The Development of a Handset for Telephone Stations *

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A number of factors contribute to the difficulties involved in the design of a telephone handset which gives as good service performance as a deskstand. The handset transmitter, for example, not only is used in a wider range of positions but also is moved much more frequently, so that wider variations are experienced in its characteristics.

Further difficulties are introduced by the close physical connection of the receiver and transmitter, in that "howling" tends to be set up.

The handset has been developed so that it overcomes all these difficulties and is interchangeable with the deskstand in existing telephone plant without important reaction on either transmission or signaling performance.

MANY interesting development problems are presented in the design for general use of a handset which provides the convenience of this arrangement of a telephone set without a sacrifice in the performance of the system. It is the object of this paper to discuss some of these problems and to describe their solution as embodied in the handset now being furnished by the Bell System.

The idea of mounting a telephone transmitter and receiver on a common handle to form a handset was conceived early in the development of the telephone. In 1878, only a few years after the invention of the telephone, handsets of the type shown in Fig. 1 were in use by operators in the Gold and Stock exchange in New York City.[1] Variable resistance transmitters of the Edison type were used in these handsets. This transmitter employed a relatively insensitive lamp black resistance element which was soon superseded by the more sensitive granular carbon type in order to permit the extension of telephone service to greater distances. The basic ideas underlying the variable resistance transmitter and the many advantages of granular carbon over the numerous other materials which have been tried have been discussed elsewhere.[2] It is sufficient to point out here that the large amplification afforded at low cost by a well designed granular carbon transmitter makes it unlikely that any other structure will offer successful competition in general telephone application for some time to come.

When an attempt was made to use granular carbon transmitters with handsets it soon became evident that a satisfactory design in-

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[1] "Beginnings of Telephony," F. L. Rhodes, Harper and Brother, 1st Edition, p. 153.

[2] "The Development of the Microphone," H. A. Frederick, *Journal of the Acoustical Society of America*, July 1931, Part 2, p. 17; *Bell Telephone Quarterly*, July 1931.

volved more than the mounting of the available types of transmitters and receivers on a common handle and that considerable development of the instruments as well as the means for coupling them would be required before a handset suitable for general use were obtained. For this reason, the telephone system in this country has in general been built up around the wall set and the deskstand which permitted the utilization of the available transmitters and receivers to best advantage.

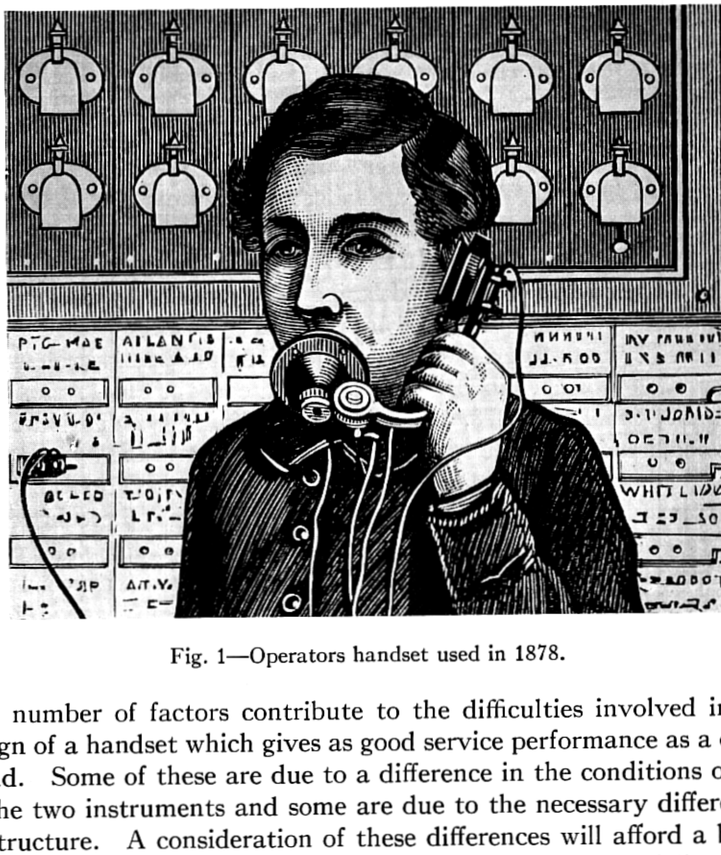

Fig. 1—Operators handset used in 1878.

A number of factors contribute to the difficulties involved in the design of a handset which gives as good service performance as a deskstand. Some of these are due to a difference in the conditions of use of the two instruments and some are due to the necessary differences in structure. A consideration of these differences will afford a background for the subsequent description of the line of attack followed in providing a satisfactory handset.

Difference in Usage

The controlling differences in service conditions are due to the fact that the handset permits the user much more freedom than the deskstand. The handset transmitter, accordingly, is not only used in a wider range of positions but is also moved much more frequently with the result that, in general, much wider variations are experienced in its transmission characteristics and resistance. If the transmitter is not suitably designed these variations may be sufficiently large to render the transmission of a handset unsatisfactory, and to interfere with the operation of associated relays and other signalling apparatus.

The more severe use to which the handset is subjected also has a tendency to materially accelerate changes in the contact surfaces of the carbon and the electrodes. These changes are evidenced principally by increased carbon noise and resistance which affect both transmission and signalling and appreciably shorten the useful life of the transmitter unless proper design measures are taken to reduce these aging effects.

Differences in Structure

It is undesirable in any telephone set, designed for use by the general public, to require the user to perform any switching operation in changing from talking to listening. For this reason, practically all commercial telephone sets are of the so-called "invariable" type, in which the transmitter and receiver are at all times connected to the line while the set is being used.[3] Part of the output of the transmitter, therefore, is transmitted to the receiver of the local telephone set. This electrical connection between the transmitter and receiver of the same set is known as the "sidetone" path, and the resulting sound in the receiver as "sidetone." In addition to this electrical coupling between the instruments, there is acoustical coupling through the air and in the case of the handset mechanical coupling through the handle. If the amplification afforded by the transmitter is greater than the aggregate losses in the sidetone path, the receiver, the air and the handle, sustained oscillation or "howling" may be set up. Any such condition, is, of course, not only unpleasant but fatal to transmission. It has been found necessary, in fact, to keep well below the howling point to avoid serious transmission impairment due to transient oscillations.

In the case of the deskstand, the sidetone path and the air path provide the only coupling between the instruments and the losses are of sufficient magnitude that howling does not occur even with the most efficient transmitters and receivers. In the case of the handset, however, the handle may add appreciably to the coupling. Without proper design of the handle, instruments, and means for mounting the instru-

[3] "Transmission Circuits for Telephonic Communication," K. S. Johnson, D. Van Nostrand Co., 4th printing, p. 105.

ments on the handle this additional coupling is often sufficient to cause howling.

Since with the deskstand a flexible cord forms the only connection between the transmitter and receiver, the user is always able to hold the receiver to his ear and at the same time to speak with his lips directly in front of the transmitter. The handset handle, however, definitely establishes the distance between the two instruments. If it

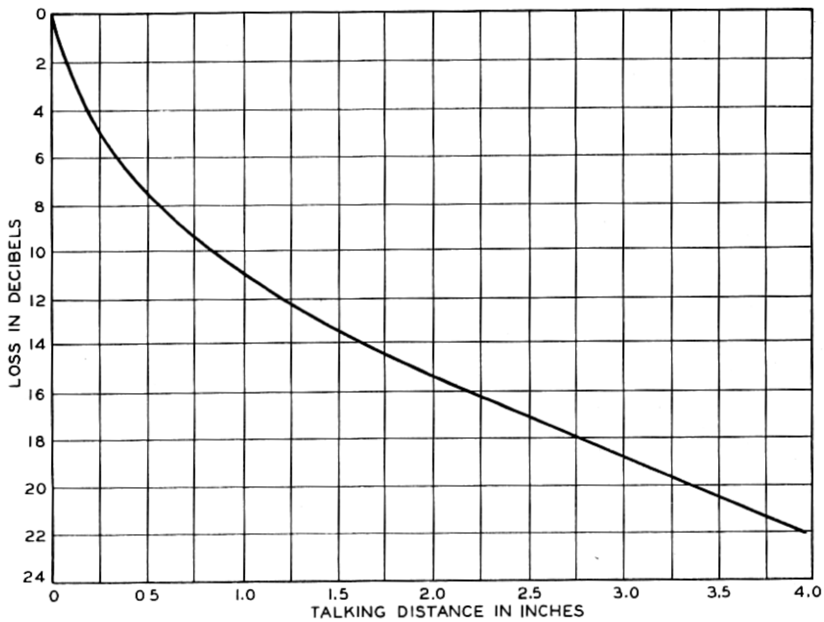

Fig. 2—Loss in transmitter output with distance from the mouthpiece.

is too short, many users are unable to hold the receiver on the ear when the transmitter is in front of the lips. This difficulty has often been avoided by making the handle long enough to accommodate any user. If this is carried to an extreme, the distance between the transmitter and the lips is greater than necessary, and introduces an avoidable transmission loss for the majority of users. As may be seen from the curve shown in Fig. 2, this loss may be quite large and warrants every effort to minimize it.

If the convenience of the handset is to be fully realized, it is important that the handle be shaped to fit comfortably in the hand and that the complete handset be sufficiently light to avoid fatigue on the part of the user. These structural limitations add a further problem in design.

Description of the Handset

While many incidental problems have required solution during the development of the present handset, which is shown with its mounting in Fig. 3, this design is largely the result of a systematic attack on the

Fig. 3—Station handset and its mounting.

more fundamental problems that have been discussed. In describing the handset, therefore, particular attention will be given to those features which are of importance in the solution of these problems. Some of the most important and interesting of these are embodied in the transmitter.

Transmitter

Referring to the cross-sectional view of the handset, Fig. 4, it will be observed that the various parts of the transmitter are assembled in a die cast aluminum housing to form a unit which mounts in a threaded brass bushing in the handle. One electrical connection is made through this bushing, the other through a contact which engages a spring in the base of the housing. The molded phenol plastic mouthpiece, dome and spacing ring, which form the external parts of the

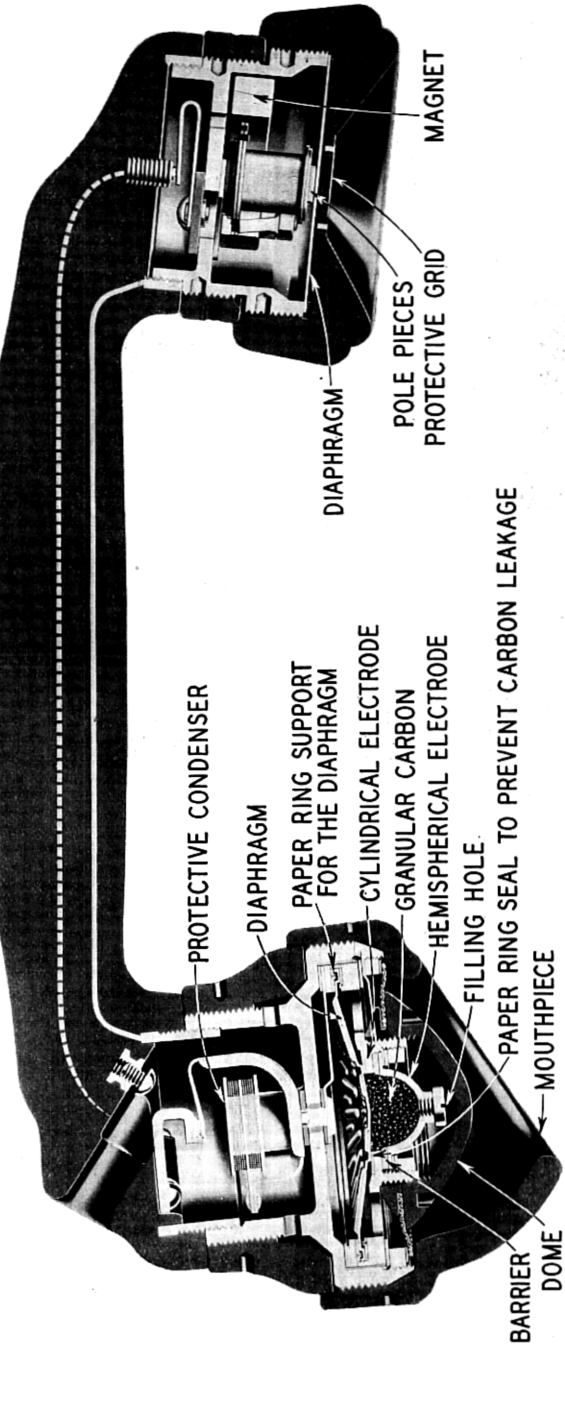

Fig. 4—Cross section of the station handset.

transmitter, insulate the metal parts in the electrical circuit so that they cannot come into contact with the user. The spacing ring also serves to lock the transmitter to the handle and align the mouthpiece with the axis of the handle.

Effect of Angular Position on Resistance

The carbon chamber of the transmitter is often referred to as a "barrier" type and differs radically from the conventional form of "direct action" resistance element, which has been employed for years

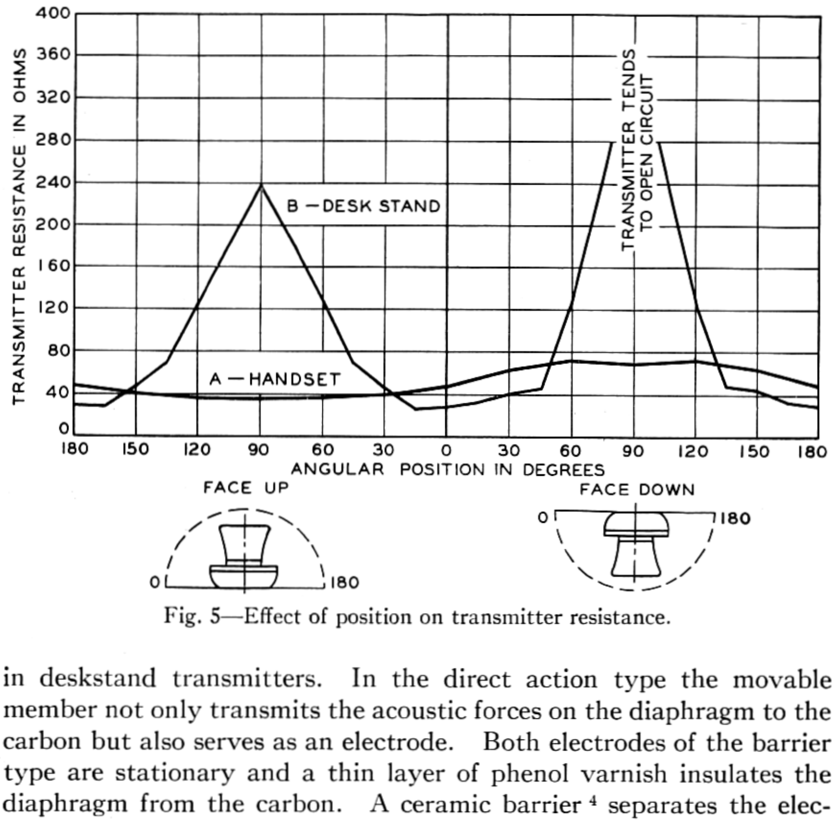

Fig. 5—Effect of position on transmitter resistance.

in deskstand transmitters. In the direct action type the movable member not only transmits the acoustic forces on the diaphragm to the carbon but also serves as an electrode. Both electrodes of the barrier type are stationary and a thin layer of phenol varnish insulates the diaphragm from the carbon. A ceramic barrier [4] separates the electrodes from one another and defines the current path through the carbon. The electrode surface adjacent to the diaphragm is cylindrical in shape, the other hemispherical. Both are gold plated. By adopting this electrode arrangement good contact is maintained be-

[4] "Manufacture of Thin Porcelain Parts of Close Dimensional Tolerances," L. I. Shaw, A. O. Johnson and W. J. Scott, *Journal of Ceramic Society*, Nov. 1931, pp. 851–854.

tween the carbon granules and the electrode surfaces and between the granules themselves, in all of the positions in which the transmitter is likely to be held while in use. This uniformity of contact pressure makes the resistance of the transmitter nearly independent of angular position as shown by Curve A, Fig. 5.

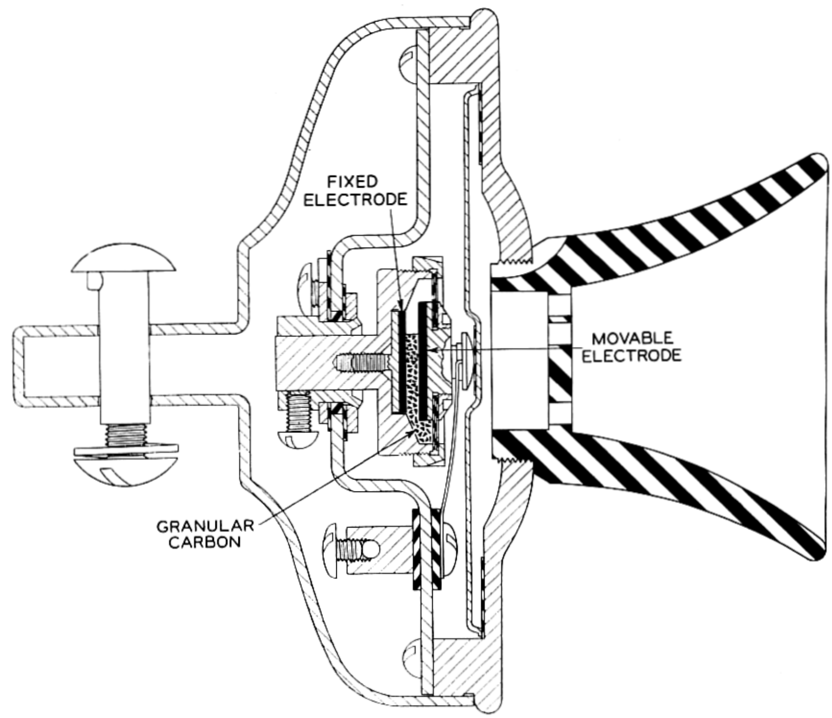

Fig. 6—Cross section of a typical deskstand transmitter.

The substantially uniform resistance of the present handset transmitter in various positions represents an outstanding improvement over that obtained with a typical deskstand transmitter such as that shown in cross-section in Fig. 6. Referring to curve B, Fig. 5, it will be observed that the resistance of this transmitter is markedly dependent upon angular position, two prominent peaks occurring where the electrodes are practically horizontal and the carbon falls away from the surface of the upper electrode. This is typical of the performance of the older types of transmitters employing the conventional form of direct action structure. While this characteristic is not important in deskstand service it renders this type of transmitter unsuitable for the more severe conditions encountered in the use of a handset.

Effect of Angular Position on Carbon Noise

Another transmitter characteristic which is likely to be influenced by the position in which the handset is held is carbon noise. In addition to the adsorbed gas on the surface of the granule there is also an appreciable amount of gas absorbed in the pores in its surface.[5] When a voltage is impressed on the transmitter the temperature[6] of the

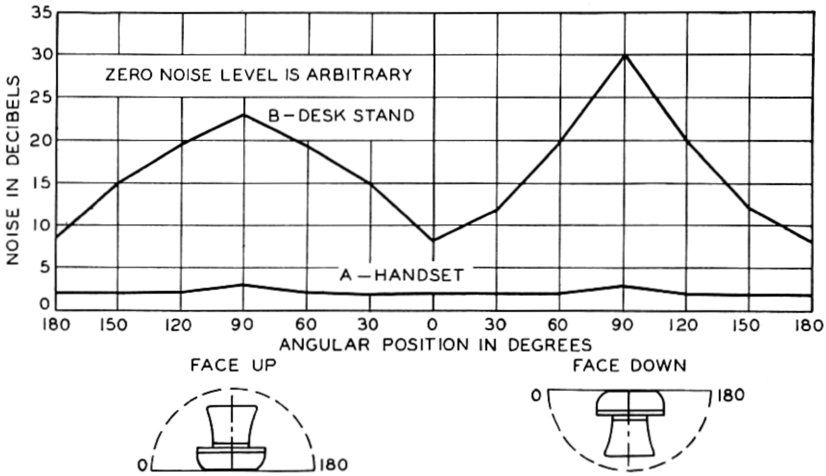

Fig. 7—Effect of position on carbon noise.

points of contact between the granules is increased and a certain amount of the gas is driven off, forcing the granules apart and giving rise to non-periodic changes in resistance. These disturbances result in noise in the receiver which tend to mask incoming speech. It is evident that a given efflux of gas will produce a larger change in resistance when the contact forces are low than when they are high. Hence, if as a result of turning the transmitter through the various angles in which it is likely to be used, the contact pressure is lowered and the resistance raised, a sufficient increase in temperature may occur to cause a vigorous evolution of gas and increased noise. It would, therefore, seem reasonable to expect that, inasmuch as the contact

[5] "The Effect of Gases on the Resistance of Granular Carbon Contacts," P. S. Olmstead, *Journal of Physical Chemistry*, Jan. 1929, pp. 69–80.

[6] "Über Kontaktwiderstände besonders bei Kohlekontakten," Von Ragnar Holm, *Zeitschrift für Technische Physik*, Sept. 1922, pp. 290–294, Oct. 1922, pp. 320–326, and Nov. 1922, pp. 349–357.

pressures and the resistance of the handset transmitter are substantially independent of angular position, the change in noise with position would be practically negligible. That this condition is realized is evident from the data shown in Fig. 7. Not only is the average carbon noise negligible even under severe conditions of service, but the maximum variation of the noise in any position of the transmitter is only about one db. On the other hand, the noise developed by a typical deskstand transmitter in the optimum position is approximately five

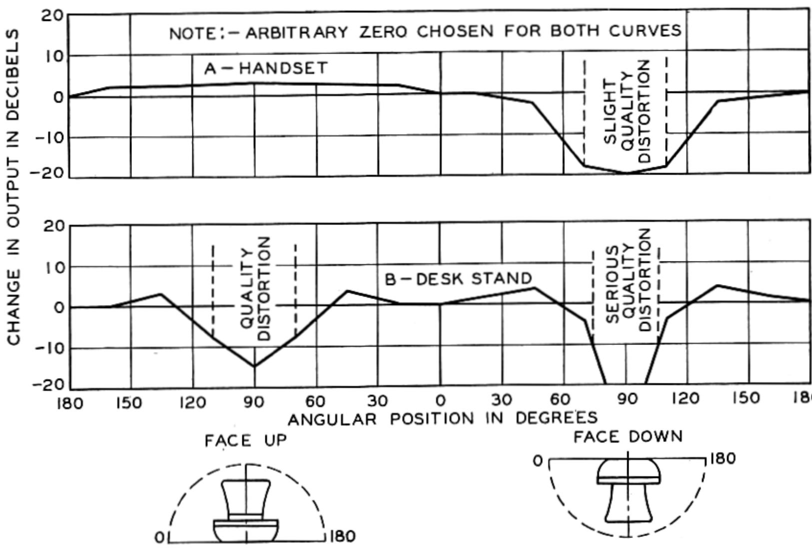

Fig. 8—Effect of position on transmitter output.

db higher, and in its worst position nearly thirty db higher than the noise produced by the handset transmitter. Noise of such a magnitude would constitute an appreciable transmission impairment.

Effect of Angular Position on Output

One of the unique features of this new handset transmitter is the fact that the carbon chamber is located in front rather than in back of the diaphragm as has been customary in the past. By adopting this arrangement the carbon granules are held in intimate contact with the diaphragm in all of the positions in which the handset is likely to be held and uniform output and faithful reproduction of the speech sounds obtained. There are, however, angular positions in the region of 90 degrees face down where the carbon tends to fall away from the diaphragm, but as is shown by curve A, Fig. 8, the resultant loss in the output and the degradation of the quality are limited to a rather narrow range of positions in which the handset is seldom held. A loss in output and a serious impairment of quality occurs when the usual type of deskstand transmitter is held in the positions which would frequently occur if it were used for handset service. This effect is shown by curve *B*, Fig. 8.

Response

The diaphragm of the transmitter is made from thin duralumin formed into a truncated cone with radial stiffening ribs. This reduces the effective mass to about one-tenth that of the deskstand transmitter and provides sufficient rigidity to insure vibration as a unit throughout the frequency range of interest. A number of impregnated paper rings each approximately four ten-thousandths of an inch in thickness support the edge of the diaphragm. The dimensions of the recess into which these rings assemble are so chosen that they separate slightly from one another. This construction provides a resilient support for the diaphragm and adds a certain amount of mechanical resistance due to the viscosity of the air films between adjacent layers of paper and the friction between the layers. An appreciable improvement in response results from the lower mass and stiffness and the higher damping. The range in response of the handset transmitter in the frequency range from 300 to 3000 cycles per second, is about 20 db as compared with approximately 40 db for the deskstand transmitter over the same frequency range. The more uniform response of the handset transmitter causes a marked improvement in articulation over that obtained with the deskstand instrument.

Aging

As previously mentioned, after a granular carbon transmitter has been in use for a time, changes take place which often cause an increase in resistance and carbon noise and a loss in sensitivity. These changes in the contact conditions have been traced to two principal causes, the abrasive action of one granule on another, and the deterioration of the surface of the granules due to high temperatures resulting from excessive contact voltage. The former is usually referred to as "mechanical aging," the latter as "electrical aging."

The aging of the deskstand transmitter is primarily electrical, for although it is picked up occasionally and moved from one location to another on the desk or table, it is not in general subjected to shocks or jars which cause an appreciable motion of the carbon granules. Be-cause of the more severe service conditions, the predominant factor in the aging of the handset transmitter is mechanical.

Laboratory aging tests equivalent to about four years of handset service under severe conditions, indicate an increase in carbon noise of only 6 to 8 db above the initial value. Neither before nor after aging is the noise produced by the handset transmitter of practical importance.

The output of the handset transmitter is decreased somewhat and the average resistance increased to about double its initial value as the result of aging. The relatively small change of resistance with position in this design, however, effectively prevents the frequent occurrence of resistances sufficiently high to interfere with the operation of signalling apparatus in circuit with the transmitter. In this respect the new design represents a notable improvement over earlier types of instruments.

The method adopted for filling the handset transmitter contributes materially to keeping the aging rate low. In most of the transmitters which preceded the present instrument, the carbon occupied only about three-quarters of the volume of the carbon chamber. This allowed the granules to move freely and caused rapid aging. Obviously, the movement of the granules would be reduced to a minimum if the chamber were filled full of carbon. Inasmuch as the space occupied by a given weight of granular material is dependent upon the configuration of the granules, it is evident that a full filling cannot be obtained merely by pouring carbon into the chamber. Definite means, therefore, must be provided for bringing the carbon into a minimum volume state if a full filling is to be obtained.

A machine has been designed for this purpose which vibrates the transmitter during the filling operation. This settles the carbon in much the same way as if the transmitter were held in the hand and tapped. The carbon chamber cannot only be filled full of carbon in this way, but the effect of differences in the volume of the chamber, due to the commercial variations in the size of the parts, is eliminated.

It has been found that the loss in sensitivity which results from filling a transmitter in this manner is relatively small. There is, however, one feature of a full filling, often referred to as "mechanical packing," which is objectionable and has led to a filling slightly less than full. If the diaphragm of a transmitter which has been filled full by the method described, is displaced sufficiently to permit the granules to change their configuration, the volume of the filling will increase and the diaphragm will not return to its original position. A marked increase in contact pressure and lowered sensitivity takes place. When mechanical packing of this nature occurs, the initial sensitivity can be restored only by tapping the transmitter until the granules assume their original configuration. By filling the chamber about 5 per cent less than full, it has been found possible to avoid this packing without effecting an appreciable increase in the initial resistance and noise or the aging rate.

Breathing

In many granular carbon transmitters, variations in resistance and sensitivity of considerable magnitude occur from changes in the dimen-

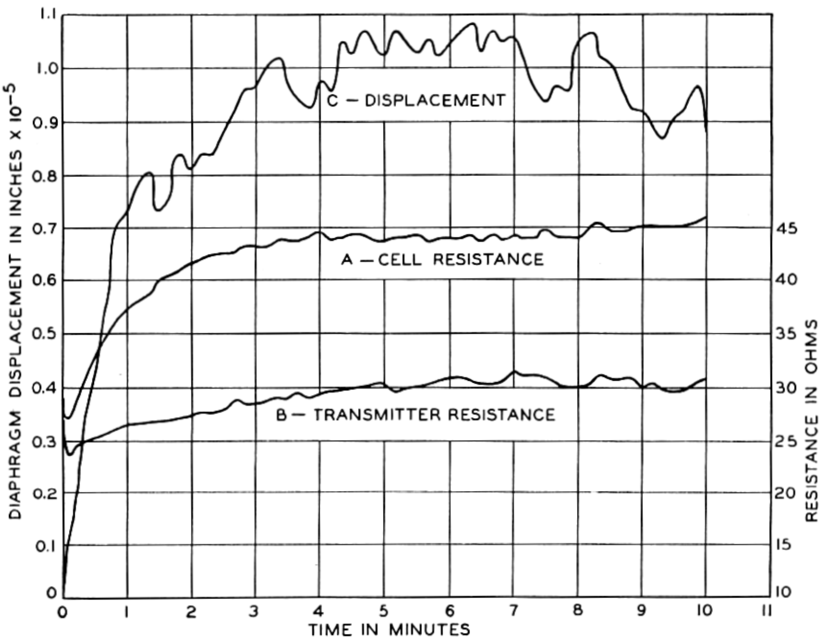

Fig. 9—Transmitter breathing.

sions of the various parts of the carbon chamber, caused by the heating effect of the direct current. These changes in resistance usually take place rather slowly and often extend over a period of several minutes. It is customary to refer to them as "breathing." In a handset transmitter, it is particularly important to eliminate any sources of variation of this kind, since they are likely to be more serious in their effects.

Interesting means of breathing control have been provided. If the diaphragm is removed and a block of lavite substituted, the resistance after being connected in circuit changes with time in the manner shown by curve *A*, Fig. 9. The large increase in resistance is caused by the expansion of the walls of the chamber and a reduction in the contact pressure between the granules. An increase of this magnitude would be objectionable in commercial use, for it would not only make it more difficult to meet the resistance requirements but would also increase the contact voltages, especially in aged instruments, to a point where undesirable carbon noise would result. To counteract the effect of the expansion of the walls of the carbon chamber, the portion of the diaphragm in contact with the carbon is coned slightly, so that, as the walls expand, the diaphragm moves inward sufficiently to maintain substantially constant contact pressures between the granules. The extent to which this feature is effective in reducing breathing is shown by curve *B*, Fig. 9.

Cohering

In common with a number of other materials, granular carbon is susceptible to cohering. When cohering occurs the resistance and sensitivity of the carbon are lowered and remain so until the transmitter is subjected to mechanical agitation. Experience has shown that cohering will greatly reduce the output of the handset transmitter and that fairly loud talking or a sharp mechanical shock is required to restore it to its initial sensitivity. Not infrequently cohering results from breaking the circuit connecting the transmitter to the battery, as for example, when the subscriber depresses the switch in the mounting in order to attract the attention of the operator. A study of the electrical conditions responsible for cohering under these circumstances has shown that the distributed capacity and the inductance of the component parts of the station set are such that transient oscillations of a frequency of several thousand kilocycles per second are set up by the breaking of the circuit. Further investigation has shown that the transmitter can be protected from the cohering effect of these oscillations, without introducing a transmission loss at voice frequencies, by connecting a condenser of a few thousandths of a microfarad capacity across the transmitter to by-pass these transient currents.

In the case of the deskstand transmitter, these cohering effects have not been important for several reasons. Probably the principal one is that the mechanical impact incident to switchhook operation is carried directly to the transmitter and prevents appreciable cohering.

Carbon Preparation

Substantial improvements in the technique of granular carbon manufacture have been made in conjunction with the development of the new transmitter. Roasting processes have been adopted which subject each granule to substantially the same heat treatment and produce carbon of unusually uniform electrical properties. Uniformity is further insured by the use of a magnetic separator to remove granules having an undesirably high iron content, and the removal in an air stream of flat, wedge-shaped particles which tend to cause carbon leakage in the transmitter by working their way between the layers of paper which form the closure between the carbon chamber and diaphragm.

Measures of this kind have been of particular value, not only in bettering the transmission characteristics of the individual transmitter, but in securing a uniform commercial product. Without these improvements, indeed, it is doubtful if the production of the transmitter could be maintained at the high rate now required without a sacrifice in the average quality of the product.

Receiver

The parts of the handset receiver are assembled in a die cast aluminum housing, and form a unit which mounts in a threaded bushing in the handle in much the same manner as the transmitter unit. One connection to the winding is made through the threaded portion of the case, the other through a contact spring in the base. The cap and spacing ring are made of phenol plastic and thoroughly insulate the metal parts so that the user cannot come in contact with any portion of the receiver which forms a part of the electrical circuit. The spacing ring also serves as a lock ring for holding the receiver on the handle. A grid in the cap prevents damage to the diaphragm from the projecting portions of the mounting. The layout of the holes in the grid is such that a dent in the diaphragm caused by inserting a pencil or other sharp object through the grid, will not occur at a point over the pole faces and interfere with the operation of the receiver.

While in general the design of this receiver follows conventional lines, the choice of materials and the design of the magnetic circuit have resulted in an increase in efficiency of several db as compared with the deskstand receiver. It has not been considered desirable, however, to make use directly of this increase in efficiency for several reasons.

Although greater receiving efficiency raises the intensity of the incoming speech, it also increases the intensity of any noise present on the line or picked up as sidetone. Since, therefore, the ratio between the received speech and the noise is not improved, the general reception would be little benefited by an increase in receiving efficiency alone. Furthermore, the increased sidetone causes an effective loss in transmitting level by causing the speaker to lower the intensity of his speech.

The higher efficiency of the handset receiver is, however, of appreciable indirect value, and has been used in two ways, at the same time maintaining the same intensity of the received speech as is obtained with the deskstand.

By lowering the impedance to about half that of the deskstand receiver, the loss in the sidetone path and the transmitting efficiency of the set have been increased. The lower sidetone tends to increase the speaker's talking level, giving a further effective gain in transmitting efficiency. The reduction in the room noise appearing in the sidetone also results in an effective receiving gain as compared to the deskstand.

The separation between the diaphragm and the pole pieces has been increased so as to minimize the "freezing" of the diaphragm on the pole pieces, which is likely to occur when clamped diaphragm receivers are subjected to sudden changes in temperature of considerable magnitude.

Assembled Handset

The dimensions and proportioning of the handle and the assembled handset are the result of rather extensive investigation. They represent an effort both to meet the technical requirements and to produce a mechanically rugged structure, light in weight and comfortable to hold, as well as attractive in appearance and in harmony with the mounting.

Prevention of Howling

One of the major objections to the handset in the past has been the tendency to howl. While a certain degree of howling control can be realized in the electrical coupling by the design of the station circuit, such control cannot be depended upon to take care of extreme circuit conditions where the coupling is greatest and howling most likely to occur.

From an economic standpoint, moreover, it is desirable that the handset should be completely interchangeable with the deskstand without the necessity for changes in the set or other parts of the telephone plant. If this is to be realized, the handset must be so designed as to be inherently free from the danger of howling under any conditions encountered.

Mechanical disturbances set up by the receiver produce transverse vibration in the handle which moves the transmitter as a whole. The solid phenol plastic handle employed in the present handset has a relatively high resonant frequency and provides a comparatively inefficient medium for the transmission of mechanical disturbances from the receiver to the transmitter in the frequency range where the instruments respond most readily.

A further and perhaps a major factor in eliminating the danger of howling is to be found in the characteristics of the transmitter. The

Fig. 10—Use of gauge for head measurements.

response of a transmitter to bodily movement of the whole structure is of course very different from its response to acoustical pressures, and depends largely on the mechanical impedance of the diaphragm and its supporting structure. The extremely light and highly damped diaphragm of this transmitter is ideally suited for minimum response to mechanical vibration.

Under the worst conditions encountered, a margin of at least 15 db is realized with this structure which effectively eliminates howling as a limiting factor in the general use of the handset.

Determination of Dimensions

Particular effort has been made to proportion the handset so that the transmitter mouthpiece may be as near as possible to the lips of the

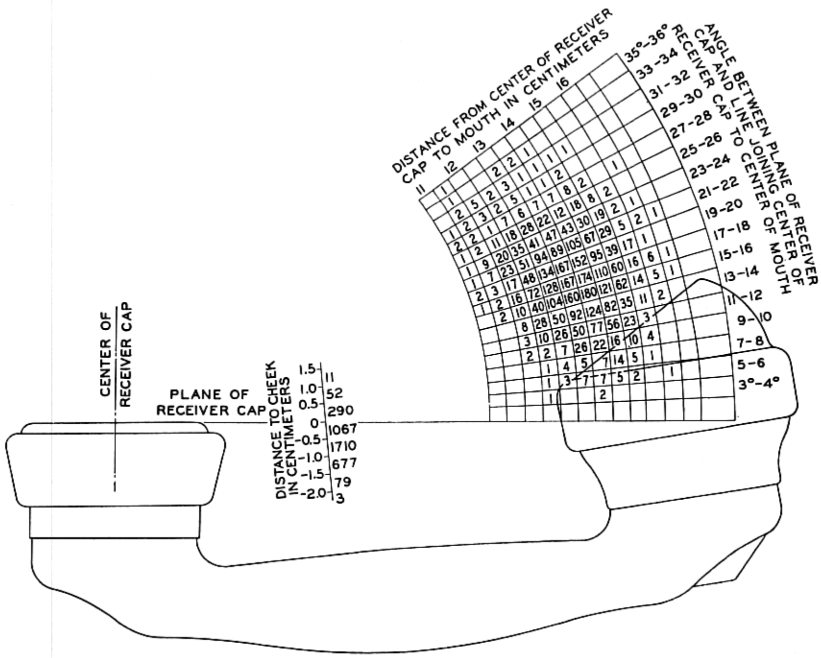

Fig. 11—Distribution of the head measurement data.

talker, thereby avoiding unnecessary transmitting loss. Care has been taken also to provide adequate clearance between his hand and cheek. In determining the proper dimensions of the handle and assembly, about 4000 measurements of head dimensions were made. The subjects selected for these measurements included both sexes and the various races in about the proportion indicated by the census figures.

The head measurements were made with a special gauge as shown in Fig. 10. The receiver cap was held to the ear and the pin placed in contact with the cheek. The slider was moved along the calibrated bar until it touched the lips. A record was made of the dimensions which determined the position of the center of the lips relative to the center of the receiver cap and the clearance between the handset handle and the cheek.

The data obtained are shown graphically on Fig. 11 together with an outline of the handset drawn to the same scale. All except about 3 per cent of the persons shown on the chart can use the handset by holding the receiver to the ear in a normal manner. The others can be accommodated by a slight shift of the receiver on the ear. The effect of such a shift on received speech, for a small number of persons, is unimportant in comparison with the large improvement in transmitting performance for the great majority which results from the decrease in the average distance of the mouthpiece from the lips.

Performance in Service

Since the initial introduction of the handset, close contact has been maintained with its performance by tests and observations under actual service conditions, and by the examination of instruments returned from service.

It has been shown by these observations that, although the output of the handset transmitter as used by the subscriber is on the average lower than that of deskstand transmitters of the most efficient types, the improved response and articulation are an adequate compensation for the lower level. The transmission performance of the handset as rated by the repetitions,[7] has been found to be as good as that obtained with the deskstand.

Undesirable variations in transmission and resistance with change in position, excessive carbon noise, and howling, all of which have heretofore presented serious obstacles to the adoption of a handset for general use, have been successfully overcome in the design which has been described. It has been found practicable to use this handset interchangeably with the deskstand in the existing telephone plant, without important reactions on either transmission or signalling performance.

That the design, in addition, meets the desires of the public for the convenience of a hand telephone set is best evidenced by the steady increase in demand to more than one million a year at the present time.

[7] "Rating the Transmission Performance of Telephone Circuits," W. H. Martin, *Bell System Technical Journal*, Jan. 1931, pp. 116–131.