The Trend in the Design of Telephone Transmitters and Receivers [1]

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This is a report of the Joint Subcommittee on Development and Research, National Electric Light Association and Bell Telephone System. It was prepared by the Chairmen, respectively for the Bell System and the N.E.L.A., of the Project Committee assigned to this study.

The report reviews the history and present trend of the design of telephone transmitters and receivers, particularly from the standpoint of their response frequency characteristics, and discusses the possibility of obtaining a reduction in the effect of line noise by shifting their points of maximum response. It is concluded that no advantage from this standpoint is indicated inasmuch as it has been found that the distribution with frequency of the extraneous energy on telephone toll lines is approximately uniform over the more important portion of the frequency range. It is further stated that the present trend in improvement of the response characteristics of transmitters and receivers is in the direction of reducing the difference between their maximum and average response.

IN the beginnings of the telephone, the outstanding marvel was that the devices used as transmitters and receivers could perform the necessary conversions between speech sound waves and electrical waves. In the application of these devices, however, it was early appreciated that the range and cost of telephone circuits were directly

[1] Editor's Note: In this issue of the *Bell System Technical Journal* there are two papers and one report dealing with various phases of the inductive coordination problem, which have had their origin in the work of the Joint Subcommittee on Development and Research of the National Electric Light Association and the Bell Telephone System.

This organization is one of the subcommittees of the Joint General Committee of the N.E.L.A. and Bell Telephone System, which has for its general objective the working out of methods of procedure whereby problems involving the physical relations between the plants of the electric supply companies and the telephone companies may be handled cooperatively on mutually satisfactory bases. The questions involved are largely of an engineering character, and to carry on that phase of the work the Engineering Subcommittee of the Joint General Committee was appointed. The Engineering Subcommittee has recommended certain broad principles of cooperation as well as the adoption of more detailed principles and practices, which were accepted by the Joint General Committee and published in 1922.

As a result of further recommendations by the Engineering Subcommittee the Joint Subcommittee on Development and Research was organized. It is charged with the conduct of technical investigations, the accumulation of data, and the development of engineering methods for use in the solution of problems of coordination. Its work is organized under a number of subordinate committees known as "Project Committees," each of which is assigned a certain range of subjects for study.

The first volume of Engineering Reports of the Joint Subcommittee on Development and Research, containing a considerable part of the technical information thus far developed by the subcommittee has recently been published (April, 1930).

[2] N. E. L. A. Bulletin, Aug., 1930.

dependent upon the efficiency with which these instruments made these conversions. Experimental activities were, therefore, soon directed to increasing the efficiency of these instruments and especially to getting a more efficient transmitter than the forerunner of the present telephone receiver which initially was used both as a transmitter and a receiver. The outcome was the carbon contact transmitter which provided a means for drawing upon an outside source of energy in the process of converting sound waves into electrical waves and thus combined in the transmitter the function of a converter of energy with that of an amplifier.

Since that time numerous important improvements have been effected in both the carbon transmitter and the magnetic receiver but the general principles of both are still employed today in the best practical instruments for commercial telephony. Both of these instruments employ vibrating diaphragms which, like other mechanical vibrating systems, have regions of maximum response due to resonance between the mass and elasticity of the diaphragm. With these resonant effects inherent in the structure, it was natural to place them in the frequency range so as to obtain the maximum benefit. In accordance with this, the reproductions of speech sounds obtained with these resonances located at different points were listened to and the judgment reached, taking into account both the intelligibility and naturalness of the reproduced sounds, that they should be placed around 1,000 cycles. It was found that a material shift in the point of maximum response of the circuit to a lower value made the output sounds "boomy" and to a higher value rendered them "thin." While precise means for measuring the effects were not available at that time, subsequent work has substantiated this choice as a wise one. Investigations of the frequency components of speech sounds have shown that the principal components of about half the vowel sounds lie below 1,000 cycles and of the other half are about equally divided above and below this point. Articulation tests have demonstrated that the frequency range which covers about an octave each side of 1,000 cycles, namely from about 500 to 2,000 cycles, includes the more important frequency components in speech from the standpoint of intelligibility. The frequencies below this range are important primarily for naturalness and those above for intelligibility and also for naturalness. The location of the region of maximum response of the telephone circuit in the neighborhood of 1,000 cycles emphasizes then this 500 to 2,000-cycle range and meets well the requirements of both intelligibility and naturalness.

In addition to the diaphragm resonances there are also inherent resonances in the enclosed cavities which are associated with these diaphragms, such, for example, as the mouthpiece of the transmitter and the cases in which the transmitter and receiver units are placed. In the present type of deskstand transmitter the several resonances are so located as to give a fairly broad maximum response in the range between 1,000 and 2,000 cycles and the resonance of the receiver has been placed so that its maximum response is around 1,000 cycles. It is seen then that the inherent resonances of these instruments have been located in the more important part of the voice-frequency range and have been utilized to increase their efficiencies in that range.

The remarkable performance of the granular carbon type of transmitter merits some indication of its accomplishment. Its conversion of the complex speech waves into equivalent electrical waves has been improved from time to time and now the most efficient type of transmitter which is in general use, when energized with the direct current which it gets on short loops, has an electrical output which is more than a thousand times the magnitude of the acoustical power which is delivered by the speaker. Furthermore, it provides this conversion and large amplification at a low cost. Since the average energy given out by a speaker in carrying on a telephone conversation is of the order of 10 microwatts, the large stepup in power from the acoustic waves entering the transmitter to the electrical waves leaving it is of vital importance in affording telephone service at a reasonable cost and also in rendering the telephone system less susceptible to the effects of interference currents.

While large improvements have been made in the receiver, the efficiency of the present instrument is very low in comparison with many other types of energy converters which it is considered practicable to use. For the receiver, the average ratio of the acoustic power output to the electrical power input is below 1 per cent. It is possible to increase materially the efficiency of the receiver used in commercial telephony but this would bring up the noises on the telephone circuit. Also there are limitations upon the maximum efficiency of the combination of transmitter and receiver due to crosstalk between telephone circuits and to the fact that with loud talkers over short telephone connections the combination of present instruments is close to the point of giving uncomfortably loud sounds in the ear of the listener.

In considering the performance of the transmitter in the plant, it is customary for many reasons, important among which is the battery supply circuit, to take the combination of a transmitter, a station set, a typical loop connecting the set to the central office and the cord circuit from which is supplied the direct current for energizing the transmitter. Likewise, the receiving system of the circuit may be considered to consist of the cord circuit, the loop, the set and the receiver. For the connection of such transmitting and receiving systems through a distortionless trunk, the response characteristic of the overall circuit, giving the relation between the power delivered by the receiver and the power available at the transmitter, shows a variation of about 30 db in the range from 500 to 2,000 cycles with the maximum response slightly above 1,000 cycles. This characteristic applies to the type of deskstand apparatus which is now the most generally used station equipment in the Bell System.

With the development of the telephone art numerous ideas have naturally been investigated for improving the performance of the transmitter and the receiver. Taking into account the various considerations and possibilities, the present procedure is on the basis that further improvements should come from reduction in distortion rather than from increases in the maximum response. For practical instruments the desire is primarily to reduce the distortion without sacrificing the average efficiency over the important part of the voice range. Means have been developed for reducing the distortion in these instruments but in general such improvements have involved material reductions in efficiency. For example, a very high degree of freedom from distortion is realized in the type of carbon transmitter which has been so widely used for pickup work in radio broadcasting. This transmitter, however, requires a powerful amplifier to bring its output to a value comparable with the type of transmitter used in commercial telephony. It has been possible also to obtain large reductions in the distortion of the receiver but here, too, large sacrifices in efficiency have attended this accomplishment. Material progress has been made, however, toward the ideal of a combination of low distortion without sacrifice in efficiency.

Some of these improvements have been incorporated in the transmitter which is used in the handset type of station apparatus. The frequency response characteristic of transmitting and receiving systems such as described above, but using the handset instruments instead of the deskstand, shows a variation of only about 20 db in the range from 500 to 2,000 cycles, and with the handset instruments this same variation of 20 db covers the range from 500 to 3,000 cycles. The handset transmitter presents, therefore, a material advance from the standpoint of reducing distortion.

The proposal has been made at various times that the interference situation might be helped by providing still more efficient transmitters. The various possible means of still further increasing the transmitter efficiency, however, are attended by many difficulties and complications. The efficiency at the point of maximum response could, of course, be increased by piling up the several resonances which have been referred to, but this would give serious distortion effects which would more than offset any increase in loudness which was obtained. In general, it has been found that any improvements which might permit higher maximum responses can be utilized to give greater benefit in the reduction of distortion. Moreover, any large increase in the transmitter efficiency would require measures such as the reduction of the efficiencies of the receivers in order to avoid increased crosstalk effects between circuits and uncomfortably loud transmission over short connections.

When the program of the joint development and research work of the N. E. L. A. and Bell System was formulated there was the idea that in view of the resonant characteristic of the telephone receiver, some benefit might be obtained in the performance of the telephone circuits in the presence of line noise by shifting the point of maximum response of this instrument. Some cases had arisen where pronounced harmonics in the power system in the neighborhood of 1,000 cycles caused serious troubles in nearby telephone circuits and it was felt that if this condition were found to be prevalent in power circuits, some relief in the interference situation might be obtained by shifting the point of maximum response away from this region. The investigations which have been carried out under Project 4 of the N. E. L. A.-Bell System Joint Development and Research Subcommittee, of the noise on telephone lines in different parts of the country have shown that the average distribution of energy with frequency is approximately uniform over the range from 300 to 2,000 cycles with, however, a pronounced dip in the region around 1,000 cycles. A similar decrease in the energy of the components around 1,000 cycles is also shown by the results of the investigations made under Project 5 on the wave shapes of electrical power machinery. With this situation, shifting the maximum response of the telephone receiver away from its present location would thus in the average case be placing it in a region in which larger amounts of interfering currents are to be found. Moreover, examination of the data showing the distribution with frequency of noise currents, indicates that on particular circuits this distribution is by no means uniform but in many cases is materially higher in the region below 1,000 cycles and in other cases materially higher in the upper regions. It would not appear, therefore, that a shift in the maximum response of the telephone receiver would on the average give an improvement from the interference standpoint.

Furthermore, any compromise in the instrument characteristics to favor the line noise conditions, should not have an adverse effect on the many connections on which noise from power systems is unimportant. As has been noted, a material shift in this maximum response would have a marked effect on the naturalness of the reproduced sounds. On the whole, then, no advantage to the interference situation has yet been indicated for shifting the resonance of the receiver.

In accordance with these considerations, the present effort in the development of telephone transmitters and receivers is being directed along the lines of reducing the deviation between their maximum and average responses. Any improvements in the instruments which it may be found practicable to make will be in the direction of increasing the intelligibility and naturalness of the telephone conversations, and the justification for their adoption will include their effectiveness in the presence of typical distributions of interfering currents on the telephone lines.