Transmission Features of the New Telephone Sets *

By A. H. INGLIS

The new telephone instruments now being introduced by the Bell System result in an outstanding improvement in transmission performance in service. The evidence for this, as obtained by comprehensive laboratory and field tests, is presented here together with a discussion of the factors responsible for this superior performance and of the consideration involved in its appraisal.

NEW telephone instruments are being applied in the plant of the Bell System to the deskstand, wallset and handset, and result in markedly improved transmission performance. The new instruments are associated with the anti-sidetone feature which is also applied to the older sets already in plant. The selection of these particular designs from the wide choice made possible by new design technique, materials and manufacturing methods, has been based on developments in the methods for quantitatively rating the relative merits of different designs. In general there has been consistent effort over a period of years to base these ratings primarily on performance in service rather than on laboratory tests.

The factors influencing service performance are so many, and so complicated in their relationship, and are in so many cases difficult or even impossible for the designer to evaluate or control, that their net effect on performance cannot be predicted with certainty by laboratory methods. Of necessity such methods involve a limited selection of primary test conditions, and an even more limited selection from the possible combination of these conditions. This is particularly true in the rating of the transmission performance of a telephone set. Laboratory tests are essential in the study and analysis of design problems, and are invaluable similarly in interpolating, supplementing, and explaining service performance results. In determining the reaction on the user of the transmission features of possible designs, however, the field performance test has been found of first importance in deciding what particular characteristics to include in the new telephone instruments and circuits.

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Important Transmission Characteristics of the New Telephone Sets

The specific transmission design features of the new instruments are described elsewhere.[1] The purpose here, therefore, is to discuss primarily the outstanding improvements in performance resulting from the application of the new instruments and the anti-sidetone feature which has been available for some time.

These improvements are

1. Those due to the station circuit, which, as compared with the previous station circuit,
   a—largely reduce the efficiency of the sidetone path between transmitter and receiver without materially affecting the electrical efficiency of the set in transmitting or receiving. This means that sounds, either noise or speech, which are picked up by the transmitter are reproduced in the receiver of the same set at a much lower level.
   b—reduce the susceptiveness for certain types of party line sets to interference with reception by noise set up by power transmission systems.
2. Those due to the physical characteristics of the transmitter and receiver.

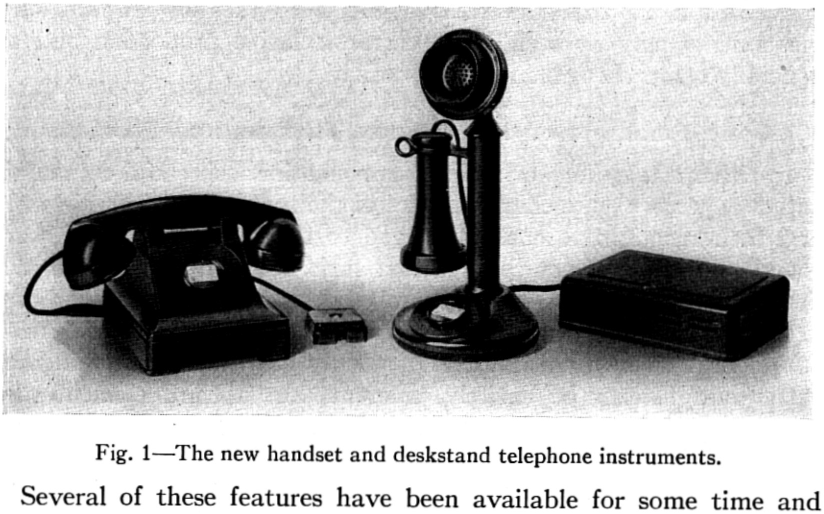

Fig. 1—The new handset and deskstand telephone instruments.

Several of these features have been available for some time and have, of course, been introduced into the plant as they became available. The new transmitter and the anti-sidetone circuit, for example, have been standard for some years and have already been installed in large numbers.

Figure 1 shows both the new handset and the deskstand forms of mounting, including all these features as integral parts of their design. The new desk type transmitter and receiver can, of course, be used with wall sets.

The schematic drawing of Fig. 2 indicates the general arrangement of parts in the new station transmission circuit for either type of set.

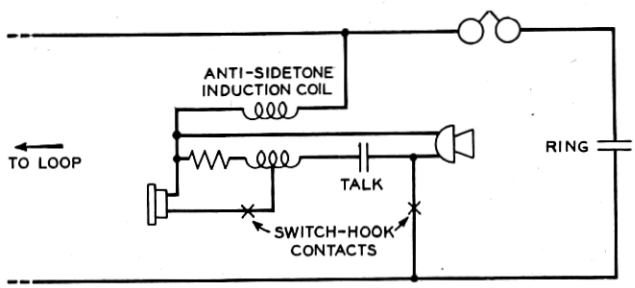

Fig. 2—Schematic transmission circuit of anti-sidetone coil.

In describing the results produced by these transmission features, and the methods employed in measuring and rating these results, it seems desirable to include some discussion of the characteristics of a telephone conversation as distinguished from a direct, face-to-face conversation, so that the various effects of the new circuits and instruments may be seen in as correct relative proportion and as generally comprehensible form as possible.

Some Elements of the Station Transmission Problem

In either a telephone or a direct conversation, successful cummunication depends on the characteristics of the talker and of the listener, and their reactions to each other and to the character of their surroundings. In a direct conversation such, for example, as across a desk, the environment is in general the same for both talker and listener, and their ears are materially aided by their eyes. In a telephone conversation, however, not only may the surroundings of talker and listener be entirely different, but a third element, the telephone system, is added to the environment of each user, which complicates his reaction, not only to his own surroundings, but also to the other party to the conversation. Furthermore, for obvious economic reasons, the natural binaural reception of direct conversation, with its advantages in discriminating between sounds from different directions, is replaced in the telephone conversation by a monaural medium.

Fundamental differences of this kind between telephone and direct conversation must be taken into account in the design of a telephone transmission system if satisfactory results are to be obtained. For example, the talker is accustomed in a direct conversation to regulate his talking volume by what he himself hears under prevailing noise conditions (which incidentally are the same for the listener), by the ease with which he hears the other party, and by the ease with which the listener appears to hear him. By experience, under ordinary conditions, the first factor mentioned, the loudness with which the talker hears himself, probably comes to be the primary control on his talking volume.

These various factors also serve to regulate talking volumes in conversation by telephone, but their magnitudes and the relations between them differ from the condition of face-to-face air path conversation and vary from one type of telephone connection to another. For example, the "sidetone" of the telephone set, being materially higher than the air-path sidetone, deceives the talker, not only by making him think he is talking louder than he really is, but also by apparently modifying the noise conditions under which he is talking in the pickup and amplification of room noise by his telephone transmitter. Since, in addition the efficiency of the telephone circuit itself may be different in the two directions of transmission, the loudness heard by one party may differ more from that heard by the other than in the case of air transmission. Then, too, noise conditions may be and frequently are quite different at the two ends of the telephone circuit. Figure *3A* shows the probability of noise of various average intensities at subscribers' stations as determined by several surveys covering a large number of locations. On the assumption that any one of the stations represented by these data may with equal probability call any other one, Fig. *3B* has been computed, showing the probability of noise at the two stations of a telephone connection differing by more than a certain amount. It will be noted that there is about an even chance of the noise at the two ends differing by more than 12 db. In view of these differences, a person's judgment of how well he is heard and understood can not be as direct as in the case of air transmission.

In addition, the transmission over the commercial telephone system affects the quality of the received speech more than the usual room surroundings in air-path transmission. While acoustic resonance and reverberation in a room do distort speech, in the extreme case to a point where understanding may be difficult, such a condition is distinctly unusual. Equal freedom from distortion in a telephone system is a more difficult and expensive condition to obtain than in direct conversation a few feet from a listener. Something less than perfect reproduction must suffice, for the present anyway, if costs are not to be prohibitive.

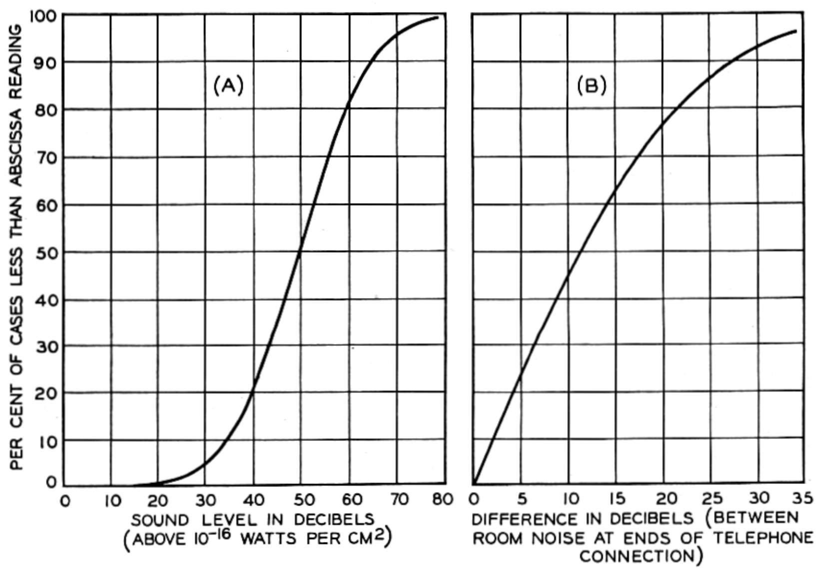

Fig. 3—Noise conditions at telephone stations.

All of these differences involve the acquiring by the user of a set of telephone habits which differ from those he has acquired in direct conversation. The problem of the transmission design of a practical telephone system requires, then, for a satisfactory solution, not only a determination of the proper speech levels to be delivered, and of the sidetone characteristics which will, under the conditions of a telephone conversation, give optimum results with the noise encountered, but also a decision as to what particular frequency range and characteristic to choose. Properly designed, a telephone transmission system should minimize, to the degree consistent with costs, its inherent differences from direct conversation, and make it easy for the ordinary user to get, without undue effort, results which are satisfactory to him in comparison with direct conversation.

In the earlier days of telephony, the problem presented appeared much simpler. It was, in effect, uni-dimensional, calling primarily for more efficient instruments and circuits; more and more power delivered to the listener's ear. While methods for the control of sidetone were not unknown, the importance of such control was not fully appreciated. Little choice was available in the quality of reproduction provided by transmitter and receiver, because of meager design knowledge.

Relatively recent and quite rapid developments in knowledge of the problems involved, in materials, methods, and measuring facilities, have now presented the necessity for a solution in essentially a three-dimensional form. These three dimensions may be described as volume, noise and quality. The solution of the problem on this basis is obviously more difficult, and has required the development of methods for quantitatively evaluating and rating their characteristics in terms of some common yardstick.

Methods of Rating Transmission

For reasons already suggested, such a yardstick must be based on service performance—on the results obtained by actual users in the course of day-to-day telephone service.

Extensive investigation has indicated that the best comparative measure of this transmission performance in local exchange service is to be found in the time rate of the occurrence of repetitions required by subscribers for understanding telephone conversations.[2] Or, more explicitly, when two transmission conditions have the same repetition rates, all other service factors being equal, these conditions are taken to be equal with respect to transmission performance. Where two conditions are not alike it is usually possible to evaluate the difference in the repetition rates for the same users by inserting distortionless loss in the better condition until both have equal repetition rates.

Thus, by taking as a reference a typical telephone circuit of specified make-up, the effects of various factors such as distortion, noise, attenuation, sidetone, or type of instrument, may all be expressed in the common terms of the reference circuit trunk which will give the same repetition rate.

Instead of making this adjustment in every case for the purpose of evaluating the relative performance of different test conditions for the same users, the evaluation may be made rather closely over a limited range by the following typical relation derived from repetition observations on circuits containing trunks, the losses of which were varied over a range of values.

$$\text{db} = 50 \log_{10} R_1/R_2,$$ [3]

where R_1, and R_2 are the repetition rates of two conditions under comparison, and the db figure is the change in the reference trunk which has the same relative effect on the repetition rate.

Such a method is, of course, somewhat cumbersome, and requires a large amount of data to iron out random variations and individual peculiarities of little general interest. But as the fundamental rating method, supplemented by laboratory test, it has been systematically used in studying the value of the anti-sidetone circuit and in selecting instrument characteristics.

Supplementing the repetition observations, it has been found useful in service rating to obtain data on speech levels delivered to the line for each condition observed. This has been done with the volume indicator, a vacuum tube voltmeter so designed that the reading is approximately proportional to mean syllabic voltage.[4] The information thus obtained is useful not only in analyzing the results of service tests but also in determining typical values for speech levels, necessary for laboratory tests.

Laboratory tests are of two general types: objective measurements, and subjective tests. Transmission measurements cover a wide field with objectives ranging from the physical analysis and study of different designs, to the determination of overall performance characteristics of structures and systems. It is these latter tests that we are more particularly interested in here, as most descriptive of the physical properties of importance in providing telephone transmission service.

Subjective tests in the laboratory may be said to be midway between physical measurements and field performance tests. Made under controlled and somewhat artificial conditions, they indicate quantitatively the capabilities of a telephone system in transmitting articulate speech under the particular conditions of the test. They cannot, of course, indicate the relative probability of occurrence, and hence importance, of these different conditions, nor predetermine how well the subscriber will avail himself of the capabilities provided.

Consideration of some of the results of investigations in both laboratory and field will do much to explain the rather large transmission improvement realized by the introduction of the new sets in actual service, particularly if examined with the conditions of a direct conversation as a basis of comparison.

The Station Circuit

There are two characteristics of the new station circuit of particular importance from a transmission standpoint.

Reduction of Sidetone

The first is the anti-sidetone induction coil through which the transmitter and receiver are coupled to the line. This coil comprises, in addition to three transformer windings, a balancing network. The circuit, made up of the four elements: transmitter, receiver, line, and network, coupled by the transformer, functions in such a manner that the transmitter and receiver are in conjugate relationship, i.e., voltages produced by the transmitter are balanced out and do not affect the receiver. Theoretically, such a circuit, with pure resistance elements, can be perfectly balanced at all frequencies with complete elimination of sidetone, and at the same time be as efficient as can any transformer coupling in an invariable telephone set,[5] for the transfer of power from the transmitter to the line, and from the line to the receiver.

This type of circuit is not new in principle, and many varieties are known and have been described.[6] Many of these arrangements, for one reason or another, are not suitable for application. Some, for example, call for impedances of transmitters or receivers differing widely from those available. Certain others are not economical for common battery service, where the transmitter must receive its battery supply from the line. Still others require relatively complicated and expensive cording and switchhook arrangements. The circuit which has been chosen for general common battery subscriber station application, and shown schematically in Fig. 2, is not only as simple and as easily adapted to Bell System conditions as any, but permits a coil design which is economical to manufacture as well as efficient in performance. Other types of anti-sidetone circuit have been adopted for local battery station service and for operators' telephone sets.

The theory of operation of this anti-sidetone circuit has already been discussed elsewhere.[7] It is intended here to show the general purposes of the application, some of the considerations involved in the design, and the kind of results accomplished.

While in theory complete elimination of sidetone is possible, as well as ideal efficiency of transformation, in practice neither objective can be entirely realized. The unavoidably wide variations in line impedance looking from the set, ranging from high positive to high negative phase angle, and from a few hundred to more than a thousand ohms in magnitude, together with other practical departures from ideal conditions, necessitate a choice between a high degree of sidetone balance and the standardization of a minimum number of coil designs. The variations in loop length and resistance, by their effect on transmitter battery supply, and consequently on transmitter resistance, furthermore cause variations in the absolute transmitting and sidetone efficiency of the terminal set, which must be taken into account in the station circuit design.

The actual design chosen is so arranged as to favor sidetone balance on average and shorter loop conditions where transmitter battery supply is greater, with consequent higher sidetone, and to favor transmitting and receiving efficiency on longer loops where battery supply is low. Since loop losses are greater for transmitting than for receiving because of transmitter battery supply loss, the ratio of the transformer is such as to favor the transmitting efficiency of the set somewhat in comparison to the receiving efficiency. This has the advantage of raising the transmitted speech level further above line noise. The same idea, of course, was followed in the design of the sidetone set.

The resultant anti-sidetone circuit adopted and here discussed, as compared with the sidetone circuit previously in general use, when equipped with the same transmitter and receiver and on the same loop and trunk, reduces sidetone on the average by about 10 db. Under the most unfavorable conditions of use, the reduction is unlikely to be less than about 7 db compared with the corresponding sidetone connection. Under the best conditions of balance encountered the reduction may be as much as 12 db. On the effective basis of transmission the average net improvement in transmission which results is about 6 db.

From the electrical circuit standpoint alone, the efficiency of the anti-sidetone arrangement is below that of the sidetone set in the order of about one or two db in transmitting and in receiving, which is necessitated by the limitations of practical design and circuit conditions discussed above.

Figures 4*a* and 4*b* show for transmitting and receiving, respectively, the difference in efficiency, with respect to frequency, of the anti-sidetone set from the sidetone set, each with the same instruments. Two subscriber loop and trunk conditions are shown: an average loop and trunk, and a long cable connection.

Figure 4*c* shows the variation in sidetone reduction with frequency, of the new set as compared with the corresponding standard sidetone set, for the same two circuit conditions as above. The curves are indicative of the effect of variation of circuit impedance on sidetone balance, in changing not only the magnitude, but the frequency range in which the best balance occurs.

Data of this sort alone do not, of course, indicate the relative transmission performance of the two sets. The beneficial effect on the telephone user of the large reduction in sidetone must be evaluated on the same yardstick as the losses in transmitting and receiving efficiencies which, in the practical case, accompany this reduction in sidetone. McKown and Emling have shown the effect of changes of this sort on the results obtained by the ordinary telephone user, in terms of net effective transmitting and receiving loss, as determined by service observations.[8] Their data, shown in Fig. 5, are relative to the sidetone of a reference set. The heavy solid lines are the original experimental data, the dotted extensions to these curves being extrapolated.

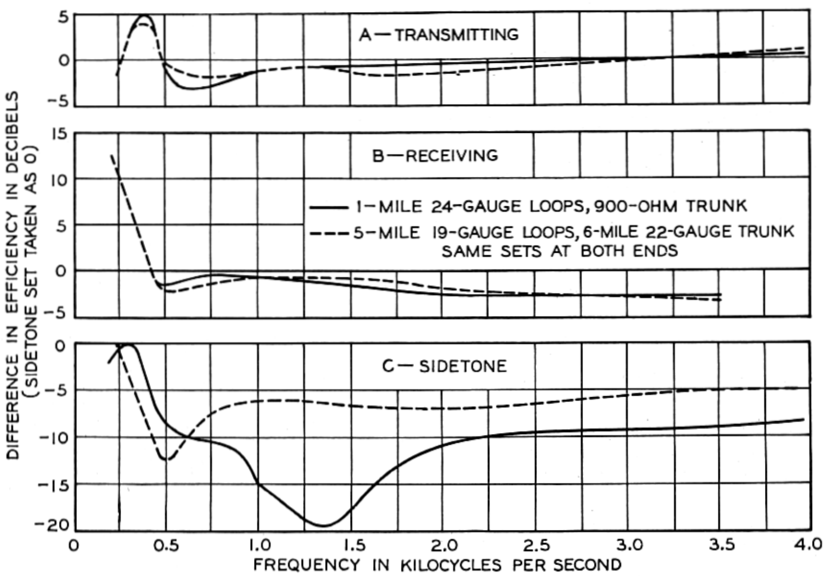

Fig. 4—Circuit efficiency of anti-sidetone circuit vs. sidetone circuit.

In addition to the original ordinates, others are shown which are of interest. They are based on the results of loudness balance tests, and while not perhaps of great precision, do approximately indicate the relationship of the sidetone of a telephone conversation to that for direct speech, and illustrate the differences in the effects of sidetone for transmitting and for receiving.

On each curve are indicated the average sidetone value of the standard sidetone and the new anti-sidetone set, each, as before, with the new transmitter and receiver. There is also shown the range of sidetone for each type of set, within which practically all service conditions will fall. This indicated range takes into account not only variations in sidetone balance due to line impedance variations, but changes (with loop resistance) in battery supply to the transmitter. It should be noted that in only a few cases is the absolute sidetone of the anti-sidetone set on the worst sidetone conditions, as high as or higher than that of the sidetone set on the best sidetone conditions, and then only by a small amount. Furthermore, in spite of the wider variations in sidetone of the anti-sidetone set, these variations are over a range such that the resultant variations in effective losses are smaller than for the sidetone set.

Considering Fig. 5*a*, it will be noted that for either sidetone or anti-sidetone sets, the sidetone is louder than for natural speech

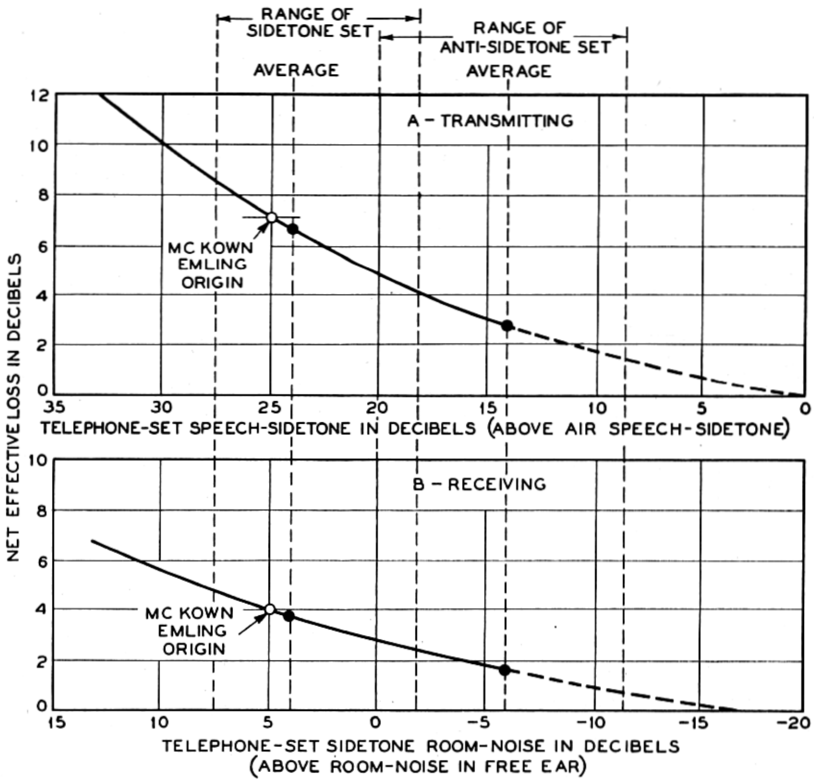

Fig. 5—Effects of sidetone on user of telephone.

sidetone, which, as noted before makes the user think he is talking louder than he actually is. The average sidetone reduction of 10 db for the anti-sidetone set results in less of this restraint on his talking level, with a resultant net effective gain in transmitting of about 4 db compared with the sidetone set.

In receiving, Fig. 5*b*, sidetone introduces an effective loss by the reproduction in the telephone ear of room noise picked up by the transmitter. It will be noted that for the anti-sidetone set, the reproduced noise is in general appreciably lower than the room noise itself. Inasmuch as room noise also interferes directly with received speech in the telephone ear by leakage under the receiver cap, the contribution to the total noise of the sidetone pickup of the anti-sidetone set is in most cases small. This is not true for the sidetone set, where in many cases the sidetone noise may constitute the principal interfering noise. The resultant net effective gain in receiving is about 2 db compared with the sidetone set.

This is a good illustration of the type of information which can be obtained only from a field study. For example, the relationships indicated on Fig. 5 are dependent on how far away from the mouthpiece of the transmitter and at what level the speaker talks, and on how tightly to his ear he holds the receiver. These in turn are resultants of all the conditions of the particular telephone conversation. If incoming levels are so high as to be uncomfortable, the receiver may well be held farther away from the ear. In that event, of course, the sidetone conditions of the set become relatively less controlling. The weight, size, and shape of the instrument in his hands may similarly affect the subscriber's use of it, the results he gets, and the relative importance of various factors of telephone design.

For such reasons, not only must laboratory performance tests be supplementary and subsidiary to field tests, but additional field tests must be the basis for determining the effect of any major changes in design, whether or not those changes are electrical, acoustical, or purely mechanical.

Considerations of this sort emphasize the importance of having clearly and explicitly in mind the conditions and relationships of direct conversation, as a general reference for the interpretation and explanation of the effects of telephone design on telephone conversations. The sidetone ordinates of Fig. 5, for example, not only suggest the difference in function of the anti-sidetone circuit in transmitting and receiving, but also emphasize the fact that the overall sidetone resulting from the combination of circuit, instruments, and method of use, is the important factor rather than the sidetone circuit efficiency only. Such matters are easily lost sight of, if design is not properly coordinated in its correct perspective.

The reduction of sidetone provided by the anti-sidetone sets is of further advantage in two rather different ways.

In attaching a transmitter (which is an amplifier) and a receiver, to a common handle which mechanically couples the two, a condition is set up in which the gain under certain conditions may exceed the loss in the path made up of handle, air, and electrical sidetone circuit. Sustained oscillation, or howling, will then result between transmitter and receiver. Even if this point is not reached, but is approached within 6 db or so, impairment of quality results from incipient oscillation. The greater sidetone circuit loss of the anti-sidetone circuit provides an additional margin of safety against any such condition.

The granular carbon of the transmitter, and the design of the transmitter itself must be carefully controlled, or serious noise—transmitter "burning"—will cause noise in the receiver of the set. The mechanical and electrical wear and tear of service tend to make this transmitter noise worse. In the new transmitters this "burning" has been kept at a low inherent value throughout life. The anti-sidetone circuit, however, provides a margin of safety against the small amount remaining, so that with this set there is less likelihood of transmitter noise causing impairment of reception.

Reduced Susceptiveness to Interference

It will be noted from the schematic circuit drawing Fig. 2 that two condensers are used in the new sets, one in the anti-sidetone transmission circuit, and a separate one with the ringer. In some types of party line practice the ringer of the set is connected for some parties from one side of the line, and for the others from the other side to ground.

Figure 6 shows schematically two such ringing arrangements during the conditions of conversation, *6a* as used in the new sets, and *6b* with one condenser common to transmission and ringing circuits. It will be noted that in the standard circuit adopted (Fig. *6a*), if any longitudinal noise voltages exist between the central office and station grounds, there is an equal voltage drop from each side of the line to ground through the ringing paths (assuming the two ringer condenser paths to be identical). The voltage drop across the terminals of the talking set is therefore zero and no noise results.

If the arrangement of Fig. *6b*, corresponding closely to previous designs, were used, however, this condition would not obtain. The condenser of the station in use being common to the transmission circuit as well as the ringing circuit, the noise voltage drop across this condenser is introduced in the transmission circuit. In addition there are other paths to ground from each side of the line through the transmission circuit which are not of equal impedance. The net result is a residual noise current through the receiver of the talking circuit.

In the actual case, the impedance of all ringers and condensers is not identical and there are often more parties connected to one side of the line than the other. Even under these relatively unfavorable conditions, however, the two-condenser arrangement adopted reduces the susceptiveness of the set to interfering noise by as much as 15 db. A further material reduction is realized by the high impedance of the ringer used in the new sets, so that in most cases interfering noise at grounded ringer stations will not differ materially from that at individual stations where the ringer is bridged across the line.

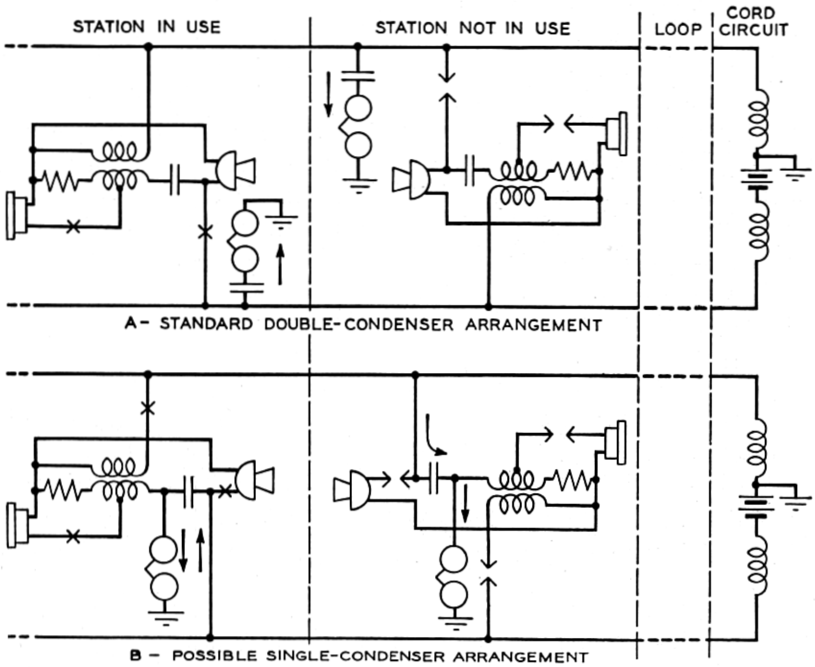

Fig. 6—Ringing arrangements for party line service.

It is interesting to note that this improvement is realized at little additional cost, since the transmission condenser, which must be of relatively high capacitance, is permanently bridged by the transmitter, so that it is protected from exposure to any large voltages, and may be of cheaper construction and smaller in size than would otherwise be the case. The ringing condenser on the other hand, while it must be constructed to withstand higher voltages, may be of relatively small capacitance, which gives more uniform and better ringing and dialing performance.

Characteristics of Transmitter and Receiver

Since the individual design characteristics of the new transmitter and receiver are discussed elsewhere,[1] attention here will be centered on the overall effects of these characteristics in the complete transmission system, as indicated both by laboratory and by field test. As stated before, the problem may be more or less arbitrarily separated into three correlated problems—volume, quality and noise.

As in the case of sidetone, these problems appear, perhaps, more nearly in a proper perspective if considered in comparison with the corresponding factors in a direct conversation. It must be remembered that telephone service does not consist in the provision of a mechanism, per se, but in the provision of facilities for conversation, to which the mechanism should be incidental, however important. Since the inherent conditions of such a conversation are quite different in many respects from those of a direct conversation with which, consciously or unconsciously, it will be compared in its overall results, the parallelism in detail should not be too exact. Departures from the conditions of direct conversation in certain respects which are relatively unavoidable, may be best compensated for by deliberate departure in certain other respects. For example, the physical absence of one party to the telephone conversation, and the monaural nature of such a conversation, may be partially compensated for by delivering to the ear of the listener a somewhat higher speech level than he is accustomed to in direct conversation. The limitation of frequency band width imposed on the telephone medium, largely for economic reasons, may be minimized in its effects if the transmission characteristics in the available band are other than a facsimile of the corresponding band in direct conversation. All such measures must be employed with knowledge of their effect on the ultimate objective, that the telephone conversation may be easy and natural.

General Requirements

It is easily seen that for any particular overall frequency characteristic of a telephone transmission system, there are practically an infinite number of ways in which it can be split up between transmitting and receiving characteristics. From this standpoint alone, then, there is no particular "best" transmitter or receiver frequency response. From other standpoints, however, certain general types of individual characteristics, both in frequency and efficiency, are to be preferred to others, particularly when considered in their practical application to an already existing telephone system. It has been pointed out [9] that in general, development has been toward a telephone system where both transmitter and receiver are relatively uniform in their frequency characteristics. Induced noise appears to be so evenly distributed with frequency that such response would not appear to magnify the interference problem.

Transmitting efficiency should be as high as required to keep the speech well above induced noise but not so high as to cause excessive crosstalk into other telephone circuits. The maximum desirable received level is determined for a given telephone system by the limitations of the human ear in accepting with comfort speech levels above a certain intensity. Finally, the practical necessity of working as satisfactorily as possible in conjunction with the telephone transmitters, receivers, and sets in the existing plant during the period of transition, places a practical limitation on the amount of change that is desirable in relative levels of either transmitting or receiving.

With regard to frequency range, previous work [10] indicated the desirability of designing circuits to transmit frequencies from 200 or 300 cycles up to about 3,000 cycles. Gains in articulation and naturalness are realized by increases in this band width, but are progressively smaller for successive equal increments in frequency. A 3,000-cycle band properly used gives good transmission both in articulation and naturalness, but frequency limitation is essentially an economic one, subject to change as conditions change. Recent work on the new multiple channel carrier systems has indicated justification in these systems for providing a somewhat wider band, from about 150 to about 3,500 cycles.[11]

Overall Frequency Response

In describing the frequency characteristic of a transmission system it has become customary to refer to it as more or less "flat," where "flat" is assumed to be synonymous with "perfect" as far as the relative transmission of various frequencies is concerned. In measurements of the elements of an electrical circuit, from which this terminology came, the word is useful since, when the measurements are properly made, at any rate, the basis of comparison implied by the word "flat" is generally understood. This is also true, although probably to a more limited extent than is generally realized, when the term is applied to electro-acoustic transmission systems, where free progressive, plane air waves of various frequencies are transferred to an electrical system, or vice versa, by means of microphones or loud speakers.

In the case of a telephone system, however, where a transmitter is placed close to the lips, and a receiver directly to one ear, and where the air waves are not free progressive, or plane, use of the word "flat" implies a basis of comparison which is not self-evident. Much effort has been given recently to establishing an appropriate reference system, sufficiently simple in concept and ease of specification, to be useful in this connection. The result of this work has been a reference telephone system which, when spoken into, would give the listener in all respects essentially the identical sensation he receives in one ear when facing the speaker directly, with an air path one meter long between the speaker's mouth and the listener's ear, in surroundings without reverberation or noise. Such a reference transmission system has tentatively been called an "orthotelephonic" system.

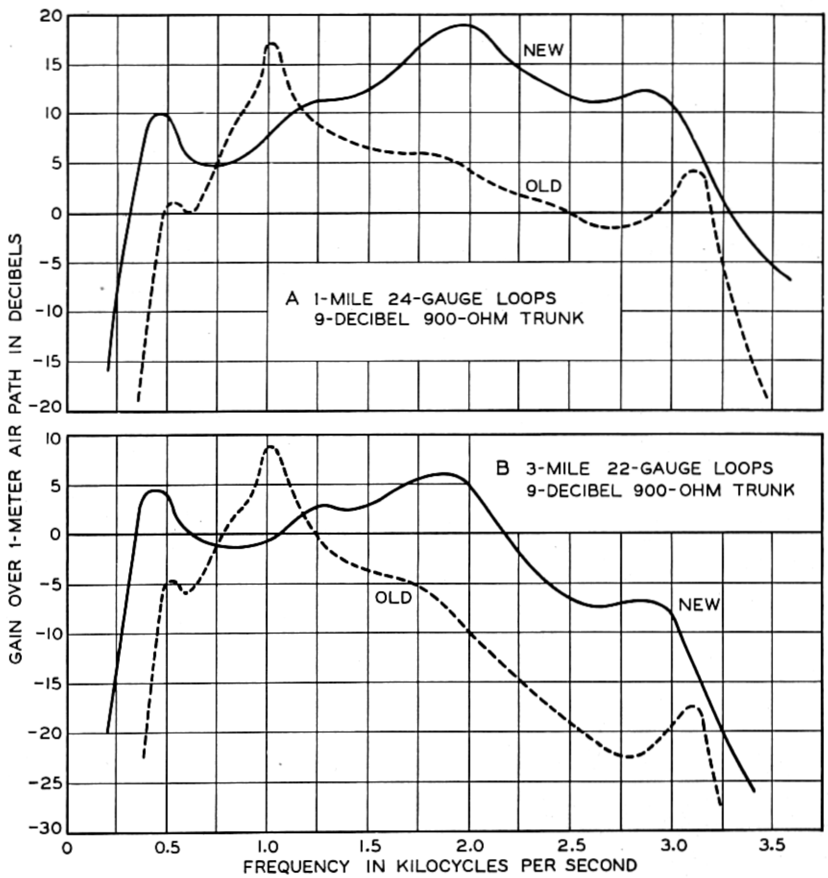

Fig. 7—Overall orthotelephonic frequency response of Typical Telephone Connections.

The point of interest here is that when measured by any suitable objective method, the frequency characteristic of this "orthotelephonic" telephone reference system is not "flat" by a considerable amount in the ordinarily accepted usage of the term. This departure from "flatness" is caused by such factors as the frequency directive characteristic of the mouth, cavity resonance of the ear, and disturbance of the sound field by the head. The individual contribution of some of these factors is not as yet definitely determined.

Furthermore, for reasons mentioned, it is not self-evident that a practical telephone system of limited frequency range should be "flat" with respect to the corresponding frequency band in this more or less basic orthotelephonic system which is not limited in frequency range. Having decided on the band width that is desirable and justifiable, it must still be determined, therefore, what particular frequency characteristics are preferable in this band.

In selecting from the many possible choices, the particular frequency response that seems best, several factors must be taken into account. This has been done by a study (under the conditions of actual service) of the relative results of several different experimental instrument designs, varying in frequency characteristics. The overall frequency characteristics of the resultant choice are indicated for two typical circuit conditions in Fig. 7. These measurements were made with the artificial mouth and ear [12] and are plotted with reference to corresponding measurements on an orthotelephonic reference telephone system. For comparison, the results of similar tests of the earlier Bell System handset [13] are shown also.

In considering these overall telephone system frequency response characteristics in the light of previous discussion, there are several points of interest:

1. The large increase in response at both higher and lower frequencies with respect to the older handset, which in itself was a notable advance in this respect over previous types. This increase amounts to 10 db or more from about 200 to 500 cycles and from about 1,700 to 3,000 cycles. This wider frequency range gives better naturalness of reproduction.
2. The type of the response. The general uniformity and absence of any marked resonance or irregularity is obvious. For either average or long loops the entire band from about 300 to over 3,000 cycles lies within a range of 15 db. It will be noted, however, that, for the average condition, the response at the higher frequencies (1,500–3,000 cycles) is distinctly above that for the frequencies below 1,500 cycles. This characteristic aids materially in the understanding of the low intensity consonant sounds. The response on the longer loops would undoubtedly be correspondingly better if the high frequencies were raised so that the overall characteristic more nearly resembled that for the average condition shown. It should be remembered,

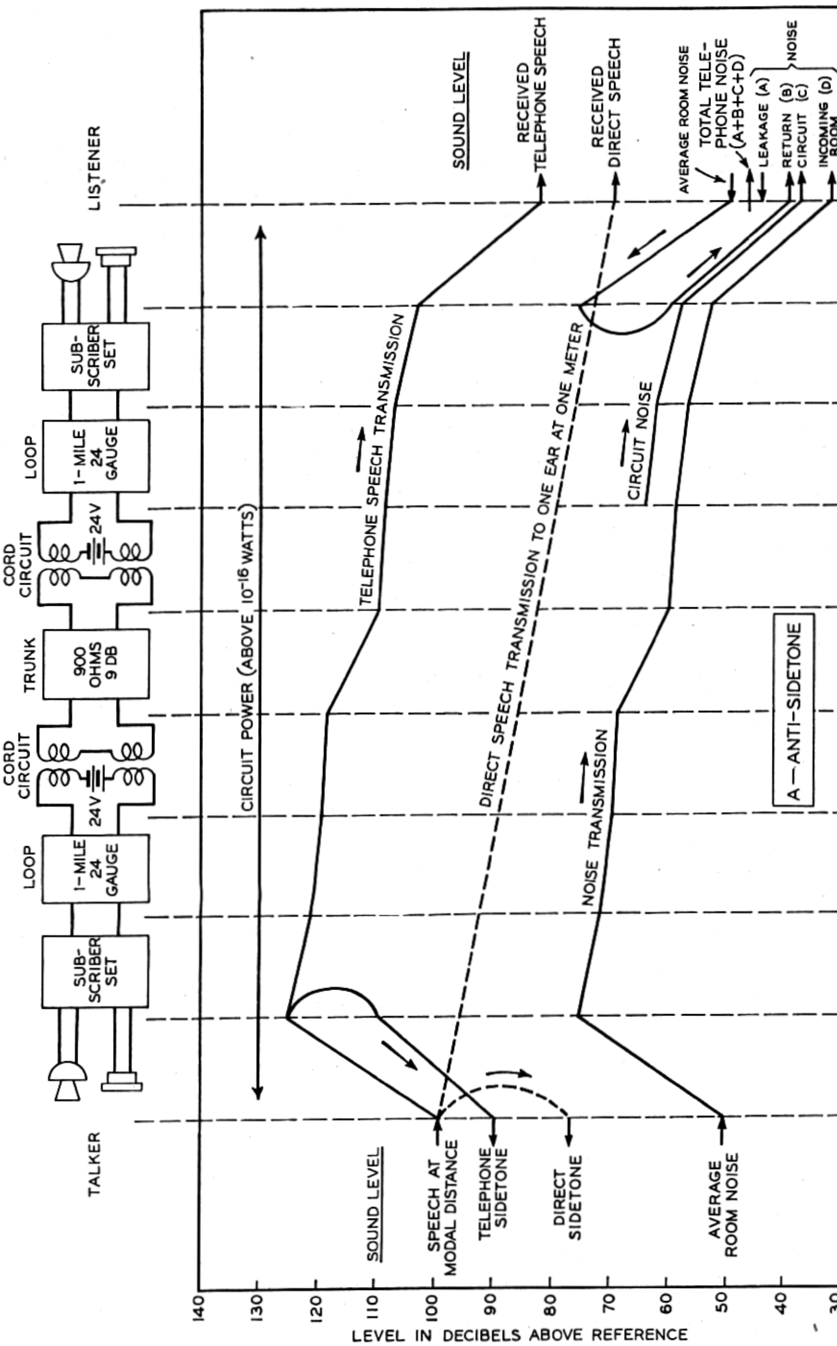

Fig. 8—Power level diagrams of typical telephone connections.

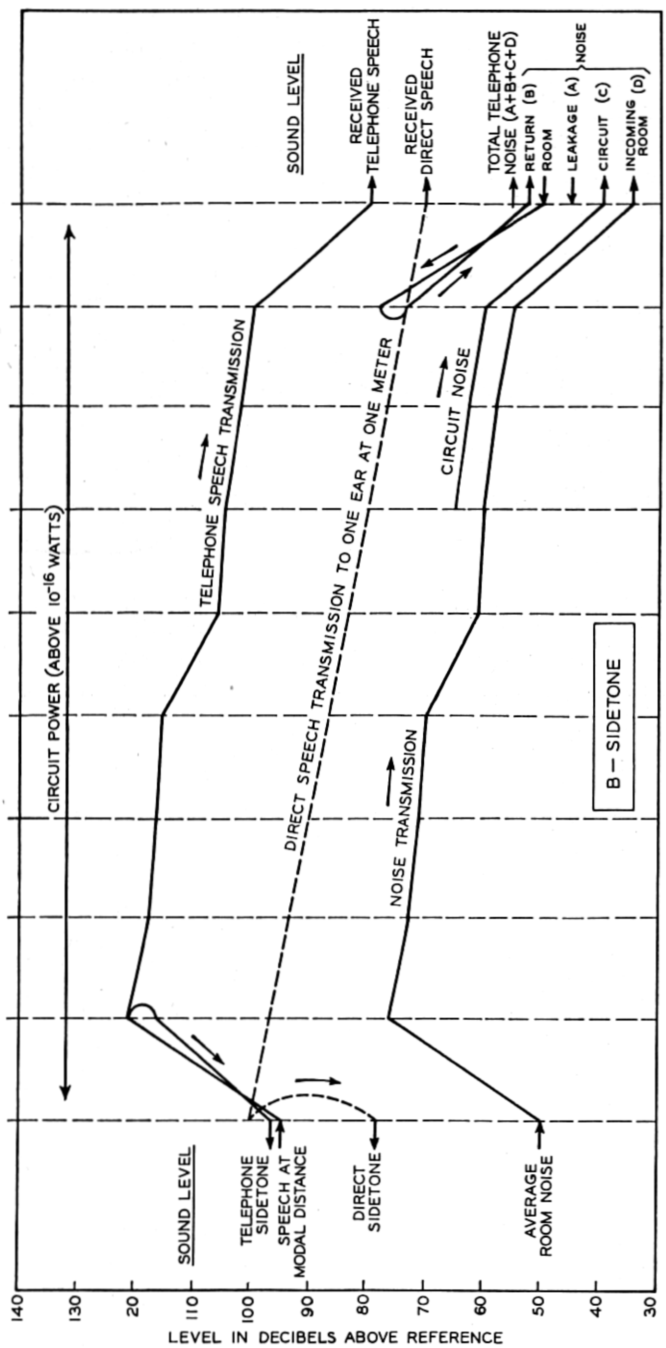

Fig. 8.—*Continued from page 376.*

however, that for a standard set, to be used on all loop conditions, a response designed solely for the long loop, with its large loss at high frequencies, would be distinctly "tinny" and disagreeable in quality on average or short loops.

3. The materially smaller losses in the transmitted band for the average telephone connection than for the orthotelephonic system. Even for the long loop conditions the losses are no greater than for this orthotelephonic system up to about 2,200 cycles. In other words, for a large majority of telephone calls the received speech level will be higher for the same talking level than in the case of direct conversation at one meter distance. The desirability of this in a monaural system of limited frequency range has already been indicated.

Combined Effects of Circuit and Instruments

The part played by the anti-sidetone circuit in permitting better utilization by the subscriber of the capabilities of the telephone system, in increasing the level of received speech, and minimizing the effect of noise is summarized by the illustrative power level diagrams in Fig. 8, using typical values of room and line noise and other conditions.

The data shown were obtained by objective measurements with the artificial mouth, sound level meter, volume indicator, and artificial ear. Frequency weightings appropriate to the levels involved were employed in the sound level measurements.

Figure 8*a* shows, for the anti-sidetone set, the losses between the talker and listener under average room noise and circuit conditions. Figure 8*b* gives corresponding information for the sidetone set. For comparison, an approximate level diagram is shown also for direct speech. The relative speech levels at the transmitter for the two telephone conditions were adjusted to give volume indicator readings on the line in accordance with the results of service observations. The upper curves in each drawing are for speech and the lower for noise picked up by the transmitters.

At the transmitting end the lower sidetone of the anti-sidetone set results in higher talking levels, with about 4 db higher speech level at the input to the circuit. In the overall circuit this gain is increased by the receiving-end effect of the anti-sidetone circuit in minimizing the effect of room noise.

The total noise in the telephone ear, as shown on the drawing, has as its principal contributing factors:

1. Leakage of noise under the receiver cap.

2. Noise picked up by the transmitter and returned via the sidetone path and receiver to the listener's ear—termed "return noise."
3. Circuit noise.
4. Room noise picked up at the far end and transmitted over the circuit.

The different relative contribution of the "return noise" for the two sets is of interest. The net result is a total noise in the telephone ear, lower than the actual room noise for the anti-sidetone set, and higher for the sidetone set.

For the circuit and room noise conditions shown, the ratio between received speech level and noise is about 25 db for the sidetone condition, and 35 db for the anti-sidetone. The corresponding ratio for air transmission to one ear under the conditions shown is in the order of 20 db.

Results of Laboratory and Field Performance Tests

It has been seen that the new sets are superior in volume and in minimizing the disturbances of noise. The frequency measurements just discussed have indicated marked superiority also in the quality of reproduction.

One measure of the effect of this reduced distortion is by means of the articulation test. Such tests have shown that for a typical telephone system equipped with the new telephone sets, 95 per cent of the letter sounds spoken into the transmitter are correctly understood by the listener. With air transmission, 98 or 99 per cent of letter sounds are correctly understood. The difference is almost entirely due to the broader frequency band transmitted by the air path.

With the final designs of the new sets, tests have been made by the methods developed for determining "effective" transmission.[2] The results of these tests have shown that the new sets under the conditions of actual service provide a marked advance in transmission performance. The average total transmitting and receiving gain is about 15 db on the effective basis of transmission, as compared to sets of the sidetone type used with the older type of instruments.[13]

Conclusion

In general it appears that the notable transmission improvement which has been achieved in the design of the new telephone sets, in their freedom from distortion, higher effective volume, lower sidetone, and general convenience in use, makes possible a closer approach to the ease of a direct conversation than has hitherto been possible commercially.

Undoubtedly, further improvements in station transmission performance will, as in the past, be forthcoming with advances in the technique of design and manufacture, and in further knowledge of the requirements of the problem.

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