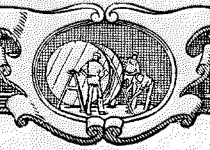

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Main Entrance to the Barcelona Exhibition

Public Address Systems in the Barcelona and Seville Exhibitions

By SANTIAGO HERRERA SERRA

Standard Eléctrica, S. A. Madrid

THE Public Address System is now an indispensable feature of large public gatherings. Among its latest applications in Europe are those at the exhibitions at Barcelona and Seville, which were opened in May this year.

In Barcelona, as most of the projectors were to be located in the interiors of buildings, it was possible to use a large number of projectors in parallel operating at a relatively low transmission level. In Seville, however, where all the projectors were required to be in the open, and none inside the pavilions, a less number of projectors, operating at relatively high level, were employed.

The total output required was about the same in each case, and necessitated three complete No. 1 Public Address Equipments for each exhibition. These installations are therefore among the largest ever made. Figure 1 shows part of the area covered by the projectors at the Barcelona exhibition, Figure 2 the Public Address Equipment at Seville, and Figure 3 a Projector Tower at Seville.

Provision was made for connecting the systems to the local broadcasting stations, so that the input to the stations might be taken and controlled direct from one of the output circuits of the Public Address System without duplicate microphones. In this way, utterances and performances at the openings of the exhibitions were transmitted throughout Spain for broadcasting from all Spanish radio stations.

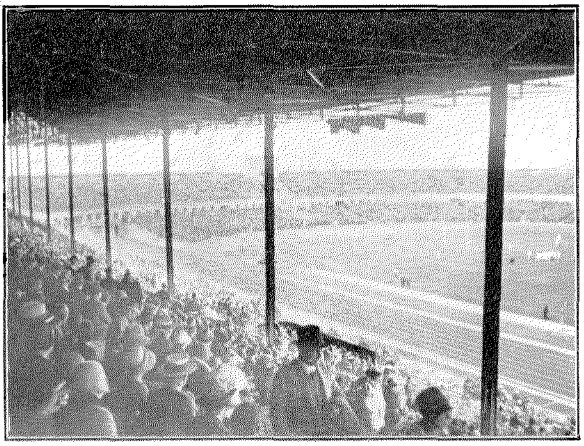


Figure 1—Barcelona Stadium.

Figure 2—Public Address Equipment—Seville.

As the installation of the Public Address equipments and lines at both exhibitions was carried out in a similar manner, a brief description of that in the Seville exhibition will suffice to explain their new features. It may, however, be here remarked that the organisers of both exhibitions were satisfied with the successful operation of the system, particularly as it had

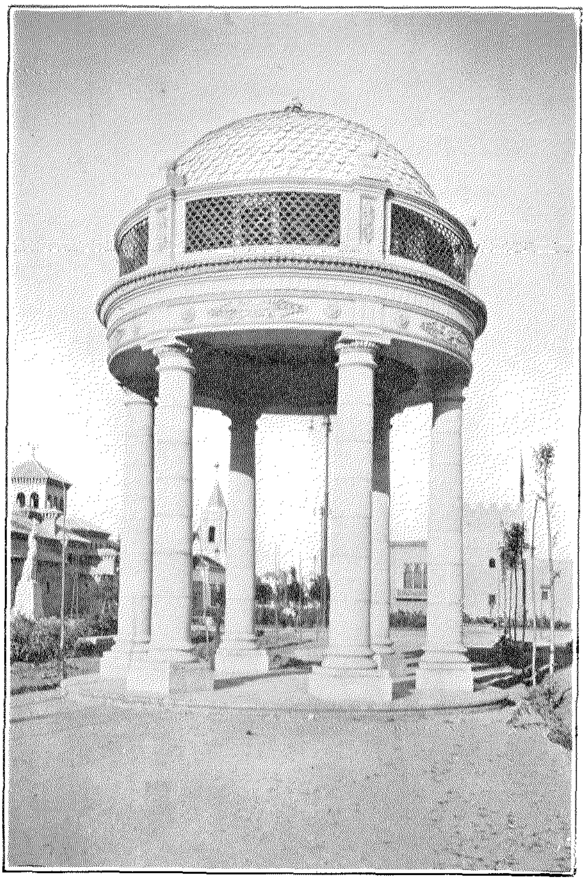


Figure 3—Projector Tower—Seville.

been installed at short notice and had to cover the greater part of the exhibition and reproduce speeches, concerts and announcements to a number of points in the exhibition grounds.

Having decided upon three No. 1 equipments, the question arose whether they should be installed separately or together. Separate installation would have had the advantage of economy in lines—a very important item, since all lines had to be underground—and in addition it would have allowed direct input from the microphones and good subdivision of the projector groups at small cost. These considerations, however, were not sufficient to justify separate installations, since it was seen that the system of control and personnel required would have to be very complicated to give the system the necessary flexibility. Accordingly, the three equipments were installed together, and the ease of control and facility of interchange of the different parts of the equipments fully justified that satisfactory arrangement.

The lines to the microphone positions presented a further problem. With the large number of positions required, the installation of separate lines to each position, while giving central control, would have been very expensive, so that a system of three separate lines, each connecting a group of positions, was adopted. Each microphone is connected when required to the line by a switch at the microphone position, controlled by an operator who is in communication with the central installation through a selective signalling system connecting the different positions to the central unit. To give the operator in the central station greater freedom of movement, the service communication lines terminate in a loud speaker in the control room.

For all the lines, 0.8 mm. and 1.6 mm. rubber insulated lead covered cables were used, laid direct in soft earth, and protected with bricks. To avoid interference, the projector lines were

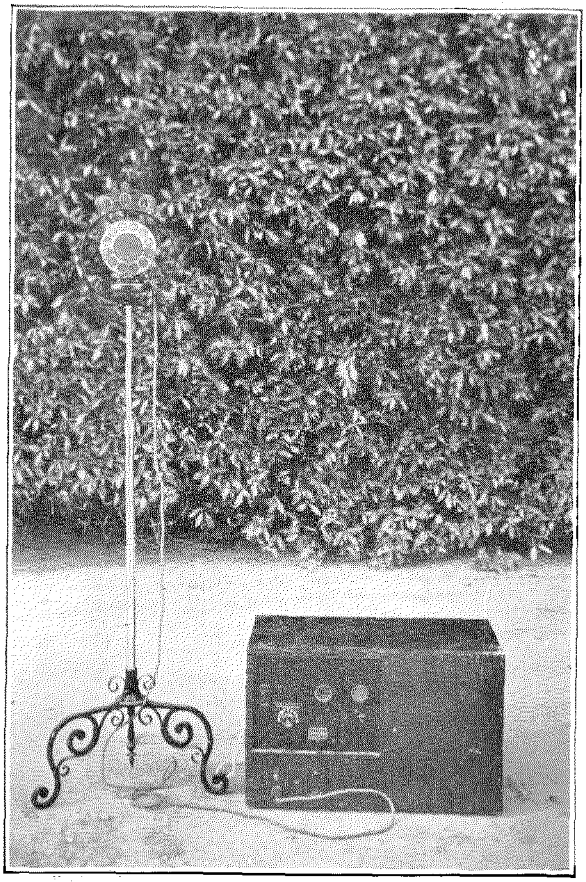


Figure 4—Preliminary Amplifying Unit.

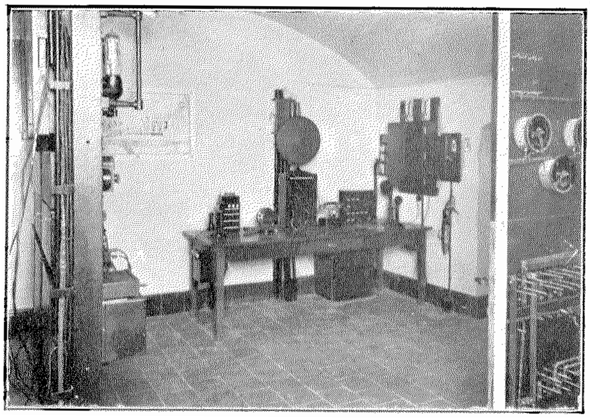


Figure 5—Control Desk—Seville.

installed apart from the other lines and shielded with heavy iron tubes wherever they are close to the microphone and service lines.

Between the microphone positions and the Public Address equipments a preliminary amplifying unit is used. In this way, instead of the three microphone lines at a low energy level which would be used normally, only two lines are required and these have the energy level high enough to overcome parasitic noises due to inductive effects. This amplifier is shown in Figure 4 mounted in a special case containing plate and filament batteries with jacks for the microphone, pilot light and terminals for connecting to the main microphone circuit and pilot light circuit.

The pilot light line is in reality a spare microphone line exactly similar to the microphone lines and installed in parallel with them, but used temporarily for supplying the pilot light on the amplifier when the main microphone line is connected to the Public Address equipment and amplifier ready to operate. If this spare circuit should be required for the microphone, supervision would be made over the service telephone line.

The three microphone lines are connected to the speech input side of the Public Address equipments through a key box shown at the left side of Figure 5. This arrangement allows any combination of the three equipments with the microphone lines to be so made that the inputs of all equipments may be connected to one microphone, or individually to different microphones. The keys also control the pilot signal lines.

For similar reasons, the projector lines are not directly connected to the volume control panels, but to a small pony board where they terminate in cords and plugs making connection with the volume control panel groups through the pony board jacks. The monitoring loud speaker is also connected by a cord circuit through this board, and is arranged to give complete interchangeability to the system.

The cord of the monitoring loud speaker of the announcer is connected to a cut-off relay which operates when the announcer's microphone is connected to the System, to avoid the pick up by the microphone of sounds from the monitoring Loud Speaker.

The supply of energy for such a large installation was no small matter, and it was at once realised that it would be uneconomical from the points of view of first cost and maintenance to

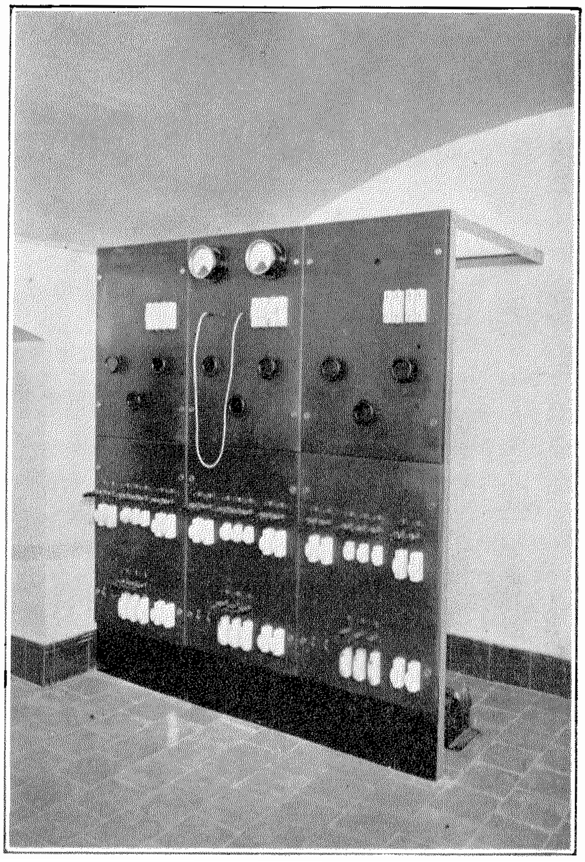


Figure 6—Power Panel—Seville.

follow the usual practice of using a system of batteries for the filament and plate circuits of the valves. Moreover, the authorities wished to be able to use the three equipments separately for other public gatherings when the exhibitions were finished. This would have required three separate battery systems which would have had to be of such capacity that the three Public Address Systems could be supplied from two battery systems in order to avoid the possibility of breakdowns on the power side of the installations.

Three motor generator groups of Spanish manufacture were therefore provided, each group being mounted on one bed plate, and made up as follows:

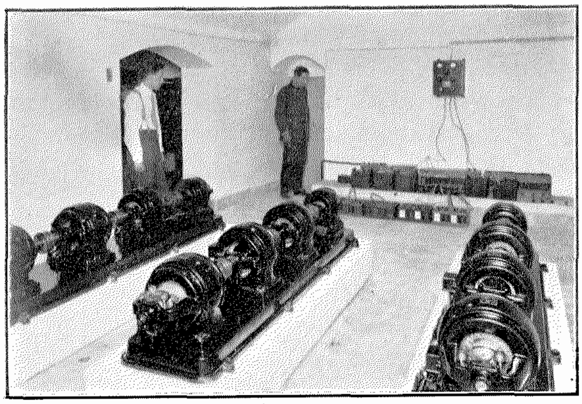


Figure 7—Machine Room—Seville.

One 3½ H. P. Three phase squirrel cage motor.

One Dynamo 15 Volts 25 amperes for the filament current.

Two Dynamos each 400 Volts 1 ampere connected in series for the plate circuits.

Filters composed of inductances and condensers were provided, and batteries floating between the generators and filaments ensured stability in the valve operating conditions. As two of these groups were able to supply the three equipments in case of emergency, a reserve group was not installed. The power panel for the generator groups is shown in Figure 6. Regulation of the filament and plate voltages was very easily obtained by means of the rheostats, controlling the dynamo fields.

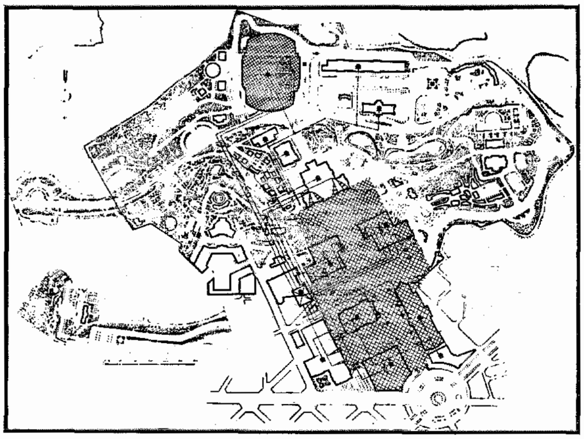


Figure 8—Plan of Barcelona Exposition and layout of public address system.

The machine room is shown in Figure 7. The Tungar charging unit, seen in the background of this illustration, is used for charging the preliminary amplifier batteries during the night.

Since the inauguration of the two exhibitions, the systems operated almost continuously during the hours of opening to the entire satisfaction of the organisers.

The exposition ground plans and the layouts of the Public Address Systems at Barcelona and Seville are shown in Figures 8 and 9. The engineering and planning of these two installations were carried out by Standard Eléctrica, S. A.

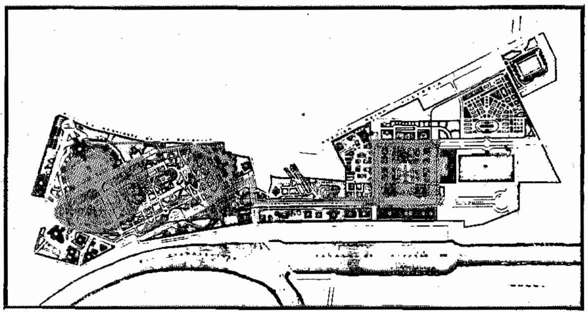


Figure 9—Plan of Seville Exposition and layout of public address system.

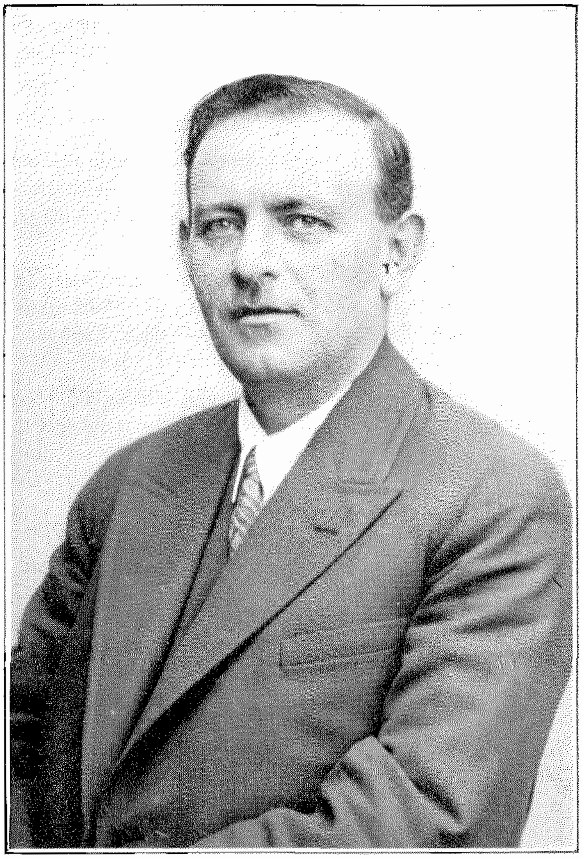
In Memoriam

DR. M. MERKER'S death in Paris on June 28th last is a loss which ELECTRICAL COMMUNICATION records with deep regret. He was of Polish nationality, for he was born in Warsaw in 1886. After completing the educational course of the Mlawa High School, in Warsaw, he applied himself from 1908 to 1910 to more advanced studies at the University of Liége. During 1911 and 1912 he was instructed in electrotechnique at the Institute Montefiore associated with the University of Liége. Thereafter he read mathematics and physics at that university, but owing to the war he did not terminate his studies until 1920, when he received the degree of Doctor of Physics and Mathematical Sciences. In November, 1921, he joined the Bell Telephone Manufacturing Company. He continued in Antwerp until he was transferred to the Paris Laboratories, on December 1, 1928.

Dr. Merker is best known in the world of telephony for his applications of mathematics to theories of probability related to automatic exchanges. His associates interested in those profound problems delighted to work with him, for his assistance was always cheerfully given. His penetrative mind was ever open to suggestions, and his genial nature led him to give them careful and sympathetic consideration.

He early realized that, to obtain the desired results, practical telephony and the theory of mathematics must go hand in hand. In the beginning of his professional career, therefore, when he lacked details of working conditions, he never hesitated to confess that he did not know, and to turn to his associates for information and guidance.

As the author of contributions to the application of the theory of probability to telephony, his name will always be remembered with distinction amongst those who from intricacies derived results of service, in a comparatively simple form, to the engineering art. He soon acquired thorough knowledge of the working of automatic exchanges. His studies in connection with "grading," "slipping," and "splitting" found great practical application in calculations appertaining to the rotary system. Amongst other results, he developed curves for "grading" which can usefully be applied by engineers familiar with traffic and switch calculations.



DR. M. MERKER

Dr. Merker possessed the heritage of his race as a linguist, for in addition to Polish, he had a good working knowledge of Russian, French, German, and English. He started many interesting studies which—without his guidance—will not easily be brought to a successful conclusion. From this brief account of him it will be seen that he was only recently transferred to the Paris Laboratories. For some time he had looked forward to that transfer as he felt that he could be more useful to the Company by devoting his knowledge and time there to the more general problems submitted for solution. Special ability, and love for the work, are two characteristics rarely to be found so closely allied or so strongly developed as they were in him.

To one so devoted to telephony as was Dr. Merker, the records of his published results constitute a tribute to his memory. It is therefore appropriate here to direct attention to the following:

1) Berechnungen der Sprechfrequenzverluste in Schnurstromkreisen mit in Brücke liegenden Scheinwiderständen; Elektrische Nachrichtentechnik. Vol. 3, No. 5, May, 1926.
2) Some notes on the use of the probability theory to determine the number of switches in an Automatic Telephone Exchange. The Post Office Electrical Engineers' Journal, Vol. 17, Part I, April, 1924.
3) Quelques remarques sur l'emploi du calcul, des probabilités dans la détermination du nombre des sélecteurs d'un bureau téléphonique automatique. Annales des Postes, Télégraphes et Téléphones No. 3, 1924.
4) Application du calcul des probabilités à la détermination du nombre d'organes et leur mode de connexion dans un bureau de téléphonie automatique. Revue Générale de l'Electricité, April 20 and 30, May 7 and 14, 1927.
5) Notes sur l'application du calcul des probabilités à l'exploitation téléphonique. Revue Générale de l'Electricité, February 21, 1925.
6) Die Berechnung der Wahlerzahl in Selbstanschlussämtern. Elektrotechnische Zeitschrift, October 9, 1924.
7) Application du calcul des probabilités à la détermination du nombre d'organes dans un bureau de téléphonie automatique. Technische Mitteilungen, February, 1928.

Calculation of the Articulation of a Telephone Circuit From the Circuit Constants[1]

By JOHN COLLARD A. C. G. I. B. Sc. (ENG.) A. M. I. E. E.

Development and Research Laboratories, International Telephone and Telegraph Corporation.

SINCE the function of a telephone circuit is to transmit speech from one subscriber to another, the final criterion of the performance of the circuit is the grade or quality of speech delivered at the end of the circuit. The quantity usually employed as a measure of the quality of speech is known as the articulation, and is defined as the percentage number of random syllables correctly received over the circuit. Once a telephone circuit has been set up, articulation tests can be carried out, and the value of articulation so obtained. Similarly, if an existing piece of apparatus is to be substituted for another in the same circuit, and it is required to know the effect on articulation of this change, the answer can be determined by carrying out a series of articulation tests. There are many instances, however, where it is required to know the articulation of a circuit before setting up that circuit or before making up a certain piece of apparatus. In these cases it is impossible to carry out articulation tests, since the circuit or apparatus is not in existence. Some method of predetermining the articulation is, therefore, required, and the object of this paper is to develop a method by means of which the articulation of the circuit can be calculated from a knowledge of its constants.

A detailed study of speech and hearing has been carried out, and as a result, a complete and rigid theory has been built up in connection with the transmission of sounds over a telephone circuit. From this theory a series of algebraic formulae have been worked out which enable the articulation of the circuit to be calculated from a knowledge of such factors as the attenuation of the circuit and the amount of noise present in the circuit.

Speech is carried over a telephone circuit by means of certain frequency components, produced by the voice of the speaker at one end of the circuit, and received by the ear of the listener at the other end. Owing to effects such as attenuation and line noise in the circuit, these components reach the listener in a more or less distorted manner. It is only those components which reach the listener's ear at a level above his threshold of hearing, which can play any part in enabling him to understand what has been said. The method consists, therefore, essentially of a determination, for any given case, of which of the frequency components are above threshold at the receiving end. Then from the general study of speech, the relative importance of the different frequency components is determined, and hence the value of articulation for the circuit can be worked out.

The theory has been presented in such a form that its practical application to any given case requires only about half-an-hour, as compared to a total time of about 50 hours, which would be required if the same result were obtained by actual measurement. A comparison is given between the calculated and measured results for a number of actual cases, and the results show that the theory is capable of giving results in close agreement with practice.

This method of calculating articulation has the following applications:

(1) It enables articulation or intelligibility of the telephone circuit to be calculated from the knowledge of the circuit constants.

(2) It enables the effect on speech of any proposed change on a circuit or piece of apparatus to be predetermined, without the necessity of lengthy tests.

(3) It enables the effect on speech of various quantities, such as crosstalk attenuation and noise to be determined, and, therefore, allows limiting values of these quantities to be fixed.

Introduction

Since the object of a telephone circuit is to transmit speech from one subscriber to another,

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[1] Presented before World Engineering Congress, Tokyo, Section 6, October 30, 1929.

the final criterion of the performance of that circuit must always be the grade or quality of speech delivered at the end of the circuit.

Several quantities have been used as a measure of the quality of the speech transmitted over a telephone circuit amongst which may be mentioned the intelligibility and the word, syllable or sound articulation. In a previous paper ([12]) by the author, it was shown that a perfectly definite relation existed between all these quantities, and algebraic formulae were developed from fundamental considerations giving each of the above quantities in terms of the ideal sound articulation.

The value of articulation obtained over a given telephone circuit by a given testing crew depends partly on factors such as distortion, which are functions of the circuit characteristics and partly on factors such as faulty pronunciation, which are functions of the testing crew. The factors depending on the testing crew vary from crew to crew, so that the articulation obtained over a given circuit will also vary from crew to crew. To avoid this difficulty and to obtain a quantity which is a true measure of the characteristics of the circuit alone, the ideal sound articulation is used. This quantity is the value of sound articulation that would be obtained if it were possible to use an ideal testing crew which never committed faults such as careless pronunciation or inattention during a test. The value so obtained is consequently a true criterion of the circuit characteristics and does not depend on the characteristics of the testing crew. For these reasons it is proposed in the work described here to deal only with the ideal sound articulation.

The word "sound" is here used to denote any single vowel or consonant sound of speech, of which a list is given later. For the purposes of articulation testing these sounds are formed into syllables of the form, consonant-vowel, vowel-consonant or consonant-vowel-consonant, which are called over the circuit to be tested. Since the object of an articulation test is to obtain a measure of the quality of speech transmission obtainable over the circuit, the frequency of occurrence of the different sounds in the articulation lists is arranged to be the same as that for speech.

Once a circuit has been set up, articulation tests can be made on it and the value of sound articulation obtained. Similarly, if an existing piece of apparatus is to be substituted for another in the same circuit, and it is required to know the effect on speech of this change, the answer can be determined by carrying out actual articulation tests.

There are many instances, however, in which it is desired to know, before setting up a given circuit or before making a certain piece of apparatus, what quality of speech will be obtainable over the given circuit or with the given piece of apparatus. In these instances it is obviously impossible to carry out tests since the circuit or apparatus is not in existence. Even in cases where it is possible to determine the articulation by actual tests it will often be quicker, and certainly will be more economical, to determine the value by calculation. In this connection it is interesting to note that Fletcher states ([13]) that to obtain a value of articulation with a probable error of one per cent it is necessary to call 5,000 syllables over the circuit. In any investigation where a number of alternatives are to be compared and, say, ten values of articulation are to be determined, about 50,000 syllables would have to be used or, including the calibration of the testing crew, about 60,000 syllables. Since the syllables are called at the rate of about 20 per minute, a total time of 50 hours would be required for the calling alone, quite apart from the preparations, checking of lists, etc.

Some method of predetermining the articulation is therefore required and the object of this work was to develop a method by which the articulation of a given telephone circuit could be calculated from a knowledge of the circuit constants.

A complete description of the method together with the mathematical development of the basic theory is given in the sections, *Development of Formulae* and *Determination of Constants*. Owing to the large number of details in connection with speech and hearing which have to be mentioned in describing the mathematical development of the theory, these sections tend to make the method of calculating articulation appear much

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[12] For numerical references in parentheses, see *Bibliography.*

more complicated than it really is. For this reason this paper has been arranged in the following way. In the section *Practical Application* is given a description of the way in which the method of calculating articulation is applied to a practical case, and a simple example is worked out. Then in the section *General Theory* a general description of the theory is given in non-mathematical language. This is followed by a complete description of the development of the theory in the section *Development of Formulae.*

The formulae involved in this method for calculating articulation contain certain constants whose values depend on certain characteristics of speech and hearing. Part of the work therefore consists of the evaluation of these constants.

It was estimated that this part of the work might require a period of one or two years before all the necessary data could be obtained. Before deciding whether it was worth while carrying out this work, some indication was naturally required of the accuracy with which the theoretical formulae could be applied to practical cases. It was decided, therefore, to carry out an approximate evaluation of the constants using such information on speech and hearing as had already been published. If the results obtained by the theory, using these approximate values of the constants, were reasonably accurate, the work required for the more accurate evaluation of the constants would be undertaken. The approximate determination of the constants is described in the section *Determination of Constants.* It should be realised, in judging the accuracy with which the measured values of articulation agree with the calculated values, that the latter are based only on the approximate determination of the constants, so that differences are likely to occur in some instances. Even so, the agreement between the measured and calculated results is so close as to provide convincing evidence as to the accuracy of the theory, and the work required for the accurate determination of the constants has consequently been undertaken.

Some of the physical data is original, but a large part of it has been obtained from the many papers published on the subject by various members of the Bell Laboratories in America. In particular considerable use has been made of the book *Speech and Hearing* by Dr. Harvey Fletcher, which collects together a very large amount of most useful information on the theory and practice of speech and hearing. A bibliography is given at the end of this paper in which are included all the articles from which information has been obtained.

The whole study has been made in connection with the English language and small modifications may be required to make the method applicable to other languages. The previous study (12) has shown, however, that articulation results for English, French, German, and Italian are in close agreement, so that the whole method, without modifications, can probably be used for these four languages with sufficient accuracy for practical purposes.

Practical Application

Speech is carried over a telephone circuit by means of certain frequency components produced by the voice of the speaker at one end of the circuit and received by the ear of the listener at the other end. If the components arriving at the listener's ear are exactly the same as when they left the speaker's mouth, we might regard the circuit as being perfect. Few circuits reach this high degree of performance and in general the components arriving at the listener's ear are not the same as those leaving the speaker's mouth, for two reasons. Firstly, the overall attenuation of the circuit is different at different frequencies so that the components arrive in a distorted form. Secondly, additional components, which were not originally present, are produced in the circuit, either due to noise or due to overloading of some part of the circuit. The effect of the additional frequencies is, as shown by Wegel and Lane (2), equivalent to raising the threshold values of the ear by a certain number of decibels. It is therefore equivalent to adding the same number of decibels to the attenuation of the circuit.

Assume that it is required to calculate the articulation for a given telephone circuit whose air to air attenuation is given for different frequency bands by column 2 in the following table. Assume also that the threshold shift at the different frequencies, due to line noise, is that given in column 3 of the table.

The method of calculating the articulation of the circuit is then as follows: Add directly the threshold shift values, expressed in decibels, to the air to air attenuation values, also expressed in decibels. The result is given in column 4. Then from tables of $p \Delta b$, of which an extract is given in the section *Determination of Constants*, read off the values of the quantity $p \Delta b$ corresponding to the values of column 4 for each frequency band. Add up these values for all the frequency bands; this gives a value of b of .4867. From the curve of Figure 1 read off the value of d_i corresponding to the value of b of .4867. This value of d_i is the required value of the ideal sound articulation for the circuit which is therefore 84.3%.

(1) Frequency Region	(2) Air to Air Attenuation (Decibels)	(3) Threshold Shift due to noise (Decibels)	(4) Resultant Attenuation (Decibels)	(5) $p \Delta b$.
0– 200	70	0	70	.0036
200– 400	68	1	69	.0300
400– 600	65	5	70	.0883
600– 800	60	9	69	.0858
800–1000	53	13	66	.0698
1000–1200	50	16	66	.0583
1200–1400	55	18	73	.0534
1400–1600	60	19	79	.0383
1600–1800	65	19	84	.0270
1800–2000	69	18	87	.0178
2000–2200	73	18	91	.0076
2200–2400	76	17	93	.0043
2400–2600	79	17	96	.0016
2600–2800	82	16	98	.0007
2800–3000	84	16	100	.0002
			$\Sigma\ p \Delta b$	.4867

The short time required to calculate a value of articulation in this way is in striking contrast to the long time required to obtain the same value by measurement.

General Theory

The ear is so constructed that, at each frequency, there is a minimum threshold pressure below which no audible sensation is experienced. If a speech component at a given frequency arrives at the ear with a pressure lower than the threshold value at that frequency, then it is not perceived by the listener and can therefore play no part in assisting him to distinguish one sound from another. A given speech component may be reduced below threshold either by being attenuated by some part of the circuit through which it passes, or by being masked by some other frequency due to line noise or overloading in some part of the circuit. The problem therefore resolves itself into two parts, a determination of how many of the speech components, in any given case, reach the listener at such a level as to be above threshold, and the calculation of the articulation from the knowledge of which of the speech components are above threshold.

An examination of oscillographic records and frequency spectra of the various speech sounds (8) (13), shows that each sound consists of a large number of components at different frequencies throughout the audible range.

The prominent frequencies, however, occur in one or more little groups or bands of frequencies. An idea of this will be obtained from Figure 2, which shows the frequency spectrum for an imaginary speech sound. It will be seen that this imaginary sound contains two groups or bands of prominent components. A study of certain data, referred to in the section *Determination of Constants*, has enabled these bands to be determined for all the speech sounds. Some sounds have only one of these bands while others have as many as four or five bands. The frequencies at which these bands occur are different for the different sounds and it is by noting where these prominent bands occur that the ear is able to distinguish one sound from another. For this reason these bands have been called the characteristic bands of speech. The frequency components outside these bands are very small and play practically no part in assisting the listener to distinguish one sound from another. This conception of the characteristic bands of speech is important because the whole theory developed here is based on it.

In a previous paper (12) it was shown that, when random words were called over a telephone circuit, there was a perfectly definite relation between the percentage number of words correctly received and the percentage number of individual sounds received correctly. An algebraic formula was given by means of which the word articulation could be calculated for any given case if the corresponding value of sound articulation was known.

In an exactly similar way a formula can be obtained which will give the relation between the number of sounds a listener will receive correctly and the number of the characteristic bands he will receive correctly. A curve showing the relation between these two quantities is given in Figure 1. If, therefore, we know what we may call the band articulation of a given circuit, i.e., the percentage number of characteristic bands correctly received when an articulation test is made over a circuit, we can immediately determine the corresponding value of the sound articulation. It may at first appear an unnecessary complication to bring in this new quantity, the band articulation, and it may be found a little confusing to think of the listener as receiving the characteristic bands. The reason for introducing the band articulation, however, is that it has a very useful property not possessed by the sound articulation. This property is described in the following paragraphs.

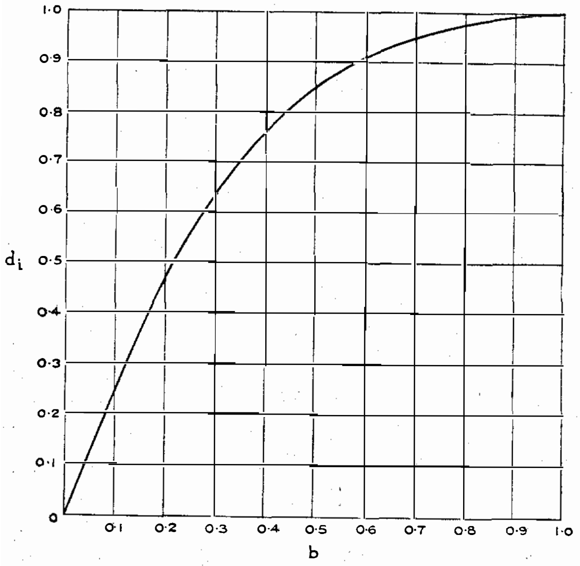

Figure 1

Suppose that a telephone circuit has been constructed which allows all frequency components between f_1 and f_2 to pass without distortion while suppressing all other frequencies, and suppose that under these conditions, when an articulation test is made on the circuit, the average sound articulation is found to be d_{12} and the average band articulation is b_{12}.

Now, suppose that the circuit is changed so that it only passes frequencies in the region f_3 to f_4, and let the sound articulation be d_{34} and the band articulation be b_{34}. The problem now is, if the circuit is again changed so that it will now pass both the range f_1 to f_2 and the range f_3 to f_4, what will be the relation between the new sound articulation d_{1234}, d_{12} and d_{34}, or what will be the relation between the new band articulation b_{1234}, and b_{12} and b_{34}.

The answer to the first question is that there is no simple relation between d_{1234}, d_{12} and d_{34}. There is, however, a simple relation between b_{1234}, b_{12} and b_{34}; it is $b_{1234}=b_{12}+b_{34}$.

It is this property of the band articulation which makes it so valuable as an aid to calculating the sound articulation for a given circuit. It enables us to determine the effect on articulation of the different frequency regions in the audible range. For example, if the sound articulation obtained over a circuit which passes all frequencies from 0 to 1500 periods per second, but suppresses all others, is found to be 63% and the articulation for a circuit passing all frequencies from 0 to 1600 periods per second is 67%, then the corresponding values of the band articulation will, from Figure 1, be approximately 29% and 33%, and the difference will be 4%. This means that the frequency region from 1500 to 1600 periods per second contributes an amount 4% to the band articulation. Hence, since $b_{1234}=b_{12}+b_{34}$, whenever the region 1500 to 1600 is transmitted to the listener it will always contribute this same amount, 4%, to the band articulation.

The value of band articulation for all 100-period frequency regions from 0 to 6000 has been determined by the method outlined above for the region 1500 to 1600 periods per second. Further particulars of this are given in the section *Determination of Constants.*

The method for calculating the articulation is then briefly as follows: The frequency regions which are reaching the listener at a level above threshold are determined, and then the values of band articulation are added together for these regions and so the total value of band articulation for the circuit is obtained. The curve of Figure 1 at once gives us the corresponding value of sound articulation.

This solves one-half of the problem and we are only left with the problem of determining what frequency components reach the listener above threshold. Consider the frequency spectra of Figure 2. Since we are concerned with finding out how many of the speech components are above threshold it is convenient to consider the amplitude of a speech component as being so many decibels above threshold. This has been done in Figure 2 which therefore shows the amplitude of the different components above threshold and not as absolute values. It will be clear that the amplitude of each component depends on two things; (a) the degree of loudness, or the level, at which the sound is spoken, and (b) the threshold curve for the listener. If the speaker calls the sound in a louder voice, all the components in the figure will be correspondingly higher; if he calls in a quieter voice all the components will be lower. If the listener is deaf his threshold values will be high, since he requires a greater pressure to produce an audible sensation, and consequently the height of the components of the sound above his threshold will be very small. If the listener has very good hearing, his threshold values will be low and hence the components will be a long way above his threshold.

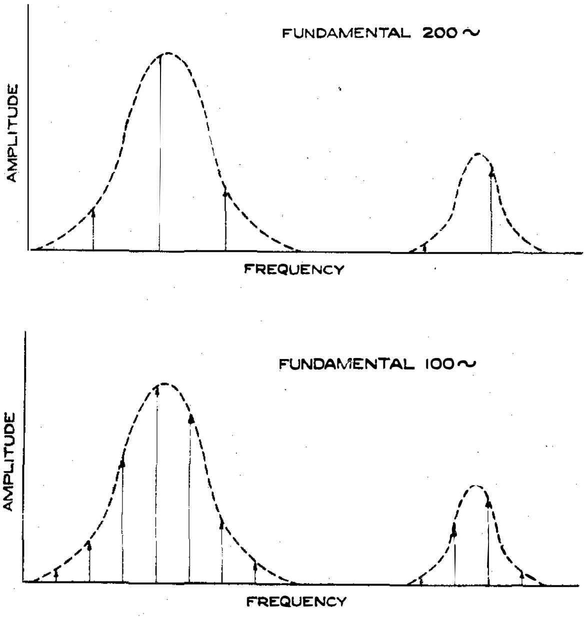

Figure 2

It follows from this that a different frequency spectrum curve like Figure 2 would be obtained for each pair of speaker and listener. A series of such curves is shown in Figure 3 for a one band sound. Owing to these variations from speaker to speaker and listener to listener, it is convenient to deal with the average curve. This is taken as the curve which has as many curves above it as there are below. In other words, if we were to take curves for all possible combinations of speaker and listener, half the pairs would have a curve above the mean and half below. The mean curve is indicated by a dotted line in Figure 3.

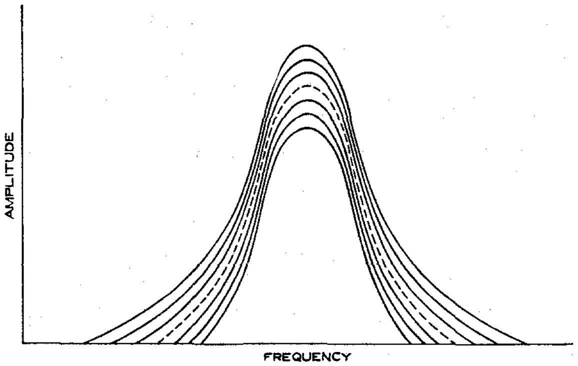

Figure 3

By a method described in the section *Determination of Constants* it has been possible to determine the mid-frequency of each of the characteristic bands of speech and also the level of the mean curve for each band. These values have been plotted with frequency and level as axes and a mean curve has been drawn through the points. (This curve is shown in Figure 4. This curve shows the mean level above threshold at each frequency of the characteristic bands of speech.) The difference between this curve and the dotted curve of Figure 3 is that the curve of Figure 3 is the mean for a particular characteristic band while the curve of Figure 4 is the mean for all bands.

The curve of Figure 4 shows that for a frequency region of, say, f_1 to f_2 the mean height above threshold of the speech components is A decibels. From the definition of the mean curve given above, it follows that if articulation tests were made with all possible speaker-listener combinations, half the combinations would have their speech components in the region f_1 to f_2

at a level above threshold which was greater than A and half would have them at a level less than A. If a circuit were arranged so that in the region f_1 to f_2 it introduced an overall attenuation of exactly A decibels, then the speech components in the region f_1 to f_2 would fail to reach the listener for half the total speaker-listener combinations. In other words, considering the speech components in the region f_1 to f_2, the probability of these components being transmitted for a speaker-listener combination is just one half what it would be if the components were transmitted for all combinations.

If, therefore, the value of the band articulation for the region was found to be b_{12} for the case when all speaker-listener combinations were able to transmit their components, and we wish to know the value of band articulation for this region in the case of a circuit whose overall attenuation is A decibels, we must take $\frac{1}{2}$ b_{12} as being the amount that the region f_1 to f_2 will contribute to the band articulation.

The case has been considered here in which the circuit had an attenuation of exactly A decibels. It is clear, however, that a similar state of affairs will exist for any value of attenuation. If the attenuation is less than A, more than 50% of the speaker-listener combinations will succeed in getting their speech components in the region f_1 to f_2 to the listener at a level above his threshold. If the attenuation is greater than A, less than 50% will succeed. In each case the corresponding proportion of b_{12} is taken. The method of determining this proportion for different values of attenuation is given in the section *Determination of Constants.*

In this way the whole problem is solved since we have shown how to determine how many of the speech components reach the listener above threshold and how from this to calculate the articulation.

The application of the method is made very simple by means of the table of which a part is given in the section *Determination of Constants.* This table gives, for each 100 period region, the correct value of band articulation to take for different values of overall attenuation of the circuit.

The method employed for calculating the articulation for a given circuit is then as follows: Having determined the overall air to air attenuation of the circuit for each 100-period frequency region, read off from the table the corresponding value of band articulation. Add up all the values of band articulation, giving the total value of band articulation. Then from the curve of Figure 1 read off the corresponding value of ideal sound articulation.

Development of Formulae

This section gives a detailed description of the fundamental theory and the development of the formulae from which the articulation is calculated. To some extent it repeats what has already been said in the previous section.

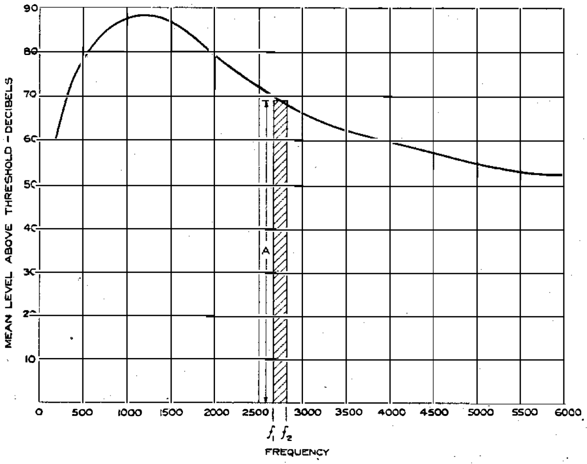

Figure 4

From the point of view of this study it is unnecessary to consider in great detail the different theories that have been put forward to explain the production of speech sounds. These theories have been described and discussed in various publications to which reference is given in the Bibliography. In particular, the book *Speech and Hearing* recently written by Dr. Harvey Fletcher gives a very complete discussion of the subject.

All that is necessary to know here is that a speech sound consists of a large number of components distributed throughout the audible frequency range. Due to the effect of certain resonant cavities of the mouth and throat, some of these components are considerably greater in amplitude than the others, and it is by noting at what frequencies these prominent components occur that the brain is able to distinguish one sound from another. Owing to the fact that the resonance of the mouth and throat give rather flat resonant curves, the prominent components occur in little groups of frequencies rather than as single isolated frequencies. This fact is clearly brought out by the frequency spectra given by Fletcher (13) and other authors for the different sounds.

Since it is by the position in the frequency range of these little groups or bands of frequencies that one sound is distinguished from another, they are called the characteristic bands of the sounds. Some sounds have only one characteristic band while others have as many as five.

The actual frequency components present in a given sound differ for different speakers, and even for one speaker they may differ from moment to moment. They always occur, however, in approximately the same frequency region or band. In order to make this clear, Figure 2 has been prepared. This shows two frequency spectra for an imaginary two band sound. In one case the fundamental cord tone of the speaker is assumed to be 200 periods per second. In this case the frequency components occur at intervals of 200 periods. In the second case the fundamental is assumed to be 100 periods per second, and in this case the components occur at intervals of 100 periods. In the second case, therefore, there are twice as many components as in the first case, but, owing to the fact that the prominent components still occur in the same frequency bands, the listener is able to recognise the two spectra as representing the same speech sound.

The next step in the development of the theory of articulation is to consider what happens when a conversation is taking place over a telephone circuit. As each sound is spoken at the transmitting end of the circuit, the various frequency components are transformed into electrical energy, are transmitted to the receiving end of the circuit with varying attenuation, and are finally reproduced at the listener's ear in a more or less distorted condition.

When the attenuation of the telephone circuit varies with frequency, the different characteristic bands arrive at the listener's ear with such distortion that he often mistakes one for another. A further factor tending to make it difficult for the listener to distinguish one sound from another is the presence of additional frequency components due either to noise in the telephone circuit or in the room, or to asymmetric distortion in the circuit.

Assume that, when an articulation test is carried out over a telephone circuit, the probability that the listener will receive a characteristic band correctly is, on the average, b. This means that, if it were possible to transmit the characteristic bands of speech one by one over the circuit, a fraction b of the bands would be correctly received. On the average, therefore, ceah band can be mistaken for $\frac{1}{b}$ other bands.

Now suppose that by some means it were possible to form at random groups of l characteristic bands from the total number of possible bands. These groups would not necessarily be actual sounds although some of them, of course, might happen to be. Suppose, also, that it were possible to produce these groups and to transmit them over a telephone circuit to the listener who has some means of recording what he thinks he has received.

Since b is the average probability of receiving a band correctly, the probability of receiving a group of l bands correctly is b^l. Hence there are $\frac{1}{b^l}$ alternatives for which the correct group of l bands can be mistaken. We can, therefore, consider the listener as setting out mentally the $\frac{1}{b^l}$ alternatives and just selecting one of them at random. The probability of his choosing the right alternative is, of course, b^l.

The next step is to assume that groups of l characteristic bands are being transmitted over a circuit but that, this time, each group is actually a sound and not a random group as before. Assume also that the listener knows he is to receive actual sounds and not random groupings. Then, as before, there will be $\frac{1}{b^l}$ alternatives from which the listener has to select one. This time, however, if he carries out his mental review of the $\frac{1}{b^l}$ possible alternatives, he will notice that some of them are not actual sounds. He thus rejects all these alternatives and is, therefore, left with a certain fraction of the $\frac{1}{b^l}$ alternatives which are actual sounds.

Of the total $\frac{1}{b^l}$ alternatives, one is the correct one and is, therefore, necessarily an actual speech sound. There are thus $\frac{1}{b^l}-1$ alternatives which may or may not be actual sounds. The proportion of these alternatives which are actual sounds depends, of course, on the number of the total possible combinations which are used as sounds. Let this proportion be c_l for sounds having l characteristic bands.

Then $c_l\left(\frac{1}{b^l}-1\right)$ of the $\frac{1}{b^l}-1$ alternatives will be actual sounds. The listener is, therefore, left with the $c_l\left(\frac{1}{b^l}-1\right)$ alternatives, plus the correct one, from which he has to make his choice. The probability that he will choose the correct one is, therefore,

$$\frac{1}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

But the probability of his choosing the correct alternative is the sound articulation d_l, for sounds of l characteristic bands.

Hence

$$d_l=\frac{1}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

From this it follows that the average ideal sound articulation for all sounds is given by the expression

$$d_i=\sum\frac{k_l}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

where k_l is the proportion of sounds in speech having l characteristic bands and b is the average band articulation.

This expression thus gives the average ideal sound articulation for a given circuit in terms of the average band articulation. The problem, therefore, resolves itself into the determination of the band articulation for the given circuit.

A statement was made in the previous section to the effect that, if b_{12} was the band articulation obtained over a circuit so arranged as to pass only frequencies in the range f_1 to f_2, and if b_{34} was the corresponding value for the range f_3 to f_4, then, if b_{1234} was the band articulation when both frequency ranges were passed together, these quantities were connected by the equation

$$b_{12}+b_{34}=b_{1234}$$

No conclusive theoretical proof of this relation has so far been discovered but, as the result of numerous tests, it has been found that this relation does hold in practice, except in certain limited cases which do not usually occur. These cases are mentioned in the section *Determination of Constants.*

In general, therefore, we can take the expression

$$b=\Sigma\,\Delta\,b$$

where Δ b is the band articulation for a small frequency region, and b is the total band articulation.

The factors that determine whether a given frequency region is transmitted from the speaker to the listener are:

(a) The amount of energy in this region produced by the speaker's voice.

(b) The attenuation of the circuit and apparatus transmitting the speech from the speaker's mouth to the listener's ear.

(c) The sensitivity of the listener's ear in the frequency range.

It should be noted that the effects of asymmetric distortion and noise are not considered here; they will be dealt with later.

If we determine the average relative amounts of energy present in the voice at different frequencies and express them as so many decibels above or below some given reference value, and then determine the average sensitivity of the are at different frequencies, also expressed in decibels above or below the same reference value, the difference between these two curves will give the average amount, in decibels, at different frequencies that the energy in the voice is above the minimum amount required to produce an audible sensation. In other words, this average speech level-threshold curve indicates the average amount by which a component of speech at a frequency f_1 must be attenuated before it becomes inaudible. This curve is shown in Figure 4.

If we assume for a moment that for all voices all the components in speech at a given frequency have the same level above threshold and that all ears have the same threshold value, then obviously, if we attenuate a given frequency by an amount greater than that given by the average speech level-threshold curve, that component will be inaudible, and will contribute nothing to the articulation. In order, therefore, to determine the articulation obtainable over a circuit having different amounts of attenuation at different frequencies, all we have to do is to determine what frequencies are attenuated so as to be below threshold, and what frequencies remain above threshold. Then we add up the value of Δ b for the frequency ranges above threshold, and so determine the total value of b for all frequency regions above threshold. Finally, we determine the corresponding value of the ideal sound articulation d_i, by means of the expression

$$d_i = \sum \frac{k_l}{1 + c_l\left(\frac{1}{b^l} - 1\right)}$$

It should be noted that in speaking here of the attenuation of a circuit, what is meant is the air-to-air attenuation of the circuit, so that this value includes not only the attenuation of the telephone circuit itself, but also of the transmitter and receiver.

Actually the method of determining the articulation for a circuit is not so simple as that described above. This is due to the following reasons:

(a) The ear threshold curves for individual listeners differ considerably from the average curve.

(b) The components, at a given frequency, for individual sounds differ from the average value at that frequency for all sounds.

(c) The loudness with which a speaker talks varies from speaker to speaker, and even in the case of a given speaker the loudness will vary from time to time.

The result of all these effects can best be understood by considering a circuit arranged to pass only those frequency components within a range f_1 to f_2. Assume that a number of different speakers are taking it in turn to talk over the circuit, and that a number of listeners are taking it in turn to listen. Then assume that the attenuation of the circuit in the range f_1 to f_2 is gradually increased from zero to a very large value.

At first when the attenuation is small the components between f_1 and f_2 of the different sounds will be heard by all listeners and for all speakers. As the attenuation is increased those sounds which have only small components in the range f_1 to f_2 will fail to be heard, and even some of the louder components will fail to get through if they happen to be spoken by someone who speaks in a quiet voice, or if they happen to be received by someone who is rather deaf.

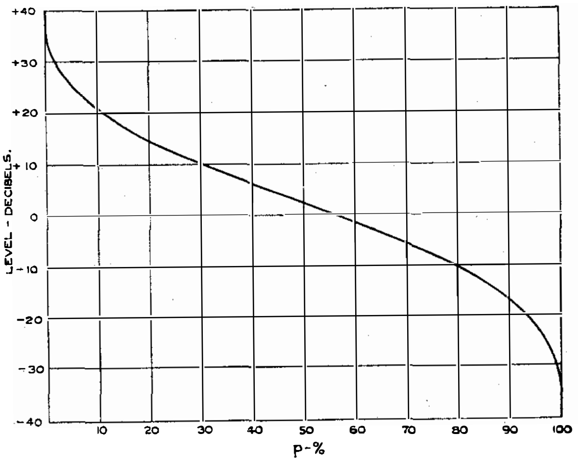

Figure 5

As the attenuation is increased, more and more of the components will fail to get through until finally the attenuation will be so great that no sounds at all will get through, even with the loudest speaker and the listener with the most acute hearing.

If we were to carry out an experiment of this nature, and were to determine for each level the percentage number of components that get through, we could plot a curve showing the number of components as a function of the level.

Such a curve is shown in Figure 5, the level in this case being expressed as so many decibels above or below the mean level above threshold.

The procedure in determining the articulation for a given circuit is then as follows: Divide the frequency range up into a number of small intervals, say, 100 periods. Consider the curve given in Figure 6, where Curve No. 1 is the average speech level-threshold curve given in Figure 4. Curve No. 2 is the air-to-air attenuation curve of the given circuit.

Consider one of the 100 period frequency bands f_1 to f_2. The ordinate A gives the average level of speech above threshold in this range f_1 to f_2. Ordinate C is the overall attenuation in this range introduced by the telephone circuit. Hence $B = A - C$ is the average level above threshold at which the speech arrives at the listener's ear.

Now, from the curve given in Figure 5, we can determine what proportion p of the components in speech between f_1 and f_2 are above threshold when the mean level in that range is B decibels above threshold. Since, for the interval f_1 to f_2, only p of the speech components are above threshold and b_{12} is the value of band articulation for the interval f_1 to f_2 when all components in the interval are above threshold, the probability of receiving a characteristic band correctly in the present case is pb_{12}.

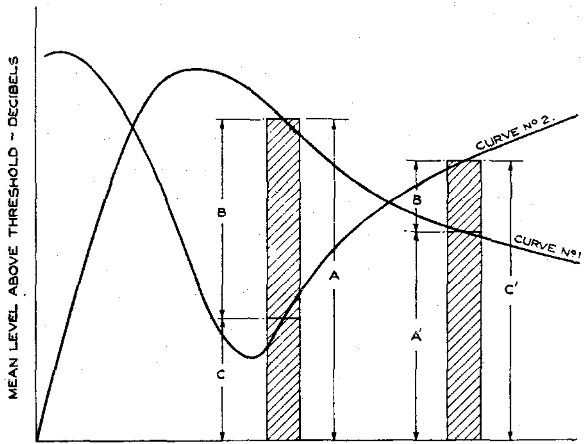

Figure 6

Hence the total band articulation is given by the expression

$$b = \Sigma\, p\, b$$

Having obtained the value of b in this way the corresponding value of d^i is obtained from the expression

$$d^i = \sum \frac{k_l}{1 + c_l \left(\frac{1}{b^l} - 1\right)}$$

So far only the effect of attenuation on the articulation of the circuit has been considered.

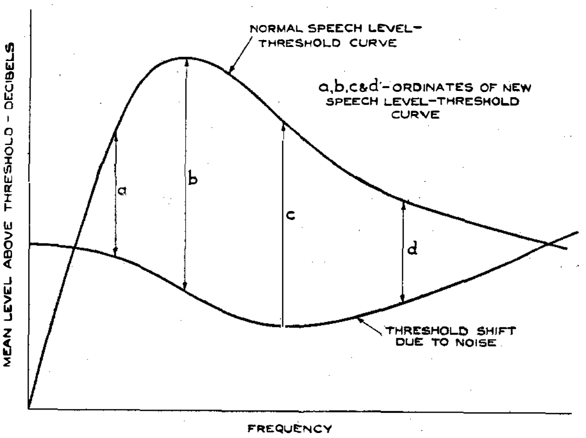

Figure 7

A second factor materially affecting the articulation is the presence of noise in the circuit due to crosstalk from some other circuit, induction from neighbouring power systems, bad contacts in some part of the circuit, or to some other cause.

Wegel and Lane (^{2}) have shown that if a single frequency is introduced into the ear the effect is to raise the threshold for other frequencies in the neighbourhood. In other words, the amount of the second frequency which is required to give an audible sensation is greater when the first frequency is present than it is when the second frequency is introduced into the ear alone. The effect of a single frequency component on the ear is to set the basilar membrane into vibration. The amplitude of the vibration of the membrane is greater at one point and falls off on either side of this maximum point. This point of maximum amplitude of vibration varies according to the frequency which is causing the vibration.

Since the effect of introducing frequency components into the ear is to shift the threshold value by different amounts at different frequencies, the effect of noise on articulation can be taken into account by determining the amount of threshold shift produced by the noise. This modified threshold curve is then used to determine the speech level-threshold curve instead of the normal threshold curve used in Figure 4. In other words, a threshold shift of, say, 50 decibels at a given frequency is equivalent to increasing the attenuation of the circuit at that frequency by 50 decibels.

The threshold shift produced by a given complex tone can either be measured by an exploring tone, or, if the frequency spectrum of the noise is known, an approximate idea of the masking at various frequencies can be obtained in the following way:

The resultant masking of a complex tone is due, of course, to the combined effect of the masking by the individual frequency components. The threshold shift at different frequencies due to a given frequency at a given level can be obtained from the masking curves of Wegel and Lane. The problem is, therefore, how are the threshold shifts at a given frequency due to several different frequency components to be combined to give the resultant threshold shift.

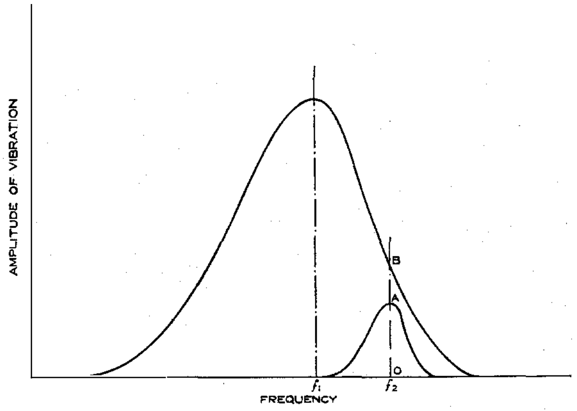

Figure 8

Figure 8 represents what happens when an exploring frequency f$_2$ is used to determine the amount of masking at f$_2$ due to the frequency f$_1$. The level of the exploring frequency f$_2$ is increased until it is just audible in the presence of f$_1$. The height OB represents the amplitude of vibration of the basilar membrane at the point O due to the masking frequency f$_1$. The point O is the point of maximum amplitude of vibration of the membrane for the frequency f$_2$. Since the basilar membrane is already in movement at the point O due to the presence of f$_1$, the introduction of the frequency f$_2$ has the effect of increasing the amplitude of vibration at the point O. If the level of f$_2$ is increased until f$_2$ is just audible in the presence of f$_1$, then OA is the amplitude of vibration due to f$_2$ which, when added to the existing amplitude of vibration OB, produces an increase in vibration which is just perceptible. Wegel and Lane state that the value of OA is approximately equal to OB. This means that the amplitude of vibration of the basilar membrane at a frequency f$_2$ due to a frequency f$_1$ is equal to the amplitude of vibration produced by an exploring frequency f$_2$ at such a level that it is just perceptible in the presence of f$_1$. The amplitude of vibration of the basilar membrane V in terms of the threshold amplitude, is, therefore, determined from the expression $20 \log_{10} V = S_t$, where S_t is the threshold shift given by the masking curves.

Having determined V for the different frequencies present in the masking tone, the resultant value V^1 is found by summing as the square root of the sum of the squares.

The corresponding value of resultant threshold shift S_t^1 is then determined from the expression $20 \log_{10} V^1 = S_t^1$. This procedure is repeated for any given point along the basilar membrane and so the resultant threshold shift frequency curve is obtained.

The effect of noise, then, is to raise the threshold by different amounts at different frequencies and so produce a new threshold curve. This effect can, therefore, be allowed for by taking this new threshold curve, instead of the normal one, when constructing the speech level-threshold curve.

In other words, the threshold shift in decibels at each frequency is added to the corresponding air-to-air attenuation in decibels. An example is shown in Figure 7.

In addition to the effect of ordinary distortion and noise on articulation, there is a third factor whose effect is rather in the nature of a combination of the first two. This third factor is asymmetric distortion which occurs when some part of the circuit departs from a linear characteristic. Some of the common causes of asymmetric distortion are overloading of iron cored coils and vacuum tubes, carbon microphones and overloading taking place in the ear.

Very little has been published on the question of asymmetric distortion and, owing to lack of time, not much work has been done on this subject in connection with the present study. The method of taking into account the effect on articulation of asymmetric distortion is therefore not very fully developed. So far as it has gone, however, it has given reasonable results, so a short description has been given here as a matter of interest.

The question of asymmetric distortion and its effect on articulation is a very important one, since all commercial telephone circuits are subject to a certain amount of such distortion. Further work on this subject is therefore being planned. In general, it can be said that the effect of asymmetric distortion is to produce in the circuit or ear all the harmonic series of any frequency originally present. As the amplitude of the original frequency increases, the amplitude of the harmonics due to asymmetric distortion increases very rapidly until the latter may become as large as the original frequency.

The effect of asymmetric distortion is similar to that of noise; that is to say, the harmonics cause masking of the speech components. There is the essential difference, however, that the effect varies with the volume of speech and depends on the particular sound being spoken. The masking curves published by Wegel and Lane(2) show that the masking effect of a given frequency on frequencies below it is small compared with the effect of the frequency on frequencies above it. This effect is due to the asymmetric distortion taking place in the ear.

Except at very large volumes, the amplitude of one frequency must be considerably greater than that of the second before the first will cause any appreciable masking of the second. We should expect, therefore, that it would only be in the case of those sounds that have a high level low frequency component and a low level high frequency component that the effect of asymmetric distortion would be noticeable. From an inspection of Fletcher's curves(13) of articulation against level for individual sounds, together with the list of frequencies and levels for the characteristic bands given in this paper, it will be seen that this is the case. Sounds having only one characteristic band do not, therefore, show signs of the overloading of the ear, nor do sounds in which the different bands have about the same level.

From a knowledge of the relation between input and output voltage at different levels for any piece of apparatus causing asymmetric distortion, it is possible to calculate by simple mathematical formulae the magnitude of the different harmonics caused by asymmetric distortion when a given voltage is applied to the apparatus. These formulae are too well known to require to be given here. Once the magnitude of the harmonics is known, the masking effect when these harmonics are introduced into the ear is determined in the same way as for noise.

The effect of asymmetric distortion has only been considered, so far as this study has gone at present, in connection with the overloading effect taking place in the ear itself. In this case the method has given good results, but as to whether it would give equally good results for other types of asymmetric distortion has not yet been tried owing to the lack of the necessary data.

The method employed in connection with the overloading of the ear was as follows: Since the maximum level of speech above threshold occurs at about 1200 periods and is about 88 decibels, as shown in Figure 4, the effect of asymmetric distortion was considered as though it were due only to a 1200 period component. For any particular sound this will not give correct results, but on the average it does give results which agree with practical measurements. The level at which this 1200 period component arrives at the ear for any given circuit is 88 decibels minus any attenuation at that frequency produced by the circuit. The masking of other frequencies produced by this 1200 period tone is determined from the curves of Wegel and Lane, and the effect on articulation is determined in the same way as that described for noise. It should be noted, however, that the effect of asymmetric distortion only occurs in the case of about 10 of the 36 sounds, so that a resultant value of b is obtained by taking 10 times the value of b calculated with asymmetric distortion and 26 times the value without asymmetric distortion, adding the two together and dividing by 36. It will be obvious that there are a number of approximations and assumptions used in this method, but it would appear that they are permissible since they give results in good agreement with measured values. A further study of this part of the subject is being undertaken.

Determination of Constants

The formulae developed in the previous section for the calculation of the sound articulation were:

$$d_i = \sum \frac{k_l}{1 + c_l \left(\frac{1}{b^l} - 1\right)}$$

$$b = \Sigma\, p\, \Delta\, b$$

The following constants have, therefore, to be determined: p, Δ b, l, c_l, and k_l.

In his book *Speech and Hearing,* Fletcher gives curves which show the variation of articulation for the different sounds when the cut-off frequency of his high quality circuit is changed. Two curves are given for each sound, one curve corresponding to the case when all frequencies from the given frequency to infinity are passed, and the other curve corresponding to the case when all frequencies from zero up to the given frequency are passed.

The high quality circuit was constructed so as to pass all speech components in the pass range without distortion, and to suppress entirely all components outside the pass range.

It will be seen that each pair of curves cross, or would cross if carried far enough, at a certain frequency. This crossing frequency is different for different sounds. The articulation corresponding to this crossing frequency is the value obtained either by passing all components from the crossing frequency to infinity, or by passing all components from zero to the crossing frequency. It follows that the value of β of the band articulation for all components from zero to the crossing frequency will be the same as the value of β for all components from the crossing frequency to infinity.

But the probability of receiving a band correctly when all frequencies are passed is unity in the ideal case. Hence the value of β for either of the regions, zero to the crossing frequency, or crossing frequency to infinity, must be 0.5 since $\beta = \Sigma\, \Delta\, \beta$.

If d_i^1 is the articulation corresponding to the crossing frequency, then we can write the expression

$$d_i^1 = \frac{1}{1 + c_l\ (2^l - 1)}$$

This expression contains two unknowns, c_l and l. It would, of course, be possible to evaluate these two unknowns if we knew some other corresponding values of d and β. A second pair of values could be obtained, for instance, by dividing up the frequency range zero to the crossing frequency in such a way that the articulation for the range zero to the new frequency was the same as that for the range from the new frequency to the crossing frequency. We should then know that the value of β for either of these sub-ranges would be 0.25.

Since, however, no information of this nature is available, it is necessary to determine both l and c_l from the one relation; and fortunately this can be done.

It is found that c_l does not vary greatly for different values of l. It follows, therefore, from the expression

$$d_i^1 = \frac{1}{1 + c_l\ (2^l - 1)}$$

that the greater the value of l the smaller will be the value of d_i^1. Those sounds having the largest values of d_i^1 will, therefore, be one band sounds; the next largest will be two bands sounds, and so on. From an examination of various published oscillograms, and analyses of speech sounds, it is possible to determine fairly definitely how many bands there are in some of the sounds, and this information, together with the values of d_i^1 enables us to determine values of l for all the sounds. It is possible that in some instances errors may have occurred; but, owing to lack of sufficient data, it is impossible at the moment to determine the values in any more exact manner. It is probable, however, that the effect on the final result will be small due to any errors that may have occurred in this way. As soon as further data are available, these values can be checked.

Having obtained a value for l in this way, the value of c_l for each sound can be determined directly from the expression

$$d_i^1 = \frac{1}{1+c_l\,(2^l-1)}$$

The value of k_l, the fraction of the total number of sounds which has l bands, follows at once from the evaluation of l for the different sounds.

Finally, having determined the values of k_l, c_l, and l, the relation between d_i^1 and b can be evaluated from the expression

$$d_i = \sum \frac{k_l}{1+c_l\left(\frac{1}{b^l}-1\right)}$$

A curve for this expression has been worked out and is given in Figure 1.

In order to determine the value of Δ b, which is the average probability of receiving a characteristic band correctly when a small frequency region f_1 to f_2 only is passed to the listener, use is made of the curve given in Figure 136 of *Speech and Hearing*. This curve gives the average syllable articulation for the high quality circuit for different cut-off frequencies. As was pointed out in a previous paper, (12) and as Fletcher himself points out, (13) the relation between sound and syllable articulation for his lists is given by the expression

$$s = 0.2\, d^2 + 0.8\, d^3$$

Hence, by using this expression and the curve between d_i and b just obtained, it is possible to obtain from Fletcher's syllable articulation against cut-off curves, corresponding curves of b against cut off.

Now, since $b = \Sigma\ \Delta\ b$, we can obtain the value of Δ b for any frequency region f_1 to f_2 by determining values of b corresponding to f_1 and f_2 from either the low pass or high pass curves, and subtracting one from the other. If the theory developed here is correct, the corresponding values of Δ b, determined from the two curves, high pass and low pass, should be the same. Actually this is the case for frequencies from O up to 2500 periods. Above 2500 periods the frequency regions contribute less to articulation when frequencies from O to 1500 periods are present than they do when these latter frequencies are absent. This is due to the frequency spectra of the sounds such as S and Z. Figure 9 illustrates the frequency spectra for S and SH. It will be clear from this that the ear is in the habit of associating the SH sound with two bands; one from 500 to 2000, and one from 2000 to 4000. The sound S is associated with three bands, the first two being approximately the same as for SH, while the third is from 4000 to 6000.

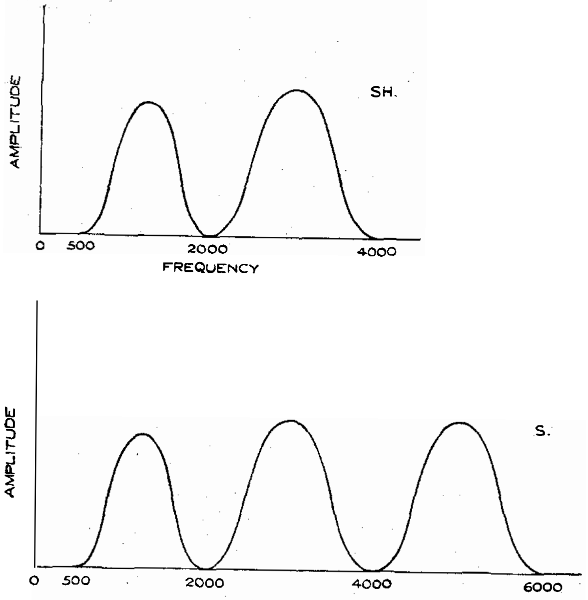

Figure 9

When frequencies from O to 2000 only are passed, the two sounds have very nearly the same spectra, but neither is the one usually presented to the ear. The listener, therefore, will not know whether a given sound is S or SH, but each will seem equally likely to him. He is thus likely to guess the sound as S 50% of the time, and as SH the other 50%.

When the range 2000 to 4000 is passed as well as the range O to 2000, the state of affairs is very different. Now the listener is receiving the whole spectrum for SH so that the articulation for this becomes 100%. When S is called, however, the listener receives very nearly the same spectrum as he is in the habit of associating with SH. Hence, for quite a large number of times he will mistake S for SH, so that the articulation of S will fall.

Finally, when the range 4000 to 6000 is passed as well as the other two, the listener receives the full spectrum for both S and SH.

When the region 0 to 2000 is absent, and only the region 2000 to 4000 is passed, the spectra for S and SH are the same, but neither are what the listener is used to receiving. The effect of the region 2000 to 4000 is now approximately the same for both sounds.

Hence, the value of the region 2000 to 4000, from the point of view of articulation, will depend for certain sounds on whether the region 500 to 2000 is present or not. If the latter is present, then the region 2000 to 4000, instead of helping articulation, actually hinders it. A similar state of affairs exists for certain other pairs of sounds.

Since for all practical circuits the region 500 to 2000 is present, it is the values of Δb determined from the low pass curve that we should take. A curve giving values of Δb for frequency bands of 100 periods is given in Figure 10, for this case. For certain exceptional cases where the region 500 to 2000 is wholly or partially suppressed, it is necessary to take different values for Δb in the region 2000 to 4000, but, since this so seldom occurs, it has not been necessary to go into the question more fully at the present time.

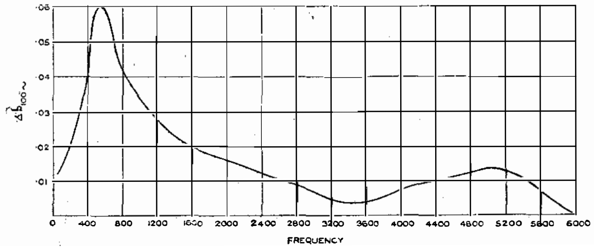

Figure 10

There only remains to be determined the value of p. If the speech components in a certain range f_1 to f_2 are passed from the speaker to the listener without distortion, but with a certain uniform attenuation, then, if a very large number of speakers take it in turn to talk to a very large number of listeners, p is the fraction of the total number of conversations in which the region f_1 to f_2 reaches the listener at such a level to be above threshold. It is, therefore, the average probability that the region f_1 to f_2 will reach the listener above threshold, when the given loss is introduced in the region. Its value can, therefore, be obtained by determining for the given range f_1 to f_2 the probability that a speaker will have a mean speech level a given amount above or below the average of all speakers, the probability that a speech sound will have a level a given amount above or below the average for all sounds, and the probability that a listener's threshold will be a given amount above or below the average for all listeners, and then combining the three probability frequency curves.

Values for the variation from speaker to speaker were obtained from a curve published by Fletcher(5). Values of the variation from sound to sound were obtained from the figures published by Sacia and Beck(9), on the assumption that the variations for the different frequency regions are the same as the variations of peak power. The variations of threshold from listener to listener were actually measured, since no data appeared to have been published.

The combined result of these three curves is given in Figure 5.

Apart from the constants which have now been evaluated, there still remains to be determined the speech level-threshold curve shown in Figure 4. This curve gives at each frequency the average level of speech components above threshold for initial speech intensity. It should be noted that we are only concerned here with those frequency components of the sounds which actually serve to distinguish one sound from another. The average level of these components for any frequency region is not necessarily the same as the average energy level for the same regions, because a sound may have quite a large amount of energy in some frequency region without this region contributing in any way to the articulation. It is not sufficient, therefore, to use the average energy spectrum for speech for determining the speech level-threshold curve, and it is necessary to arrive at the desired result by a rather roundabout method.

If the mean frequency and mean level above threshold could be obtained for each of the characteristic bands of speech, the speech level-threshold could be obtained by plotting points on frequency-level axes and drawing a mean curve through the points. This has been done, and the resulting curve is given in Figure 4. The method of obtaining the mean frequency and level for each characteristic band is by means of two sets of curves published by Fletcher(13). The first, from which the mean frequency is obtained, is the set of curves giving articulation against cut-off frequency for the different sounds when transmitted over the high quality circuit.

From the relation

$$d_l = \frac{1}{1 + c_l \left[\frac{1}{\beta^l} - 1 \right]}$$

a series of curves can be constructed from the articulation cut-off curves of Fletcher, giving β against cut-off frequency. For each sound there will be two curves corresponding to the high pass and low pass circuits.

If a one band sound is taken and the characteristic band is divided into two parts by a frequency f so that the value of β for each part is equal, i.e., $\beta = 0.5$, then the frequency f can be considered as the mean frequency of the band. Hence for one band sounds the mean frequency is taken as that frequency corresponding to a value of β of 0.5 on the curves just constructed.

For a two band sound the mean frequency of the first band is that frequency corresponding to a value of β of 0.25 on the low pass curve or 0.75 on the high pass curve. Similarly, the mean frequency of the second band corresponds to a value of β of 0.75 on the low pass curve or 0.25 on the high pass curve.

In a similar way the mean frequencies for a three band sound correspond to values of β of 0.166, 0.5 and 0.883, and so on for other numbers of bands.

The second set of curves, from which the mean levels of the different bands are determined, is the set giving the articulation against intensity level for each sound. As before, these curves are transformed into a corresponding set of curves giving β against intensity level.

For a one band sound the mean level is that corresponding to a value of β of 0.5.

For a two band sound, if the levels of the two bands are such that when the intensity level has been dropped so as to cut one band out entirely the whole of the other still remains above threshold, the mean levels correspond to values of β of 0.25 and 0.75, respectively.

If the two bands overlap as regards level, the above rules do not apply, and a different method must be used. It has been found that for one band sounds the shape of the curve of β against intensity level is approximately the same whatever the mean frequency of the band. In fact, this curve is merely the same curve as that previously given in Figure 5, since one curve gives the probability that a band will be received above threshold while the other gives the proportion of cases in which the components in a given frequency range will reach the listener at a level above threshold.

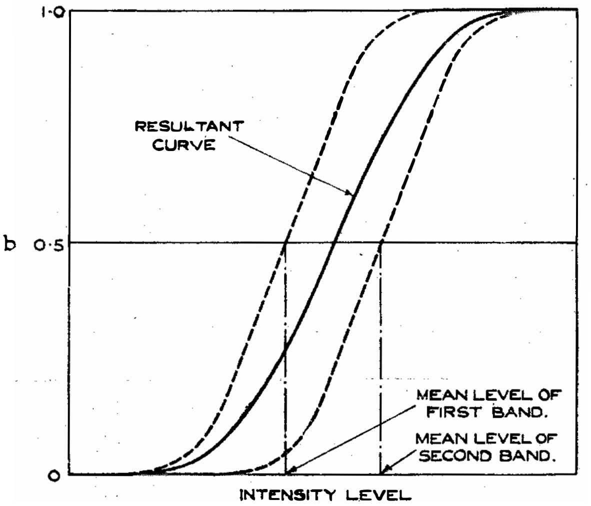

Figure 11

For a two band sound the curve of β against intensity level will be obtained by combining two of the curves for one band sounds, the two curves being placed so that the value of β of 0.5 in each case occurs at the mean level for the band. An example is shown in Figure 11. By trial and error it is possible to find for each of the two band sounds, the position of the two component curves such that the resultant curve fits the particular curve of β against level for the sound. The levels of the two bands of the sound are the same as the levels corresponding to the two component curves.

For sounds having a greater number of bands the same principle can be applied but with greater difficulty, of course.

In this way the mean frequency and mean level can be determined for each band in a sound, but, since the frequencies and levels are determined separately, there is no means of telling which particular level belongs to a particular frequency in the case of a multi-band sound. This difficulty was overcome partly by reference to oscillograms of the various sounds, and partly by the use of a curve giving the mean level of speech energy above threshold. This curve was obtained by combining the mean threshold curve and energy frequency spectrum of average speech given by Fletcher in his book, *Speech and Hearing*. This curve so obtained is not necessarily exactly the same as the curve giving the mean level above threshold of the characteristic bands of speech. It is, however, a sufficiently close approximation to it to enable us to allot the different levels to the different frequencies in this case.

LIST OF SOUNDS AND KEY WORDS

SOUND	KEY WORD	SOUND	KEY WORD
Ē	ME	H	HE
E	GET	J	JUST
AH	PART	K	KICK
Ī	MY	L	LET
I	IN	M	ME
Ā	PAY	N	NO
A	AT	P	UP
Ō	NO	R	RED
O̅O̅	TOO	S	SO
OO	GOOD	T	IT
U	MUCH	V	GIVE
OW	HOW	W	WIN
AW	LAW	Y	YES
ER	HER	Z	PRIZE
B	BY	CH	WHICH
D	DO	SH	SHE
F	IF	TH	THAT
G	GET	EG	RING

In order to reduce the time required to calculate the articulation for a given circuit, values of $p \Delta b$ have been worked out for each 100-period frequency region from O to 6000 periods and for different values of overall attenuation. These values have been tabulated and a small section of the whole table is given below. This section is given merely to indicate the way in which the table is drawn up. The values in it are based only on the approximate determination of the constants, so that it was considered desirable not to give the complete table until the more exact evaluation of the constants has been completed.

The way in which the values of this table were obtained can be seen from Figure 6. Consider the frequency region f_1 to f_2 and let it be required to determine the value of $p \Delta b$ for this region for an overall attenuation of C decibels. The average level above threshold A of speech components in the region f_1 to f_2 is known from the speech level-threshold curve, curve No. 1, Figure 6. Hence the value $B = A - C$ is obtained. From the curve of Figure 5 we know that if the speech components are B decibels below the mean curve, the value of p has a certain value. From the curve of Figure 10 we also know the value of Δb for the region f_1 to f_2. The value of p is multiplied by the value of Δb and the value is inserted in the table at the point corresponding to the frequency region f_1 to f_2 and the attenuation C.

Comparison of Calculated and Measured Results

In order to show with what accuracy the articulation can be calculated by the method described in this paper, a number of examples are given for which the articulation has been calculated and for which actual measured results are available. In judging these results, it should be remembered that the constants used in the calculated values of articulation are only approximate, so that when the final evaluation of these constants is made the agreement between measured and calculated results should be even better than it is now.

The examples which have been worked out here have been taken from Fletcher's book, *Speech and Hearing*, and the values he gives are the values of syllable articulation actually measured by his testing crews. The values of ideal sound articulation calculated by the method described

MEAN FREQUENCY AND LEVEL OF ARTICULATION BANDS

Sound.	No. of Bands.	Freq.	Level.	Freq.	Level.	Freq.	Level.	Freq.	Level.	Freq.	Level.
Ē	1	1575	90								
L	1	1000	80								
NG	1	1725	82								
Y	1	2125	84								
Ī	1	1425	87								
R	2	1250	85	2000	85						
I	2	600	92	2000	87						
Ā	2	500	93	1900	98						
D	2	1375	76	3125	71						
CW	2	900	98	1375	93						
O̅O̅	2	650	85	1900	85						
SH	2	1720	86	2700	86						
Ō	2	700	81	1225	101						
W	22	825	81	1125	86						
J	2	1050	82	2900	82						
A	2	875	93	2100	83						
H	2	1100	80	1575	50						
N	2	1000	85	3200	65						
AW	2	875	86	1375	106						
CH	2	1575	92	3250	62						
M	2	775	72	2000	67						
B	2	500	79	2375	59						
K	2	1375	78	3125	58						
G	2	1360	82	2625	62						
V	2	750	66	3000	46						
AH	2	790	92	2050	92						
T	2	1875	78	4500	68						
Z	2	1250	70	4250	45						
ER	3	750	98	1625	98	2400	93				
P	3	1075	85	1925	65	2750	50				
E	3	650	85	1000	85	1750	85				
F	3	1000	96	2250	66	4200	56				
U	3	625	84	1250	104	2125	78				
S	3	1350	60	2700	60	5500	60				
OO	4	250	69	800	105	1700	95	3000	79		
TH	5	200	20	625	110	1875	100	3800	70	6600	40

VALUES OF p Δ b.

FREQUENCY	OVERALL ATTENUATION (DECIBELS)							
	52–54	54–56	56–58	58–60	60–62	62–64	64–66	66–68
1200–1300	0206	0259	0258	0257	0255	0252	0249	0245
1300–1400	0240	0239	0238	0236	0234	0231	0228	0222
1400–1500	0220	0219	0218	0217	0215	0212	0209	0204
1500–1600	0199	0199	0198	0196	0194	0191	0188	0184
1600–1700	0189	0188	0187	0185	0183	0180	0176	0172
1700–1800	0178	0177	0175	0173	0171	0167	0164	0160
1800–1900	0168	0167	0165	0162	0160	0156	0153	0149
1900–2000	0157	0155	0153	0151	0147	0144	0140	0136
2000–2100	0150	0148	0146	0143	0140	0135	0131	0126
2100–2200	0140	0137	0134	0131	0128	0125	0121	0115
2200–2300	0129	0126	0123	0120	0116	0113	0107	0102
2300–2400	0118	0115	0113	0110	0104	0102	0098	0092
2400–2500	0107	0105	0102	0099	0097	0092	0088	0082
2500–2600	0096	0094	0090	0088	0084	0080	0075	0069
2600–2700	0090	0088	0085	0082	0078	0073	0068	0063
2700–2800	0079	0076	0074	0070	0066	0061	0057	0052

in this paper have, therefore, been converted to the corresponding ideal syllable articulation for comparison with Fletcher's results. The calculated values of syllable articulation will, of course, always be a little higher than the measured values because the calculated values are the ideal values and the measured are not. In most of Fletcher's results the measured values are very near the ideal values because his testing crews were so highly trained as to approximate very nearly to the ideal crew. In some cases sufficient information was available to enable the constant Z of Fletcher's crew to be determined; in these cases the actual measured results have been corrected to the corresponding ideal syllable articulation, using the method given in the appendix.

The cases worked out are as follows:

(1) The articulation for the high quality circuit at different intensity levels. The results are given in Figure 12. The measured curve is Fletcher's mean curve and the points are values of ideal syllable articulation obtained by correcting one set of his measured values using a crew constant of $Z=.95$. The crew constant of 0.95 was obtained by noting the value of articulation obtained by the crew at an intensity level of 75 decibels, since the value of b for this level is 0.5.

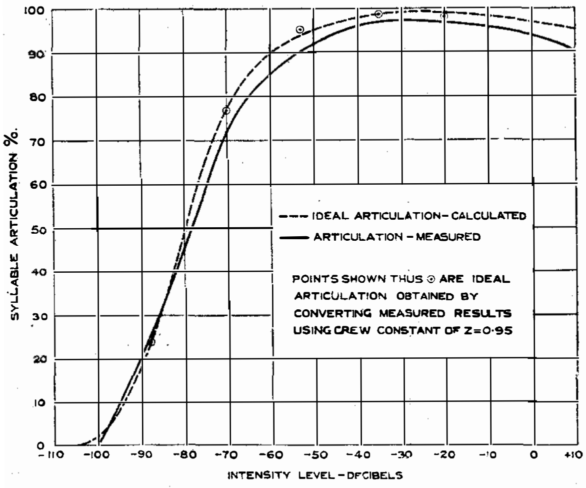

Figure 12

The measured curve, as would be expected, is a little lower than the calculated, but the corrected points lie very well on the calculated curve.

(2) The high quality circuit with a resonant circuit tuned to 1100 periods per second and a damping of 450 bels per second.

The calculated value of ideal syllable articulation was 94% and the measured value was 92%.

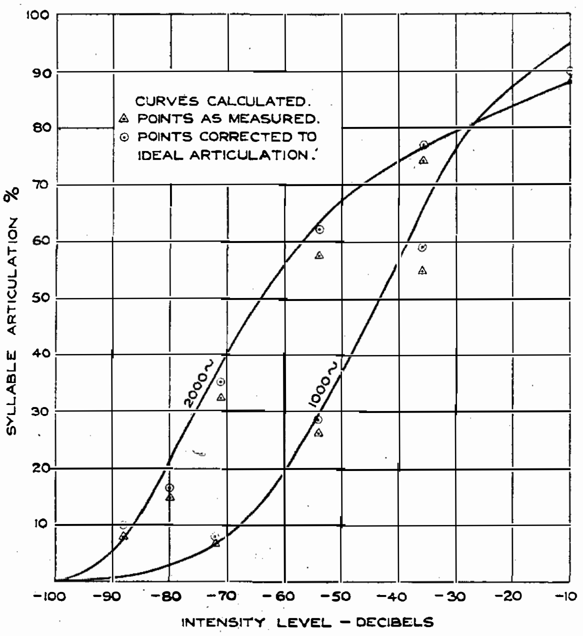

Figure 13

(3) The same as above but with the resonant circuit having a damping of 35 bels per second.

The calculated value of ideal syllable articulation was 83.5% and the measured value was 80%.

(4) The high quality circuit with added 1000 period and 2000 period noise. The results are given in Figure 13.

The upper points were obtained by correcting the measured results with a crew constant of $Z=0.95$. The lower points are the actual measured values.

The corrected figures are in good agreement with the calculated curves.

On the whole the measured and calculated results are in good agreement; where the actual crew constant could be obtained the agreement is still closer.

In the case of the upper parts of the curves given in Figures 12 and 13, and in the case of the values given for cases (2) and (3) the allowance for overloading had to be made. It appears to give reasonable results.

Conclusions

As pointed out at the beginning of this paper, the evaluation of the constants is approximate only, since it was carried out with the aid of such data as had been published, and was done in order to determine, before going more fully into the subject, whether the theory was capable of giving results in agreement with practice. This point should be kept in mind when considering the results since it explains differences which occur in some instances between calculated and measured results. In spite of the approximate values of the constants, the agreement between the calculated articulation and the measured values is, in most cases, quite good and within the limits of experimental error. There are, admittedly, still many points which require further investigation, and it is hoped in the course of the next year to devote time to the study of these points in addition to a more accurate evaluation of the constants.

In conclusion, it can be said that, except for minor modifications, the theory can be taken as representing the actual conditions with sufficient accuracy to enable it to be applied to the calculation of articulation in practical cases. Further, the tabular form in which the results have been presented makes it possible to calculate the articulation for a given circuit in a very short space of time. The use of the Ideal Sound Articulation as a criterion of the quality of speech obtainable over a circuit deserves some mention. This quantity is independent of errors due to the testing crew and is, therefore, a true measure of the characteristics of the circuit.

This fact, together with the easy method described here for converting the articulation as measured by a given crew to the corresponding ideal sound articulation, makes the Ideal Sound Articulation particularly useful as a measure of the performance of a telephone circuit. An added advantage is the fact that syllable articulation, word articulation, intelligibility and time efficiency can all be calculated from the Ideal Sound Articulation.

Before concluding this paper, the author would like to express his appreciation of the many papers written by members of the Bell Laboratories of America, to which constant reference has been made throughout this work. It is no exaggeration to say that without the results published in these papers, this preliminary demonstration of the accuracy of the theory could not have been made at the present time. In addition, thanks are due to those members of the staff of the Development and Research Laboratories of the International Telephone and Telegraph Corporation who have helped in the work and the preparation of this paper.

LIST OF SYMBOLS

b = Average band articulation for all sounds.
β = The band articulation for a given sound.
Δb = The value of b for a small frequency range f_1 to f_2.
l = Number of characteristic bands in a sound.
c_l = Constant depending on the total number of groups of l characteristic bands and the number of sounds having l characteristic bands.
k_l = Proportion of sounds in speech having l characteristic bands.
d_l = Sound articulation for sounds with l characteristic bands.
d_i = Average Ideal Sound Articulation.
d_i^1 = Value of d_i at frequency where high pass and low pass articulation-frequency curves cross.
d = Average sound articulation obtained by a given testing crew.
P = Proportion of speech components in a given range which are above threshold for a given level of speech.
Z = Crew Constant.
= Average probability that a given crew will receive a characteristic band correctly over a circuit for which $b=1$.

BIBLIOGRAPHY

Where reference numbers occur in the text they refer to the correspondingly numbered work in this bibliography.

1. Physical Measurements of Audition and their Bearing on the Theory of Hearing. H. Fletcher. Bell System Technical Journal. October 1923.
2. Auditory Masking and Dynamics of the Inner Ear. R. L. Wegel and C. E. Lane. Physical Review. February 1924.
3. A Dynamical Study of the Vowel Sounds. I. B. Crandall and C. F. Sacia. Bell System Technical Journal. April 1924.
4. Dependence of Loudness of a complex Sound upon the Energy. H. Fletcher and J. C. Steinberg. Bell System Technical Journal. September 1924.
5. Useful Numerical Constants of Speech and Hearing. H. Fletcher. Bell System Technical Journal. July 1925.

6. The Loudness of Speech and its Physical Stimulus. J. C. Steinberg. Physical Review. October 1925.
7. Speech Power and Energy. C. F. Sacia. Bell System Technical Journal. October 1925.
8. The Sounds of Speech. I. B. Crandall. Bell System Technical Journal. October 1925.
9. The Power of Fundamental Speech Sounds. C. F. Sacia and C. J. Beck. Bell System Technical Journal. July 1926.
10. Dynamical Study of the Vowel Sounds. II. I. B. Crandall. Bell System Technical Journal. January 1927.
11. A Direct Comparison of the Loudness of Pure Tones. B. A. Kingsbury. Physical Review. April 1927.
12. A Theoretical Study of the Articulation and Intelligibility of a Telephone Circuit. John Collard. Electrical Communication. January 1929.
13. Speech and Hearing. H. Fletcher. Published by D. Van Nostrand Co., Inc.

APPENDIX

Calibration of Articulation Testing Crew

The whole of this work has been based on the ideal sound articulation which is, by definition, the value that would be obtained by an ideal testing crew. This value is used because it is independent of the crew and is, therefore, a true measure of the quality of speech obtainable over a circuit.

The actual value of articulation obtained by any given crew will fall short of the ideal value due to errors introduced by the crew. These errors will be of two kinds, errors due to faulty pronunciation of the caller, and errors due to inattention and other causes affecting the listener. Some method of determining the ideal sound articulation from a value of actual articulation measured by a given crew is therefore necessary.

In a previous paper the following expression was given

$$D = D_i \times D_e$$

where D is the percentage sound articulation, D_i is the ideal sound articulation, D_e is a constant for a given testing crew and is the value of articulation that crew would obtain over an ideal circuit.

Actually, tests have shown that this relation does not hold in practice and a further study of the theory indicates that it could not be expected to.

The form of this expression is correct, but instead of using the sound articulation it is necessary to use b, the probability of receiving a characteristic band correctly. This is obviously the case since it is the characteristic bands of speech that are either recognised or not recognised by the listener. The relation between ideal and actual sound articulation will, of course, depend on the relation.

$$d_l = \frac{1}{1 + c_l\left(\frac{1}{\beta_l} - 1\right)}$$

and will not be of the simple form $D = D_i \times D_e$.

The expression for the sound articulation as measured by a given crew then becomes

$$d = \sum \frac{k_l}{1 + c_l\left[\frac{1}{Z^l\, b^l} - 1\right]}$$

where Z is a constant for a given crew and is the average probability that the crew will receive a characteristic band correctly over an ideal circuit.

This expression has been checked by actual tests and has been found to be correct within the limit of the experimental error of the test results.

The value of Z for the ideal crew is therefore unity, so that the expression for the ideal sound articulation is, as before,

$$d_i = \sum \frac{k_l}{1 + c_l\left[\frac{1}{b_l} - 1\right]}$$

In order to determine the value of Z for a given crew, it is sufficient to obtain a measured value of articulation with the crew on a circuit for which b is known. It is preferable to use a circuit having a value of b approximating to that obtained on ordinary telephone circuits, i.e., a value of about 0.5. A circuit having a value of b of 0.5 can, of course, be constructed by using a high quality circuit in conjunction with a filter designed to cut off all frequencies above 1550 periods per second.

The curve given in Figure 4 gives values for d_i and b for the expression

$$d_i = \sum \frac{k_l}{1 + c_l\left[\frac{1}{b^l} - 1\right]}$$

The same curve can, therefore, be used to give the relation between d and Zb in the expression

$$d=\sum\frac{k_l}{1+c_l\left[\frac{1}{Z^l b^l}-1\right]}$$

In order to determine Z for a given crew the procedure is as follows: Measure the articulation with the given crew for the circuit where b is known; let this value be d^1. From the curve the corresponding value of Zb is obtained and, since b is known, the value of Z is obtained directly. Then if a value of articulation of d is measured on a circuit for which the ideal sound articulation is required, the value of Zb corresponding to d is obtained from the curve. Since Z is known, the value of b can be calculated and, using the curve once more, the corresponding value of d_i is obtained.

The Training of Local Staff in Ceylon for Communication Engineering Works

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Chief Engineer, Ceylon Telegraph Department

NOT the least of the difficulties which the Communication Engineer in the tropics has to face is the formation and adequate training of a staff capable of installing and maintaining, in an efficient manner, any or all of the diverse types of plant which the rapid developments in the science of communications now demand, and it has been suggested that a short description of what is being done in Ceylon to achieve this end may be useful to other Administrations similarly placed.

First of all, a few words about the country and its people. Ceylon is regarded as the premier Crown Colony of the British Empire, and is situated near the southern point of India. It does not, however, as many people imagine, form part of British India, either politically or otherwise, notwithstanding the poetical description sometimes given to it as "the pearl on the brow of India." It has an area of over 25,000 square miles, about half the size of England, the most northerly point being only 9° 50′ north of the Equator, while the southern point reaches to within 5° 55′ of the Circle. Its population is approximately 5½ millions, consisting of Sinhalese, Tamils, Moors, Burghers, Eurasians, Malays, and Europeans, the Sinhalese largely preponderating in numbers.

The centre of the Island possesses an extensive mountainous region reaching an altitude of 8,300 feet, and in consequence of this, the climatic conditions met with are very varied. There are two monsoons, viz., the southwest, blowing from May to September, and the northeast, from November to February. These generally bring considerable rain, which is deposited on the windward side of the central hills, some portions of these receiving so much as 200-250 inches per annum, while the southwest maritime districts average 75-150 inches per annum.

Over the greater portion of the low country the percentage humidity exceeds 90% during the

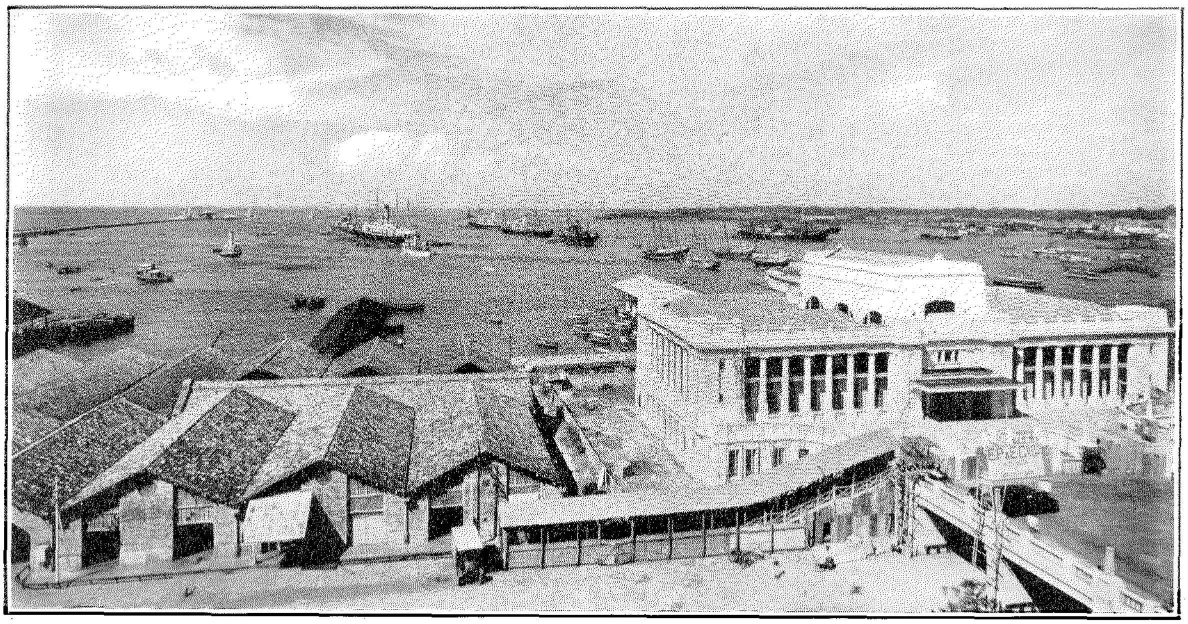

Figure 1—Colombo Harbour. Known to Many as the "Clapham Junction of the East."

greater part of the year, with mean shade temperatures varying from about 78° to 85° Fahrenheit. At certain up-country stations the temperature frequently drops to freezing point during the nights in the early months of the year, as much as 12° of frost having been recorded quite recently in some places. The high percentage humidity and temperature in the low country add considerably to the difficulties of maintaining many types of telephone plant as compared with more temperate regions.

The central and southwestern districts are highly developed agriculturally, the centre of the Island being devoted almost exclusively to the cultivation of tea and rubber, while in the coastal districts cocoanuts largely predominate.

The value of these three principal exports for the year 1927, in Rupees, amounted to:

Tea	Rs. 213,691,876
Rubber	Rs. 119,174,347
Cocoanut Products. .	Rs. 77,048,541

In addition to the above, Ceylon grows Cocoa of the finest quality obtainable, and exports it to the value of nearly three million rupees per annum, while other important crops are Cinnamon, Citronella Oil, Tobacco, Cardamoms, and Areca Nuts. Plumbago is the principal mineral export; and Ceylon gem stones, particularly sapphires, are world famous.

There are 900 miles of railways operated by the State, and an excellent system of roads covers the Island. As a consequence of the latter, motor road transport has developed enormously during the past five years.

The capital of the country is Colombo, which is the headquarters of the Administration, and the centre of mercantile activity. The population is estimated at approximately 300,000. It possesses a very fine artificial harbour that covers 643 acres, of which 400 acres have a depth of over 30 feet. It is equipped with electric and steam cranes, up-to-date coaling jetties, and a large oil depot.

Trincomalee Harbour, on the east coast, is noted as one of the finest natural harbours in the world.

A start has been made with the construction of a hydro-electric power scheme estimated to develop 15,000 kw. of electric power, distributed by 88,000 volt main transmission lines.

The total revenue and expenditure of the Colony for the financial years 1926–27 amounted to Rs. 129,358,916 and Rs. 121,046,299, respectively.

It will be gathered from the above brief description that Ceylon is one of the most progressive of eastern countries; and the Telephone and Telegraph Department does not lag behind in this respect. Although the telegraph system has been under the control of the Ceylon Government for many years, the telephone system was only taken over in 1910. The Great War and subsequent trade depression prevented the service being seriously developed until 1922. Since then, however, much has been done to make up leeway, and the demand for further facilities shows no signs of abating. What has been done during the past six years may, in fact, be regarded as only touching the fringe of future development if the Colony continues to prosper.

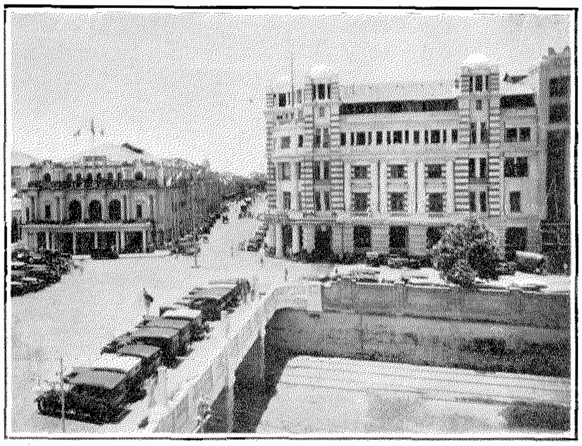

Figure 2—York Street, Colombo, with Grand Oriental Hotel on right.

Seven years ago, the telephone system extended only to a limited number of the principal towns in the country, the exchange apparatus consisting of simple magneto switchboards, the prevailing impression then being that more modern types of apparatus could not satisfactorily be maintained, owing to the severe climatic conditions which prevail. Systematic tests, however, quickly dispelled this illusion, and there are now being satisfactorily worked several C. B. and small automatic exchanges, in addition to many C. B. private branch exchanges, while schemes

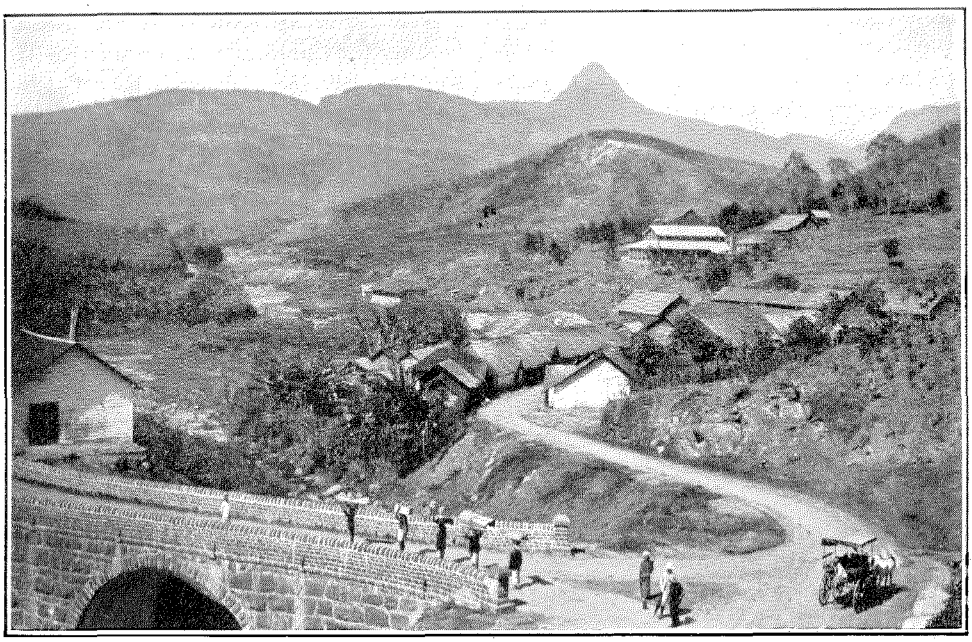

Figure 3—Ceylon. Typical Tea Country. Adam's Peak (7,400 ft.) in background.

are in hand to modernise the remainder of the plant. Plans have been approved for the conversion of the Colombo exchange service to automatic, and a start will be made with the first of the exchanges in 1930. Simultaneously, the telephone system has been extended to include all but three of the principal towns in the country, and it is expected that these will be connected within the next two years.

The underground cable system has been greatly increased and now includes a 27 pair loaded trunk cable, together with a similar unloaded main telegraph cable, each 30 miles in length, recently installed by Standard Telephones & Cables, Ltd., forming part of a scheme which, when completed, will extend to Galle—72 miles distant from Colombo.

Telephone repeaters have been installed at Kandy, the principal town in the centre of the Island, and a single channel carrier circuit will be fitted next year to work between two important towns.

Considerable attention has been given to the development of rural exchanges, particularly to the possibilities of working these automatically or semi-automatically with a view to giving the subscribers connected to them a twenty-four hour service, and several rural type automatic and semi-automatic switchboards have been ordered for schemes at present under construction. In an agricultural country like Ceylon, there is great scope for the development of such services.

The telegraph system has simultaneously been considerably modernised. Teleprinters of the start-stop type have been fitted at several of the more important offices, and their use is being rapidly extended. An extensive system of these instruments is at present being installed for the Police Department.

Ceylon was early in the field in the matter of broadcasting. In order to meet the public demand, the Government agreed in 1924 to introduce a limited broadcasting service. A small improvised transmitter was first used for the purpose, followed, in 1925, by a 1.75 kw. transmitter, designed and built locally by the writer, using Standard Telephones & Cables' microphones and amplifiers, which have rendered good service during this period. This was the first regularly operated and successful broadcasting service in the East.

The Telephone and Telegraph Department is also responsible for all the electrical safety plant and communications on the Railway System, and equally important developments have been undertaken in these during the past five years, including a network of train control telephones, supplied by Standard Telephones & Cables, Ltd., an extensive electrical flood alarm scheme protecting 200 miles of track, a great extension of track circuiting, etc., while schemes are being prepared for the immediate introduction of colour light signalling, electrically worked points and signals, and other modern developments in railway safety and signalling practice.

All these matters are, of course, the commonplaces of the Communication Engineer's profession, and the writer only refers to them in order to demonstrate the importance of the proper training of the personnel who have to install and maintain this plant.

When it is remembered that, with the exception of the Headquarters Engineers, the experience of the remainder of the staff was limited to the simplest form of telephone and telegraph plant, and that this staff has had to be increased approximately 200% to cope with the developments, the need for systematic and intensive training of these will be manifest.

A school equipped with every type of apparatus to be handled, and officers fully competent to impart the necessary tuition, should be regarded as an essential part of every Administration, and will prove one of the best possible investments if organised on sound lines.

A start was made with such a school in Ceylon about five years ago, but owing to the lack of a suitable building, not much progress could be made until two years later.

Description of School

The school now consists of the following sections:

(a) Telephones and Telegraphs.
(b) Railway Signalling.
(c) Underground cable jointing and plumbing.
(d) Overhead line construction.
(e) Technical Laboratory.

It will perhaps be best to describe briefly the equipment of these sections before dealing with the instruction given therein.

(a) *Telephones and Telegraphs Section.* Two photographs, Figures 4 and 5, show the general layout. One half of the centre of the room (vide Figure 4) is fitted with apparatus tables which are used by the students for the dual purpose of taking notes during lectures, and for the layout and use of demonstration apparatus. A series of panels, some of which can be seen on the table in the foreground of Figure 4, are provided, on which certain portions of telephone apparatus are fitted, wired up in skeleton fashion, to assist the student to visualize most effectively the circuit wiring of different types of telephones, switchboards, cord circuits, etc. These panels are much more effective for the purpose than the usual paper diagrams, as they put before the beginner, in concrete form, the actual apparatus he will have to handle. The wiring is easily stripped, and the students are required, at frequent intervals, to rewire them from memory.

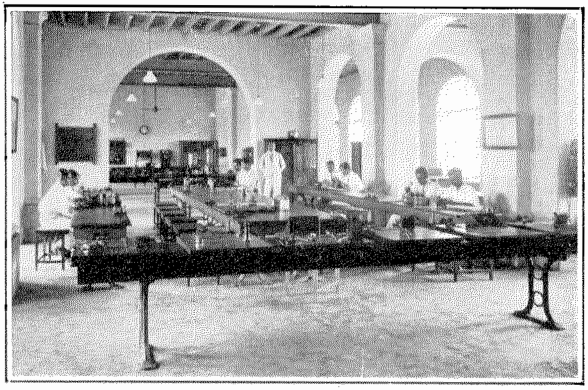

Figure 4—Telegraph Department Training School. General View of Telephone and Telegraph Section.

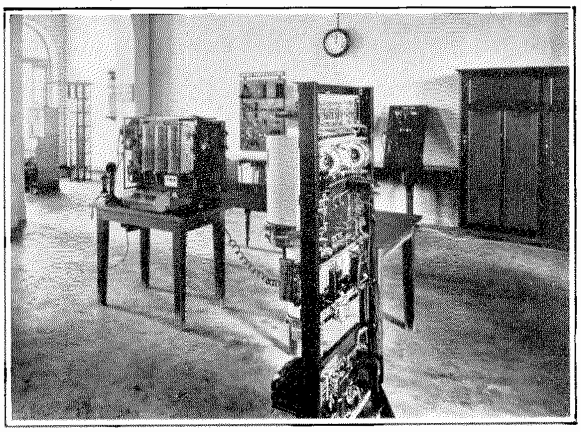

Figure 5—Telegraph Department Training School. Telephone and Telegraph Section. Automatic demonstration sets in foreground. Model office in rear at left.

A fairly complete set of the different types of telephones, switchboards, and auxiliary apparatus in actual use is provided. These are used for various demonstrations, and to put on faults for the student to locate and clear.

Three types of automatic demonstration sets have been fitted, two step-by-step and one relay type, and it is hoped shortly to add another of the rotary type. With these, the main principles of automatic working can be shown to the students, and correct methods of dialing and making adjustments can be taught. These auto sets can be seen in Figure 5.

One section of the room is fitted as a model small office, and is complete with switchboard, distributing frame, and telegraph instrument table, all wired in the standard approved methods.

Another section is devoted to a small power plant with secondary cells which are used for tuition purposes, and also to supply the necessary current for operating the apparatus in the school.

Correct methods of wiring the tagging switchboard jacks and cables are taught in one of the aisles of the main hall. Another aisle is devoted to telegraph apparatus, fitted with start-stop teleprinters, and Morse instruments for simplex, duplex, and quadruplex working.

(b) *Railway Signalling Section.* This section is equipped with a complete miniature railway, so arranged that every type of safety apparatus in use on the Ceylon Government Railways can be demonstrated.

A model track of $1\frac{3}{4}''$ gauge and over 250 feet in length is fitted on trestle tables arranged along the sides of the room with a "run round" at each end. The track is divided into three double line sections, and four single line sections with seven stations.

These stations are arranged with crossovers, model signals and other equipment to represent actual working conditions, the double line stations being fitted for lock and block working and track circuiting, the actual full size apparatus being used, of course, for this purpose. Similarly, the single line stations are equipped with complete sets of tablet apparatus and other accessories. Model electrically driven trains are used to demonstrate the working of the various apparatus. The centre of the room is arranged for lecturing purposes. The general layout is illustrated in Figure 6. Figure 7 illustrates one of the stations.

(c) *Underground Cable Jointing and Plumbing Section.* For the purpose of training men in this class of work, a series of small square wooden benches have been provided. The tops of these benches are zinc covered, and are fitted with clamps at each end, which will grip tightly any size cable. The joints are made between each two adjacent tables, the distance between them being adjusted to suit the length of joint to be made. Scrap lengths of cable are, of course, used for training purposes. Between the spacing of adjacent tables are arranged zinc trays to catch the scrap copper and plumbers' metal. The usual tools for jointing and plumbing, with detectors and meggers for taking the ordinary conductivity and insulation tests, are provided. The general layout is indicated in Figure 8.

Figure 8—Telegraph Department Training School. Underground Cable Section.

(d) *Overhead Lines Section.* A series of model poles is erected in the open air outside the main building, on which can be demonstrated straight, twisted, and transposed methods of wiring and terminating. Some of the poles have been shortened, as shown in Figure 9, to enable the tutor easily to watch the men under training, and correct their mistakes. Full size model distributing poles with terminating underground cable, and also models of every type of insulator, joint, and method of terminating are also provided.

(e) *Technical Laboratory.* Although, strictly speaking, this is not regarded as part of the training school, it serves the dual purpose of providing for all the technical tests required in the Department, and for more advanced training in radio work, transmission measurements, and other experimental investigations which have to be carried out. It is housed in the same building as the other sections, and is equipped with, amongst other apparatus, the following:

A fairly complete set of apparatus for measurements at radio frequencies.
Cathode Ray Oscillograph.
Low Frequency and High Frequency Oscillators.
A. C. Bridges.
Transmission Measuring Sets.
Terminating Network.
Cross Talk Sets.
Precision Wheatstone Bridges, Standard Inductances, Capacities, etc.

Each of the sections is in charge of an officer carefully selected for his ability to impart a sound practical knowledge to the men under training, the whole being controlled by a senior officer who, needless to say, must be still more carefully selected, as the success of the school largely depends on him.

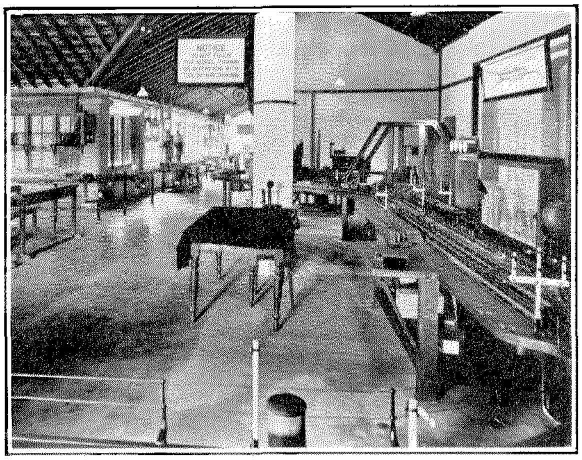

Figure 6—Telegraph Department Training School. Railway Signalling Section. General Layout.

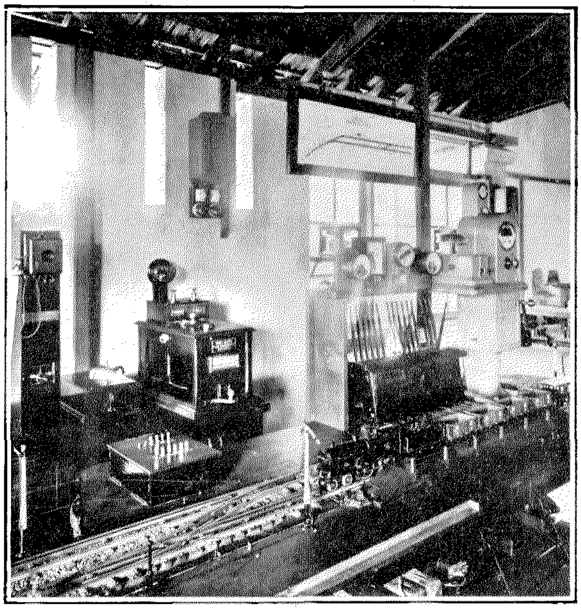

Figure 7—Telegraph Department Training School. Railway Signalling Section. Model station with tablet working on single line to left, and lock and block with double line to right. Note the model train standing at the station.

Scheme of Training

The primary object of a school such as that here described is, of course, to produce officers capable of maintaining satisfactorily any or all of the types of plant referred to earlier in these notes, or who can take charge of small working parties for the construction and installation of such plant. They must be given a sufficient training in the theory and principles of operation to enable them to do so intelligently, but, above all, they must be thoroughly practical men who can, in turn, train the workmen under them.

The greatest care is taken in the first instance to select candidates of the right class with a sufficient basis of general education on which to build. Much more satisfactory results are obtained by selecting youths who have just left school than from ex-motor mechanics, or others who have received a smattering of training elsewhere. After the training has commenced, the process of weeding out unsuitable individuals is pursued ruthlessly, in order that those who are ultimately given permanent appointments represent the "survival of the fittest."

The standard of general education required in Ceylon for those candidates who are to be given the full course of training is that of the Cambridge Senior examination. They are entered as Overseers-in-training, and are given a preliminary course extending at present over ten months, four of which are absorbed in the Telephone and Telegraph Section, and two in the Railway Signalling Section.

If passed as satisfactory, they are then sent out on actual field work in company with more experienced officers.

It is intended, as soon as the pressure is relaxed, to extend this preliminary course to twelve months, and to bring in these men for further training at intervals, until they can be regarded as thoroughly trained.

The twelve months' course is allocated as follows:

1 month General Principles.
3 months Telephones.
1 month Telegraphs.
2 months Lines and Cables.
3 months Railway Signalling.
1 month Stores and Office Routine.
1 month Workshops.

Total 12 Months

During the past two years 118 candidates have passed through the full course, and the rejections have amounted to 18%. Seventy-six men of other grades have been given shorter courses.

For the grades of Inspectors and officers up to the rank of Assistant Engineer, a more comprehensive course of training is in force.

Candidates for these grades are selected from young men between the ages of 17 and 22 years. As regards general education, the Matriculation standard is preferred, but the Cambridge Senior standard is accepted if the candidate is otherwise satisfactory. In each case preference is given to those who have passed in Mathematics, Physics, Applied Mathematics and (or) Chemistry.

Selected candidates are required to undergo a five years' course of training before they become eligible for appointment as Inspectors.

This period is made up of two years at the Government Technical College, attending classes on Telephone and Telegraph Engineering, Radio Communication, and Electrical Engineering followed by three years' practical training as follows:

6 months Departmental Workshops.
3 months Telegraph Apparatus.
6 months Telephone Subscribers' Apparatus.
6 months Telephone Switchboards and Testing.
2 months Stores and Office Routine.
4 months Railway Signalling, etc.
6 months External Construction and Maintenance.
2 months Radio Engineering.
1 month Drawing Office.

Total 3 years.

The Technical School's curriculum is specially drawn up to meet the requirements of the Department, and a good deal of the actual lecturing is given by the Department's Engineers. Before commencing their practical training, the students are required to pass a preliminary examination. During the period of practical training, it is obligatory to attend evening classes on Building Construction, and to pass prescribed examinations in Telephony and Telegraphy.

This scheme has now been in operation seven years, and has been successful in producing a type of young officer in whose hands the future well-being of the services is assured.

Finally, a word about the training of Ceylonese for the grades of Headquarters' Engineers. It has been the policy of the Ceylon Government for many years to encourage the local staff to qualify for the higher posts in the technical departments, but, owing to limited facilities available for training, it was not practicable to make a serious start in the Telegraph Department until six years ago.

A scheme was then prepared to give a three years' comprehensive course of training in England to selected Celonese senior Inspectors. By the courtesy of the Postmaster General and Engineer-in-Chief of the British Post Office, it was arranged that two years should be spent in that Department, the third year being devoted to training in Railway Signalling and visits to Works. Each officer was required to pass the Associate Membership examination of the Institution of Electrical Engineers before his return. Several have sucessfully completed this training.

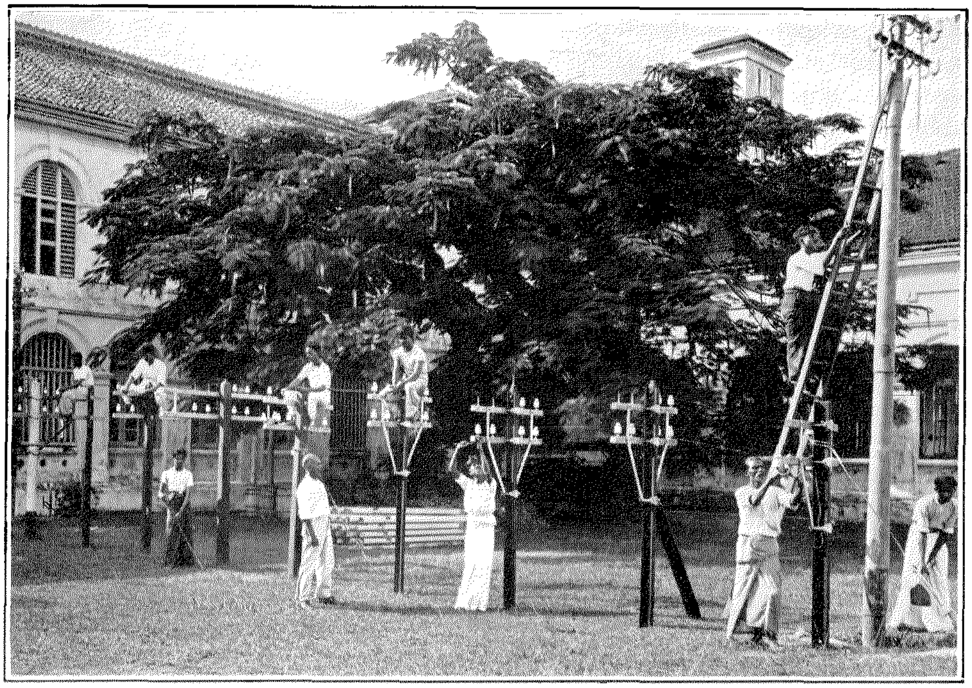

Figure 9—Telegraph Department Training School. Overhead Lines Section.

A further improvement on this arrangement has just been authorized. Scholarships tenable for 3½ years are to be awarded by Government to selected students of the Ceylon University College who have taken their Science degree. These students are to be sent for a two years' course in electrical and communication engineering at the London University, during which period they are required to obtain the Engineering degree of this Institution. This is to be followed by 1½ years' practical training in the British Post Office, and with approved manufacturing firms.

In giving this outline of the various training schemes now in operation in the Ceylon Telegraph Department, it is not suggested that they contain any original ideas. They may, however, serve as a useful indication of what can be done by other small Administrations in the matter of providing a thoroughly trained technical staff, and, as the whole of these schemes have been brought to maturity during the short period of seven years, there is no need to defer to the Greek Kalends the development of vital communication services, even in those countries where such development is still in the embryo stage, if the training of the local staff is taken in hand energetically and systematically.

APPENDIX

Synopsis of Training Courses

(a) *Telephone and Telegraph Section.*

General electrical theory. Meaning of terms. Practical units. Ohm's law. Theory of magnetism. Magnetic properties of iron and steel. Magnetic effects of a current and generation of currents by means of magnets. Direct and alternating currents. Induction and capacity.

Primary batteries. Description and explanation of Leclanche, "A. D." Edison (Caustic Soda) and dry cells. Practical maintenance of them and purposes used for. Testing voltage, Internal resistance and general condition. Connecting up cells in series and parallel.

Telephone apparatus. Description and elementary explanation of working of magnets and Central battery instruments, manual and automatic switchboards, and auxiliary apparatus. Practical handling, assembling, dismantling, and maintenance of all types of apparatus used by the Department. Testing and localising faults on apparatus and switchboards. Practical wiring and connecting up. Testing of circuits from main distributing frame. Jumpering. Switchboard wiring and cabling. Fault records, etc. Power Plant. Description of D.C. and A.C. motors and generators. Secondary batteries, description and explanation of different types. Specific gravity of acid. Practical maintenance, charging, and discharging Rectifiers.

Telegraph apparatus. Simplex, duplex and quadruplex working. Description and practical maintenance and adjustment of apparatus. C. B. working. Start-Stop machine telegraphs (teleprinters). Morse signalling and receiving.

Testing Apparatus. Theory and use of Wheatstone bridge, megger, Varley loop test. Testing by Voltmeter, etc.

(b) *Railway Signalling Section.*

General principles of Signalling and Safety Working. Double and single lines. Functions of different types of Signals and where placed. Points, trailing and facing. Principles of interlocking.

Double line working. Lock and Block. Procedure in working a train through a L & B section. Electrical circuits and mechanical locking. Practical assembly and adjustments of instruments. Maintenance and testing for faults.

Single line working. General explanation and system. Tablet working. Procedure in working a train through a single line section. Description of tablet instruments. Failures and how caused. Transference of tablets. Procedure in case a tablet is lost or damaged. Practical assembly and adjustments. Maintenance and testing for faults. Bank Staff working. Method of operating. Description of Staff box and electrical interlocking with tablet instrument. Auxiliary and special arrangements.

Track Circuiting. Functions. Description of different types of circuits and apparatus. Rail bonding and insulating. Applications to double and single line working. Control of signals and points. Illuminated track diagrams at stations. Maintenance routine.

Signal Repeaters. Description of repeaters for arm and light or arm only. Electrical circuits. Routine testing, adjusting and maintenance.

Flood Alarms. Functions. Description of apparatus fitted at controlling station, terminal station, and cooly lines. Electrical circuits. Testing and flood localisation by means of potentiometer. Routine when alarm is given and in resetting circuits. Fitting of flood traps. Adjustment and maintenance routine.

(c) *Underground Cable Section.*

The different classes and types of cable used. Care of cables and how they should be handled. Protection of cable ends. Earthenware ducts. C. I. and steel pipes, how they are laid. Jointing chambers and manholes. Dimensions and methods of construction in brick and concrete. Drawing in cable and use of winches and rope tackle. Method of opening cable. Numberings and Colour Scheme. Correct methods of testing and jointing, and special precautions to be observed in the Tropics. Head sleeves and plumbing of joints. Pressure testing. Desiccating. Preparation of cable distribution plugs and potheads. Terminating on distributing pole with enamel and cotton covered twin lead cable. Numbering and testing out on D. P's. Methods of testing, localising, and clearing faults in cables. Use and proper care of tools.

(d) *Overhead Line Section.*

Description of the different classes of poles, arm, insulators, and fittings used by the Department. Methods of erection. Special precautions to be used in handling reinforced concrete poles. Conditions necessitating use of stays and struts. Determination of staying requirements for angle and terminal poles. Use of copper, bronze, and iron wire. Methods of erection, regulation, binding in a termination. Different types of joint. Correct use of soldering bolt and special wiring tools. Inductive disturbances on telephone loops, and how prevented by means of (a) twist system, and (b) transposition system. Cable distribution poles. Protection of wires crossing power circuits. Use of safety belts and rubber gloves. Procedure to be adopted in case of accident or electric shock

A New Contribution to the Rational Design of Telephone Cables[1]

By D. P. DALZELL

Development and Research Laboratories, International Telephone and Telegraph Corporation

TELEPHONE cables were first introduced for urban communication in the form of "loop cables" consisting of a large number of pairs of small gauge conductors. When, however, communication by telephone between different towns became important, large gauge conductors were used in open wire lines owing to the necessity of reducing the conductor resistance to as low a value as possible. Open wire lines are, however, unsuited to the handling of a dense traffic and are likely to be damaged by storms. Both these conditions made the use of cables for interurban telephony very desirable and this was accomplished by the introduction of loading and the use of phantom circuits, so that the strength, quality and number of the received messages could very greatly exceed what could be obtained in similar circumstances with loop cables. These improvements, however, not only affected the message proper, but also improved the transmission of disturbances from other circuits caused, largely, by capacity unbalances, i.e., by irregularities in the distribution of capacities between the conductors of any circuit and those of other circuits. The way capacity unbalances cause mutual disturbances between circuits may be understood by regarding the two wires, say, of each of two pair circuits to be at opposite corners of a Wheatstone bridge with, however, capacities in the various arms instead of resistances. There must, then, be a relation of symmetry between the capacities involved when currents in one pair circuit do not generate potential differences in the other. In cables there are always unavoidable irregularities in the distribution of the capacities between the various conductors and capacity unbalances between the various circuits result.

The effects of capacity unbalances were still more aggravated by the introduction of repeaters and could in certain circumstances produce singing, which may occur when there is a possibility of the output circuit of a repeater influencing the input circuit; capacity unbalances provide a means of such influence.

The reduction of capacity unbalances thus became a matter of the first importance and has led to developments in the manufacture of cables greatly in advance of the methods formerly employed for loop cables. Uniformity in both the electrical and mechanical properties of the copper conductors is secured as far as manufacturing conditions permit and the possible influence of any residual irregularities is minimised by making the two wires of a pair from halves of the same continuous length of wire, while in the insulating process, these two wires are passed in immediate succession through the same machine. Similarly the strips of paper used for insulating the two wires of a pair are taken from adjacent positions in the original roll from which they are cut. By these, and similar methods, the greatest care is exercised for ensuring the maximum degree of similarity between the various conductors associated together in pairs, quads or other collective units. In this way cables were produced which could satisfactorily be used for transcontinental telephony. Detailed inspection of the quality of cables showed, however, that something was still lacking, for some types of capacity unbalances would sometimes have unexpectedly high values. The cause of this was traced, after exhaustive statistical examination of results, to the occurrence of peculiar combinations of twist lengths in the various pairs or quads of the cable. Mathematical investigation of the phenomenon was initiated and the problem was satisfactorily solved by the methods expounded below.

Considerations Introductory to the Theory of Capacity Unbalances

The construction of a theory of capacity unbalances depends upon a preliminary examina-

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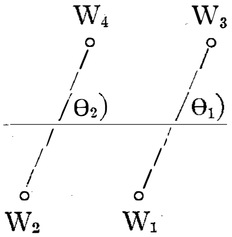
[1] Presented before World Engineering Congress, Tokyo, Section 6, October 30, 1929.

tion of the effect of twisting upon the set of direct capacities in a system of twisted circuits. Consider, first, four parallel wires W_1 ,W_2, W_3, and W_4, whereof W_1 and W_3 are alike and are to be considered as one pair circuit and W_2 and W_4 are alike and to be considered as another pair circuit. Suppose that the plane of the pair W_1W_3 make an angle of θ_1 with a fixed plane parallel to all four wires and that the plane of the pair W_2W_4 make an angle θ_2 with the same fixed plane, as shown in the figure. Then any one of the uniformly distributed direct capacities measured, say, in microfarads per mile between one of W_1 and W_3 and one of W_2 and W_4 is a function of θ_1 and θ_2 and of these alone, if they be the only variable elements of the system.



Thus the distributed direct capacity C_{12} between W_1 and W_2 may be written as

$$C_{12}=f\ (\theta_1\ \theta_2)$$

where $f\ (\theta_1+2\pi,\ \theta_2)=f\ (\theta_1,\ \theta_2)$

$$f\ (\theta_1,\ \theta_2+2\pi)=f\ (\theta_1,\ \theta_2)$$

because a rotation of one complete turn of either pair leaves the system unaltered.

The two wires W_1 and W_3 are interchanged by a rotation of one half so that

$$C_{22}=f\ (\theta_1+\pi,\ \theta_2)$$

Similarly the two wires W_2 and W_4 are interchanged by a rotation of one half turn so that

$$C_{14}=f\ (\theta_1,\ \theta_2+\pi)$$

$$\text{and } C_{34}=f\ (\theta_1+\pi,\ \theta_2+\pi)$$

Thus all the four distributed direct capacities are expressible in terms of one function.

The uniformly distributed capacity unbalance between the two circuits, measured in microfarads per mile may be taken to be $U\ (\theta_1,\ \theta_2)$ where $U\ (\theta_1,\ \theta_2)=C_{12}+C_{34}-C_{32}-C_{14}$

Thus, substituting the expression found above for the distributed direct capacities, we have

$$U\ (\theta_1,\ \theta_2)=f\ (\theta_1,\ \theta_2)+f\ (\theta_1+\pi,\ \theta_2+\pi)$$
$$-f\ (\theta_1+\pi,\ \theta_2)-f\ (\theta_1,\ \theta_2+\pi)$$

Now since

$$f\ (\theta_1+2\pi,\ \theta_2)=f\ (\theta_1,\ \theta_2)$$

and $f\ (\theta_1,\ \theta_2+2\pi)=f\ (\theta_1,\ \theta_2)$

the function $f\ (\theta_1,\ \theta_2)$ is periodic in each of the two variables θ_1 and θ_2 and may be expressed in the form of a multiple trigonometric series, say

$$f\ (\theta_1,\ \theta_2)=\sum_{m,n} C_{m,n} \cos\ (n\theta_1+\beta_n)\ \cos\ (m\theta_2+\beta_n)$$

where n and m are integers and $C_{m,n}$, β_n and β_m are independent of θ_1 and θ_2; or, substituting for the products of cosines by means of the addition theorem for the cosine function, we get

$$f\ (\theta_1,\ \theta_2)=\sum_{m,n} C'_{m,n}\ \cos\ (n\theta_1+m\theta_2+\eta_{m,n}$$

when $C'_{m,n}$ and $\eta_{m,n}$ are independent of θ_1 and θ_2.

Basic Assumptions and the General Theory

This result must now be applied to the consideration of twisted circuits. The lengths of twist may be supposed to be long compared with the lateral dimensions of the circuits in question, and with this supposition the distributed direct capacities at a given place may be taken to be identical with those of an untwisted system whose configuration is the same as that of the system of twisted circuits at that place. This procedure does not differ from the usual neglect of "end effects" involved in the investigation of three dimensional physical systems by means of an imaginary two-dimensional system. Then, at a place where the inclinations of the twisted circuits to a fixed plane are θ_1 and θ_2, the distributed unbalance, or local unbalance may be taken to be $U\ (\theta_1,\ \theta_2)$ as defined above, where now θ_1 and θ_2 are no longer invariable but can be expressed in terms of the distance x along the circuit; thus

$$\theta_1=\frac{2x}{T_1}+\alpha_1$$

$$\theta_2=\frac{2x}{T_2}+\alpha_2$$

where T_1 and T_2 are the lengths of twist of the pairs W_1W_3 and W_2W_4 respectively and α_1 and α_2 are the values of θ_1 and θ_2 when $x=0$.

The result of the preceding article may be stated, by extension, to be that in a perfectly twisted set of circuits, a local capacity unbalance U between two such circuits of the set may be represented by a trigonometric series, so that, say

$$U = \Sigma C\ (n_1\ n_2 \ldots\ldots\ldots\ldots\ldots\ldots n_N) \cos \left\{ \left(\frac{2\pi n_1}{T_1} + \frac{2\pi n_2}{T_2} + \ldots\ldots \frac{2\pi n_N}{T_N} \right) \varkappa + \eta\ (n_1\ n_2 \ldots n_N) \right\}$$

where the numbers C $(n_1\ n_2 \ldots\ldots\ldots n_N)$ are the constant coefficients of the series, and the numbers η $(n_1,\ n_2 \ldots\ldots\ldots n_N)$ are the phase constants. The integers $n_1\ n_2 \ldots\ldots\ldots n_N$ may be positive, negative or zero. The numbers $T_1\ T_2\ T_3 \ldots\ldots\ldots T_N$ are the various lengths of twist, which may be considered to affect the unbalance, T_1 and T_2 being, say, the lengths of twist of the two circuits under consideration and the other twist lengths being those which may affect, for example, the distance between these two circuits, and generally represent the effect of any circumstance which may have a periodic influence upon the mutual relations of the two circuits.

In order somewhat to simplify notation the various terms of the trigonometric series may be renumbered by means of a single suffix v, so that $U = C_v \cos\ (2\pi\xi_v\ \varkappa + \eta_v)$

where $\xi_v = \frac{n_1}{T_2} + \frac{n_2}{T_2} + \ldots\ldots\ldots \frac{n_N}{T_N}$

where the single integer v corresponds with the set of integers $n_1\ n_2 \ldots\ldots\ldots n_N$. The numbers ξ_v are called compounded torsions, and when the twist lengths are in inches, the compounded torsions represent revolutions per inch. The total unbalance over a distance X would then be obtained simply by integration, if the assumption of perfect twisting were maintained. This assumption is, however, in no case legitimate, and some discussion should be made of the nature of irregularities in twisting and of the appropriate theoretical treatment. A single term in the series whose sum represents the local unbalance is

$$C_v \cos\ (2\pi\xi_v\ \varkappa + \eta_v)$$

where ξ_v depends upon the integers $n_1\ n_2 \ldots\ldots n_N$ so that

$$\xi_v = \frac{n_1}{T_2} + \frac{n_2}{T_2} + \frac{n_2}{T_3} \ldots\ldots\ldots\ldots \frac{n_N}{T_N}$$

Clearly the amplitude C_v and the phase constant η_v of this term are illdetermined when any one of the numbers $n_1\ n_2 \ldots\ldots\ldots n_N$ is large, and in practice these numbers can be fixed in value for a considerable distance only when $n_1\ n_2 \ldots\ldots n_N$ are all fairly small. The actual state of affairs is not precisely known, but we may suppose for purposes of calculation, that with each compounded torsion ξ_v is associated, in a given set of circuits, a series of spans each of length σ_v in which the amplitude C_v and phase constant η_v in the term

$$C_v \cos\ (2\pi\xi_v\varkappa + \eta_v)$$

are both constant, but that the values are independent in any two distinct spans, subject, however, to the limitation that the mean square of all values of C_v in the various spans of the various pairs of circuits is A^2_v.

In order to complete the succeeding calculations an assumption concerning the spans σ_v for the various sets of circuits is required. In this case, we shall use the following law of distribution,

$$dP = h_v^2 \sigma e^{-h_v^2 \sigma} d\sigma$$

for the span σ_v associated with a given compounded torsion ξ_v, so that dP is the proportion of the whole number of pairs of circuits for which the span σ_v lies in the range $(\sigma,\ \sigma + d\sigma)$. In this case, the constant h_v is connected with the mean span, denoted by t_v, by the equation

$$h_v\ t_v = 2$$

Although the assumptions seem to be only slightly connected with the conception of continuous variation of the compounded torsions and the amplitudes, yet the final results required are only those dependent upon average values and may be accepted as of the correct general form.

We proceed, then, by recalling that the local distributed unbalance is represented by a series

$$U = \sum_v C_v \cos\ (2\pi\xi_v\varkappa + \eta_v)$$

For one span from

$$\varkappa - \tfrac{1}{2}\ \sigma_v \text{ to } \varkappa + \tfrac{1}{2}\ \sigma_v$$

the resultant unbalance $\overline{U}$ is given by integration, so that

$$\overline{U} = \sum_v \frac{C_v}{\pi\xi_v} \sin\ \pi\xi_v\ d_v \cos\ (2\pi\xi_v\varkappa + \eta_v)$$

The number of spans of length σ_1 in a length X is between

$$\frac{X}{\sigma_1} - 1 \text{ and } \frac{X}{\sigma_1} + 1$$

so that if $\frac{X}{\sigma_v}$ be large, it may be taken as the number of spans in a circuit of length X.

Thus, in a given circuit, the unbalance associated with a given compounded torsion ξ_v will result from $\frac{X}{\sigma_v}$ terms each resulting from one span. The mean square unbalance in a group of circuits all having the same span σ_v associated with the torsion ξ_v may now be written down as

$$X \sum_v \frac{A^2_v}{2\pi\xi^2_v\sigma_v} \sin^2 \pi\xi_v\sigma_v$$

Our assumption concerning the distribution of spans then leads to the final approximate expression for the root mean square value M of all unbalances.

$$M^2 = X \sum_v \frac{A^2_v}{2\pi\xi^2_v} \int_0^\infty (\sin \pi\xi_v\sigma)\, h^2_v\, e^{-h_v\sigma} d\sigma$$

$$= X \sum_v \frac{A^2_v\, h^v}{h_v^2 + 4\pi^2\xi_v^2}$$

When the mean span t_v is inserted instead of h_v where

$$h_v\, t_v = 2$$

the final result is

$$2M^2 = X \sum_v \frac{A^2_v\, t_v}{1 + \pi^2 t^2_v \xi_v^2}$$

Deductions from the General Theory

In the formula for the mean square unbalance M^2 our sole concern is the mode of variation of the root mean square unbalance M^2 with the lengths of twist involved in the compounded torsions ξ_v when the various coefficients and the other variables have fixed values. In these circumstances the individual term

$$\frac{A^2_v\, t_v}{1 + \pi^2 t_v^2 \xi_v^2}$$

attains its greatest value

$$A^2_v\, t_v \qquad \text{when } \xi = 0.$$

According to the present theory, this condition is precisely the one to be avoided, and is called a "critical condition." The whole set of critical conditions depends upon the original choice of the aggregate of trigonometrical terms used to represent the given configuration of circuits and little consideration is needed to show that many of the critical conditions must be superfluous. Thus the complete representation of a periodic function involves, in general, an infinite number of terms of successively decreasing periods, and there must certainly be a period sufficiently short to preclude the possibility of its accurate determination in the manufacture of telephone cable, and this state of affairs is represented in the theory by the use of a short mean span.

Consider now the expression for M^2 as a function of one of the twist lengths, say T_1, involved in it. Each term in the series for M^2 which involves T_1 in a suitable manner will attain a maximum value for some one value T_1.

Then M^2 is the sum of a number of terms each with single maxima for various values of T_1 and there is, on general mathematical grounds, no reason to suppose that the maxima of the sum of the series for M^2 will occur in the neighbourhood of the maxima of the individual terms unless the latter are very marked. The sharpness of the maxima of the individual terms depends upon the values of the mean span, that is, upon the consistency with which the successive periods involved in the compounded torsion are reproduced. In the light of these remarks the theory may be said to lead to the conclusion that the collection of all critical conditions derived from the most general trigonometric representation of the system of circuits indicates all the possibilities of systematic occurrence of exceptionally large unbalances between circuits of a telephone cable owing to peculiarities in the system of twists, but that only a small number of these possibilities are realised. In order to anticipate which of the critical conditions must, in fact, be considered, recourse to observation is not necessary except by way of confirmation of our conclusions.

Consider a system of circuits involving n twist lengths $T_1\, T_2 \ldots\ldots\ldots T_n$. Then the capacity unbalance between two circuits of the system may be regarded as depending on some or all of these n twist lengths, and any one compounded torsion ξ will be of the form

$$\xi = \frac{n_1}{T_1} + \frac{n_2}{T_2} + \ldots\ldots\ldots \frac{n_N}{T_N}$$

where $n_1\ n_2 \ldots\ldots n_N$ are integers, positive, negative or zero.

The values of $n_1\ n_2 \ldots\ldots n_N$ greater than unity are associated with periods which are submultiples of the fundamental twist lengths or periods and the corresponding term in the trigonometrical series is associated with a long mean span only when the shapes of the circuits in successive twist lengths or periods are accurately similar. Owing to unavoidable slight variations in the properties of raw materials, and in the effects upon them of the manufacturing processes and to the complication of the structure of the complete cable, this consistency can hardly be supposed to be maintained. Thus we may anticipate that, in ordinary cases, the only compounded torsions to be considered are those of the form

$$\xi = \pm\frac{1}{T_{r1}} \pm \frac{1}{T_{r2}} \pm \frac{1}{T_{r3}} \pm \ldots\ldots \pm \frac{1}{T_{r_s}}$$

where the twist lengths involved are all or some of total of n twist lengths.

A compounded torsion which does not involve fractions of the lengths of twist is called a torsion of the first order.

Thus we may enunciate the principle that only critical conditions of the first order need consideration, and that these critical conditions are to be deduced from a trigonometric expression for the local unbalances. As an example of the formulation of critical conditions a convenient example is that of capacity unbalance between the phantom of one quad and a pair of an adjacent quad in a quadded cable. In this case, let T_1 and T_2 be the phantom twists of the two quads and let T be the pair twist of one of the pairs in the quad whose phantom twist is T_1. In this case, the local unbalance may be represented by a trigonometric function of the form

$$\left\{ a + b\cos\left(\frac{2\pi\varkappa}{T_1} + \eta_1\right)\right\} \cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right) \cos\left(\frac{2\pi\varkappa}{T} + \eta\right)$$

where a, b, η, η_1 and η_2 vary only slightly with $\varkappa$. The construction of the above expression may be explained by noting that if the pair were not in a quad then b would be zero. The fact that the pair is one of two pairs in its quad means that its distance from the other quad varies with a period T_1 and this variation is represented by the term whose coefficient is b. This expression is the sum of two parts; one part is

$$a\cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right) \cos\left(\frac{2\pi\varkappa}{T} + \eta\right)$$

and leads to the commonplace critical equation

$$T = T_2$$

The second part is

$$b\cos\left(\frac{2\pi\varkappa}{T} + \eta\right) \cos\left(\frac{2\pi\varkappa}{T_1} + \eta_1\right) \cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right)$$

and when rearranged by means of the addition theorem for the cosine function involves compounded torsions of the form

$$\xi = \pm\frac{1}{T} \pm \frac{1}{T_1} \pm \frac{1}{T_2}$$

and the critical equations are of the form

$$\xi = 0.$$

Of the various equations which result, two only are possible; these are

$$T = \frac{T_1 T_2}{T_1 - T_2} \quad \text{and} \quad T = \frac{T_1 T_2}{T_1 + T_2}$$

Thus there are two critical twist lengths for the pair, both of which would be associated with abnormally large values of capacity unbalance between that pair and the neighbouring phantom.

The Indicial Theory

When the assumption is made that only torsions of the first order are to be considered the critical conditions may be deduced very simply. Thus, suppose that a system of circuits involve the twist lengths of periods $T_1\ T_2 \ldots\ldots T_n$ so that a term in the trigonometrical representation of the local unbalance is of the first order and of the form

$$\cos\left(\frac{2\pi\varkappa}{T_1} + \eta_1\right) \cos\left(\frac{2\pi\varkappa}{T_2} + \eta_2\right) + \ldots \cos\left(\frac{2\pi\varkappa}{T_n} + \eta_n\right)$$

When this expression is rearranged by means of the addition formula for the cosine it becomes

$$\frac{1}{2^{n-1}} \sum_{p} \cos\left(2\pi\xi_p\varkappa + \lambda_p\right)$$

where ξ_p are the 2^{n-1} first order torsions derived from $T_1, T_2 \ldots\ldots T_n$.

Integration over a span of length σ then gives

$$\frac{1}{2^{n-1}} \sum_{p} \frac{\sin 2\pi\ \xi_p\sigma}{\pi\ \xi_p} \cos\left(2\pi\ \xi_p\varkappa + \lambda_p\right)$$

and the mean square of this last expression with respect to independent variations of σ and $\varkappa$ is

$$\frac{1}{\pi^2 2^{2n}} \sum_p \frac{1}{\xi^2_p}$$

and this last expression becomes infinite when

$$\xi_p = 0.$$

We may call the reciprocal of ξ_p a compounded twist length, and the root mean square J of all compounded twist lengths may be called the index, so that

$$2^{n-1}\, J^2 = \sum_p \frac{1}{\xi^2_p}$$

Thus the critical conditions are summed up in the equation $J = \infty$ where J is any index derived from the twist lengths and periods involved in the system of circuits.

The method of constructing the index may be used with advantage in the considerations of a case not included conveniently in the general analysis. When the two circuits are in adjacent layers they only approach each other at regular intervals so that two successive points of approach are separated by a fixed distance R. In this case the index may be constructed by summation and not by integration. As before, a term in the trigonometrical representation of the local unbalance of the form

$$\cos\left(\frac{2\pi\varkappa}{T_1}+\eta_1\right)\cos\left(\frac{2\pi\varkappa}{T_2}+\eta_2\right)\ldots\cos\left(\frac{2\pi\varkappa}{T_n}+\eta_n\right)$$

may be rearranged as

$$\frac{1}{2^{n-1}} \sum_p \cos\,(2\pi\xi_p\varkappa+\lambda_p)$$

Now by summing over N points of contact the following expression is obtained

$$2^{-n+1} \sum_p \sum_{r=0}^{r=N-1} \cos\left\{2\pi\xi_p\,(\varkappa+rR)+\lambda_p\right\}$$

$$=2^{-n+1} \sum_p \frac{\sin N\pi\xi_p R}{\sin \pi\xi_p R} \cos\,(2\pi\,\xi_p\varkappa+N\pi\xi_p R+\lambda_p)$$

The mean square value of this for variations of $\varkappa$ is, accordingly

$$2^{-2n+1} \sum_p \frac{(\sin N\pi\xi_p R)^2}{\sin \pi\xi_p R}$$

and, finally when N is large the mean for small variations of R is

$$2^{-2n+1} \sum_p \operatorname{cosec}^2\,(\pi\xi_p R)$$

and thus the index J can, in this case, be defined as a mean square by the equation

$$2^{n-1}\, J^2 = \pi^2 R^2 \sum_p \operatorname{cosec}^2\,(\pi\xi_p R)$$

The critical equations are then of the form

$$J = \infty,$$

which is the case when, and only when

$$R\xi_v = m$$

for some compounded torsion ξ_v and some integer m, positive, negative or zero.

In the particular case of two circuits of twist lengths T_1 and T_2 in contact only at points at equal distances R apart, and unaffected by any periodic influence, the critical equations are

$$\frac{1}{T_1} \pm \frac{1}{T_2} = \frac{m}{R}$$

where m is an integer.

Concluding Remarks

The various cases treated above both by the general analysis and by the indicial theory constitute the whole present extent of the theory, so far as it is relevant to the usual conditions in a telephone cable. Some of the simpler cases can be treated by an elementary geometrical method but this treatment has the defect that the operating causes are not analysed and examined; whereas the more elaborate treatment has the advantage that, by obtaining an expression for total unbalance from a definite scheme of basic assumptions, all possibilities resulting from these assumptions are found.

The theory, being based merely upon an examination of the way various periodicities interfere, is not restricted to any one type of cable and can be applied to paired cable, spiral four cable, quaded cable and other similar types, so that a considerable range of cable design acquires a certainty which, before, could not be attained.

In many cases the application of the theory has not only removed exceptionally or unexpectedly large values of unbalance, but has effected an all-round improvement, as represented by averages, of 50% in some types of capacity unbalance.

Czechoslovakian Cable System

By F. J. STRINGER, W. F. MARRIAGE and E. L. E. PAWLEY

European Engineering Department, International Standard Electric Corporation

THE Republic of Czechoslovakia comprises three main regions: Bohemia in the west, Moravia in the centre, and Slovakia in the east. The chief cities of these regions are Prague, Brno, and Bratislava, respectively.

Bohemia and Moravia have a number of important manufacturing centres, producing machinery, textiles, beer, pottery, chemicals, and high quality glass. Highly developed coal and iron fields exist in these regions. Sugar beet is produced on a large scale, and many sugar factories are distributed throughout the country.

Slovakia is chiefly agricultural, and includes large tracts of forest. There are several important manufacturing cities; the boot and shoe industry is one of the best developed in the world. Slovakian factories export shoes to practically all European countries and to America.

The Republic, which celebrated in 1928 the tenth anniversary of the recovery of its independence, has made remarkable progress during the past decade, and its industries are developing rapidly. A striking sign of the rapidity of the growth of prosperity is that the business and shopping quarters of the capital have been practically rebuilt in the last few years, large modern buildings taking the place of the older ones which no longer suited the new conditions.

It was realised early by the Czechoslovakian Administration that a really efficient long distance telephone service between the chief centres would materially help in the development of the Republic, and plans were drawn for connecting these by a modern toll cable network.

Further, Czechoslovakia is so situated in the centre of Europe, having boundaries to no fewer than five neighbouring countries, that it forms a natural highway of international communication. Czechoslovakia itself has, of course, a large volume of business with its neighbours, necessitating terminating international circuits, but in addition, it offers the best means of communication between the northern and southern neighbouring countries, so that an important transit international traffic was to be expected.

The Administration plans, therefore, were to connect Prague, Brno and Bratislava in the first case, and also to provide connections with Germany via Lovosice, and Dresden, Austria, via Břeclav and Vienna, and Hungary via Bratislava. At the same time, the ultimate requirements were carefully studied so that the first cables should form part of a well planned general scheme covering the whole of the Republic and properly coördinated with the networks of the neighbouring states.

Figure 1 shows the general plan of the Czechoslovakian cable network, and indicates the extent to which the project has been carried out up to the present date.

The cables were manufactured in Czechoslovakia at the following three cable factories, viz.,

Bratislava Kabelfabrik A. G.
Kablo Aktien-Kabel-und-Drahtseil-Fabrik, Kladno.
Fr. Krizik, Kabelfabrik und electrotechnische Werke, Bodenbach.

In order to carry out the installation of the cables and loading coils, the Long Distance Cable Construction Company (L. D. C. C. Co.) was formed, and the whole of this work was done by Czechoslovakian labour.

The orders for the repeater equipment and loading coils were placed on the Hekaphon Western Electric, Praha, Vrsovice (now the Standard Electric Doms a Společnost.)

The repeater equipment was manufactured by the Bell Telephone Manufacturing Company of Antwerp, and was installed by the Long Distance Cable Construction Company with the aid and advice of the Antwerp Company, which also provided a number of skilled installers for this work.

The loading coils were manufactured by Standard Telephones & Cables, Ltd., of London,

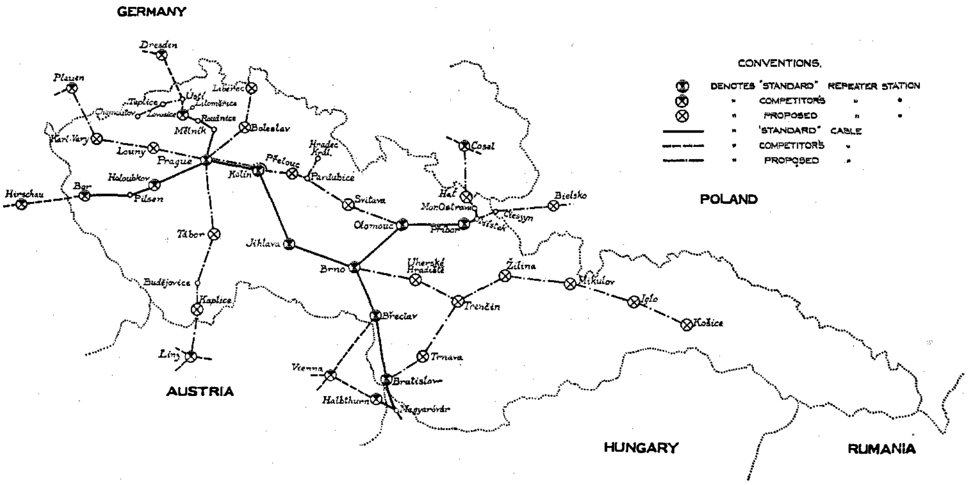


Figure 1—Czechoslovakian Toll Cable System, 1929.

by the Bell Telephone Manufacturing Company of Antwerp, and by Le Matériel Téléphonique of Paris.

The first part of the network to be installed was the Prague-Kolín cable. This cable, in common with all subsequent cables in the Republic, excepting only those sections which actually cross the Austrian and German frontiers, is of "Standard" type, and was manufactured and installed with the advice of the International Standard Electric Corporation.

During the manufacture of the cable, schools were started for training the jointers and testers who were supplied either by the Administration, or by the Cable Companies. The schools were continued for two months, so that when the

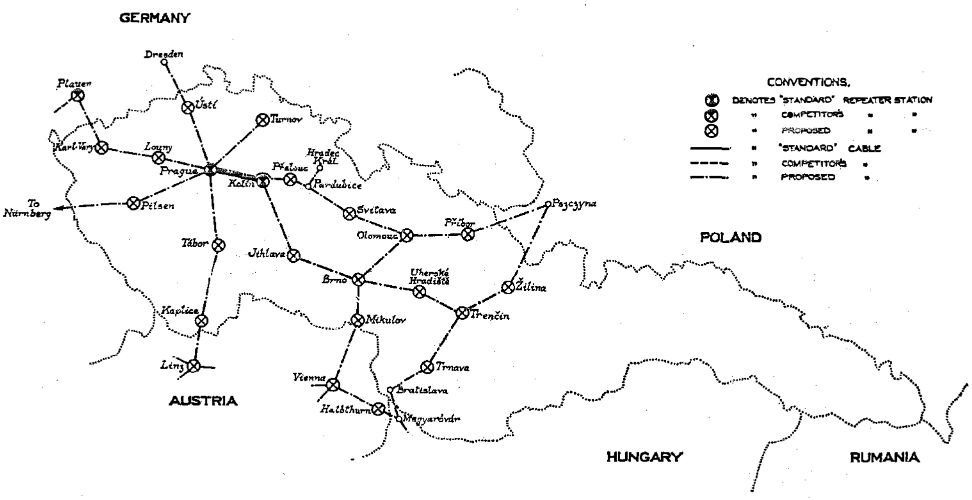


Figure 2—Czechoslovakian Toll Cable System, 1925.

manufacture of the cable was sufficiently advanced, a trained staff was available to commence installation. Installation of this first cable was started in August, 1925, since which time a total of 857.3 Kms. of toll cable has been laid in Czechoslovakia.

The map of Czechoslovakia (Figure 1) in addition to the existing cable routes shows those on which it is proposed to lay cable in the near future. A glance at this map reveals the extensive development of long-distance facilities which is being carried out by the Czechoslovakian Administration. It is interesting here to compare Figure 1 with Figure 2, which shows the cable routes of 1925.

General Description

The map in Figure 1 shows in full lines the routes followed by the cables, and indicates the spacing of the repeater stations.

The survey of the first cable route, Prague-Kolín, was carried out jointly by the International Standard Electric Corporation, and the L. D. C. C. Co., whilst subsequent surveys were made entirely by the L. D. C. C. Co.

The cable is armoured, and is laid throughout direct in the ground. The trench following the side of the road or along a footpath was dug by manual labour to a depth of 80 centimetres, and is about 30 centimetres wide. The depth was increased at road crossings and in towns to about 120 centimetres. After the cable had been placed, a covering of 10 centimetres of sifted earth was thrown in prior to filling. In the open country, further protection is provided by a layer of bricks, placed transversely across the cable, as shown in Figure 3, whilst in the towns, rectangular concrete channel blocks with removable tops are provided. At bridge crossings, the cable either is protected and supported with iron troughing, as shown in Figure 4, or is pulled into iron piping. Joints in the armoured cable other than at the loading points are protected by means of split couplings of cast iron buried directly in the earth.

Horse-drawn wagons or motor tractors were used for laying the cable in the trench; the former method is shown in Figure 5.

The following table gives details of the various cables installed, and indicates the dates when the various sections were commenced and completed. It will be noted that the first cable to be installed was between Prague and Kolín. It was opened for service in May, 1926, and was extended to Jihlava a year later, service over the Prague-Jihlava section being opened in May, 1927. The growth of the traffic was so rapid that a second installment of loading had to be added, and this was completed in October, 1928.

CABLE SECTION	Length in Kms.	CABLE SIZE			Radio	INSTALLATION DATES	
		1.3 mm. quads 2-wire	0.9 mm. quads 2-wire	0.9 mm. quads 4-wire		Commenced	Completed
Lovosice-Prague	75.3	36*	6	30	1 LC quad 0.9 mm.	Oct. 1926	Nov. 1927
Prague-Kolín	56.9	44	6	26	....	Oct. 1925	May 1926
Kolín-Jihlava	82.1	37	6	30	....	May 1926	Oct. 1928
Jihlava-Brno	87.7	37	6	30	....	April 1927	Oct. 1928
Brno-Břeclav	61.3	20	18	40	1 screened pair 1.3 mm.	Aug. 1927	Oct. 1928
Břeclav-Bratislava	81.7	11	5	16	1 screened pair 1.3 mm.	Sept. 1927	Oct. 1928
Bratislava Frontier	9.3	12	4	16	....	May 1927	Oct. 1927
Brno-Olomouc	73.9	36	6	30	2 screened pairs 1.3 mm.	April 1928	Oct. 1928
Olomouc-Mistek	91.0	20	12	46	2 screened pairs 1.3 mm.	May 1929	....
Mistek-Mor Ostrava	20	11	6	40	1 screened pair 1.3 mm.	....	....
Prague-Pilsen	94.0	36*	6	30	1 LC quad 0.9 mm.	May 1928	May 1929
Pilsen-Bor	51.2	20*	6	22	1 LC quad 0.9 mm.	Aug. 1928	May 1929

* 1.4 mm. Conductors.

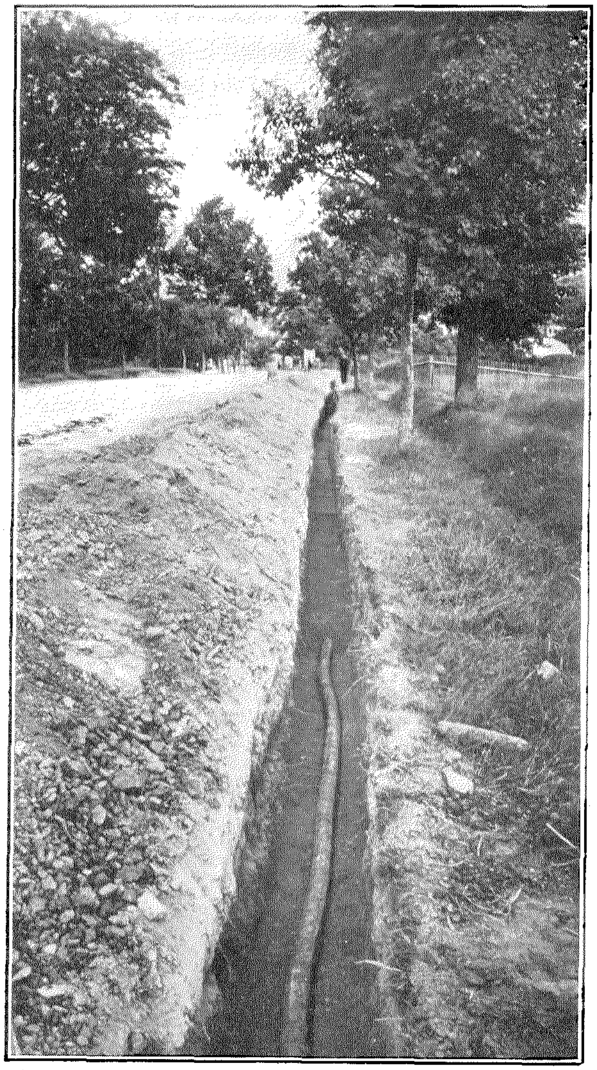


Figure 3—Cable Trench During Filling Operation.

Cross section diagrams of the various cables are seen in Figure 6.

All the cables in Czechoslovakia, with the exception of the sections crossing the German and Austrian frontiers, were installed in accordance with the cross-splicing method of reducing capacity unbalances. Test joints were made in each loading section for capacity unbalance reduction, and in addition, the circuit capacity deviations were reduced at the centre joint of each loading section. The usual direct current tests were made for insulation and copper resistance. Figures 7 and 8 show testers and jointers at work.

Two types of loading were used on the cable, viz., H-177-63 and H-44-25,[1] on a spacing of approximately 1,830 metres. Broadcasting circuits were loaded with 15.5 mH coils for 1.3 mm. screened pairs, and with 177-9.5 units for 0.9 mm. screened quads. Figure 9 shows the method of connecting the single stub cable to the main cable. This method enables the loading coil case to be connected to the cable without undue congestion of the joints. Figure 9 also indicates the type of concrete loading coil manhole used throughout the job.

Figure 10 shows a loading coil case being lowered into such a manhole as that depicted in Figure 9.

Figure 11 shows a pressure test being made on the cable.

The cable is designed to provide three types of circuit:

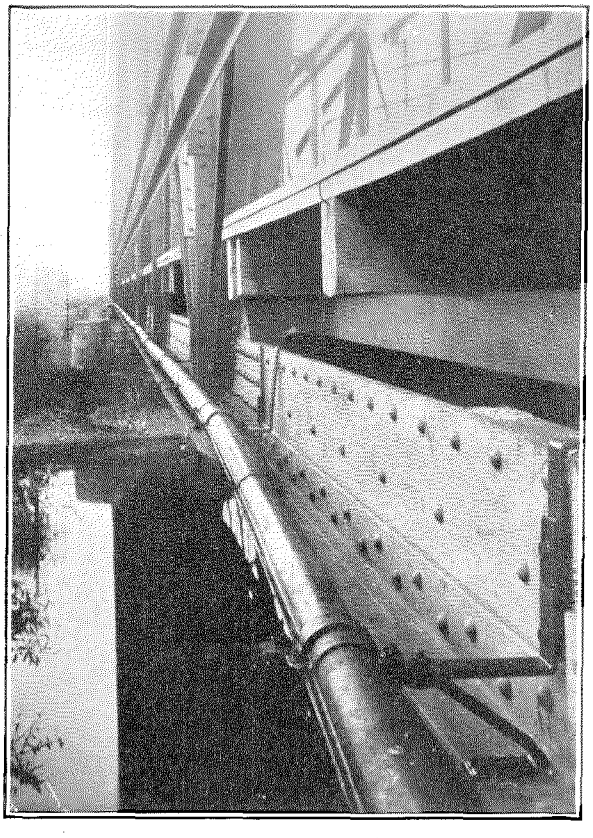


Figure 4—Bridge Crossing with Iron Troughing.

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[1] For explanation of designations, see "Development and Application of Loading for Telephone Circuits," by Thomas Shaw and William Fondiller, *Electrical Communication*, April, 1926, pp. 258–276, and July, 1926, pp. 38–53.

(a) two-wire loaded H-177-63 for the shorter circuits.
(b) four-wire loaded H-177-63 for long distance traffic.
(c) four-wire loaded H-44-25 for international traffic.

The total number of toll lines at present in operation is about 157.

The extension of international circuits at present depends entirely upon the extent to which Administrations of surrounding countries take up the circuits.

The installation of the Prague-Lovosice cable placed Czechoslovakia in connection with the German cable network, and provided circuits from Prague to Berlin, Paris, and other important towns in northern and western Europe.

The Prague-Bratislava system links up Czechoslovakia with the Hungarian network via the Budapest-Bratislava cable, providing not only communication between the two countries, but transit traffic from northern and western Europe to Hungary. When the Hungarian cable between Budapest and Szeged is completed, this transit traffic will be extended through to the proposed Jugoslavian network to Belgrade and the Balkan States.

The completion of the Brno-Olomouc-German and Polish borders cable will provide circuits from Czechoslovakia, Austria (via the Vienna-Břeclav Cable) and Hungary to eastern Germany, Poland, and the Baltic States.

The Prague-Pilsen-Bor cable will provide circuits from Czechoslovakia to southern Germany, Switzerland, England, France, and Holland.

Repeater Equipment

There is a total of eleven repeater stations on the Czechoslovakian Toll Cable System, and so rapid has been the growth of traffic, that the initial equipment in many of these stations has had to be increased after a few months service. Of these eleven repeater stations, eight have been installed according to the "Standard" system.

The following table gives the principal items of repeater equipment at each station:

	4-wire Repeater		2-wire Repeater		V. F. Ringers		4-wire Term. Sets		20~ Ringers	
	Init.	Ult.	Init.	Ult.	Init.	Ult.	Init.	Ult.	Init.	Ult.
Prague	26	177	11	49	80	334	18	102	23	39
Kolín	16	39	56	90	5	9	2	2	65	84
Jihlava	21	47	27	39	..	..	..	..	25	37
Brno	26	118	62	100	16	20	1	4	27	32
Břeclav	15	59	43	81	..	..	..	..	31	41
Bratislava	9	17	7	14	10	18	1	2	5	7
Olomouc	10	57	16	41	8	5	..	..	17	35
Příbor			Equipment not		yet engineered					

The layout of the equipment in the repeater stations embodies the most up-to-date practices, the underlying aim having been to provide the maximum possible flexibility in the arrangement of the apparatus, so that any circuit or any arrangement of apparatus might be set up or modified.

With this end in view, the apparatus was assembled in groups of the same type, each group being terminated at the distributing frame, for connection by means of jumper wires into the required circuit combinations. Emergencies or unforeseen traffic demands can easily be met by simple changes in the jumper wiring. In order still further to increase the station flexibility, the equipment is so jacked that if for any reason any piece of apparatus breaks down, spare apparatus may be patched in with only a very short interruption of service.

The main cable is terminated at each repeater station by splicing it at a convenient point inside the station to several silk and cotton insulated lead covered cables which are so arranged as to maintain the segregation effected in the main cable, and which are connected to protectors on the combined distributing frame. From the protectors, the cable circuits are connected to the toll test board, shown in Figure 12, and thence through jacks to the repeating coils and the necessary circuit equipment.

The No. 5 Toll Test Board, which is installed in all stations except Kolín, contains testing equipment consisting of Voltmeter and Wheatstone Bridge circuits as well as facilities for talking and ringing on the cable circuits, and is so designed that routine tests and fault locations can be made quickly on any cable circuit. By means of its jack circuits, it also provides a rapid means for bringing into service spare circuits or equipment when necessary.

An article by Mr. A. B. Hart dealing with the London-Glasgow Trunk Cable[2] described in detail repeater station equipment, which is very similar to that installed on the Czechoslovakian cable system, and it seems unnecessary therefore to enter into a detailed description of this equipment in the present instance.

In all repeater stations, excepting the earlier installation in Kolín, unit type repeater and ringer bays are used. These bays are completely wired and tested in the factory, thus reducing the installation and testing work considerably.

Figures 12, 13, and 14 show views of some of the equipment at a typical repeater station. The Toll Test Board, combined distributing frame, and repeating coil rack are closely associated, so that the cable runs from the point of entrance of the cable to the repeating coils may be as short as possible in order to keep the danger of crosstalk between phantom and side circuits down to a minimum.

Figure 5—Horse-drawn Cable Wagon.

Adequate gangways are provided, and a sufficiency of space has been reserved for future extensions. In all stations racks are provided for No. 6 type Transmission Measuring Sets and associated No. 10 type Oscillators, this apparatus being used in making the line transmission tests as well as the station routine maintenance tests.

At all stations except Prague, the power plant provides current for the repeaters and their associated equipment only. At Prague, the main battery supplies both the repeater station and the manual exchange equipment, but it is planned to install separate power equipment for the

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[2] "The London-Glasgow Trunk Telephone Cable and its Repeater Stations," *Electrical Communication*, October, 1926, p. 119–156.

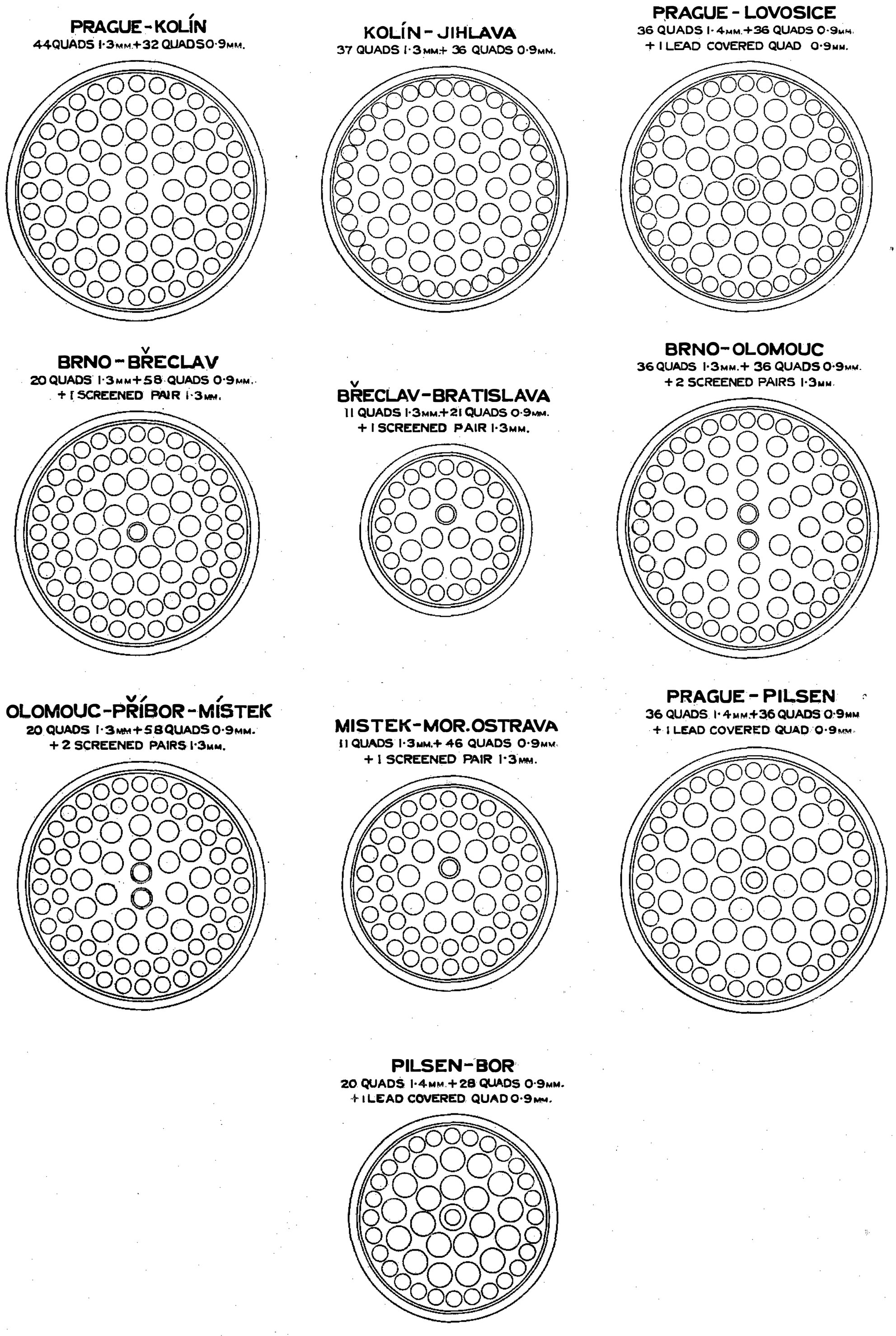

Figure 6—Cross-sections of Czechoslovakian Cables.

Figure 7—Field Testing.

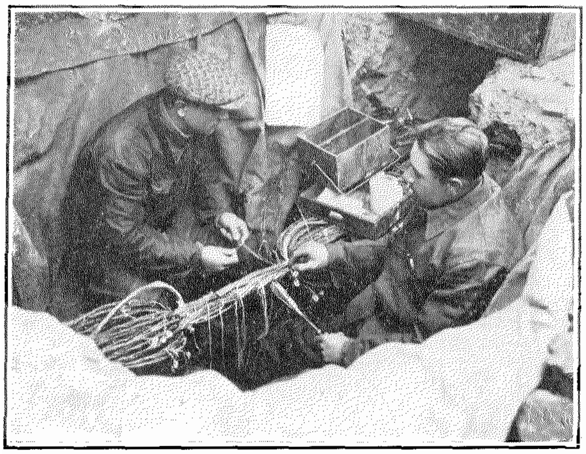

Figure 8—Jointing Work in Progress.

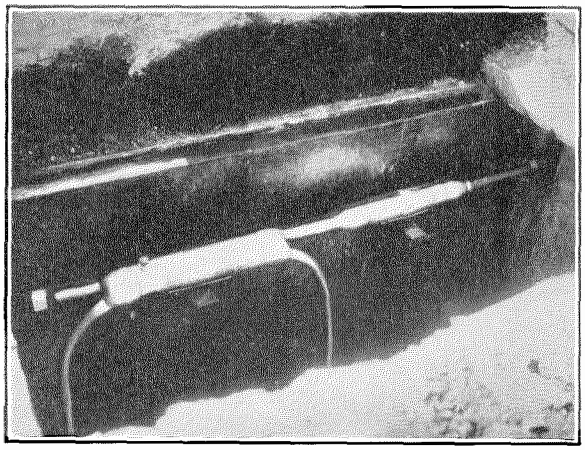

Figure 9—Concrete Loading Coil Manhole.

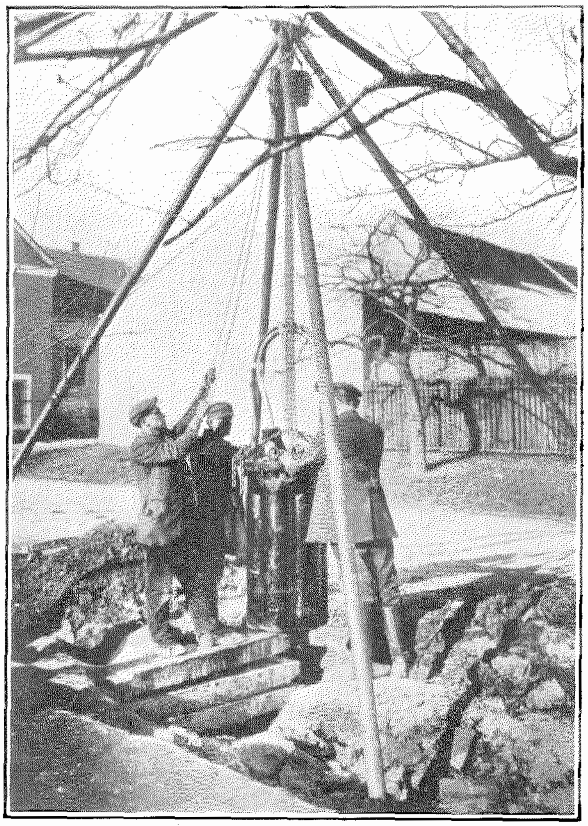

Figure 10—Placing of Loading Coil Case in Manhole.

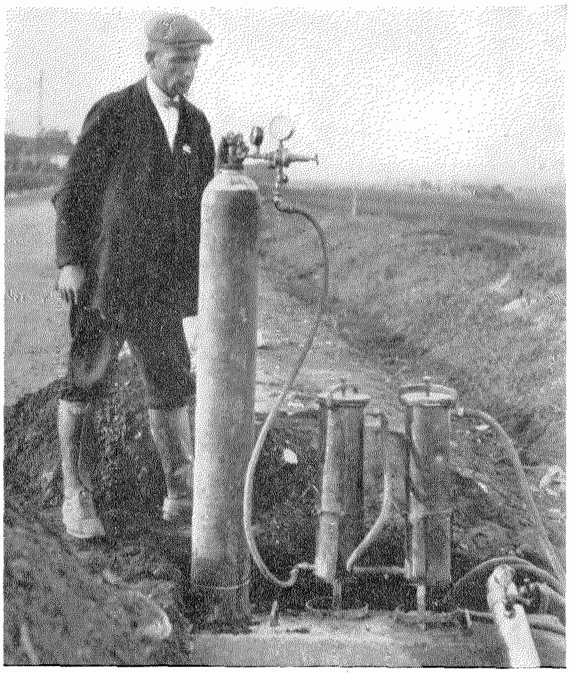

Figure 11—Pressure Testing.

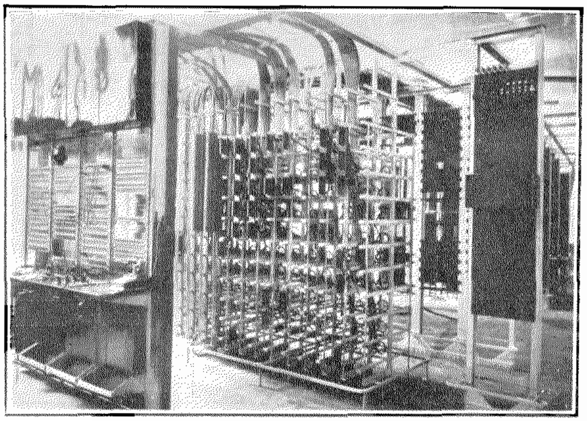

Figure 12—No. 5 Toll Test Board (Kolín).

station in the near future. At all stations an outside power supply is available, and motor-driven generator sets are employed for charging the filament and plate batteries. Duplicate sets of filament, plate and grid batteries are supplied at all stations. The filament battery is operated on a floating routine, and a special noise filter is installed in the battery charging circuit to prevent generator noises entering the toll circuits. The use of the battery floating system makes it possible to obtain closer regulation of the repeater filament voltage, and proves in practice to be far more economical than the charge-discharge system. On the other hand, the plate batteries are operated on the charge-discharge principle, and a separate motor generator is provided for charging purposes. The grid batteries are also operated on the charge-discharge system, and are charged directly from the filament battery through a suitable resistance.

As a provision against the failure of the outside power supply, each station is equipped with an internal combustion engine-generator set using as fuel paraffin or petrol. The plate and filament battery generators are driven directly from this engine.

Duplicate sets of 20-period ringing machines are provided at each station, and in addition, at those stations where the voice frequency ringing circuits terminate, duplicate sets of 500-period voice frequency ringing generators are installed.

Figures 15 and 16 show typical power plant arrangements.

Transmission Tests

As soon as each repeater section had been completed, a series of measurements was made to ascertain whether the cable and loading coils were satisfactory, and whether the required degree of regularity had been obtained. The results of these tests are also of considerable assistance to the transmission engineer during the setting up of the repeatered circuits.

These tests, which include measurements of crosstalk singing point, impedance and attenuation, are discussed briefly.

CROSSTALK

Crosstalk tests were made on each repeater section. Near-end crosstalk was measured from each end of every section, and far-end crosstalk from one end only. The source of tone used was a 20-c test set which provided a complex tone.

Table No. 1 gives a complete summary of

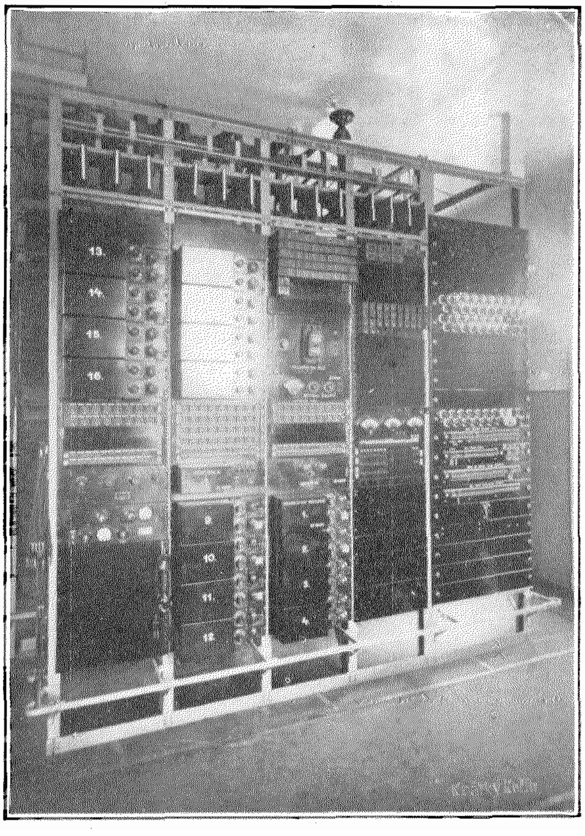

Figure 13—Two-wire Repeater Rack (Kolín).

the results of crosstalk tests made on the Jihlava-Brno repeater section. These results are typical of those obtained throughout the system.

TABLE NO. I.

CROSSTALK SUMMARY JIHLAVA–BRNO CABLE 87.7 Km.

			NEAR END				FAR END			
			AVERAGE		MAXIMUM		AVERAGE		MAXIMUM	
			Cross-talk Units	Nepers	Cross-talk Units	Nepers	Cross-talk Units	Nepers	Cross-talk Units	Nepers
CROSSTALK BETWEEN CIRCUITS IN THE SAME QUAD	2-wire 1.3 mm. H-177-63	PH-S	140	8.9	200	8.5	170	8.7	280	8.2
		S-S	80	9.4	120	9.0	80	9.4	175	8.6
	Separators 0.9 mm. H-177-63	PH-S	120	9.0	150	8.8	70	9.6	95	9.25
		S-S	80	9.4	90	9.3	45	10.0	65	9.6
	4-wire 0.9 mm. H-177-63	PH-S	110	9.1	190	8.6	85	9.4	125	9.0
		S-S	65	9.6	150	8.8	40	10.1	65	9.6
	4-wire 0.9 mm. H-44-25	PH-S	100	9.2	200	8.5	10	11.6	35	10.3
		S-S	50	9.9	80	9.4	5	12.2	20	10.8
CROSSTALK BETWEEN CIRCUITS IN DIFFERENT QUADS IN THE SAME GROUP	2-wire 1.3 mm. H-177-63	PH-PH	95	9.25	200	8.5	90	9.3	250	8.4
		PH-PR	75	9.5	150	8.8	75	9.5	105	9.1
		PR-PR	75	9.5	150	8.8	70	9.6	175	8.6
	Separators 0.9 mm. H-177-63	PH-PH	120	9.0	270	8.2	125	9.0	210	8.5
		PH-PR	95	9.25	180	8.6	40	10.1	60	9.7
		PR-PR	110	9.1	200	8.5	30	10.4	35	10.3
	4-wire 0.9 mm. H-177-63	PH-PH	125	9.0	350	8.0	45	10.0	80	9.4
		PH-PR	70	9.6	130	8.9	45	10.0	60	9.7
		PR-PR	95	9.25	120	9.0	40	10.1	40	10.1
	4-wire 0.9 mm. H-44-25	PH-PH	45	10.0	160	8.7	5	12.2	43	10.0
		PH-PR	35	10.3	80	9.4	5	12.2	20	10.8
		PR-PR	30	10.4	60	9.7	5	12.2	10	11.6
CROSSTALK BETWEEN CIRCUITS IN DIFFERENT GROUPS	1.3 mm. H-177-63 to 0.9 mm. H-44-25	PH-PH	15	11.3	25	10.6	......	......	......	......
		PH-PR	15	11.3	30	10.4	......	......	......	......
		PR-PR	15	11.3	30	10.4	......	......	......	......
	Separators to 0.9 mm. H-44-25 4-wire	PH-PH	30	10.4	100	9.2	10	11.6	45	10.0
		PH-PR	20	10.8	50	9.9	0	..∞..	0	..∞..
		PR-PR	20	10.8	60	9.7	0	..∞..	10	11.6
	0.9 mm. H-177-63 to 0.9 mm. H-44-25*	PH-PH	50	9.9	250	8.4	40	10.1	80	9.4
		PH-PR	45	10.0	110	9.1	15	11.3	25	10.6
		PR-PR	60	9.7	100	9.2	10	11.6	25	10.6

* Four-Wire Medium Heavy to Extra Light in same direction. The crosstalk between four-wire groups in opposite directions was in all cases negligible.

Average Near End crosstalk is average of readings from Jihlava and Brno. The maximum is the maximum observed either in Jihlava or Brno.

SINGING POINT

Three methods of determining the singing point were used. Some circuits were measured by means of the No. 2-A impedance unbalance set, which measures the singing point directly by means of an attenuation measuring circuit at any desired frequency. The majority of the repeater sections were measured by means of the well known "21" test using a calibrated two-wire repeater. On the Bratislava-Hungarian Frontier cable impedance curves were taken on all two-wire 1.3 mm. circuits, and the singing point was calculated from these.

In the singing point tests, the circuit was properly terminated to eliminate reflections from the distant end. Where direct singing point measurements were taken, the line was balanced against a basic network having average characteristics, plus a building-out condenser. The building-out condenser was adjusted to give the best singing point for the circuit under test.

In the case of four-wire H-44-25 circuits, for which no balancing networks are provided, a circuit was chosen at random as a standard, and all similar circuits were measured against it. The impedance curve of the standard circuit was then measured.

From the results of the singing point tests, representative circuits of each type were chosen, and these were measured for impedance frequency characteristics.

Table No. II gives a summary of the values of singing point obtained in a typical repeater section.

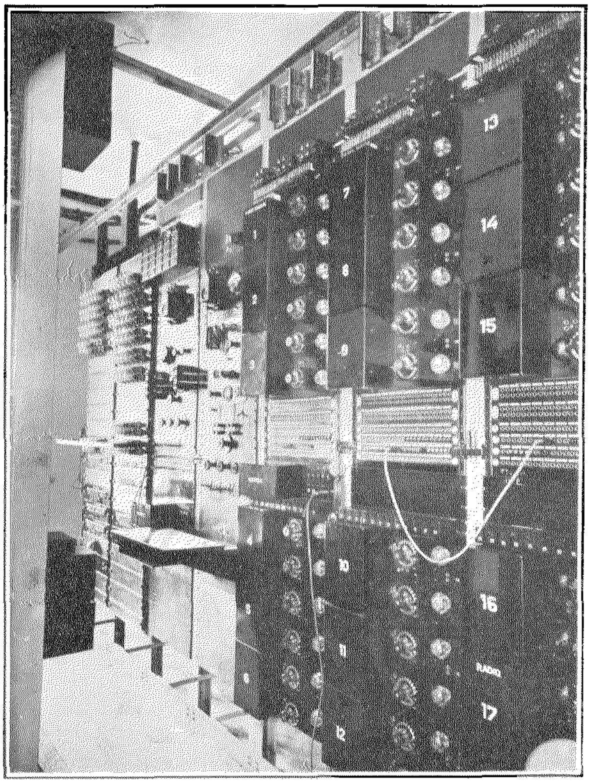

Figure 14—Four-wire Repeater Rack (Jihlava).

IMPEDANCE

As explained under "Singing Point," impedance frequency curves were taken on representative circuits, and these were used to check the results of the direct singing point measurements.

Typical impedance curves are shown in Figures 17 to 22.

ATTENUATION

Measurements of attenuation at 800 and 1,900 periods per second were made on all circuits in

TABLE NO. II.

SINGING POINT SUMMARY REPEATER SECTION BRNO–BŘECLAV

	SINGING POINT (DECIBELS)						
	Measured by 21-test			Calculated from Impedance Curves			
	Average	Maximum	Minimum	Average	Maximum	Minimum	
1.3 mm. H-177-63 Side	26	28	24	26	28	25	From Brno
1.3 mm. H-177-63 Phantom	32	36	28	33	34	28	
0.9 mm. H-177-63 Side	28	..	26	29	..	28	
0.9 mm. H-177-63 Phantom	34	38	30	32	36	29	
1.3 mm. H-177-63 Side	27	29	25	27	29	26	From Břeclav
1.3 mm. H-177-63 Phantom	31	33	29	29	29	27	
0.9 mm. H-177-63 Side	27	29	25	..	26	23	
0.9 mm. H-177-63 Phantom	33	35	29	..	32	29	

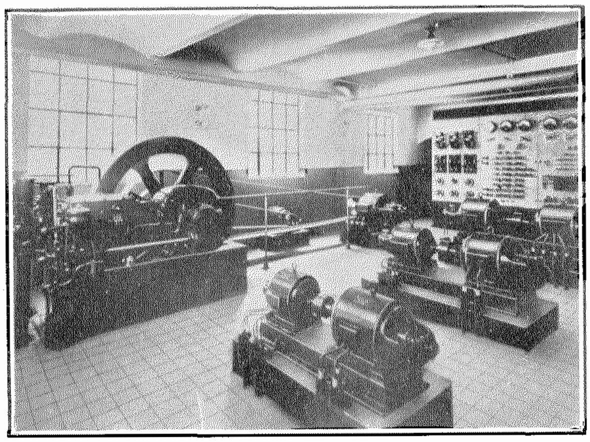

Figure 15—Power Room (Kolín).

each repeater section. Table No. III shows a summary of these measurements.

Attenuation-frequency runs were made on representative circuits of each type. Typical curves are given in Figures 23 to 25.

TABLE NO. III

Average Attenuation Constants at 800 and 1,900 periods per second, and + 15° C.

Average Attenuation at + 15° C.

Type of Circuit	800 periods per sec.		1,900 periods per sec.	
	db/Km.	Neper/Km.	db/Km.	Neper/Km.
1.4 mm. Si.	0.0856	0.00986	0.108	0.0124
H-177-63 Ph.	0.0880	0.0101	0.0995	0.0114
1.3 mm. Si.	0.098	0.0113	0.122	0.0140
H-177-63 Ph.	0.100	0.0115	0.113	0.0130
0.9 mm. Si.	0.176	0.0203	0.198	0.0228
H-177-63 Ph.	0.182	0.0209	0.193	0.0222
0.9 mm. Si.	0.306	0.0352	0.318	0.0366
H-44-25 Ph.	0.253	0.0291	0.265	0.0305

OVERALL TESTS ON REPEATERED CIRCUITS

All four-wire repeatered circuits, after having been set up for service, were measured for transmission level, overall loss, attenuation-frequency characteristics, and crosstalk.

Two-wire circuits were tested for transmission loss at 300, 800 and 2,000 periods per second, and for crosstalk. Observations of stability were also made on all circuits, as laid down by the C. C. I.

The four-wire circuits so far put into service terminate outside Czechoslovakia, and it is the practice in the neighbouring countries to adjust the circuit to the theoretical overall loss, so that figures of the values obtained are of little interest. In general, the circuits are set up to give an overall loss of 10 db.

Overall attenuation-frequency characteristics on the Czechoslovakian sections are shown for typical four-wire H-44-25 circuits (Figures 26 and 27).

Table IV shows the results of attenuation measurements on typical two-wire H-177-63 circuits.

BROADCASTING CIRCUITS

In all repeater sections, other than those between Prague and Brno, special screened broadcasting circuits, either pairs or phantoms, are provided. These circuits have a cut-off frequency of around 9,000 periods per second.

Between Prague and Brno, normal 0.9 mm. H-44-25 circuits have been adapted to broadcasting requirements, as a temporary expedient.

The broadcasting circuit between Brno and Bratislava is also in service. This circuit is arranged so that any one of the three broadcasting stations, Brno, Bratislava, and Vienna, can transmit simultaneously to the other two.

Change-over in the transmission direction in this circuit is necessary as the circuit is of course one way only. This is at present carried out by

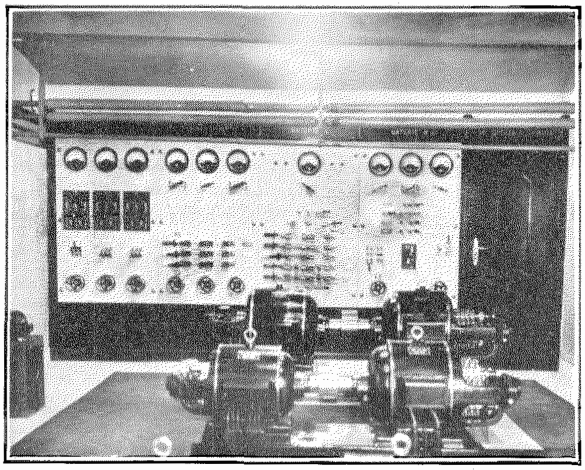

Figure 16—Power Room (Jihlava).

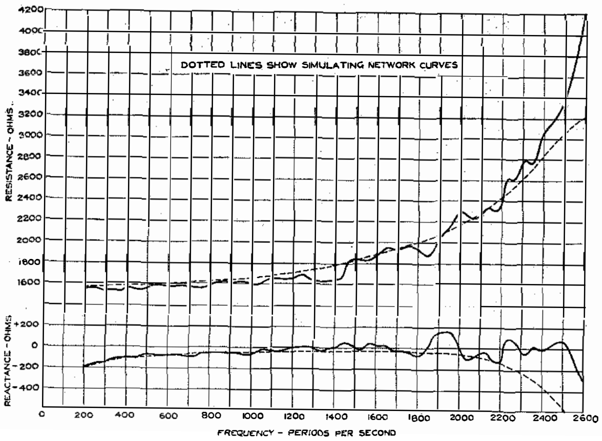

Figure 17—Impedance Curves—1.3 mm. H-177-63 Side Circuit.

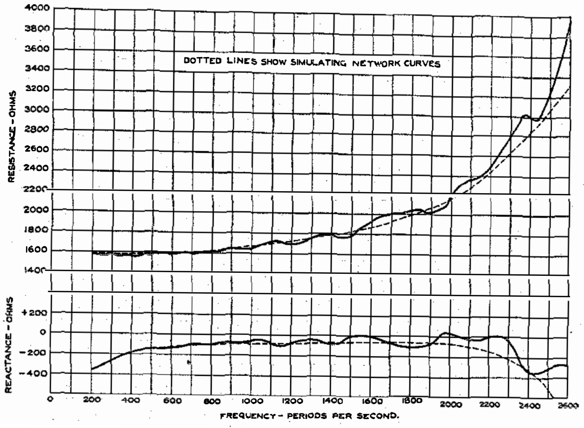

Figure 19—Impedance Curves—0.9 mm. H-177-63 Side Circuit.

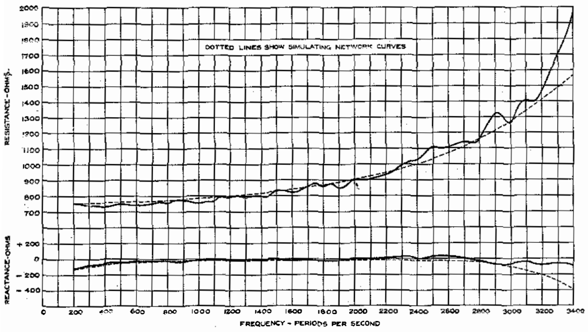

Figure 18—Impedance Curves—1.3 mm. H-177-63 Phantom Circuit.

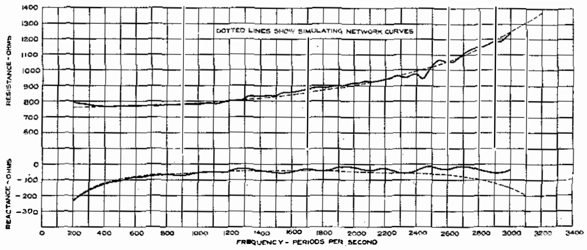

Figure 20—Impedance Curves—0.9 mm. H-177-63 Phantom Circuit.

TABLE NO. IV.

Typical Overall Loss Measurements on Two-Wire Repeatered Circuits

			OVERALL LOSS			
			E–W		W–E	
	DETAILS OF CIRCUIT	FREQUENCY PERIODS PER SECOND	db.	neper	db.	neper
CIRCUITS WITH ONE TWO-WIRE REPEATER	BRNO–VIENNA SIDES 1.3 mm. H-177-63 Brno to Břeclav, 1.4 mm. 2 Km.-190-70 Břeclav to Vienna. Repeatered in Břeclav.	300 500 2000	10.5 9.6 11.6	1.21 1.09 1.34	10.9 9.2 12.6	1.25 1.05 1.45
	Ditto. PHANTOMS.	300 800 2000	10.9 9.1 10.5	1.25 1.04 1.21	10.4 9.2 10.9	1.20 1.05 1.25
CIRCUITS WITH TWO TWO-WIRE REPEATERS	PRAGUE–VIENNA SIDES 1.3 mm. H-177-63 from Prague to Břeclav, 1.4 mm. 2 Km.-190-70 from Břeclav to Vienna. Repeatered in Kolín and Brno.	300 800 2000	9.2 10.4 19.0	1.06 1.20 2.9	9.9 10.8 20.8	1.14 1.24 2.40
CIRCUITS WITH FOUR TWO-WIRE REPEATERS	PRAGUE–BUDAPEST PHANTOMS 1.3 mm. H-177-63. Repeatered in Kolín, Brno, Bratislava and Gyor.	300 800 2000	13.9 10.0 17.1	1.60 1.15 1.97	14.1 10.0 17.6	1.62 1.15 1.97

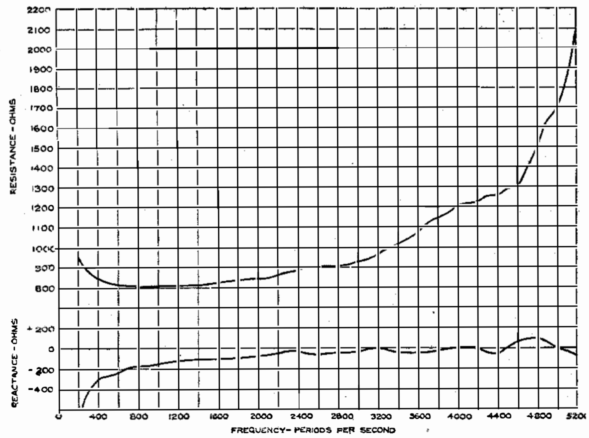

Figure 21—Impedance Curves—0.9 mm. H-44-25 Side Circuit.

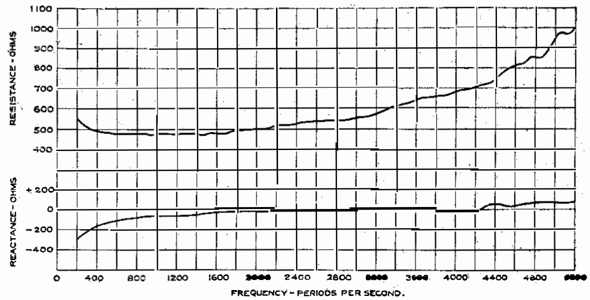

Figure 22—Impedance Curves—0.9 mm. H-44-25 Phantom Circuit.

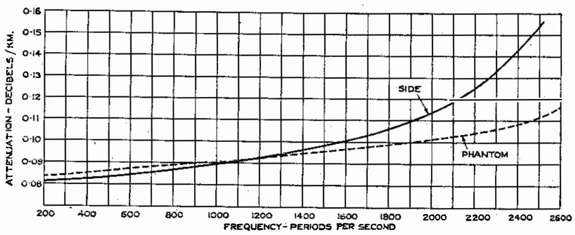

Figure 23—Attenuation-Frequency Curves—1.4 mm. H-177-63 Side and Phantom Circuits.

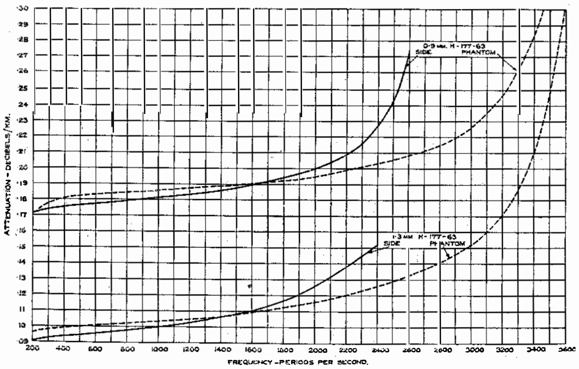

Figure 24—Attenuation-Frequency Curves—1.3 mm. and 0.9 mm. H-177-63 Side and Phantom Circuits.

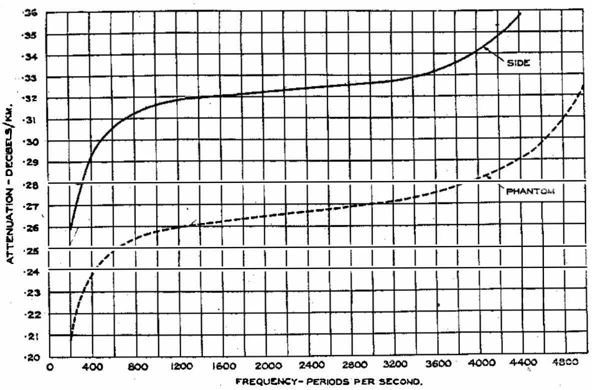

Figure 25—Attenuation-Frequency Curves—0.9 mm. H-44-25 Side and Phantom Circuits.

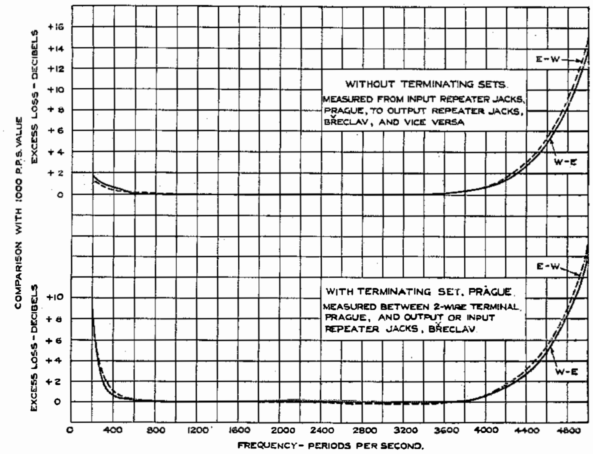

Figure 26—Overall Transmission Frequency Characteristics —0.9 mm. Four-wire H-44-25 Side Circuit.

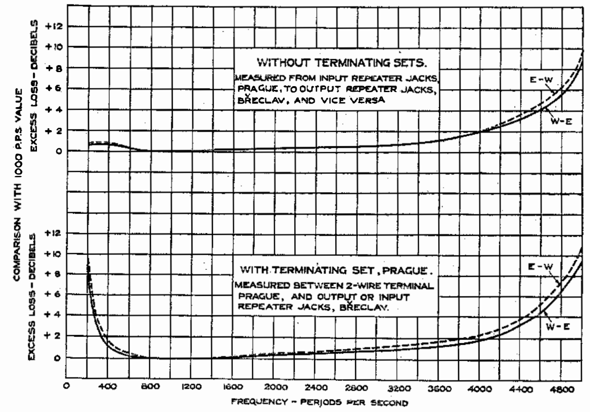

Figure 27—Overall Transmission Frequency Characteristics —0.9 mm. Four-wire H-44-25 Phantom Circuit.

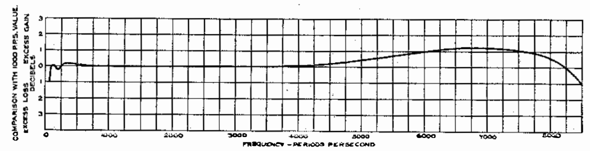

Figure 28—Overall Transmission Frequency Characteristics —Břeclav-Brno Broadcasting Circuit (preliminary set-up).

a three-position manual switching arrangement in each repeater station.

The circuit is equalized so that a substantially flat attenuation-frequency curve is obtained between Brno and Bratislava, independent of the direction of transmission, and at the same time the output to the Vienna branch is also flat.

Arrangements have been made to equalize to Brno and Bratislava with Vienna transmitting, but this change is awaiting the installation of the necessary repeater in Vienna.

Figure 28 shows the results obtained on the first set-up of the broadcasting circuit. These will be improved at the low frequencies later, when equalization will be carried down to 50 periods per second.

A third broadcast circuit, Prague-Berlin, will also be put into service shortly; this is awaiting the equalization of the circuit on German territory.

Conclusion

It is possible in the space available to deal but briefly with such an extensive toll cable network. It is believed, however, that the facts enumerated are sufficient to outline the more important technical features of the Czechoslovakian cable system, and to show that the installation of this network and its associated equipment has placed the long-distance telephone system in Czechoslovakia in the front rank of telephone communication in Europe. Not only has the network furnished an important link in the European international network, but also has made available within the country a most efficient toll system.

Lightning Damage to Toll Cable

DURING the violent thunder-storms with which Europe was visited to an unusual degree in the year 1929, toll cable networks were damaged in isolated instances. Injury occurred at Arlberg in the Tirol, then on the Prag-Kolín, Budapest-Lakihegy and Györ-Magyaróvár cable sections. The last-named case is especially interesting.

The lightning struck a strong acacia tree about 21 km. from Györ, in the direction of Magyaróvár-Vienna, and severed the trunk transversely in two parts. The upper portion was partially buried in the ground and left standing vertically beside the stump of the tree, as illustrated in Figure 1, from which it might be inferred that two trees were involved.

From the trunk, the lightning made its way along the root for about 1 m. under the surface of the ground to the Budapest-Vienna cable, 6 m. distant from the tree and 0.7 m. below the earth's surface. The path of the lightning could be traced through a channel of about 130–200 square millimeters cross section. The earth, notwithstanding the heavy thunder-shower, was almost as dry as dust.

At the place of entrance the lightning had flattened and bent the cable for a length of about 80 cm., as illustrated in Figure 2. About 1.70 m. distant from the entrance section the lead cable sheath had become opened up and partially disintegrated by the heat.

During the repair work, it was noted that the lightning had traveled along the lead sheath for several kilometers and had injured the insulation of the copper conductors nearest the sheath, so that even at about 2 km. from the point where the cable had been struck many broken wires were located.

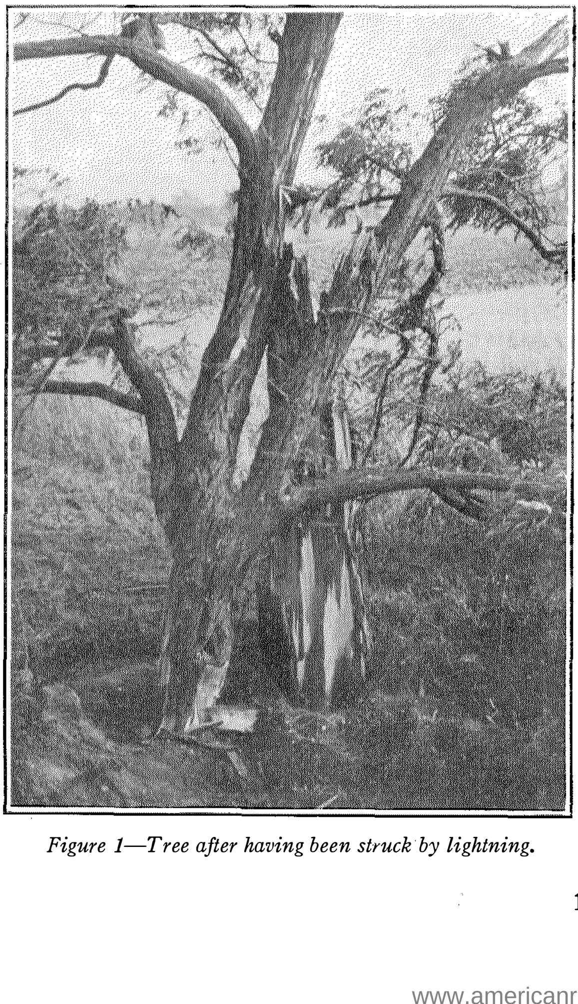

Figure 1—Tree after having been struck by lightning.

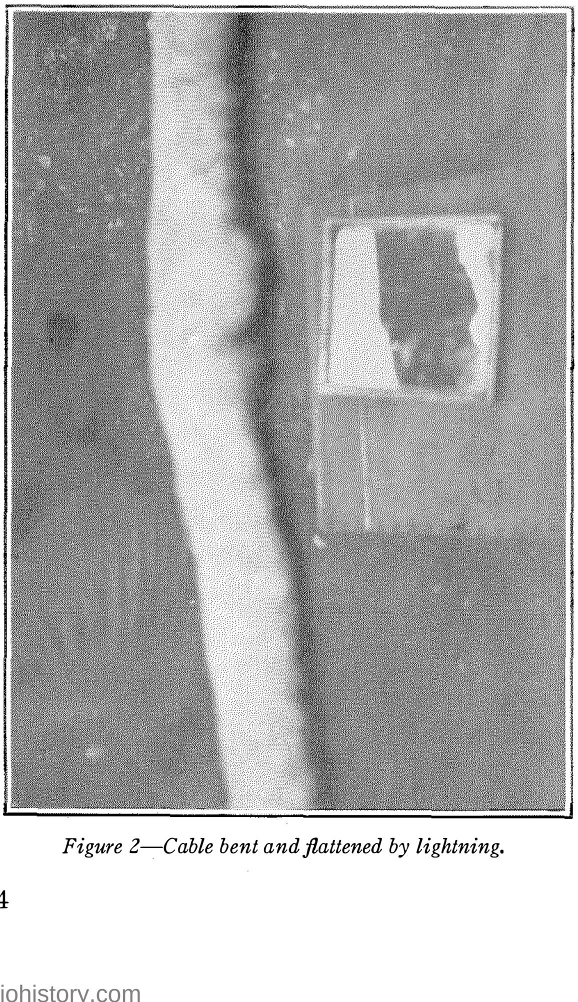

Figure 2—Cable bent and flattened by lightning.

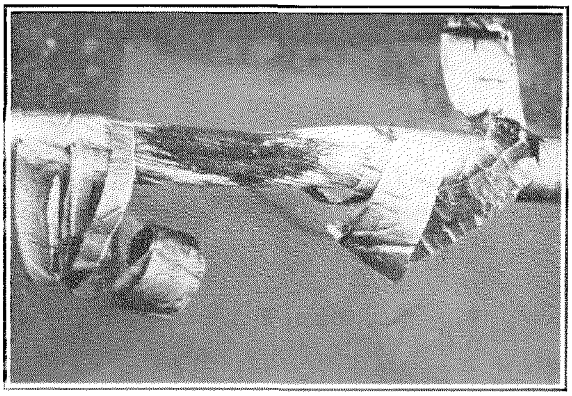

Figure 3—Showing the Appearance of the Cable After the Metal Protective Covering Had Been Removed.

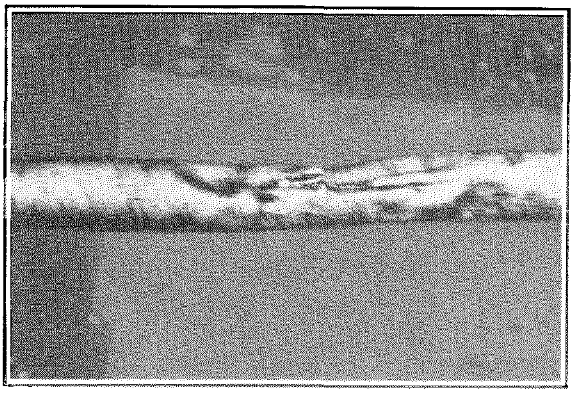

Figure 4—Showing the Cable Core Where the Lightning Struck the Cable.

Notwithstanding the seriousness of the damage done the entire cable was once more in working condition within a time interval of forty-eight hours after the occurrence, thus proving plainly that regardless of the severity of injury to a toll cable from a phenomenon of nature, complete restoration can be effected in minimum time.

The London-Paris-Madrid Telephone Service

By L. G. FREETH

European Engineering Department, International Standard Electric Corporation

Up to the year 1924, when the Compañía Telefónica Nacional de España under concession from the Spanish Government took over the operation of the telephone system in Spain, that country had not been considered by the other European nations for inclusion in the international toll network. At that time long distance telephony in Spain was undeveloped and in fact, almost non-existent. Under the progressive policy of the Compañía Telefónica Nacional de España, the situation was completely altered and it soon became evident that Spain was destined to play an important part in European telephony.

One of the greatest problems which the Spanish Company had to solve was that of providing circuits into the international network. The geographical situation of Spain was such that there was no access to the extensive European toll cable network—this having been designed to interconnect the more heavily populated districts of Western and Central Europe. The only outlet for Spain was through the narrow French-Spanish border, and the only means of communication was over some open-wire lines, leading to Paris via Bordeaux. At this time, these lines were not in sufficiently good condition to permit speech beyond Bordeaux from Madrid, since their maintenance was not up to the highest standard, and crosstalk and the noise induced from neighbouring power lines prevented transmission of normal conversations. Even though the open wires were continuous from the Spanish Border right up to Paris, Paris had no reliable telephone communication with any town south of Bordeaux. At Bordeaux there were one or two cord circuit repeaters of an early type—relics of the Great War—which had been turned over to the French Administration by the American Army, but these repeaters, which were intended for switched communications beyond Bordeaux, were rarely used.

To provide international communication, the Compañía Telefónica Nacional de España (C.T.N.E.) concentrated upon the construction of a first class open wire route from Madrid to the French Border at Hendaye, passing through Zaragoza and San Sebastián. As soon as this was ready, the French Government was asked to provide a through circuit from Paris to a point where their line terminated. The engineers of the French Postes, Télégraphes et Téléphones (P.T.T.) expressed their willingness to co-operate with the C.T.N.E. in an endeavour to establish a circuit between Paris and Madrid. It was soon discovered that an improved condition of the lines and better maintenance routines would be required if success were to be obtained. The International Standard Electric Corporation (I.S.E.C.) was asked to co-operate with the C.T.N.E., to bring about a solution of the problem. A survey of the French lines was made, and based on the results obtained, certain recommendations were laid before the authorities by means of which it was expected to obtain stable and satisfactory transmission. The traffic carried on this line was sufficiently heavy to indicate to the Spanish Telephone Company and to the French Administration that such a circuit, if effectively maintained, would prove to be a sound proposition.

In 1927, the traffic had developed to such an extent that the two Administrations decided to instal a three-channel carrier system between the French capital and Madrid. The route, shown in Figure 1, passes through Versailles, Saumur, Saintes, Bordeaux, San Sebastián and Zaragoza. The carrier terminals were located at Versailles and Zaragoza, the voice-frequency link between Paris and Versailles being provided by means of non-loaded cable circuits, and that between Zaragoza and Madrid by means of open-wire and entrance cable circuits. While this system was being installed, the open wire lines in the French territory were subjected to a close investigation. To improve the already existing communications between Paris and Madrid, which had by that time increased to two physical circuits, the French Government installed two through line repeaters of modern type at Bordeaux. The lines were now so improved between Paris and Madrid, that it was suggested at that time to extend the circuit beyond Paris to London. For this purpose, cord circuit repeaters were installed at Paris. The Paris-Madrid circuits were, as yet, not in perfect condition, and although actual speech tests were carried out between London and Madrid over this switched voice-frequency circuit, it was not actually put into service. It so happened that the carrier system was completed just about the time of these tests, and arrangements were made with the British Post Office and the French Telephone Administration for supplying a direct circuit between London and Madrid, using one of the three carrier channels—the other two channels being used for the Madrid-Paris service. The London channel was extended beyond Paris by means of circuits in the Paris-Boulogne, Boulogne-Canterbury and London-Canterbury cables. The Paris-Boulogne cable was installed in 1926 by the Lignes Télégraphiques et Téléphoniques (L.T.T.), an allied Company of the I.S.E.C. The submarine cable between Boulogne and Canterbury was installed in 1927, and is continuously loaded. The London-Canterbury cable was installed in 1926 by Standard Telephones and Cables Limited.

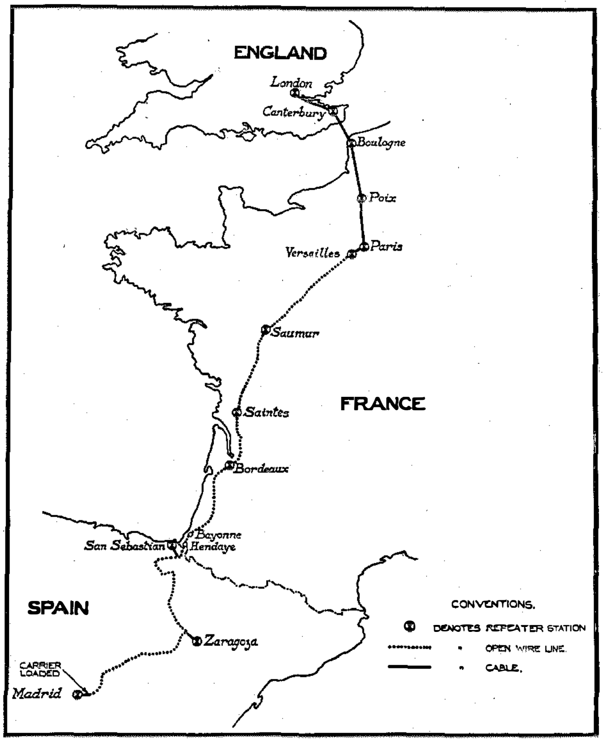

Figure 1—Route of the London-Paris-Madrid Telephone Circuits.

A difficulty in providing a 4-wire circuit between Paris and London was that only 2-wire circuits were available between Paris and Boulogne. It was therefore necessary to select two 2-wire circuits and to arrange for the 2-wire repeaters to operate in one direction only so as to simulate 4-wire working. At this time, the submarine cable circuit was also operated as a 4-wire circuit. Between Paris and Versailles, the link consisted of a 4-wire circuit located in a non-loaded underground cable of a very old type. Since the 1,000 cycle equivalent of this circuit was approximately 15 db, it was decided that in order not to introduce excessive distortion, this circuit should be equalised over the range of transmitted frequencies. For this purpose equalisers were installed at Paris and Versailles, that is to say, at the receiving end of the east and

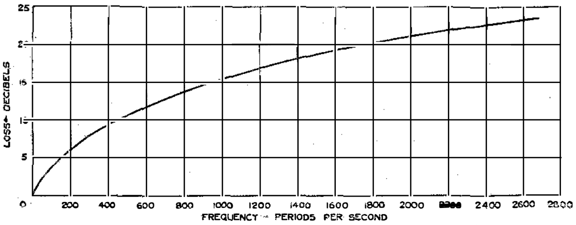

Figure 2— Non-equalised characteristic of the Paris-Versailles link.

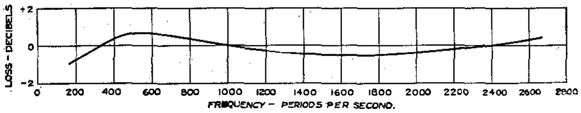

Figure 3—Equalised characteristic of the Paris-Versailles link.

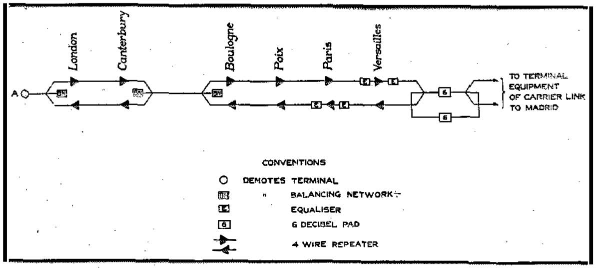

Figure 4—Layout of the London-Versailles audio-frequency circuit.

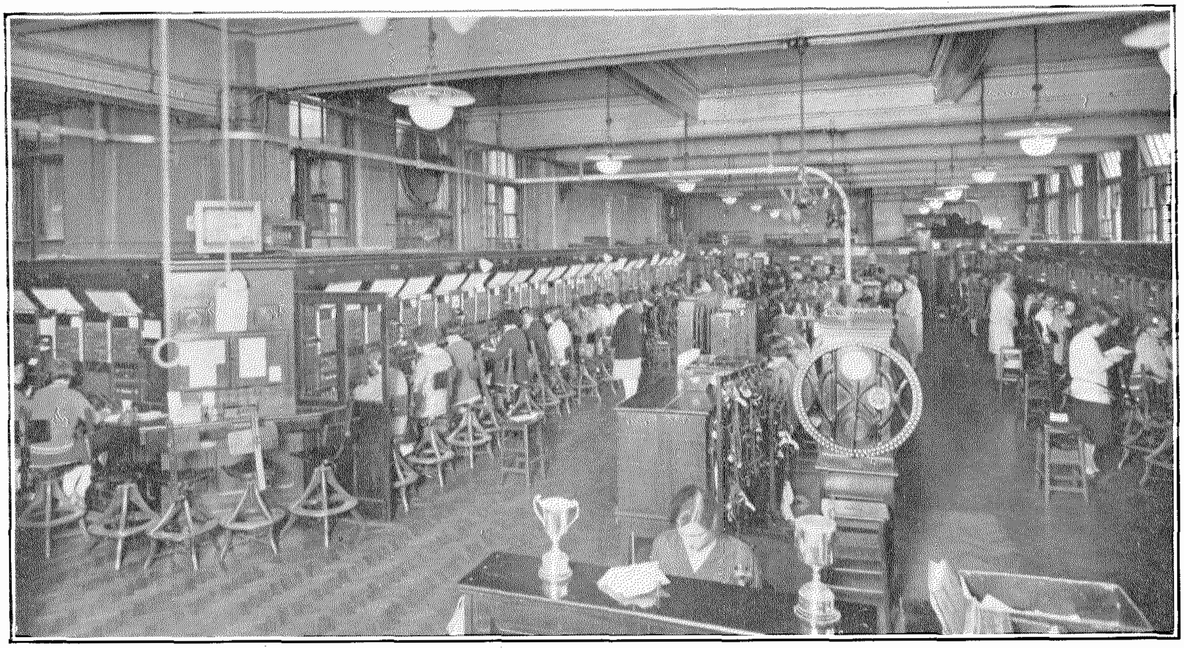

Figure 5—London trunk exchange.

west going circuits. Figures 2 and 3 show typical non-equalised and equalised characteristics of these circuits. At Versailles, the connection was made between the audio and carrier frequency links by connecting the line and network terminals of the terminating set, and of the hybrid coil, through resistance pads having a 6 db loss. In this manner, the use of balancing networks was avoided and a high degree of balance was obtained. The layout of the circuit was now as shown in Figure 4, except that, at that time, continuous 4-wire operation was obtained between Versailles and London.

In Figure 5 is shown the London Trunk Exchange. The location of the London terminal is towards the far end, on the right hand side. In Figures 6, 7 and 8, are shown, respectively, Versailles terminal (carrier and audio-frequency) equipment, Saumur carrier repeater equipment and Zaragoza carrier terminal equipment on the first system.

Other illustrations relating to the line construction are, Figure 9, a section of the line near Bordeaux indicating, on the pole in the foreground, the method of making transpositions, Figure 10, the "guerite," or test hut, at Saintes, and Figure 11, the "guerite" at Thiers, near Bordeaux. From these views, the congested nature of the line at certain points on the route between Paris and Bordeaux can be seen—a condition which will, no doubt, be considerably alleviated by the recent cut-over of the Paris-Bordeaux cable.

The opening of this three channel carrier system demonstrated, not only that it enables additional circuits to be obtained without stringing additional copper circuits, but that it possesses high value in providing satisfactory transmission over lines the condition of which precluded satisfactory voice-frequency telephony.

Not many months passed before it was appreciated that additional circuits would soon be

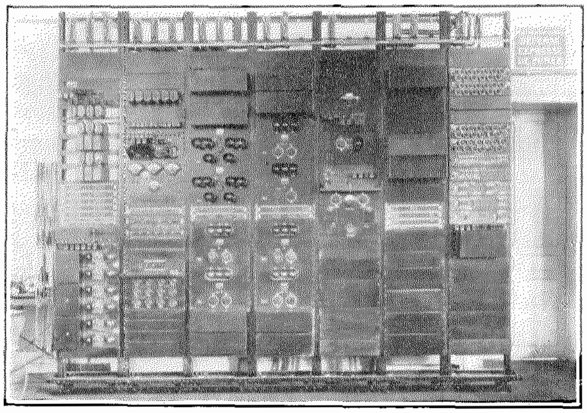

Figure 6—Versailles—1st system terminal.

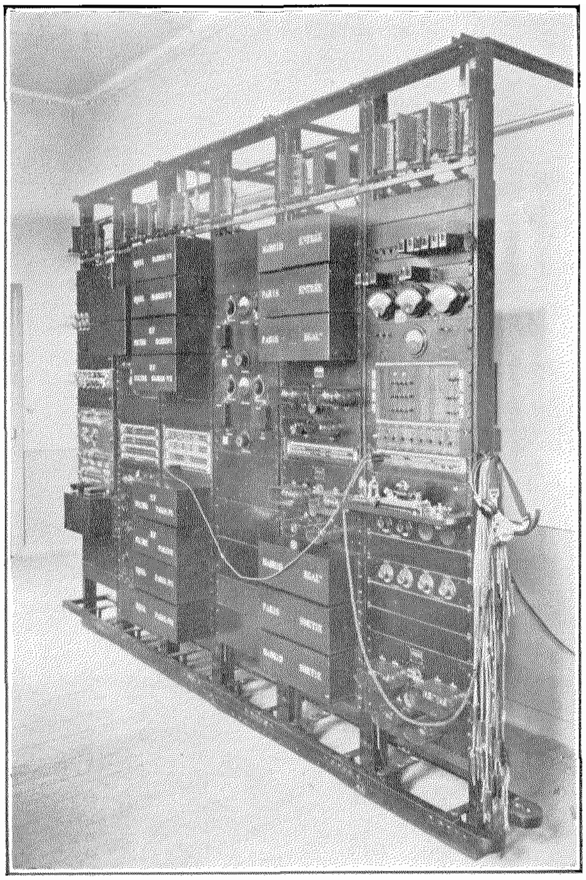

Figure 7—Saumur carrier repeater equipment.

necessary to carry the large increase of traffic. The demand accordingly was made for a second three channel system, and the possibility of providing it was investigated. A survey was made which revealed that, although another pair of wires could be provided between Versailles and the Spanish border, this circuit would require a considerable amount of rebuilding in order to render it suitable for carrier operation. This work consisted in replacing certain short lengths of underground cable by means of open wire lines, the selection of lines on the basis of crosstalk measurements, and the clearing of the route generally from line troubles. The additional channels were brought into Paris from Versailles by means of non-loaded cable circuits reserved for the French Government. These were equalised over the range of transmitted frequencies, as explained above. A 4-wire circuit, similar to that of the first system, was provided in the cable between Paris and Boulogne. Between London and Canterbury there was no difficulty in providing a second 4-wire circuit, similar to that of the first system. For the cross-Channel connection, however, a real difficulty was encountered. Owing to the heavy traffic carried over this link between Great Britain and the Continent, there were no spare circuits available in the submarine cable.

The means chosen for obtaining the additional channel required was that of splitting the 4-wire circuit used for the first London-Madrid circuit into two 2-wire circuits, necessitating the provision at Canterbury and Boulogne of 4-wire terminating sets and balancing networks. The ultimate layout was as shown in Figure 4. There

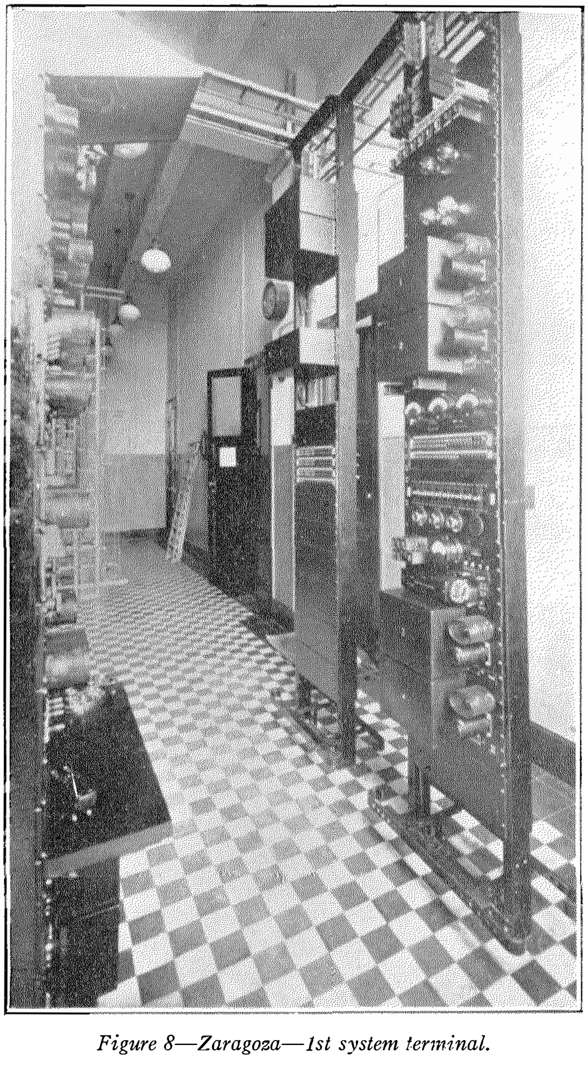

Figure 8—Zaragoza—1st system terminal.

Figure 9—The line near Bordeaux.

was also a circuit shortage between Madrid and the French border; because of this, it was decided to transfer the carrier terminal of the first system from Zaragoza to Madrid, and to employ one of the two circuits rendered spare between Madrid and Zaragoza by this device for the second system. The make-up of the circuits was thus in accordance with the following table:

Section	*Length in km.*	*Type of circuit*
(a) London-Canterbury	99	1.27 mm. 4-wire, medium-heavy loaded, cable circuit.
(b) Canterbury-Boulogne	93	2.01 mm. 2-wire, continuously loaded, submarine cable circuit.
(c) Boulogne-Paris.....	239	1.5 mm. 4-wire, medium-heavy loaded, cable circuit.
(d) Paris-Versailles.....	22	1.0 mm. 4-wire, non-loaded, cable circuit.
(e) Versailles-Madrid...	1412	Carrier link.

The total length of the connection is approximately 1,870 kms. It is made up of not less than four different types of circuits. Referring to Figure 4, it shows that voice-frequency telephone repeaters are located at London, Canterbury, Boulogne, Poix, Paris, Versailles, and from Figure 1 it appears that carrier frequency telephone repeaters are located at Versailles, Saumur, Saintes, Bordeaux, San Sebastián, Zaragoza and Madrid.

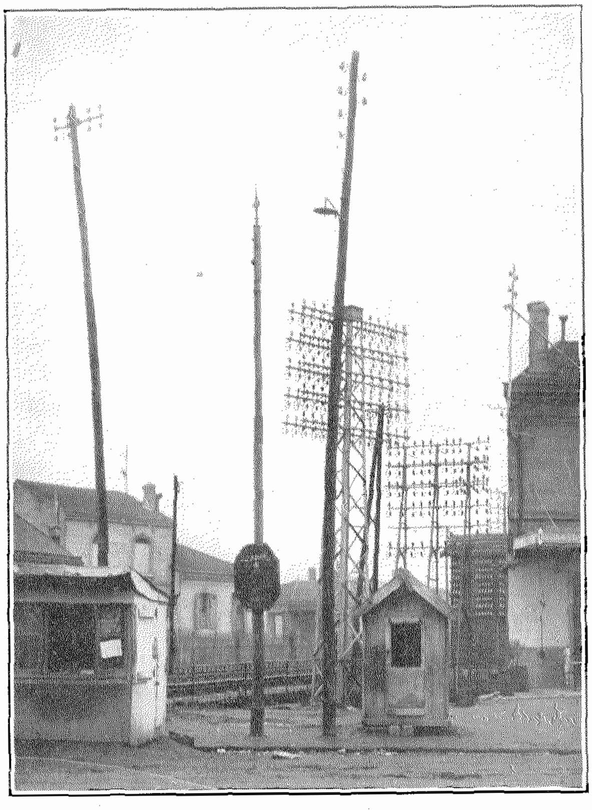

Figure 10—Guerite at Saintes.

Figure 12 indicates that the terminal equipment at Versailles, after the installation of the second system includes, in addition to the carrier terminal equipment, the 4-wire voice-frequency repeaters, equalisers and terminating sets of the cable circuits. It will be noted that each of the two carrier systems is equipped with a pilot regulating and alarm circuit. This precaution was taken owing to the instability of the open-wire lines.

The circuits were set up in such a manner that the loss on the cable circuits between the London terminal and the carrier terminal at Versailles was zero. The overall circuits therefore operated at the net loss value of the carrier frequency link. Figure 13 is the transmission characteristic of the cable circuits between London and Versailles, and Figure 14 that of the overall circuits between London and Madrid.

The second system was cut-over into service on January 1, 1929, there being, therefore, since that time, four circuits between Madrid and Paris, and two between Madrid and London.

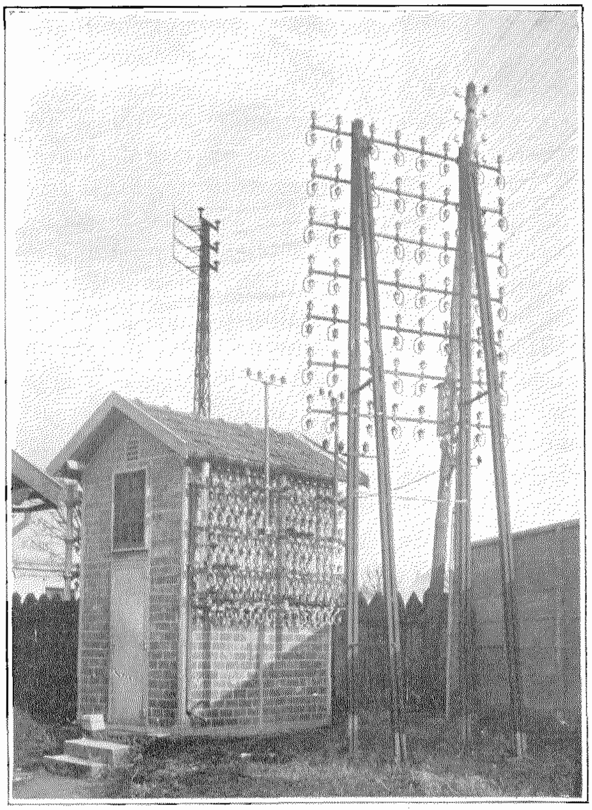

Figure 11—Guerite at Bordeaux.

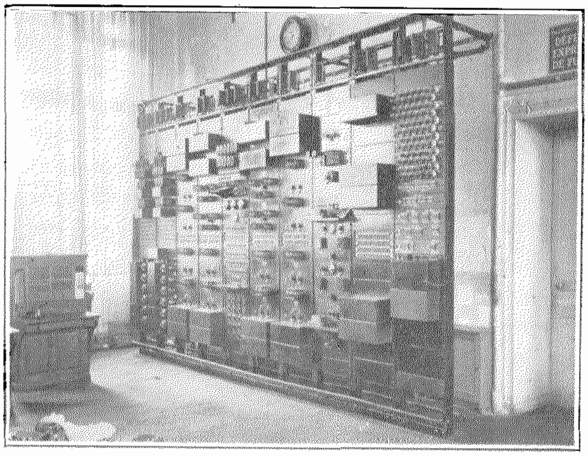

Figure 12—Versailles—1st and 2nd systems terminal.

There are indications that still more circuits will be required in the near future. The difficulty of providing these will be somewhat reduced in view of the recent cut-over of the Paris-Bordeaux cable, which solves the problem of the shortage of circuits over that section of the route. Therefore, by the time this article is in print, the carrier terminal will have been transferred from Versailles to Bordeaux, marking a further stage in the development of the service. There will remain, however, the problem of the shortage of circuits between Bordeaux and San Sebastián; but with the aid of the French Administration, this difficulty should be overcome, until the extension of the Bordeaux cable to the Spanish border—under consideration—is accomplished.

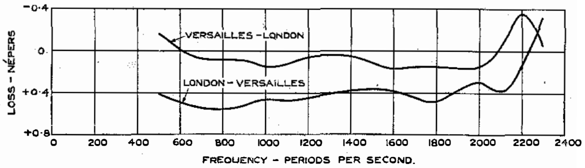

Figure 13—Transmission characteristic of the London-Versailles link.

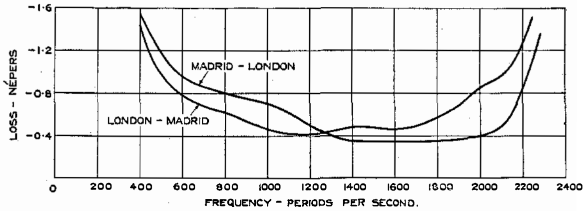

Figure 14—Overall transmission characteristic of the London-Madrid circuits.

Electrical Communication in 1929

WHATEVER else may be said of electrical communication when its history for the year 1929 is finally written, from the viewpoint of progress in long distance telephony it doubtless will be considered outstanding. While this issue of "Electrical Communication" went to press too early to permit obtaining a full picture of the year's happenings in the field of communication throughout the world, the following is a synopsis of most of the important events.

The year 1929 witnessed vigorous growth in the number of short wave radio telephone circuits. Additional short wave channels have been cut into service between the United States and England, making a total of three short wave channels and one long wave channel in operation. At the English end of the link, the equipment for one channel was built by the British Post Office and that for the other channels by Standard Telephones and Cables, Limited. Through cooperation between the American Telephone and Telegraph Company and the British Post Office a transatlantic telephone cable connecting Great Britain and America is also projected.

The North Atlantic radio service was heretofore available to the public only between the hours of 6:30 A. M. and 10:00 P. M., but it is now being furnished on a twenty-four hour basis. A person to person service is also availabe between the United States and England and the seventeen other countries already in telephone connection with Great Britain.

A momentous event occurred on Columbus Day, October 12, when Madrid and Buenos Aires were linked by radio telephone by the International Telephone and Telegraph Corporation. As a result, the International's telephone systems in Argentina and Uruguay, were placed in direct telephone communication with the Spanish Telephone System. The Madrid-Buenos Aires link is the longest of its type in commercial operation, and through the long distance lines of the Compañía Telefónica Nacional de España may connect all the principal countries of Europe with Argentina and Uruguay, and later with Chili. Connection with these South American countries in turn is made possible by reason of the completion in 1928 of the South American transcontinental telephone circuits of the International Telephone and Telegraph Corporation.

The Buenos Aires-Madrid link is especially important in that it represents a radio telephone channel connecting telephone networks to telephone networks as distinguished from "point to point" systems. With the exception of the service between the United States and England, it is the only network to network system in commercial operation in the world today.

During 1929 North Atlantic telephone service was opened between the United States and Czechoslovakia; also extended in Italy by the addition of facilities to Genoa. In Great Britain the transatlantic telephone service was extended to Belfast and Dublin, Ireland, and to the Isle of Man.

The Anglo-Polish service was extended into Poland to Cracow, Lodz, Poznan, and other towns. The Lodz exchange was connected by long distance with the Swiss telephone system. Nine additional departments of France were given telephone service with Switzerland so that the whole of that country, with the exception of Corsica, is now connected with the Swiss network. In addition, telephone communication between Copenhagen, Genoa, Milan, and Turin has been established via Switzerland.

Telephone service between Great Britain and Finland, Paris and Finland, Rome and London, Switzerland and Italy, Hungary and Denmark, and Hungary and Poland is now available. Service between Stockholm and Revel, Esthonia, via Helsingfors, Finland, has also been established.

In September, the new underground Paris-Lyon-Marseilles telephone cable was opened for service. It is 800 km. long and contains 130 circuits. In October, the new Italian underground cable linking Naples with Florence was inaugurated. The year also saw the underground telephone cable between Vienna and Graz extended to the Jugoslavian frontier, as well as the laying of the new East Prussian submarine cable between Leba and Pillau.

Long distance voice frequency dialing was first demonstrated successfully in 1929 on the recently inaugurated Rome to Florence cable.

There was a continued increase in the application of carrier current telephony and telegraphy for the efficient use of existing plants in America, in Europe, especially in Spain, France, and Italy, and in Australasia and in other localities. In Australia and New Zealand notable advance has been made in carrier current communication where the great distances are peculiarly adapted to this type of operation.

In Spain during 1929, the increase in long distance traffic was of the order of 40%, in Chile it was of the order of 60%. In these countries as in all others, long distance traffic has increased rapidly when improved service was furnished. That long distance telephony including international telephony is coming into its own is attested by the fact that in Copenhagen an international telephone directory has been published which generally describes international telephone service, gives information about circuits, details of toll rates and lists some 12,000 firms in 27 countries, classified under various trades and indexed alphabetically.

Experiments in the radio field have been conducted on very long switched radio telephone circuits, notably trials by the American Telephone and Telegraph Company and the British Post Office linking New York with Sydney, Australia, by means of the short wave radio link from New York to London and the British system from London to Australia.

Experimental or commercial "point to point" radio telephony was undertaken in connection with radio telegraph stations, such as Nauen-Buenos Aires and Paris-Buenos Aires.

The British Radio Cable merger went into effect on September 30th. Doubtless this will greatly facilitate the handling of overseas telegraph business.

Long distance commercial radio telephone service between land lines and the S. S. *Leviathan* has recently been announced by the American Telephone and Telegraph Company. Radio telephone experiments were also conducted by the International Telephone and Telegraph Corporation on the S. S. *Berengaria* and the S. S. *Olympic* and it is expected that early in 1930 commercial service will be inaugurated on a number of the larger transatlantic liners.

Technically, important radio and telephone development has been the wide acceptance and general adoption of crystal controlled transmitters. By placing the crystals in temperature ovens the frequency stability of crystal controlled transmitters has been improved so that the frequency band necessary for a given service has been reduced and consequently more stations can be operated in a given width of the radio spectrum.

The year has also seen an increase in the types and numbers of directional radio systems. Most of the important long distance point-to-point radio telephone and telegraph circuits now employ directional antennae at one or both terminals.

Further work has been done on radio telephone secrecy systems. A privacy system is in use on the Madrid-Buenos Aires radio link.

Much research work has been done on radio telephony and telegraphy as applied to aeroplanes. There have been developed radio beacons which indicate to a pilot whether he is on his right course and which show the side of deviation from the course; also a light weight radio telephone transmitter and receiver. The latter equipment permits two way radio telephone communication between planes and the ground for ranges up to about 100 miles.

Broadcasting in 1929 may be said to have reached the trans-oceanic stage. In September, a 500 word speech was transmitted by trans-Atlantic radio telephone and simultaneously broadcast throughout Europe. Other programs were also broadcast across the Atlantic.

The Czechoslovakian Government during the year placed an order for a 120 kw. broadcasting station at Prague. So far as is known, this is the largest station which has been planned up to the present time.

Considerable experimental work has been done on picture transmission and television. Picture transmission systems developed in America, Europe, and Japan are in commercial operation, At more or less regular times certain broadcasting stations send out television transmissions and the Bell Telephone Laboratories have given a demonstration of color television. Satisfactory commercial television, however, still appears to be some distance in the future.

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