Master Reference System for Telephone Transmission[1]

By W. H. MARTIN and C. H. G. GRAY

The telephone transmission system described here is the Master Reference System of the Bell System for the expression of transmission standards and the ratings of the transmission performance of telephone circuits. The transmitter and receiver elements of this system are reference standards for the ratings of the transmitting and receiving performance of terminal station sets.

A replica of this reference system, installed in Paris, has been adopted as the Master Reference System of the International Advisory Committee on Long Distance Telephone Communication in Europe. The establishment of these two master systems provides a common reference for the telephone transmission work of the Bell System and the telephone administrations which are members of this International Advisory Committee.

THE Master Reference System for Telephone Transmission, as its name indicates, is to serve as the fundamental circuit in the ratings of the transmission performance of telephone circuits. In describing this system, therefore, it will be advantageous to outline first the general considerations underlying the methods of determining and specifying these ratings and their applications.

The conversions and transfers of energy which constitute the process of telephone transmission result in general in a difference between the speech sounds at the sending end of the telephone circuit and the sounds reproduced at the other end in the ear of the listener. These reproduced sounds may differ from the original in three important respects; their loudness, their distortion or degree to which their wave shape departs from facsimile reproduction, and the amount of extraneous sound or noise which accompanies them. From the standpoint of telephony, the major importance of a difference between the original and reproduced sounds is determined by its effect on "intelligibility," that is, the degree to which the latter sounds can be recognized and understood by the listener when carrying on a telephone conversation. The tolerable departure of the reproduced from the original sounds is limited also by certain effects which are noticeable to the listener before they materially affect intelligibility, such as loss of naturalness.

Measurements of intelligibility are of utmost importance in rating the performance of telephone circuits, but they are unduly cumbersome for direct use in the detailed development and design of telephone circuits and their many parts, particularly where small effects are concerned. It has been desirable, therefore, to handle telephone

[1] Presented before A. I. E. E. Summer Convention, June 24–28, 1929.

transmission work in two steps. One natural division is suggested by the statement that intelligibility is a function of the relation between the output and input speech sounds, and of the psychological reaction of the listener to these output sounds. Because of the complex nature of the speech sound waves, however, it has been found more practicable to treat the transmission performance of telephone circuits in the following two parts: (1) the physical performance of the circuit, and (2) the relation between physical performance and intelligibility. The physical performance of a circuit is taken here to cover the transmission characteristics which can be specified in terms of the performance for single frequencies, a number of frequencies being taken to cover the range which is important for the reproduction of speech sounds. These measurements of physical performance cover such things as the response-frequency characteristic of the circuit over the range of speech frequencies, the distortion due to non-linear elements, phase distortion and the extraneous currents which cause noise. These determinations of physical performance do not include measurements of the speech sounds themselves, nor of the functioning of the talker and listener. This differentiation is advantageous in segregating the studies of speech sounds and of the psychological phases of the work, and permits the design of the operating plant and a large portion of the development work to be carried out on a physical basis.

The determination of the relation between intelligibility and the physical performance of a telephone circuit is a laborious process, because persons play the parts of generators and meters and a number of people must be used in both parts to take into account the normal ranges of their performance. The goal of this portion of the work has been, therefore, to establish suitable relations which will permit the determination of the intelligibility of a circuit by computations which start with the physical characteristics of the circuit. This work [2] has involved determinations of the capabilities of circuits having various kinds of physical characteristics to reproduce intelligible speech, investigations of the nature of speech sounds and hearing, and of people's customs in using the telephone.

Prior to the time when suitable means were available for measuring the physical performance of telephone circuits, and when the kinds of circuits in commercial use were quite similar in their distortion characteristics, the practice was adopted of rating the performance of a circuit by comparing it on a loudness basis with a reference circuit which was adjustable in attenuation, and whose distortion was closely similar to that of the commercial circuits. In such a comparison, a

[2] "Speech and Hearing," by H. Fletcher, published by D. Van Nostrand Co.

determination is made of the equivalence of loudness or volume of these two circuits by talking alternately over them and adjusting the reference circuit until the sounds coming out of the two receivers are judged to be equal. For the conditions where volume is the important controllable characteristic of telephone circuits, these loudness comparisons constitute a practicable and effective means of indicating the performance of these circuits.

The reference circuit adopted about twenty-five years ago for these loudness comparisons consisted of transmitters, receivers, station sets, cord circuits and a line, of types which were then used commercially. In this reference circuit the line was an adjustable artificial line simulating a 19 AWG. cable circuit having a capacity per loop mile of 0.054 mf. The amount of cable in this line to give a loudness

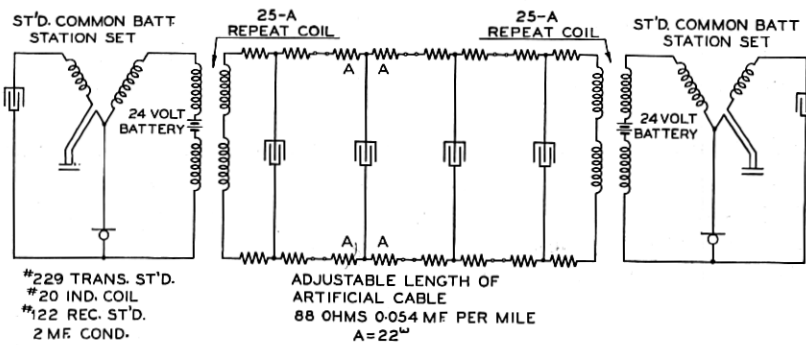


Fig. 1—Standard cable reference system.

balance was taken as the rating of the circuit under comparison. This reference system, shown schematically in Fig. 1, has been called the Standard Cable Reference System.

In addition to this rating of the performance of a telephone circuit, this standard cable reference system has had other applications. Certain settings of this reference system were selected as specifying the standards of transmission which were to be provided in the design and operation of commercial circuits for the several kinds of service, such as local and toll. The effect of introducing or changing any part in a commercial circuit was rated in terms of the amount of cable by which it was necessary to change the line of the reference system to produce the same effect on the loudness of the reproduced speech sounds. Likewise, the transmitters and receivers of this reference system were used as reference instruments for the comparison and rating of other transmitters and receivers.

This cable reference system has played a very important and necessary part in the development of telephone transmission, in that it has provided a ready means of rating the performance of the various parts of the system and of any changes, and made it possible to design commercial circuits to provide a predetermined grade of service. The performance of this system was specified by stating the kinds of apparatus and circuits used. The performance of the elements of the electrical portion of the system could be checked by voltage, current and impedance measurements, but for the transmitters and receivers reliance for constancy of performance was placed primarily upon the careful maintenance and frequent cross comparisons of a group of transmitters and receivers which were specially constructed to reduce some of the sources of variation in the regular product instruments. In this way, reasonable assurance of the performance of the reference system was secured. This system has been widely used both in this country and in other parts of the world, and the performances of the various systems have been kept in accord by frequent circulation of calibrated transmitters and receivers.

As the telephone art has developed, modifications have been found to be desirable in this reference system to make it more suitable for its purpose. Telephone instruments and circuits have been designed and used which have less distortion than existed in the corresponding parts of the cable reference system. For this reason it is desirable to have as a new reference system one with which the transmission over the most perfect telephone circuit or over some less perfect one may be simulated at will. The change of the unit of transmission from the mile of standard cable to the decibel [3] has brought about the need for a change in the line of the reference system.

In selecting a new reference system, it is obviously desirable to eliminate as far as possible the factors which are not subject to exact measurement, or which may possibly vary with time. For this reason, the elements of the new system have been chosen so that their performance may be definitely measurable at any time, and may remain as far as possible invariable. This applies also to those elements which are provided for insertion in the system when it is wished to produce some distortion which will make more easily possible a loudness balance between the reference system and the circuit under investigation.

A reference system such as that described here, in which the essential elements are so constructed as to reproduce speech with a high degree

[3] "Decibel" (db) is the name for the Transmission Unit which has superseded the "mile of standard cable." W. H. Martin, *Bell System Technical Journal*, January, 1929, and *A. I. E. E. Journal*, March, 1929.

of perfection, and with which provision may be made for modifying the speech in definite and reproducible ways, affords a convenient means for studying the capabilities of telephone circuits of different physical performances. These investigations, however, are outside the purpose of this paper, which is to describe the new reference system and its application in making volume ratings.

General Requirements

The outstanding conception of the new reference system is that its performance should be suitable to serve as a reference base line for indicating the performance of all telephone circuits and that the transmitter and receiver elements of the new system should provide similar base lines for the performance of electroacoustic converters. To meet these needs properly the performance of the system and its parts should be capable of being measured and definitely specified in terms of physical quantities. In this connection, there arises a matter which has been the subject of much discussion, namely, as to whether or not the specified performances of the reference transmitter and receiver should be those which are realized when used as telephone instruments. In regard to the transmitter, the difficulty comes in specifying the input when it is placed in front of the mouth of the talker. This is due to the non-uniformity of the sound field from the speaker's mouth, the nature of the waves of speech sounds and the reflections of these waves from the transmitter. In regard to the receiver, the difficulty is due to determining the output when the receiver is held to the ear. To obviate these, it has been decided to specify the performance of the transmitter in terms of the electrical output for a given pressure on the diaphragm of the transmitter and of the receiver in terms of pressure set up in a simple closed chamber for a given electrical input to the receiver. These conditions are definite and reproducible.

The most important requirement, then, for the reference system is that the physical performance of the system and of its component parts should be capable of being measured and definitely specified in terms of physical quantities. If this requirement is realized, a system providing the specified performance can be set up wherever desired. This has been the main criterion in the design of the master reference system for telephone transmission which is described here.

The second main requirement is that specifiable and predeterminable changes can be made with respect to the performance which is selected as the reference. These changes must be capable of varying the relation between the loudness of the reproduced sounds with respect to the initial sounds, the distortion of the wave shape of these reproduced sounds, and also the amount of noise accompanying these reproduced sounds.

For convenience in specifying these requirements, it has been found desirable to impose another requirement, namely, that the system be capable of giving a performance which is as free as possible from distortion and noise. It should be noted that two kinds of distortion must be taken into account: that due to unequal efficiency for sounds of different frequencies and that due to non-linearity causing unequal efficiency for sounds of different magnitudes. This requirement is also of advantage in insuring that the reference system and its parts will have less distortion than any circuit or instrument with which it may be compared. This will permit the simulation of the distortion of such instruments or circuits by the insertion of distortion in the reference system.

For convenience in use, it is highly desirable that the performance of the reference system and its parts be constant for a reasonable time under normal operating conditions.

General Features

The master reference system [4] employs a transmitter and receiver which are capable of a high degree of freedom from distortion. The transmitter is of the condenser type and the receiver is of the moving coil type. Both these instruments are materially lower in efficiency than commercial types of apparatus, but this condition is compensated for by the use of multi-stage vacuum tube amplifiers. These instruments, together with their associated amplifiers, constitute reference standards for converters between acoustic and electrical energy. The third necessary element of a telephone transmission system, namely the line, is provided by a network of resistance elements. Such a line can be made to provide uniform attenuation over a wide frequency range, and can be made to control the magnitude of this attenuation over a large range. This line is taken as giving a reference performance for lines.

The specification of the performance of such a system is based on the principle of the thermophone, which is a converter of electrical energy into acoustic waves by means of the heat generated by the passage of an electrical current through a resistance. From a knowledge of the form and physical constants of this resistance element, of the medium in which it is used, and of the electrical input to the element, the acoustic pressure generated in a chamber of known size

[4] A discussion of a preliminary model of this system was given in "A Telephone Transmission Reference System," by L. J. Sivian, *Electrical Communication*, October, 1924.

can be determined by theoretical considerations.[5] The performance of the condenser transmitter is determined by making its diaphragm a wall of a simple closed chamber in which the thermophone is placed. By this means a known pressure wave of any frequency over the range desired can be impressed upon the diaphragm of the transmitter. The voltage output of the transmitter for a specified circuit condition is then measured. From this measurement the ratio of the voltage output to the acoustic pressure on the diaphragm is established for that instrument and circuit condition. With the performance of the transmitter thus established, the performance of the receiver element of the reference system is measured by acoustically coupling the receiver to the condenser transmitter, so that the receiver actuates the transmitter, and then determining the relation of the pressure generated by the receiver in the coupler to the voltage input to the receiver. The performance of the line element is determined by well-known means. The performance of the whole system can then be expressed in terms of the pressure produced by the receiver with respect to the pressure on the diaphragm of the transmitter.

The performance of this system is practically free from distortion for the energies which it is required to handle, and probably materially excels in this respect that of any previous system. With this system, volume relations between output and input sounds can be varied over a wide range with practically no accompanying distortion. In comparing such a system, however, with commercial systems, it is advantageous also to be able to control distortion. This is particularly the case when using the instruments of the master system for rating the volume efficiency of commercial types of transmitters and receivers. To facilitate this, arrangements are made for the introduction into the amplifiers associated with the transmitter and receiver, of networks which may be designed to give a variation of efficiency with frequency which corresponds to that obtained with commercial apparatus. These networks and their distortion effect can, of course, be definitely specified. The line element of this master system can be replaced by a line or network giving any type of distortion desired. Also, known amounts of extraneous currents to produce noise can be introduced into this circuit without otherwise appreciably affecting its performance. This is accomplished by connecting a relatively high impedance source of voltage of the desired wave shape across a circuit element of relatively low resistance.

This system provides a performance which is definitely known, and

[5] The theory of the thermophone as a precision source of sound is outlined in papers by H. D. Arnold and I. B. Crandall, *Physical Review*, July, 1917, and by E. C. Wente in the *Physical Review*, April, 1922.

which can be varied over a range of volume and distortion. It well meets the requirements and represents a material advance over the standard cable reference system which it now replaces. In order to tie together ratings established in terms of the old system with those of the new system, comparisons of the two have been made to determine the adjustments of the new system which make its loudness performance correspond with that of the old.

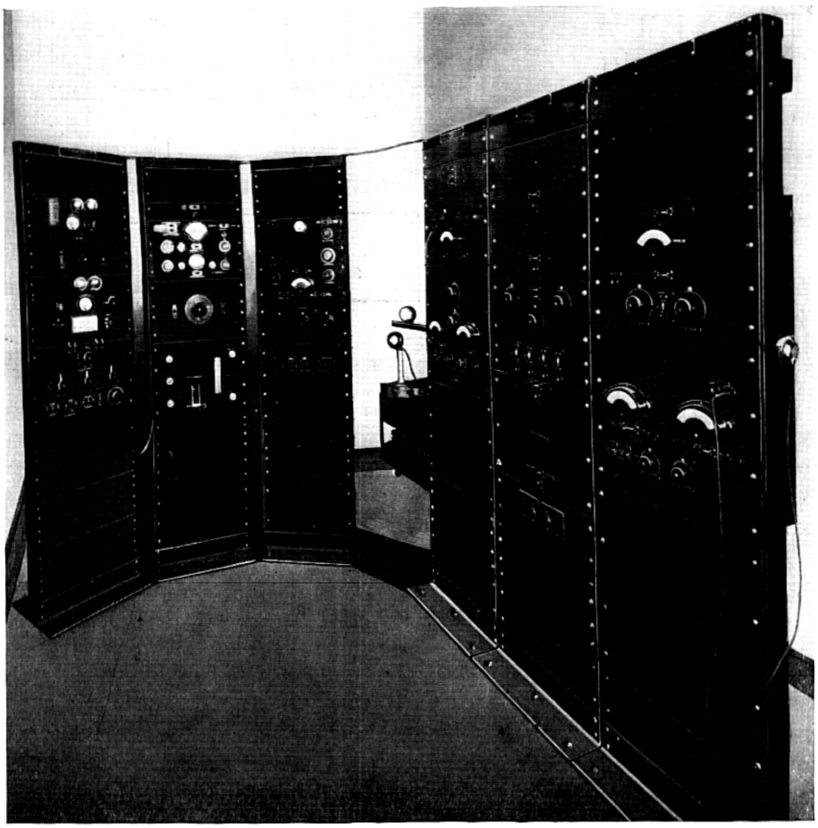


Fig. 2—Master reference system for telephone transmission with associated calibration apparatus.

Description of Master Reference System

The master reference system with associated calibration apparatus is shown in Fig. 2. This equipment, mounted on steel panels and racks, and arranged as shown, is installed in a room, shielded from acoustical and electrical disturbances, at the Bell Telephone Laboratories in New York City. In Fig. 2 the transmitter, line, and receiver of the reference system are shown on the three racks at the right. The calibration apparatus, consisting of an oscillator, thermophone, vacuum tube voltmeter and volume indicator are shown on the other three racks. A schematic diagram of the master reference system is shown in Fig. 3.

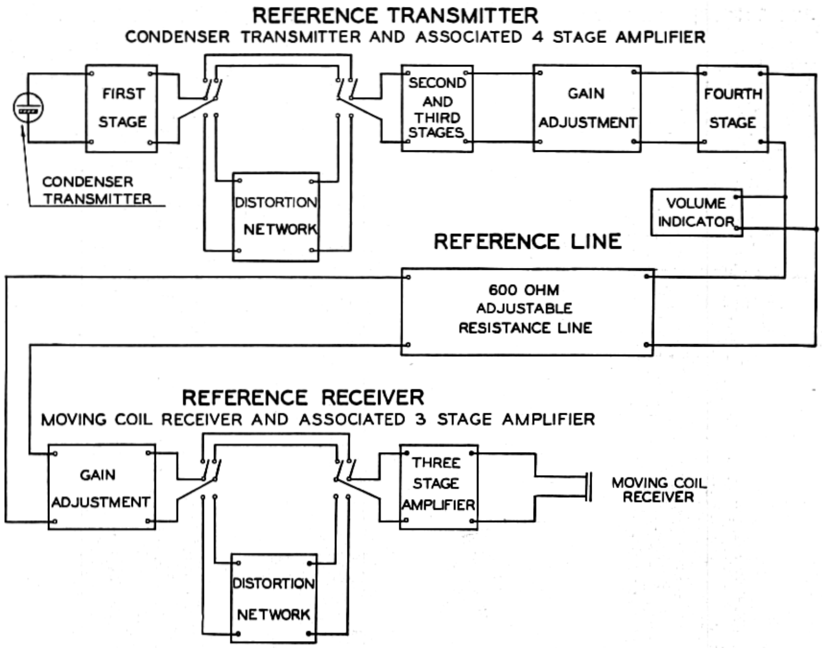


Fig. 3—Schematic diagram of master reference system.

The reference transmitter consists of a condenser transmitter and associated four-stage amplifier. The condenser transmitter is simple and rugged in construction. It has been available for work of this nature for several years during which time considerable experience has been obtained with it. In this system the condenser transmitter is held in an adjustable mounting and is equipped with a guard by means of which the speaker can keep his lips at a fixed distance from the diaphragm. This guard consists of a wire ring 4.7 cms. in diameter, held parallel to and at a distance of 4.1 cms. from the diaphragm of the transmitter by three wire supports. A volume indicator with meter visible to the speaker enables him to maintain an approximately constant talking intensity. In the condenser transmitter,[6] shown in

[6] The theory and operation of this transmitter are discussed in papers by I. B. Crandall, *Physical Review*, June, 1918, and E. C. Wente, *Physical Review*, July, 1917, and *Physical Review*, May, 1922.

Fig. 4 and in cross-section in Fig. 5, a thin highly stretched duralumin diaphragm is mounted close and parallel to a steel plate grooved and

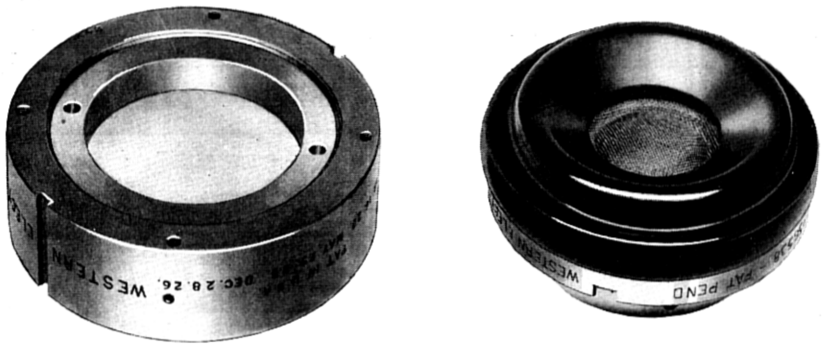


Fig. 4—Condenser transmitter and moving coil receiver.

perforated for air damping. This diaphragm and plate form the electrodes of a condenser polarized by a battery through a high

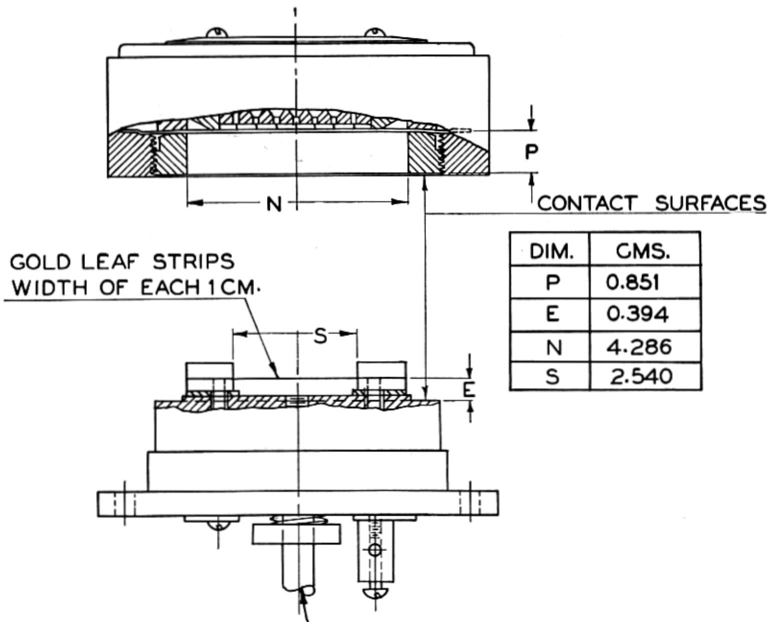


Fig. 5—Schematic of condenser transmitter and thermophone.

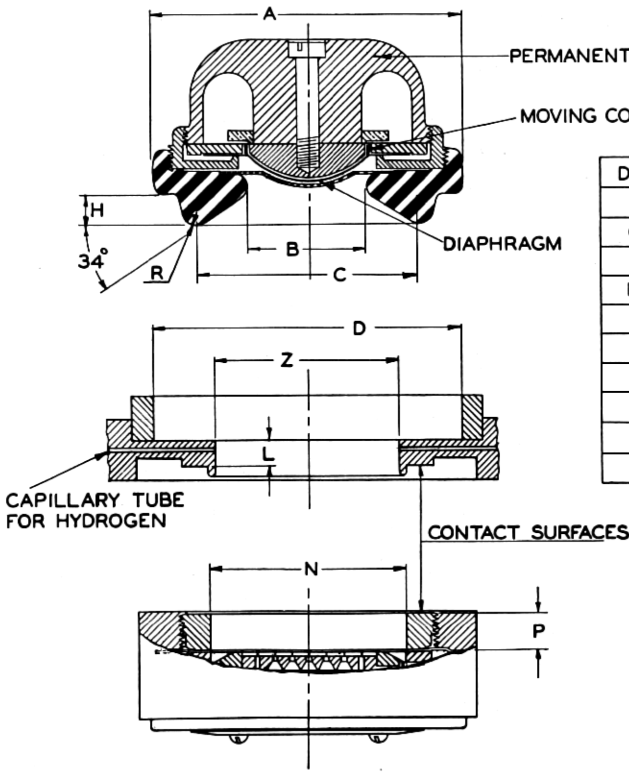
resistance. Sound vibrations impinging on the diaphragm actuate it and produce variations in the capacity of this instrument. The resulting alternating potentials, faithfully representing the sound pressure waves, are amplified by the associated amplifier. Between the first and second stages of this amplifier, provision has been made for the introduction of distortion networks to simulate the distortion of any transmitting system. Between the last two stages are attenuating networks permitting adjustment of the relation between transmitter input and transmitter output over a range of 22 db in steps of

Fig. 6—Thermophone in chamber for calibrating transmitter.

0.1 db. The output impedance of the amplifier is 600 ohms with negligible phase angle.

The reference line consists of a series of balanced resistance networks. This line has a characteristic impedance of 600 ohms matching the output impedance of the reference transmitter and the input impedance of the reference receiver, thereby eliminating any reflection effects at these junctions. By means of suitable controls the attenuation may be varied over a range of 101 db in steps of 0.2 db.

The reference receiver consists of a moving coil receiver and associated three-stage amplifier. Means are provided for adjusting the relation between the input to the receiver and its output over a range of 22 db in steps of 0.1 db. As in the case of the reference transmitter, provision has been made for the introduction of distortion networks to simulate the distortion of any receiving system. In the moving coil receiver [7] shown in Fig. 4 and in cross-section in Fig. 7, a coil of aluminum ribbon, by vibrating relatively to a fixed permanent magnet, actuates a clamped, unstretched, thin duralumin diaphragm to which



DIM.	CMS.
B	2.54
C	4.76
L	0.49
N	4.286
P	0.851
Z	3.97
A	6.67
D	6.68
H	0.64
R	0.36

Fig. 7—Schematic of moving coil receiver, coupler and condenser transmitter.

it is attached. Air damping in this receiver is secured by an arrangement somewhat similar to that employed in the condenser transmitter. The structure is simple, rugged, and, from the standpoint of freedom from distortion, its performance is comparable to that of the condenser transmitter. The central surface of the diaphragm is protected by a meshed wire screen instead of by the more usual type of receiver cap. This construction avoids resonance effects which

[7] This instrument, which is similar in many respects to one described by E. C. Wente and A. L. Thuras in the *Bell System Technical Journal*, January, 1928, will be discussed in a future paper by the same authors.

would otherwise occur in the confined air space between diaphragm and cap. The contour of the ear piece, resembling that of the familiar telephone receiver, permits the listener to readily center the receiver on his ear.

In order that an individual part of any telephone circuit may be compared with the corresponding element of the master reference system, the system is arranged so that the reference transmitter, reference line or reference receiver, may be replaced by the corresponding part to be rated.

Calibration of Master Reference System

To specify adequately the performance of the master reference system, in terms of definite physical quantities, apparatus is associated with the system for making electroacoustic calibrations of the reference transmitter and reference receiver, and electrical calibrations of the circuits. In general, the method employed in these calibrations is to adjust the setting of an attenuator to obtain a deflection on the galvanometer of a vacuum tube voltmeter, equal to the deflection produced when measuring the output of the element under calibration. This avoids the necessity for an absolute calibration of the measuring device.

The source of alternating currents, used for calibrating purposes, is an oscillator, capable of producing currents with a harmonic output usually less than 3 per cent of the fundamental.

The measuring equipment used for making the above calibrations consists of a two-stage vacuum tube voltmeter in conjunction with a tuned circuit connected across its input. By means of this tuned circuit, harmonics of the fundamental frequency to be measured are attenuated by at least 20 db.

The calibration of the condenser transmitter is made with a thermophone, the gold leaf thermal elements being shown in Fig. 6. In Fig. 5 is shown a cross-section of a condenser transmitter and a thermophone. Petrolatum is used to form a seal between the instrument and the thermophone block. The air in this small enclosed chamber, formed by the walls and diaphragm of the condenser transmitter and the thermophone block, is replaced by hydrogen. Since the velocity of sound in hydrogen is approximately four times that in air, the frequency range over which measurements may be made before standing wave effects are experienced is extended by the use of this gas. In addition, the efficiency of the thermophone is increased, the constant of diffusivity for hydrogen being greater than that for air. Both alternating and direct currents are passed through the gold leaf thermal elements, the direct current being sufficiently large to make negligible the double-frequency effect resulting when alternating current is supplied to the thermophone. The alternating current passing through the thermal-elements (gold leaf being selected because of its low heat capacity) causes variations in their temperature. Periodic expansions and contractions of the surrounding gas, resulting from the varying heat transfer occasioned by the periodic temperature changes of the thermal elements, constitute sound waves of precisely determinable pressure. These sound waves actuate the transmitter and the ratio of the voltage output to the sound pressure gives the transmitter calibration. The process involved is as follows: Referring to Fig. 8.

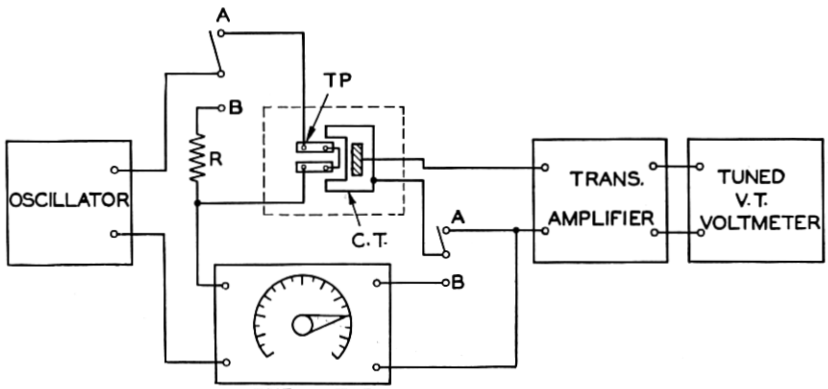


Fig. 8—Circuit for calibrating condenser transmitter.

E_T = Voltage generated by condenser transmitter per bar (one dyne/cm.^{2}).
I_1 = Alternating current through thermophone and attenuator.
P = Pressure developed by thermophone per volt alternating current across it.
V_{VM} = Voltage across voltmeter.
A = Ratio of voltage delivered to 600-ohm load by the transmitter amplifier to voltage impressed in series with condenser transmitter.
V_0 = Voltage across attenuator input.
R_1 = Input impedance of attenuator.
R = Thermophone resistance.
N = Attenuator setting in db.
TP = Thermophone.
CT = Condenser transmitter.

With the switches in Fig. 8 in position "A," the alternating current input to the thermophone and the amplifier gain are adjusted to obtain a convenient voltmeter deflection (V_{VM}). Then:

$$V_{VM} = I_1 RPE_T A.$$

Operating the switches to position "B" and manipulating the attenuator to attain the same voltmeter deflection as before we obtain

$$V_{VM} = V_0 A \times 10^{(-0.05N)} = I_1 R_1 A \times 10^{(-0.05N)}.$$

Then:

$$E_T = \frac{R_1 \times 10^{(-0.05N)}}{RP}.$$

The moving coil receivers are also calibrated in a sealed chamber in an atmosphere of hydrogen by an arrangement shown in cross-section

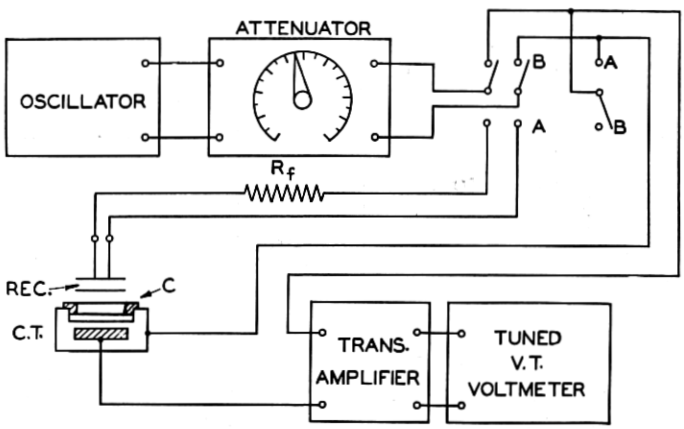


Fig. 9—Circuit for calibrating receiver.

in Fig. 7. A condenser transmitter, calibrated in the above manner, is actuated by the sound output of the receiver under test driven by the oscillator. The process involved is as follows: Referring to Fig. 9.

V_{VM} = Voltage across voltmeter.
V_0 = Voltage across attenuator input.
V_R = Voltage across receiver terminals

$$= \frac{V_0 R_R}{R_R + R_f} \times 10^{(-0.05N_a)}.$$

R_R = Impedance of receiver plus cord.
R_f = Fixed resistance.
P_R = Pressure developed by receiver per volt across receiver terminals.
E_T = Voltage developed by condenser transmitter per bar (one dyne/cm².).
A = Ratio of voltage delivered to 600-ohm load by the transmitter amplifier to voltage impressed in series with condenser transmitter.
N_a = Attenuator reading with switches on "A."
N_b = Attenuator reading with switches on "B."
C = Coupler (Fig. 7).
CT = Condenser transmitter.

With the switches indicated in Fig. 9 in position "A" the attenuator is adjusted to position N_a to produce a convenient deflection on the voltmeter (V_{VM}). Then:

$$V_{VM} = V_0 \frac{R_R}{R_R + R_f} P_R E_T A \times 10^{(-0.05 N_a)}.$$

Operating the switches to position "B" and adjusting the attenuator to some position N_b to reproduce the above voltmeter deflection V_{VM} we obtain:

$$V_{VM} = V_0 A \times 10^{(-0.05 N_b)}.$$

Then:

$$P_R = \frac{(R_R + R_f) \times 10^{0.05(N_a - N_b)}}{R_R E_T}.$$

The calibrations of the purely electrical elements of the circuit are made by measurements of input, output, and impedance.

Fig. 10 shows, for particular amplifier adjustments which are discussed below, the frequency response characteristics of the reference transmitter, reference receiver and the complete reference system with 0 db in the line. The characteristic of the reference transmitter and also of the reference receiver, in each instance, is that of the instrument and associated amplifier combined. However, as the frequency response of each of the amplifiers is uniform within 2 db from about 50 to 10,000 cycles per second, the curves shown are essentially the calibrations of the instruments determined as described above. The primary purpose of these characteristics is to show the performance of these elements for definitely specified physical conditions. Consequently, no corrections are included in these curves for the effect on the sound field of the speaker when talking into the condenser transmitter. Neither have corrections been applied for the effect of leakage between the listener's ear and the earpiece of the receiver nor

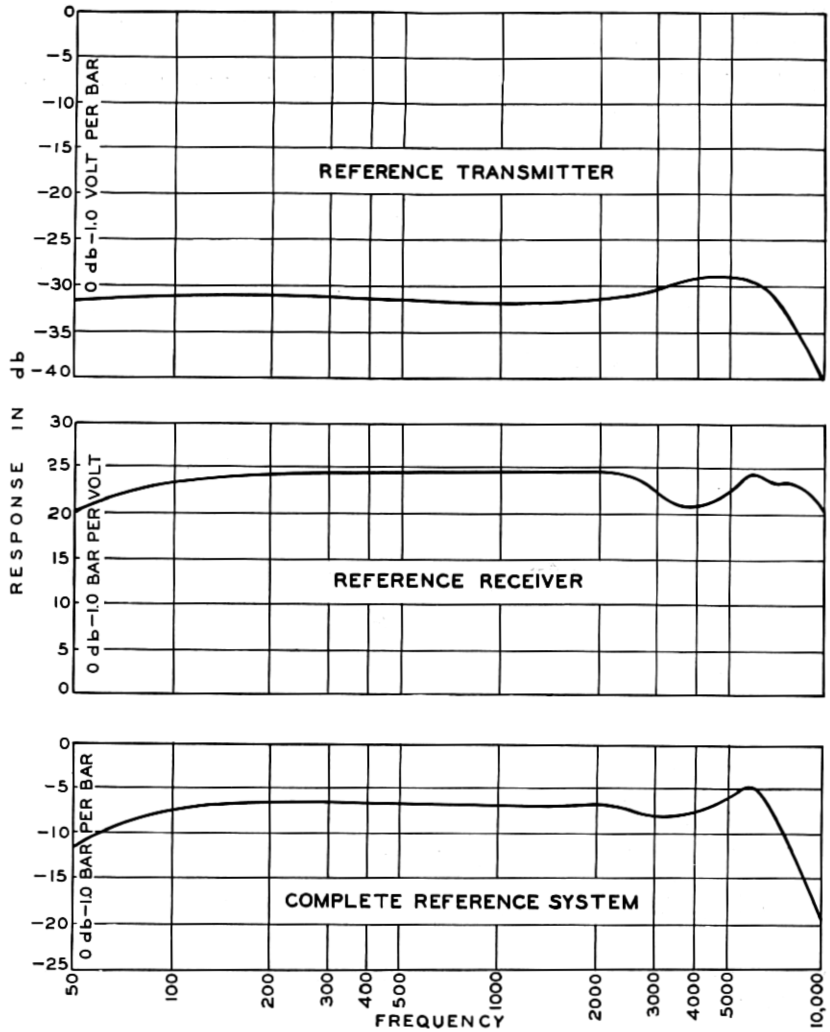


Fig. 10—Response characteristics of reference transmitter, reference receiver and complete reference system with 0 db in the line.

for the difference between the volume enclosed in the sealed chamber when making the calibration as compared with the volume enclosed in the ear canal when the receiver is held to the ear. The reference line, consisting of balanced resistance networks, has a uniform frequency response characteristic. The characteristic of the complete system, therefore, except as its level is affected by the attenuation in the reference line, is that of the reference transmitter and reference receiver combined, there being no reflection effects at the junctions of the reference line with either the reference transmitter or receiver.

Fig. 11 shows the effect of introducing distortion networks in both the reference transmitter and reference receiver. The distortion net-

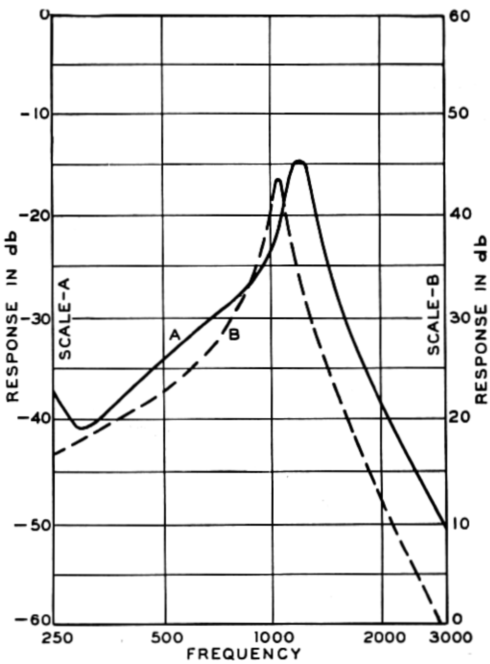


Fig. 11—Response characteristics of reference transmitter and receiver with distortion networks.
A = Reference transmitter—0 db—1.0 volt per bar.
B = Reference receiver—0 db—1.0 bar per volt.

work introduced in the reference transmitter simulates the distortion in the transmitter, station set and cord circuit, of the standard cable reference system. Similarly, the distortion network introduced in the reference receiver simulates the distortion of the receiver, station set and cord circuit, of the standard cable reference system. These two networks are designated, respectively, Transmitter Distortion Network No. 1 and Receiver Distortion Network No. 1. The distortion of any transmitter, receiver, or station set may be similarly simulated by the design and introduction in the master reference system of a proper network. The advantage of such a procedure will be evident to those familiar with the difficulties of making voice volume balances between instruments of widely different frequency characteristics. The volume efficiency of any instrument can also be reproduced by adjustment of the controls in the amplifiers of the reference transmitter or receiver as the case may be. The results of voice volume balances made with the distorted reference system can be referred to the undistorted master reference system by applying a correction for the volume effect of the distortion network in the master reference system, this effect being determined independently as a rating of the distortion network.

Experience has shown that amplifiers properly designed and constructed remain essentially constant with time. Such changes in gain as may occur because of replacement of vacuum tubes or other apparatus may be readily compensated for by adjustments of potentiometers provided for this purpose. Condenser transmitters are affected to some extent by variations in temperature and barometric pressure. The magnitude of variation at any frequency between 50 and 10,000 cycles per second from these causes may be as much as 2.5 db, although under normal operating conditions such as those experienced in buildings in this climate, the variation is usually not more than 1 db. Since changes of this character are gradual in nature, their magnitude can be readily determined by a thermophone calibration. Corrections for any change in sensitivity of the instrument may then be made by adjustment of the controls in the amplifier associated with the condenser transmitter to maintain the proper gain in the reference transmitter. Similarly, any variations in the response of the moving coil receiver may be compensated for by adjustment of the gain controls in the amplifier associated with this receiver. The magnitude of the variations, at any frequency between 50 and 10,000 cycles per second, in the moving coil receiver may be as much as 3 db although usually variations of less than 1.5 db are observed. The calibration of the condenser transmitters, and indirectly of the moving coil receivers, is dependent upon the gold leaf thermophone, whose pressure characteristic is computed from physical measurements. Results obtained with thermophones can be held within about 0.5 db of the average obtained by using a group.

Comparison of Master Reference System and Standard Cable Reference System

Since the master reference system is to replace the standard cable reference system for volume ratings, the two systems have been compared by means of voice volume balances so that data obtained in the future may be directly comparable in this respect with those obtained in the past. The respective elements of the two systems, as well as the systems as a whole have been compared. The station set and cord circuit at the sending end of the standard cable system are taken as comprising the transmitting element of that system and, likewise, the corresponding apparatus at the listening end as the receiving element. In these measurements the reflection gain at the junction of the standard cable line and the output terminals of the transmitting element of the standard cable reference system has been taken as part of the transmitting efficiency of that element. Similarly, the reflection gain at the junction of the standard cable line and the input terminals of the receiving element of the standard cable reference system has been taken as part of the receiving efficiency of this element.

In the voice calibration of the master reference system to determine the adjustments which make this system equivalent on a volume basis to the standard cable reference system, eight series of voice tests were made. The purpose of the first five series of these tests was to determine the adjustments which make the master reference system with transmitter distortion network No. 1 and receiver distortion network No. 1 inserted in their respective elements, equivalent on a volume basis to the standard cable reference system. The purpose of the sixth and seventh series of tests was to determine the volume effects of the insertion of these distortion networks in the reference transmitter and receiver. The eighth series of tests was a direct comparison of the master system without distortion networks and the standard cable system, and so serves as an overall check on the determinations of the preceding tests.

In the first series of tests a comparison was made of the reference receiver with its distortion network and the receiving element of the standard cable system by interchanging the two in the standard cable system, with 24 miles of artificial cable in the line. The receiving element of the master system was adjusted so that its sound output was judged to be equal for this condition to that of the receiving element of the standard cable system. In the second series of tests a similar comparison was made of the reference transmitter with its distortion network and the transmitting element of the standard cable reference system. These transmitting elements were connected in turn to a 24-mile standard cable line terminated by the reference receiver with its distortion network, the receiver being adjusted in accordance with the results of the first series of tests. In the third and fourth series of tests the master reference system with the distortion networks in both the transmitter and receiver was compared with the standard cable reference system, the line of the master system serving as the adjustable element. These two series of tests were similar except that 24 miles of standard cable were used in one series of tests and 14 miles of standard cable in the other. The adjustments for the reference transmitter and reference receiver in these tests were those determined from the first and second series. From the results obtained in the third and fourth series of tests, the magnitudes were determined of the reflection gain at the junction of the standard cable line with either the reference transmitter or the reference receiver, and of the volume equivalent of 1 mile of standard cable in terms of db. The reference transmitter and reference receiver, each with its distortion network, were then readjusted in accordance with these data. The fifth series of tests served as a check on the results of the previous four series. In this fifth series, the master reference system with transmitter and receiver distortion networks and 24 db in the line was compared with the standard cable reference system with 24 miles of standard cable in its line.

In the sixth series of tests the adjustment of the reference receiver without distortion was determined to make it equivalent on a volume basis to the reference receiver with distortion. The reference transmitter with distortion and the reference line with 24 db formed the rest of the system during these comparisons. In the seventh series of tests the sound output of the master reference system without distortion was compared to the sound output of this same system with distortion networks in the reference transmitter and reference receiver, the reference transmitter being adjusted to obtain a balance. During these tests 24 db was kept in the reference line. The final series of tests, serving as a check on all of the above determinations, consisted of a comparison between the master reference system without distortion and the standard cable reference system, the line of the master system being adjusted in making this comparison.

In making voice tests to determine the above settings, the speaker, whose position with respect to the transmitters was kept constant, called standard testing sentences in a conversational tone. A given intensity of calling was maintained by watching the deflections on a volume indicator connected across the output of the transmitting element. An observer, located in a quiet room removed from the systems or instruments under test, determined when the two systems under comparison gave output sounds of equal loudness. Each testing team, consisting of a speaker and observer, made 12 balances. In order to attain a suitable precision in the final results of these tests, a large number of testing teams were used, the number being largest for the tests where the difference in the quality of the output sounds of the two systems under comparison was greatest. For example, for the first series of tests, six teams were used, for the fifth 25 teams, and for the eighth series, where the master reference system without distortion was compared with the standard cable system, balances were made with 37 teams. In all, over 2,000 individual balances were made. The standard deviation of the determination for each of the first five series is of the order of 0.5 db and for each of the last three series about 1 db.

The response characteristics of the transmitter and receiver elements of the master reference system, when adjusted on the basis of the results of the voice tests, to be equivalent on a volume or loudness basis to the corresponding parts of the standard cable reference system, are shown in Fig. 10. The mean values weighted from the standpoint of importance for volume are 0.027 volt per bar for the reference transmitter, 16 bars per volt for the reference receiver and 0.43 bar per bar for the complete master reference system with 0 db in the reference line. Further consideration is being given to the values of these response characteristics of the reference transmitter and receiver to be adopted as standards.

The response characteristics of the reference transmitter with transmitter distortion network No. 1 and of the reference receiver with receiver distortion network No. 1, when these elements are adjusted on the basis of the above voice tests to be equivalent on a volume or loudness basis to the corresponding parts of the standard cable reference system, are shown in Fig. 11.

Application of the System

The results of articulation tests over the master reference system when adjusted for optimum volume are practically equivalent to those obtained in direct air transmission in a quiet room. This system and replicas of it, are particularly adapted for use in making articulation studies, since they provide an approximately ideal system with which the loudness of the output sounds can be varied distortionlessly over a wide range and in which distortion networks of various types and controlled amounts of noise can be introduced. In this way the effects on articulation of various kinds of physical performance of a telephone circuit can be investigated.

The master reference system itself will be used chiefly for the important work of rating working standard systems and instruments. These working standards can be simpler than the master system and can be provided in any number required to handle the rating of commercial circuits and apparatus.

The working standard may be of several forms. It can be similar to the master reference system, simplified in its detailed construction but capable of calibration by the means employed for calibrating the master reference system. Such a system would probably find employment in laboratories and factories where the volume of testing is sufficient to justify the use of such apparatus. Another form may include electrostatic or electrodynamic instruments which are not capable of being measured by the calibration equipment of the master reference system. A third form which the working standard may take is that involving the use of transmitters, receivers and station sets such as have been used in the standard cable reference system. These latter types of working standards can be calibrated by volume comparisons with the master system or with the first type of working standard. They will find their chief field of usefulness at such points as shops for the repair and recovery of station apparatus, where the volume of work is not sufficient to justify the expense involved in maintaining more elaborate working standards.

European Master Reference System

In Europe the recommendation of technical standards for telephony is a function of the Comité Consultatif International des Communications Telephoniques a Grande Distance (C.C.I.), which is composed of representatives of the various European telephone administrations. In 1926, at the invitation of the C.C.I., representatives of the Bell System met in London with a committee appointed by the C.C.I. to consider the adoption of a transmission reference system. This committee recommended that the C.C.I. adopt as their master reference system a system essentially the same as the one described in this paper, and that such a system, which would be a replica of one in New York, be installed in Paris in the laboratory of the C.C.I. and be known as the European Master Reference System. This recommendation was adopted by the C.C.I.

Subsequently, some improvements were made in the system, and two duplicate systems, each with its associated calibrating apparatus, have been constructed. One of these is now in the Bell Telephone

Laboratories in New York and the other in the laboratory of the C.C.I. in Paris. The C.C.I. further recommended that primary and working standard systems, used in the telephone administrations adhering to the C.C.I., be calibrated in terms of the Master Reference System. The establishment of these two master systems insures the use of a common base line for the expression of transmission standards, and for the ratings of the transmission performance of telephone circuits in the two continents where the telephone system has had its greatest development.