An Improved Telephone Set

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A new common battery telephone set has been developed and is now in production which is materially better than previous types in performance and convenience to the user. This paper describes this set, and discusses, as typical of Bell System dleveopment processes, the contributions of the operating, development, and manufacturing organizations to the final design. It also describes the evaluation of the design by the controlled service trial, in terms of the results produced in actual service in the hands of the public.

THE Bell System is now introducing a new and improved common battery telephone set, intended to supplement the present well known combined set first introduced in 1937.[1, 2] In view of the established merits of the earlier set, of which something like 25,000,000 are now in the plant, it is of obvious interest to point out the nature and magnitude of the improvements represented in the new set which justify the effort and expense of such a change, to discuss some of the factors influencing its introduction at the present time, and to describe the set itself and its characteristics.

Before proceeding with this, it is pertinent to define what is meant by an improvement, what sort of changes come under this heading, and what means are available for appraising them. In the Bell System the answers to these questions are looked for in a combination of laboratory and field experience using the effect on service as a major criterion.

Design for Service

Improvements may be classified under two general headings. First, there are changes in form and in technical characteristics which improve the quality of the service and increase the satisfaction of the subscriber; the new design may be more acceptable in appearance, easier and more convenient to handle and manipulate, and provide easier and more natural conversation with less effort. Such factors, however, valuable as they are in themselves, cannot be considered apart from the second important kind of improvement, which is cost reduction. An improvement, ideally, should offer possibility both of better service and of lower cost. Furthermore a new set may have improved features but, in addition, must offer all the essential service facilities that are currently offered, and work with the existing operating conditions of the plant as it finds them.

This sort of objective poses important problems of design coordinated with economy which require for a successful solution the knowledge, effort and teamwork such as is provided by the close cooperation developed over the years among the operating, development and manufacturing organizations.

An important phase of the development of the new telephone set has been the contribution made by the Western Electric Company. Many of the parts for the development models were made by the Western so that the skills or facilities at the manufacturing plant could be brought to bear on the projects at the earliest possible date. As a result of this activity on Western's part, many changes in design important in large scale manufacture were introduced in the development stage so that later tooling for production could proceed with directness and assurance. During the course of the development of the various components and assembly of these into a set, joint studies by the Western engineers and the Laboratories were made to bring about a set that would not only meet the basic objectives but that would also be suitable for large scale manufacture at the lowest possible cost.

From the field, the laboratory, and the factory comes knowledge of service needs, systematic advances in technical knowledge of structures and materials, invention, and production skill. This reservoir of knowledge is ordinarily tapped deeply to produce a new telephone set which can fully satisfy the severe requirements imposed. The reservoir must be refilled to permit further significant and worthwhile improvement, and can be profitably tapped only as this has occurred. Both these processes were delayed some five years by the war.

Toward the end of that time comparison of technical possibilities with service needs gave promise of worthwhile accomplishment, with one important proviso: the design would have to be completely integrated and considered as a unit structure. Each component would thus be considered only on its merits in contributing to the overall result. The development was undertaken on this basis and its justification is embodied in the values produced and demonstrated in the 500-type set. This set is new in concept, in execution, and in performance.

Broadly the new set provides improved technical performance in all functions: transmission, dialing and ringing. It is compatible with existing plant operating conditions, needs fewer codes to provide the same scope of plant and commercial flexibility, and, as far as experience so far can determine, in laboratory test and in the field requires less maintenance effort. These performance advantages are accompanied by better appearance and by added general convenience and ease of use to the subscriber.

These are large claims, and it is only reasonable to ask how they can be substantiated and evaluated at such an early stage of actual experience with the set. The answer can be given with considerable confidence because teamwork, consistently applied, has evolved continually improved attack on such problems at all stages. A thorough knowledge of the field needs, a pyramiding technical know-how of physical principles, materials, and structures, and their application in design and in production, and an increasingly comprehensive grasp of measurement technology, guided systematically by correlation with effects on performance in the hands of the public, provides a solid foundation for this confidence.

By no means the least important factor in this result is that of measurement in its broad aspects, conceived and developed as a method of evaluation of design in terms of realized performance.

Methods of Evaluation

The invention of the vacuum tube gave great impetus to quantitative physical measurement in all phases of the telephone art, as pointed out in W. H. Martin's article in this issue of the Journal.[3] Along with this, development and application of statistical and sampling theory and analysis, and continuing use of the so-called psychophysical test—a big new name for the traditional Bell System habit of remembering the human factor—have provided increasingly powerful tools for laboratory test of new designs. It should be realized that the value of such tests is only in direct proportion to the deliberate effort made to correlate their results, as well as those of the traditional laboratory "life" test, with effects in actual service. It is, perhaps in this grafting of newer measurement technology on the sturdy and dependable stock of the "trial installation" that resides the greatest assurance of the significance of the answers. A further assurance that the subscriber gets what he wants is the increasing practice of asking him directly, by means of carefully constructed opinion surveys.

All of these techniques of evaluation, plus the inevitably intense self criticism which is a matter of course in all Bell System projects, has been applied in the evolution of the new set from the first model to service trial and production.

General Features

The illustrations (Figs. 1 & 2) show the new set to be of completely new form, inside and out, low and sweeping in its lines and pleasing to the eye of the great majority of users. On the appearance design, laboratory engineers worked with Mr. Henry Dreyfuss, one of the country's leading exponents of functional design. The handset is smaller, and some twenty-five per cent lighter than the existing type. The dial characters are external to the periphery of the fingerwheel where they are more easily seen over wider angles of vision, and are not subject to the inevitable wear of the surface which occurs under the fingerwheel. The cords are jacketed with neoprene, grommeted at the handset end for longer trouble-free life, and are less subject to twisting. The ringer is provided with a manually adjustable volume control which permits the subscriber to change the loudness over a considerable range.

Less evident at first glance, but of greater importance both to user and Telephone Company are some of the more technical aspects of the electrical and mechanical design features.

A schematic circuit of the set is shown in Fig. 3. This circuit is a variation of one of the commonly used Campbell anti-sidetone circuits[4] long

Fig. 1—External view of 500-set.

standard in the Bell System, with improvements added to meet tougher requirements in all functional categories.

The mechanical arrangement of components in the assembly is entirely new, and is built around several concepts arising directly from service and manufacturing experience. In general, controls and adjustments are reduced or eliminated, and parts are enclosed and protected wherever possible against effects of dirt, moisture or mechanical damage.

Where field or repair shop replacement of components is to be anticipated, as in the dial, ringer, handset, and cords, removal and replacement are designed to be easy. Other components are permanently mounted, and are replaceable only in a shop. Switch assembly and transmission circuit components are so mounted and are completely enclosed and protected. The dial has no adjustments to be made in the field, and the ringer only one, bias tension which is rarely changed. The set functions completely with the cover removed. No parts or wiring are attached to the cover. This facilitates both production assembly and field servicing.

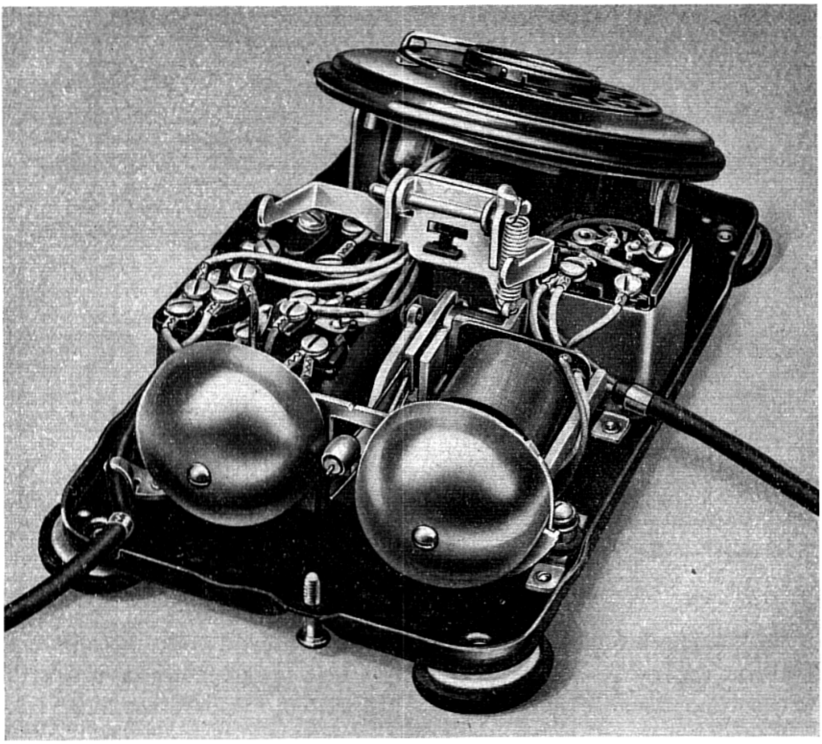

Fig. 2—Internal view of 500-set.

The success of such a design depends, of course, on precise knowledge of the service conditions to be met, how to meet them technically, and how to design and manufacture a set so it will keep on meeting them with the minimum of attention or expense thereafter.

Functional Design in Relation to Objectives

The main objective of the new set design was to realize acceptable performance requirements over longer distances from the central office, or with finer gauge cable conductors, and to do this with existing central office facilities. This means of course that all the functional characteristics of the set must realize this objective. If, for example, extended range of transmission were not accompanied by a corresponding increase in dialing and ringing range, the entire potential value would not be realized.

A second objective was to reduce the transmission variations now experienced between individual users, and between the station most distant and that nearest the central office. A related objective of minimizing the variety of sets needed suggested the desirability of combining in one set, in so far as was economic, the required number of circuit arrangements to satisfy individual, party line, and measured service.

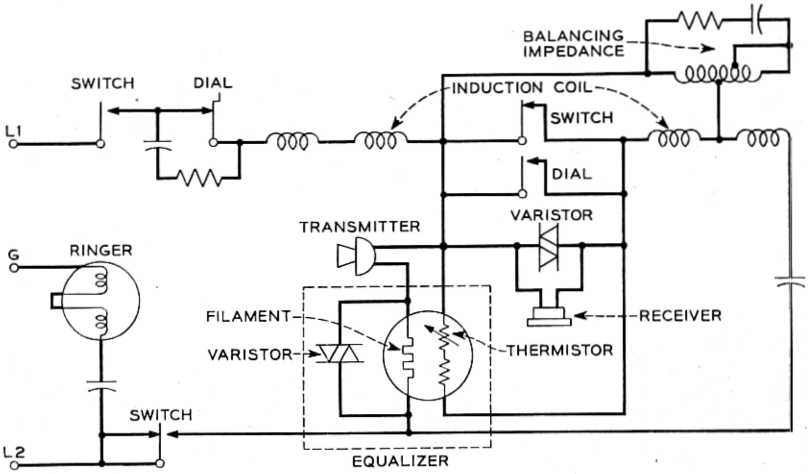

Fig. 3—Circuit schematic of 500-set.

There was, of course, plenty of incentive to incorporate in the design whatever experience had indicated might be done to retain or better the excellent maintenance performance of the current standard combined set.

With these general objectives in mind somewhat more detailed description of the circuit and design is in order. It will perhaps be somewhat clearer to take up each of the main functions in turn and to show for each how the specific objective was approached. It might be stated at this point that the description is based of necessity on the design as it was in the early production. The usual Bell System process is underway to find more economical and reliable ways to accomplish the objectives. The characteristics described herein will in general apply equally to any such modifications.

Transmission

The general objective called for the maximum usable increase in transmitting and receiving volume on long loops. This meant gains in each direction not to exceed about 5 db, due primarily to noise and crosstalk problems introduced with larger values. Along with this volume gain, improvements in quality were desirable.

Any such volume gains over present levels would of course be intolerably loud on short loops, so if limitations in the variety of sets and the attendant administrative, production, and merchandising benefits were to be retained, it meant designing a set with transmission performance suitably adjusted for short and long loops. Inasmuch as on cutovers and on P.B.X. extensions and the like, the same set would be at times on long and at others on effectively short loops, it also meant that this change in performance should automatically take place with change in connection rather than require manual reconnection or adjustment.

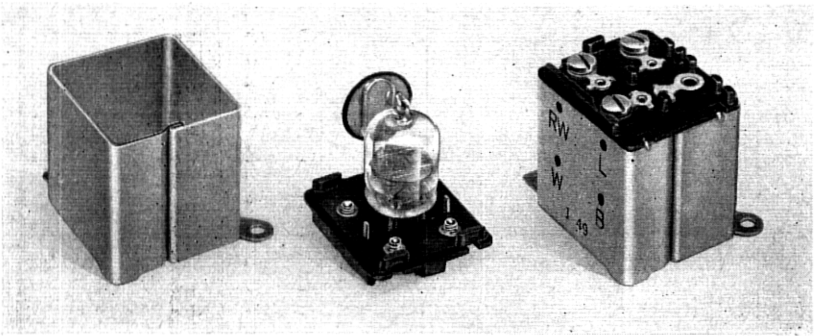

Fig. 4—View of equalizer.

This has been achieved in the present design by including an automatic transmission equalizer, Fig. 4, which is adjusted in its inserted loss characteristics by the magnitude of the d-c. line current through the set. One element of the initial design (other preferable methods may develop in the future) provides a tungsten ballast filament in series with the transmitter so proportioned that the effect on transmitting on long loops is small, but on short loops with high values of d-c., the combined battery supply and a-c. circuit loss inserted is about 5 db.

A corresponding graduated receiving loss is obtained by including a thermistor bead thermally coupled to the tungsten filament in the same structure. This bead, in series with a loss limiting resistance, is bridged across the receiver.

The filament is protected against abnormal voltages by a bridged silicon carbide varistor. The resistance current characteristics of the elements of this equalizer are shown in Fig. 5.

The required gains in transmission called for completely new transmitter and receiver design. In the case of the receiver, the design was new in basic principles and resulted in the so-called "ring armature" structure which was discussed in the January 1951 issue of the Bell System Technical Journal.[5] This structure is not only five db more efficient than the present handset receiver, but also permits extending the upper frequency range by some 500 cycles. For compatibility with existing plant characteristics the general response of the new receiver was kept flat as measured on a standard 6 cc coupler as in the present receiver.

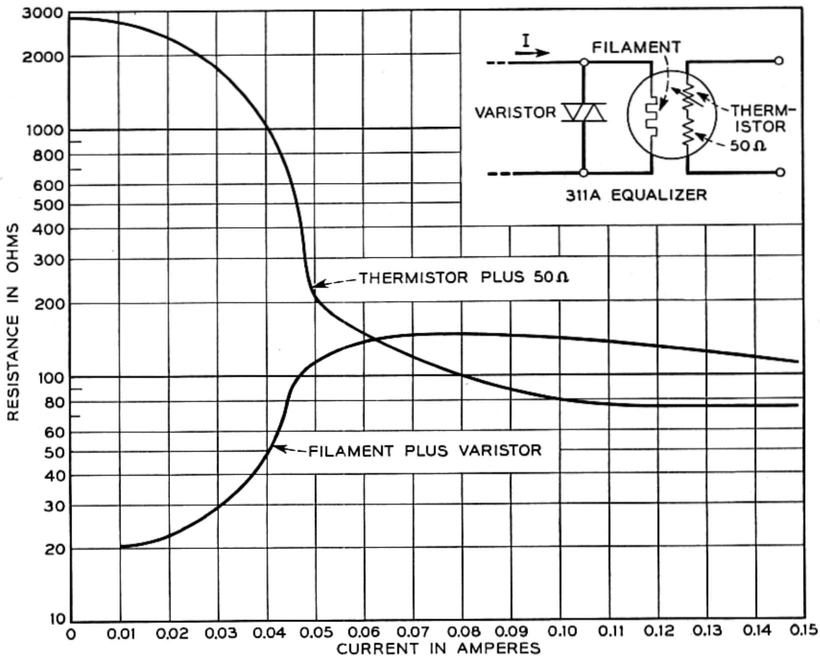

Fig. 5—Equalizer characteristics.

While the transmitter design resembles superficially the current design, it differs in many important respects. To get the required 5 db volume gain on long loops required taking advantage of every design expedient in the transmitter itself, as well as in the handset in which it was mounted. Modulation of the carbon was increased, and the effective working acoustic pressures were raised by using smaller parts and locating the transmitter more advantageously with respect to the mouth. This is of particular benefit to women, whose transmitted levels have hitherto been considerably less than for men.

Advantage was taken of new knowledge of granular carbon processing to get initial d-c. power gain over present type transmitters, and by a new preconditioning and heat treatment, to maintain the improved modulating performance better over longer periods. At the same time the rate of resistance increase with age is markedly reduced.

Along with these several factors contributing to increased volume output of the transmitter, the response was altered in an attempt to provide more nearly orthotelephonic overall response.

To assure that these instrument gains would be realized in actual service introduced one of the principal technical problems of the transmission design, the better control of sidetone. Without a better job on sidetone, much

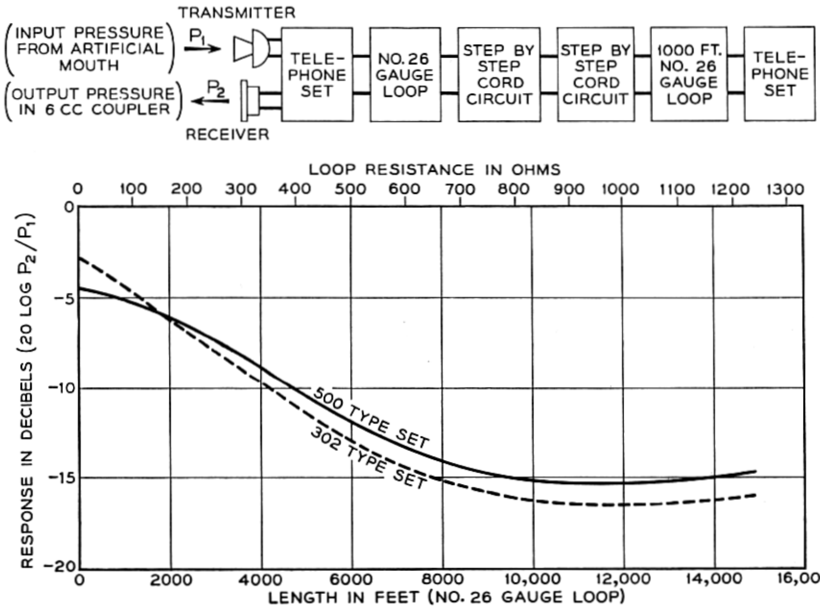

Fig. 6—Comparative sidetone levels.

of the value of the higher instrument efficiencies on long loops would fail of realization because of resulting lower acoustic talking levels, and increase of the masking effect on incoming speech of room noise picked up by the transmitter. The solution adopted for the initial design lay in choosing a more complex impedance to give the best overall balance over the frequency range for the loop and trunk conditions with which it must function. The relative sidetone of the two sets as a function of loop length for a typical circuit is shown in Fig. 6. The solution has given a set with essentially the same sidetone as the present set in spite of a ten db increase in instrument efficiencies, thus assuring the full effective gain represented by this increase.

Typical loop loss characteristics for the 500-type set compared to the 302-

set are shown on Fig. 7 which also illustrates the effect of the equalizer. Overall air-to-air frequency responses of the two types of set are shown on Fig. 8 for long and short loops. The broader frequency range and the notable reduction in spread between long-and short-loop performance are evident.

Subsidiary but essential transmission features of the new set include a copper oxide click reducer across the receiver particularly desirable for a receiver of such high efficiency; low susceptance to power interference on party lines by the high impedance of the ringer and by shaping the receiver response below 300 cycles;[5] and effective suppression of dialing interference

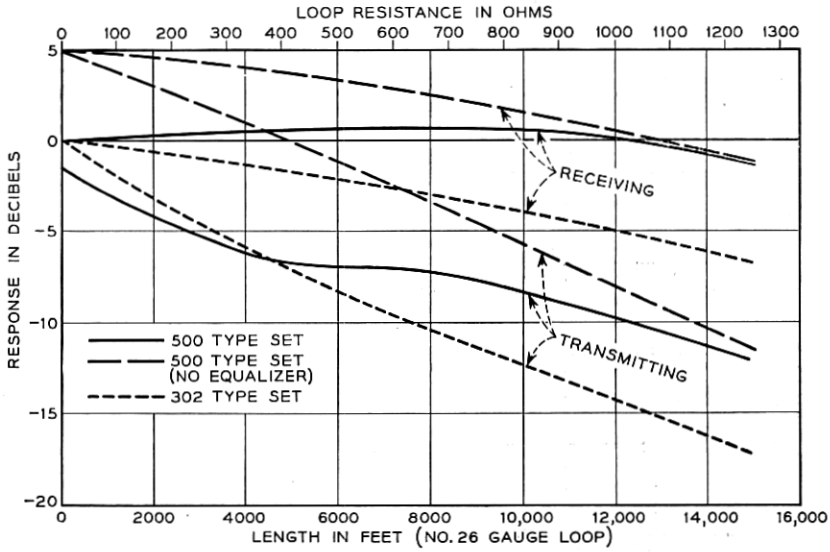

Fig. 7—Relative volume levels.

with radio and television reception by a small capacitance and resistance associated with the inductance of the line winding of the induction coil. The integrated design employed assures these features at minimum cost.

Dialing

A controlling limitation on dialing range is to be found in the degree to which the pulse characteristics vary from the optimum value from dial to dial and from time to time over the period of service. The new dial design by better governing and cam control of the individual pulse form provides the required improvement in loop range by assuring much better uniformity in every respect.

Service experience has shown that the better visibility and greater convenience of operation are in fact realized and appreciated by most users, and that accuracy and speed of dialing by the subscriber have not been sacrificed.

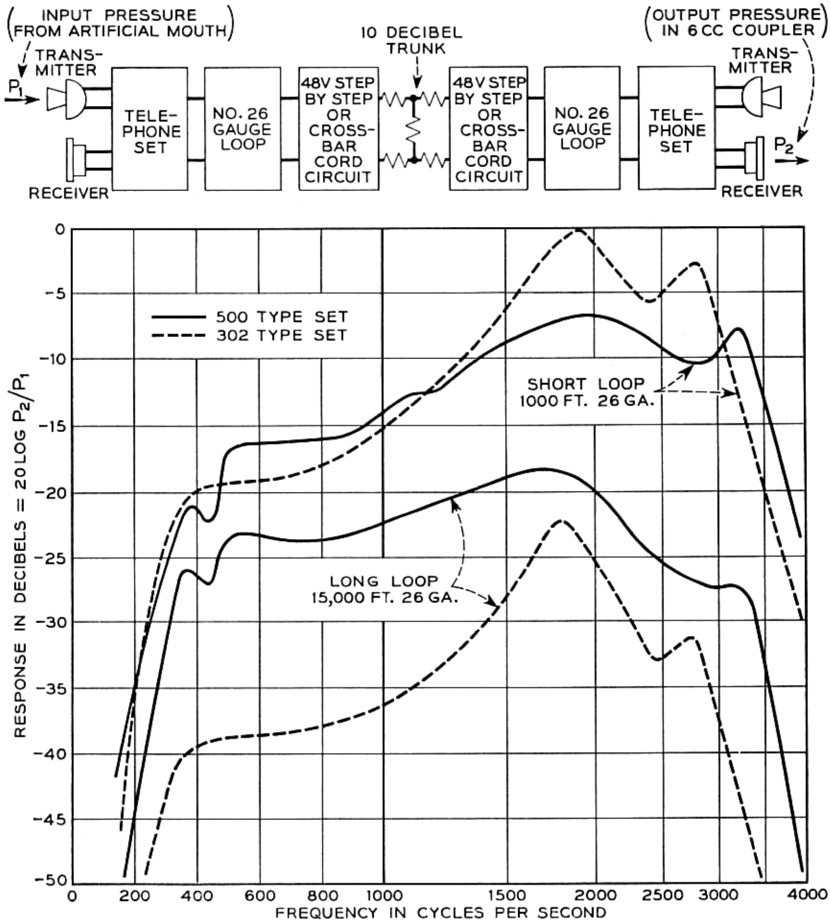

Fig. 8—Overall frequency response.

Ringing

The new ringer design offers a particularly interesting example of the impact of field experience and knowledge of service requirements on station apparatus design.

Acoustic surveys of typical subscribers' premises have furnished data on the acoustic transmission losses for ringing sounds, caused by interfering noise, the absorption of walls and hangings, and by doorways, both open and closed. These data indicated that for a satisfactory minimum audibility of the ringing signal at positions where the ringer should be heard, over the range of conditions encountered in service, a louder ringing signal than that of the present station ringer would be desirable. A lower pitched signal was also indicated as carrying better, particularly for that considerable portion of the population whose hearing has deteriorated with age.

It was also known, however, that any such increase in ringing level, if not adjustable at will, would increase the all-too-frequent requests for the telephone man to come and adjust the sound to suit the subscriber's needs at the moment.

The new ringer, by combination of magnetic design skill with mechanical ingenuity, has succeeded in apparently meeting all these requirements most satisfactorily to all concerned. It is lower pitched, and more efficient as well as more effective. The easy volume adjustment provided the subscriber has in fact nearly eliminated his requests for such readjustment by the maintenance man. In view of the lower pitch of the signal, and the minimum level which can be set by the subscriber, the manual adjustment feature apparently has not increased the number of cases where the bell cannot be heard.

The ringer electro-magnetic design provides a structure which is more efficient and higher in impedance than previous designs. This permits adequate loop range with greater numbers of connected extension or party line stations. The higher impedance at audio frequencies combined with a reduction in low frequency receiver response limits the inductive susceptiveness of the set to as low values as with previous sets having 5 db less receiving sensitivity.

The foregoing description of general objectives, methods and results provides some background for more detailed consideration of the design of the components of the set and of the contributions of the Western Electric Company manufacturing department in working out with the development engineers practical methods and designs for efficient quantity production.

Each of the components of the set as well as the over-all assembly has novel and valuable features contributing to the final results. It is these significant features, rather than the complete design of each component, which are discussed in the following paragraphs.

Component Design

Handset

As already pointed out the handset, Fig. 9, is of a radically new form, smaller, lighter and easier to use than previous types. As in the case of its predecessor, it is made of phenol plastic, a molded-in cavity through the handle serving as a conduit for the separate leads to the receiver. Contact

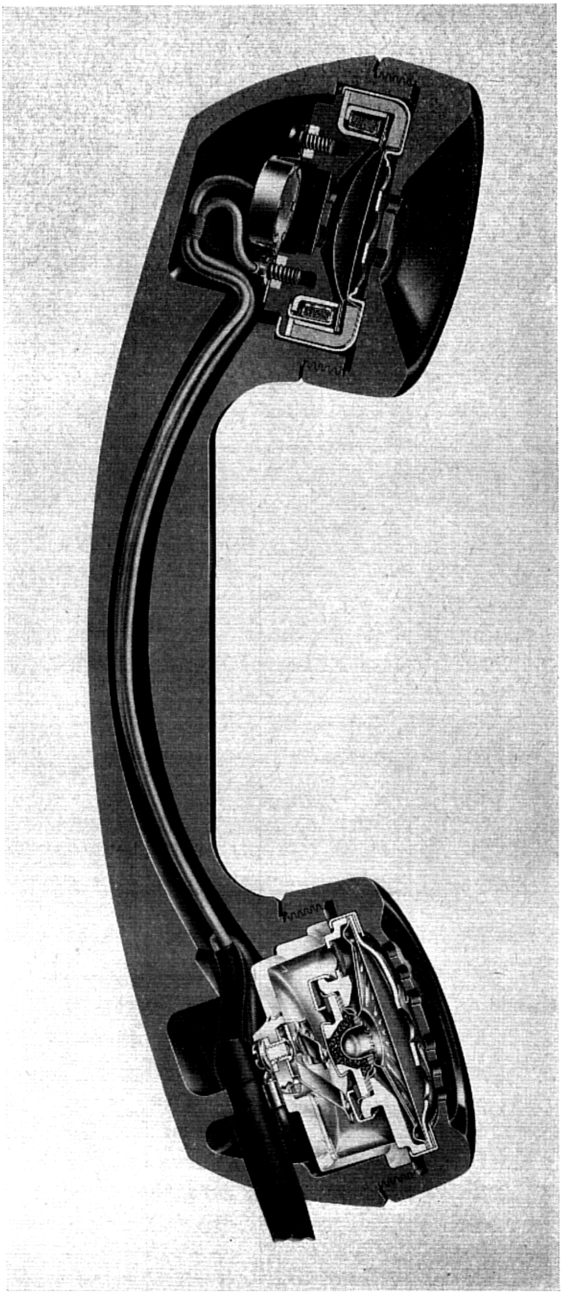

Fig. 9—Cross-section of new handset.

to the transmitter terminals is obtained by means of contact springs supported in a separate plastic cup which serves also as a controlled acoustic cavity for the transmitter and as an acoustic shield between the transmitter and receiver. Such a shield is necessary, as otherwise the transmitter and receiver would be directly coupled acoustically.

Transmitter

While the transmitter unit is similar in structural design in some ways to the transmitter of the previous handset,[1] it differs in many important details. The diaphragm of the new unit is rigidly clamped at its periphery, thus increasing the output in the upper frequency range as compared to the paper clamped diaphragm transmitter of previous design. This is essential to achieve a quality of transmission that approximates the orthotelephonic objective.

The simple conventional system, consisting of a clamped diaphragm, back cavity and carbon chamber, has a response characterized by a single sharp resonant peak, whereas it was desired to provide a gradual increase in output with frequency with a broad maximum in the region of 3000 cps. This might be accomplished by a sufficiently damped structure with its resonance in the region of 3500 cps, but only at the expense of efficiency. In the new transmitter the desired response is obtained with high efficiency by coupling the diaphragm to a doubly resonant system composed of the cavity within the unit behind the diaphragm and the chamber between the unit and the plastic cup. These two cavities are connected by holes covered by woven fabric having carefully controlled resistance to the flow of air.

The equivalent circuit of such an acoustic system and its acoustic impedance characteristic as a function of frequency for some limiting and typical values of the component impedances are shown on Fig. 10, where

S3 is the stiffness of the chamber in the transmitter behind the diaphragm,
S4 is the stiffness of the chamber formed by the plastic cup,
M4 is the mass of the air in the holes coupling the two cavities,
R4 is the acoustic resistance of the coupling holes.

The stiffness impedance of the cavity S3 behind the transmitter diaphragm acting alone is shown by Curve 1. Curve 2 shows the impedance of both cavities S3 and S4 combined, with zero leakage impedance between them. Curve 3 shows the impedance of the acoustic system composed of both cavities coupled together by an impedance having typical value of mass but zero damping resistance, while Curve 4 shows the characteristic of the same system with coupling impedance having zero mass and a typical value of damping resistance. Finally, Curve 5 shows the acoustic impedance of the two-cavity system in which values are assumed for both the mass and resistance of the coupling impedance, such as would occur in the transmitter.

The acoustic design of such a system requires exact control of the individual elements to prevent large irregularities in the overall transmitter response. The control of R4 is particularly critical as illustrated by Curve 3,

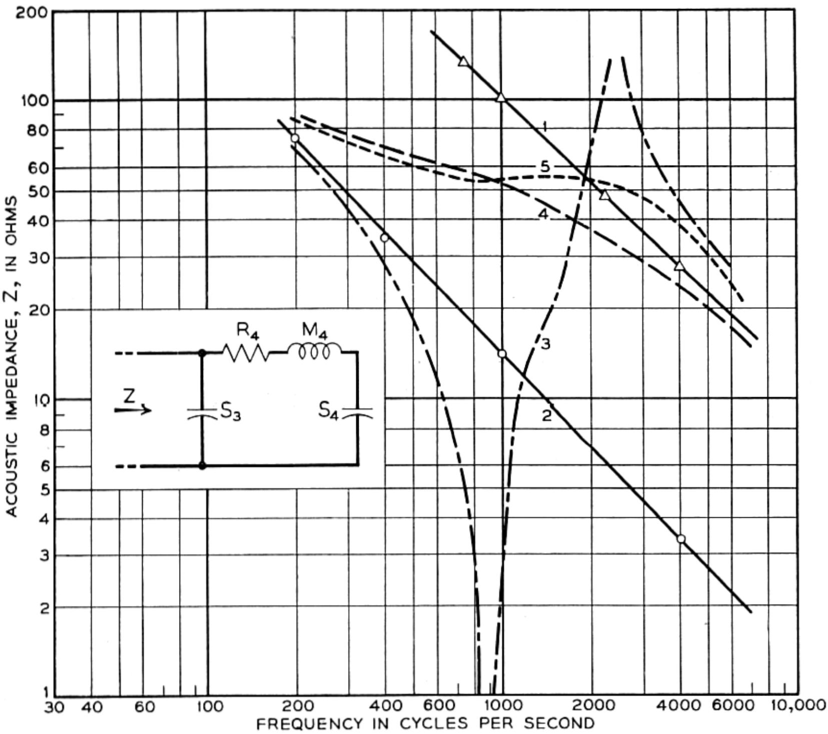

Fig. 10—Transmitter acoustic impedances.

which shows the large decrease in acoustic impedance at resonance with a corresponding increase at anti-resonance of the system when the damping resistance R4 becomes very small. This will cause a sharp peak and dip respectively in the transmitter response at these frequencies.

Correct balance of the acoustic impedances, as illustrated in Curve 5, will result in an acoustic network having an impedance at low frequencies approaching that of the combined cavities, Curve 2, with gradual transformation as the frequency increases, reaching the impedance of the single smaller cavity, Curve 1, at high frequencies.

By combining this acoustic system with a diaphragm and associated carbon chamber that resonates at the anti-resonant frequency of the acoustic network, it is possible to obtain an overall response free from resonances with uniformly rising output with frequency to about 2500 cps, followed by a broad maximum output extending to approximately 3500 cps, then dropping off in output at higher frequencies as shown in Fig. 11. This shows the complete equivalent circuit, the computed response and the response measured with constant sound pressure at the diaphragm.

The carbon chamber of the new transmitter unit, although similar in general to previous designs, has been modified in many important dctails in order to decrease the mechanical impedance of the carbon in the interest of higher modulating efficiency. Also, better positional performance has been obtained by changes in the carbon chamber contour and effective head of carbon.

Receiver

The receiver unit of the new handset, as shown in Fig. 9 differs radically in design from any previous commercial receiver. It is referred to as a "ring armature" receiver and employs a completely new magnetic and vibratory system.[5] The diaphragm, which in previous receivers has been a simple disc of magnetic alloy, is now a composite design consisting of a ring of magnetic material (permendur) with a center of phenolic impregnated fabric material formed in the shape of a dome. This required, of course, an entirely new type of magnetic circuit. The magnetic ring or armature is supported at its outer edge on a ring of non-magnetic material which provides the diaphragm seat. The inner edge of the armature is associated in the design with a ring pole piece which carries the flux from a ring-shaped permanent magnet. The use of the composite diaphragm in the new receiver results in a lower mechanical impedance and an appreciable increase in the ratio of effective area to effective mass. This accounts for an improvement in receiving efficiency as compared to the previous handset receiver of approximately 5 db along with an extension of the frequency range. Also, because of the lower mechanical impedance of the diaphragm system, the loss in intelligibility when it is held off the ear, as may occur in service, is greatly reduced.

Because of the higher efficiency and greater power output capacity of the new receiver as compared to its predecessor, a peak limiting device (click reducer) is provided to prevent the user from receiving uncomfortably high acoustic levels. A copper oxide varistor element is therefore incorporated in the design as an integral part of the receiver. This varistor also protects the receiver magnet from possible demagnetization caused by transient electrical disturbances. Less magnet material is therefore needed.

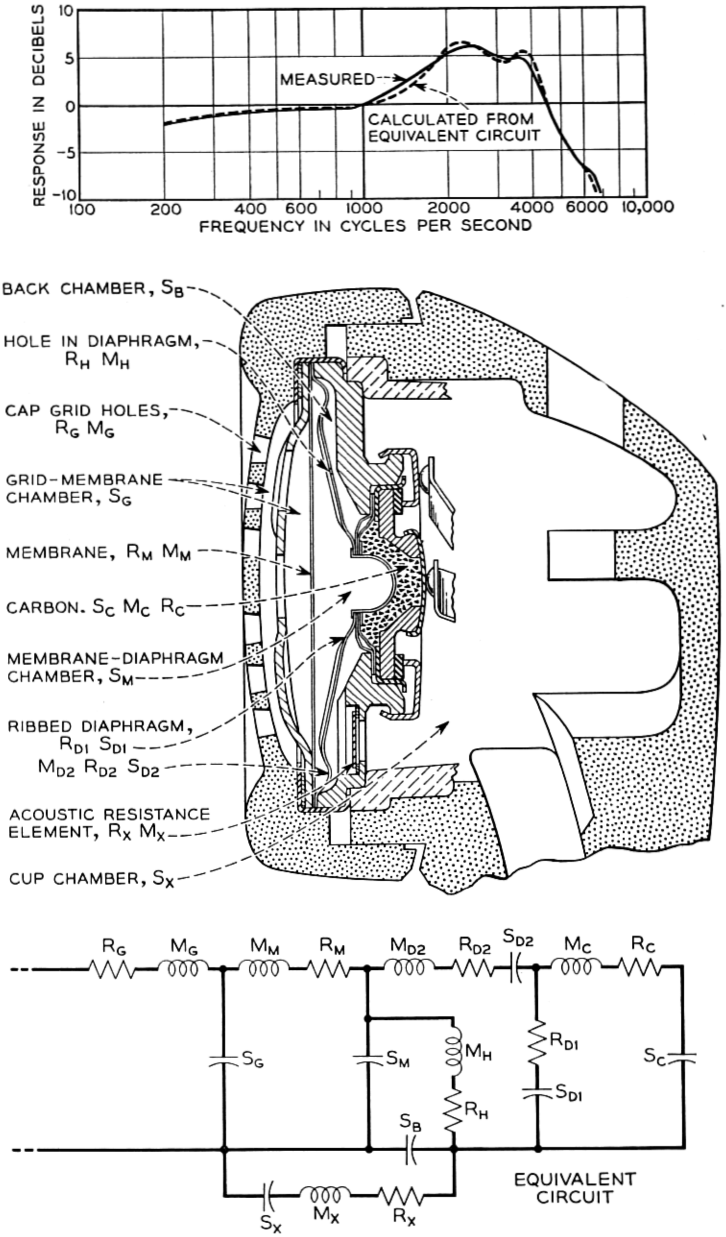

Fig. 11—Equivalent circuit and frequency response of transmitter.

Cords

Neoprene jacketed handset and mounting cords are used with the new set. In locations where cord maintenance is unusually high, and especially where severe moisture conditions prevail, neoprene jacketed cords are used with the present combined set.

A four-conductor handset cord is used to separate the transmitter and receiver circuits. This introduced design problems in providing a cord of pleasing appearance, small diameter and light weight appropriate for the new handset. A new tinsel cord construction was developed employing fewer tinsel threads and a reduced size of center core thread which resulted in a 15% decrease in the overall diameter of the handset cord even though the number of conductors has been increased from three to four.

A grommet molded to this cord reinforces it at the point where it enters the handset. By properly proportioning the taper of the grommet the severe flexing that would normally occur in service is distributed over an appreciable length of the cord thus decreasing the effect of such flexing on the life of the cord. The grommet also provides an acoustic seal for the cavity through the handset handle to the back of the receiver, thus preventing extraneous acoustic noises from reaching the back of the receiver unit. It also has a notch which fits a projection in the handle, thus anchoring the cord in the handset. Laboratories tests on the new cord with the grommet indicate that its service life will exceed that of previous designs.

In the new cord the conductors are not twisted but lie straight and parallel for the length of the cord. The parallel construction facilitates manufacture with respect to automatic stripping of the jacket and tipping of the conductors at the cord terminations.

Dial

As previously discussed, the new dial presents an entirely new appearance feature in the set. In addition, the dial mechanism is a complete new development in the interest of improved performance and economy of manufacture and is protected against dirt. Improved performance of the dial arises chiefly from the closer control realized both in manufacture and in service over the pulsing characteristics and speed regulation of the dial. By controlling the time of both the break and make of the dial pulsing contacts to narrower limits than in the present dial appreciable extension of dialing range is possible.

In the new dial a tolerance of $\pm$ 2% was set for the per cent break of the pulsing contacts. This is in contrast to double this range for the present dial. The normal operating speed of the dial is controlled to 10 $\pm$ 0.5 pulses per second instead of 9.5 $\pm$ 1 pulses per second as at present. Further, the design is such that it is confidently expected that this better performance will also apply over the service life of the dial, hence no field adjustment will be necessary.

An exploded view of the new dial is shown in Fig. 12. A zinc base die cast frame serves as a mounting for the various dial details as well as providing facilities for mounting the dial in the set. The gear train is a precision assembly depending upon careful dimensional control of gears, shafts and bearing plates to insure smooth and dependable operation. The governor assembly is driven through a band type of clutch which decouples the inertia of the governor during "wind-up" of the dial. The drive bar and the weights are sintered brass which results in substantial manufacturing advantages. The pulsing mechanism of the dial consists of a single lobe cam, a pawl and two pulsing springs. The cam and pawl are injection molded of nylon. The pulsing springs as well as the receiver off-normal springs are molded in a phenol plastic block. The springs are held in accurate alignment during the molding process, and adjustment of contact forces is made after assembly of the spring block to the dial.

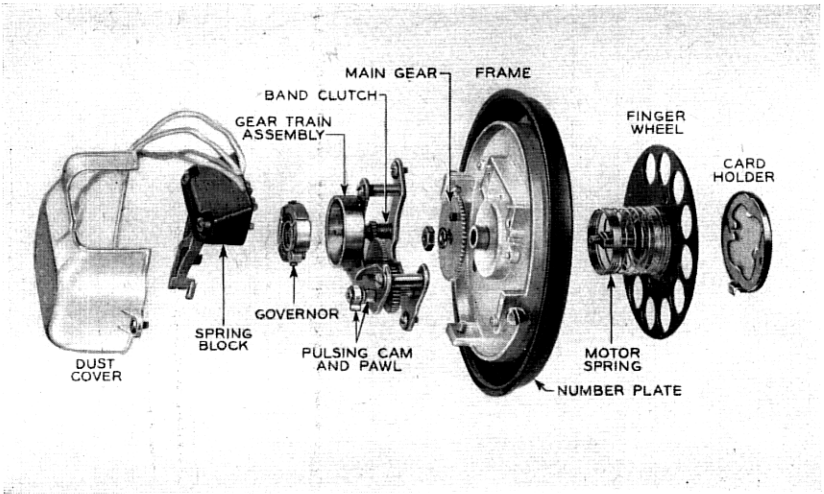

Fig. 12—View of new dial.

Figure 13 shows the general layout of the pulsing mechanism. The cam is fastened to the pulsing shaft which has a 12:1 gear ratio with the fingerwheel. The spacing of the holes in the fingerwheel is such that, if D is the number of the digit dialed, the pulsing shaft and therefore the cam rotate D + 1 revolutions. The nylon pawl is coupled to the cam shaft through a spring friction drive and rotates with the shaft through the angle β between two stops as shown. When the dial is wound up, the pawl moves to Position 1.

With the pawl in this position both springs follow the motion of the cam so that the bifurcated contact does not open. During "rundown" when impulses are sent to the central office the pawl moves to Position 2 with the first revolution of the cam shaft and remains there during successive revolutions. Only the bottom pulsing spring then follows the cam, the top spring being restricted by the pawl. The contacts are therefore opened and closed D times for every D + 1 revolutions of the cam shaft. In effect, this action of the pawl during "rundown" eliminates what would be the first pulse of each sequence, thus providing a minimum interval of one-pulse

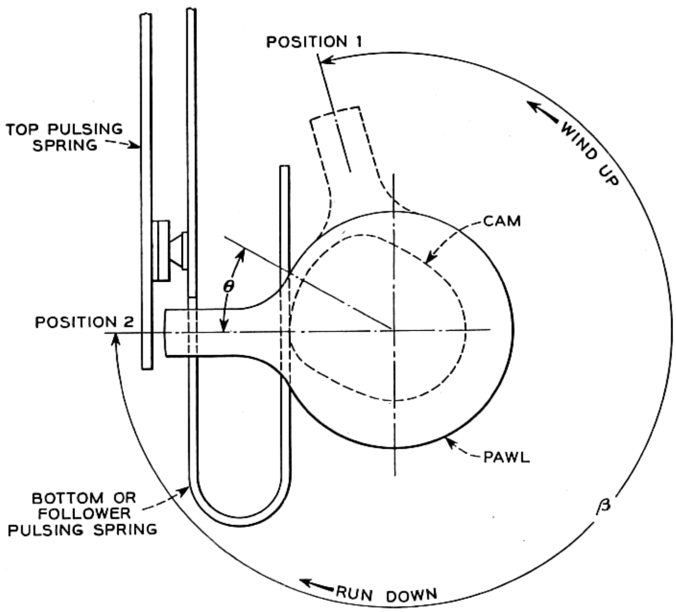

Fig. 13—Pulsing mechanism schematic.

cycle between successive pulse sequences. The per cent break or portion of the pulse cycle during which the contacts are open is controlled by the shape of the cam itself and by adjusting the height of the shepherd's crook portion of the cam follower spring.

An important improvement in the pulsing mechanism of the new dial over its predecessor is in its pulse to pulse uniformity. This is accomplished by closer regulation of speed and by the use of a single-lobe cam in contrast to the ten-lobe cam in the former dial. With the ten-lobe cam unavoidable variations in dimensions between lobes result in variations between pulses.

Closely associated with the action of the pulsing mechanism is the operation of the off-normal or receiver shorting contacts. In the new dial a pair of contacts operated by a rubber stud on the main gear close and short the receiver whenever the fingerwheel is rotated from its normal stopped position. When the dial returns to normal after "rundown" these contacts are opened. The cam is assembled on the pulsing shaft so that its major axis is rotated in the rundown direction through the angle θ as shown in Fig. 13 in order to provide an adequate interval between the last closure of the pulsing contacts and the opening of the receiver shorting contacts.

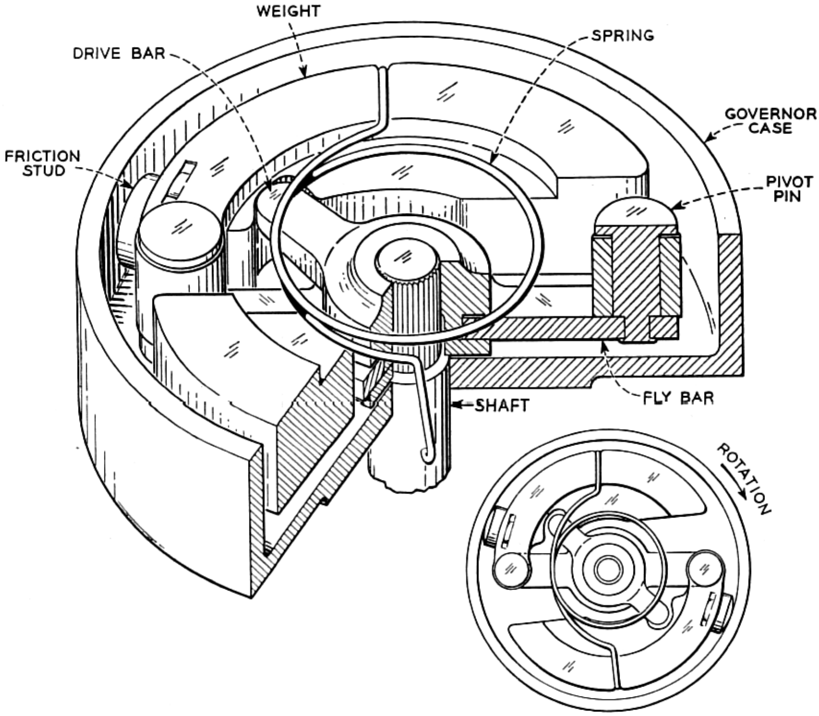

Fig. 14—Dial governor.

During this time, pulsing transients decay sufficiently so that clicks are not present when the receiver short is removed.

In achieving the close control of the make-and-break time in the pulsing mechanism, improved speed regulation of the dial plays a very important part. This is accomplished by a new type of governor, Fig. 14, in which an auxiliary bar has been added to drive the weights in the opposite direction and at a higher speed than in previous governors. As a result the new governor maintains a more constant dial speed under conditions of varying coefficient of friction between the braking studs and the case and varying input torque, as shown on Fig. 15.

Ringer

The ringer of the new telephone set, Fig. 16, uses a single coil with a laminated silicon steel core instead of the two coils used in previous type ringers,[6] thus obtaining an appreciable saving in copper. The single coil has two windings which make it possible to use the same ringer and set for a variety of service conditions including individual or two-party message rate service.

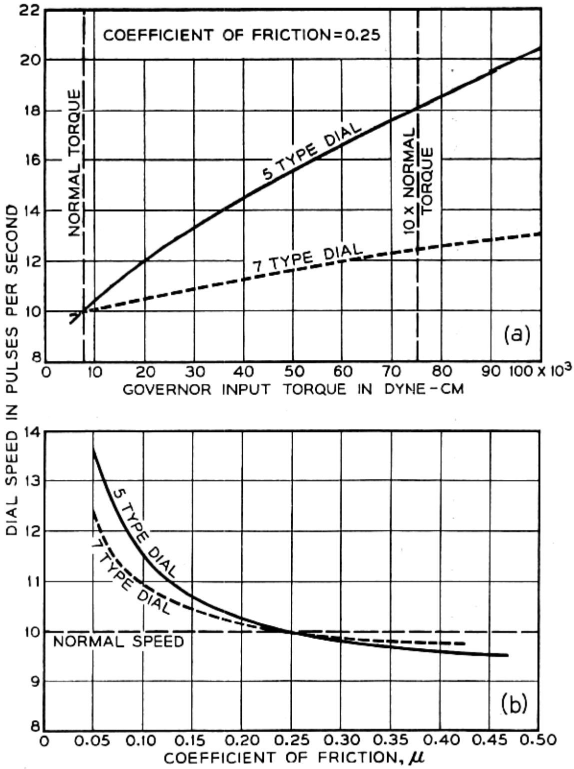

Fig. 15—Dial speed vs. torque and coefficient of friction.

Instead of the usual U shaped magnet, the new ringer employs a small cylindrical magnet of Alnico V, which results in considerably higher permanent magnet flux.

In addition to providing the required operating characteristics, such as adequate sensitivity and protection against cross ring and bell tapping, it is desirable to be able to use more bridged ringers on a single line than is possible at present in some types of central offices without pretripping of ringing. This means that the new ringer must have much higher impedance at ringing frequencies. Furthermore, because of the high receiving efficiency of the new set, the ringer impedance must be high at voice frequencies to keep induced noise from power line interference to a value no greater and if possible less than with present sets. With the new design these objectives have been realized and five ringers per line or between each wire and ground are permitted in place of the usual four. The increased impedance has been accomplished by the use of a magnetic shunt and the physical arrangement of the

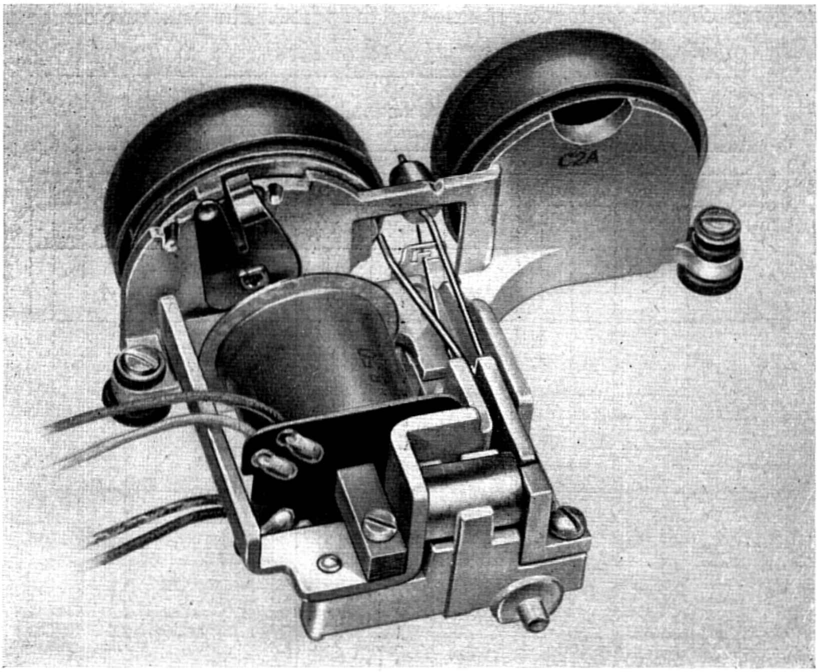

FIG. 16—View of Ringer.

ringer coil winding. Figure 17 shows the impedance frequency characteristic of the new ringer as compared to an earlier type.

The sound output of the new ringer has been increased by means of resonators that are designed as an integral part of the ringer. These resonators are formed aluminum shells mounted beneath the ringer gongs and greatly increase the fundamental gong tones. In previous ringers, resonators were added when required to increase the sound output at a particular location. Figure 18 shows the sound output spectrum of the new ringer as compared with the ringer of the former set. It should be noted that the fundamental frequencies of the two gongs of the new ringer are lower than the previous design, which results in a more pleasing and effective tone. The two gongs differ in their fundamental frequencies by a major third to produce a harmonious sound.

An outstanding feature of the new ringer is that the sound output is adjustable by the subscriber. A notched wheel that projects through the base of the set can be shifted to four different positions for four levels of sound output. This wheel simultaneously controls the armature stroke and clearance between gong and clapper ball so that the force of the clapper striking the gongs changes with each position of the wheel. The armature stroke is

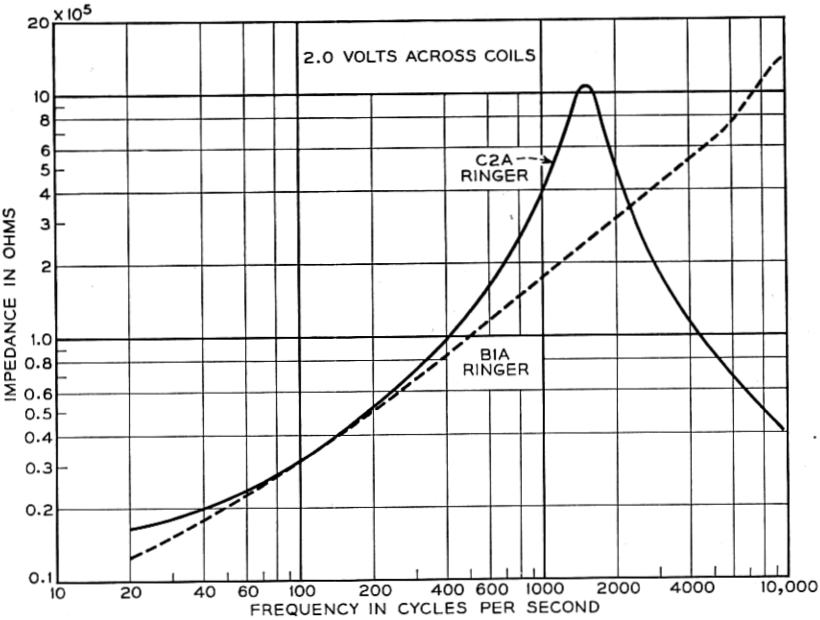

Fig. 17—Ringer impedance characteristics.

controlled by the position of a cam which moves in relation to the armature stop rod as the notched wheel is shifted from one position to another. In this manner, fairly uniform steps in volume control are obtained for the 4 positions of the notched wheel. A range of approximately 14 db may be obtained by means of the volume control feature. A mechanical stop on the volume control is provided so that the customer cannot adjust the level below a certain minimum.

The higher static forces required in the new ringer impose problems of adjustment much more critical than in any previous design. The strong permanent magnet flux tends to keep the armature in the operated position in spite of the restoring force of the biasing spring. To counteract this tendency to "stick", the armature is mounted on a spring reed or hinge, the stiffness of which is intended to balance the negative stiffness of the magnetic field. This balance must be quite accurately maintained in spite of variations in strength of magnet and stiffness of the reed spring. One or the other of these constants must therefore be adjusted in each ringer. Since it is easier to operate with precision on the strength of the permanent magnet than on the stiffness of the reed spring, the magnet of the ringer is demagnetized in successive steps until balance is reached. In addition to this balancing adjustment, it is also necessary to adjust properly the bias forces to meet the required operate and non-operate current values; and this is accomplished by the bending of the biasing spring.

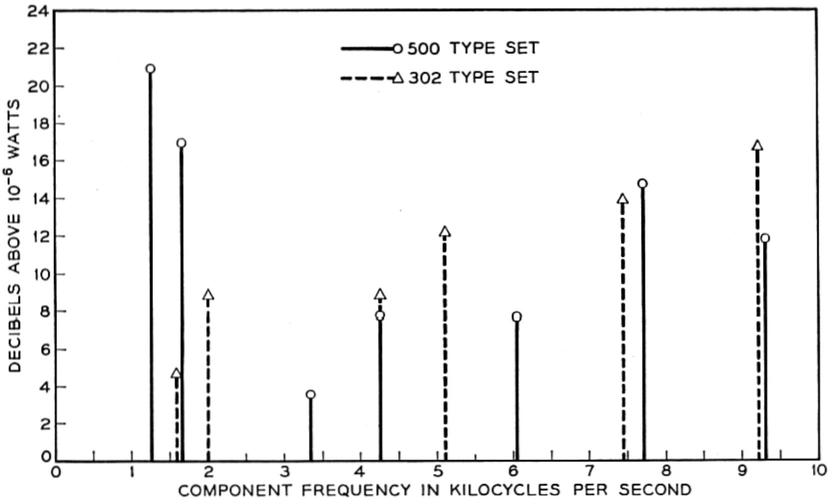

Fig. 18—Ringer output spectrum.

Since the magnetic field also affects the operate current for the ringer, the adjustment of the permanent magnet and of the biasing spring are interdependent and must be coordinated to produce a satisfactory ringer. To do this manually would be a slow, tedious and costly process. It is not too much to say that large scale production with uniform adjustment of the new ringer by conventional methods would have involved prohibitive manufacturing costs. The solution here described—automatic adjustment of ringers—provides another example of the close cooperation between development and manufacturing organizations to assure performance with economy. Figure 19 illustrates the automatic adjusting process schematically. The ringer, fully magnetized and with an overtensioned biasing spring, is held in a fixture between the poles of an electromagnet. A shaft with a forked end and connected to a bending motor straddles the biasing spring. The permanent magnet can therefore be demagnetized in controlled steps by

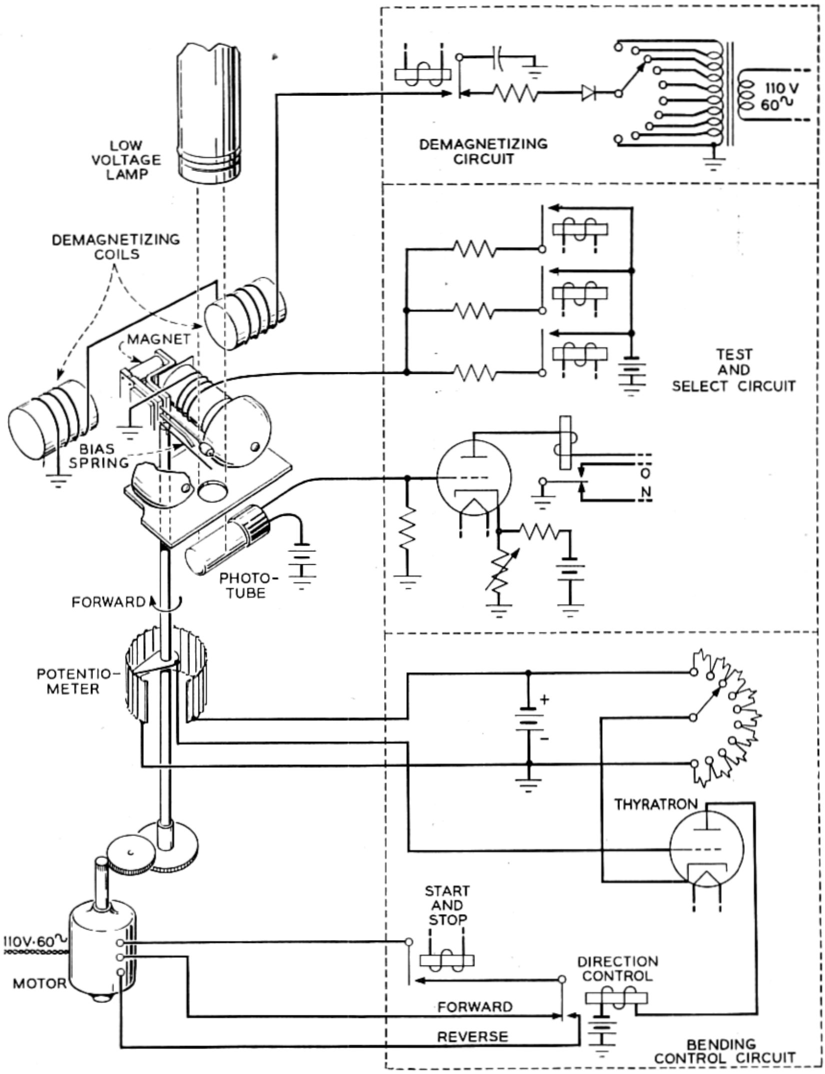

Fig. 19—Schematic of automatic ringer adjusting equipment.

discharging a condenser through the electromagnet and the biasing spring can be bent in controlled steps by rotating the fork. Alternating with these demagnetizing and bending adjustments automatic tests determine what additional adjustments are required. These tests consist of observing photoelectrically whether the armature responds to direct current equivalent in effect to the required operate and non-operate 20-cycle alternating current values. This is accomplished by focusing a light beam on the clapper ball in such a manner that a photoelectric cell underneath will indicate the position of the clapper and hence of the armature. This procedure of alternating magnet and biasing spring adjustments with operational tests is repeated automatically and at high speed until the ringer meets its final complete adjustment requirements. This is analogous to the way in which the magnetic circuit and volume efficiency of the individual handset receiver have been automatically adjusted for some time past.

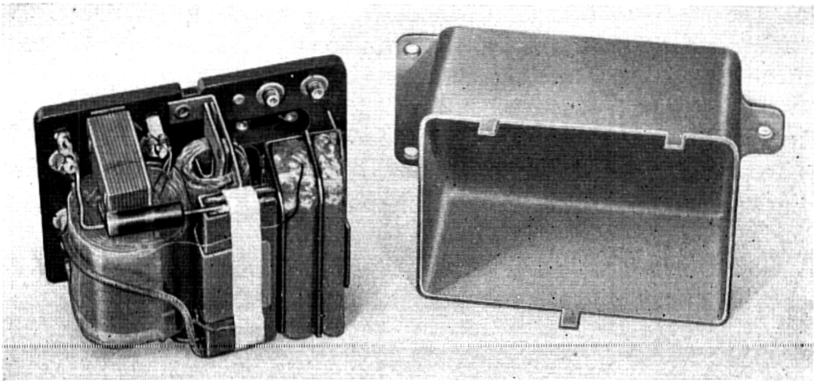

Fig. 20—View of network.

Network

The network, which comprises the basic telephone set circuit, is also constructed in a form not previously used in this type of apparatus. All components are compactly mounted on a common terminal plate and, after wiring, the assembly is housed and impregnated, Fig. 20. In addition to compactness, this type of assembly provides many other advantages. Wiring is simplified, since the interwiring of components is accomplished largely without recourse to separate wires, the terminal wires of the components being used wherever possible. "Bee-line" wiring can be employed, since the wires will subsequently be protected by the housing and impregnation. The number of terminals required is also reduced. A substantial manufacturing benefit is realized by utilizing common impregnation which obviates the necessity for protective finishes and coatings of the individual components. The assembling and wiring of the telephone set is greatly simplified. An added benefit is realized in the field where the mechanical protection provided by the network housing eliminates the possibility of damage to the parts in the process of servicing the set.

The use of deposited metal on lacquered paper for the capacitor elements provides very small, but dependable capacitors at low cost.[7, 8] For example, the 2 mf element is only $\frac{7}{8}''$ wide x $1\frac{1}{2}''$ long by $\frac{5}{16}''$ thick, which is approximately one quarter the volume of the older type. The small size of these capacitor elements is the chief factor in making possible a small, compact network with common impregnation of the parts. Their self-healing characteristic should largely eliminate service failure from breakdown.

A feature of the network is the use of an autotransformer in the sidetone balancing circuit. This element provides inductance and, through the use of a short-circuited winding, resistance in the balancing circuit. It also serves to couple a resistance and capacitor to this circuit at the correct impedance level. The improved sidetone balance over the range of subscriber loop conditions, which was mentioned earlier, is accomplished by carefully proportioning these impedance elements.

In the interests of universality, a split primary winding is used in the induction coil. Contacts are provided in the switch for closing both sides of the line and for disconnecting the ringing circuit when required. These features permit a simple conversion of the circuit in the field for the various individual and party line services for which it is intended.

A filter is provided in the network which serves to increase the dial contact life as well as to suppress radio frequency induction.

Switch

In previous designs, the weight of the handset was sufficient to operate the switch through a direct linkage acting against the force of the contact springs. Because of the lighter handset of the new set, it is impractical to utilize such an arrangement. In the new switch, the activating force is furnished by a coil spring, and the contact springs are biased to oppose this force, thus acting as a counterbalance. The handset weight, through lever arms, is thus required to overcome only the force differential between the coil spring and the contact springs.

The contact springs are positioned relatively by means of a stationary notched detail or card which maintains the proper spring separations and sequences. The operating springs are actuated by a second card which is coupled to the lever arm in such a manner as to become disengaged when the contact springs reach the end of their travel. This permits the lever arm and plungers to travel in excess of the amount required for contact operation with reasonable length of springs thus accommodating a wide variation in dimensional tolerances, and eliminating the need for hand adjustment of the springs during assembly in manufacture.

At the point where the contact springs reach the end of their stroke and the activating card disengages, the full force of the coil spring comes into play. At this point, however, the coil spring mechanism is approaching dead center, and very little buildup in operating force is encountered. This assures correct seating of the lightweight handset on the mounting.

The switch is base mounted with the contact springs vertical to make efficient use of the space available. A plastic cover is provided to protect the spring assembly. Simplicity of design has been maintained in order to facilitate manufacture. Only two screws are required in the complete assembly, most of the parts being held together by snap-on arrangements.

Set Assembly

In the design of the new telephone set, full advantage was taken of the fact that all the components were being developed simultaneously. Thus, for instance, the ringer and network have been designed to nest together to save space. The switch mounting has been designed to accommodate a flexible support for mounting one end of the ringer. The switch has been laid out to require as little space as possible at the base, where space is at a premium, and spreads out at the top where more space is available.

Means are provided for the production of other varieties of set from the basic set assembly. The dial bracket is punched to permit the addition of a ten-terminal block for sets to be used in key systems. Holes are provided in the base for mounting a turn button key and a cold cathode tube for selective ringing. The switch bracket is punched to accept the mounting lug of an exclusion key. The housing is molded with a welled section which is easily drilled out to support the stem of a turn button key. These features permit the manufacture, on a single assembly line, of a variety of sets starting with the basic set, which may be modified at special stations on the line or by running the various types alternately on the one line.

The basic set has the following components: the handset and cords, the ringer, network, switch, dial and equalizer. The internal wiring is done by means of eleven leads from the switch assembly, four leads from the dial, and four leads from the ringer. The housing merely serves as a cover and is assembled at the final position on the line.

The network, equalizer and switch are permanently attached to the base. Dial, ringer, handset and cords may be replaced by disconnecting spade tips from readily accessible screw terminals. Wiring modifications for various types of service are accomplished in the field by rearranging spade tips.

Field Trials

As invariably is done with developments of major importance, the new set designs have been given a comprehensive service trial. This is essential in verifying laboratory tests and engineering assumptions. The locations for such trials were chosen to represent the range of service and climatic conditions to be expected. Insofar as practicable, measurements and observations of such factors as volume levels, dialing accuracy and speed, answering times, and the number of "don't answers" were made.

Two separate trials were made of the 500-set. The first in the summer and fall of 1948 was on a relatively small scale with some 50 pre-production models. These were used intensively, at first to sample public opinion on appearance and performance factors, and in the later phases to provide strictly comparable service experience by some 100 selected subscribers, half of whom used new present standard sets and half the 500-set. After some weeks the sets were interchanged between the two groups, so that each of the trial group of subscribers used each type of set. This trial was intended to disclose quickly any significant factors requiring immediate changes in manufacturing planning for production. The results of the trial were so favorable to the new design that it was decided to proceed, using early production sets for subsequent trials. The initial trial established an overall preference for the new set by some 90% of the users. It also indicated that every one of the new features was noticed and favorably commented on by a substantial majority of the subscribers. All told, some three hundred persons in four operating company areas saw and used these fifty sets, and expressed preferences.

In addition, performance data obtained during the trial confirmed engineering expectations. Such factors, of course, as determination of the relative maintenance effort required had to be left for a larger scale trial over a much longer period.

This more comprehensive trial was started with the first four thousand production sets in November 1949. Ten locations in the territories of six Bell System Associated Companies were chosen. In this choice, range of climatic conditions was represented, from Manhattan and Staten Island on the east coast, to San Francisco and Los Angeles on the west, and from Chicago and St. Paul in the north to New Orleans in the south. In these various places, step-by-step, panel, crossbar and P.B.X. connected stations, business and residence, individual and party, measured and flat rate, as well as multi-party rural conditions, were included. Many sets were installed on normal inward movement, some on cutover from manual to dial, and some by substitution. In fact there was a deliberate and successful attempt to include in the trial a broad coverage of all important conditions experienced in plant and commercial operation.

For each 500-type set installed a newly made set of the present standard 302-type was installed in a comparable location and by the same plant forces. In this way, a balanced exposure to conditions for both types was insured.

Samples of each type of set were examined and measured in the laboratory prior to installation. Company records of station plant maintenance effort for both types of set were marked for easy subsequent review and the sets individually numbered. On any service troubles requiring removal, the set was returned to the Laboratories for examination.

The phases of the trial relating to the relative maintenance effort required for the two types of set were expected to last for several years. This trial was not expected to show any marked difference for the first year or two of service unless there should be major defects not uncovered in the initial trial. Thus far there has been no indication of any such factor. One very definite reduction in maintenance effort has been the essential elimination of station visits to adjust ringer volume.

The trials have indicated that dialing and ringing performance in service are at least equivalent to present design with respect to circuit holding time, although dialing over a much wider range of positions is possible and the subscriber has been given control over his ringer volume.

The trials have also provided confirmation of the potential value of the better transmission, dialing, and ringing capabilities of the new set. These gains can be used either for extension of range of operations from the central office or in increased use of finer gauge cable conductors. Other advantages are provided including the fact that the new set can be used at most stations where present practice calls for local battery talking sets. Equalization, together with the better dimensional fit of the handset, particularly for women, decreases the range of transmitted levels. This is brought about by a decrease in the proportion of low levels without affecting the high.

Acknowledgements

The development of the 500-set offers a good example of Bell System integration of development, manufacturing and operating experience in the production of apparatus which is of value both to the telephone company and to the public in providing the best telephone service in the most economical manner. The process of development will continue while the 500-set is in production and improvements in the direction of lower costs or of better performance, as they become available, will be incorporated. As this work continues, the primary responsibility for maintaining the intent of the design uniformly in the product is in the hands of the Western Electric Company. The Bell Telephone Laboratories cooperates with the Western Electric Co. in this work and prepares reports for the use of the operating organizations of the system on the quality of the product.

A roster of individual contributors to the development of the new set is too long to be included here. This also applies to the names of those to whom the authors are so greatly indebted for assistance in the preparation of this paper.

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