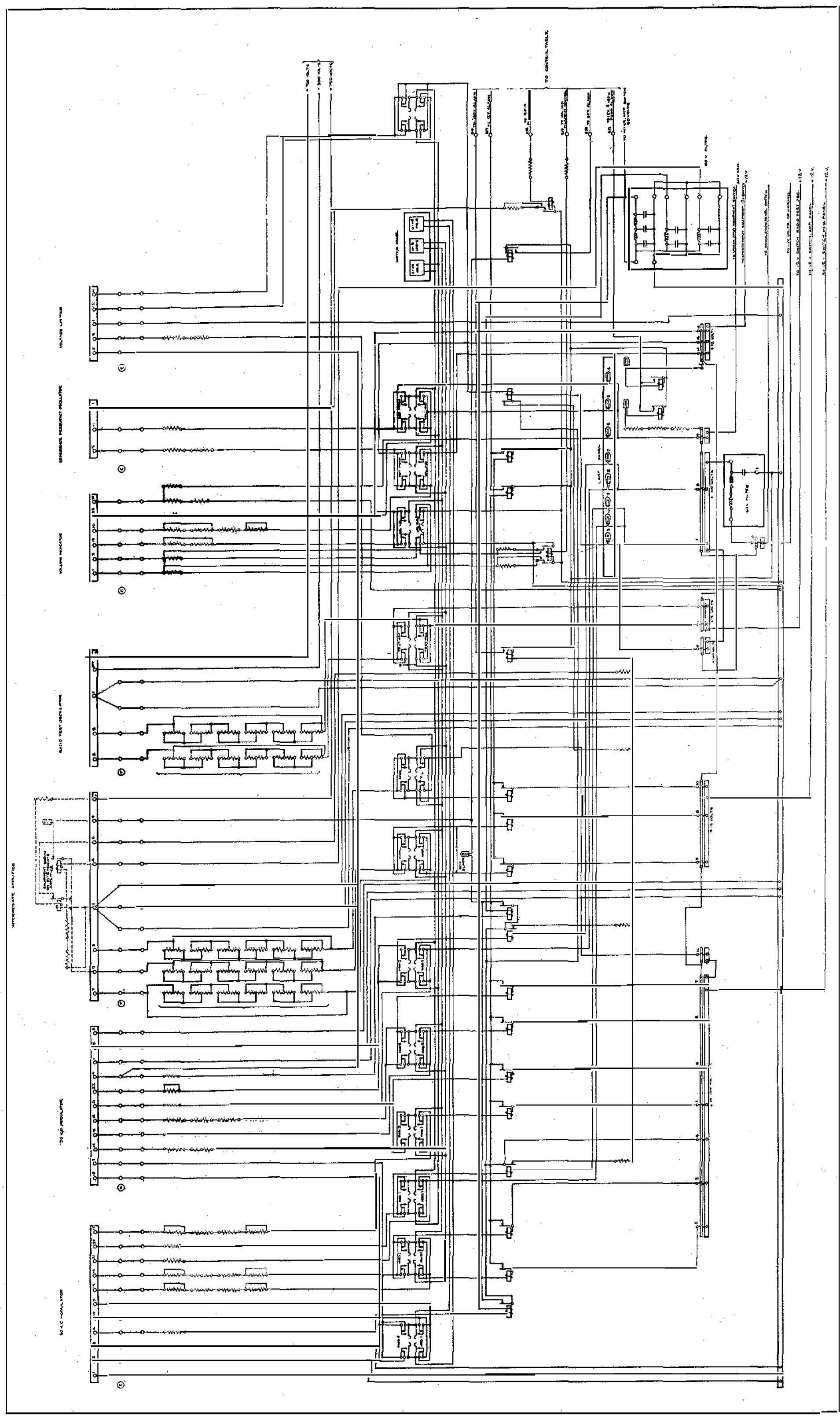


Figure 5—Input Equipment Power Circuit Diagram

in the 160-volt circuit in the form of individual lamps connected in series with each tube or group of tubes forming a unit. The individual alarm relays close master relays associated with four circuits on the control table, marked filament, grid, plate and fuse alarm. Any alarm, if operated, lights the corresponding lamp at the control table and rings a bell.

The power for the input equipment is obtained from two motor generator sets, each having two generators on a common shaft. The first set supplies the filaments of all the tubes, and the plates of the smaller tubes. The second set supplies the grids, and the alarm and control circuits from one generator, and the plates of the 50-watt tubes from the other generator. These machines were supplied to Post Office specification by Messrs. Newton Brothers (Derby), Ltd.

The commutator ripples of the various generators are eliminated by filters inserted in the supply lines to the input equipment. The filter in the filament supply is provided with two electrolytic condensers having capacities of approximately 1,000 microfarads each.

High-Frequency Power Amplifier

The power delivered by the input equipment must be amplified with minimum distortion and good efficiency to the level necessary for satisfactory transmission, that is, from about 25 watts to more than 100 kilowatts. This is accomplished in three stages of amplification employing one, three and thirty water-cooled tubes, respectively. The latter are all of the standard type of 10-kilowatt water-cooled tube shown in Figure 6 manufactured by the Standard Telephones and Cables, Limited, at their works at New Southgate, London.

The copper anode of the tube is cylindrical and is held in a jacket, at the bottom of which water enters tangentially and is given a whirling motion. The heat produced by energy dissipation in the tube is carried away by the cooling water, the temperature of the anode during normal operation being kept below 70° F. The copper anode has an outside diameter of 2″ and a length of 9″. By a special process which has been fully described,[3] it is sealed directly to the glass bulb, which supports the filament and the grid structure, and has an outside diameter of 3½″ and a length of 5″. The filament connections are made through copper-to-glass seals to outside terminals at the base of the tube, and the grid terminal is supported by a glass insulating rod approximately 4″ long. The overall

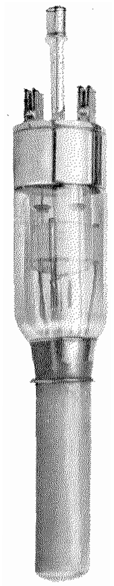


Figure 6—Ten Kilowatt Water-cooled Tube

length of the tube is 20½″. The filament which is 16″ in length, is made of pure tungsten wire of 0.035″ diameter and the grid structure is made of molybdenum, a wire of 0.008″ diameter being wound with a pitch of one-fifteenth of an inch on three supporting rods.

The necessary filament emission is obtained with a filament current of 41 amperes between 21 and 24 volts. The tubes are classified by half-volt steps in six classes and a letter corresponding to each class is engraved on the glass of the bulb. The operating plate voltage is 10,000 volts and the normal operating plate current 1.4 amperes. The grid current may be as high as 0.3 ampere. The plate can dissipate a power of 10 kw. and the grid a power of 250 watts with an ample factor of safety. The amplification constant of the tube is approximately 38, so that the negative grid voltage necessary to bring the plate current to cut-off with an anode voltage of 10,000 volts is 265 volts. The 10 kw. tube will develop an output power of 10 kw. at a single frequency when work-

[3] "A New Type of High Power Vacuum Tube", W. Wilson, *Electrical Communication*, Vol. I, No. 1, August, 1922.

ing into a suitable output circuit. When a number of tubes are used in parallel to amplify a band of frequencies and to work into an output circuit coupled to a radiating antenna and adjusted to have the necessary band width, the conditions are somewhat different. It is very difficult to design economically for the wavelength employed an efficient antenna system to meet in a satisfactory manner the output circuit requirements for a band of frequencies of the width required for satisfactory transmission of speech. Difficulties also arise on account of the tendency of the tubes to generate spurious oscillations and on account of the large capacity of the anode power supply source as compared with the power capacity of one tube. It will be understood, therefore, that the power obtainable at a single frequency from a bank of 10 kw. tubes when arranged to amplify a band of frequencies and to deliver energy into an efficient antenna will be somewhat less than 10 kilowatts per tube.

The principles involved in the design and operation of high-power radio-frequency amplifiers have already been described.[4] In this paper we shall confine ourselves more particularly to a description of the Rugby apparatus, and a few general remarks to explain the arrangements.

In order to obtain high quality reproduction, voice-frequency amplifiers operate on the straight part of the tube characteristic, and the grid input voltage is kept low enough to prevent the grid becoming positive. The efficiency of this type of amplifier is low and the power obtainable per tube is small compared with the rated power of the same tube when used as an oscillator. A voice-frequency amplifier could be made to deliver more power and to do so with increased efficiency by increasing the negative grid polarizing voltage and increasing the grid input voltage; but distortion would result. The energy dissipated in the tube is the time-integrated product of the instantaneous plate voltage and the instantaneous plate current. With the above method of operation no current would be flowing in the tube when the plate voltage is high, because the grid would be highly negative at the same time. Assuming that a suitable output circuit is used, the plate voltage would be small when the plate current is a maximum, and the efficiency of the amplifier would be high; but, since the operation of the tube would extend well over the linear portion of the characteristic, the shape of the amplified wave would be considerably distorted, with the consequent production of harmonics of large amplitude. The harmonics of the low-frequency speech currents would be inside the band of frequencies amplified and would add, therefore, to the original speech frequencies. It is possible however, to work a high-frequency amplifier in the above manner. The bands of harmonics thus produced are well separated from the signal band and it is comparatively easy to eliminate the harmonics from the desired signal and to prevent almost completely their radiation from the transmitting antenna. An efficient amplifier of this type is used at Rugby.

The large amplitude of grid alternating voltage brings the grid to high positive values with respect to the filament. During this portion of the cycle the grid passes a large current, and the grid filament impedance is low. During the next portion of the cycle, the grid becomes highly negative and the grid filament impedance is large. In order to prevent these impedance variations from causing reaction by affecting the anode circuit of the previous stage, it is necessary to include in the interstage circuits a parallel path, between grid and filament, of impedance low enough to reduce to a minimum the effect of the variable impedance of the grid circuit.

The interstage circuits are designed to receive efficiently the energy delivered by the previous stage and to deliver part of this energy at the proper voltage to the grids of the next stage. The circuits are, in effect, step down transformers which present the correct impedance to the anode of the previous stage and a low enough impedance to the grids of the following stage. There is a progressive increase of output power in the successive stages but practically no voltage amplification. The interstage circuits are of the parallel-tuned type. The inductive leg is made of a combination of inductance in series with a parallel arrangement of inductance and resistance on the ground side of the coupling circuit. The grid driving voltage is taken across the parallel inductance and resistance circuit.

[4] A. A. Oswald and J. C. Schelleng, Proc. I. R. E., June, 1925.

This type of circuit, besides meeting the requirements of grid and plate impedance, has a good coupling efficiency for the frequencies within the band to be transmitted, and is inefficient for the bands of harmonics. The circuit has a low reactance for currents at harmonic frequencies, and these are by-passed from plate to ground, very little energy at harmonic frequencies being thus transferred to the next stage.

To apply the above method of interstage coupling, and to provide sufficient flexibility, it was considered necessary to perform the amplification in three steps. The first stage has one tube, the second stage three tubes in parallel and the last stage thirty tubes in parallel. The latter is divided into two units of 15 tubes each, either or both of which can be used to deliver energy into the antenna.

The prevention of harmonic radiation from the antenna is a very important consideration in a system of this kind. As already stated, each interstage circuit eliminates to a large extent the harmonics produced by the previous stage. The output circuit consists essentially of a parallel combination of capacity and inductance, the inductive branch being divided into two sections, one of which is used for tuning and the other for coupling to the antenna system. The circuit is tuned to the mid-frequency of the transmitted band and offers to currents of that frequency an impedance which is determined by band-width considerations and which is of the order of the combined plate-filament impedance of the tubes in the last stage under the actual operating conditions. The circuit has a low reactance for currents at harmonic frequencies, and these are by-passed from plate to ground, most of the energy in the harmonics being dissipated inside the tubes.

The delivery of energy to the anodes of the tubes is pulsating at frequencies from zero to the highest audio frequency in the signal band. The inductance of the high-frequency choke coils inserted between the D.C. supply and the anodes consequently must be low in order to pass these currents without modulating the plate voltage to an undesirable extent. This inductance, however, must be large compared with that of the tuning inductance and it must have a distributed capacity which is small compared with the tuning capacity in order to prevent the choke coil affecting the tuning of the corresponding circuit to an undesirable extent. The reactance of the choke coils used in the various grid circuits must be kept low also in order to prevent the grid currents modulating the grid polarizing potential. It is important also to keep the resistance of the D.C. grid path low inasmuch as the flow of positive grid current through these resistances produces a drop of voltage which is added to the grid polarizing voltage. The function of the blocking condensers is to isolate the high-frequency circuits from the D.C. supply and to by-pass the high-frequency currents to the tuned coupling or output circuits. The reactance of these condensers must be small compared with the impedance of the corresponding tuned circuit.

High-Frequency Power Amplifier

The general arrangement of the power amplifier is shown in Figure 7. The apparatus will

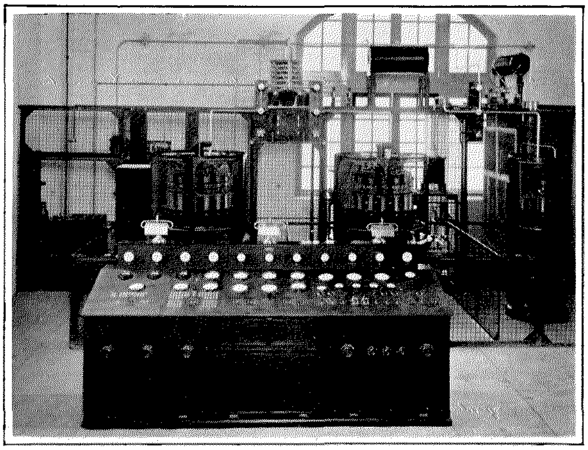


Figure 7—Power Amplifier and Control Table

be described in the following order: one-tube unit, three-tube unit, second interstage circuit, fifteen-tube units, output circuit, power supply system, and controls and protections.

The one-tube unit is shown in Figure 8. It is divided into three compartments, the input circuit, the tube compartment, and the output circuit. The unit is installed in a shielded room and the input circuit is further shielded and is enclosed in a brass box. The input circuit consists essentially of a coupling resistance, a coil which by-passes the rectified grid currents, and a high-frequency by-pass condenser. The negative grid potential is supplied through a filter of two sections, composed of series iron core inductances and shunt condensers. The water is supplied to the tube through a double hose coil, which provides the necessary insulation between the water jacket and ground. The grid and plate are protected against abnormal voltages by spark gaps associated with relays which operate to remove the grid and plate supply in the case of a grid gap, and the plate supply above in the case of a plate gap. The output circuit, which is the first interstage circuit, is mounted at the back of an insulated panel. The tuning inductance and grid inductance can be changed in steps by tappings at the front of the panel. A variometer provides fine tuning adjustment. The circuit is tuned when the radio-frequency currents in the inductive and capacitative legs bear a certain calculated ratio.

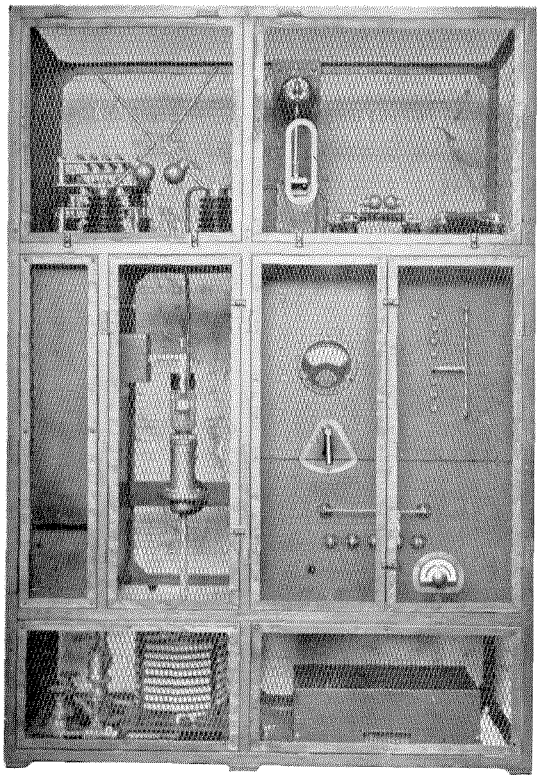


Figure 8—One Tube Unit

An ammeter is switched from one leg of the circuit to the other without breaking the circuit, and the inductance or capacity is adjusted until the correct ratio is obtained. The unit is completely enclosed by metal screening, and if any door is opened, safety switches operate, which trip the D.C. supply.

The three-tube unit can be seen in Figure 7; it is similar in construction to the fifteen-tube

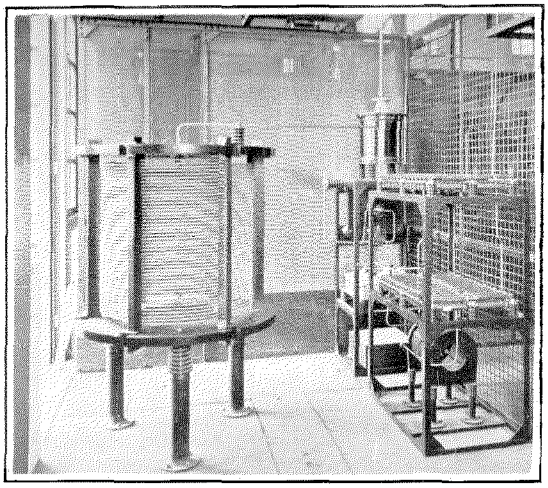


Figure 9—Second Interstage Circuit

unit, and most of the apparatus is detailed in the description of the fifteen-tube unit.

The second interstage circuit, which forms the coupling between the three-tube unit and the two fifteen-tube units, is mounted in three parts: a condenser unit, a tuning inductance, and a grid resistance unit, respectively. It is located in the high-voltage enclosure and can be seen in Figure 9. The negative grid voltage is supplied through a remote-controlled power potentiometer.

Figure 10 shows a fifteen-tube unit prior to installation with the screens removed. The unit is an assembly of the tube mountings, insulating water columns, and apparatus directly associated with the individual tubes. The tubes have their input and output electrodes, respectively, connected to closed bus-bars, which are in the form of circular rings. The whole unit is symmetrical about a vertical axis. The use of such an arrangement leads to an equal distribution of the load between the tubes and a decreased tendency to generate undesired oscillations. The unit is built up in circular tiers and is mounted on a base casting supported on legs from a base ring which rests on the cement floor of the chase. The height of the legs is such that the bottom of the base casting is on a level with the floor around the unit, and the filament transformers, seen at the bottom of

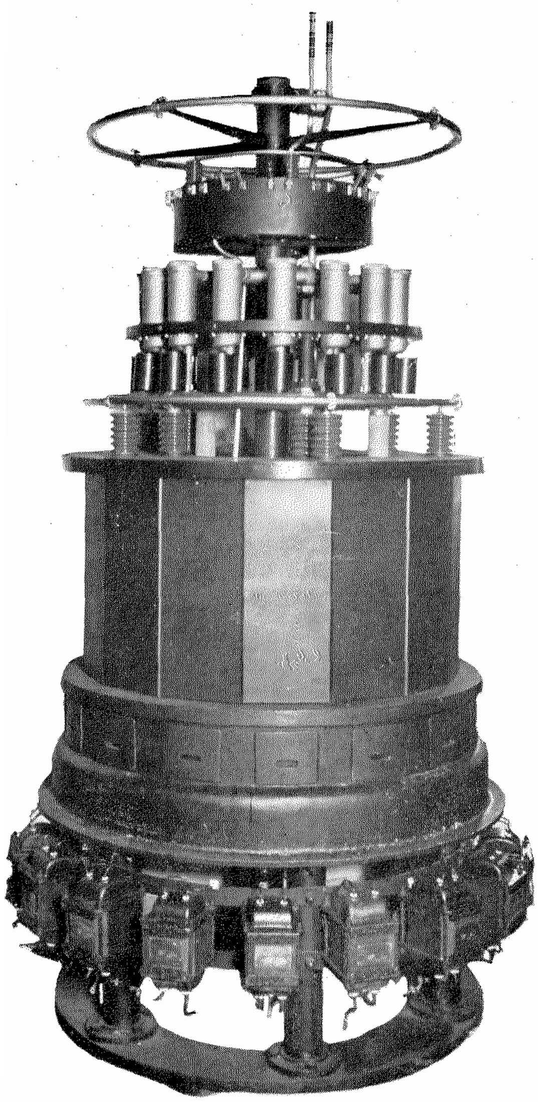


Figure 10—Fifteen Tube Unit

Figure 10, are located below the floor level. The insulating hose coil, which leads the water to and from the tubes, is used as a base for supporting the inlet water header and the tubes. The filament by-pass condensers are carried in a circular tray, and flexible knife switches arranged around the outside of the tray connect directly to the filament terminals of the tubes. In order to prevent certain types of inter-tube oscillations, the anode of each tube is connected to the supply bus through an anti-singing circuit, consisting of a small inductance in parallel with a resistance, and also to an equalizing bus through a resistance. The upper part of the unit is completely enclosed by a metallic screen arranged for quick removal, which affords protection to the operator and also provides a certain amount of shielding between the two units. Access to the unit is obtained thorugh the enclosure gate, which is fitted with a switch arranged to trip the high-voltage oil switch, if the gate is opened when the power is on.

The anode bus-bars of the two banks of fifteen tubes are connected in parallel through anode-disconnect switches and a suitable choke coil to the high-voltage bus-bar. It is, therefore, possible to operate the amplifier with only one bank of tubes in the last stage. When the disconnect switches are in the grounded position, the various protective devices are rendered inoperative. The grid bus-bars of the two banks are connected in parallel through an anti-singing network, which prevents inter-bank oscillations. The tubes are protected against excessive anode and grid voltages as in the case of the other units.

The output circuit comprises essentially a stopping condenser, tuning condensers, a tuning coil, an antenna coupling coil and an antenna tuning coil. The condensers were supplied by Messrs. Dubilier Condenser Company, Ltd., to Post Office specification. The tuning condenser consists of four units in series, two of which are seen in Figure 11. When the two banks of tubes are used in the last stage, the anode tap is connected to the high-voltage terminal of the unit, which is nearest to ground, and is taken one unit higher when only one bank is used. This preserves the relation between the output impedance of the tubes and the impedance of the output circuit. The output circuit coils were designed by the Engineering Department of the British Post Office, which carried out a considerable amount of experimental work to determine the most suitable insulating material for transmitting coils of this type. It was found that American white-wood has a lower dielectric loss than any other material. The coils therefore, are wound on white-wood spiders, which are supported on a wooden framework. The conductor used consists of a very large number of strands, each strand being enamelled and cotton- or silk-insulated. The tuning coil is shown in Figure 12; the antenna tuning and coupling coils are somewhat similar.

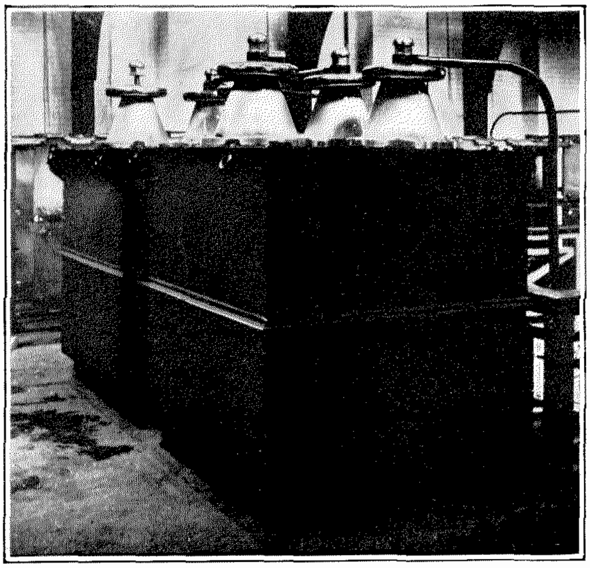


Figure 11—Output Circuit Tuning Condenser*

The antenna used for the telephone transmitter[5] is approximately 1¼ miles long and consists of a cage of eight wires of heavy gauge spaced on spreaders, 12″ in diameter, and supported on six masts arranged in a U shape. The masts were constructed by Messrs. Head Wrightson and Company to Post Office specifications and are of the pivoted and stayed type. Figure 13 is a view of the base of a mast; below the pivot are columns of insulators and a granite cube. The masts are of triangular form with 10 ft. sides and are 820 ft. high; they are designed to withstand a horizontal antenna pull of 10 tons. The earth system consists of an extensive network of copper wires buried a few inches below the ground.

The low resistance of the antenna results in a narrow resonance curve which leads to certain complications which are not encountered in a telegraph set, and the transmission of high quality speech presents a difficult problem notwithstanding the advantage of the single side-band system in this respect. The adjustment of the output circuit, however, is such as to obtain a satisfactory input-response characteristic which is considerably wider than the antenna resonance curve. This widening of the transmission band is accomplished at the expense of additional requirements placed on the water-cooled tubes.

Power Supply

The power supply for the high-frequency power amplifier comprises essentially the filament, the grid, and the anode supplies.

The filament power for the second and third stages is obtained from a 416-volt, 3-phase, 100-cycle system, each tube being supplied from a separate transformer. This arrangement has the advantage of making it possible to measure the D.C. plate current of each tube at a point near ground potential and also permits the insertion of individual current overload relays, in the same part of the circuit. The three-tube unit is supplied from the three phases of the 416-volt, 100-cycle supply. The fifteen-tube units are divided into three sections of five tubes, and each section is supplied from a separate phase. The power for the one-tube unit is sup-

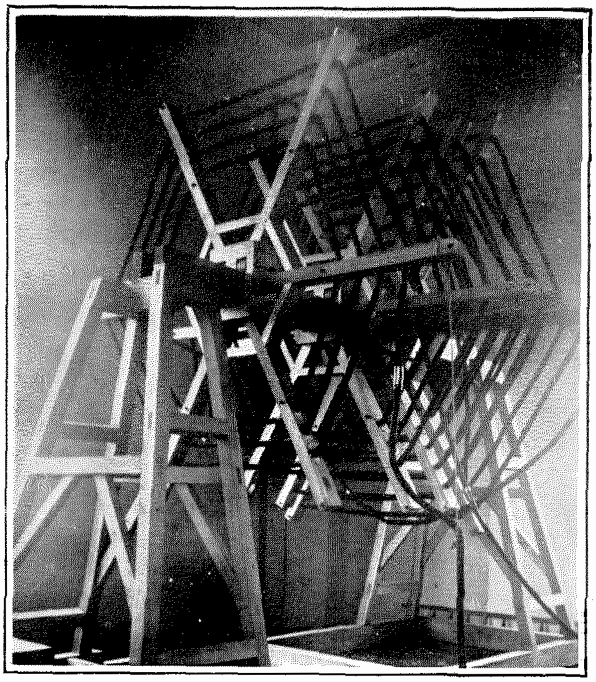


Figure 12—Output Circuit Tuning Coil*

[5] "The Rugby Radio Station", E. H. Shaughnessy, O.B.E., M.I.E.E. Paper read before the Wireless Section of the Institution of Electrical Engineers, April 14, 1926.

*(*Reproduced by Courtesy of the General Post Office*)

plied from a D.C. generator. This arrangement of the filament circuit was found to reduce to a minimum the ripple due to A.C. heating. A six-step rheostat is connected in series with the primary of each transformer to introduce compensating resistances corresponding to the differ-

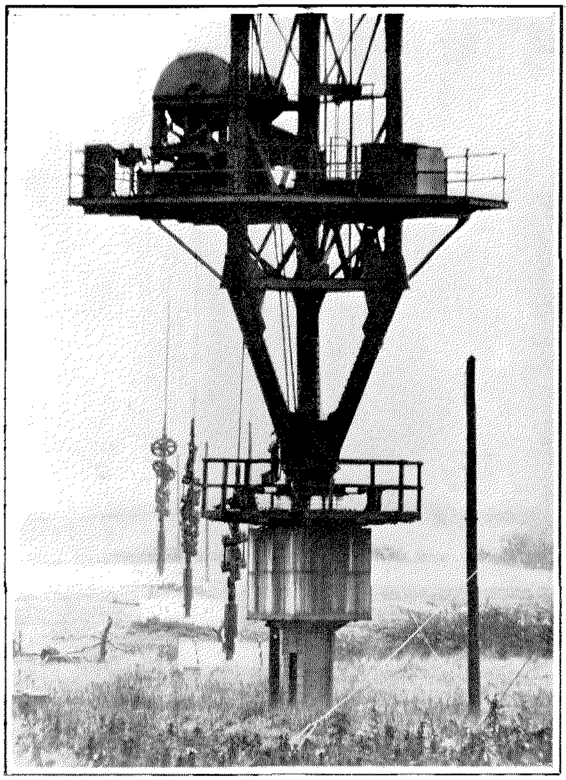


Figure 13—Base of Antenna Mast

ent classes of tubes used. The A.C. filament power is obtained from two 200 K.V.A. frequency converter sets, which were supplied by Messrs. Newton Brothers to British Post Office specification. Each set consists of a 416-volt, 50-cycle, synchronous motor driving a 100-cycle, 3-phase alternator. Tirrill regulators are provided to limit the voltage fluctuations to a very small fraction of the normal voltage.

The grids are supplied with D.C. polarizing voltage through three potentiometers, one for each stage. The impedances of these potentiometers must be relatively low in order to prevent the variations in the D.C. grid current causing distortion by changing the value of the grid polarizing potential. The potentiometer in the third stage of the amplifier is consequently of comparatively large dimensions and dissipates a power of several kilowatts. The supply is obtained from a motor-generator comprising an induction motor with remote-control starting, and a D.C. generator with field control, the voltage being adjusted from the radio transmitting room.

The D.C. anode power is obtained from special high-voltage motor-generator sets supplied by The British Thomson Houston Company to British Post Office specification. Normally two sets are used in series; each set consists essentially of a 2,000-volt, 3-phase motor, coupled to two D.C. generators connected in series. Each generator has an output of 250 kw. at 3,000 volts. The base plates of the sets are insulated from ground, and the mid-connection of the two generators of each set and the neutral point of the motor stator are electrically connected to the base plate. In this way the potential of any portion of the set to the frame is limited to 3,000 volts D.C. When working in series, and for an anode voltage of 12,000 volts, the first base plate would be 3,000 volts above ground, and the second 9,000 volts above ground. The motor of each set is supplied through a separate insulating transformer. Each generator is protected by a high-speed circuit breaker, which inserts a blocking resistance to limit the current and, at the same time, trips the generator field contact. The action of this breaker is very rapid, and a short circuit of the anode supply to ground is of no consequence so far as the power supply is concerned. A general view of the machine room is shown in Figure 14. Two of the three high-voltage motor generator sets appear in the foreground. The sets for filament supply may be seen in the background.

The impedance of the anode power source to the low-frequency currents taken by the amplifier, must be low in order to prevent remodulation by variation of the anode potential. This requirement is more difficult to meet in a single side-band system than in the ordinary system employing both side-bands and carrier. A large by-pass condenser capable of withstanding the full D.C. anode voltage is connected across the machines, in order to reduce the impedance of the source to a satisfactory value. This condenser is shown in Figure 15. The high-voltage supply from the generator bus-bars is connected to the radio transmitting room through high-voltage cables terminating in a steel cubicle provided with an earthing switch, a voltmeter, and an electrically-operated oil circuit breaker with overload and no-voltage trips. The no-volt trip coil of this switch forms part of the scheme of securities described in the next section.

Figure 14—Machine Room

Controls and Protections

In order that serious interruptions of the transmitter may be prevented, and that operation may be efficient and continuous, it is obvious that the system must include an extensive arrangement of controls and protections. The whole of the Rugby control equipment is centralized and located at a control table, which can be seen in Figures 16 and 7. The arrangement of the control table is such as to enable the operator in charge of the transmitter to check easily the important voltages and currents, and to adjust those which need to be held constant within a narrow margin. Meters are arranged to read the individual plate current of any tube. For this purpose the current from the centre point of the secondary winding of each filament-heating transformer is connected to ground through a jack on the control table. By inserting a dummy plug into this jack, the plate current of the tube is passed through a plate current meter. Provision is made also for reading the total grid current on each stage, and the peak alternating plate voltage on the third stage. These meters occupy the first and second sections on the left of the control table. Those on the third section register the potential of the filament bus and the potential of the negative grid bus for the input equipment, the anode D.C. bus voltage, the total anode current, the negative grid polarizing potentials, and the filament primary voltage for the power amplifier. The next section comprises three high-frequency ammeters measuring the antenna current and

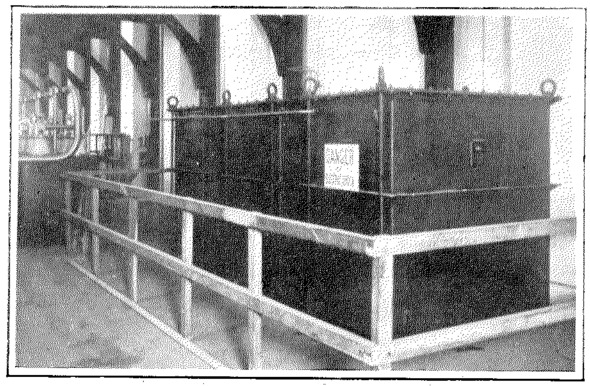


Figure 15—High Voltage Smoothing Condenser

the high-frequency currents in the inductive and the capacitative legs of the output circuit. Below these are five smaller meters, the first one reading the level of the incoming speech, the second the grid input voltage to the power amplifier, and the last three the peak amplitude of the antenna currents. The instrument on the last section indicates the water pressure. The various instruments on the vertical section of

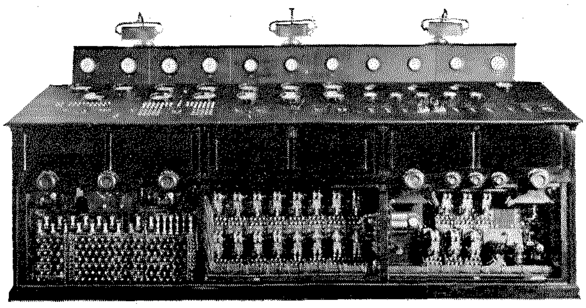


Figure 16—Control Table

the control table are thermometers registering the temperatures of the cooling water, and electric clocks recording the life of the tubes. The thermometers have electric contacts which actuate relays when the temperature exceeds a safe value. Various machines can be started and stopped and circuit breakers opened or closed from the control position.

The control circuits have interlocking features arranged to ensure that power is applied in the proper sequence and only under safe conditions. For example, it is not possible to close the filament-heating circuits or the high-voltage oil switch without the correct amount of circulating water at a safe temperature; it is not possible to close the high-voltage switch without first applying the negative grid potentials and shutting the gates of the enclosure. When in operation, the transmitter is protected against abnormal conditions by a number of interlocked relays. There is, for example, an overload relay connected in the lead from the mid-tap of the secondaries of each filament transformer. Any tube passing a plate current exceeding the safe limit for the tube, will operate a relay and trip the high-voltage switch. Safety air gaps are provided on the anode and the grid bus of each unit. If any one of these bus-bars attains a voltage exceeding a predetermined value, the gap will break down and a relay will trip the high-voltage D.C. oil switch in case of a spark at an anode gap, and the D.C. oil switch and the grid polarizing circuit breaker if a spark occurs at a grid gap. Relays are operated also by the flow and the temperature of the water. If the flow of water is not sufficient, or if the temperature is too high, both the high-voltage oil switch and the filament supply switches will be opened.

If any unit is out of service the corresponding anode-disconnect switch is opened and the high-voltage D.C. bus-bar on the unit is grounded. This automatically closes contacts which render inoperative all the securities connected to that particular unit. This facilitates testing of the unit, since it is then possible to close circuits without regard to a given sequence, or to leave circuits open which normally should be closed.

A feature incorporated in the control system which proved to be of great value, is the provision of a number of small lamps operated by contacts on the various relays. The lamps indicate the origin of any abnormal condition.

Signal-Strength Measurements

By E. H. ULLRICH

European Engineering Department, International Standard Electric Corporation

IN the progress which has been made during the past few years in placing radio transmission upon a quantitative basis, perhaps the most important factor is the development of means for accurately measuring the field strength of the transmitted and the received waves. An engineering undertaking such, for example, as a transatlantic radio telephonic circuit, cannot be economically installed and maintained unless measurements are made both of signal-strength and of atmospheric radio noise. Furthermore, measurements of signal-strength are essential in determining the radiation characteristics of a transmitting station and in locating receiving stations advantageously.

The first type of signal-strength measuring set to be described is very simple and is intended only for the measurement of field strength near a transmitting station in order to determine its radiation characteristics. It consists of a receiving loop with tuning condenser and a calibrated tube-voltmeter to measure the potential difference set up across the loop as a result of the incoming signal voltage. When the tuning condenser has been adjusted to give maximum voltage across the loop, the signal-strength can be calculated as follows:

Let V = Maximum potential difference across the loop.

R = High frequency resistance of the loop and tuning condenser.

L = Inductance of the loop in henries.

$\frac{\omega}{2\pi}$ = Frequency of the incoming waves.

λ = Wave-length of the incoming waves in metres.

E = Signal-strength of the incoming waves in volts per metre.

h = Effective height of the loop in metres.

A = Area of the receiving loop in square metres.

T = Number of turns of wire in the receiving loop.

Then

$$V = hE\left[1+\frac{\omega^2 L^2}{R^2}\right]^{\frac{1}{2}}$$

and

$$h = \frac{2\pi\ A\ T}{\lambda}$$

The high frequency resistance is measured by a substitution method with apparatus that can be used also to find the antennae resistance, thus rendering possible an evaluation of the efficiency of generation of high frequency energy by a transmitting station. It consists simply of a shielded oscillator, loosely coupled to a secondary circuit containing a variable known high frequency resistance, a thermo-junction and a tuning condenser. By adjustment of the variable resistance, the thermocouple current is made the same for the two cases:

(1) When the output terminals of the secondary are short-circuited.

(2) When the circuit to be measured is connected across the output terminals.

Provided that the secondary circuit is tuned in both cases, the difference in the variable resistance readings gives the high frequency resistance required.

As the variation of high frequency resistance of one or both of the two tuning condensers might show appreciable variation with condenser setting, it is desirable that in Case (2) the tuning should be carried out by means of the condenser belonging to the loop. In other words, the condenser used for tuning the secondary circuit in Case (1) should not be changed when the transfer is made to Case (2). The sensitiveness of the apparatus can be varied by adding resistance at the middle of the loop. Inasmuch as the deflection of a tube-voltmeter is roughly proportional to the square of the input and falls off rapidly as the distance is increased, the apparatus can be used successfully only in the immediate vicinity of a radio station.

The second type of set, which is capable of measuring weak electric fields, has actually been used over the wide wave length range of 40 metres to 18,000 metres, although its major use has been that of measuring transatlantic transmission on some 5,000 metres. The principle is described in the paper [1] read before the

[1] "Radio Transmission Measurements," by Bowen, Englund and Friis. Proceedings of the Institute of Radio Engineers, Vol. 2, No. 2.

Institute of Radio Engineers on March 21, 1923, although it was at that time restricted to the range of long wave-lengths of say 18,000–5,000 metres. Figure 1 illustrates the set connections

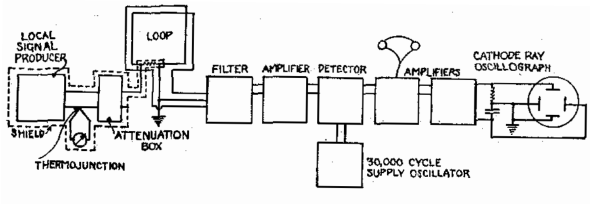


Fig. 1—Simplified Diagram of Long Wave Field Strength Set, Type 2

schematically and Figure 2 shows the apparatus that has been used since the summer of 1924 at Chedzoy, Bridgwater, England, for the measurement of American stations between these wave-lengths. Some 20,000 observations of field strength between 18,000 and 5,000 metres have been made in England with apparatus of this type. The description, which follows, relates more particularly to the long wave set, the slight modification in the shorter wave apparatus being pointed out later.

The signal received on the loop aerial is compared directly with a variable local signal introduced into the loop across a small resistance at its centre and set to the same frequency as the incoming signal, by the method of beats. The local voltage is obtained from a shielded oscillator, the current output of which, after being measured with a thermo-junction, is passed through an artificial line of known variable attenuation and finally through the resistance at the centre of the loop. The local signal voltage, which is equal to the product of the known current and the known resistance, is adjusted to equality with the incoming voltage, a superheterodyne receiver being used as an indicator. If prearranged continuous wave signals are being sent from the transmitting station, adjustment of the local signal may be made aurally during short periods of silence of the incoming note. If a station is being measured on traffic, a visual comparison is made, as it is then desirable to turn the loop in order to remove the incoming waves while the local signal is being adjusted. At Chedzoy a cathode ray oscillograph is employed, the respective voltages across the two pairs of plates being obtained by tapping across a resistance and condenser, respectively, in series in the output circuit of the receiver. The trace produced by a continuous wave signal received under these conditions is an ellipse, the major axis of which may be measured. On account of the possibility of different noise-strengths in the two directions

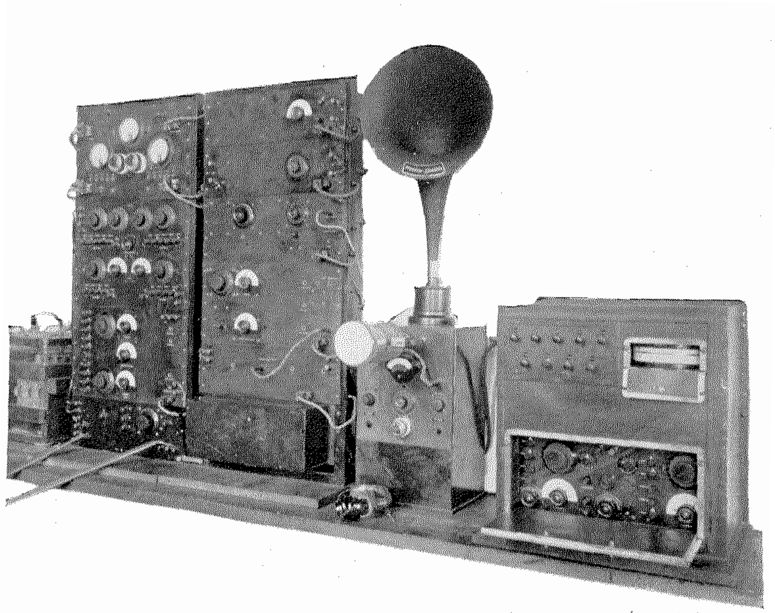


Fig. 2—Long Wave Field Strength Measuring Set, Type 2

of the loop, the aural method breaks down when the loop is rotated; in such a condition the ear is no longer accurate in its comparisons.

The chief sources of error are the following:

(1) The artificial line actually used is variable in steps of one mile of standard cable (i.e., a factor of 0.9) so that intermediate values cannot be obtained.

(2) The personal error in adjusting the incoming and local signals to equality.

(3) The presence of harmonics in the local signal. The harmonics increase the current going through the thermocouple but they are not effective in setting up an appreciable voltage across the ends of the loop, which is tuned to the fundamental.

(4) Attenuation of the local signal current, due to capacity between wires after it has left the artificial line.

(5) Direct "pick-up," into the loop, of local signal, due to inductive or capacitative effects.

No. (1) means that there is a 10 per cent. difference between two adjacent settings of the artificial line. It is possible so to choose the nearest setting that the error is not more than ± 5 per cent. For the purposes of the measurements, this was considered to be sufficiently accurate. The error can be made much smaller by making the steps of the artificial line less than one mile of standard cable.

No. (2) does not involve an error of more than about 2½ per cent., except when, owing to the radio noise, the signal is not clearly audible.

No. (3) can be made entirely negligible by employing an oscillator that is near the point of non-oscillation and using, if necessary, coupled tuned circuits. In the apparatus mentioned above, no elaborate precautions were taken, but the strength of the second harmonic was only 3 per cent. of the fundamental.

No. (4) is entirely negligible, on account of the low resistance (0.638 ohm) through which the circuit is closed, unless the out and return conductors are brought very close together for long distances.

No. (5) in the long wave set is not discernible; in the short wave set it is just discernible but still quite negligible. It is known that statements to the contrary have been published, i.e., to the effect that the error involved in direct "pick-up" is 20 per cent., even under the most favorable conditions; and it is further known that these statements, made originally by investigators on the assumption that the apparatus is not shielded, have been accepted by others as final and as applicable when the apparatus is shielded. These contrary suggestions, however, are not supported by present experience. If the local signal oscillator is doubly shielded and if its inductances are made of toroidal windings on iron-dust cores, there is no detectable leakage at all to the receiving set at 5,000 metres. It is further to be noted that if such leakage did exist, there would be no possibility of its being overlooked, for it would make itself heard in the telephones of the receiver or seen on the oscillograph. Even in the early hours of the morning, when radio noise has fallen to zero, when, in fact, a signal of 0.1 microvolts per metre at 57 kilocycles can be heard quite distinctly—although the minimum signal audible through the noise in the afternoon is of the order of 1 microvolt per metre—no leakage at all can be detected. When it is borne in mind that sets can be operated successfully on just this same principle down at 40 metres, no further refutation of the suggestion that there is a "pick-up" error is needed.

The short wave set already referred to is designed to measure weak fields over the range of 120 to 40 metres. This set, which was constructed in the Bell Telephone Laboratories, affords striking testimony of what can be accomplished by effective shielding. The inner brass box, in which the apparatus is mounted, has a removable back, held in position by a large number of screws placed at intervals of about half an inch. The whole is placed inside a second brass box. The meter recording the d.c. output of the thermocouple is mounted inside the set, so as to be visible from the front. The current divider, although of resistance wire with minimum inductance and distributed capacity, has had to be calibrated for frequency.

The receiving set is a superheterodyne employing four stages of high frequency amplification after the first detector. The "pick-up" is audible when the full amplification is used, but it is, of course, a constant error, not a percentage, and is quite unimportant even at 40 metres in comparison with the signals that traverse the Atlantic.

Sets for the broadcasting range differ in certain respects from the preceding. They are portable and employ a potentiometer current divider instead of an artificial line. Figure 3 is a photograph of a set working over the range of 225 to 2,000 metres and capable of measuring signals from about 10 to 100,000 microvolts per metre. The receiver is a superheterodyne set employing three stages of intermediate frequency amplification. As an indicator of the strength of the signal for adjustment purposes, a microammeter is plugged into the second detector, the steady plate-current of which is balanced out in the usual way. The connection between the local signal generator and the receiver is made by means of the brass-shielded connecting piece seen on the left of the set in Figure 3. The direct "pick-up" into the loop is just audible within the broadcasting wave-length range, but not large enough to be measured. No special precautions have been taken for the elimination of harmonics in the local signal. A high degree of accuracy is not required inasmuch as the only function of the set is to obtain sufficiently accurate signal-strength measurements to aid in the choice of sites for broadcasting stations.

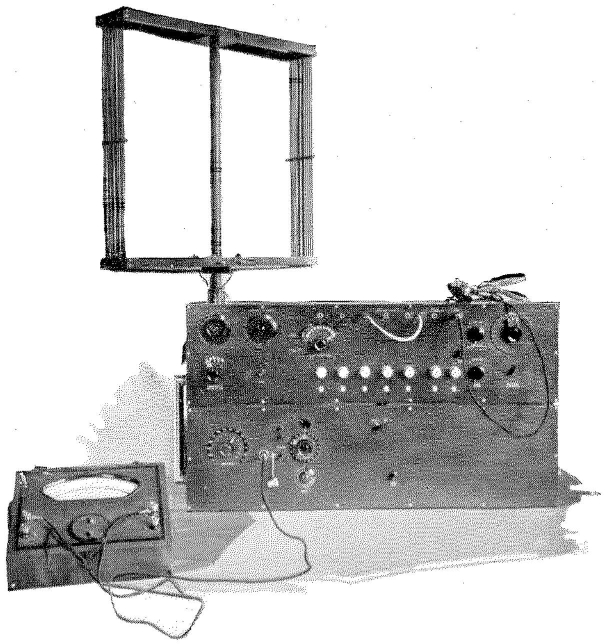
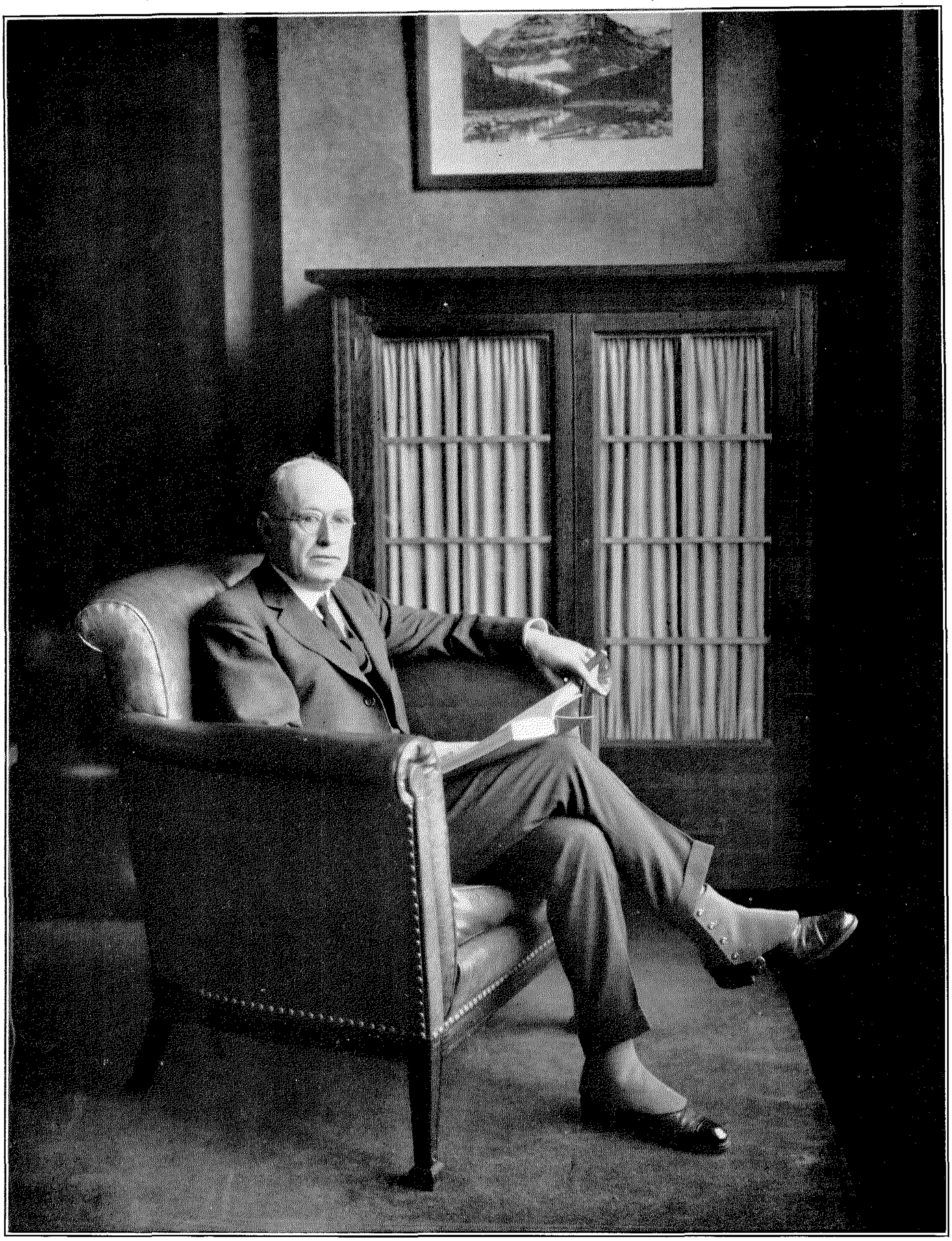


Fig. 3—Portable Field Strength Measuring Set for the Broadcasting Range



Henry Fleetwood Albright
1868-1926

In Memoriam
Henry Fleetwood Albright

Henry Fleetwood Albright, Vice President in Charge of Manufacturing and a director of the Western Electric Company, died in New York on Tuesday, May 11, 1926, at the age of fifty-eight.

Mr. Albright's connection with the Western Electric Company covered a period of thirty-four years. His outstanding contributions to the progress of the company were made while in charge of its manufacturing problems. He was largely responsible for building the great works of that company at Hawthorne, Illinois, near Chicago, which were begun in 1904. In this plant as many as forty thousand people have been employed at one time. His most recent achievement was the planning and construction of the new large works of the Western Electric Company at Kearny, New Jersey, near New York.

His connection with the International Standard Electric Corporation and its predecessor companies dated from the year 1903 when he was consulted regarding the plans for the North Woolwich cable plant of the associated London Company. Beginning with that year, he also visited the plants of our associated companies in a number of European cities and studied general plans for future expansion, including not only problems involving the acquisition of land and the erection of buildings but also details regarding machinery and equipment.

From time to time, he prepared ultimate detailed development plans for new factory facilities at Antwerp and Paris. Certain of the buildings projected are now in course of construction, some have been completed and others are still to be erected. When as a result of post-war telephone expansion the associated London Company was faced with the necessity of increasing its manufacturing plant, he participated in the discussions which led to the choice of the site at Wembley. After the earthquake in Japan in September, 1923, he visited Tokyo and advised on the ultimate plans for the reconstruction and development of the plants of the Nippon Electric Company, Ltd. In all these projects, he displayed great engineering knowledge and vision.

Mr. Albright was generally recognized as a pioneer in scientific management and introduced functionalization in manufacture. Previously each department in the shop had its own punch presses, lathes, drill presses, etc. He noticed that one department operated punch presses more efficiently than the others, another drill presses, and so on. Thereafter he had the best men on punch presses do that work for all departments and the same with other machinery. Thus each department confined its efforts to work which it could perform most efficiently.

In business he was a hard man—towards slackers. He was abhorrent of alibis, but he once remarked that he always had increased respect for a man who frankly confessed a mistake. He was a driver but he drove no one as hard as himself and even those who thought him hard were forced to agree on one thing—that he was fair.

The Board of Directors of the International Standard Electric Corporation has passed the following resolution as a mark of its respect and appreciation:

Whereas, The Board of Directors of the International Standard Electric Corporation, formerly International Western Electric Company, has learned with deep sorrow of the untimely death on Tuesday, May 11, 1926, of Henry Fleetwood Albright, a former director of this corporation.

And Whereas, Mr. Albright has rendered great service to this corporation through many years and in many lands, in the design of manufacturing plants and in their operation; and has given freely of his prudent, forceful and wise counsel; and further has left many warm friends on this board and among the officers and employees of this corporation;

Therefore, on motion, duly made, seconded and unanimously carried it was

Resolved, That this board record its deep appreciation of Mr. Albright's long and conspicuous services in the foreign business of this corporation, and express its deepest sympathy to his family, and it was

Further Resolved, That a copy of these minutes be sent to Mr. Albright's family.

Time Clock Systems

By W. G. BRITTEN

Engineering Department, International Standard Electric Corporation

INASMUCH as time is a controlling factor in the co-ordination of human activities, it is essential that there be a common time system in each community or nation in harmony with the systems used in other localities. Consequently, it is desirable that all time clocks in a community agree with each other and with the standard time in use elsewhere. A universal time system, which is capable of meeting these requirements with a high degree of accuracy, is described in this paper.

The correct time of day is obtained by the observation of certain fixed stars which cross the meridian at a known time. In the United States, observation is made by the Government at certain centers from which time is transmitted electrically over land wires at noon each day to other distributing points throughout the country. It is also transmitted by wireless from various wireless stations thereby making it possible to obtain the correct time at least once each day on land and at sea.

In determining the correct time, the passage of the star over each of several lines, which are marked on the transit telescope lens, is recorded on a chronograph as are also the second beats received electrically from a high grade, accurately adjusted master clock. By comparing these records on the chronograph the accuracy of the master clock is determined and proper adjustments are made in the regulation of the clock if any are necessary.

The Washington master clock is equipped with contacts to transmit correct time over telegraph circuits to various important centers of the country where other master clocks owned and operated by the Telegraph Company are installed. By means of chronographs the accuracy of the several master clocks is compared once each day with the time received from the Washington clock.

The transmission of time from the Washington master clock is accomplished by means of contacts in the clock which are operated automatically to complete a cycle every five minutes in the twenty-four hours as shown graphically in Figure 1. This figure represents the signals as they would be recorded on a chronograph where a pen draws a line on a sheet of paper, moving along at a uniform rate, and is

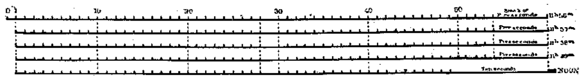


Figure 1—Time Signals from Washington Master Clock

actuated by an electromagnet to make a mark at each tick of the transmitting clock. Each day at 11:55 A.M. the clock circuits, operated from relays connected to the master clock, are closed and during four of the five minutes, second impulses are transmitted with silent periods during the 29th, 55th, 56th, 57th, 58th and 59th seconds as shown in the figure. During the fifth minute the transmission of second impulses differs from the first four minutes in that the last silent interval extends for a period of ten seconds from the 49th to the 59th second. The first impulse after the ten second silent period is exactly 12 o'clock noon.

The several breaks in the second impulses enable those listening to a telegraph sounder or selector bell in a telegraph or telephone office to recognize the middle and end of each minute and particularly the end of the last minute with the ten second interval.

The master clocks operated by the Telegraph Company and located in important cities serve the purpose of furnishing correct time over large areas. By means of spring contacts in the clocks and necessary relay equipments, circuits are provided which repeat the time in several ways to meet various requirements. These consist of circuits over which second impulses are continuously repeated, circuits for synchronizing other clocks every hour and circuits for transmitting time during the five minute noon period as above described.

One of the most important uses of this time system is the correction of time clocks in railway service where, in order to obtain successful railway operation, it is necessary that all clocks and watches agree. Here the time is received by the railroad companies from the Telegraph Company once each day and is retransmitted by them over their own telegraph circuits and train dispatching circuits to all stations. The time circuit is connected direct to the telephone and telegraph circuits through repeating relays which repeat the second impulses in unison with the impulses received from the master clocks. The second beats are then received by each station through the means of telegraph sounders or selector bells which tap each time an impulse is received, making it possible to check the local clocks. If the clocks in the several stations are equipped with synchronizing mechanism they may be synchronized automatically. High grade clocks which are synchronized once each hour by the master clock are also usually located at railway division points by means of which the dispatchers and operators can furnish correct time and check time pieces whenever desired. In this way it is possible to keep all time pieces over the entire system in agreement.

A complete clock system manufactured by the Self Winding Clock Co. for public and office buildings, telephone exchanges, railroads, factories, universities or other organizations, consists in general of a number of clocks operated from one master clock and grouped in a manner some-

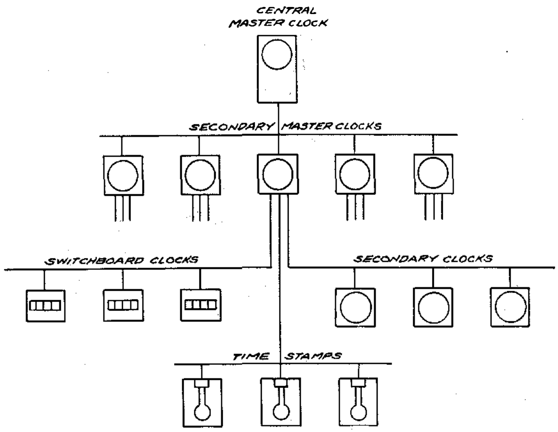


Figure 2—Schematic of Complete Clock System

what similar to Figure 2. The master clock is a high grade self-winding clock of the 60 beat mercurial compensated pendulum type shown in Figure 3 and known as the District Master Clock. The adjustments provided are such that the clock can be made to keep very accurate time over a long period. Operation is continuous since winding is accomplished every hour by means of a small motor located in the clock

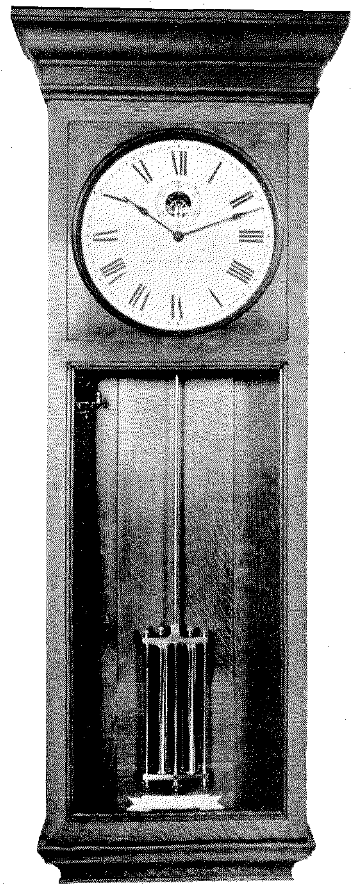


Figure 3—District Master Clock

and automatically operated through the closure of winding contacts. Three other sets of contacts may be provided to close at various intervals for operating and controlling, through suitable relay equipments, local master clocks, secondary clocks, switchboard clocks and time stamps.

One set of contacts, called the synchronizing contacts, closes once each hour on the even hour and sends out an impulse which brings the local master clocks and program clocks connected to this circuit into synchronism with the District Master Clock.

The second set of contacts is for operating secondary clocks of the electromagnet type. These contacts close twice each minute on the

20th and 40th seconds and for each closure the hands of all secondary clocks are stepped forward one-half minute.

The third set of contacts is arranged to close ten times per minute at six second intervals and will operate magnetic switchboard clocks.

An additional set of contacts, closing once each minute for operating time stamps, can be added to the master clock.

In a system comprising a large number of clocks of various kinds it is desirable to use the master clock for synchronizing purposes only and install several local master clocks for operating the several clock circuits. This prevents overloading the central master clock with contacts which might otherwise affect its accuracy and simplifies the system from a maintenance standpoint.

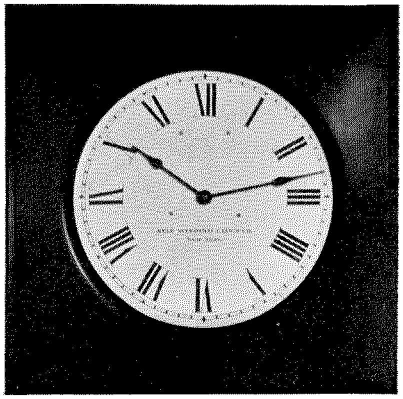


Figure 4—Local or Secondary Master Clock

The local or secondary master clocks, Figure 4, which are synchronized by the general master clock are regular clock units of the self-winding, 120 beat movement type. They are so constructed that the time is corrected once each hour by an impulse from the central master clock so that the maximum variation of the clock from correct time is the amount it is apt to gain or lose in one hour. This synchronizing is effected by an electromechanical resetting arrangement, forming part of each clock, which comes into phase for operation during a four minute period every hour. The period usually begins at two minutes to and ends at two minutes past the hour, these limits being sufficient to take care of the maximum hourly error which is ever apt to occur in a clock of this type. The requirements, however, are that the clock shall not gain or lose more than thirty seconds in twenty-four hours regardless of synchronization. At no other period is the synchronizing mechanism in phase for being operated so that it is not affected by currents which may pass over the line during periods outside the four minute intervals. This feature permits tests being made at any time when synchronizing impulses are not being transmitted.

The secondary master clocks may be equipped with contacts for operating secondary clocks and switchboard clocks in the same manner as that described for the general master clock and contacts may be furnished also for controlling time stamps.

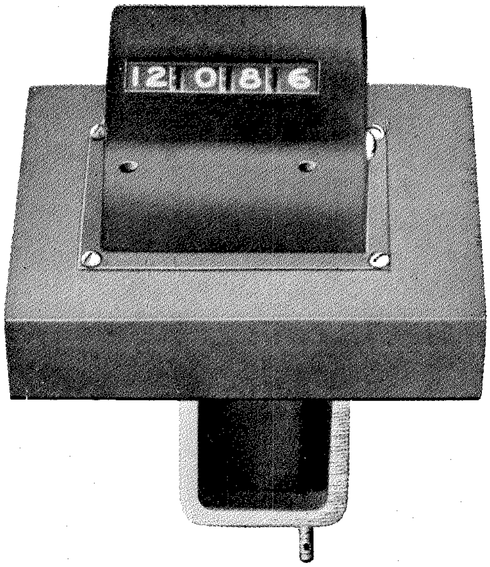


Figure 5—Electromagnetic Clock used in Telephone Exchange

The secondary clocks are of the same general appearance as the secondary master clock. They differ, however, in that the regular clock movement is replaced by a magnetic device for operating the clock hands. An impulse received from a central master or a secondary master clock twice each minute on the 20th and 40th seconds causes the magnetic device to advance the clock hand one-half minute for each impulse. The secondary clocks are therefore always correct with the master clock within the limit of twenty seconds and since they have no regular clock movements they require little attention.

The electromagnetic clock shown in Figure 5 is similar to a message register, familiar to telephone men, and gives the time in hours,

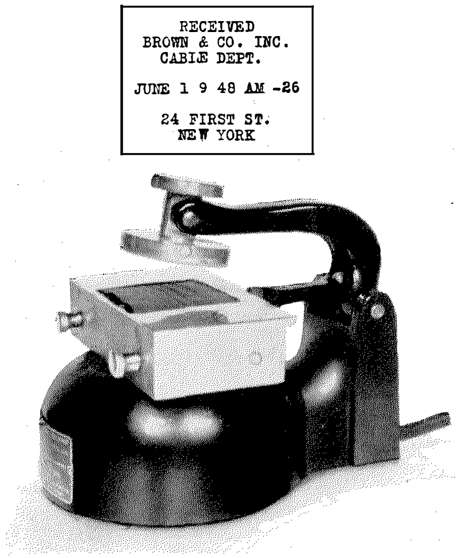


Figure 6—Time Stamp and Sample Stamping Attached

minutes and tenths of minutes. It differs from a standard type clock in that there is no regular clock dial or clock movement and the time is read numerically. For example a reading of 12086 would be interpreted as eight and six-tenths minutes after twelve o'clock. This type of clock is used quite extensively in telephone exchanges for timing calls and therefore is arranged to mount in the switchboard keyshelf in order to be easily observed by the operator.

Time stamps are necessary in commercial houses, telegraph offices, factories, etc., for the purpose of stamping the time of receipt or transmittal of papers and orders. For such purposes it is very desirable to record the correct time. This is possible with the electric time stamp when arranged to be controlled by a master clock. The mechanism in the body of the stamp consists of a small electromagnet which advances the time indicator on the stamp once each minute in response to impulses received over the circuit from the master clock. The time stamp and a specimen ticket stamped by it are shown in Figure 6.

The clock known as a program clock is a self-winding, pendulum type clock with or without synchronizing mechanism. In addition to furnishing time, by means of a standard dial, it is arranged with a mechanism for opening and closing one or two electric circuits at certain definite intervals during the day. The duration of each closure is from three to five seconds and the time between closures is not less than five minutes. Such a clock is suitable for automatically ringing a large number of bells at definite periods each day and the time of ringing is correct, within the slight variation of the particular clock, when it is synchronized hourly by the central master clock.

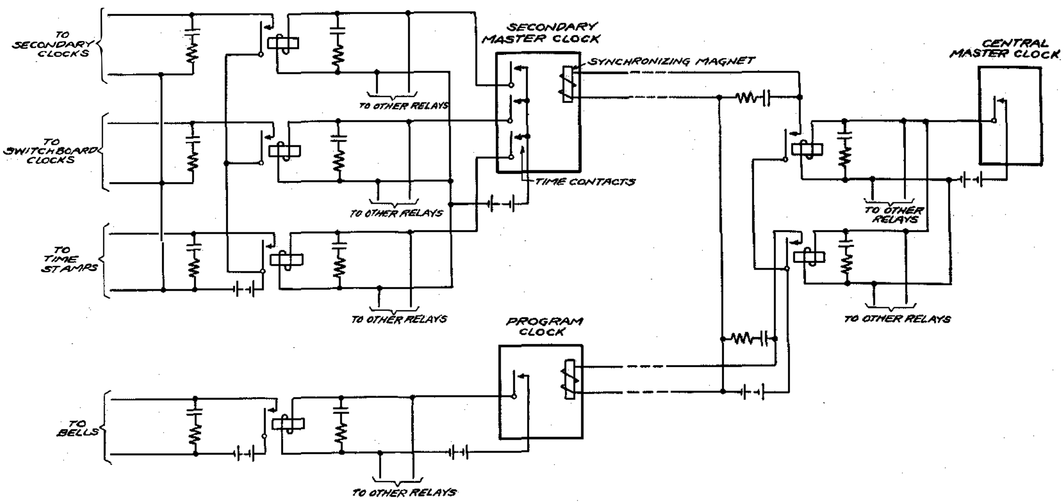


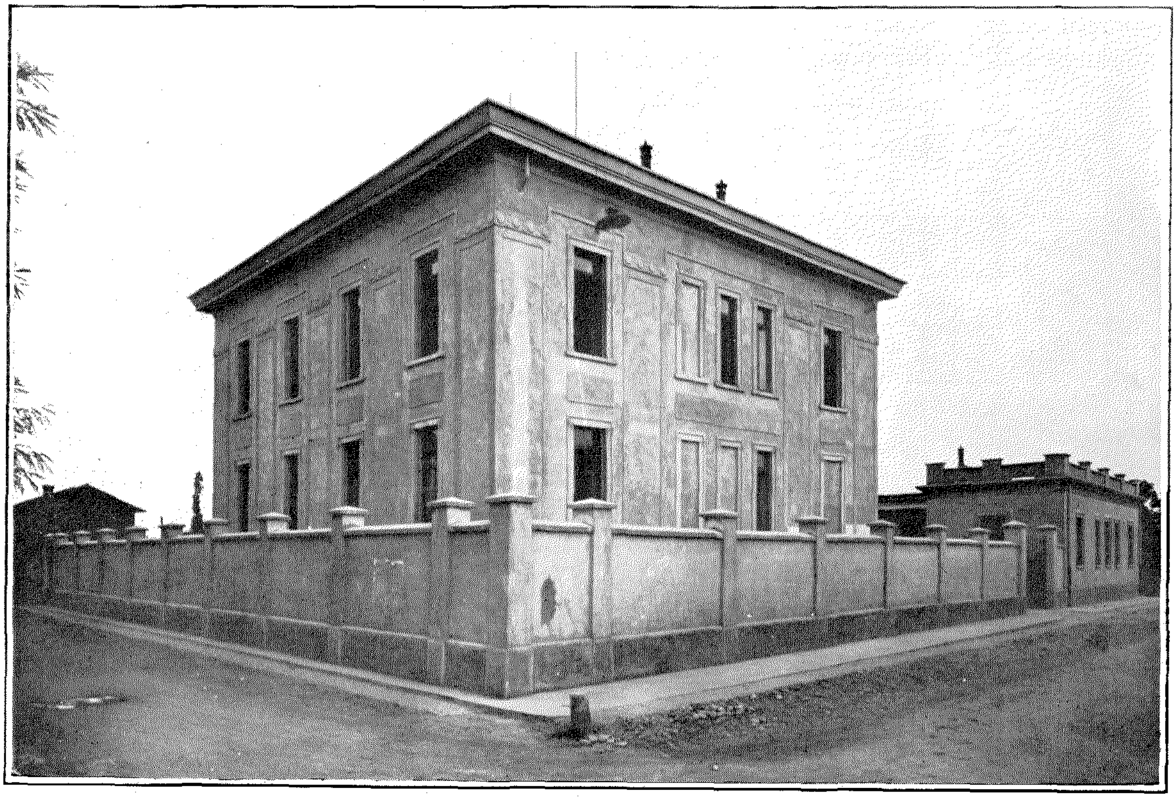
Figure 7—Clock System, Wire Diagram

There is another service derived from clock systems which is valuable to jewelers. It consists of a circuit over which an impulse is transmitted each second in unison with the swing of a master clock pendulum. By means of sounders connected to this circuit jewelers may receive audible second beats which are desirable in connection with the general repair and manufacture of clocks.

In any clock system where a large number of clocks or time stamps are in operation it is necessary to transmit the impulses through relays as shown in the wiring sketch, Figure 7. By the use of relays the current passing through any set of contacts is limited to the proper amount thereby preventing contact trouble. Increasing the number of relays in a system permits an increase in the number of clocks with the result that one central master clock will operate a large number of local master clocks, secondary clocks and time stamps.

The battery necessary for operating a clock system should consist of a continuous supply of at least 24 volts and of sufficient capacity to operate the ultimate number of clocks which may be installed. A 24 volt battery of 60 ampere capacity is large enough to operate over a period of several days a system consisting of two master clocks, 24 secondary clocks, 24 switchboard clocks and 50 time stamps.

In the foregoing an attempt is made to show how time, regulated by master clocks, may be dispensed with great accuracy. It will be evident that the system described may be extended considerably and its application broadened to operate other electro-magnetic devices, such as whistles and sirens to indicate the beginning and end of working periods. Due to its great flexibility, all actions controlled by a time schedule may, in fact, be directed accurately by the master controlled clock system.



Repeater Station at San Guilian. Milan—Turin—Genoa Cable

Spowart Enclosed Gear Type Earth Boring Machine

By H. P. MILLER

China Electric Company, Limited

HIGH wage scales and emphasis on cost reduction have prompted development in the last few years of many labor saving devices for the construction and maintenance of outside telephone plant. That their use is fully justified by the savings effected has been proved by experience. Economies result not only from a marked reduction in field forces and consequent decreased labor cost, both direct and supervisory, but also in capital charges during construction due to acceleration of the work.

Among devices for outside plant construction work previously described,[1] the earth boring machine undoubtedly ranks among the foremost in the saving of labor and time in pole line construction. Within the past two years it has been found possible to increase its usefulness through greater flexibility in design; the improved device is known as the Spowart Enclosed Gear Type Earth Boring Machine. This paper describes the new machine and gives an indication of the results that can be obtained by its use.

The new Spowart model is readily convertible to regular truck service and consequently can be proved in by companies having no extensive construction program in prospect. Essentially it differs from the earlier machine in the use of a standard construction truck body. It employs a modified design F. W. D. truck chassis and is equipped with the earth boring mechanism and, when required, a derrick. Figure 1 shows a Spowart machine owned by a public utility corporation ready for service.

The F. W. D. truck chassis is designed especially to meet severe field conditions. Basically it is the same as the truck which proved so valuable to the Allies in the World War. Power is transmitted to all four wheels, thus insuring longer life, increased pulling power, and lower operating costs.

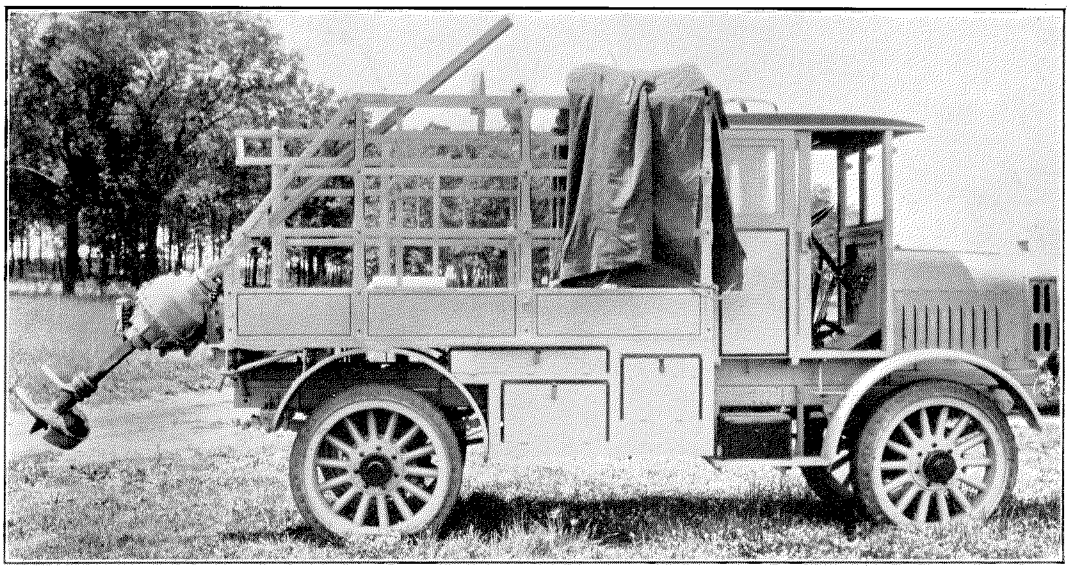


Figure 1—Spowart Machine owned by Public Service Utility Corp.

The power from the motor follows through a multiple disc clutch to a jaw clutch type of transmission. With this transmission the gears are always in mesh and there is no chance of stripping them. At the rear of the transmission and driven by the transmission shaft is a rugged

[1] Use of Labor Saving Apparatus in Outside Plant Construction Work, Electrical Communication, Vol. II, No. 1, 1923.

sprocket which drives a five-inch silent chain. This chain runs over a second and larger sprocket inside of which is placed a center differential. From this differential, propeller shafts with in-

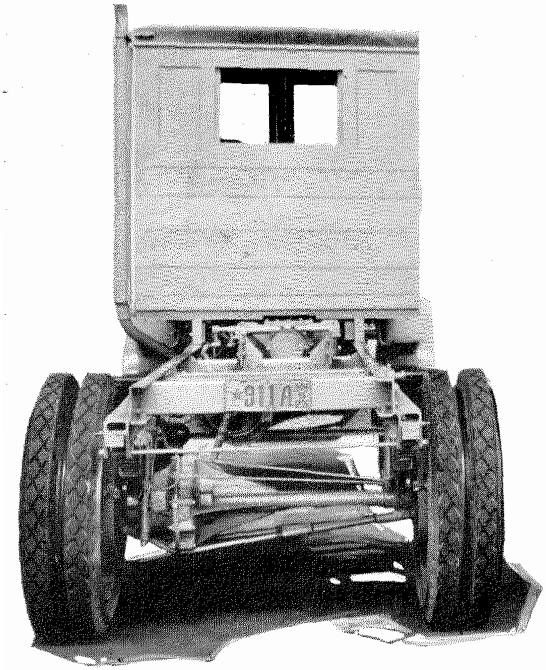


Figure 2—Truck Chassis—Rear View

tegral pinion gears transmit power to the bevel gears and full floating axles. The chassis specifications are as follows:

Load capacity—		6,000 lbs.
Chassis weight—		7,300 lbs.
Cylinders—		4-cast in pairs
		4¾" bore
		5½" stroke
		¾" offset
Tires—	Solid:	Front: 40" x 7" single
		Rear: 40" x 5" dual
Wheel base—		133"
Tread—		56"
Turning radius—		34'—6"
Speed: High—		15¾ miles per hour
Intermediate		7⅞ miles per hour
Low—		2½ miles per hour
Control—		Left hand drive and right hand shift, H type shifting gate. 3 speeds forward and reverse. Service foot brake operating on all four wheels. Emergency hand brake operates on rear wheel drums.

Figures 2 and 4 show the front and rear of the truck chassis.

The winch is driven by the truck motor through the truck clutch by means of a power take-off having gears in mesh with the transmission gears. It has three speeds forward and one reverse and together with the variation in motor speed will permit of a cable speed of from 25 to 250 feet per minute. It can be operated either at high speed with light loads or at low speed with heavy loads. The working cable pull is 5,000 pounds and the maximum pull is 10,000 pounds.

All controls are located in the operator's cab within easy reach of the truck operator, permit-

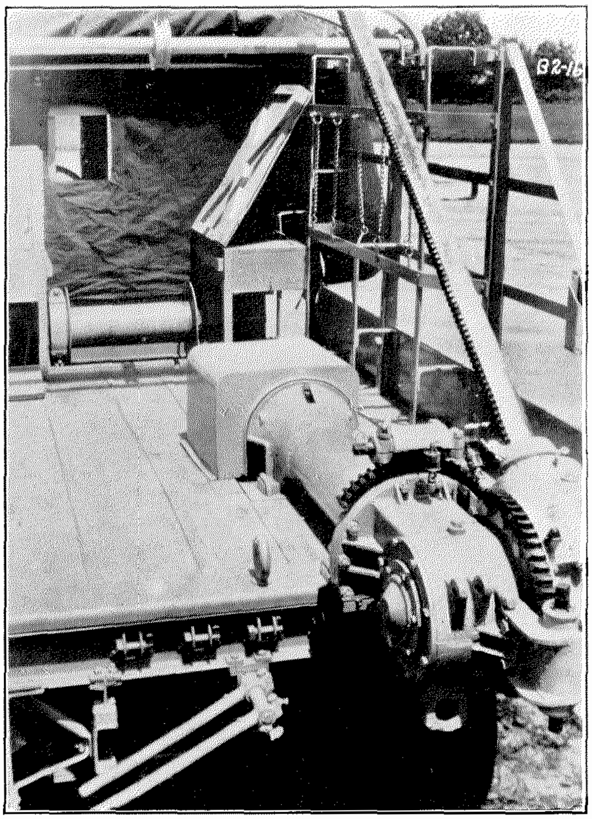


Figure 3—Truck showing Winch in Position

ting one man to operate both the winch and the truck. The lifting or lowering of the load can be stopped instantly by releasing the truck clutch, the design being such that the load cannot drive the winch. By releasing a positive dog type clutch controlled from the cab, the drum becomes free to rotate on its shaft, a feature which is useful in paying out manually. Figure 3 shows the winch in position, just to the rear of the cab.

The body is of steel and hardwood construction with removable bows which can be stored in a special pocket at the front of the body. Steel racks are provided for carrying ladders, wire, pike poles and other tools or construction materials, also compartment lockers on each side of the truck for carrying hand tools, bolts, nuts and supplies. Lockers built beneath the body serve to carry shovels, picks, tamping tools and the auger shaft when it is not in use. On the rear of the body are attachments for mounting the derrick and in addition a place is provided for carrying the derrick when knocked down.

A tarpaulin cover open at the rear is provided for covering the entire body, including the sides and front. It is made of eight ounce duck, especially treated for mildew and can be rolled up and carried in a place provided for it on top of the cab. Figure 4 shows the truck with the tarpaulin cover in place.

The earth boring mechanism is of an enclosed gear type and is driven by the truck motor through a special transmission counter shaft. This permits full engine torque and the use of any desired speed of the truck transmission for every phase of boring operations. The truck counter shaft is extended by means of a propeller shaft to the boring machine counter shaft which carries the chain sprocket, driving up to the clutches of the boring machine proper. There are two gear trains in the horizontal section of the boring mechanism, one running within and through the other; one rotates the auger shaft and the other the vertical movement of the auger rack.

The auger is controlled by two levers placed at the rear of the truck and just to the left of the boring head in such a position as to permit the operator to see clearly every phase of the hole boring cycle. One lever controls the drive and another the feed.

The boring heads, which can be rigidly locked in any desired position, are universal in movement and adjustable to 45 degrees in any direction by means of a worm and sector on each head. The universal movement permits the auger racks to be quickly brought into a perpendicular position, regardless of the inequality of the ground. Levels are provided on each boring head to guide the operator in the leveling operations. Figures 5 and 6 along with Figure 1 show the boring mechanism and control levers with the auger rack in three different positions.

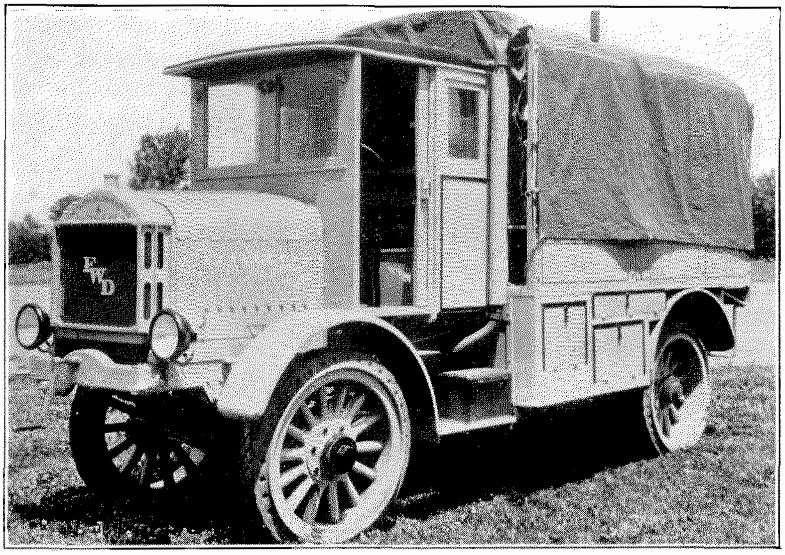


Figure 4—Truck with Tarpaulin Cover in place

The Spowart Earth Auger with a standard 12 foot rack will dig a hole six to seven feet deep. Longer auger racks can be supplied for digging deeper holes where desired. One 20 inch and one 24 inch auger are carried ordinarily for use with the 12 foot rack, but 16 inch and 30 inch augers are also available. For anchor holes a special three flight 8 inch auger is obtainable.

The boring machine is readily detachable from the truck body by loosening four U-bolts and uncoupling the drive chain and control links, leaving the body clear of every obstruction. Replacement of the boring unit can be accomplished easily and quickly. This makes the truck readily available for regular maintenance work and as an earth boring device in effect places it in the class of a tool rather than a heavy and costly machine.

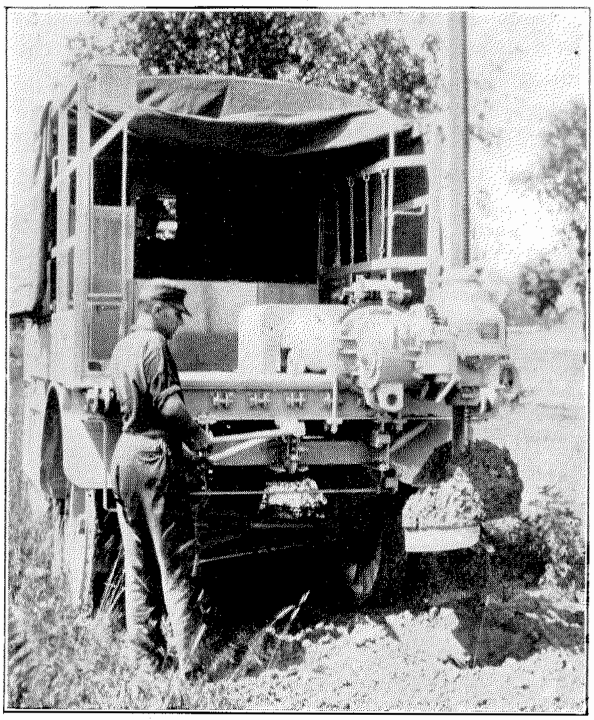


Figure 5—Boring Mechanism and Control Levers with Auger Rack in Vertical position

Only two men are required to handle both the truck and the boring machine throughout the entire cycle of boring the hole and setting the pole, although a third man as helper can be of considerable assistance, such as in placing cable around the pole while the hole is being bored.

Poles up to 35 feet in length can be set by using a derrick sheave attached to the top of the auger rack. For longer poles up to 75 feet, a tubular steel corner type derrick (Figure 7) is used. This derrick differs from the more common middle type derrick in that it operates along the right side line instead of the center line of the truck, thus permitting the use of the boring machine with the derrick in position. It is desirable to equip the truck with a corner type derrick due to the added facility with which short poles can be handled and to the advisability of being prepared to handle long poles when necessary.

The F. W. D. truck chassis, used with the Spowart type borer has a draw-bar pull of 7,500 pounds, with 40 inch tires. A pintle hook is attached to the rear of the truck and a trailer load of poles or crossarms can be hauled without interfering with the boring machine.

Results obtained with the Spowart machine will vary according to differences in soil conditions and distances to be travelled between holes. Ordinarily digging holes by hand is the slowest operation in line construction; the Spowart machine on the average will bore holes and place poles at the rate of 75 or more per eight hour day. With all conditions favorable, a daily performance with this machine as high as 100 holes bored and poles placed can be expected. Probably the best way to compare pole setting by the manual method with the machine method is to give briefly the experiences of a number of companies with earth boring machines. While the following

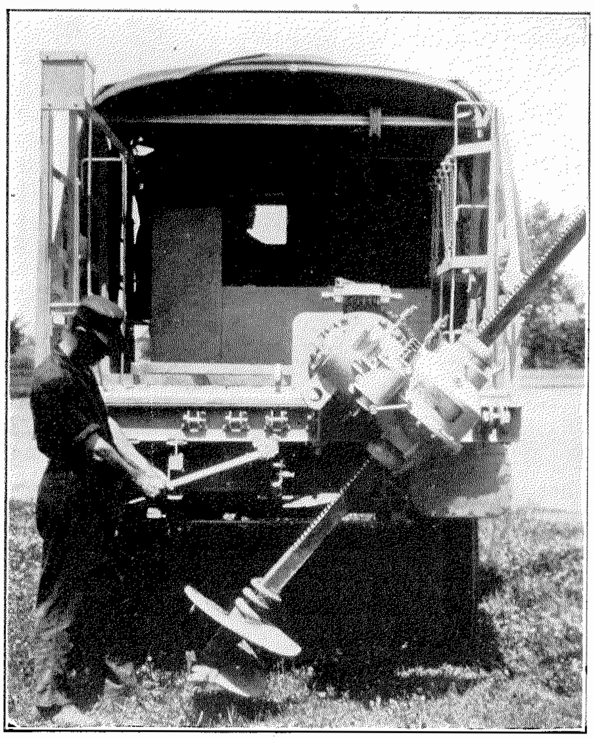


Figure 6—Boring Mechanism and Control Levers with Auger Rack in Inclined position

figures are based on the older type machine, they should be applicable also to the improved type.

The Postal Telegraph Company in the construction of a telegraph line from El Paso, Texas, to Los Angeles, California, used three machines, setting over 30,000 poles with an average saving of $5.00 per hole bored and pole set or a total saving of over $150,000. The best record for one of these machines was 283 holes bored and poles set in 16 hours, or an average of 3 minutes and 23 seconds to bore a hole, set a pole, move the machine 146 feet and get in position for the next hole.

The Los Angeles Electric Company reported that in forty days they bored 1,000 holes and set the poles at a saving of between $4.00 and $5.00 per hole bored and pole set while the Public Service Corporation of New Jersey reported an average saving of $3.00 to $4.00 per hole bored and pole set for two machines. Other cases might be cited but these are given as concrete examples to show that the savings effected are appreciable.

The following table gives figures on one earth boring machine in each of three states during a period of about one year:

	Wisconsin	Michigan	Illinois
Total Days Operated	99	111	84
Miles Covered (Total)	1068	2385	1679
Poles Set (Total)	2764	2068	1852
Poles per Day (Average)	28	19	22
Poles per Mile (Average)	2.588	.867	1.103
Miles per Day (Average)	10.78	21.49	19.98
*Hand Method Cost–Each	$ 4.56	$ 6.72	$ 8.33
*Machine Cost—Each	2.23	3.88	3.32
Savings with Machine	2.33	2.84	5.01
Hand Method Cost (Total)	12603.84	13896.96	15427.16
Machine Cost (Total)	6163.72	8023.84	6148.64
Total Savings	6440.12	5873.12	9278.52

*Includes placing pole in hole. Tamping, back filling, etc., not included, as this charge would be the same for both cases. Hand method includes supervision and tool expense at 35% of labor cost.

Depreciation on earth boring machine figured at 25%. Interest on investment at 5%, taxes, repairs, garage rental, administration, insurance and operating expenses are included.

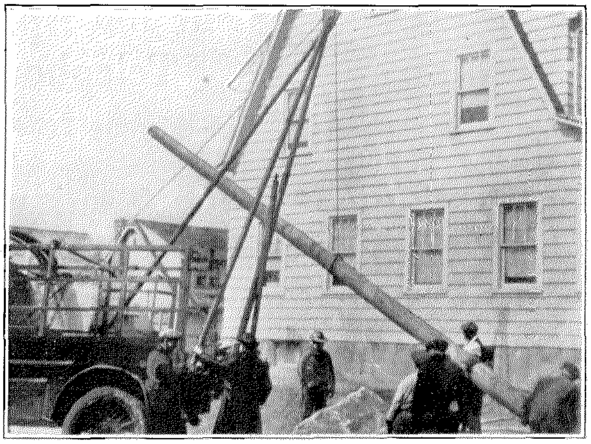


Figure 7—Truck equipped with Tubular Steel corner type Derrick

Conclusion

It has been the endeavor in this article to describe the construction and operating features of the Spowart type earth borer and to give briefly data showing what economies can be expected under average conditions.

The Spowart type borer embodies improvements in design that are the result of several years' field experience. It has been demonstrated conclusively that four wheel traction is of great advantage in getting the machine over the various types of soil and surface. Poles must be set in location regardless of soil conditions and the four wheel drive will carry a chassis to places where no two wheel drive truck could go. The borer will go through practically any soil except solid rock and even in that case, with slight changes, a rock drill can be attached to the auger to facilitate drilling for blasting charges.

The ease with which the boring mechanism can be removed, making the truck ready in a few moments for use as a construction truck, is of particular interest to companies not having enough holes to bore each year to justify the purchase of a machine for hole boring and pole setting exclusively. It is believed that, in general, telephone or power companies having a minimum of 1,000 holes to bore annually, will find the Spowart type boring machine an economical investment.

Development and Application of Loading for Telephone Circuits

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Editor's Note: Conclusion of paper which appeared in part in the April, 1926, issue of "Electrical Communication."

H-63-P versus H-106-P Loading (Continued). It was found inadvisable to make a similar change in the H-44-25 loading system owing to cross-talk reactions following from the necessary use of higher repeater gains in the phantom circuit. These undesirable reactions, though present to a lesser degree in the case of the H-174-63 system were offset by the factors already described. The size of the H-25-P coil was, however, reduced to conform to the potting method adopted for H-174-63 loading.

From the standpoint of repeater circuits the H-174-63 system is inherently better than the H-245-155 system because of its higher velocity and higher cut-off, with resulting higher quality of transmission. Furthermore, as far as non-repeatered circuits are concerned, there is a negligibly small difference between the transmission performances, considering frequency distortion effects as well as volume efficiency effects. The standardization of the H-174-63 phantom group loading system, therefore, marked the abandonment of use in new facilities of the old standard H-245-155 phantom-group loading system.

Attenuation—Frequency Distortion. In addition to their improved velocity and cut-off frequency characteristics, the H-44-25 and H-174-63 loading systems have an important advantage from the standpoint of attenuation-frequency distortion effects as is illustrated in Figs. 10 and 11. The frequency distortion effects illustrated in Fig. 10 may become very serious in very long lines. An indication of this is given in Fig. 11. The heavy line curves in this diagram illustrate the attenuation-frequency characteristics of a 500-mile 19 A.w.g. cable circuit involving the various types of loading noted, assuming that "perfect repeaters" are used in each case to reduce the total line loss to 10 TU at 1,000 cycles. The foregoing "perfect repeater" is assumed to have the same amplification at all frequencies. Of course, in order to have the same over-all efficiency in the different types of circuits at 1,000 cycles, it is necessary

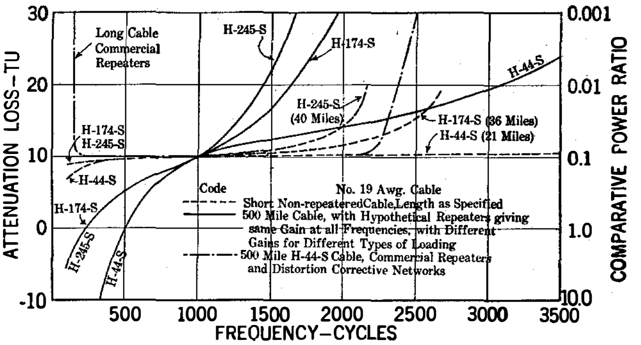

Figure 11—Attenuation-frequency Characteristics of Short and Long Loaded Toll Cable Circuits Having a Net Attenuation Loss of 10 TU at 1,000 Cycles

to assume different total amounts of repeater gain. The dotted lines in Fig. 11 illustrate corresponding frequency characteristics of short non-repeatered cables having the same types of loading as before; in each case the length of 19 A.w.g. cable circuit being chosen so that the non-repeatered circuits have the same loss (10 TU) at 1,000 cycles. A visual inspection of the dotted and heavy line curves indicates how the line losses pile up in long connections. In the old standard low cut-off loading, the accumulated losses in very long lines amount to a suppression effect for frequencies above 1,600 cycles.

In very long lines having the newer grades of loading, the line losses are still sufficient to cause serious attenuation distortion effects if allowed to go uncorrected. The improved types of repeaters now used on long loaded circuits provide somewhat higher gains at the upper speech frequencies, thereby obtaining approximately a flat frequency characteristic over a wider frequency range. In repeaters used in conjunction with the H-44-25 loading, losses are introduced at the lower speech frequencies by auxiliaries to the repeater circuit, for the purpose of flattening the frequency characteristic at low frequencies. An indication of the improvement obtainable in the above ways is given by a dot-dash curve in Fig. 11, which illustrates the attenuation-frequency characteristic of a 500-mile H-44S circuit having the best types of repeaters now commercially available.

In view of the difficulties brought into repeatered circuits by the use of loading, the question comes up: "Why not use more repeaters and do without the loading?" In the case of long cable circuits the answer to this question is that the coil loading substantially improves the attenuation and substantially reduces the frequency distortion at a cost which is much lower than the cost of the additional repeaters and distortion corrective networks which would be required to give the same grade of transmission without using loading.

Long Repeatered Open Wire Lines. In the case of the long open wire lines, the present day answer to the foregoing question is unfavorable to the use of loading. The use of improved types of repeaters now makes it possible to secure better transmission results in long repeatered circuits without loading, than can be secured in loaded repeatered lines. In this connection it should be noted that in the case of non-loaded open wire lines the distributed inductance is sufficiently large to keep the attenuation-frequency distortion low. Also the velocity of transmission is very high relative to that of a coil loaded line and there is no cut-off effect except that produced by the filters and other apparatus in the repeater sets.

These general transmission considerations are resulting in the removal of coil loading from high grade open wire lines. This dismantling work is being accelerated in order to adapt the open wire plant for a much more extensive application of carrier telephone and carrier telegraph systems.

The present expectations are that in the future new applications of open wire loading will generally be limited to isolated cases of short lines where carrier telephone or telegraph systems are not contemplated and where the maintenance and operating conditions are unfavorable to the use of telephone repeaters.

Cable Loading Installation Features. Cost considerations make it desirable to use aerial cable in the long toll cable installations, so this type of construction is generally used in the open country. In the vicinity of large population centers, underground cable is used.

Typical aerial cable loading installations are illustrated in Figs. 12 and 13. On the main

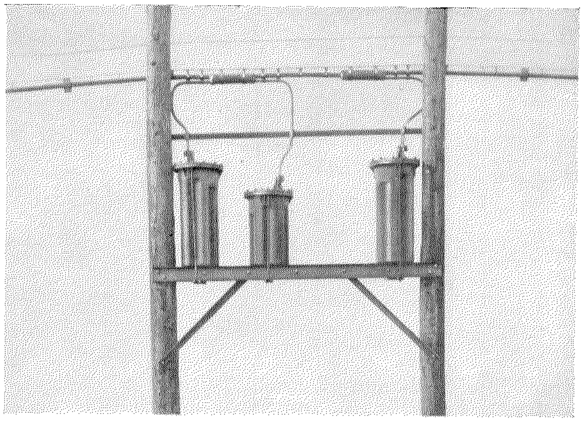

Figure 12—Installation of Aerial Toll Cable Loading on 4-case "H" Fixture

trunk cables two-pole *H* fixtures capable of supporting four to six large coil cases are usually required. Fig. 12 illustrates a fixture of this type designed for supporting four cases, three of which are already in place. On the smaller branch cables a single pole fixture such as illustrated in Fig. 13 is commonly used.

At the time a toll cable is installed, provision is made in the cable splices for the ultimate requirements as well as for the initial loading installation. Ordinary splices are made for the coils which are installed at the time the cable is placed, and "balloon" splices which provide the slack wire required for splicing are arranged for subsequent installations.

III. Loading for Incidental Cables in Open Wire Lines

In the loading applications discussed in the preceding sections, the primary purpose of the loading is to reduce line attenuation losses and frequency distortion effects. In the case of incidental pieces of cable in open wire lines, however, the primary function of the loading is to give the inserted cable approximately the same impedance characteristics as the open wire line, in order to minimize reflection effects at the junction of the cable and the open wire construction. An incidental cable occurring at a line terminal is ordinarily known as a toll entrance or a terminal cable; when occurring at an intermediate point, it is known as an intermediate cable.

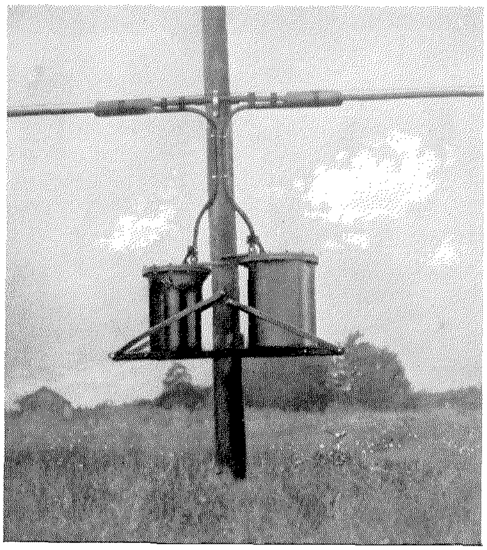

Figure 13—Installation of Aerial Toll Cable Loading—Single Pole Fixture for Small Branch Cables

The reduction of junction impedance irregularities has become especially important during recent years as a result of the rapidly increasing use of telephone repeaters, since in repeatered circuits, line impedance irregularities, by virtue of their effect upon the repeater circuit balance, may reduce the effective repeater gain and thereby impair transmission by an amount much larger than the ordinary reflection loss. Prior to the general use of telephone repeaters, satisfactory results were obtained by using some one of the standard heavy or medium weight cable loading systems on the entrance and intermediate cables associated with loaded open wire lines, and a special weight of loading was used on the incidental cables in the non-loaded open wire lines. In some cases ordinary medium loading was used, with suitable types of step-up or step-down transformers at the terminals of the inserted cable.

Incidental Cables in Loaded Open Wire Lines. In toll entrance and intermediate cables associated with loaded open wire lines, the primary requirements for matching impedance are that the nominal impedance and the cut-off frequency of the cable loading and of the loaded open wire line should be closely the same. To a first degree of approximation this means that the cable loading sections should have the same total mutual capacitance as the open wire loading sections, which, of course, requires a very much closer spacing. The cable loading system which was standardized for use in association with loaded open wire lines is designated "E-248-154". Its primary electrical characteristics are given in Table XII. Besides meeting the impedance requirements for use in association with repeat-

TABLE XII

Typical Loading Systems for Toll Entrance and Intermediate Cables

Loading System Designation	Type Circuit	Coil Inductance (Henrys)	Coil Spacing (Miles)	Nominal Impedance (Ohms)	Cut-off Frequency (Cycles)	Attenuation Loss TU per Mile at 1000 Cycles
E-28-16	Side Phantom	0.028 0.016	1.09 1.09	650 400	7200 7800	0.15 0.13 (13 A.w.g.)
CE-4.1-12.8	Side Phantom	0.0041 0.0128	0.176 1.09	600 400	45000 8500	0.22 0.19 (13 A.w.g.)
M-44-25	Side Phantom	0.044 0.025	1.66 1.66	650 400	4600 4900	0.29 0.24 (16 A.w.g.)
E-248-154	Side Phantom	0.248 0.154	1.09 1.09	1950 1200	2400 2500	0.081 0.070 (13 A.w.g.)

NOTE. Cable capacitance is assumed to be 0.062 μf per mile for side circuits, and 0.100 μf per mile for phantoms.

ered open wire lines, it is also very satisfactory with respect to attenuation characteristics. In placing this loading, it is customary to locate the first loading point in the cable at such a distance from the last loading point in the open wire line that the total capacitance of the junction loading section is closely the same as that in the regular open wire loading sections.

Incidental Cables in Non-Loaded Open Wire Lines. The problem of designing coil loading for incidental cables in non-loaded open wire lines is considerably more complicated than the case above discussed, primarily because it involves an impedance match between a smooth line and a lumpy line. Broadly stated, the first part of the problem is to design a loaded cable of such characteristics that its corresponding smooth line is closely similar to the non-loaded open wire line. The second and more complicated part of the problem is to determine the coil spacing. This usually involves some degree of compromise, because of the dependence of the impedance of a loaded cable upon the loading termination.

The first general requirement is that the ratio of inductance to capacitance to resistance per unit length in the loaded cable should be the same as the corresponding ratio in the non-loaded open wire line. Ordinarily, the loading coil resistance does not play an important part in the determination of the optimum resistance for the loaded cable, the choice of conductor gage being far more important. From this point of view, No. 13 A.w.g. is practically the best gage of conductor for entrance cable circuits connecting with 165-mil open wire lines. For the optimum impedance match on cables connecting with 104-mil open wire lines, it is necessary to use much higher resistance conductors, the choice between Nos. 16 and 19 A.w.g. conductors depending upon a number of factors which space limits do not allow to be discussed.

As noted in the discussion under "Theory" in the first part of the paper, the characteristic impedance of a uniform line is substantially a pure resistance, having the value $\sqrt{L/C}$ over the frequency range throughout which the inductive reactance per unit length is large with reference to the resistance. On the other hand, the characteristic impedance of a coil loaded cable varies over a wide range with frequency, depending upon the particular loading termination used.

Typical impedance-frequency curves for mid-coil and mid-section terminations are illustrated in Fig. 3. As will be seen from this diagram, the rising slope of the mid-section termination and the drooping slope of the mid-coil termination do not deviate greatly from a straight line relation for frequencies below approximately 0.5 of the cut-off frequency. The higher the cut-off frequency is, the more closely will the impedance-frequency characteristic of the loaded cable approach the flat characteristic of the non-loaded open wire line over the range of frequencies involved in speech transmission. In this connection, it is to be noted that the repeaters now used on open wire lines are designed to transmit frequencies between approximately 200 and 2,600 cycles. Of course, the higher the cut-off frequency, the more expensive will be the loading. Practical reasons make it desirable to space the loading coils on the cable circuits connecting with non-loaded open wire lines at the same intervals as the coils which are used on the cable circuits connected with the loaded open wire lines. This consideration, in combination with the nominal impedance requirement previously mentioned, fixes the cut-off characteristics and, hence, the slope of the termination impedance-frequency characteristic.

These general considerations have led to the standardization of the E-28-16 loading system for use on entrance cable and intermediate cable conductors associated with non-loaded open wire lines. General data for this system are given in Table XII, and the computed impedance characteristics are illustrated in Fig. 14, which also gives the characteristic impedance curves for the non-loaded open wire line and the non-loaded cable. Since the E-28-16 loading system is a low impedance loading, the attenuation improvement is small relative to that of other types of loading system which are primarily installed for attenuation improvement.

Table XII also gives general data regarding the M-44-25 entrance cable loading system which has been used to some extent as a substitute for the E-28-16 loading system on cables connected to non-loaded open wire lines. The M-44-25 system used higher inductance loading coils and considerably longer spacing intervals than the E-28-16 system, and was consequently less expensive. The impedance characteristics, however, were not so satisfactory at the upper speech frequencies because of the greater slope

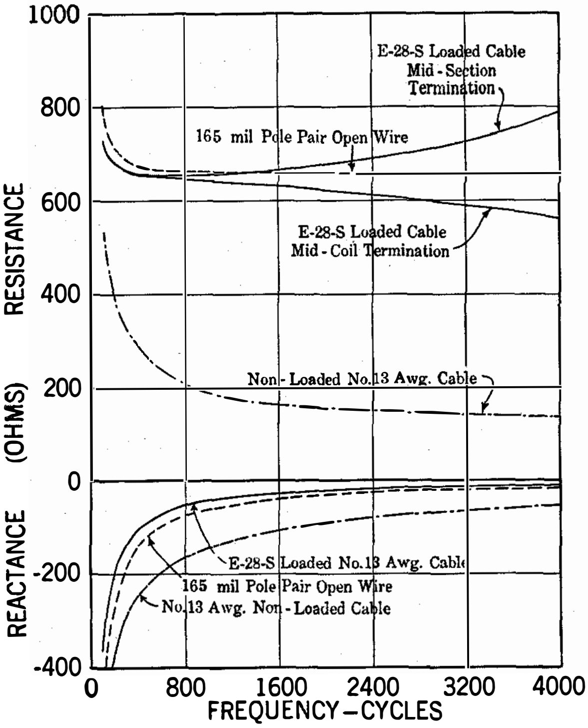

Figure 14—Typical Impedance-frequency Characteristics of Loaded and Non-loaded Entrance Cable and Non-loaded Open Wire Line

of the impedance-frequency characteristic, due to the lower cut-off.

Carrier Frequency Loading. Special types of entrance cable loading have been developed for use on incidental cables in open wire lines on which carrier telephone or carrier telegraph systems are superposed. Loading system CE-4.1-12.8 listed in Table XII exemplifies this type of loading. The present standard carrier telephone systems operate up to frequencies of the order of 30,000 cycles.[23]

In order to get satisfactory impedance and attenuation characteristics in the loaded incidental cables, a cut-off frequency of approximately 45,000 cycles is used.

The highest working frequency in carrier loaded cables is approximately 0.75 of the cut-off frequency. The ordinary mid-coil and mid-section terminations do not give sufficiently close approximation to a flat impedance-frequency characteristic over this wide range of frequencies, so it has been necessary to use at the terminals of carrier loaded cables, a simple impedance corrective network.

Data regarding attenuation losses in a typical carrier loaded cable are given in Table XIII.

TABLE XIII

Carrier Frequency Loading

Frequency Kilocycles	Attenuation Loss-TU per Mile (13 A.w.g. Cable)		Resistance-Ohms per Carrier Loading Coil
	Non-Loaded	C-4.1 Loading	
1	0.49	0.23	1.5
5	0.78	0.27	1.6
10	0.90	0.33	1.9
20	1.14	0.52	4.1
30	1.37	0.90	8.1

For purposes of comparison similar data are given on a corresponding non-loaded cable. Effective resistance values of the carrier loading coil are also included.

The high frequency loading is used only on the side circuits, since at the present time it is not customary to operate carrier telephone systems over phantom circuits. The associated phantom circuit loading is designed for ordinary speech transmission. In order to transmit the high frequency carrier currents over the side circuits, it is necessary to have the side circuit loading coils spaced much more closely than for the ordinary voice frequency loading coils in the phantom circuit. On this account the theoretically best loading points for the carrier circuits frequently occur at places where it is inconvenient to locate the loading coils. The actual loading sections in such cases are made shorter than the theoretical lengths, and the deficiencies in loading section capacitance are remedied by adding lumped capacitances in the form of "building-out condensers." Recently, special types of stub cable designed specially for building out purposes have come into use as substitutes for building-out condensers.

Loading Coils. The design of the coils used in the E-28-16 and M-44-25 loading systems is generally similar to the toll cable loading coils

[23] "Carrier Current Telephony and Telegraphy," E. H. Colpitts and O. B. Blackwell, Trans. A. I. E. E., Vol. 40, 1921, p. 205.

having 35-permeability compressed powdered iron cores already described. The loading coils used in the E-248-154 loading system are larger coils of the air-gap type 65-permeability wire core construction listed in Table VII.

As regards the carrier loading system, CE-4.1-12.8, since this involves the transmission through the loading coils of frequencies up to 30,000 cycles or somewhat higher, special coil designs are required. The coil which loads the audio frequency phantom circuit, aside from being specially balanced for association with the side circuit coils, is generally similar in construction to the compressed powdered iron core phantom coil for toll cables.

The side circuit coil, however, is used for loading the high frequency circuit, and more severe requirements are, therefore, imposed on it owing to the multi-frequency transmission. Ordinarily the circuits are equipped to provide three or four carrier telephone channels or 10 carrier telegraph channels over a pair of wires, in addition to the ordinary audio frequency telephone and grounded telegraph channels. The primary added requirements as regards the loading coils are freedom from intermodulation between channels, and low energy losses at carrier frequencies. The most satisfactory solution as regards freedom from magnetic modulation is the avoidance of the use of ferro-magnetic core materials. The side circuit loading coils were, accordingly, designed as toroidal wood core coils, with finely stranded copper windings in order to limit the eddy-current losses. Data regarding resistance-frequency characteristics are included in Table XIII.

The air core side circuit coils have a small leakage inductance which must be allowed for in determining the phantom coil inductance. For this reason the phantom coil inductance is lower than in the E-28-16 system (Table XII). In order to avoid impedance irregularity in the carrier circuits at the phantom loading points, it is necessary that the combination carrier-phantom loading units should have closely the same total inductance and shunt capacitance as the ordinary carrier loading coils. This requires the use of a different type of carrier loading coil at the phantom loading point from that at the non-phantom loading points, having a lower inductance and capacitance corresponding to the leakage inductance and shunt capacitance of the associated phantom coil. Other refinements of design are involved in these combination loading units.[24]

IV. Cross-Talk

One of the greatest practical difficulties which has been encountered in extending the commercial range of long distance telephone service is that of keeping at a tolerably low value, the speech overhearing effects known as cross-talk, which occur between adjacent telephone transmission circuits whenever there is an appreciable amount of electromagnetic or electrostatic coupling between them.

From the early days of telephony great care has been exercised in plant design and construction work to avoid circuit and apparatus unbalances, but as is to be expected from the nature of the problem, it is practically impossible to obtain and maintain absolutely perfect balance. In short telephone circuits, there is no particular difficulty in keeping the unbalance effects small enough so that the over-all cross-talk is not serious. As the length of the line increases, however, there are more and more opportunities for unbalances in the lines and in the associated apparatus in the lines and offices. In repeatered lines, moreover, the repeaters amplify the cross-talk as well as the speech transmission. Thus we have the cumulative effects of cross-talk from successive sections in the long repeatered lines. From the service standpoint, moreover, it is necessary that the cross-talk in the very long lines should be within the limits set for the shorter lines.

The problem of keeping cross-talk low between a phantom circuit and its associated side circuits, and between the two associated side circuits of a phantom group, is by far the most difficult phase of the general cross-talk problem in long repeatered cables. It is present in the cables, the loading coils, the terminating apparatus and the office cabling. Of these, the cable and associated loading coils are the major sources of unbalances.

The phantom-to-side and side-to-side cross-talk unbalances in the cable quads are reduced to small values by exercising great care both in the various manufacturing processes and in the

[24] U. S. Patents Nos. 1,501,959, Martin and Shaw; 1,501,926, Shaw.

selection of raw materials. When the cable is installed in the field, a large improvement in cross-talk conditions is secured by splicing adjacent lengths of cable together in such a way that the unbalances in one length of cable substantially neutralize the unbalances contributed by the adjacent length of cable. Usually, three such "capacity-unbalance test" splices are made at symmetrical points in each loading section and as a result the average over-all capacity unbalance in a loading section is reduced to about one-tenth of the magnitude which would hold if these test splices were not made.

In the design of the standard phantom circuit and side circuit loading coils, special care was taken to make them substantially free from inherent unbalances. Also in the manufacture of the coils, great care is exercised to realize the benefits of the inherent symmetry of the designs. In the early days before telephone repeaters came into general use on loaded lines, satisfactory results from the standpoint of self inductance and mutual inductance unbalances were obtained by adjusting the different windings to the nearest turn; i.e., a condition of balance where either adding or subtracting one turn to one of the line windings would increase the cross-talk rather than reduce it.

Later when repeaters came into general use, it was found necessary to obtain much more refined adjustments. Further improvements have been worked out in manufacturing methods and processes which allow a greater degree of symmetry. As a result of these various improvements, the phantom-to-side cross-talk unbalances in the loading coils have been reduced approximately 75 per cent. or more below the values obtained before repeaters came into general use on small gage toll cable. The coil cross-talk unbalances are now nearly as low as the cross-talk unbalances in the associated cable sections after the completion of the capacity unbalance test splicing.

The loading coils used in the very long circuits having H-44-25 loading obviously are more important from the standpoint of cross-talk limitations than the coils used in the shorter circuits having H-174-63 loading, and somewhat greater care is required in their manufacture. These coils are adjusted and tested in a factory test circuit which at the cross-talk test frequency simulates the service impedance conditions. In the phantom-to-side cross-talk test, the disturbing test current is superposed on the phantom circuit, and measurements of the cross-talk are made in the side circuits, the cross-talk being expressed in millionths of the current into a transformer connected to the phantom circuit and of such ratio as to make the impedance at its input equal to that of the side circuit. As a result of the improvements previously mentioned, the average cross-talk in the coils used for the H-44-25 loading is now about 20 millionths. This corresponds to an attenuation of about 95 TU.

To assist in visualizing the real achievement which this minute value of phantom-to-side cross-talk represents, Table XIV gives information regarding the cross-talk of different elementary types of unbalance in H-44-25 loading coils:

TABLE XIV

Cross-talk Due to Unbalance in H-44-25 Loading Coils

Type of Unbalance	Amount of Cross-talk
1 ohm resistance	400 millionths (68 TU)
1 micro-henry inductance	2.5 " (112 TU)
1 turn of winding	280 " (71 TU)
1 micro-microfarad capacitance	0.94 " (121 TU)

These values apply at 1,000 cycles.

In the loading coils designed for H-174-63 loading, the cross-talk per unit of electromagnetic unbalance tends to be smaller and the cross-talk per unit of electrostatic unbalance larger, in rough proportion to the differences in line impedance between the H-44-25 and H-174-63 circuits.

Side-to-side cross-talk is uniformly lower than phantom-to-side cross-talk, as would be expected from the less intimate coupling between circuits. Accordingly, the special adjustments which are made are primarily for the purpose of reducing phantom-to-side cross-talk.

In the loading coils intended for H-44-25 circuits the special cross-talk adjustments are applied for minimizing "far-end" cross-talk or for minimizing "near-end" cross-talk, according as the coils are required for four-wire or two-wire repeatered circuits, respectively. The term "far-end" cross-talk applies to cross-talk heard at the distant end of the disturbed circuit, and correspondingly the term "near-end" cross-talk applies to the cross-talk heard at the end of the disturbed circuit near the talker.

Considering now the cross-talk between four-wire circuits in the same quad, it is to be noted that the directional effects of the telephone repeaters block the transmission of cross-talk in the one-way path back to the near end of the circuit, and consequently the special cross-talk adjustments on the coils for four-wire H-44-25 circuits are made primarily for reducing far-end cross-talk.

In two-wire circuits, near-end and far-end cross-talk both occur, and generally near-end cross-talk is much greater because its "average" cross-talk path has less attenuation than that of the far-end cross-talk. Consequently, the special cross-talk adjustments made in the two-wire circuit coils are for the purpose of reducing the near-end cross-talk to a minimum.

In the foregoing connection, it is to be noted that the cross-talk current caused by electromagnetic unbalances flows around the two ends of the disturbed circuit in series. On the other hand, the cross-talk current caused by electrostatic unbalances divides and flows from its point of origin in opposite directions around the two ends of the circuit in parallel. Consequently, when electrostatic and electromagnetic cross-talk currents are in phase at one end of the circuit, they will be practically in phase opposition at the other end of the circuit. The special cross-talk adjustments are made in such a way as to get the maximum benefit from the phase opposition at the particular end of the circuit where the reduction is more important.

In the four-wire type of circuit used in very long cable circuits, relatively large amplification gains are possible in the repeaters because of the characteristic circuit feature which allows the repeaters to act as one-way amplifiers. As a result of these high amplifications, there are large differences in power level on the input and output sides of the repeaters. This fact has made it desirable for cross-talk reasons to segregate the oppositely transmitting branches of the four-wire circuits. In the cables, the "east-bound" and "west-bound" branches of the four-wire circuits are in different groups. This segregation is also carried out in the loading coil pots, and in the office cabling.[25]

[25] U. S. Patent No. 1,394,062—O. B. Blackwell.

With loading coils as manufactured at present, the cross-talk unbalances in the loaded cables are such that the resultant over-all cross-talk is expected to be tolerable for the longest circuits now definitely planned in cable. The margin below commercial limits is much less in two-wire circuits than in four-wire circuits. At present, there is a growing tendency to use two-wire circuits for longer distances than formerly, for reasons of plant economy. This trend thus increases the severity of the cross-talk requirements.

Unbalances in loaded circuits which contribute to noise due to induction from power transmission and distribution circuits are similar in nature to those contributing to cross-talk. The precautions which are taken in the design, manufacture, and installation of loaded circuits to reduce unbalances have the effect, therefore, of reducing both cross-talk and noise.

V. Telegraphy Over Loaded Telephone Circuits

It has been the practise in the Bell System, before the advent of loading, to employ circuits for simultaneously transmitting telephone and telegraph currents. Two methods were in general use, (1) the composite system, in which each line wire of the telephone circuit provided a telegraph channel with ground return, and (2) the simplex system, in which the two conductors in parallel were used with a ground return.

It was very desirable to continue to superpose d-c. telegraph currents on telephone circuits after the introduction of loading. The possible detrimental effects of the superposed telegraph and telephone currents passing through the loading coils did not require serious consideration so long as the circuits were relatively short, since the magnetic modulation in the loading coil cores due to superposed hysteresis effects was sufficiently small to be negligible. As the length of the loaded circuit was increased, the interaction between the telegraph and telephone currents which has been designated in an Institute paper[26] as "flutter," was aggravated and serious distortion of speech resulted.

Measurements of flutter effects obtained with

[26] "Hysteresis Effects with Varying Superposed Magnetizing Forces," W. Fondiller and W. H. Martin, Trans. A. I. E. E., Vol. 40, 1921, p. 443.

the two grades of core material then in use, viz., 65-permeability and 95-permeability wire, showed the lower permeability core material to be substantially better in this respect. This material has already been adopted for the high efficiency loading coils used on the large gage toll cable circuits, and for open wire lines used in spanning considerable distances.

In order to obtain improved transmission over composited and loaded Nos. 16 and 19 A.w.g. cables, the side circuit and phantom loading coils for this grade of service were redesigned in 1913 to employ 65-permeability cores working to the same over-all dimensions. In addition to improved flutter characteristics, the replacing loading coils had somewhat lower iron losses, and their cost was slightly higher.

A substantial reduction in flutter distortion effects was later obtained in superposed telegraphy over loaded open wire lines and long coarse gage cable circuits, with the adoption of the air-gap type of loading coils already described (Table VIII) as the latter had considerably better hysteresis characteristics than the corresponding types of continuous wire core coils which they superseded.

The operating requirements for the grounded telegraph systems referred to above, necessitated the use of telegraph currents of very large amplitude relative to the telephone currents; consequently on such circuits it was impracticable to realize the benefits of reduced flutter distortion which would have resulted from the use of small amplitude telegraph currents. These possibilities, however, have been fully realized by the development of a metallic polar duplex telegraph system [27] to meet the special requirements imposed by superposed telegraph operation over long small gage telephone circuits. In this system, the superposed telegraph current is of the same order of magnitude as the telephone current. Under these favorable operating conditions, the flutter distortion effects caused by modulation in the cores of the present standard 35-permeability compressed iron powder core loading coils, are within satisfactory limits on the longest circuits which are used simultaneously for telegraph and telephone service.

The recent development of a voice frequency carrier telegraph system [28] providing 10 or more independent channels over a loaded four-wire cable circuit has made it economical to concentrate a large part of the telegraph service over the long repeatered cables on a special group of wires which are not used simultaneously for telephone purposes. This method of operation obviously eliminates all possibility of modulation effects between the carrier telegraph circuits and the speech transmission circuits. However, the possibility of intermodulation effects between the different superposed carrier telegraph channels involves the same fundamental requirements in the loading coils as when the telegraph circuits are superposed on telephone circuits. The requirements of these systems are satisfactorily met by the 35-permeability compressed iron powder core loading coils now standard for use in toll cable loading.

VI. Recent Improvements in Loading for Exchange Area Cables

The developments discussed in the preceding sections were directed to improving and extending the range of long distance telephone service. During the greater part of this period the loading standards for exchange area trunk cables remained fixed. The first important change occurred about 1916, when compressed powdered iron core coils came into general use in place of the old standard wire core coils.

In the period 1922-4, the use of new types of fine wire cables had reached a point which required that certain changes be made in the old standard loading systems. Accordingly a new series of improved loading systems having a considerably higher cut-off frequency than the original standard systems, described in Table II, were developed.

Cable Developments. Notable advances have been made in the art of cable manufacture during the last decade or so, including the standardization of 450-pair 19-A.w.g. cable, 900-pair 22-A.w.g. cable, and 1,200-pair 24-A.w.g. cable, all contained in standard full size sheaths (2⅝ in. outside diameter). For each of the conductor gages involved, each of these new maximum size

[27] "Metallic Polar-Duplex Telegraph System for Cables," Messrs. Bell, Shanck and Branson, Trans. A. I. E. E., 44:337, 1925.

[28] "Voice-Frequency Carrier Telegraph Systems for Cables," Messrs. Hamilton, Nyquist, Long and Phelps, Trans. A. I. E. E., Vol. 44, 1925, p. 327.

cables has approximately 50 per cent. more conductors than the previous maximum size cable, typified by the old standard 300-pair No. 19-A.w.g. or 600-pair No. 22-A.w.g. cables.

The newer types of cables have a smaller amount of paper insulation on the individual conductors with a resultant increase in mutual capacitance.

About 1921 the methods of stranding the newer types of fine wire cables (No. 22 and 24 A.w.g.) were changed in order to improve their balance characteristics. These changes made the cables suitable for the application of loading.

The use of the old standard loading systems on the new types of cables would have resulted in an objectionable impairment of quality, due to the reduction of the cut-off frequency resulting from the increased cable capacitance. Also the types of coils available were more expensive than could be justified for permanent standards on the low cost fine wire cables. Accordingly the development of new loading systems and less expensive coils was undertaken.

Determination of New Cut-Off Frequency Standard. The coil design cost-balance study was taken up as one phase of a general transmission-cost study of exchange area transmission, which also included a theoretical investigation of cut-off frequency standards.

In this work use was made of recent investigations of the effect of variations in the frequency distortion and volume efficiency of a telephone circuit on the capability of the circuit to transmit and reproduce intelligible speech.

In the cost studies, allowance was made for the reduced costs of the new types of cable facilities, and the use of less expensive types of coils proportioned to be in approximate cost-equilibrium with these facilities. On the basis of these new cost relations, it was found that an increase in the cut-off frequency of exchange area loading could be justified. Further studies showed that if the cut-off frequency should be raised materially above 3,000 cycles the increased costs would be large in proportion to the resultant improvement in transmission. On this basis, it was decided to adopt 2,900 cycles as the cut-off frequency standard for the new loading, when used on higher capacitance cables. This corresponds to a cut-off frequency of approximately 3,200 cycles on the older types of low capacitance cables.

New Standard Loading Systems. Having decided upon a new cut-off frequency standard, the next step was to choose coil spacings and inductance values. Obviously, in order to make full use of available loading manholes and vaults, it is desirable to adhere to the established spacing standards. Also, it is desirable to make as much use as practicable of the old standard loading coil inductance values, in order to minimize the expense of rearranging the existing loading to conform to the new standards. Furthermore, there are important advantages in having a graded series of standards. This avoids economic waste otherwise involved in the use of expensive loading on trunks where a less expensive loading is good enough.

The foregoing general considerations resulted in the standardization of certain new loading systems, the principal transmission features of which are summarized in Table XV.

TABLE XV

New Loading Standards for Exchange Area Trunks

Loading Designation	Coil Spacing (Feet)	Coil Code Nos.	Approx. Cut-off Frequency (Cycles)	
			High Capacitance Cable	Low Capacitance Cable
M-88	9000	602	2900	3200
H-135	6000	603	2800	3200
H-175	6000	574	——	2800
D-175	4500	574	2900	3200

NOTE. High capacitance cable has approximately 0.083 μf per mile. Low capacitance cable has approximately 0.066 μf per mile.

The M-88 system is especially suitable for the shorter lengths of fine wire trunk cables which constitute the predominating bulk of the exchange area trunk mileage. In longer trunks, the other more expensive loading systems find their field of service. The H-175 system is limited to low capacitance cables because of the lower cut-off effects on high capacitance cables, but has considerable commercial importance because of the large number of low capacitance cables now in the plant.

Table XVI gives general transmission data on typical exchange area trunks using the new loading systems, including also non-loaded

TABLE XVI

Transmission Characteristics of Typical Exchange Area Trunks

Cable Conductor A.w.g.	Capacitance μf/Mile	System	Coil Code No.	Cut-off Frequency (Cycles)	Circuit Impedance (Ohms)	Attenuation Loss TU per Mile
24	0.079	Non-loaded	——	——	740	2.2
22	0.083	"	——	——	570	1.8
24	0.079	M-88	602	2900	900	1.48
22	0.083	M-88	602	2900	990	0.96
22	0.083	H-135	603	2800	1300	0.68
19	0.085	Non-loaded	——	——	400	1.27
22	0.083	D-175	574	2900	1690	0.53
19	0.083	M-88	602	2800	860	0.51
19	0.085	H-135	603	2800	1280	0.38
19	0.066	H-175	574	2800	1640	0.29
19	0.085	D-175	574	2800	1680	0.30
16	0.066	M-88	602	3200	960	0.24
16	0.066	H-135	603	3200	1420	0.20
16	0.066	H-175	574	2800	1640	0.17

NOTE. The impedance and attenuation figures hold at 1000 cycles. Impedance values for loaded circuits assume mid-section termination.

trunks. Attenuation-frequency characteristics of some of these trunks are given in Fig. 15. A dotted line curve shows the characteristics of

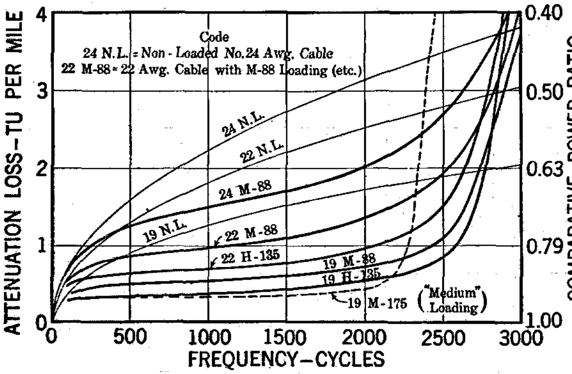

Figure 15—Attenuation-frequency Characteristics of Typical Exchange Area Loaded and Non-Loaded Cables

the old standard medium loading when used on 0.065 μf per mi. No. 19 A.w.g. cable.

The position of the different types of facility in Table XVI indicates in a general way the sequence in regard to costs of the different types of facility; i.e., No. 24-A.w.g. non-loaded cable circuits are the least expensive of those listed and H-175 loaded No. 16-A.w.g. cable the most expensive, the intermediate facilities being correspondingly intermediate in cost.

In general, it will be noted from Table XVI that the facility cost is in reverse order to the transmission efficiency. However, there are exceptions to this general tendency: for instance, non-loaded No. 19-A.w.g. cable is less efficient and more expensive than No. 22-A.w.g cable with M-88 or H-135 loading. From this it will be apparent that non-loaded No. 19-A.w.g. cable has practically no economical field of service on a competitive basis with loaded No. 22-A.w.g. cable.

The problem of the plant engineer in laying out trunk cable is to determine for each trunk group the type of facility which will meet the established transmission standards with the lowest cost. The permissible loss in a given length of trunk in a particular area depends on the type of service involved; for instance, a larger loss is allowable in a direct interoffice trunk than in other types of trunks forming part of a toll connection.

The allowable loss for a given length and type of trunk varies widely among different metropolitan areas, due to local conditions. These limits are established by means of "loop-and-trunk" studies which determine for a particular area the most economical allocation of the permissible over-all loss between the subscriber loops and the interoffice trunks. On account of the wide range of local conditions the fields of service of the different types of loaded and non-loaded trunks cannot be sharply defined. An indication of the service uses is given in the upper part of Fig. 16, which illustrates the possible applications of the new standard types of facilities for direct interoffice trunk service, assuming maximum allowable losses of 11 and 15 TU, respectively. The diagram shows, for instance, that M-88 loading on No. 22-A.w.g. cable is the preferred construction for trunks from 7.5 to 11.5 miles long, when working to an 11-TU limit. The lower part of Fig. 16 indicates on a cumulative-percentage basis the distribu-

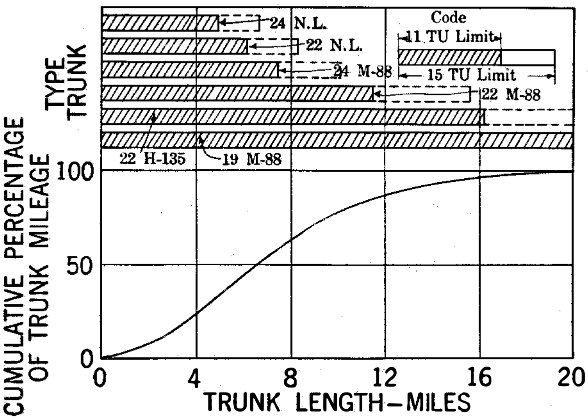

Figure 16—Direct Interoffice Trunks. Field of Use of Different Types of Loaded and Non-loaded Facilities, Working to 11 to 15 TU Limits on Attenuation Loss. Curve in Lower Part of Diagram Shows Distribution of Trunks with Respect to Trunk Length

tion of direct interoffice trunk lengths in the Bell System.

In the design of the exchange area trunk plant, it is, of course, necessary to consider the signaling characteristics of the facilities and associated equipment, as well as the transmission characteristics. After a certain length is reached in a given type of facility, it may become necessary to use relatively expensive signaling equipment for working longer distances. In some cases of this kind, the total facility cost may be reduced by using a more expensive grade of circuit which will allow less expensive signaling equipment.

In the application of the new standard loading systems, the same standards of over-all attenuation loss are adhered to, as in the older loading systems. In consequence, there is an appreciable improvement in the intelligibility of transmission, due to the ability of the new loading systems to transmit efficiently a range of high frequency voice over-tones which are suppressed by the old standard 2,300-cycle cut-off.

Along with this improvement in service, the new loading systems substantially reduce the plant cost; partly due to the economies which result from the extension of the transmission range of the new types of fine wire cables, and partly because of the use of materially less expensive types of loading coils.

Loading Coils and Cases. As previously noted, the first important change in the coils used for exchange area loading from the early 95-permeability wire core type was the substitution of compressed powdered iron in place of wire for the cores. Initially, only coils having powdered iron cores with a permeability of 60 were designed, as this value corresponds to the effective value of the cores displaced. More recently, in order to better fit in with the requirements of the new cut-off frequency standard, coils using 35-permeability powdered iron cores have been developed. In Table XVII are listed data for the coils now used in exchange area loading.

TABLE XVII

Coils for Loading Exchange Area Cables

Coil Code No.	Inductance (Henrys)	Core Permeability	Resistance-(Ohms)		Over-all Dimensions (Inches)	
			D-C.	1000 Cycles	Diameter	Height
602	0.088	35	8.9	10.5	3.6	1.3
603	0.135	35	12.8	14.1	3.6	1.3
574	0.175	60	4.6	10.6	4.5	2.1

Effective resistance values are for a line current of 0.001 ampere.

The standardization of the small size Nos. 602 and 603 loading coils has made it possible to design containing cases and assembly methods which permit much larger numbers of coils to be enclosed in cases conforming to the dimensional limitations set by existing vault conditions. A series of cases having capacities up to 300 coils has now been developed. The use of these large potting complements will be of considerable value in reducing the space congestion encountered in the "downtown" sections of the larger metropolitan areas.

In the 300-coil case, a total of 1,200 soldered joints are required to connect the coil terminals to the stub cable conductors. It was accordingly very important that the assembly method should involve a minimum liability to open circuits, crosses, or grounds. To accomplish this, a method was devised whereby the various spindles of coils were assembled to a skeleton frame to which the cable stub containing the 600 terminal pairs is also attached. All splices to the outgoing conductors are made immediately adjacent to the individual coil terminals, after which the skeleton unit consisting of the coils and stub cable with case cover attached, is picked up with suitable tackle, and the coil unit inserted in the case. Fig. 17 illustrates this stage of the assembly. The case is subsequently filled with moisture-proof compound and sealed in the usual manner.

Installation Features. In general, the exchange area cables on which loading is required are run in underground ducts and consequently the

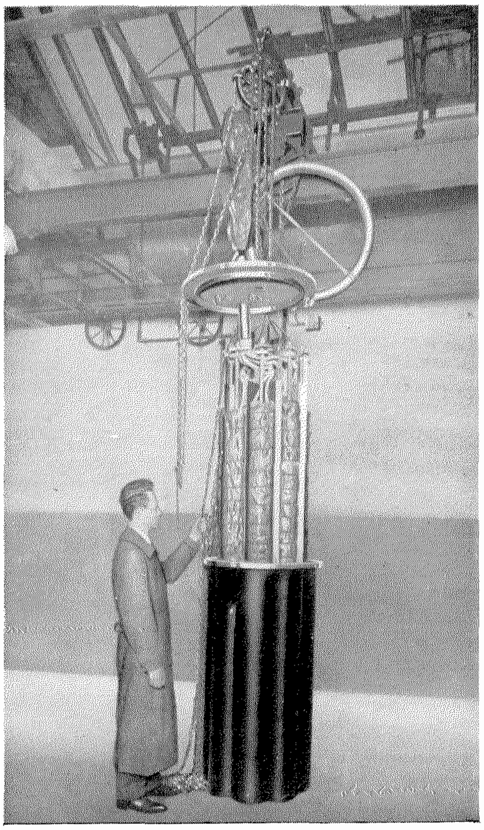

Figure 17—Assembly of 300-coil Case. Lowering Loading Coils Into Case After Coil Spindles Have Been Mounted on Frame and Coil Terminals Spliced to Stub Cable Conductors

great bulk of the exchange area loading is installed in underground vaults. Fig. 18 shows a typical loading installation in a "double-deck" vault in New York City. The loading coil cases are placed in the lower part of the vault permitting the coil terminal stub cables to be brought up vertically behind the horizontal cable runs and spliced to the trunk cables in such a way as to minimize the difficulties of future work on the

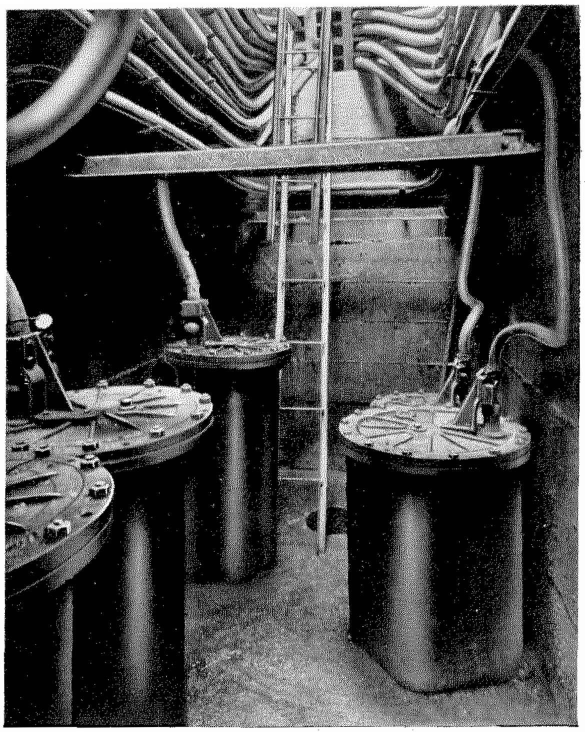

Figure 18—Underground Cable Loading Coil Installation in Metropolitan Area. Double-deck Vault Having ultimate capacity of 14 Large Coil Cases

cables passing through the vault. The trunk cables enter the vault through ducts which may be seen at the top of the picture, and are supported on racks mounted on the upper side walls of the vault.

At present, a total of eight loading coil cases is installed in the vault illustrated in Fig. 18. Only five of these, however, appear in the picture. The cases now in place contain a total of 645 loading coils. The vault has space for six additional large cases, on which basis it is estimated that this vault will ultimately contain about 2,400 coils. Some of the largest vaults are capable of accommodating a total of 30 large cases containing a total of 9,000 coils.

VII. Loading for Submarine Cables

Coil Loading. The special problem of applying coil loading to submarine cables is a mechanical one, rather than one concerning the principles of loading. The situation in the United States is

TABLE XVIII

Coil Loaded Submarine Cables

Location	Year of Installation	Length of Cable (Miles)	No. of Load Points	Number of Loaded Ccts.	Spacing of Coils-(Miles)	Coil Inductance (Henrys)
Chesapeake Bay No. 1......	1910	4.5	2	17 pr. 13 A.w.g.	1.97	0.117
Chesapeake Bay No. 2......	1916	4.0	1	12 qd. 13 A.w.g.	2.0	0.067-S 0.042-P
Tarrytown-Nyack..........	1916	2.7	2	37 qd. 16 A.w.g.	0.89	0.250-S 0.155-P
Raritan Bay No. 1.........	1917	5.3	5	37 qd. 16 A.w.g.	0.91	0.250-S 0.155-P
Raritan Bay No. 2.........	1918	5.3	5	37 qd. 16 A.w.g.	0.89	0.250-S 0.155-P

such that only a few coil loaded submarine cables have been required; this, of course, does not refer to the considerable number of instances where the submarine cables are so short that ordinary types of coils installed at the terminals satisfy the transmission requirements.

To date there have been installed in the United States a total of five cables having submarine coil loading; details of which are given in Table XVIII.

The Raritan Bay cables each have 37 quads loaded at five points, 111 coils at each point, constituting the largest installation of submarine coil loading in the world. The depth of water in which these cables are installed is about 35 feet.

In each of the above instances, dry core paper cables were used. The design of the coil was made to fit the special designs required for the submarine loading pots. The case design was such as to furnish complete protection of the coils against moisture penetration and adequate mechanical strength for taking up the tension in the cable. In installing the cables, the procedure was to splice the loading coil cases into the cable while the cable was coiled on a barge, and then lay the cable and coils as a continuous operation. The service record of these loaded submarine cables is excellent, thus demonstrating a satisfactory solution of the many difficult mechanical problems involved.

Continuous Loading. Another form of submarine cable loading, first put into practise by the Danish engineer, C. E. Krarup,[29] is to wind an iron wire or tape spirally around the copper conductor. This gives a continuous loading which has found important applications in the case of telephone and telegraph cables laid in deep water. So far as land cables are concerned, it has been found that continuous loading is uneconomical in comparison with coil loading. The only instances of continuous loading in the plant of the Bell System are the Florida-Cuba cables,[30] connecting Key West and Havana, which are the longest and most deeply submerged cables in use for telephonic communication in the world.

VIII. Extent of Commercial Application

The following data will assist in visualizing the practical importance of the developments which have been described in this paper.

In 1911, when Mr. Gherardi addressed this Institute on the subject of loading practise in this country, there were about 125,000 loading coils in service which loaded about 85,000 miles of open wire circuits, and 170,000 miles of cable circuits. Although precise figures are not yet available regarding the number of loading coils in service in the Bell System as of January 1, 1926, conservative estimates set this total at about 1,250,000 coils. These coils load about 1,600,000 miles of cable circuits and 250,000

[29] C. E. Krarup, Submarine Telephone Cables with Increased Self-Induction, *ETZ.*, 23:344, April 17, 1902.

[30] W. H. Martin, G. A. Anderegg, B. W. Kendall, "Key West-Havana Submarine Telephone Cable System," Trans. A. I. E. E., Vol. 41, 1922, p. 184.

miles of open wire. In round numbers, 500,000 coils are installed on non-quadded local area trunk cables and 700,000 in toll and toll entrance cables (the bulk of these being quadded cables). Nearly two-thirds of the total number of coils have compressed iron powder cores, all of these being installed on cable circuits. About 4500 coils having wooden cores are installed on carrier loaded entrance cables. The remainder have iron wire cores, approximately 60,000 being of the so-called "air-gap" types.

Prior to the development of satisfactory types of telephone repeaters, the principal use of loading coils was in exchange area trunk cables in large metropolitan areas such as New York, Chicago, Philadelphia, and Boston. The successful application of telephone repeaters to loaded small gage cables has greatly increased the use of loading in the telephone plant. As illustrating this trend, approximately 150,000 toll cable coils were manufactured for the Bell System in 1925, and approximately 100,000 exchange area cable coils. Recent estimates of the loading coil requirements for the next five years indicate an annual demand at a rate which would double the total number of loading coils in service about 1930.

As regards the field of application for cable loading in terms of cable lengths, the entrance and intermediate cables represent the minimum lengths; for instance, pieces as short as 500 feet when present in carrier telephone systems may require loading. In the local exchange areas, toll switching trunks as short as two miles may require loading. On the other hand, as illustrating the longest circuit now entirely in cable, a connection between Boston and Milwaukee—via New York, Pittsburgh, Cleveland, and Chicago—typifies the possibilities in the existing repeatered loaded cable plant. The over-all length of such a circuit is approximately 1200 miles. There is no technical obstacle to the use of repeatered loaded cables for distances several times as great; i.e., in the present state of the art this is primarily a question of economics rather than of development.

IX. Conclusion

It will be appreciated from the foregoing account that the invention of coil loading was the beginning of an era of intensive development which has been marked by enormous advances in the design of telephone transmission lines, and that there has been no slackening of the inventional or development activity devoted to this subject. It is significant that at present more engineers and physicists in the departments represented by the authors are engaged on loading development problems than at any previous time.

In this account of the progress of the loading art during the past quarter century, the authors have endeavored to point out the relation of the loading developments to other phases of telephone development such as cables, repeaters, telegraph working, and carrier telephone and telegraph systems. In the space that is available, it would be impracticable to assign full credit to the many individuals who have been engaged in the development work on loading and the related problems. The final accomplishments should be regarded as the result of well coordinated efforts along many lines.

In conclusion, it may be of interest to note what the development and use of loading has meant to the telephone using public from an economic standpoint. Leaving out of consideration altogether loading on long toll cables—where the interdependence of repeaters and loading is such that it is impracticable to assign to each its share of the savings—and taking into consideration only the loading of interoffice trunks and toll open wire circuits, it has been estimated that the larger wires which would have been required to give the present grade of transmission if loading had not been available, taken together with the heavier pole lines and additional underground ducts, would have entailed an additional investment in Bell System telephone plant of over $100,000,000.

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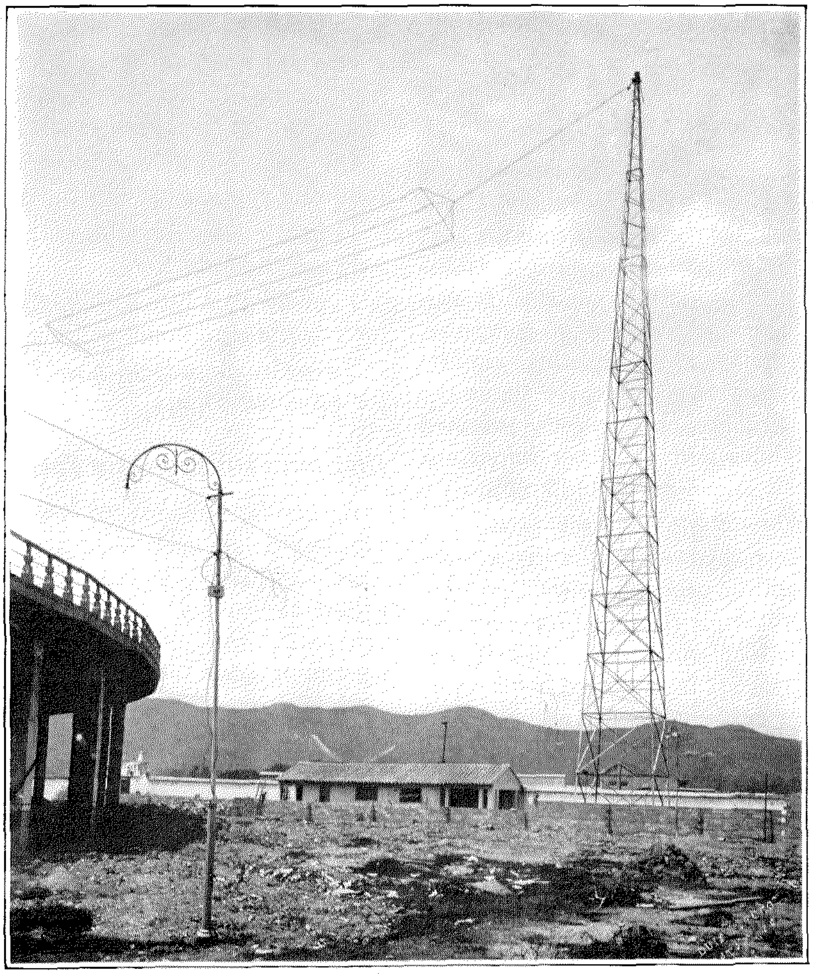

Antenna System of Radio Broadcasting Station AYRE with Bullring to the Left. The station capacity is 1-kw. and the wave-length is 375 meters. The equipment was furnished and installed by the International Standard Electric Corporation for the Empresa Venezolana de Radiotelefonia, Caracas, Venezuela, which has an exclusive Government concession for broadcasting in Venezuela. The station went on the air April 27, 1926

The Stockholm-Norrköping Telephone Cable

By N. HEDÉN

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THE electrification of the main line of the Stockholm - Gothenburg State Railway, which is expected to be completed in 1926, necessitated removal of the open wire telephone circuits along the railway track. Some of these circuits have been placed on pole lines and others in cables. A number pass through the Stockholm-Gothenburg cable,[1] which was finished in 1923. For the south-going circuits, the new Stockholm-Norrköping cable described in this paper has been provided, which is projected to form part of the Stockholm-Malmö cable.

Computation of the Number of Circuits

To determine the number of circuits required in the Stockholm-Norrköping Telephone Cable an estimate was made of the traffic needs for 1940 when the Stockholm-Gothenburg cable is assumed to reach its ultimate capacity. It was found that the average number of computed traffic hours in relation to existing circuits amounted to between two and three times the present number. Still greater increase is assumed for international lines and for other important long lines. Transit lines for Finland traffic with the Continent also have been contemplated.

As a rule, the costs for cable circuits will diminish as the size of the cable increases, but there is a certain size which for technical reasons cannot be exceeded. In planning this cable it was therefore necessary first to determine for what sections a full-size cable would be required and for what sections a smaller cable would be sufficient. Special studies were carried out to determine the numbers and types of conductors to be adopted.

These investigations showed that while a full-size cable would be necessary between Stockholm and Nyköping, a somewhat smaller cable would be sufficient for the Nyköping-Norrköping section. A full-size cable is assumed to be required south of Norrköping as far as Linköping, beyond which in the central portion of the route the cable will be tapered down and increased again towards Malmö.

Types of Circuits

To provide better speech-transmission than on the Gothenburg cable, it is intended to introduce on the Malmö cable a later system of loading and also, for a certain type of circuit, the four-wire transmission system. Whereas medium-medium loading was used on the Stockholm-Gothenburg cable, other systems with medium-heavy and extra-light loading have been chosen for the Stockholm-Norrköping cable. Thus an increase of the cut-off frequency is obtained.

On the Stockholm-Malmö cable project the following types of circuits have been used:

Four-wire circuits with extra light loading for long international lines.

Four-wire circuits with medium-heavy loading for other international and long inland lines.

Two-wire circuits with medium-heavy loading for remaining lines.

Division into Repeater Sections

As a rule, light-loaded 4-wire circuits will be repeatered at each repeater station and the medium-heavy loaded 4-wire circuits at alternate repeater stations. Two-wire circuits will be repeatered at each or at alternate repeater-stations, depending upon the attenuation in each case.

The values of the final losses in the circuits have been stipulated as follows:

	βL	TU.
4-wire circuits	0.7—1.0	6.08— 8.69
2-wire circuits for switched traffic	0.8—1.1	6.95— 9.56
2-wire circuits for terminal traffic	1.0—1.5	8.69—13.04

After various alternatives concerning location of repeater stations had been discussed, and the costs involved estimated, it was determined to place repeater stations at Västerljung and Norrköping. Thus the length of the section Västerljung-Stockholm became 76.2 km. and the section Västerljung-Norrköping 100.5 km.

[1] "The Stockholm-Gothenburg Cable," by E. Ekeberg. "Electrical Communication," April, 1924.

Arrangements pending completion of the Stockholm-Malmö Project

A special plan for the circuit arrangements was drawn up to be in force while the cable terminates at Norrköping and while the circuits south thereof are open wires. Such long circuits as are in the future to be used for 4-wire working can without inconvenience and with less cost be used for 2-wire working on the relatively short Stockholm-Norrköping section. Four-wire circuits, therefore, are employed at present only to such extent as is necessary to gain practical experience with the system.

As is the case on the Gothenburg cable, only two-thirds of the Norrköping cable is at present loaded. The further loading to be carried out will chiefly affect 4-wire circuits.

Table I shows the size of the cable and the amount of the loading.

TABLE I

Type of circuits	Number of quads					
	Stockholm-Nyköping			Nyköping-Norrköping		
	Loaded	Non-loaded	Total	Loaded	Non-loaded	Total
0.9 mm. 4-wire extra light loaded.....	12	..	12	12	..	12
0.9 mm. 4-wire medium-heavy loaded	8	40	48	8	40	48
1.3 mm. 2-wire medium-heavy loaded	40	4	44	40	4	44
0.9 mm. 2-wire medium-heavy loaded	10	..	10	5	..	5
Total........	70	44	114	65	44	109

Detail Planning

During the summer and autumn of 1923, the cable route to Norrköping (Figure 1) had been surveyed in accordance with the various alternatives discussed, and ultimate terrain sections had been staked out. From this survey the loading plan was made and the lengths of the loading sections were fixed. In the repeater-section Stockholm-Västerljung the average loading-section length is 1821 meters, and in the section Västerljung-Norrköping the corresponding length is 1828 metres.

Terrain routes have been taken into consideration for two reasons:

(1) To shorten the total cable length and to obtain an even number of loading-sections of normal length.

(2) To avoid the neighborhood of the railway line with due regard to its future electrification.

For the first reason a 2.5 km. terrain section with 230 metres of submarine cable across a lake was necessary between Stockholm and Södertälje. This shortened the cable by 1.1 km. and permitted 20 uniform loading sections between Stockholm and Södertälje. For the same reason a number of terrain routes were selected between Västerljung and Norrköping to reduce the total length of this repeater-section. To obtain the necessary separation from the railway track, three terrain routes 12.3, 3.1, and 1.5 km. in length were used. Early in May, 1924, everything was prepared for starting the outside cable work.

Placing of the Cable

As cable deliveries were delayed unavoidably, it was not until June 10, 1924, that laying operations could begin. Simultaneously with the placing of the Stockholm-Norrköping toll cable a local cable (Figure 2) was laid between Stockholm-Södertälje-Järna. All the cables were of underground type. Between Stockholm and Södertälje the route was along the main road, which had recently been reconstructed. In order not to injure the crown of the road the cables were placed close to the side. As this prevented the use of a motor roller during replacement of the road, the trench was carefully tamped by manual labor. This method was used also on the road between Norrköping and Åby where the traffic is very heavy. On the remainder of the cable route the road-ways were restored by means of motor rollers. The trenching was chiefly done by hand labor. Only one digging machine was employed, it dug almost 30 km., i.e., about 18 per cent of the entire trench.

The difference in the results obtained by trained laborers and by those of "new-employed" men was great. Laborers temporarily employed showed an output of rather less than 40% of that of the best workers.

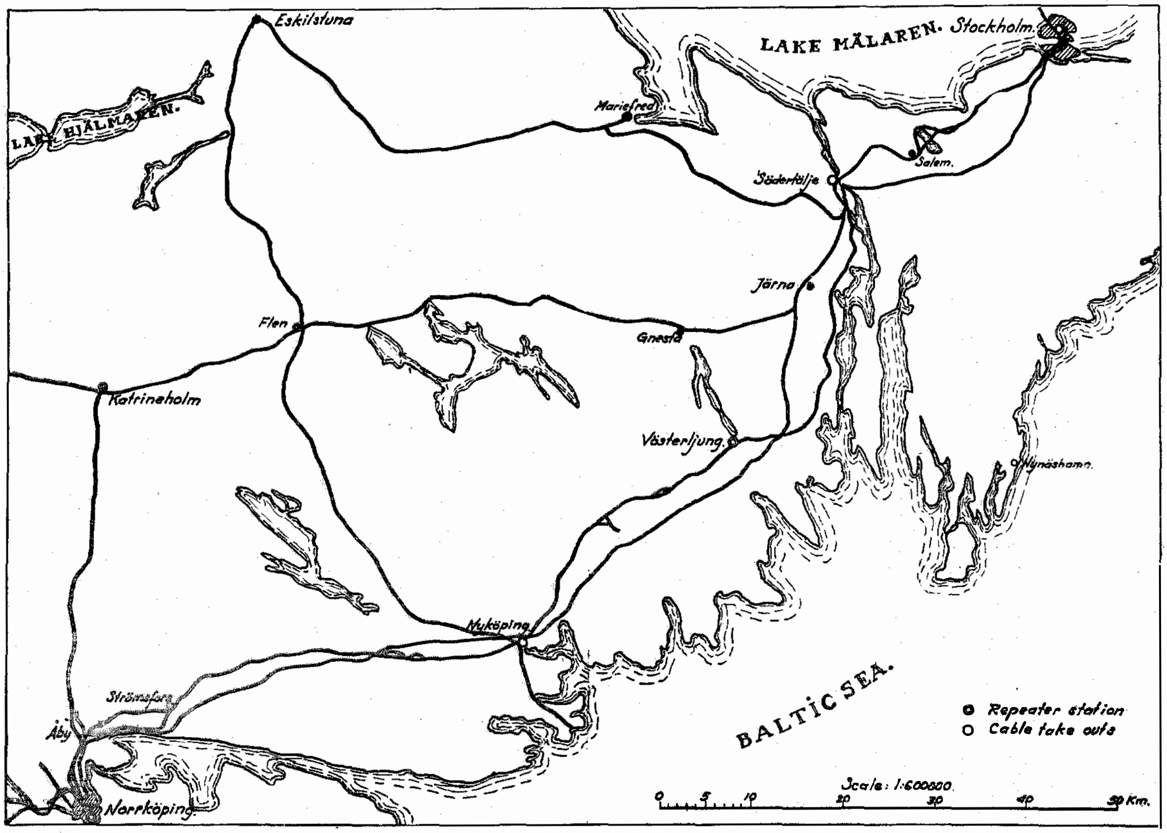


Figure 1—Map of Stockholm-Norrköping Cable Route

In the Stockholm-Södertälje section, and in other sections where the cable-route runs comparatively near to the railway line, the cables are armored with two layers of iron bands; the remainder are unarmored. The iron of the armored cables forms an appreciable protection against injury. As an extra protection during the period in which the earth is frozen, a creosoted board is placed 8—10 centimetres above the cable to indicate its location and to serve as an obstacle to further digging. The unarmored cable is placed in wood ducts as on the Gothenburg cable. This method of laying is very suitable for Swedish conditions and in the past has proved the cheapest way of protecting the cable.

Only the two-wheel type of cable-trailer has been used. As a rule a gang of 10 men would place 1.5—2 km. per day. The longest section placed in one day was 3.6 km. The total number of motor vehicles, including the cars of the supervisory staff, amounted to 31 cars and 14 motor cycles. To supply the laborers with food and lodging on the spot, tent camps and canteens were erected in the neighborhood of the working places.

Splicing and Loading

On account of the large size of the cable, the separation of the conductors into different groups, and the simultaneous splicing of the Södertälje cable, a considerable number of splicing gangs and testers were required. In November, 1924, the cable splicing reached its peak and at that time there were 21 gangs for splicing in the cable and 8 gangs for splicing in the loading coils together with 25 testers, under the supervision of 2 foremen and 3 technical supervisors At the splicing of the Norrköping cable, in order to reduce capacity unbalance and capacity deviation, the Western Electric method of crossing the conductors was used.

In the entire Stockholm-Västerljung repeater section and in the first 13 and last 12 loading-sections between Västerljung and Norrköping, capacity-balancing was carried out in seven splices of each loading-section. In the remaining loading-sections, located in the middle of the repeater section Västerljung-Norrköping, capacity-balancing was performed only in three splices per loading-section. Each loading-section comprised 8 lengths of cable. The average cutting length

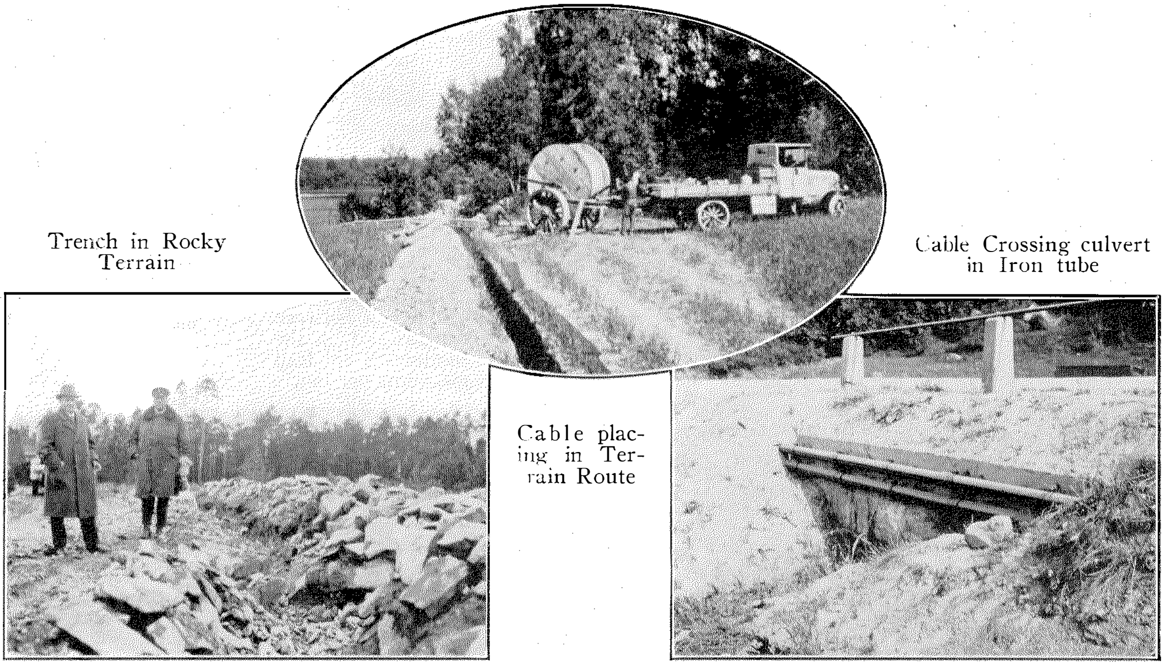


Figure 2—Placing of Stockholm-Norrköping Toll Cable and a Local Cable between Stockholm, Södertälje, Järna

was 230 metres. At each splice, the following groups of conductors had to be kept separated:

0.9 mm. conductors, 4-wire, direction A-B, 30 quads.

0.9 mm. conductors, 4-wire, direction B-A, 30 quads.

1.3 mm. conductors, 2-wire, 44 quads.

0.9 mm. conductors, 2-wire, 10 (5) quads.

Where there are only one or two groups of circuits in a cable not too great in size, the tester can immediately after testing give instructions to the splicer regarding crossing of conductors for jointing, so that the splicing can start at once. While the splicing is going on the tester can complete his calculations. In the present case, however, the number of conductors in the cable was so great that testing and splicing could not be performed in one day, nor could the test sheets be finished during the course of the work. It was necessary, therefore, for the measurements and the test-sheets to be sent to an office located in the neighborhood of the splicing place. During the night a special staff finished the balancing calculations. Next morning the completed test-sheets were handed to the tester for use at the jointing. By this practice great accuracy and uniformity of the balancing work were attained; this is reflected in the good results reached with regard to crosstalk.

In order to reduce the variations in mutual capacity, deviation tests were made in the middle splice of every loading-section so that within each loading-section all circuits belonging to the same group obtained as nearly as possible identical capacity.

By a suitable allocation, in the factory, of the lengths in the loading-sections, the average mutual capacity of any group of circuits within a loading-section did not deviate by more than 2 per cent from the average mutual capacity of this group, for all loading-sections of the repeater section.

As soon as the splicing of a loading-section was finished, the splicing-in of the loading coils commenced. At each loading point, two loading pots are connected-in, and room is left for the third one to be spliced-in later when the cable is completely loaded. The loading pots are buried in the earth and the splices are protected by concrete covers.

In general, the splicing points of the unarmored cable are protected by the customary wooden splice boxes. For certain parts of the armored cable, cast iron boxes were adopted, while for the remainder, wooden splice-boxes of a somewhat modified construction were used.

Particulars of Cable

The order for the Stockholm-Norrköping cable was placed with Max Sieverts Fabriks Aktiebolag, Sundbyberg, Sweden. Owing to delays in the transport of cabling machinery for this factory, the manufacture of 36 km. of cable for the section Västerljung-Nyköping was entrusted to the Western Electric Company.

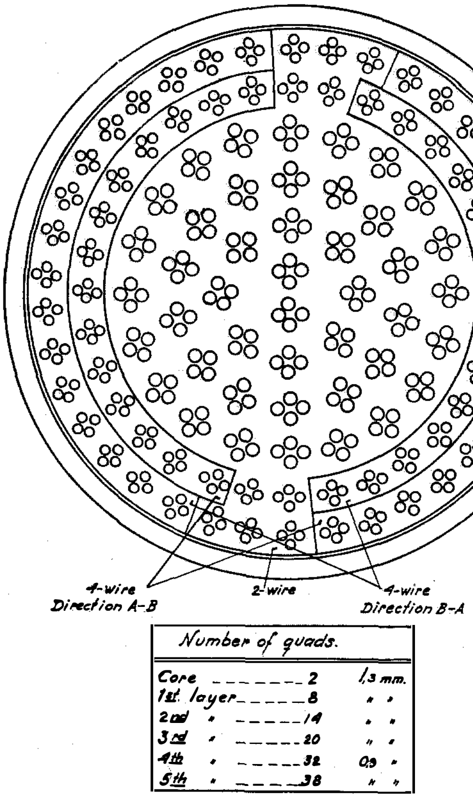


Figure 3—Cross section of cable

As already mentioned, two types of cable were manufactured; i. e., type A, containing 114 quads, intended for the Stockholm-Nyköping section, and type B containing 109 quads, intended for the Nyköping-Norrköping section. The cable construction is shown in Figure 3.

MECHANICAL DETAILS

	Stockholm-Nyköping			Nyköping-Norrköping	
	Unarmored	Armored	Submarine	Unarmored	Armored
Length of cable delivered, kilometers	71.4	42.2	1.0	52.5	13.0
Weight, kgs. per meter..........	11.23	15.03	23.97	11.00	14.75
Thickness of lead sheath, mm......	3.0	3.0	4.0	3.0	3.0
Overall diam., approximately, mm.	65	77.5	92.5	64.5	77.

ELECTRICAL DETAILS

	Contracted Values	Values Measured
Insulation Resistance between one conductor and all the others connected to lead sheath, megohms per km.	5000	Greater than Contract values
Insulation Breakdown in volts, measured with alternating current of 50 p.p.s. during 1 minute		
Between one conductor and all the others connected to lead sheath	500	Greater than Contract values
Between all conductors taken together and the lead sheath	1000	Greater than Contract values
Mutual Capacity at 800 p. p. s. average per repeater-section in microfarads per kilometer		
Side circuits	0.0395	S–Vlj 0.0369 Vlj–N 0.0374
Phantom circuits	0.0660	S–Vlj 0.0600 Vlj–N 0.0609
Capacity Unbalance for factory lengths of 230 meters, in micro-microfarads	Aver. Max.	
Side to side of same quad (S-S)	40 120	Well within contract limits
Phantom to side of same quad (Ph-S)	150 720	
Between other circuits	75 245	
Between opposite going 4-wire circuits	10 80	
Between the conductors of a pair and earth	150 720	
Conductor Resistance in factory lengths per km. conductor at +15° C. in ohms, average		
1.3 mm. conductors	13.2	Average 12.69
0.9 mm. conductors	27.5	Average 26.85
Resistance Unbalance in factory lengths, that is the difference in resistance of the two conductors of a pair compared with the resistance of the pair	Less than 3%	2.5%
Average of these values in a factory length	Less than 1%	0.41%
Leakance at 800 p. p. s. and +15° C. in a factory length, mhos. per km.		
For pairs	1.0×10^{-6}	Within contract limits
For phantoms	1.67×10^{-6}	

Loading

The loading equipment was delivered by the Western Electric Company, London (now Standard Telephones and Cables, Limited), and was manufactured in accordance with the three-coil system of that company. All loaded quads thus provide three circuits.

	Inductance of coils, milli-henries	Calculated cut-off frequency in the circuit, periods per second
Medium heavy loaded circuits		
Side	177	2800
Phantom	63	3700
Extra light loaded circuits		
Side	44	5500
Phantom	25	5900

Between Stockholm and Nyköping two loading pots, one type A_1 and one type B, each containing 35 loading units, are installed at each loading point. Between Nyköping and Norrköping, one type A_2 loading pot containing 30 loading units and one type B are installed at each loading point. The distribution of loading units within the different types of loading coil cases is shown in Table II.

TABLE II

Type	Number of quads				
	Medium heavy loaded			Extra light loaded	Total
	4-wire	2-wire			
	0.9 mm. conductor	1.3 mm. conductor	0.9 mm. conductor	4-wire 0.9 mm. conductor	
A_1	8	5	10	12	35
A_2	8	5	5	12	30
B	..	35	..	..	35

Very strict regulations were fixed regarding the limits of allowable crosstalk between the circuits in the loading coil cases. Thus the crosstalk values specified by the Swedish Administration expressed in attenuation (βL) at 800 periods per second were not allowed to fall below:

	Average βL.	Minimum βL.
Side to side in the same unit.......	10.6	9.2
Side to phantom in the same unit...	9.7	8.5
Side to side of different units.......	11	10.5
Side to phantom of different units..	10.9	9.9
Between opposite going 4-wire circuits	12	12

Corresponding (TU values) would be as follows:

	Average TU.	Minimum TU.
Side to side in the same unit.......	92	80
Side to phantom in the same unit...	84.3	73.8
Side to side of different units.......	95.5	91.2
Side to phantom of different units..	94.7	86
Between opposite going 4-wire circuits	104	104

From the contract values, the attenuation per km. was computed to have the following values at 800 p. p. s.

MEDIUM HEAVY LOADED

	β
1.3 mm. conductors, side and phantom.........	0.0120
0.9 mm. conductors, side and phantom.	0.0214

EXTRA LIGHT LOADED

0.9 mm. conductors, side......................	0.0377
0.9 mm. conductors, phantom.................	0.0320

Acceptance Tests

Measurements were carried out on separate drums of cable, on certain loading sections, and also on both repeater-sections, after completion of the splicing and loading work. The chief purpose was to ensure that deliveries complied with the terms of contract. At the same time, the measurements indicated the influence of different

TABLE III

	Stockholm-Västerljung		Västerljung-Norrköping	
	Aver. Value	Min. Value	Aver. Value	Min. Value
Insulation Resistance for one conductor connected to terminals, megohms per km.	30,000 approx	11,000	35,000 approx	14,500
Attenuation β at 1000 p. p. s. and +15°C, for medium loaded circuits				
1.3 mm. side	0.0108	..	0.0116	..
phantom	0.0107	..	0.0115	..
0.9 mm. side	0.0212	..	0.0218	..
phantom	0.0201	..	0.0209	..
For extra light loaded circuits				
0.9 mm. side	0.0351	..	0.0351	..
phantom	0.0298	..	0.0298	..
Crosstalk expressed in attenuation βL with mixed tone				
Side to side of same quad	9.50	9.05	9.45	8.85
Phantom to side of same quad	8.85	8.45	8.85	8.35
Between circuits of same type				
a) Between different sides	10.05	9.40	10.10	9.40
b) Between sides and phantoms	10.10	9.55	9.95	9.35
c) Between different phantoms	9.30	8.30	9.45	8.35
Between opposite going circuits of 4-wire groups	10.75	10.40	10.90	10.40

types of construction and manufacturing methods on the electrical properties of the cable and the changes in these properties caused by the laying of the cable.

The results of the acceptance tests on completed repeater sections are summarised in Tables III and IV.

The corresponding Crosstalk values expressed in (TU's) are as follows:

	Stockholm-Västerljung		Västerljung-Norrköping	
	Aver. Value	Min. Value	Aver. Value	Min. Value
Side to side of same quad	82.5	78.6	82.1	76.9
Phantom to side of same quad	76.9	73.5	76.9	72.5
Between circuits of same type				
a) Between different sides	87.4	81.7	87.7	81.7
b) Between sides and phantoms	87.7	83	86.5	81.2
c) Between different phantoms	80.8	72.1	82.1	72.5
Between opposite going circuits of 4-wire groups	93.4	90.4	94.7	90.4

With the Singing-point Test Set available, no higher values could be measured than 33 S. M. for side circuits and 33.7 S. M. for phantoms. For measurements on the extra light loaded circuits special arrangements had to be made. The singing-point values obtained are very high and uniform; this allows the repeaters to be worked with high gains. That the capacity of the jointed cable, and the inductances of the loading coils are uniform can be concluded also from the impedance curves. As an example, two of these curves

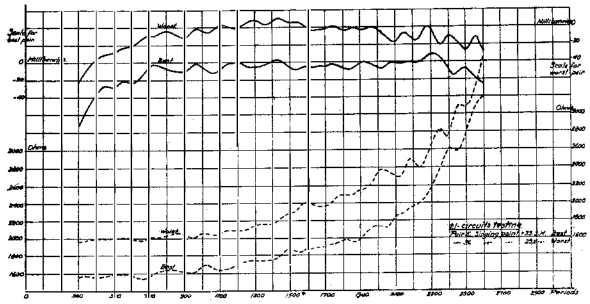


Figure 4—Stockholm-Norrköping Cable—Impedance curves in repeater section II from Norrköping to Västerljung for best pair (No. 5) and worst pair (No. 36) of medium heavy loaded 1.3 mm. side circuits

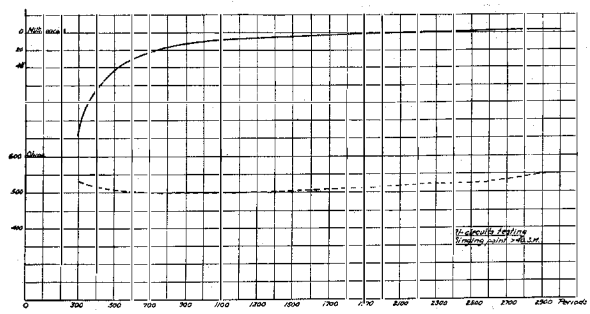


Figure 5—Stockholm-Norrköping Cable—Impedance curve in repeater section I, from Västerljung to Stockholm. Extra light loaded 0.9 mm. phantom circuit (pairs 401/402)

TABLE IV

	Stockholm-Västerljung				Västerljung-Norrköping			
	Measured from				Measured from			
	Stockholm		Västerljung		Västerljung		Norrköpimg	
	Ave.	Min.	Ave.	Min.	Ave.	Min.	Ave.	Min.
Singing Point measured in miles of standard cable (S. M.)								
2-wire circuits:								
1.3 mm. side	31.1	27.0	>33	29.5	>33	31.5	>33	29.5
1.3 mm. phantom	30.5	28.5	>33.7	31.0	32.0	30.5	32.6	30.5
0.9 mm. side	32.1	30.0	32.0	28.0	>33	30.5	>33	>33
0.9 mm. phantom	>33.7	32.7	31.6	31.0	32.6	32.0	31.7	31.0
4-wire circuits:								
Medium heavy loaded:								
0.9 mm. side	>33	32	>33	28.0	>33	32.5	>33	>33
0.9 mm. phantom	>33.7	>33.7	31.3	31.0	32.1	32.0	32.3	31.0
Extra light loaded:								
0.9 mm. side 0.9 mm. phantom	all values about 40 S. M.							

> = greater than < = less than

are shown in Figure 4 corresponding respectively to best and worst 1.3 mm. medium-heavy loaded side circuits between Västerljung and Norrköping. Figure 5 is a typical curve for an extra light loaded 0.9 mm. Stockholm-Västerljung phantom circuit.

Repeater Stations

In Stockholm the cable is terminated in the test-room of the toll telephone office. At Norrköping the repeater equipment is installed in rooms specially arranged for this purpose in the

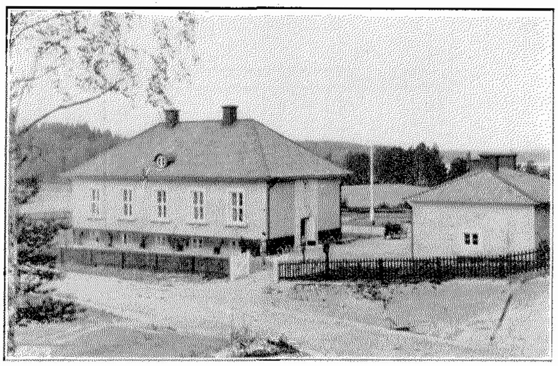


Figure 6—Repeater Station at Västerljung

telephone station. At Västerljung a new repeater-station and dwelling houses for the staff (Figure 6) had to be erected. The floor plans for the Västerljung station differ considerably from those adopted for previous Swedish repeater stations. They are shown in Figure 7.

To bring the equipment of the repeater stations into conformity with the standard equipment of Swedish telephone stations, it was determined to utilize Swedish constructions to the greatest possible extent. New special constructions for terminal boxes, terminal strips, testing jacks, toll test boards, signalling devices, etc., were drawn up in the Construction Office of the Telegraph Administration, and existing types of distributing frames, coil racks, etc., were used after necessary modificatoins. The equipment thus constructed and comprising also repeating coils and networks was manufactured at the Administration factory, Nynashamn.

In Figure 8 is shown a repeater rack for Western Electric 2-wire repeaters. On the left there is a battery-supply bay; next there are seven repeater bays, each containing 10 repeaters except the first where the space of 4 repeaters is occupied by the gain measuring set. Such a repeater rack, four metres in length, provides room for 66 repeaters, for which number the battery supply bay is constructed. On the top of this battery-supply bay are placed 33 fixed and 33 adjustable resistances for the filament current, every two repeaters having the filament-circuit in common. Below the resistances is mounted a milli-ammeter relay for the grid current and below that relay are mounted measuring instruments for the filament and plate currents. Under the meter-panel is a key panel for cutting-in repeaters and meters, and underneath this the fuse panel. At the bottom are mounted relays and condensers. In the condenser group is placed a device by means of which the four different grid voltages required are obtained.

On the repeater racks patching jacks for repeaters, lines and networks are mounted; also trunk jacks, and in alternate panels, a telephone set for monitoring, speaking, and calling on the repeaters. While the 4-wire repeater rack is also equipped in accordance with this arrangement, each bay contains only seven repeaters.

The new and distinctive features of the repeater stations on the Stockholm-Norrköping cable are the following:

(1) The use of cable terminal boxes mounted with fuses and protectors.

(2) The jacks in the toll test-boards are arranged with the two wires of one pair in the same jack. The jack is equipped with double inner springs, thus providing for disconnection and parallel connection in the same jack by the use of different plugs.

(3) The arrangement of coils and networks is more compressed. This makes it possible to use the standard racks of the Administration. All the fuses, resistances and keys for the battery supply are located in one bay.

Experience has shown that the new constructions are well adapted to their purpose; they are simple and they are economical of space.

For long lines it is intended to employ voice-frequency signalling, whereby the signalling current is amplified in the repeaters as are the speech currents. On the relatively short Stockholm-Norrköping section only 20-cycle ringing current is used for both 4-wire and 2-wire lines. Therefore, no special arrangements are necessary at the terminating points of the 2-wire circuits, signalling relays being required only at the repeaters.

The following numbers of repeaters are installed on the Norrköping cable:

	4-wire	2-wire	Total
Stockholm	12	5	17
Västerljung	6	78	84
Norrköping	12	45	57

The installation work in the repeater stations, which was started in 1924, could not continue at the desired rate until important deliveries of material had been executed. The essential part of the equipment was installed, however, by the end of June, 1925. The first circuits were cut in for traffic in May, 1925. The cutting in of the

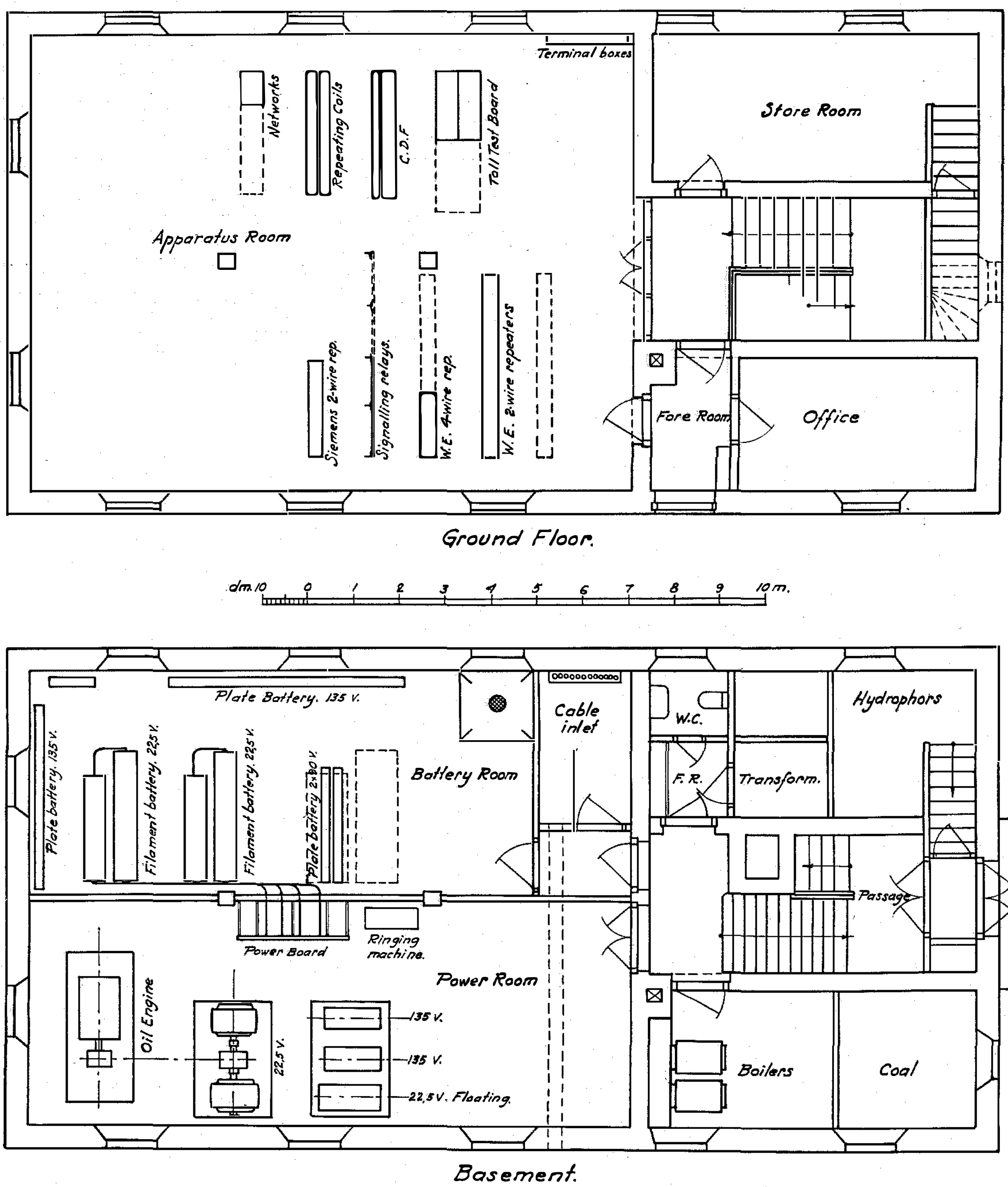


Figure 7—Västerljung Repeater Station—Floor Plan

repeatered circuits started in the middle of June of that year and was completed in about two months.

Telegraphing Over the Cable Circuits

Telegraph lines going south from Stockholm, which are used for high-speed systems, are for the present to remain as open wire lines, whereas all the telegraph lines for the Morse system will pass through the cable. The Morse lines are arranged as metallic circuits with direct currents of opposite directions. At the terminating points of the cable special telegraph repeaters are used. The cable circuits for telegraph purposes are provided by superposing the phantom telephone circuits so that two quads together form the two branches of a telegraph circuit.

Extent of the Cable Circuits

The total length of circuits obtained with the present amount of loading is 40,500 km. When the loading has been completed entirely the corresponding length will be about 63,000 km.

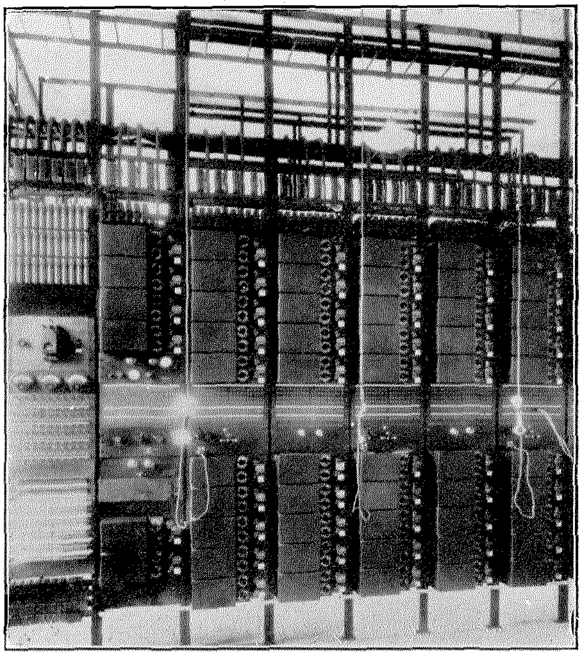


Figure 8—Västerljung Repeater Station—Repeater Rack for Western Electric 2 Wire Repeaters

Long Distance Telephone Communication at the Locarno Conference

By T. R. GUBBINS

European Engineering Department, International Standard Electric Corporation

IN connection with the Locarno Conference, the Swiss Administration was faced with the problem of providing the necessary telephone and telegraph facilities at extremely short notice, and of doing so at a place which normally dealt with only a very moderate traffic. Actually, it was only a week before the commencement of the Conference that the Administration with certainty knew that Locarno had been definitely selected for the Conference in preference to Lucerne or Lausanne, which had also been suggested.

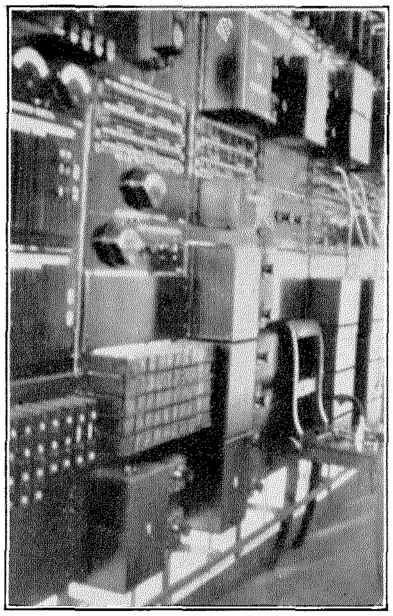


Fig. 1—Repeater Rack No. 1, Zurich Repeater Station

As soon as the place had been definitely chosen, the Administration took all steps to ensure that the facilities available would be ample and efficient. It may be interesting to give a brief description of what was accomplished in linking up Locarno with the European capitals most concerned.

The International Standard Electric Corporation through its associated company, the Bell Telephone Manufacturing Company, was fortunately able to render the Swiss Administration some assistance in connection with the long distance circuits involved, owing to the fact that during 1925 the latter Company was engaged in the installation of repeater stations for the Swiss Administration at Berne, Zurich and Basle. The Berne station was completed in August of that year. The Zurich station was nearing completion towards the end of September, when on the 29th of that month the Administration was definitely informed that the Conference would take place at Locarno on October 5th. In order to provide the long distance circuits required between Locarno and the European capitals, it was found that it would be necessary to employ telephone repeaters at Zurich, and accordingly every effort was made to have a certain minimum number of repeaters ready before the commencement of the Conference. Fortunately, by adopting emergency measures, it was found possible to do so, and two permanent circuits were established through Zurich from Locarno to Berlin and connections were also made as required with Paris, Frankfort and Berne.

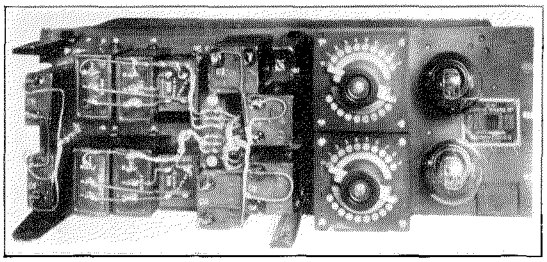
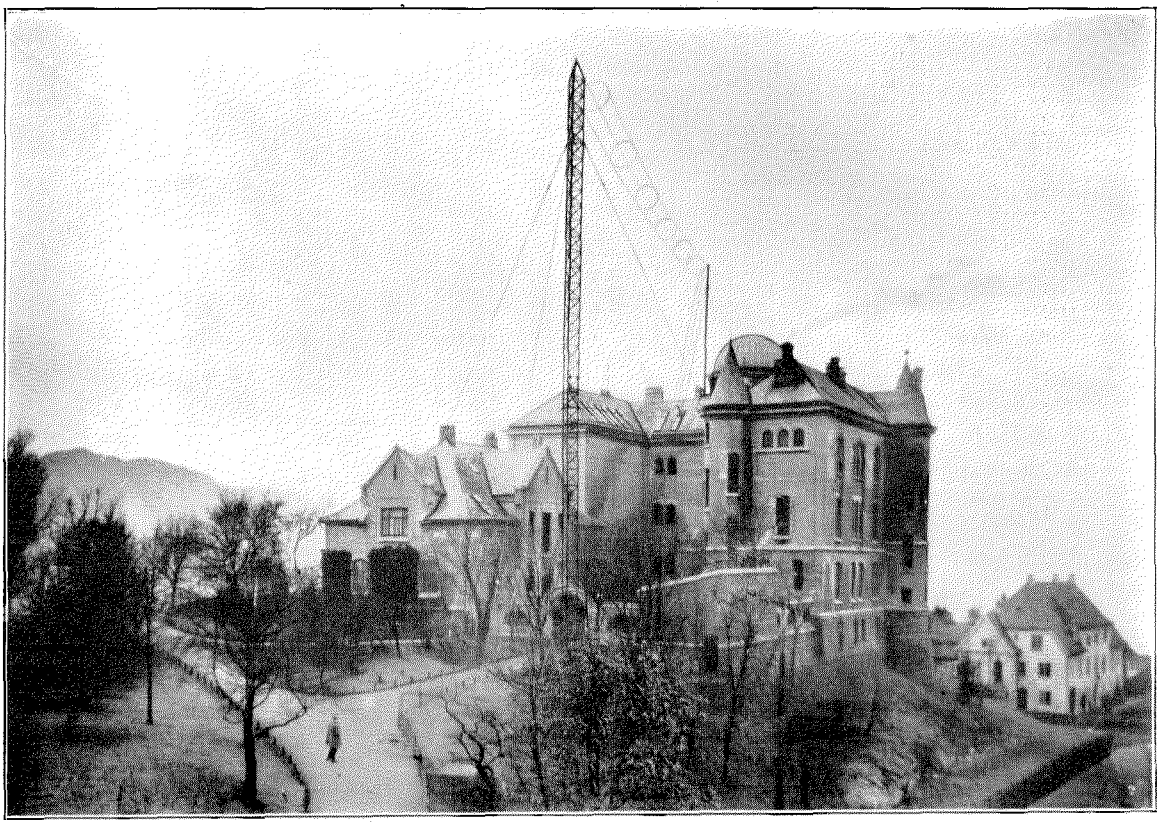


Fig. 2—22-A-1 Telephone Repeater, Front View

All these circuits worked satisfactorily, and the statesmen and journalists assembled at Locarno were unanimous in their praise of the long distance telephone facilities furnished by the Swiss Administration.

Figure 1 shows part of the Zurich Repeater Station. The repeaters employed during the Conference are in the background immediately above and below the temporary connecting cords. These repeaters were of the standard type, known as the No. 22-A-1, telephone repeater (see Figure 2), which is the type adopted for two-wire toll circuits, and were equipped with intermediate ringers designed to relay 20 cycle signalling currents. The usual "gain" measuring and testing facilities were furnished as well as the line repeating coils and networks for balancing the lines. The equipment comprised a total of 18 2-wire repeaters. The existing power plant was used for supplying the filament current, while additional batteries were provided for the plate and grid circuits.

From Zurich southward, the line circuits followed the Swiss underground toll cable route as far as the Altdorf Repeater Station; from there on, the circuits proceeded by open wire to Locarno except for the section of cable in the St. Gotthard tunnel. The circuits from Zurich to Germany followed the Swiss underground toll cable route to Basle, and from there continued by open wire to Karlsruhe where they joined the German Cable System. From Zurich to Karlsruhe the circuits were of the regular 2-wire type, employing 20 cycle ringing; from Karlsruhe to Berlin, however, the circuits were of the 4-wire type equipped with 4-wire repeaters and employing voice frequency signalling current. The circuit from Zurich to Paris was a heavy gauge open wire line, and the circuit from Zurich to Berne followed the underground toll cable route via Olten. Except for the open wire line to Paris, standard "side" or "phantom" circuit networks were used for all the cable circuits.



Bergen School of Navigation. The antenna is part of a Western Electric type radio broadcasting station furnished for temporary use pending completion by Standard Electric Aktieselskap, Oslo, of a permanent 1-kw. installation for the Bergen Broadcasting Company

Telephone and Telegraph Statistics of the World

Compiled by Chief Statician's Division American Telephone and Telegraph Company

Telephone Development of the World, by Countries

January 1, 1925

	Number of Telephones			Per Cent of Total World	Telephones per 100 Population	Increase in Number of Telephones During 1924
	Government Systems	Private Companies	Total			
NORTH AMERICA:						
United States	—	16,072,758	16,072,758	61.73%	14.2	839,407
Canada	202,089	870,365	1,072,454	4.12%	11.6	63,251
Central America	6,317	11,613	17,930	.07%	0.3	926
Mexico	1,749	49,231	50,980	.19%	0.4	620
West Indies:						
Cuba	700	54,214	54,914	.21%	1.7	7,128
Porto Rico	780	11,334	12,114	.05%	0.9	672
Other W. I. Places*	3,992	11,269	15,261	.06%	0.3	147
Other No. Am. Places*	75	3,733	3,808	.01%	1.1	143
Total	215,702	17,084,517	17,300,219	66.44%	11.2	912,294
SOUTH AMERICA:						
Argentine	—	173,605	173,605	.66%	1.8	16,564
Bolivia	—	1,824	1,824	.01%	0.1	—400*
Brazil	587	97,977	98,564	.38%	0.3	4,718
Chile	—	30,895	30,895	.12%	0.7	623
Colombia	—	14,923	14,923	.06%	0.2	3,460
Ecuador	1,691	2,827	4,518	.02%	0.2	—
Paraguay	183	278	461	.002%	0.04	69
Peru	—	9,552	9,552	.03%	0.2	412
Uruguay	—	25,241	25,241	.10%	1.5	1,057
Venezuela	527	10,520	11,047	.04%	0.4	497
Other Places	2,527	—	2,527	.01%	0.5	214
Total	5,515	367,642	373,157	1.43%	0.5	27,214
EUROPE:						
Austria	145,141	—	145,141	.56%	2.2	9,302
Belgium	136,944	—	136,944	.53%	1.8	22,137
Bulgaria	8,097	—	8,097	.03%	0.2	814
Czechoslovakia	115,738	—	115,738	.44%	0.8	12,132
Denmark	12,066†	295,911	307,977	1.18%	9.0	15,207
Finland	—	83,000	83,000	.32%	2.4	3,000
France	660,127	—	660,127	2.53%	1.7	56,341
Germany	2,385,177	—	2,385,177	9.16%	3.9	142,845
Great Britain and No. Ireland	1,264,024	—	1,264,024	4.85%	2.8	115,929
Greece*	5,450	—	5,450	.02%	0.1	50
Hungary	78,612	—	78,612	.30%	1.0	3,405
Irish Free State (March 31, 1925)	21,641	—	21,641	.08%	0.7	373
Italy*	‡	172,900‡	172,900	.66%	0.4	20,000
Jugo-Slavia*	27,500	—	27,500	.11%	0.2	1,500
Latvia (March 31, 1925)	15,557	—	15,557	.06%	0.8	4,199
Netherlands	202,868	—	202,868	.78%	2.8	9,600
Norway	97,433#	71,085	168,518	.65%	6.1	1,510
Poland	75,000*	44,985	119,985	.46%	0.4	9,837
Portugal	2,300*	17,456	19,756	.08%	0.3	897
Roumania	34,580	—	34,580	.13%	0.2	2,965
Russia, including Siberia*	150,000	—	150,000	.58%	0.1	19,722
Spain	—	105,213	105,213	.40%	0.5	15,000*
Sweden	416,584	1,734	418,318	1.61%	6.9	15,929
Switzerland	189,429	—	189,429	.73%	4.8	9,149
Other Places in Europe*	45,346	13,467	58,813	.23%	0.7	2,247
Total	6,089,614	805,751	6,895,365	26.48%	1.4	494,090
ASIA:						
British India (March 31, 1925)	14,785	26,455	41,240	.16%	0.01	2,390
China*	77,844	34,226	112,070	.43%	0.03	10,645
Japan (March 31, 1925)	544,433¶	—	544,433¶	2.09%	0.9	71,628
Other Places in Asia*	88,610	16,055	104,665	.40%	0.1	9,913
Total	725,672	76,736	802,408	3.08%	0.1	94,576
AFRICA:						
Egypt	33,808	—	33,808	.13%	0.2	2,945
Union of South Africa†	71,448	—	71,448	.27%	1.0	6,265
Other Places in Africa*	47,044	1,203	48,247	.19%	0.04	4,662
Total	152,300	1,203	153,503	.59%	0.1	13,872
OCEANIA:						
Australia (June 30, 1924)	318,279	—	318,279	1.23%	5.5	36,576
Dutch East Indies	36,272	2,997	39,269	.15%	0.1	682
Hawaii	—	17,707	17,707	.07%	6.2	891
New Zealand (March 31, 1925)	120,097	—	120,097	.46%	8.7	8,656
Philippine Islands*	2,550	13,200	15,750	.06%	0.1	750
Other Places in Oceania*	2,309	445	2,754	.01%	0.2	69
Total	479,507	34,349	513,856	1.98%	0.7	47,624
TOTAL WORLD	7,668,310	18,370,198	26,038,508	100.00%	1.4	1,589,670

* Partly estimated. † March 31, 1925. # June 30, 1924.

‡ As all local telephone service was transferred to private companies during 1925, the estimated number of telephones is shown under **Private** Companies.

¶ Excludes 23,800 telephones temporarily out of service as a result of the earthquake.

Telephone and Telegraph Wire of the World, by Countries
January 1, 1925

	Service Operated by (See Note)	Miles of Telephone Wire: Number of Miles	Miles of Telephone Wire: Per Cent of Total World	Per 100 Population	Miles of Telegraph Wire (See Note): Number of Miles	Miles of Telegraph Wire (See Note): Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	46,500,000	61.05%	41.0	1,925,000	29.39%	1.7
Canada	P. G.	2,793,596	3.67%	30.3	316,113	4.83%	3.4
Central America	P. G.	35,362	.05%	0.6	21,021	.32%	0.3
Mexico	P. G.	122,968	.16%	0.9	76,105¶	1.16%	0.5
West Indies:							
Cuba	P. G.	165,098	.22%	5.2	10,799	.16%	0.3
Porto Rico	P. G.	24,135	.03%	1.8	1,061	.02%	0.1
Other W. I. Places*	P. G.	36,385	.05%	0.6	5,426	.08%	0.1
Other No. Am. Places*	P. G.	7,616	.01%	2.2	9,700	.15%	2.8
Total		49,685,160	65.24%	32.3	2,365,225	36.11%	1.5
SOUTH AMERICA:							
Argentine	P.	540,588	.71%	5.5	189,588	2.90%	1.9
Bolivia	P.	3,589	.01%	0.1	6,957*	.11%	0.2
Brazil	P. G.	259,455	.34%	0.8	97,223	1.48%	0.3
Chile	P.	49,665	.06%	1.1	38,090¶	.58%	0.8
Colombia	P.	18,304	.02%	0.2	14,413	.22%	0.2
Ecuador	P. G.	5,083	.01%	0.2	4,321	.07%	0.2
Paraguay	P. G.	138	.0002%	0.01	1,841	.03%	0.2
Peru	P.	32,852	.04%	0.6	10,640	.16%	0.2
Uruguay	P.	44,434	.06%	2.7	6,404	.10%	0.4
Venezuela	P. G.	27,943	.04%	1.1	6,726	.10%	0.3
Other Places	G.	4,658	.01%	1.0	779	.01%	0.2
Total		986,709	1.30%	1.4	376,982	5.76%	0.5
EUROPE:							
Austria	G.	373,769	.49%	5.6	47,479	.72%	0.7
Belgium	G.	519,821	.68%	6.7	27,678	.42%	0.4
Bulgaria	G.	30,528	.04%	0.6	17,264	.26%	0.3
Czechoslovakia	G.	204,090	.27%	1.5	44,541	.68%	0.3
Denmark	P. G.	743,137	.98%	21.8	9,149	.14%	0.3
Finland	P.	98,183	.13%	2.8	10,114	.15%	0.3
France	G.	1,963,890	2.58%	4.9	473,969	7.24%	1.2
Germany	G.	7,417,263	9.74%	12.0	531,960	8.12%	0.9
Great Britain and No. Ireland†	G.	4,966,746	6.52%	10.8	312,356	4.77%	0.7
Greece*	G.	6,200	.01%	0.1	26,700	.41%	0.5
Hungary	G.	226,839	.30%	2.8	51,632	.79%	0.6
Irish Free State†	G.	55,545	.07%	1.7	22,800	.35%	0.7
Italy*	P. G.	550,000	.72%	1.3	260,000	3.97%	0.6
Jugo-Slavia*	G.	63,300	.08%	0.5	35,700	.55%	0.3
Latvia (March 31, 1925)	G.	82,117	.11%	4.5	5,642	.09%	0.3
Netherlands	G.	417,669	.55%	5.7	32,654	.50%	0.4
Norway (June 30, 1924)	P. G.	410,628	.54%	14.9	20,442	.31%	0.7
Poland*	P. G.	415,635	.55%	1.5	115,000	1.76%	0.4
Portugal*	P. G.	65,158	.08%	1.0	19,100	.29%	0.3
Roumania	G.	80,991	.11%	0.5	48,388	.74%	0.3
Russia (including Siberia)	G.	450,000*	.59%	0.3	374,989	5.73%	0.3
Spain*	P.	210,000	.28%	0.9	82,000	1.25%	0.4
Sweden	G.	921,509	1.21%	15.3	54,021	.82%	0.9
Switzerland	G.	482,091	.63%	12.3	24,138	.37%	0.6
Other Places in Europe*	P. G.	125,661	.16%	1.5	15,024	.23%	0.2
Total		20,880,770	27.42%	4.2	2,662,740	40.66%	0.5
ASIA:							
British India (March 31, 1925)	P. G.	293,340	.38%	0.1	352,994	5.39%	0.1
China*	P. G.	166,373	.22%	0.04	90,000	1.37%	0.02
Japan (March 31, 1925)	.G	1,537,237	2.02%	2.6	163,000*	2.49%	0.3
Other Places in Asia*	P. G.	230,728	.30%	0.2	186,116	2.84%	0.2
Total		2,227,678	2.92%	0.2	792,110	12.09%	0.1
AFRICA:							
Egypt	G.	117,862	.15%	0.6	25,659	.39%	0.1
Union of South Africa†	G.	246,246	.32%	3.3	43,855	.67%	0.6
Other Places in Africa*	P. G.	96,590	.13%	0.1	124,146	1.90%	0.1
Total		460,698	.60%	0.3	193,660	2.96%	0.1
OCEANIA:							
Australia (June 30, 1924)	G.	1,266,825	1.66%	21.8	103,260	1.58%	1.8
Dutch East Indies	P. G.	189,909	.25%	0.4	20,292	.31%	0.04
Hawaii	P.	63,026	.08%	22.0	0	.00%	0.0
New Zealand (March 31, 1925)	G.	363,361	.48%	26.3	24,486	.37%	1.8
Philippine Islands*	P. G.	32,600	.04%	0.3	9,500	.14%	0.1
Other Places in Oceania*	P. G.	5,091	.01%	0.3	1,301	.02%	0.1
Total		1,920,812	2.52%	2.8	158,839	2.42%	0.2
TOTAL WORLD		76,161,827	100.00%	4.1	6,549,556	100.00%	0.4

Note: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates telephone service operated by private companies, G. by the Government, and P. G. by both private companies and the Government.

* Partly estimated. † March 31, 1925. ¶ January 1, 1924.

Telephone Development of Cities

January 1, 1925

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
ARGENTINE:			
Buenos Aires	2,000,000	97,838	4.9
AUSTRALIA:			
Adelaide	290,000	22,778	7.9
Brisbane	245,000	16,945	6.9
Melbourne	886,000	67,734	7.6
Sydney	1,008,000	80,900	8.0
AUSTRIA:			
Gratz	155,000	6,159	4.0
Vienna	1,900,000	94,318	5.0
BELGIUM:			
Antwerp	490,000	19,662	4.0
Brussels	887,000	47,528	5.4
Charleroi	212,000	4,269	2.0
Ghent	280,000	5,957	2.1
Liege	410,000	9,978	2.4
CANADA:			
Montreal	799,000	123,994	15.5
Ottawa	173,000	31,404	18.2
Toronto	615,000	142,292	23.2
CHINA:*			
Canton	918,000	2,800	0.3
Shanghai	1,545,000	23,011	1.5
Tientsin	824,000	7,704	0.9
Peking	1,339,000	39,035	2.9
CUBA:			
Havana	494,000	38,696	7.8
CZECHOSLOVAKIA:			
Prague	697,000	26,870	3.9
DANZIG, FREE CITY OF	373,000	14,440	3.9
DENMARK:			
Copenhagen	750,000	119,078	15.9
FRANCE:			
Bordeaux	274,000	10,757	3.9
Lille	206,000	8,706	4.2
Lyons	577,000	15,844	2.7
Marseilles	601,000	17,251	2.9
Paris	2,980,000	226,552	7.6
GERMANY:			
Berlin	3,948,000	392,172	9.9
Bremen	286,000	25,621	9.0
Breslau	548,000	33,934	6.2
Chemnitz	321,000	19,017	5.9
Cologne	687,000	52,460	7.6
Dresden	605,000	46,270	7.6
Dusseldorf	428,000	32,766	7.7
Essen	460,000	18,907	4.1
Frankfort-on-Main	456.000	48,749	10.7
Hamburg-Altona	1,236,000	127,783	10.3
Hannover	412,000	28,077	6.8
Leipzig	657,000	53,435	8.1
Magdeburg	287,000	18,282	6.3
Munich	668,000	57,946	8.7
Nuremburg	382,000	28,903	7.6
Stuttgart	335,000	30,333	9.1
GREAT BRITAIN AND NORTHERN IRELAND:#			
Belfast	426,000	11,720	2.8
Birmingham	1,324,000	37,720	2.9
Blackburn	253,000	6,243	2.4
Bolton	290,000	6,634	2.3
Bradford	391,000	16,003	4.1
Bristol	421,000	12,598	3.0
Edinburgh	436,000	19,777	4.5
Glasgow	1,311,000	48,387	3.7
Hull	337,000	14,426	4.3
Leeds	557,000	16,939	3.0
Liverpool	1,238,000	46,493	3.8
London	7,354,000	432,303	5.9
Manchester	1,655,000	59,954	3.6
Newcastle	621,000	16,547	2.7
Nottingham	347,000	11,554	3.3
Plymouth	240,000	5,041	2.1
Sheffield	525,000	14,386	2.7

* Partly estimated. # March 31, 1925.

Telephone Development of Cities—(*Concluded*)

January 1, 1925

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
HUNGARY:			
Budapest	953,000	48,680	5.1
Szegedin	113,000	2,083	1.8
IRISH FREE STATE:#			
Dublin	402,000	12,650*	3.2
ITALY:‡			
Milan	714,000	17,992	2.5
Naples	785,000	6,786	0.9
Rome	648,000	14,261	2.2
Turin	509,000	7,953	1.6
JAPAN:#			
Kobe	727,000	22,627	3.1
Kyoto	681,000	21,448	3.1
Nagoya	671,000	18,938	2.8
Osaka	1,532,000	72,967	4.8
Tokio	1,917,000	102,457	5.3
Yokohama	390,000	7,124	1.8
LATVIA:#			
Riga	338,000	9,090	2.7
NETHERLANDS:			
Amsterdam	712,000	37,019	5.2
The Hague	391,000	27,430	7.0
Rotterdam	544,000	30,693	5.6
NEW ZEALAND:#			
Auckland	181,000	12,581	7.0
Christchurch	118,000	9,425	8.0
Wellington	118,000	13,547	11.5
NORWAY:#			
Oslo	265,000	36,908	13.9
POLAND:			
Warsaw	950,000	32,747	3.4
ROUMANIA:			
Bucharest	361,000	10,200	2.8
RUSSIA:			
Kazan	162,000	1,498	0.9
Kharkov	325,000	3,100	1.0
Leningrad	1,093,000	26,256	2.4
Moscow	1,558,000	39,078	2.5
Odessa	327,000	1,884	0.6
SPAIN:			
Barcelona	716,000	17,342	2.4
Madrid	756,000	16,067	2.1
Seville	206,000	1,727	0.8
Valencia	233,000	4,029	1.7
SWEDEN:			
Goteborg	230,000	27,963	12.2
Malmo	116,000	14,291	12.3
Stockholm	439,000	109,024	24.8
SWITZERLAND:			
Basel	137,000	13,652	10.0
Berne	105,000	11,696	11.1
Geneva	128,000	14,626	11.4
Zurich	205,000	24,719	12.1
UNITED STATES:**			
New York	6,059,000	1,315,368	21.7
Chicago	2,967,000	741,883	25.0
Los Angeles	1,100,000	260,567	23.7
Total of the 8 cities with over 1,000,000 population	17,251,000	3,588,629	20.8
San Francisco	675,000	201,515	29.9
Cincinnati	649,000	131,541	20.3
Milwaukee	587,000	112,254	19.1
Total of the 9 cities with 500,000-1,000,000 population	5,912,000	1,075,832	18.2
Washington	468,000	118,278	25.3
Minneapolis	443,000	110,420	24.9
Portland, Ore	330,000	79,221	24.0
Omaha	218,000	62,007	28.5
Total of the 30 cities with 200,000-500,000 population	8,735,000	1,622,564	18.6
Total of the 47 cities with over 200,000 population	31,899,000	6,287,025	19.7

March 31, 1925. * Partly estimated. ‡ June 30, 1923. † June 30, 1924.

** There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups and the development of certain representative cities within each of such groups.

Telephone Development of Large and Small Communities

January 1, 1925

Country	Service Operated by (See Note)	Number of Telephones: In Communities of 100,000 Population and Over	Number of Telephones: In Communities of less than 100,000 Population	Telephones per 100 Population: In Communities of 100,000 Population and Over	Telephones per 100 Population: In Communities of less than 100,000 Population
Australia	G.	199,228	137,050*	7.6	4.2
Austria	G.	100,477	44,664	4.9	1.0
Belgium	G.	87,394	49,550	3.8	0.9
Canada	P. G.	416,689	655,765	19.3	9.3
Czechoslovakia	G.	35,535	80,203	3.8	0.6
Denmark	P. G.	119,078	188,899	15.9	7.1
France	G.	331,704	328,423	5.3	1.0
Germany	G.	1,270,646	1,114,531	8.1	2.4
Great Britain and Northern Ireland‡	G.	930,766	363,231	3.9	1.7
Hungary	G.	52,447	26,165	4.5	0.4
Italy (June 30, 1923)	P. G.	80,406	62,197	1.5	0.2
Japan (March 31, 1925)	G.	290,352	254,081	3.7	0.5
Netherlands	G.	107,289	95,579	5.6	1.8
New Zealand (March 31, 1925)	G.	35,553	84,544	8.5	8.8
Norway (June 30, 1924)	P. G.	36,908	131,610	13.9	5.3
Poland*	P. G.	53,320	66,665	2.6	0.3
Sweden	G.	151,278	267,040	19.3#	5.1
Switzerland	G.	64,693	124,736	11.3	3.7
United States	P.	7,352,826	8,719,932	19.1	11.6

Note: P. indicates telephone service operated by private companies, G. by the Government, and P. G. by both private companies and the Government.
The majority of this development is due to Stockholm.
* Partly estimated. ‡ March 31, 1925.

Telephones in United States—Distribution by States

January 1, 1925 and January 1, 1926

State	Number of Telephones: January 1, 1925	Number of Telephones: January 1, 1926
Alabama	101,636	109,512
Arizona	27,690	29,728
Arkansas	108,890	113,667
California	953,288	1,027,552
Colorado	163,071	170,575
Connecticut	240,237	256,813
Delaware	25,397	26,406
District of Columbia	117,205	127,977
Florida	106,935	127,594
Georgia	151,594	158,440
Idaho	50,068	51,617
Illinois	1,437,441	1,522,959
Indiana	517,532	535,426
Iowa	556,610	566,085
Kansas	370,684	380,509
Kentucky	219,596	223,444
Louisiana	108,660	118,969
Maine	124,640	127,030
Maryland	174,154	180,826
Massachusetts	795,960	808,194
Michigan	582,118	631,141
Minnesota	435,892	455,451
Mississippi	68,430	71,543
Missouri	595,931	620,492
Montana	55,079	56,221
Nebraska	282,784	284,695
Nevada	11,123	11,720
New Hampshire	77,865	79,195
New Jersey	474,473	512,048
New Mexico	19,018	19,921
New York	2,137,188	2,292,650
North Carolina	135,068	142,738
North Dakota	80,360	83,276
Ohio	1,005,698	1,054,426
Oklahoma	240,897	256,719
Oregon	160,807	169,613
Pennsylvania	1,210,950	1,281,314
Rhode Island	105,781	106,706
South Carolina	58,441	60,708
South Dakota	106,575	110,119
Tennessee	192,699	203,289
Texas	525,600	557,889
Utah	56,755	59,423
Vermont	57,044	58,357
Virginia	163,635	170,637
Washington	258,901	271,453
West Virginia	136,016	141,027
Wisconsin	459,507	482,353
Wyoming	26,835	27,471
United States	16,072,758	16,935,918

Telephone Conversations and Telegrams

Year 1924

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	Per Cent of Total Wire Communications: Telephone Conversations	Per Cent of Total Wire Communications: Telegrams	Wire Communication Per Capita: Telephone Conversations	Wire Communication Per Capita: Telegrams	Wire Communication Per Capita: Total
Australia	275,368,000	17,267,000	292,635,000	94.1	5.9	47.7	3.0	50.7
Austria	458,741,000	3,861,000	462,602,000	99.2	0.8	69.2	0.6	69.8
Belgium	162,703,000	5,677,000	168,380,000	96.6	3.4	21.1	0.7	21.8
Czechoslovakia	176,331,000	3,304,000	179,635,000	98.2	1.8	12.6	0.2	12.8
Denmark	442,987,000	2,396,000	445,383,000	99.5	0.5	130.7	0.7	131.4
France	808,433,000	60,831,000	869,264,000	93.0	7.0	20.3	1.5	21.8
Germany	1,820,353,000	36,627,000	1,856,980,000	98.0	2.0	30.1	0.6	30.7
Gt. Britain and No. Ireland	1,030,251,000	62,178,000	1,092,429,000	94.3	5.7	22.5	1.4	23.9
Hungary	281,072,000	4,698,000	285,770,000	98.4	1.6	34.5	0.6	35.1
Italy‡	361,351,000	18,457,000	379,808,000	95.1	4.9	9.0	0.5	9.5
Japan	1,763,259,000	59,408,000‡	1,822,667,000	96.7	3.3	29.9	1.0	30.9
Netherlands	369,233,000	5,705,000	374,938,000	98.5	1.5	50.8	0.8	51.6
Norway	310,060,000	4,077,000	314,137,000	98.7	1.3	113.0	1.5	114.5
Sweden	635,554,000*	3,873,000	639,427,000	99.4	0.6	105.6	0.6	106.2
Switzerland	147,438,000	3,168,000	150,606,000	97.9	2.1	37.7	0.8	38.5
United States	21,500,000,000	195,000,000	21,695,000,000	99.1	0.9	190.8	1.7	192.5

Note: Telephone conversations include local and toll or long distance conversations. Number of telephone conversations in the United States includes completed messages only.
‡ Fiscal year 1923. * Partly estimated.

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