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A Revised Telephone Transmission Rating Plan

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Although the telephone appears to be a relatively simple device, it is in fact one of the more complex elements of the telephone business, primarily because its operation depends on transforming sound waves into electrical waves and vice-versa. This fact makes its performance difficult to evaluate and measure. It is not surprising, therefore, that the problem of evaluation and measurement, that is, of "rating", has been the subject of much thought and work over many years and that even today widely different methods are used in different parts of the world.

The Bell System has done its full share of work in this connection and as the art and state of knowledge have changed, several different rating methods have been used. In the past twenty-five years or so the methods have come almost full circle from "loudness" through "effective transmission" to "loudness" again; but with a significant difference. The earlier ratings (loudness originally, effective later) were always in terms of so many db poorer or better than a standard rating. While this standard was specifically defined, only a few people were sufficiently familiar with it to appreciate thoroughly whether something which was rated, say, 6 db better than the standard was good, bad or indifferent.

The new rating system avoids this problem by not having any fixed standard at all. It is based primarily on the ratio of the loudness of the sounds into the listener's ear to the loudness of the sounds out of the talker's mouth but with suitable modifications to take care of factors other than loudness which affect ease of conversation.

This system also has the advantage that "gain" and "loss" have acceptable connotations; that is, an over-all gain means that the weighted sound pressures out of the receiver are greater than the weighted sound pressures at the talker's lips and a loss means the reverse. Thus this system should not be rendered out of date by any foreseeable developments in subsets or other transmission instrumentalities.

While the quantities used in the new rating method strictly speaking are not decibels, it is expected that the adoption of this method will have no effect on the usage of the term "decibel" either inside or outside of the Bell System.

This article discusses the over-all problem, gives a brief historical review and describes in some detail the new rating system now being adopted.

INTRODUCTION

In the years prior to about 1930, performance ratings were assigned to telephone transmission circuits in terms of loss of speech volume or loudness. The adverse effects on transmission quality of such parameters as sidetone, distortion and noise were recognized, but until the 1930's no way was known of incorporating them, together with loudness loss, into a single figure of merit for rating transmission performance.

Anti sidetone station sets were first used in quantity in the Bell System in 1932, followed in 1937 by the 302-type combined sets. While these instrumentalities did not yield appreciably greater loudness than their predecessors, they exhibited marked improvements in such characteristics as sidetone, frequency response and nonlinear distortion, which have a marked effect on the ability of a listener to *understand* as well as to *hear* transmitted speech. Thus it became necessary to devise a rating system which would give adequate recognition to the contributions of these improvements to over-all transmission performance. There resulted the "effective loss" method of transmission rating.[1, 2]

The effective loss rating system assigned a figure of merit to a customer-to-customer transmission circuit, based fundamentally on the rate at which listeners requested repetition of what the talkers had said. This basis evaluated transmission circuits from the standpoint of transmitted intelligibility, as well as loudness. In practice, the circuit to be rated was compared with a "working reference system,"[2] which consisted of representative subscriber loops and station sets, and a variable, distortionless

[1] W. H. Martin, Rating the Transmission Performance of Telephone Circuits, B. S. T. J., **10,** p. 116, Jan., 1931.

[2] F. W. McKown and J. W. Emling, A System of Effective Transmission Data for Rating Telephone Circuits, B. S. T. J., **12,** p. 331, July, 1933.

trunk. In principle at least, the trunk of the reference system was adjusted until the repetition rate was the same on both circuits. The attenuation of the trunk in decibels was then a measure of the effective loss of the circuit under test.

An effective loss of zero on the working reference system was a theoretical point, arbitrarily assigned so that the system tied in numerically with its predecessor. If a listener could not hear *and understand* a given talker as well over the circuit being rated as over the reference system at its zero point, the circuit under test was said to have a *positive* effective loss. If the reverse was true, the circuit was said to have a *negative* effective loss. Effective loss was expressed in db and, from a practical point of view, may be considered an *equivalent* loss in loudness.

While the effective loss system has served an important purpose in giving due weight to important transmission characteristics other than loudness efficiency, it has a number of practical disadvantages. For example, the effective losses of circuits containing electro-acoustic transducers, such as telephone transmitters and receivers, cannot be measured by objective methods. Hence they must be determined statistically by time consuming subjective methods such as repetition tests. Relatively few people have had the experience, personally, of listening to speech over the reference system; hence there is little tie-in between effective transmission and practical experience.

Also, the telephone transmitters and receivers used in the reference system were of obsolete types, their frequency characteristics were far from flat and the circuits in which they were used introduced both sidetone and nonlinear distortion. Hence, modern station sets invariably exhibit performance superior to those used in the reference system and thus yield negative effective losses. The combination of positive and negative losses, together with the inability of the practical user to correlate the net result with any physical bench mark with which he was familiar, often prevented complete understanding and acceptance of the rating system, except by transmission specialists. Although transmission engineers have become expert in designing exchange area plant based upon effective loss techniques, the fact that effective losses cannot be measured directly prevents close correlation between design and maintenance. This is an important drawback because wherever practicable it is very desirable to be able to measure performance of all parts of the plant in the same terms that are used in laying it out.

The telephone art has now advanced to a point where a much simpler rating system appears practicable. It is the purpose of this paper to describe the more significant features of a modified system which, it is believed, will eliminate most of the practical disadvantages of the effective loss plan.

PROPOSED RATING PLAN

As pointed out above, the effective loss method of rating transmission circuits was adopted in order to give proper recognition to factors such as sidetone, frequency response and nonlinear distortion, which, in combination with loudness, determine the over-all performance of a telephone circuit. Today, between 80 and 90 per cent of Bell System telephones provide reasonably effective antisidetone features and it seems evident that on the average little additional effective gain can be accomplished by further reducing sidetone. Also, in the case of the modern 302- and 500-type station sets, which constitute a constantly increasing portion of the station plant, impairments due to frequency response and nonlinear distortion are so small that they leave little need for improvement in future designs. It seems evident, therefore, that loudness has again become the main variable factor in plant design and is likely to be the most important consideration in future telephone set design. In view of this situation it seems desirable to return to a rating system based primarily upon loudness considerations.

While one of the chief reasons for returning to a loudness basis is the need for a rating system in which the parameters can be measured by objective methods, it is recognized that, strictly speaking, loudness itself is a subjective factor which can be measured only by the composite judgment of a number of human observers. As used here, however, loudness is determined by objective measurements which do not always duplicate true loudness determinations precisely, but which are sufficiently good approximations for practical purposes.

Although it is contemplated that *loudness* loss will be used in the great majority of day-to-day engineering problems, other factors contributing to effective loss will not be disregarded. In special cases, where these may assume importance, allowances may be made for them in the form of "penalties" to be added to *loudness* loss. The resulting rating, including all penalties, will be referred to as *subjective* loss to distinguish it from *loudness* loss and the present *effective* loss. It is contemplated that the use of subjective losses will be necessary only for some special service applications, for the design of apparatus and systems, and for cases in which noise is important. It is recognized that occasionally there may be special types of speech transmission systems in which factors other than loudness are controlling. In such cases it may be more practicable to provide ratings by means of over-all subjective tests rather than by measurements of loudness corrected by the penalties referred to above.

To provide maximum usefulness in the engineering of the telephone transmission plant, a rating system must include means not only for appraising an over-all telephone connection but also for assigning figures of merit for the various components making up the connection. Thus it is highly desirable that it make possible the rating of transmitting circuits, connecting lines, and receiving circuits as separate entities.

Definitions covering the rating of component portions of a telephone system must, of course, be consistent with the definition for over-all system rating. It becomes necessary, therefore, to specify under what conditions the sum of the component ratings is equal to the over-all rating; other conditions require reflection corrections in order that the rating system be consistent.

The rating definitions involve both acoustic pressures and electric voltages. They are based on the use of speech, or an equivalent complex voice frequency test tone and artificial mouth, as a source of acoustic energy, and on meter indications of voltage or sound pressure suitably weighted to simulate the loudness perception of human hearing.

OVER-ALL LOUDNESS RATING

A loudness transmission rating of zero is assigned to an over-all telephone connection in which the output acoustic speech pressure delivered by the telephone receiver to the ear of the listener is equal to the input acoustic speech pressure at the lips of the talker. The measurement of talking pressure is made under free field conditions, that is, with the telephone transmitter removed from in front of the talker's lips or other sound source. During the measurement of output pressure, the transmitter of the talking telephone set is placed in the modal position with respect to the sound source.[3]

As shown in Fig. 1, if S_L is the output pressure at the listening end in microbars (dynes per square centimeter) or millibars (thousands of dynes per square centimeter), and S_T is the corresponding input pressure at the talking end of an over-all telephone connection, the transmission loss, or rating, of the connection, R_0, is

[3] The modal position is the same distance from, and angular position with respect to, the sound source as the transmitter would assume when used correctly by a talker whose facial measurements are the mode of a very large distribution representative of telephone subscribers. See W. C. Jones and A. H. Inglis, The Development of a Handset for Telephone Stations, B. S. T. J., **11,** p. 262, April, 1932.

$$R_0 = -20 \log_{10} \frac{S_L}{S_T}$$ [4]

Thus losses are defined by positive numbers, and gains by negative numbers.

It will be noted that speech pressures, rather than speech powers, have been chosen as references; this has been done for two reasons. In the first place, speech power is very difficult, whereas speech pressure is relatively easy, to measure. Secondly, the ear appears to be a pressure sensitive rather than a power absorbing device, in the same sense that the input circuit of a vacuum tube is considered to be voltage actuated rather than power absorbing. When a telephone receiver is held close to the ear, the acoustic impedance presented to it is largely reactive. The real part of the acoustic impedance is largely due to the leakage path to the outside air between the receiver cap and the ear. Consequently the acoustic power is dissipated, for the most part, in this leakage path. Hence, whereas power rating would provide a satisfactory measure of the merit of a receiver as a loudspeaker, it seems more reasonable to use pressure in rating its effectiveness as a transducer when held close to the ear.

LOUDNESS RATING OF TRANSMITTING COMPONENTS

When figures of merit are to be assigned to the components of a telephone connection apart from the over-all rating described in the previous section, it is convenient first to divide the connection into two basic categories, one of which includes the transmitting transducer and the other the receiving transducer. In this section we consider components which include the transmitting transducer, while those which include the receiving transducer are treated in the following section.

For engineering purposes the transmitting component of greatest interest is probably the transmitting telephone set itself. A transmitting telephone set has a transmission rating of zero when the voltage (in volts) it delivers across a 900-ohm resistive load is equal to the pressure (in millibars) at the talker's lips. As in all ratings involving transmitters, the measurement of talking pressure is a free field one with the transmitter

[4] Since the ratios in this equation and those which follow involve either pressures across dissimilar acoustic impedances or an acoustic pressure and an electric voltage, the resulting ratings should not be expressed in decibels. However, the equations yield db-like quantities which may be measured on meters equipped with scales calibrated in decibels which will give numerically accurate results. The use of logarithmic units is highly desirable since this makes possible the direct addition of component ratings to give the over-all rating of a particular connection.

removed from in front of the sound source, while the output measurement is made with the transmitter in the modal position with respect to the sound source. Thus the rating, R_T, of any transmitting set is:

$$R_T = -20 \log_{10} \frac{V_T}{S_T} \quad (4)$$

where V_T is the voltage across the load and S_T is the talking pressure in millibars. It may be noted that the same numerical ratings will be obtained if the voltage is expressed in millivolts and the pressure in microbars.

Since the transmitting efficiencies of commercial telephone sets vary with the direct current in the transmitter, it is necessary to specify an appropriate value of line current or voltage representative of typical operation, when expressing the transmission rating of a transmitting telephone set. For present commercial sets with carbon-type transmitters the value of line current specified is 100 milliamperes, which is appropriate because it represents nearly the maximum dc obtainable on short loops. Any departure from 100 milliamperes in a commercial telephone connection using present sets causes a current supply loss (or gain), which is added algebraically to the transmission rating of the transmitting telephone set to obtain the transmitting conversion loss. The sign of the transmitting current supply loss will usually be positive for currents less than 100 ma, and negative (a gain) for currents greater than 100 ma.

Transmitting loop losses can be defined and measured in the same way as the rating of a transmitting telephone set if the 900-ohm resistive load is located at the output (central office end) of the loop instead of at the output of the transmitting telephone set. In this case the rating of the

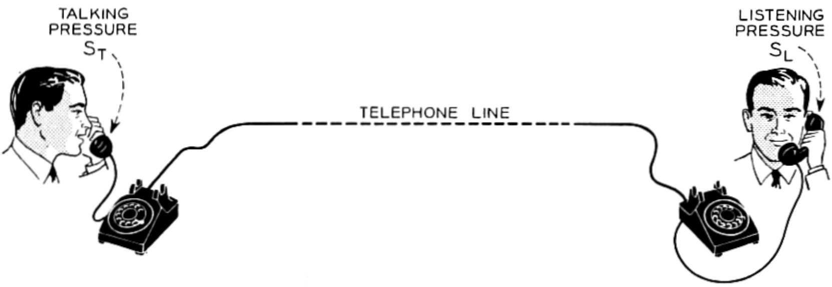

Fig. 1 — Loudness rating of an over-all telephone connection = $-20 \log_{10} S_L/S_T$. Rating is zero when $S_L = S_T$.

loop is equal to the sum of the rating of the transmitting telephone set, the transmitting current supply loss, and the insertion loss of the subscriber line between the impedance of the telephone set and the 900-ohm termination. The last is called the subscriber line loss.

LOUDNESS RATING OF RECEIVING COMPONENTS

As in the case of rating transmitting components the item of greatest engineering interest in the category containing receiving transducers is the receiving telephone set itself. To be consistent with the foregoing definitions for transmitting components and for over-all connections, its rating is defined as follows. A receiving telephone set has a loudness transmission rating of zero when the output acoustic speech pressure (in millibars) delivered by the receiver to the ear of a listener, is one half the open circuit voltage (in volts) of a 900-ohm resistive source which energizes the set as a load. The transmission rating, R_L, of any telephone set when receiving, then is

$$R_L = -20 \log_{10} \frac{S_L{}^4}{V_W/2}$$

where S_L is the listening pressure in millibars and V_W is the open circuit voltage of the 900-ohm source. As before, pressure in microbars and voltage in millivolts will give the same numerical ratings.

The same appropriate value of line current or voltage that is specified for transmitting ratings is also specified when expressing the transmission rating of a receiving telephone set. For present sets, as stated, the value is 100 milliamperes line current. Departures from this value cause a receiving current supply loss in telephone sets with current controlled equalizers. For currents less than 100 milliamperes the sign of this loss is usually negative because of the increased circuit efficiency on longer loops. The sum of the rating of the receiving telephone set and the receiving current supply loss is the receiving conversion loss. In present telephone sets without equalizers the receiving current supply loss is zero, so the receiving conversion loss is the same as the receiving rating of the set.

The foregoing equation also expresses the transmission rating of a receiving loop provided the 900-ohm source is applied to the input (central office end) of the loop instead of to the receiving telephone set. The rating of the loop, so obtained, is equal to the sum of the rating of the receiving telephone set, the receiving current supply loss, and a loss called the receiving subscriber line loss which is equal to the insertion loss of the subscriber line between 900 ohms and the impedance of the telephone set. If like facilities and instrumentalities are used for both transmitting and receiving loops, the transmitting and receiving subscriber line losses will be the same, although the loop losses will not be the same because of the different set ratings.

ADDITIVE PROPERTY OF COMPONENT RATINGS[5]

It was pointed out earlier that consistency of the definitions of the component ratings may be demonstrated by showing under what conditions the sum of the component ratings is equal to the over-all rating. The simplest telephone circuit that can be visualized for this purpose is illustrated in Fig. 2.

Here two commercial type telephone sets, each supplied with 100 milliamperes dc, are connected to each other by way of an imaginary amplifier inserted for the purpose of providing a pure resistive impedance of the right magnitude. This amplifier has input and output impedances each equal to 900 ohms pure resistance, and an image gain of zero decibels. It will be noticed that the transmitting telephone set has a 900-ohm resistive load impedance, so the ratio of the voltage V_T, across the input of the amplifier, to the talking pressure, S_T, is a measure of the transmitting rating of the telephone set by definition. Also, the output of the amplifier is a 900-ohm resistive voltage source for the receiving telephone set. If the open circuit output voltage of the amplifier is V_W, then the ratio of the listening pressure, S_L, to $V_W/2$ (shown by the dashed arrows in Fig. 2) by definition measures the receiving rating of the telephone set. Furthermore it can be shown by network theory that the open circuit output voltage of an amplifier of zero db image gain is twice the voltage across its input, provided its output and input impedances are equal. In other words, in this circuit,

$$V_W/2 = V_T.$$

Since this is so, the over-all rating of this telephone connection, measured by the ratio of listening to talking pressure, is equal to the sum of the transmitting and receiving ratings of the respective telephone sets.[6]

It is apparent from this discussion that if the two telephone sets are

[5] While it is recognized that the additive property of component ratings can be only approximate if a wide variety of frequency spectra is taken into account, nevertheless this is of little practical concern in the case of spectra usually encountered in the modern telephone plant. In this paper it is convenient for the sake of simplicity to disregard the approximation.

[6] A further note on the effect of frequency characteristics of components on the additive property of component ratings is included in Appendix A.

connected to each other back to back, without including the hypothetical amplifier of Fig. 2, the sum of their component ratings must be augmented by a reflection loss in order to equal the over-all rating. This comes about because the choice of definitions for transmitting and receiving ratings was dictated by the practical consideration that the more difficult transmission conditions occur when lines or apparatus are interposed between the sets. Thus it is advantageous to have the basic ratings more appropriate to these actual conditions.

By the definitions given here, the sum of two loop losses will also equal the over-all rating if the loops are connected to each other through the hypothetical amplifier. The majority of all actual telephone connections involves two loops connected to each other by some form or combination of trunks, instead of by the amplifier. The inclusion of trunks in the connection augments the two loop losses by the attenuation, reflection and interaction losses associated with the trunks. While there is considerable variation in the impedances of facilities making up loops and trunks, the resulting reflection and interaction losses can be minimized, and in many cases may be neglected altogether, by the choice of a compromise impedance for the rating definitions, which is reasonably representative of the entire distribution of loop and trunk impedances. These considerations dictated the particular choice of 900 ohms resistance as the terminating and source impedances in the definitions of transmitting and receiving component ratings.

One other aspect of the selection of definitions of transmitting and receiving ratings will now be discussed. We mentioned earlier that it seemed more logical to base the rating system on ratios of pressure and voltage than on power ratios because the human ear appears to be a pressure sensitive device. As a result of this decision it becomes apparent on reflection that the *numerical* apportionment of an over-all loss between

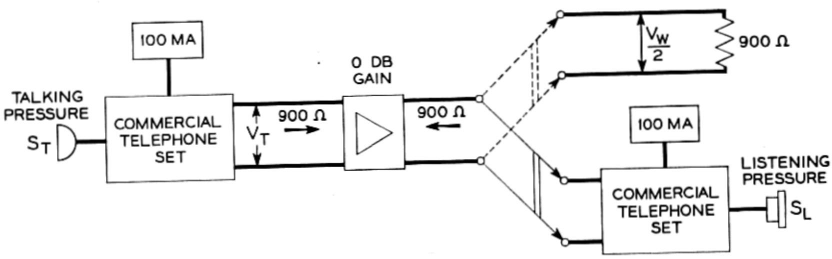

Fig. 2 — Additive property of transmission ratings. Transmitting rating: $R_T = -20 \log_{10} V_T/S_T$. Receiving rating: $R_L = -20 \log_{10} (S_L/(V_W/2)$. Since $V_w/2 = V_T$, over-all rating, $R_0 = -20 \log_{10} S_L/S_T = R_T + R_L$.

transmitting and receiving components is an arbitrary choice. The range of numbers involved can be controlled by the units in which the voltages and pressures are expressed, or by inclusion of an arbitrary numerical factor by which the voltage-pressure ratios are multiplied, without affecting the additive property of the component ratings. It is desirable to obtain an appropriate range of numbers by means of the simplest possible definitions of the transmitting and receiving ratings, if possible avoiding the use of arbitrary multiplying factors. This objective has been attained without multiplying factors by specifying that the voltages be expressed in volts and the pressures in millibars, or, which comes to the same thing, millivolts and microbars.

The range of numbers is appropriate because of the choice of units in the definitions. The transmitting ratings of present commercial sets, transmitting conversion losses and loop losses will all have negative signs, while the corresponding receiving ratings will all be positive. This is consistent with the fact that carbon transmitters produce gain and electromagnetic receivers loss as transducers between acoustic and electric energy. Even if more efficient receivers of this type are developed in the future, the definition of receiving ratings is such that the numerical values can never become negative without the aid of a gain producing device such as an amplifier.

LINE LOSSES

The line is here considered to be that portion of an over-all telephone connection between the line terminals of a transmitting telephone set and those of a receiving telephone set. In the simple circuit of Fig. 2 the "line" consists solely of the hypothetical amplifier, and the line loss, considered as a separate entity, is zero. In this case the over-all rating, as already stated, is equal to the sum of the transmitting and receiving ratings of the telephone sets. More generally, if the dc supplies for present sets are other than 100 milliamperes, the over-all rating is equal to the sum of the transmitting and receiving *conversion* losses, since conversion loss was defined as the sum of set rating and current supply loss.

If, now, the hypothetical amplifier is replaced by an actual line, consisting perhaps of two subscriber lines, battery supplies and a trunk, we are interested in the amount of loss which must be added to the conversion losses in order to equal the new over-all loss. This added amount defines the line loss, considered as an entity by itself. It is composed of reflection losses (involving the differences between reflection losses of the sets against the impedance of the line and the sets against 900 ohms), attenuation losses and interaction losses. As a practical matter, however, line loss is defined as the difference between the over-all rating of the telephone connection and the sum of the transmitting and receiving conversion losses.

The breakdown of line losses into components suitable for engineering uses is beyond the scope of this paper. Little departure from established practice in this matter is made necessary by the new transmission rating system. The general principles which have been discussed may be helpful in taking care of such departures as appear. As a final example, loop losses have been defined here as the sum of conversion losses and subscriber line losses. If loop losses are to be used for engineering purposes, it is then possible to define "connecting circuit loss," caused by a trunk or combination of trunks, as the difference between the over-all rating of the telephone connection and the sum of the two loop losses. Thus the line loss is equal to the sum of two subscriber line losses and the connecting circuit loss.

ELECTRO-ACOUSTIC MEASURING SYSTEM

It was stated earlier that one of the advantages in going to a loudness basis in the new rating plan is that it permits objective transmission measurement, whereas the subjective factors included in the effective loss system of rating make this impossible. It was pointed out that loudness itself is a subjective matter, but that objective measurements can be made which usefully approximate, although they do not duplicate, loudness determinations. While other systems are being investigated, the assembly of apparatus which has been used so far in the laboratory for this purpose is described in this section. It is called the electro-acoustic transmission measuring system. A functional diagram of its parts is shown in Fig. 3.

It is convenient for descriptive purposes to divide the electro-acoustic measuring system into three parts:

(1) The sound source, which takes the place of a human talker at the talking end of a telephone connection, as shown in Fig. 3(a).

(2) The indicating meter for acoustic pressure or electrical voltage. This is a substitute for a human listener at the receiving end of a telephone connection, and is shown in Fig. 3(b).

(3) The basic telephone connection, an intermediate link between sound source and indicating meter, which is provided with stable transducers as a substitute for commercial telephone connections for purposes which will be described further on. This appears in Fig. 3(c).

The sound source consists essentially of an electric generator of complex voice frequency waves and an artificial mouth.[7] The electrical output of the tone generator is shaped by a network to have the frequency spectrum of human speech. An equalizer is included in the circuit to correct the sound field from the artificial mouth so that it will be flat for a flat electrical input. An amplifier with variable gain permits adjustment of the acoustic level at the output of the artificial mouth to values comparable to the levels of human speech. One form of complex tone generator which has been used is a warbler oscillator in which the frequency of oscillation is varied linearly with time from 300 cps to 3,300 cps and back to 300 cps, six times per second. The sharp changes in amplitude caused by modulation products, and the frequency range, result in an acoustic output from the artificial mouth which has some of the characteristics of human speech, insofar as activation of commercial carbon type transmitters is concerned. In addition to the warbler oscillator, other types of tone source are being investigated.

The indicating meter shown in (b) of Fig. 3 is adaptable either to measurements of the acoustic pressure of real or simulated speech at the two ends of a telephone connection, or to speech voltage measurements at an intermediate point. For pressure measurements a condenser microphone is used as a transducer. Voltage measurements are made by means of a high impedance bridging connection. A high-pass filter is employed to reduce components of noise, particularly 60-cycle hum and its immediate harmonics, which are below the frequency range normally passed by telephone circuits. The meter circuit also includes a loudness shaping network which weights indications so that the difference between two measurements represents, approximately at least, the loudness difference perceived by the human ear.[8]

The basic telephone connection, parts of which may be used with portions of a commercial telephone connection to make up an over-all connection, is shown in Fig. 3(c). This is a two-way four-wire connection which makes use of electromagnetic, rather than carbon type, transmitters in order to avoid the instabilities of the latter type. However, shaping networks are employed in the transmitting portions of the two converting sets to provide the frequency characteristics of modern carbon type transmitters. The characteristic is roughly a compromise between those of the F1 and T1 transmitters. The line impedances of both trans-

[7] A. H. Inglis, C. H. G. Gray and R. T. Jenkins, A Voice and Ear for Telephone Measurements, B. S. T. J., **11**, p. 293, April, 1932.

[8] H. F. Hopkins and N. R. Stryker, Proposed Loudness-Efficiency Rating for Loudspeakers and the Determination of System Power Requirements for Enclosures, I. R. E. Proc., **36**, p. 315, March, 1948.

mitting and receiving portions of the converting sets are 900 ohms pure resistance, matching the 900-ohm distortionless connecting lines without reflection. The gain of amplifiers in the transmitting and receiving portions of the sets may be adjusted so that the sets have convenient transmitting and receiving ratings in terms of the new rating system. An additional amplifier in each converting set provides an adjustable sidetone path so that the connection will not sound dead to human talkers and listeners.

METHODS OF USE

Examples of various methods of use of the electro-acoustic measuring system are given in Figs. 4, 5, 6 and 7. Since these are laboratory meas-

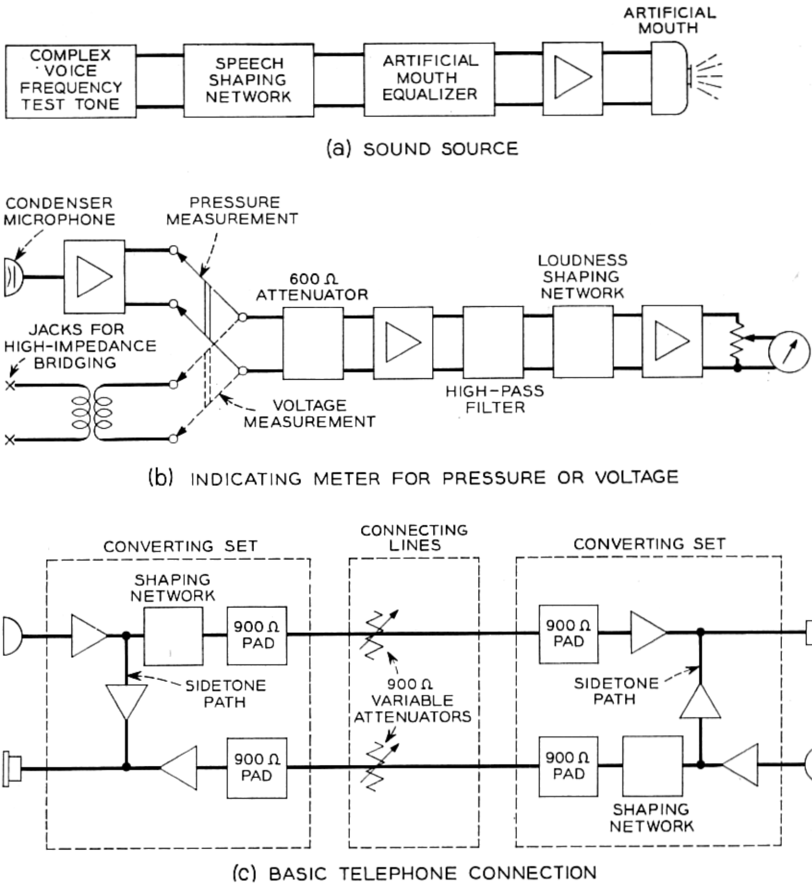

Fig. 3 — Electro-acoustic transmission measuring system.

urements, line facilities such as loops and trunks are simulated by equivalent networks. Thus both ends of telephone connections, which might be far apart in the actual case, are readily available for measurements in the laboratory.

The first example, Fig. 4, illustrates the use of the sound source and indicating meter to measure the over-all rating of a complete telephone connection. During measurement of the talking pressure, S_T, the telephone handset is removed and the condenser microphone placed at a carefully gauged position with respect to the guard ring of the artificial mouth. When this measurement has been made the handset is replaced, with the transmitter positioned by template. Different templates are necessary for F-type and G-type handsets so that each will be in the modal position with respect to the source of sound. The condenser microphone is then removed from its artificial mouth position and placed in the 6-cc coupler at the listening end of the connection. The telephone receiver is also clamped to the coupler which furnishes an acoustic termination similar in impedance to that provided by the human ear when the receiver is held tightly against it.[9] Prior to the measurement of listening pressure, as in all measurements involving carbon transmitters, the carbon must be conditioned. This is a process of physical agitation in a prescribed manner, and a momentary acoustical overload, which eliminates packing of the carbon which might otherwise occur when the handset is held rigidly in a fixture. It places the carbon in a configuration similar to that experienced under normal talking conditions. After conditioning the measurement of listening pressure is made.

The use of the sound source and indicating meter for rating a transmitting telephone set is shown in Fig. 5. Here the output measurement is one of voltage rather than pressure. For this the indicating meter is bridged to the circuit by means of a high impedance connection.

Receiving rating of a telephone set is illustrated in Fig. 6 which shows measurements of the source voltage and listening pressure. The frequency characteristic of the source voltage includes not only speech weighting but also the response characteristic of carbon transmitters. This is necessary in order that the component ratings may add up to the over-all rating, as indicated in Appendix A. A convenient way of supplying the desired frequency characteristic is to use the artificial mouth and the transmitting converting set of the basic telephone connection. The output from the 900-ohm connecting line is a voltage of proper frequency characteristic from a 900-ohm source, as required for

[9] E. E. Mott and R. C. Miner, The Ring Armature Telephone Receiver, B. S. T. J., **30**, p. 110, Jan., 1951. Fig. 4 in this reference shows the similarity in receiver response when measured in a 6-cc coupler and when measured against the human ear.

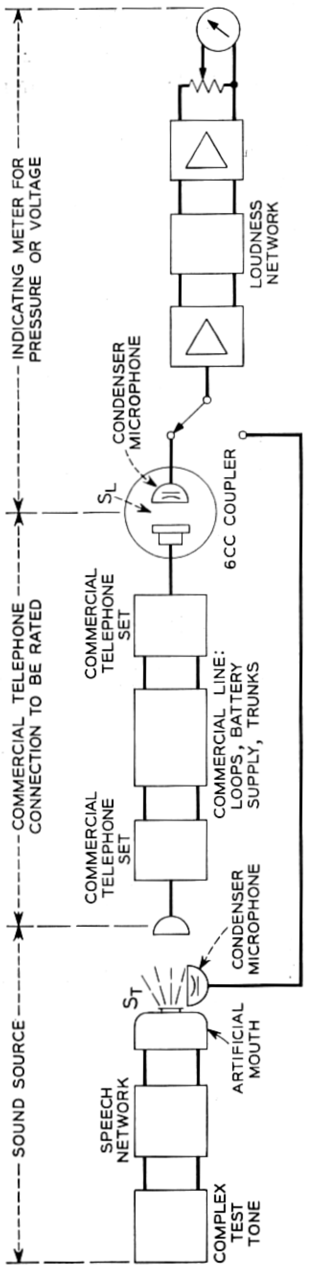

Fig. 4 — Measurement of over-all rating of a telephone connection.

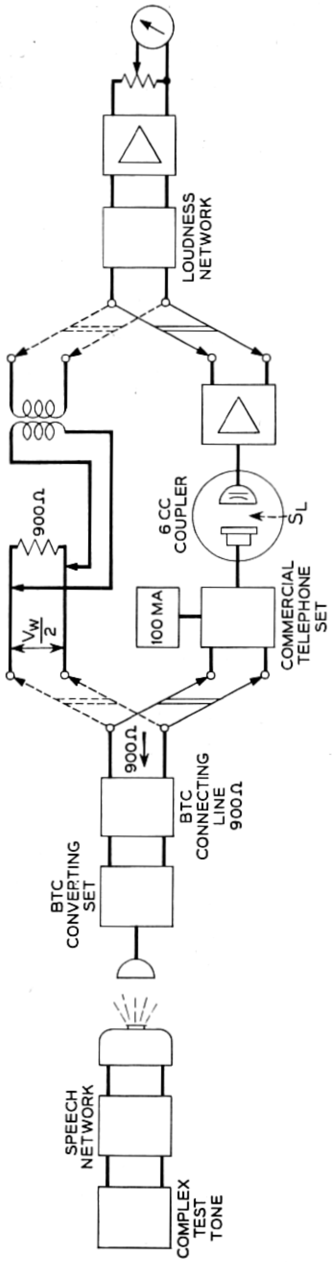

Fig. 6 — Measurement of receiving rating of a telephone set.

the receiving rating of commercial telephone sets. The measurements of source voltage and listening pressure are made in the same manner as in the previous examples. No conditioning is necessary prior to these measurements because the transmitter of the converting set is electromagnetic instead of carbon type.

Another use of the basic telephone connection is to obtain basic data for subjective rating by means of comparison tests. Subjective ratings require human talkers and listeners. An example of this use is shown by Fig. 7 in which a transmitting telephone set is rated subjectively in order to check data obtained by objective measurement. In this test the talker speaks alternately into the transmitter of the set to be rated and into that of the converting set of the basic telephone connection. The listener listens at the receiver of the basic telephone connection to speech

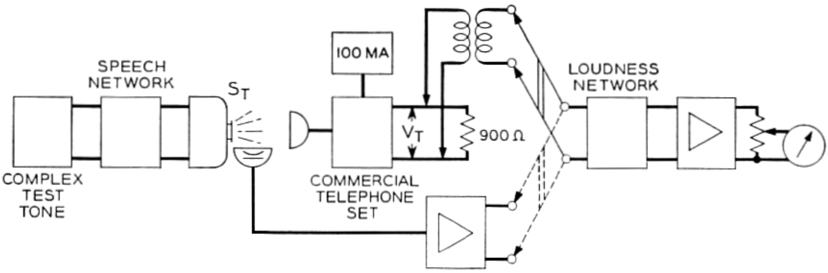

Fig. 5 — Measurement of transmitting rating of a telephone set.

from both sources. He adjusts the attenuator (B) in the basic telephone connection until he judges the two to be equal. The difference between the settings of the two attenuators is then a measure of the rating of the commercial telephone set relative to that of the converting set in the basic telephone connection. The basis of equality in the observer's judgment must be specified; loudness may be specified, or some other subjective factor such as general satisfaction. Subjective tests of this kind require a number of different listeners, and often a number of different talkers, to yield results that are useful. Other arrangements of the basic telephone connection can be used for similar comparison tests of other commercial telephone components.

APPARATUS FOR FIELD TESTING

As already stated, the transmission measuring system described in the previous sections was assembled to obtain laboratory data which will be of use to transmission engineers in the field. The data so obtained are in terms of the transmission rating system discussed in this paper. It requires no great stretch of the imagination to visualize the development of apparatus functionally similar to some of that which has been described, but much smaller, lighter in weight and far less complex, which might be used by field personnel. Elements of such a measuring system would be located in central offices. Other elements might be carried to subscribers' locations in the normal complement of tools used by installation or maintenance forces. This field transmission measuring apparatus would be used to make field transmission surveys. It might also

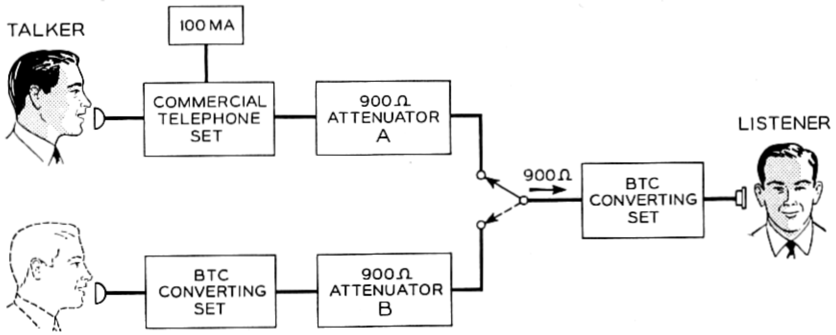

Fig. 7 — Use of basic telephone connection in subjective rating of a transmitting telephone set on a comparison basis.

be used for maintenance purposes: values of electro-acoustic transmission loss measured in the field under circumstances of suspected trouble could be compared with transmission design data. The possibilities of such uses are wide in scope. These possibilities were in mind when the loudness rating plan was devised.

SUMMARY

Some of the disadvantages of the effective loss system for rating transmission were mentioned in the introduction. It is confidently expected that the revised rating plan presented here is free from these disadvantages and has merits of its own. The basis for this confidence lies in the following advantages of the plan, which are briefly summarized.

References are dispensed with in the loudness rating plan. Instead of references, ratings are in terms of absolute physical quantities which can be readily understood, and the ratings, therefore, can be visualized. This should lead to a far wider understanding of transmission rating, and of the meaning of rating numbers.

Ratings for the transmitting and receiving components of telephone connections have additive property and, for modern station instrumentalities, result in a range of rating numbers which is appropriate.

Loudness ratings may be measured objectively, instead of being determined by time consuming subjective methods.

The rating plan permits development of light weight field transmission measuring apparatus for field survey and maintenance purposes.

In special cases, where loudness rating is inadequate, subjective ratings may be applied by the addition of transmission penalites to loudness ratings.

At the present time engineers at Bell Telephone Laboratories are engaged in an extensive program of measurements so that the new rating plan may be implemented as soon as possible.

ACKNOWLEDGMENT

The authors are indebted to their many colleagues past and present in the Bell System who have been associated at one time or another with the problem of transmission rating. This problem, looked at over the years, is one in which the requirements and needs are continuingly variable. To be successful in the solution of such a problem, a new rating plan must include the best features of all past plans with such new features as may be necessary for current needs. It is patently impossible to give individual credit where it is due. However, the authors wish to acknowledge the contributions made by N. R. Stryker to the instrumentation used to date.

APPENDIX A

THE EFFECT OF FREQUENCY CHARACTERISTICS ON THE ADDITIVE PROPERTY OF COMPONENT RATINGS

It is recognized that, strictly speaking, there is no known way to define component losses in such a way that all of them are independent of the remainder of the circuit with which they are used, and at the same time that their individual ratings add up to the over-all rating under all conditions. Consider as an extreme example an over-all connection in which the transmitting component produces frequencies only in the band from zero to 1,500 cps, and the receiving component is responsive to frequencies in the band from 1,500 to 3,000 cps. If the transmitting circuit alone were measured in a wide band measuring circuit it would be assigned a rating of, say, X. Likewise if the receiving circuit by itself were measured by a wide band measuring circuit it might be assigned a rating of Y. The two added together would provide an over-all rating of X + Y; yet obviously the actual over-all loss would be infinite. If, however, the response-frequency characteristic of the transmitting circuit were included in the source voltage for the receiving circuit measurements, the receiving rating would no longer be Y, but would be an infinite loss. In this case the receiving rating would not be independent of the rest of the circuit, but the sum of the transmitting and receiving ratings would be equal to the over-all rating.

An alternative would be to apply the response-frequency characteristic of the *receiving* circuit to the measuring circuit when measuring the output of the *transmitting* circuit. In this case it would be the transmitting circuit which shows an infinite loss, while the receiving rating would be finite; the transmitting rating would not be independent of the circuit, but the two would add up to the over-all rating.

In the example cited, which is of course an absurd extreme, one is left with the dilemma: which of the two circuits, transmitting or receiving, should be the one to be rated as an infinite loss? There is no ready answer to this question. Fortunately, in more practical cases, the choice becomes an academic one because, first, the telephone plant is designed so that its components work together rather than in opposition to each other, and secondly the response of receiving circuits is in general relatively flat with frequency. The first of these reasons means that there would be little difference in the component ratings if either alternative were adopted. The second reason permits a method of measurement under the second alternative which still allows the component ratings to add up to the over-all rating.

In the rating plan described in this paper the first of the two alternatives mentioned above was chosen: namely, that transmitting ratings are determined by measurements independent of the remainder of the circuit, while receiving ratings are determined by measurements in which the source voltage includes the frequency-response characteristic of modern carbon transmitters. Three reasons dictate this choice:

(1) It permits simple definitions of component transmitting and receiving ratings.

(2) The input and output measurements for the component ratings are conveniently made.

(3) Greater generality is provided because the additive property of component ratings does not depend on flatness of the receiver characteristic.