Technical Developments Underlying the Toll Services of the Bell System

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Early Developments

General—Telephone Instruments

TELEPHONY involves the transmission of speech to a distance by electrical means. Speech itself, physically considered, consists of rapid longitudinal variations in air pressure, or acoustic waves as they are called, traveling out from the mouth of the speaker or to the ear of the listener. Each sound has its characteristic wave form or group of wave forms and as a result these acoustic waves are of complicated and rapidly changing wave form as is illustrated by the oscillograms on Fig. 1 showing the structure of the electrical current

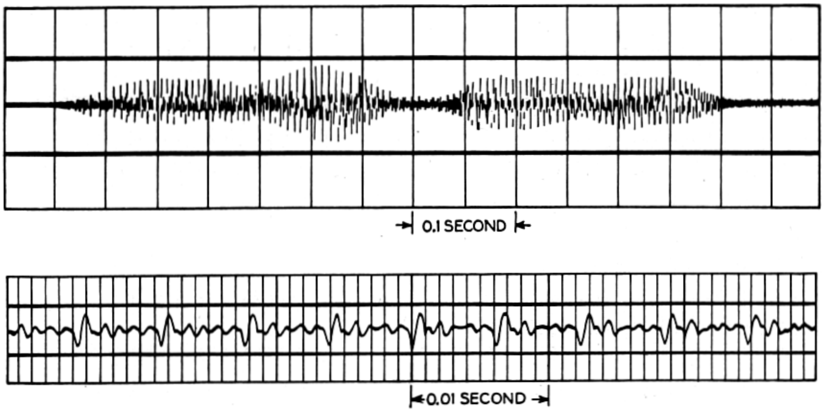


Fig. 1—Oscillograms showing electrical current in a telephone circuit resulting from spoken word "Harvard" and vowel in "Har."

in a telephone circuit resulting from the spoken word "Harvard," and, in more detail, the vowel in "Har." The telephonic transmission of speech requires, therefore, three fundamental elements:

(*a*) An instrument which, when acted upon by the acoustic waves of the speaker's voice, produces in an electrical circuit oscillations or waves suitable to represent the voice of the speaker. This is the telephone transmitter.

* At the request of the Federal Communications Commission, this pamphlet was recently prepared to give the Commission a brief account of some of the principal technical developments which have led to telephone toll service as given by the Bell System. As it brings together in concise form a summary of a large amount of information of interest to communications people generally, it is being issued with a few minor editorial revisions as a supplement to the Technical Journal.
H. S. Osborne

(*b*) A circuit from the point of transmission to the point of reception suitable to transmit these complicated electrical oscillations in the proper magnitude without undue distortion of form and without interference from electrical currents from other sources. This is the telephone circuit.

(*c*) An instrument which, receiving the electrical oscillations transmitted over the line from the telephone transmitter, reproduces acoustic waves of proper loudness and quality to correspond with those produced by the speaker's voice, by means of which waves the speech is transmitted to the listener. This is the telephone receiver.

The telephone invented by Bell in 1875 corresponded in principle to the telephone receiver of today and could be used alternately as a telephone transmitter and a telephone receiver. It consists of a diaphragm of magnetic material associated with a magnet and coils of wire. When this instrument is placed before the speaker's mouth, the variations in acoustic pressure cause the diaphragm to vibrate. The instrument is so designed that this vibration in the presence of a magnet produces electrical oscillations in the coils of wire. When these oscillations are transmitted over the telephone circuit to the coils of wire in a similar instrument, they cause variations in the strength of the magnet which, in turn, cause vibrations of the diaphragm of the receiving telephone. The vibrations of the diaphragm produce acoustic waves which reproduce the speech of the talker at the distant end of the circuit.

This instrument is very inefficient as a telephone transmitter and from earliest days efforts were directed toward the development of transmitters working on a different principle. Bell himself suggested the principle most generally used. This principle is that the vibration of the transmitter diaphragm shall vary the resistance of a local electrical circuit through which current is caused to flow by a battery. The variation in resistance can cause variations in the flow of current sufficient to induce relatively powerful electrical oscillations in the telephone circuit—in fact, the oscillations so induced may have a power several hundred times as great as that of the acoustic waves produced by the speaker. The telephone transmitters acting on this principle are, therefore, powerful amplifiers.

In his early work, Bell devised a transmitter working on this principle consisting of a small platinum wire attached to a diaphragm of goldbeaters skin and dipped very slightly into acidulated water held in a conducting cup. It was with this instrument that the first complete telephone sentence, "Mr. Watson, come here, I want you," was successfully transmitted on March 10, 1876.

Almost from the first, the efforts of inventors to develop successful telephone transmitters made use of this principle, and while many variable resistance elements were tried out with some degree of success, transmitters employing granular carbon, the resistance of which varies with pressure, were the most satisfactory. Such a transmitter devised in 1878 by Hunnings of England using powdered "engine coke" was extensively used commercially. Better performance was provided by the design in 1890 by White of the Bell System of the so-called "solid-back" transmitter. This principle and the use of carbon transmitter elements have survived through numerous improvements in transmitter design and are applied to millions of telephone instruments in use today.

The telephone station of today includes, generally speaking, a transmitter of the variable resistance type, a receiver based on the principle of Bell's original discovery, both of these instruments being modern in design, includes induction coils, condensers, etc., necessary for electrically associating the transmitter and the receiver with each other and with the telephone line and, in addition, includes such items as a bell, a switchhook, etc. which are necessary for signaling and control of the telephone circuit.

Telephone Switching Systems

Very early in the practical use of the telephone, it became evident that the full usefulness of this method of communication required the development of means by which any subscriber could quickly obtain connection between his telephone and any other telephone rather than being limited in his conversations to one other subscriber or a small group of other subscribers connected together on the same telephone circuit. The difficulties which would be encountered with a telephone plant consisting of large numbers of stations connected to one circuit are obvious, the outstanding disadvantage being that only two subscribers could carry on a conversation over the circuit at one time. These difficulties led to the development of telephone switchboards at which connection could be made between lines to any two subscribers in a given town or city.

As technical developments made toll service between different cities possible, means were needed for the rapid connection of any two subscribers in different cities. It would obviously be impracticable to connect together at the same switchboard subscribers in distant cities, and switching systems were adopted so that toll connections between any two subscribers in different cities could be established over telephone lines terminating in toll switchboards located in those cities, and trunks between the subscriber switchboards and the toll boards.

As the number of subscribers and the extent of telephone service increased, it became impractical and uneconomical to connect all telephone subscribers in the larger cities to the same switchboard; impracticable because the size of such a switchboard would be so great as to make the interconnection of two lines an unwieldy and slow procedure; uneconomical because of the relatively large amount of telephone line which would be required to connect the more distant subscribers with the central office. For these reasons means of interconnecting switchboards within a city were devised whereby a station terminated on one switchboard can be connected to a station terminated on another switchboard in the same city over a telephone line or "interoffice trunk" terminating on each switchboard. The design and layout of the subscriber and switchboard plant require careful consideration in determining the maximum economy which can be realized with the proper balance between subscriber lines and interoffice trunks.

Telephone Circuits and Cables

At the beginnings of telephone service it was found that the iron wire then used for telegraph circuits was, in many cases, not satisfactory for telephony because of the losses of energy taking place in the wires and the rapid diminution in the loudness of the transmitted speech with the distance over which it was transmitted. At first no wire was available having better electrical characteristics and at the same time sufficient mechanical strength to withstand the strains it was subjected to when strung on a pole line. Thomas B. Doolittle of the Bell System, who was familiar with certain physical properties of copper, conceived that if copper were drawn cold through a series of dies, he might obtain a wire of much greater physical strength than the soft annealed copper wire then used in a small way in the making of electrical apparatus. In November, 1877 he arranged with a manufacturer to try the process and it was so successful that in 1878 a quantity of hard-drawn copper wire was placed in service in the Bridgeport, Connecticut exchange. The success of this and subsequent installations showed that a wire which was electrically efficient and mechanically strong had been obtained by means of which telephone service could successfully be given over considerable distances.

The numbers of wires required to serve telephone subscribers in large cities led at an early date to the development of means for putting the wires underground. The early experiments starting in 1878 took advantage of the known advantageous properties of lead water pipes. Insulated copper wires were drawn into lead pipes of this character. By 1886, practical means had been developed whereby lead heated to the point of plasticity could be extruded over a compacted group of insulated conductors, thus forming the pipe tightly about the conductors, and this general principle has been followed in telephone cables to the present day. By 1890 there was a general development of insulated telephone cables in the congested parts of the larger cities. In 1891 Bell System engineers introduced the use of paper for insulating cables, and this practice is still followed in cable manufacture.

Early Toll Service

The success of the early installations of hard-drawn copper wire for short lines indicated that a type of conductor had been developed by which it might be possible to extend telephone service over considerable distances. This led to a very important experiment, the construction in 1883 of an experimental toll line between New York and Boston carrying two wires.

Prior to the construction of the New York–Boston line, telephone lines, following telegraph practice, were generally of one wire grounded at both ends, the so-called "ground return circuit." However, based upon experiments with iron wires over shorter distances, particularly between Boston and Providence, J. J. Carty of the Bell System had determined that the ground return circuit was so noisy, due to interference from telegraph lines and other causes, that such circuits could not be used over long distances, and had also discovered that by using two wires connected as a metallic circuit, the interference was very greatly reduced. Carty's metallic circuit was used with success in the New York–Boston line and was adopted for all the following construction of long toll circuits. The metallic circuit principle thus developed first for toll lines extended back into local lines so that in highly developed areas all telephone circuits are now constructed on the metallic circuit principle.

This experiment successfully demonstrated the practicability of "long distance" transmission and led to the determination to extend long distance service as widely and as rapidly as the state of the art permitted and to the incorporation in 1885 of the American Telephone and Telegraph Company for this purpose. The first telephone line constructed by this new company was the New York–Philadelphia line, using hard-drawn copper wire on a metallic circuit basis. It was found that with two or more metallic circuits on a pole line, speech currents flowing in one circuit will cause similar, weaker currents to flow in the other circuits. This is called induction or crosstalk and experience with the New York-Philadelphia line showed that so much induction between telephone circuits was obtained that intelligible crosstalk resulted; in other words, one could overhear on one circuit what was said on the others. To overcome this, systems were developed whereby, by suitably interchanging positions of the wires of a circuit, the inductive effects in that circuit from an adjacent circuit would tend to neutralize. This is illustrated in Fig. 2 for a simple case of two circuits. In this figure the circuit sections "*a*" and "*b*" are equal in length, and voltages are being induced into circuit No. 2 from circuit No. 1. The arrows show the directions in which the induced current would tend to flow in circuit No. 2, the wires of which are interchanged in position between the two sections. It will be noted that the induced voltage in section "*b*" is equal in magnitude to that in section "*a*" and, by the interchanging of wires at the

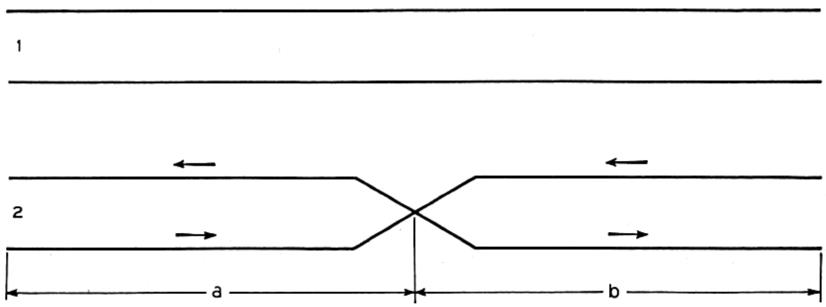
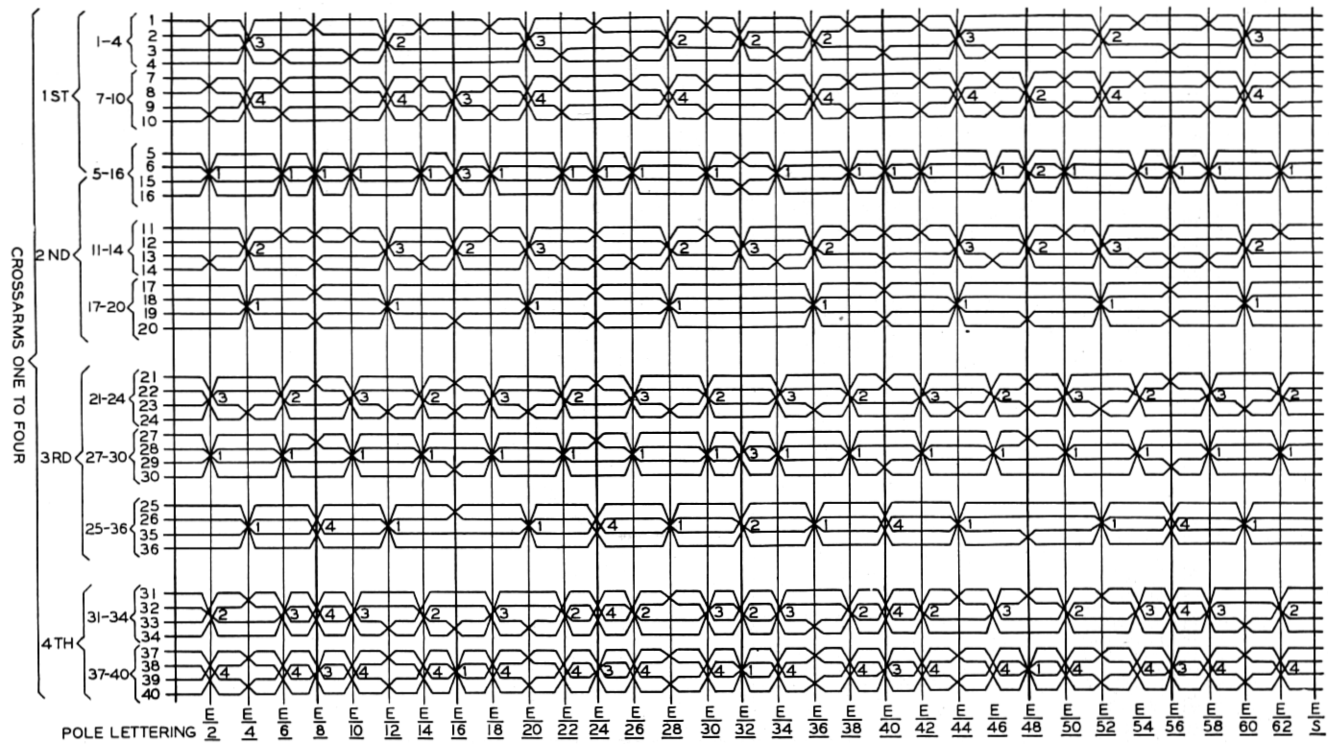


Fig. 2—Side or non-phantomed circuit transposition.

junction, is made to oppose that of section "*a*." The effect of this interchange or transposing of wires is such as to neutralize the induction in sections "*a*" and "*b*" appearing at the circuit terminals.

With a large number of circuits, the induction between each two circuits must be neutralized in each short section of line, and to accomplish this, more complicated arrangements, known as transposition systems, were developed. The first system of this sort was worked out by J. A. Barrett of the Bell System in 1886. The development of transposition systems has continued constantly since that time, the problem changing with the increase in the number of circuits on a line, developments in the transmission of electrical power on lines which sometimes are constructed near the telephone lines, the introduction of phantom telephone circuits, and of repeaters and carrier telephone circuits into the plant. Figure 3 shows a typical transposition system in use in the Bell System today.



NOTES:— LINE TRANSPOSED IN DIRECTION OF ARROW ⟶
THE FIGURE AT EACH PHANTOM TRANSPOSITION INDICATES THE TYPE. SPACE AS REGULARLY AS POSSIBLE

Fig. 3—Typical transposition system in use in Bell System today.

With the more extensive application of the cable developments mentioned above to local circuits, it was natural that they should be extended to the longer circuits used for toll business. In 1898 a 30-pair 16-gauge cable insulated with paper was extended eight miles from Boston toward Lynn, Massachusetts. Shortly after this a 30-pair 14-gauge cable was placed between Boston and Wakefield, Massachusetts, a distance of about 12 miles. It was found, however, that with the increasing distance in cable, the loss in transmission rapidly increased since cable circuits, because of the small size of the wires and the large electrical capacitance, had inherently poorer electrical characteristics for the transmission of telephone currents than the larger open wires strung on poles.

The Phantom Circuit

The phantom circuit has grown out of a conception of Jacob in 1883 which is illustrated in principle in Fig. 4. He conceived that by

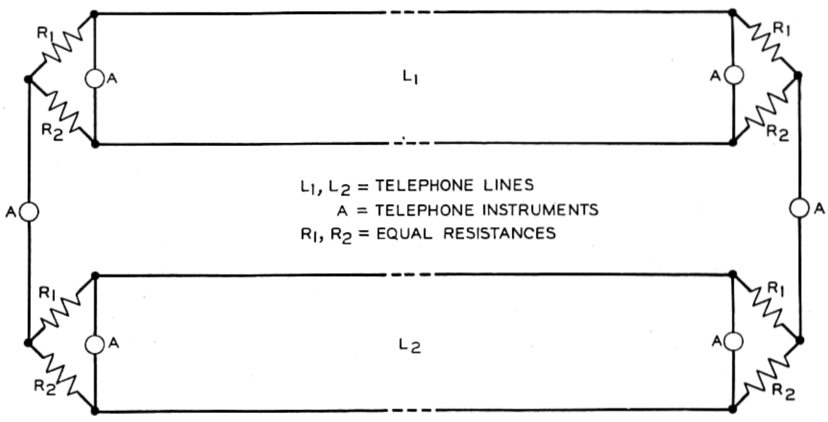


Fig. 4—Phantom circuit—conception of F. Jacob.

bridging resistances across each end of two parallel telephone circuits, a third circuit could be created as indicated by connecting telephones at each end between the midpoints of these resistances. These three telephone circuits could, therefore, use four wires without mutual interference. While this scheme was not practicable, it led to a proposal by Mr. Carty in 1886 to substitute balanced transformers (called repeating coils) in place of the resistances as indicated in Fig. 5.

In order to successfully apply this idea it was necessary to develop repeating coils that were carefully balanced, that is, which had the two halves of their windings very exactly equal in electrical characteristics, so that the current from the phantom circuit would divide equally between these two halves of the windings and not influence the other circuits (called the "side" circuits). Also, an improved technique of line construction was necessary in order to avoid high resistance joints and other irregularities in construction which would result in overhearing between the phantom and the side circuits. Furthermore, in order to avoid overhearing between different phantom circuits on the same pole line, it was necessary to interchange not merely the two wires of each pair but also all four wires of the phantom

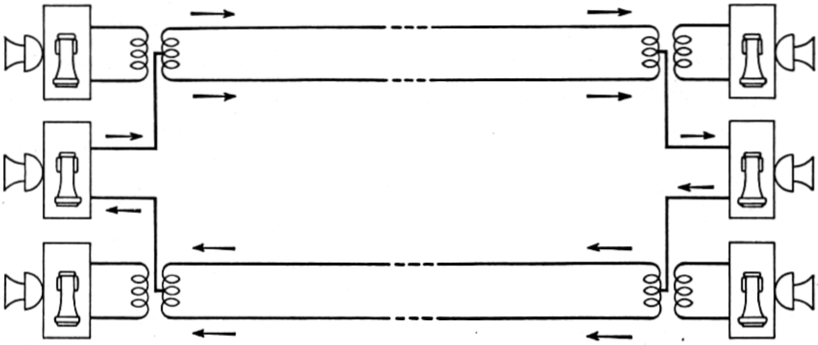


Fig. 5—Diagram of phantom circuit using balanced transformers (called repeating coils).

group as is indicated in the transposition system shown in Fig. 4. This greatly complicated the design of transposition systems. An important feature of the problem is the high degree of balance required since the transfer from the phantom circuit to the side circuit of more than one-millionth of the electrical energy carrying the telephone currents in the phantom circuit or vice versa might be sufficient to make overhearing possible. This high degree of balance was achieved by years of painstaking work and resulted in the first successful phantom circuits in the year 1903.

Today 12,400,000 miles of wire in the Bell System are installed in such a way as to be suitable for phantom operation. Without phantoming, 6,200,000 additional miles of wire would be required for the same circuit mileage.

Superposed Telegraph on Telephone Circuits

From the very beginnings of long distance telephony, the telephone wires were used also for private line telegraph service. At first, means had not been developed for using the wires simultaneously for both telephone and telegraph, and the two services were offered alternatively to the private line customers. Beginning in 1887, however, successful experiments were conducted in using telephone wires simultaneously for telephone and telegraph services by the method of superposition which is shown in Fig. 6.

The first method, called "simplexing," is an adaptation of the phantom principle for the use of telegraph on telephone circuits, the grounded telegraph circuit being introduced at the midpoint of repeating coils at the two ends of the telephone circuits, the currents dividing equally in opposite directions so that there is no interference between the telephone and telegraph circuits. The other method of simultaneous operation of telephone and telegraph circuits, however,

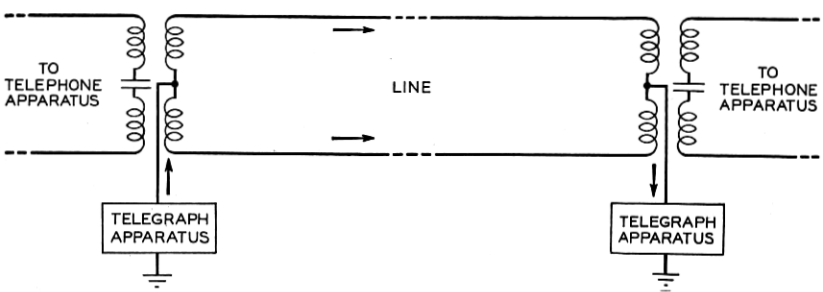


Fig. 6—Schematic of telegraph circuit superposed on a telephone circuit using the "simplex" method.

depends upon a new principle and one which has come to be of the greatest importance in the subsequent development of telephony. This principle is the selection and separation of electric currents into different channels depending upon differences in their frequency of alternation.

While the form of the electrical oscillations which transmit speech over a telephone circuit is extremely complicated, as indicated in Fig. 1, such oscillations can, by processes of analysis, be considered as made up of a large number of simple alternating currents of different frequencies. A simple current of this type, which is sometimes spoken of as a sine wave because of the mathematical law which expresses the variation in the flow with time, is shown in Fig. 7. Such a current by gradual variations at regular intervals reverses its direction of flow. Each double reversal is called a "cycle" and the number of such double reversals in a second is called the frequency of cycles per second.

An analysis of telephone currents shows that, in order to transmit satisfactory speech, it is necessary for all of the telephone apparatus and circuits involved to transmit with nearly uniform efficiency simple alternating currents over a considerable range of frequencies. For new designs of telephone circuits, the minimum range so transmitted is between about 250 and 2,750 cycles. The voice contains components of lower frequencies and also of high frequencies but it is not necessary to transmit them because their contribution to the clearness of the speech is relatively unimportant.

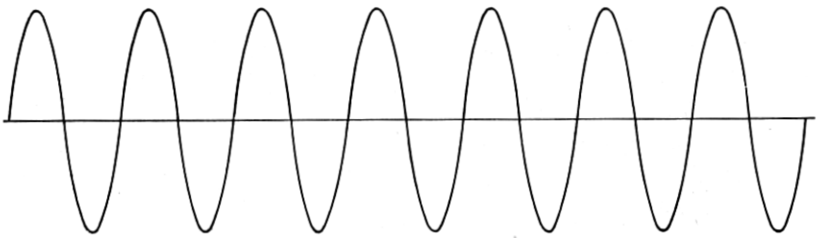


Fig. 7—Graph of a simple alternating current or "sine wave."

A similar analysis of the currents used for telegraphic transmission shows that they may be considered also as composed of simple alternating currents covering a band of frequencies—with equipment generally used in the Bell System, this band extends from zero up to roughly about 100 cycles. Components of the frequencies above about 100 cycles can be excluded from the telegraph circuit without reacting upon its efficiency of transmission with the equipment and the speeds of signaling commonly employed in private line telegraph circuits. This difference in the range of frequencies required for the transmission of telephone currents and for the transmission of telegraph currents makes possible the application of the principle of separation of electrical currents into different channels depending on the difference in their frequency of alternation mentioned above. Apparatus placed at the terminals of the circuits, which is called "composite sets," is so designed that telegraph currents and the telephone currents can be transmitted into the same wires and at the receiving end are separated into the telephone and telegraph channels, respectively, without interference. The form of this apparatus is indicated diagrammatically in Fig. 8.

The principles of simplexing and compositing have been applied extensively to the long distance circuits of the Bell System, there being now in service approximately 760,000 miles of telegraph circuit operating on these principles using wires simultaneously with their use for telephone transmission without mutual interference.

Development of the Mathematical Theory of Transmission—Loading

As telephone lines came to be extended over greater distances, it was evident that, even with the best copper telephone circuits, the loudness of speech transmitted over the circuit rapidly became less with distance, and also, particularly when the circuits were in cable, the clearness of the speech was impaired at the greater distances. At first these effects were not clearly understood, there being no adequate quantitative analysis of the effects on telephone transmission of the various electrical characteristics of the telephone circuits. Throughout all the early development period, the continued study of the

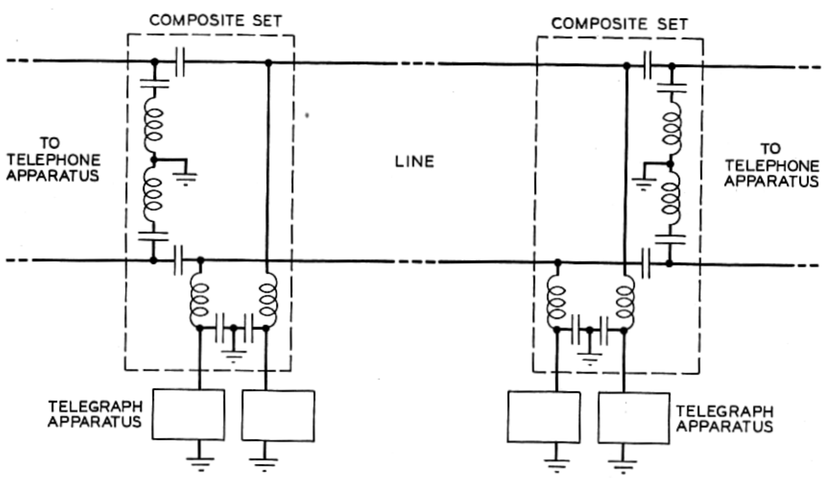


Fig. 8—Schematic of a telegraph circuit superposed on a telephone circuit using "composite sets."

mathematical theory of the transmission of currents over wires led to an increasing insight into these problems and into the conditions necessary for transmitting telephone currents over long distances efficiently and without undue distortion. The foundation was laid in the masterful, if sometimes enigmatic, papers of Oliver Heaviside published over a long period of years beginning with 1882. One result of Heaviside's work was an appreciation on his part of the unexpected fact that an improvement in transmission efficiency of telephone circuits would be brought about by an increased inductance of the telephone circuits, and he suggested in his papers that means might be found to increase the inductance artificially. This suggestion was taken up by two investigators in America, Professor M. I. Pupin of Columbia and Dr. G. A. Campbell of the Bell System who, working independently, proved by further mathematical development that this could be done practically and showed how to do it. These mathematical studies showed that, while the addition of inductance in large quantities at one or several points in the circuit destroyed its capability for transmitting telephone currents, the insertion of inductance in smaller quantities at regular and frequent intervals by means of highly efficient inductance coils would greatly improve the transmission efficiency.

Interurban Toll Cables

The development of practical means of applying the loading principle had been stimulated by the need for some practical means of improving the efficiency of toll cables. This principle led promptly to the extension of interurban toll cables, important items being the installation in 1906 of cables between New York and Philadelphia, a distance of about 90 miles, and between New York and New Haven, a distance of about 80 miles, and, in 1908, of a cable between Chicago and Milwaukee having a length of about 90 miles. At about this time experimental work was being actively conducted by the Bell System in the effort to develop a type of construction for toll cables which would permit the use of phantom circuits in the cables as well as in open wire. This required a new technique in cable construction, involving new principles and many refinements in detail to eliminate the interference which would exist between phantom circuits and the side circuits from which the phantoms are derived and also between phantom circuits in the same cable. The processes worked out included not only manufacturing methods but new types of electrical tests and new splicing procedures applied in the course of installation by means of which the unbalances in successive lengths of cable are made to largely neutralize each other. As a result of this work, a successful phantom cable was installed between Boston and Neponset, Massachusetts in 1910, a distance of six miles.

This work led to the inauguration in 1911 of a very important interurban cable project. At the time of the inauguration of President Taft on March 4, 1909, a sleet storm of unprecedented severity had broken down all the wire lines entering Washington and isolated the Capitol from the rest of the country. The Bell System management determined that, as soon as technical advances made it possible, means would be adopted for insuring against any future similar interruption of the communications between the United States Capitol and the rest of the nation. Upon the success of the experiments described above, it was decided to complete an underground cable route connecting Washington with Baltimore, Philadelphia, and New York, using large gauge conductors, the phantoming principle which had just been successfully demonstrated, and new systems of loading designed specifically for the new cable. The project was completed in 1912 and in 1913 this high grade cable route was extended to Boston, through New Haven, Hartford and Providence.

Possibilities and Problems Associated with the Use of the Telephone Repeater

The developments discussed above had done a great deal to extend the range of telephone service making possible good commercial service between the Atlantic Seaboard and Chicago and a service of a kind as far west as Denver and providing a storm-proof cable route connecting Washington and Boston and the intermediate cities of the Atlantic Seaboard. By 1912, however, it was apparent that in addition to pushing to the utmost the advantages to be gained from the technique already developed, it would be necessary, if universal service for the entire country were to be realized, to find satisfactory means for amplifying the attenuated telephone currents on a long telephone circuit so that after transmission over one section of line they could be restored, in amplitude, transmitted into a second section, and when again attenuated restored a second time and transmitted into a third section of the line and so on, without undue distortion or change in the structure of the voice currents. The device to accomplish this is called a telephone repeater. The conclusion that improved repeaters were required was reached after a careful analysis of all of the possible means of achieving further extensions in the range of long distance transmission and as a result the energies of the research forces of the Bell System were to a greater extent than before directed to the development of improved telephone repeaters and of circuits and methods of line construction which would make possible their general use.

One of the chief problems which confronted the engineers undertaking the intensive telephone repeater development work beginning in 1912, was the development of an amplifying element for a repeater which could be used generally for telephone purposes. The telephone repeater was not new in the art at that time, since a repeater giving beneficial results had been invented by H. E. Shreeve of the Bell System and first used successfully on a circuit between Amesbury, Massachusetts and Boston in 1904. The Shreeve repeater took advantage of the amplifying characteristics of a variable resistance telephone transmitter and combined in one instrument, in refined form, the fundamental elements of a telephone receiver and a transmitter. The attenuated telephone currents entering the receiver side of the device caused the vibration of a diaphragm which, in turn, actuated a variable resistance element which transmitted amplified currents to the next section of telephone line. Figure 9 shows a cross-section of the amplifying element of this repeater, commonly known as the mechanical repeater. Repeaters of this type were used in commercial service for a number of years but since development

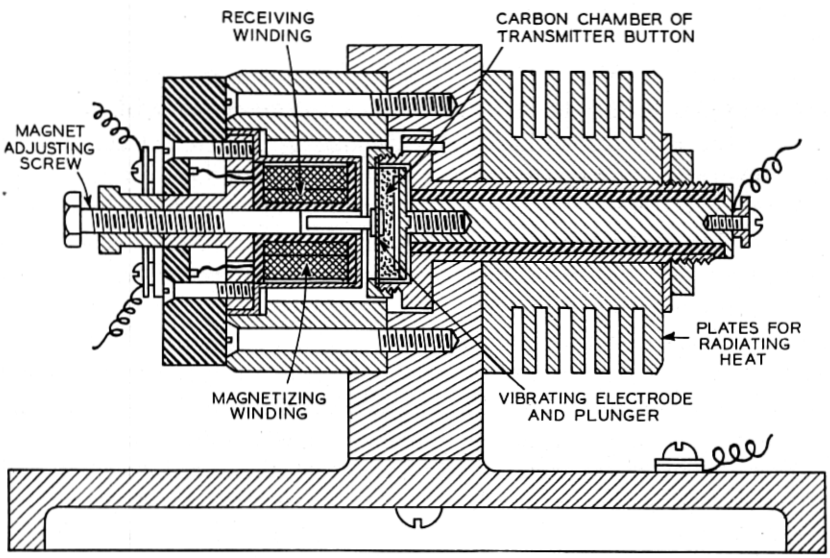


Fig. 9—Cross-sectional drawing of a mechanical type of telephone repeater.

work up to the time of the application of vacuum tubes to telephone repeaters had not overcome the fundamental difficulties of distortion, gain limitations and instability of the mechanical repeater, its use was gradually discontinued after the introduction into the telephone plant of the vacuum tube repeater. Other arrangements such as variation of the field current of a generator to produce corresponding variations in the armature voltage and the electromagnetic control of gaseous devices were tried out but were never successfully applied in any important degree to telephone circuits.

In 1906, Lee DeForest demonstrated before the American Institute of Electrical Engineers that the discharge between a hot cathode and a plate of a thermionic tube can be controlled by a third electrode.

Immediate use of this discovery was made in improving radio telegraph receivers. The tubes and circuits thus employed were not of types that could satisfactorily be used in telephone work which required a high stability of the amplifying device and freedom from distortion of speech currents. However, an intensive study of the possibilities of this device showed that the use of such tubes based on DeForest's discovery was by far the best method of amplifying telephone currents yet developed.

Development work on vacuum tubes carried on by the Bell System has included the perfection of the tubes by the use of high vacuum, scientific proportions and new types of filaments to secure improved efficiency. The performance of vacuum tubes used in the Bell System has been improved extensively through continued development work. For example, during the last twelve years the average life of the tubes used in the Bell System has been extended by a factor of 10, and, at the same time, their power consumption has been reduced appreciably.

Vacuum tubes were first applied to telephone repeaters experimentally, and to a small degree commercially as early as 1913. One of the first important uses of vacuum tube repeaters, however, was in 1915 in connection with the first transcontinental telephone service between New York and San Francisco, a distance of approximately 3400 miles. The circuit consisted of No. 8 B.W.G. open-wire copper conductors loaded at eight-mile intervals and having vacuum tube telephone repeaters located at Pittsburgh, Omaha, and Salt Lake City.

Years of experience with early forms of telephone repeaters had shown that the successful use of repeaters depended not only upon the development of a suitable amplifier but also upon the design of suitable circuit arrangements for associating the repeater with the telephone line and on improved methods of line construction. An important consideration is the fact that a telephone circuit must operate in both directions, that is, it must permit talking to be carried on from either end of the circuit. A single telephone repeater element, however, is inherently a one-way device, receiving attenuated currents at one pair of terminals and transmitting amplified currents from the other pair of terminals. The association of such one-way elements with a two-way telephone circuit is not a simple matter because if any considerable proportion of the amplified output current of the repeater reaches the input terminals, it is again amplified and results under ordinary conditions in turning the repeater into a generator of alternating currents (an oscillator) and destroying its usefulness as a repeater.

The type of circuit arrangement most commonly used to associate two repeater elements with two sections of telephone line in such a way that the operation will be satisfactory is shown schematically in Fig. 10. This is known as a 22-type repeater. Attenuated telephone current transmitted from a distant point over the west section of line passing through the transformer *A* of a special design (sometimes called a hybrid coil) enters the input of amplifier element *B* and is amplified. From the output of amplifier element *B* it passes through a second transformer *C* associated with the east section of line and a balancing network *E*. An essential function of the repeater circuit lies in the design of the transformer in such a way that the two halves (between the midpoints of which the input to the amplifier element *D* is connected) are equal and in the design of the east line and of the balancing network *E* in such a way that they offer the same impedance to the

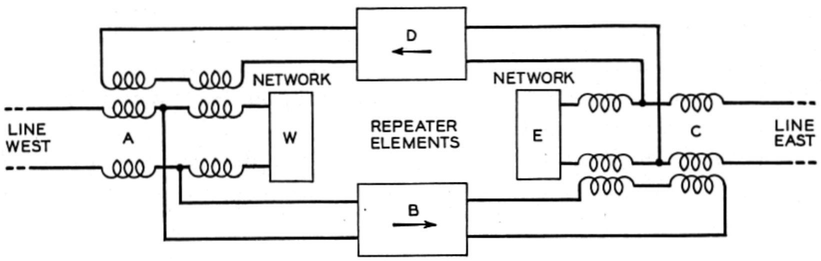


Fig. 10—Schematic 22-type telephone repeater circuit.

flow of current. Coil *C* is so designed that if this condition is exactly met, none of the ouput current from amplifier element *B* is transmitted across to the input element of amplifier *D*. However, currents transmitted in from the east section of line pass through Coil *C* to amplifier *D*, are amplified and retransmitted to Coil *A* where the condition of balance also must be applied between the west line and the balancing network *W*.

The complete repeater circuit includes many other things beside the bare essential elements shown in Fig. 10. Important among these are electrical filters to control the band of frequencies, potentiometers to control the amplification, transformers to efficiently interconnect different parts of the circuit, equalizers (see chapter on Associated Technical Developments) and arrangements for the supply of electric power to the vacuum tubes.

Obtaining a condition of balance requires that each section of line offer the same impedance to the flow of current as the balancing network associated with that section of line in the repeater circuit. A difficulty to be met arises from the fact that telephone currents are very complicated in wave form as previously indicated and involve components varying all the way from 200 or 300 to 2700 cycles per second or more. In order to provide for suitable operation, the condition of balance must be met within a close approximation for currents of all of the frequencies within this range. The reason why this requirement reacts on the construction of telephone lines is very simply illustrated by the curves of Figs. 11 and 12. Figure 11 shows the impedance of a long telephone circuit for all frequencies within that range when the circuit is of very uniform construction throughout. Figure 12 shows the corresponding impedance curve obtained if there are some irregularities in construction in the line. It is possible to design balancing networks which have the same characteristics as those indicated in Fig. 11 for the uniform line but it is not practicable without too great expense to design such networks having the same characteristics as the irregular line shown in Fig. 12. This is true since the characteristics of no two irregular lines are the same, the characteristics varying widely depending upon the nature and the location of the irregularities.

Means for the general use of repeaters on telephone circuits therefore involved the development by the Bell System of line balancing networks and the development of long telephone lines with uniform impedance characteristics over the range of frequencies used in telephony. In some cases this could be done by making the lines uniform in construction. For example, loading coils had to be designed so that they had, very accurately, equal amounts of inductance and had to be spaced at exact equal intervals along the line. Furthermore, it was found that the types of loading coil in previous use were affected by lightning and other causes so that the amounts of inductance changed enough to interfere with repeater operation. It was, therefore, necessary to develop new types of coils of very stable materials which would avoid this change in inductance.

In some cases, it is not possible to construct the line in a uniform way throughout. For example, it is often necessary for open-wire lines to be brought into towns and cities through sections of cable. For such cases, for each type of open-wire construction, a type of cable construction was worked out having such characteristics that it could be connected to the open wire without spoiling the impedance characteristics of the circuit. This involved the development of new loading systems for use on cables of this sort. In the case of circuits entirely in cable, improved uniformity in the manufacture of the cable

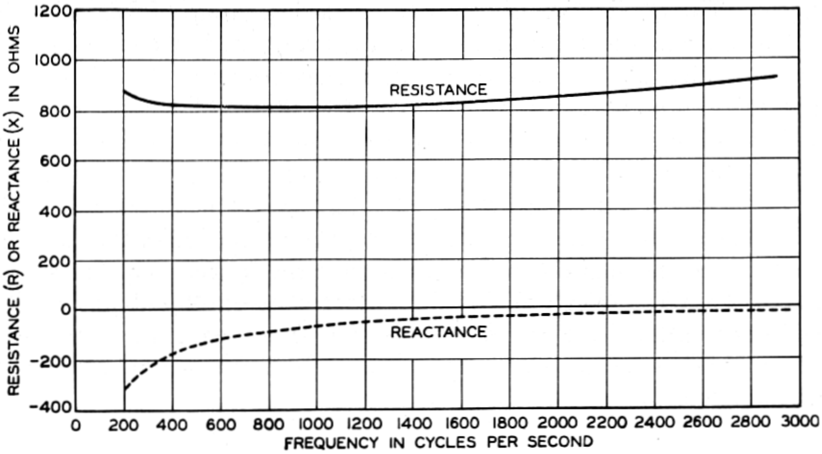


Fig. 11—Impedance-frequency characteristics of a smoothly constructed telephone line. Impedance $(Z) = \sqrt{R^2 + X^2}$.

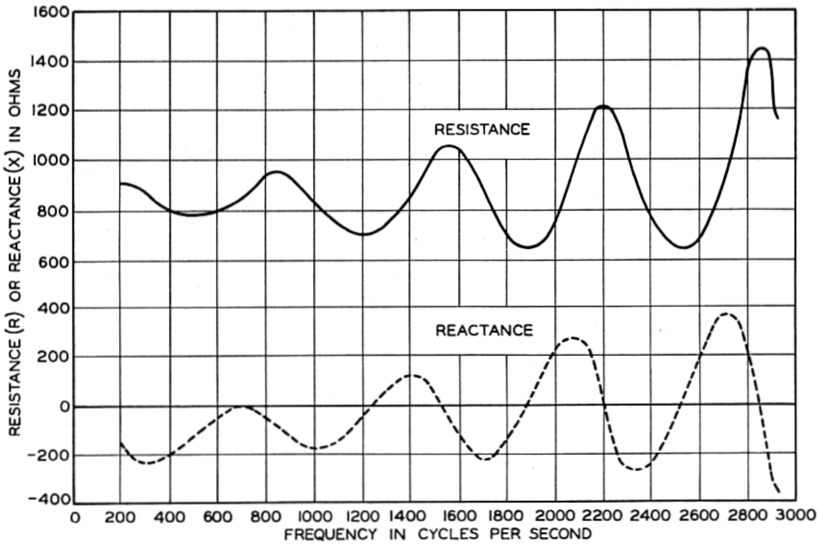


Fig. 12—Impedance-frequency characteristics of a telephone line having an impedance irregularity.

itself was required as well as improved loading coils and more exact rules for their location.

Generally speaking, repeaters are used in connection with the phantom circuit arrangements previously described, by means of which three independent telephone circuits are derived from four wires. The application of repeaters to such a group of four wires in cable (spoken of as a phantomed group or a quad) is shown schematically in Fig. 13. In this figure, the boxes denoted "Telephone Repeater" represent the complete repeater circuit shown in Fig. 10. It is necessary to separate the telephone currents of the phantom circuit from those of the two side circuits by applying to the phantom group highly balanced repeating coils, just as is done at the terminals of the circuit, and providing separate repeaters for each of the two side circuits and the phantom as is illustrated in the figure. The figure also shows a typical telegraph circuit arrangement—a metallic telegraph circuit on each pair, separated from the telephone channel by composite sets as previously described, and passing through telegraph repeaters at the telephone repeater point.

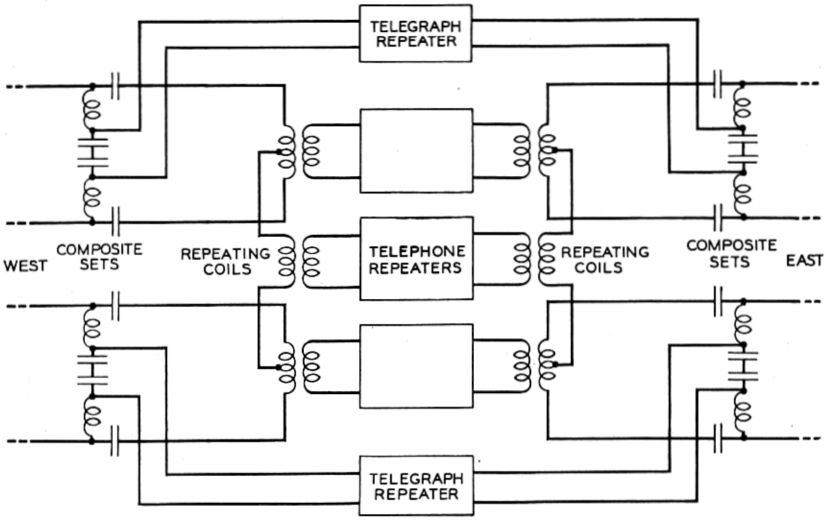


Fig. 13—Showing schematically the association of the four wires of a phantom group and composite sets, repeating coils, telephone repeaters and telegraph repeaters.

Phantom operation through cables, without crosstalk between the phantom and its side circuits and between the circuits in different quads of the cable, has involved a long train of developments in decreasing the tolerances of manufacture and increasing the uniformity in the characteristics of the cable. The cables must meet a double requirement, namely, freedom from crosstalk, which is made more difficult with the application of repeaters, and uniformity of characteristics to provide for suitable repeater operation. This double requirement has been met by niceties in design, construction, and installation, including a series of delicate electrical tests on the cable and portions of the cable during the process of installation.

With these developments, it became possible to use repeaters to provide a large improvement in the transmission efficiency of telephone circuits both in open wire and in cable, a number of repeaters where necessary being used at different points on the same circuit. The repeater element itself could be made so free from distortion that a very large number of them could be used in succession on the same circuits. The limitation in the use of repeaters, however, was determined largely by the degree of balance practicably obtainable through the more uniform construction of the telephone lines. While it was practicable to have such a degree of balance that a single repeater would amplify the telephone current often six or sevenfold, it was not generally practicable even with the use of a number of repeaters to extend the length of circuit using a given size of conductor over eight to tenfold. For transmission over very long distances or for the use of very small conductors in long toll cables, another principle was developed which was applied to toll cables and to the use of carrier systems on open wire, and will be discussed in connection with those subjects.

Toll Cable System

The success achieved in the general application of repeaters to telephone toll circuits opened the way for a great extension in the use of toll cables. Toll cables have the obvious advantage of providing a high degree of security and continuity for telephone circuits due to the fact that they are nearly immune from the effects of bad weather, particularly of sleet and of high winds which sometimes seriously interrupt open-wire telephone service by placing on the conductors and on their supporting structures loads greater than those for which they can economically be designed. Also, cables form the practical means for providing the very large numbers of circuits required to take care of the demand on very heavy routes by making it possible to crowd into one route a much greater number of circuits than could be provided by the ordinary open-wire technique.

Before the general use of repeaters became practicable, toll cables had the inherent disadvantage that, with the small conductors necessary to place a large number of circuits in one cable (until recently maximum outside diameter 2⅝ inches), the cable circuits, even when equipped with loading coils, had a very high attenuation loss per mile compared with the open-wire circuits. Even when very large conductors were used in the cable at the sacrifice of the number of circuits in order to provide circuits of high efficiency, as was done in the first cable between Washington, New York, and Boston, the losses were still high because of the close crowding together of conductors in the same circuit and of the fact that even the best insulation which could be provided, namely dry paper, resulted in considerably more energy losses to the telephone conversations than take place on open-wire circuits in which the conductors are separated at very considerable distances by air.

The use of repeaters in cable circuits made it possible to get high net efficiency over long distances using small conductors, since it was possible to compensate for the relatively large loss by the repeated gains introduced into the circuit by repeaters suitably located about 40 to 50 miles apart. That this might be done, however, required a reduction of manufacturing tolerance limits for cables, loading coils, and apparatus and care in the design, construction, and maintenance of the cable circuits. Also, new loading systems were designed which transmitted a broader band of frequencies than those transmitted by the earlier systems. This was desirable both because of the improved clearness of speech resulting from the broader band of frequencies itself and also because the use of the new loading systems made it possible to provide for better repeater balance within the band transmitted.

While these improvements made possible a very large extension in the distances over which good transmission could be given on small gauge cable circuits, it was found that, with many repeaters, the balance difficulties were still sufficient to justify the development and use for the longer circuits of a different arrangement. This arrangement, which is shown schematically in Fig. 14, consists of using for each telephone circuit two pairs or two transmission channels, each equipped simply with one-way amplifiers and thus arranged to transmit the telephone currents in one direction only. Two such one-way channels, oppositely directed, are connected together at the terminals of the circuit by apparatus similar to that used for associating amplifiers with two sections of line in the ordinary telephone repeater, including apparatus for balancing the line or the equipment to which the circuit is connected when in use. The complete circuit is thus reduced at its terminals to two wires like any other telephone circuit. From the fact that it uses two channels for transmission in opposite directions, it is called a four-wire circuit. These channels may, however, be either side or phantom circuits as in the case of an ordinary repeatered telephone circuit.

With the four-wire circuit, since the two directions of transmission are kept isolated from each other throughout, there is no need for providing balance except at the terminals of the circuit and this makes possible the use of higher repeater gains and, therefore, a higher net efficiency of transmission with such circuits for long distances than would be possible with the other form of circuit (generally called two-wire circuit). Circuits of this four-wire type are now generally used in toll cables for distances more than about 100 to 150 miles.

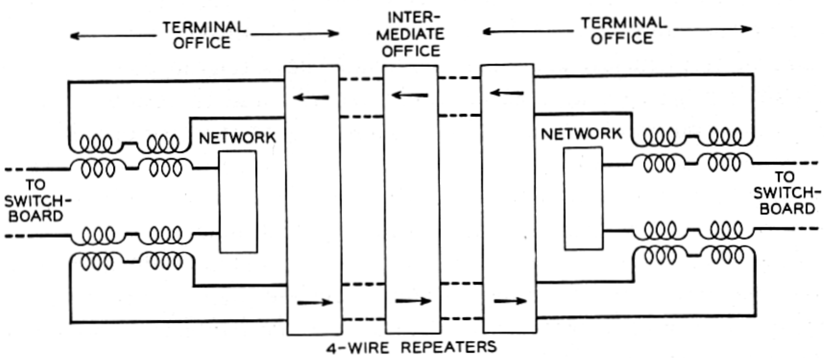


Fig. 14—Schematic of a four-wire circuit using two one-way transmission paths.

Mention was made in the first chapter of this statement of the refinements in manufacture and in installation procedures which were necessary in order to produce suitable interurban toll cables, particularly cables designed for the use of phantom circuits. With the extension of toll cables to great distances equipped at frequent intervals with telephone repeaters, additional refinement in design and in construction was necessary in order to prevent crosstalk between the different circuits in the cable. This includes the physical separation in different parts of the cable of conductors used by four-wire circuits for the opposite directions of transmission. Even with all the refinements which have been worked out, crosstalk remains today one of the major factors to be considered in the engineering of long telephone circuits.

The velocity of propagation of telephone currents over circuits is high so that in all of the early telephone development the length of time required for propagation over the longest circuits used was not sufficient to introduce any new difficulties in the problem of providing good telephone transmission. The velocity of transmission, however, varies with the type of circuit, is lower on loaded circuits than on non-loaded circuits, and in loaded circuits in cable in common use is as low as 10,000 miles a second. With the greater distances for which cable circuits of the four-wire type could be used, it was found that the time of transmission required at a velocity of 10,000 miles a second was great enough to introduce additional difficulties in the provision of satisfactory transmission. The nature of these difficulties and of the means adopted for overcoming them will be discussed a little later. However, it must be mentioned here that to overcome these difficulties, it was necessary, for these longer circuits, to devise new loading systems which provided circuits with a velocity of 20,000 miles a second and at the same time had the advantage of transmitting a broader band of frequencies, although they had the disadvantage that the circuit had higher transmission losses per mile and therefore required greater amounts of amplification. These higher velocity circuits are in general use for all long cable circuits and have been found satisfactory up to the greatest distances spanned by cables in this country at the present time, namely, approximately 2500 miles.

Cables are placed either underground or supported overhead from a steel messenger strand strung on poles. At the present time approximately 47 per cent. is overhead and 53 per cent. underground. For the most part the underground cable is pulled into permanent underground conduit of vitrified clay. Some use has been made, however, of cable buried directly in the ground, the lead sheath being protected either by layers of jute impregnated with asphaltum compounds or by a combination of such layers of jute and wrappings of steel tape. A small use has also been made of a single duct made of compressed fibre for the protection of underground cables.

The conductors used for long telephone circuits are quadded for phantom operation and are largely of 19 A.W.G. although some use has been made of 16 A.W.G. for the shorter circuits because of a possible saving in the numbers of repeaters with the larger gauge in those cases. Many of the cables include a number of special 16-gauge pairs provided specifically for program transmission circuits and equipped with loading and amplifiers designed particularly for that form of service. Figure 15 shows schematically the arrangement of conductors of a standard type of full size cable (outside diameter 2⅝ inches) which is in common use.

With these developments and other auxiliary developments which will be discussed later toll cables have come to have a very important place in the provision of toll telephone service by the Bell System. The percentage of toll wire in cable has increased from 30 per cent. in 1915 to 82 per cent. at the present time. The present toll cable network is indicated in Fig. 16. It will be noted that this network connects together almost all of the major places between the Atlantic Seaboard on the East; Atlanta, Georgia and Dallas, Texas on the South; Western Texas, Kansas City, and Omaha on the West; and Toronto, Montreal, and Bangor on the North. In addition, there are other sections of toll cable connecting important centers as San Francisco–Los Angeles and Miami–Palm Beach. These cable systems provide a storm-proof outlet for telephone circuits to 155 out of a total of 210 cities over 50,000 population in the United States and Canada, and cover the major part of the United States in which open-wire lines are subject to interruption by severe sleet storms. The cable network includes at the present time about 27,000 miles of cable and 12,500,000 miles of conductor.

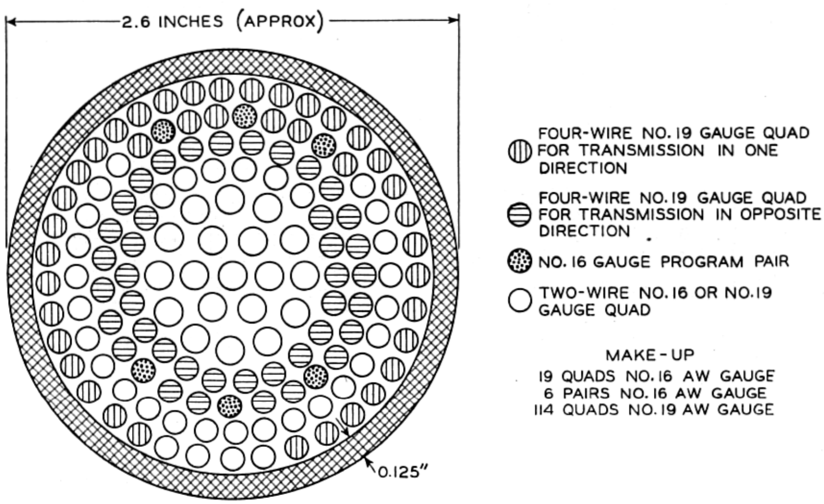


Fig. 15—Cross-section of typical toll cable.

The Time Factor In Telephone Transmission

In the above discussion of toll cable systems it was mentioned that it became desirable for the long circuits in cable to provide a type of circuit having a higher velocity of transmission than that of the loaded cable circuits previously in use. The effects of the length of time required for transmission over long circuits, while particularly noticeable in long cable circuits, are of importance in long open-wire circuits as well. These effects are briefly discussed below.

On non-loaded lines, either in open wire or in cable, the velocity of transmission of telephone currents over the line conductors is high,

Fig. 16—Main toll cable routes—Bell System.

approaching as an upper limit the velocity of propagation of light, namely, 186,000 miles a second. On loaded circuits this velocity is greatly reduced. Loaded toll cable circuits in common use over moderate distances, as already mentioned, have velocities of 10,000 miles a second and still lower velocities were associated with some of the earlier types of loaded toll cable circuit.

The transmission of telephone currents over long circuits is accompanied by reflections of a part of the current at points where the electrical characteristics of the circuit change, particularly at the terminals where it is not practicable to get a close match between the characteristics of the toll circuit and of the various local circuits and terminal equipments to which it must be connected. Considering for the moment only this terminal reflection, speech over the circuit is not only transmitted directly but also a part of the transmission current is reflected back and forth between the terminals producing delayed sounds analogous to the echoes produced when one talks in the face of a distant cliff or building. For example, over a 1000-mile circuit with a velocity of transmission of 10,000 miles a second, the time required for transmission in one direction is .1 of a second and for a round trip of the circuit .2 of a second. On such a circuit the talker may hear in his receiver the echo of his own words .2 of a second after they are spoken and the listener at the other end may hear not only the direct transmission but an echo delayed by .2 of a second. Such effects, if sufficiently great, seriously interfere with the conversation, the amount of interference increasing with the amount of delay.

The reduction in the effect of echoes is partly taken care of by improvements in the design, both increasing the velocity of transmission over the circuit and reducing the amount of reflected current. In addition, special devices known as "echo suppressors" are used to reduce further the effect of echoes. In the echo suppressor a small part of the voice current is amplified and rectified and used to control the circuit in such a way that during the conversation the circuit is operative only in one direction at a time, the interruption of the return path serving to prevent the transmission of echoes. As people speak alternately from the two ends of the circuit, this control is automatically shifted so that the words will be fully transmitted in each case.

While echo suppressors are very successful and are widely used, they have certain limitations and, in spite of their use, echoes remain an important factor to be considered when engineering and laying out long telephone circuits.

Another effect of the time of transmission arises from the fact that, generally speaking, the components of different frequencies making up the voice currents are not all transmitted with the same velocity over the circuit. Often the frequencies in the middle of the range 1,000 to 1,500 cycles arrive first and the highest and lowest frequencies arrive somewhat later. This difference is inappreciable on short circuits but for the longest circuits, if not corrected for by suitable design, may become great enough to be appreciable. Under those conditions a distortion of the speech takes place which interferes with the ease of understanding and, in extreme cases, may seriously impair transmission.

This type of effect can be compensated for by the installation at intervals along the circuit of networks designed to introduce additional delay in the transmission of the frequencies in the middle of the range so that all frequencies will arrive at the distant end more nearly at the same time. Up to the present time, the improved design of circuits used for the very long distances has sufficiently kept down the amount of this distortion so that special compensating arrangements are not necessary to message circuits but they are commonly used in circuits for some of the special services, where transmission requirements are more severe.

Still a third effect of the finite velocity of transmission over telephone circuits is to be found in the time of transmission itself. In the ordinary case, the elapsed time between the speaking of a word at one end of the circuit and its reproduction at the distant end is inappreciable but for very long circuits this requires consideration. Telephone conversations, like face-to-face conversations, involve the repeated interchange of information. Even if one person is doing the talking, he receives frequent acknowledgments from the other that he is followed and understood and, in the case of telephone conversations, those acknowledgments must be vocal in character. If too great a time is required for the transmission of the speech and the return transmission of the acknowledgment or replies, the vocal interchange of ideas is interfered with.

These considerations have led to the preliminary conclusion that the total time of transmission over any telephone circuit should not exceed about ¼ of a second. It would mean that the velocity of transmission 20,000 miles a second now used for long toll cable circuits would not be adequate at some future time for connections between widely separated parts of the earth's surface. Fortunately, the trend of development of very long circuits is for various reasons in the direction of higher velocity circuits, as will be made apparent in the next section, so that it is anticipated that this limitation, except in perhaps a few special cases, will not be difficult to overcome.

Multi-Channel Telephone Systems

It was pointed out under "Early Developments" that, for clear transmission, telephone circuits must transmit a band of frequencies, the minimum band used for new telephone circuits being between approximately 250 and 2,750 cycles. However, many telephone lines can be made suitable for transmitting a much broader band of frequencies, namely, frequencies running up into the tens of thousands or, by applying the latest developments, to hundreds of thousands of cycles. This fact naturally raised the question whether some means could not be devised for operating a multiplicity of telephone channels on one circuit using this broader frequency range.

The general idea is as old as telephony itself or older as applied to telegraphy. Alexander Graham Bell's invention of the telephone came, in part at least, through his experimentation in means of providing several telegraph channels over one circuit by using currents of different frequencies. The fundamental principles of multiplex telephony were early thought of and well understood. They involve:

(1) Means for so varying a high-frequency current (called a "carrier") that, with this variation, it represents the sounds to be transmitted over the telephone circuit just as do the voice currents produced by the telephone transmitter in the range 250 to 2,750 cycles. As ordinarily carried out, this involves the control of the amplitude of the carrier current in proportion to the instantaneous values of the voice-frequency telephone currents, this process being known as "modulation."

(2) Correspondingly, means for reproducing the sounds transmitted by suitably operating upon the modulated high-frequency current. This is done by reproducing from this current the ordinary voice current (a process known as "demodulation") and applying this voice current to an ordinary telephone receiver.

(3) Means for joining the modulated carriers of different frequencies so that they can be transmitted over the same telephone wires, and for completely separating them from each other at the receiving end by virtue of their different frequency ranges so that each modulated carrier can be demodulated in a separate receiving circuit and the various conversations carried on simultaneously without interference. This function has been termed selectivity.

While the fundamental ideas as outlined above are old, the physical means by which successful carrier current telephony could be made practicable did not become available until the period 1913 to 1918. In that period, the successful development of the vacuum tube for use in telephone repeaters produced a device which, with different circuit arrangements, could be used satisfactorily for generating carrier currents, modulating them with telephone currents, and for reproducing the telephone currents from the modulated carrier currents. At about the same time, marked advances were made in the development of means for separating into any desired groups a mixture of currents of different frequencies transmitted over the same conductors. These means may be considered in principle an elaboration of the elementary apparatus of this type, called "composite sets," long in use for separating telephone and telegraph currents transmitted over the same circuit by reason of their difference in frequency. The more complete solution of this general problem was made by the development by the Bell System of the "electrical filter."

With these new tools it became possible to develop carrier telephone systems suitable for commercial service. Such systems were first introduced into the plant of the Bell System in 1918. Since that time their use has spread widely, particularly over non-loaded open-wire circuits of the System.

The most important type of carrier telephone system in general use is the Type C. One terminal of such a system is indicated schematically in Fig. 17. With this system three carrier channels, marked *A*, *B*, and *C*, and a voice-frequency channel, marked *V*, are transmitted simultaneously over one pair of wires. The four circuits as they appear at the toll switchboard are alike and are treated indiscriminately by the operator. Coming from the switchboard as indicated at the left of Fig. 17, the three carrier channels first pass through three individual sets of carrier equipment. In each of these sets of carrier equipment, the circuit is separated into transmitting and receiving paths. The transmitting path is passed through a modulator in which the voice currents received from the switchboard act upon a carrier and produce modulated carrier currents, and through an electric filter to the general transmitting circuit indicated on the drawing. The receiving channel is connected to the general receiving circuit through an electric filter and through a demodulator by means of which the received currents are caused to reproduce voice-frequency currents similar to those delivered to the circuit at the other end.

As the next step the three transmitting channels are brought together through a common amplifier and transmitted through a "band" filter to the line filter. Similarly, the three receiving circuits are brought together by a common receiving amplifier with which is associated a "band" filter, which in turn is connected to the line filter. The line filter consists of two parts, one of which permits the carrier currents of Channels *A*, *B*, and *C*, to pass but excludes the voice-frequency currents and through this operation of the line filter the carrier currents are transmitted to the line. The voice-frequency circuit *V* is connected to the line through the other part of the line filter which permits voice-frequency currents to pass but excludes all of the carrier-frequency currents. These currents of different frequencies from four channels are then transmitted together over the line and at the receiving end are separated by apparatus similar to that indicated in this sketch.

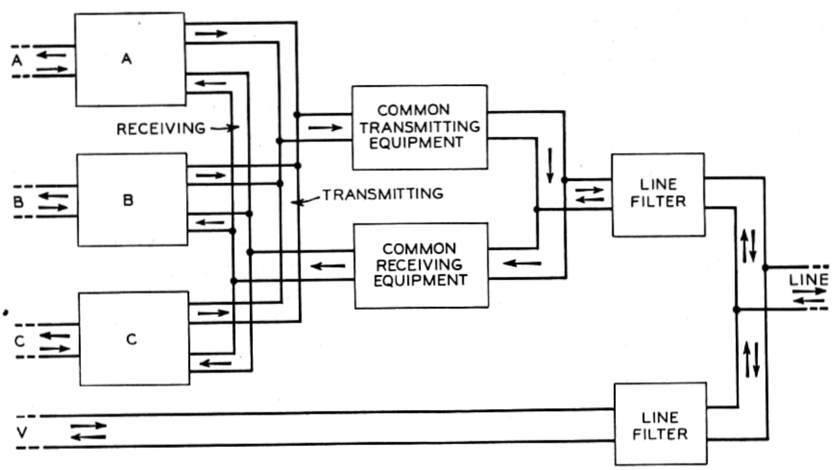


Fig. 17—Schematic arrangement showing the association of a type "C" carrier telephone terminal with the telephone line.

At intermediate points along the circuit, it is necessary to install amplifiers for the carrier-frequency currents as well as for the voice-frequency circuits. At these points, the carrier-frequency currents are separated as a whole from the voice-frequency circuit, a telephone repeater being used for the voice-frequency circuit and a carrier repeater consisting of two amplifiers with electrical filters to separate the two directions of transmission, being used to amplify the three carrier circuits as a group. After amplification, the carrier and voice-frequency currents are again brought together for transmission over another section of line.

It is to be noted that the carrier circuits, like the four-wire cable circuits, use different channels of transmission in the two directions, thus avoiding the difficulties of balance which would otherwise be encountered. In the case of the carrier systems now in general use, however, the two channels are channels of different frequencies operating in opposite directions on the same pair of wires rather than using two separate pairs of wires. As a result the Type C carrier system providing three two-way telephone channels transmits over the line six bands of carrier frequencies, one for each direction for each of the channels. The maximum frequency used by the Type C system is about 30,000 cycles.

In addition to the Type C system just described, there is used in the Bell System a simpler single-circuit carrier system (Type D) providing one carrier circuit in addition to the voice-frequency telephone circuit.

In the case of carrier systems as in the case of telephone repeaters, their application to the telephone plant involved not only the development of the system itself but the development and application of new practices to the telephone plant. This came about from the fact that the plant, heretofore designed primarily for the transmission of ordinary voice frequencies, that is, currents up to about 3,000 cycles per second in frequency, was now called upon to transmit currents up to 30,000 cycles successfully and without interference. In order to do this, it was necessary in the open-wire circuits to use non-loaded pairs and where loading was necessary in short sections of incidental cable in such circuits, to design new loading systems with loading coils of small inductance placed at frequent intervals which would transmit these higher frequency currents. A major problem of adapting the plant to the use of these currents arose from the increasing tendency with higher frequencies for currents flowing in one circuit to induce currents into other circuits in the vicinity. The transposition systems used to prevent crosstalk between voice-frequency telephone circuits on the same pole line were wholly inadequate to prevent crosstalk of the carrier currents and without extensive changes such crosstalk would have been far too great to make possible the satisfactory use of carrier systems. New systems of transpositions involving a large increase in the number of transpositions used in a given section of line were designed for this purpose. Also, it was found that for the largest use of carrier systems it would be necessary to give up the use of phantoms on the circuits involved and also to rearrange the conductors to provide less space between the two wires of the pair and greater amounts of space between the pairs on the same crossarm.

These new construction arrangements have been worked out and applied where the extensive use of carrier is sufficiently important to justify them.

As a result of these various developments, an extensive use of carrier systems has been made in the Bell System plant. This is indicated in Fig. 18, which shows the routes on which carrier systems are used at the present time. The total circuit mileage in service provided by carrier systems is about 400,000 miles, which is over 8 per cent. of the total toll circuit mileage in service.

Up to the present time, the applications of carrier have been confined to open wire, including relatively short sections of incidental cable in the open-wire circuit. Further advances in the art, particularly in the design of very stable amplifiers capable of amplifying simultaneously a large number of carrier channels of different frequencies without mutual interference and improvements in the design of electrical filters to make them less expensive and more effective have opened the way for broader applications of carrier. These broader applications include the prospective use of carrier on non-loaded cable circuits with amplifiers spaced at intervals of twenty miles or less. Systems are now being developed for this service by which it is expected to get 12 one-way channels on a single non-loaded cable pair, and with cables of special construction, such as the coaxial cable, on which experiments are now being made, several hundred one-way transmissions may be obtained on a single unit.

In view of these developments under way, and further prospective improvements in carrier systems applicable to open-wire circuits, it is evident that this form of transmission will have in the future a rapidly growing field of use in the telephone plant.

Associated Technical Developments

The successful operation in a practical telephone plant of the new types of circuit for transmission over very long distances both in cable and in open wire required, in addition to the main developments briefly outlined above, the developments of a number of associated technical arrangements. Some of the more important of these are briefly outlined in the following paragraphs.

Regulators

In the long telephone circuits made possible by the use of repeaters, having a number of repeaters at different points along the circuit, the net transmission efficiency of the circuit is the result obtained by balancing the amplification of telephone currents in the repeaters

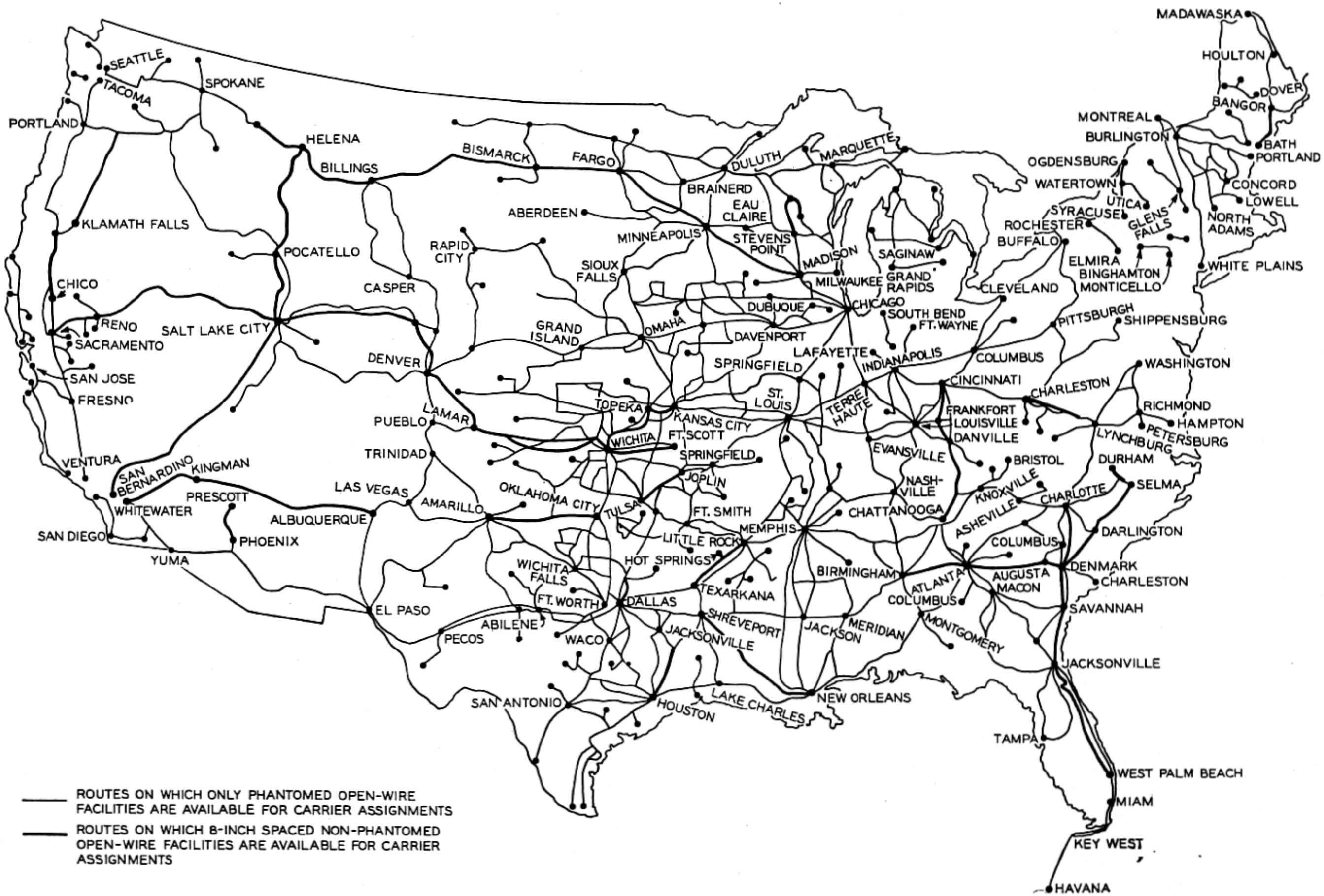


Fig. 18—Routes of the American Telephone and Telegraph Company and Associated Companies in the United States on which carrier telephone facilities are available.

against the attenuation of the telephone current in the various line sections of the circuit. As a result, with increase in length such circuits become increasingly susceptible to the effect of variations in circuit efficiency caused by changes in weather conditions. In the case of toll cable circuits this variation is primarily due to changes in temperature and in a long cable circuit such changes may in a single day make a 10,000 fold difference in the overall efficiency of the cable. In the case of open wire circuits the change is mostly due to rain and is particularly prominent in the highest frequency carrier systems.

In order to offset these variations and provide circuits of approximately constant overall net efficiency these longer circuits are equipped with regulating systems which make it possible to offset the variations in the efficiency of the circuits by either manually or automatically changing the gain of certain of the repeaters.

In the case of the cable circuits the regulation system, known as a "pilot wire regulator," is automatic. It makes use of a direct-current channel over a metallic composite circuit, variations in the resistance of this pilot wire which result from the variations in temperature causing automatic adjustment of the regulating repeaters. A single pilot wire with its associated regulating equipment can be used for controlling all of the circuits in a cable. Sometimes as many as 300 circuits or more in number are regulated with a single pilot wire. In order to get sufficiently accurate regulation and because of practical layout considerations the cable is generally regulated separately in sections of 100 to 150 miles in length.

In the case of a type C carrier system on open wire the regulating system depends upon attenuations of carrier currents transmitted over the same pair as the carrier system. On most of the type "C" systems the regulators give an indication of the net efficiency, which is kept within a prescribed limit by manual adjustment of the repeaters. In some cases apparatus providing this adjustment automatically is in use.

Equalizers

The transmission efficiency of telephone lines is generally different for the different single frequencies comprising the voice-frequency band. This variation is particularly great on some loaded cable circuits where the maximum frequencies transmitted approach the maximum frequencies which the circuit is capable of transmitting. If such variation in efficiency were permitted, resulting in the higher frequencies having much greater losses than the lower frequencies, the normal relative proportion of different frequencies would in some cases be so distorted that the transmitted speech would not be clear or even could not be recognized. In order to prevent such distortion, therefore, it was necessary to develop and apply means for compensating for the variation in the line by variations in the opposite direction. These means are called attenuation equalizers. In the telephone message circuit these attenuation equalizers are generally designed to be an integral part of the telephone repeaters themselves.

Signaling Systems

With the exception of a few special cases all telephone circuits for message telephone service are provided with a means by which signals can be transmitted from one end to the other in order to call to the circuit an operator (or sometimes in the case of dial systems, a machine) or subscriber. In the relatively short circuits used for local telephone service this signal commonly is provided either by the flow of direct current which is used to light a lamp or operate a relay or by the flow of 20-cycle alternating current which is used to ring a bell or operate a relay.

Signals based upon the use of direct current are generally used in cases where it is desired to have the signal continue to indicate the condition of a connection throughout the conversation since the direct current can continue to flow over the circuit simultaneously with the voice current during conversation without interference. The most extensive use of this type of signaling is for the shorter circuits. The method of operation of long toll circuits generally is such that no signal is required over the toll circuit during the conversation period but only before and after the conversation, and for such signals alternating current is generally used.

In the early days the alternating currents used for signals over toll circuits were generally the same as those used for signaling over local circuits, namely, 16 to 20 cycles per second. As the simultaneous use of toll circuits for telephone and telegraph expanded, this was modified because of interference which would occur between the telegraph currents and the 16 or 20-cycle signaling currents. For such cases signaling was accomplished by alternating currents of 135 cycles, sufficiently high to avoid interference with the telegraph systems then in use.

With the further development of long toll circuits having many repeaters at intermediate points and also with the development of carrier telephone systems, the satisfactory transmission of 135-cycle current from one end of the circuit to the other became more difficult. At the same time the advance in the art made possible the development of satisfactory and economical signaling systems using interrupted currents of 1,000-cycle frequency. With such a system the signaling current uses the same transmission path as the voice currents but the system is designed to discriminate between the voice and signaling current. The signaling current is transmitted from end to end over the circuit without the use of intermediate ringers which had been resorted to on the 135-cycle ringing system. This 1,000-cycle system has extended rapidly in its field of use and is now used for the majority of circuits over 100–150 miles in length.

Telegraph System

The early methods by which provision was made for the simultaneous use of telephone circuits for telephone and telegraph service were described in the section on "Early Developments." With the general extension in the telephone plant of the improved types of telephone circuits described above, and with the growth in extent and requirements of the private line telegraph service, it became important to devise new types of telegraph circuits adaptable for use with the new types of telephone circuit and suitable to meet the increased telegraph requirements.

One such new form of telegraph circuit was the metallic telegraph system designed for use on telephone toll cables simultaneously with the use of the same conductors for telephone service. In order to avoid interference between the telephone and telegraph circuits it was necessary to use relatively low voltages and currents on the telegraph circuit. With these low voltages and currents grounded telegraph circuits were impracticable because of outside interference and it was necessary to use metallic circuits in which no use was made of the ground for the transmission path. With the new metallic circuits voltages of 34 volts and currents of 4 milliamperes were used compared with 130 volts and 60 milliamperes in the grounded direct-current telegraph systems.

Another form of telegraph circuit which was developed for use over telephone toll cables is the so-called voice-frequency telegraph system. With this system by carrier current methods the telephone channel is split up into 12 telegraph channels, each of which is suitable for use as an independent telegraph circuit, one telephone circuit thus providing 12 telegraph circuits. In this case, the telephone circuit cannot be used simultaneously for telephone and telegraph circuits. This system is designed to be applied either to a four-wire cable circuit, or to a carrier telephone circuit which, like the four-wire cable circuit, consists of two channels for transmission in the opposite directions. It has large advantages for long circuits because of the fact that no apparatus is required at points intermediate between the terminals, including points where cable and open wire are joined, other than the standard telephone repeaters and associated apparatus already provided with the circuit for telephone purposes.

Still a third type of telegraph system devised to meet the new conditions is that known as the high-frequency carrier telegraph system. This system is designed for application to open wires. It applies to the provision of telegraph circuits the same principles as are applied in the carrier telephone system for the provision of telephone circuits. It uses frequencies above the voice range, roughly in the range from 3,000 to 10,000 cycles, thus permitting the continued use of the conductors for a voice-frequency telephone circuit simultaneously with its use for high-frequency carrier telegraph circuits. With this system 10 two-way telegraph circuits are provided.

Auxiliary Apparatus and Equipment

In addition to the main items described above, developments of other apparatus and equipment auxiliary to the telephone toll circuits were made necessary by the general use of repeaters and carrier systems. Power plants providing current to the filaments and plate circuits of the vacuum tubes used in repeaters and carrier systems had to be provided having much closer voltage regulation than had heretofore been necessary for the earlier types of telephone equipment. New forms of testboards were required and new types of arrangements of distributing frames and of protective apparatus. Plans were developed for the economical arrangement of the new types of equipment in large offices. All of these things while essential for the proper operation of modern toll telephone circuits probably do not need detailed discussion in this statement.

Another type of equipment which had to be developed was that for carrying out the various forms of electrical test necessary to assure the proper operation of these new telephone circuits. The development of this equipment and of the new maintenance methods which made use of this equipment is of sufficient general importance so that it is briefly discussed in the next section of this statement.

Development Of Methods Of Measurement And Maintenance For Toll Circuits

The history of toll service has been a story of the continuous application of new scientific instrumentalities. The laboratory experiments of one day become the regular service-giving apparatus of ever-growing complexity. Maintaining this complicated equipment at a high state of efficiency has been accomplished through methods of measurements, developed either to make possible the measurement of electrical quantities for which no methods of measurement existed previously or else to make possible measurements in large numbers on a routine basis at little expense which previously were delicate, expensive and confined to the laboratories. It would be out of place to include in this report a general discussion of the development of these methods. Mention will be made, however, of certain items which have particular reference to the new types of toll circuit discussed above.

An important tool in electrical measurements is the Wheatstone bridge devised originally for the accurate measurement of resistances. In dealing with telephone circuits where the performance of circuits and apparatus in the transmission of alternating currents is important, it was necessary to expand the Wheatstone bridge for alternating current use. This involved providing elements for the Wheatstone bridge having not only a known resistance to the flow of direct currents but also a known resistance and reactance to the flow of alternating currents of the frequencies at which measurements were to be made. It was soon found, however, that with frequencies as high as those required in telephone measurements, running up to two or three thousand cycles, the resistance and reactance of the elements of the Wheatstone bridge were not well known and varied depending upon the number of elements connected in the circuit. This variation was due to the effect of incidental capacitances between the elements of the bridge and between them and the ground. In order to overcome these difficulties, G. A. Campbell devised an arrangement of shields by which variation in the effect of these incidental capacitances was prevented and in this way produced bridges for alternating current use which would give accurate results over the range of frequencies required in telephonic measurements.

An interesting example of the application of the shielded impedance bridge to practical telephone measurements is presented by what is called the "capacity unbalance (testing) set." This testing set is designed to measure the very small capacitances between individual wires of a short section of toll cable or more specifically differences between these capacitances for the individual wires of two pairs or of two quads, expressing these differences in such a way that they are directly proportional to the contribution made by the capacitances in the short section of cable to crosstalk between circuits using the pairs or quads thus tested. The purpose of the test is to give information to the splicing forces, which, properly interpreted by them, enables them to splice together pairs and quads in adjacent lengths in such combinations that the crosstalk unbalances in adjacent sections tend to neutralize each other and the crosstalk between all pairs and quads in the cable when completed will be small. The capacitance differences measured in individual lengths are only a few millionths of a microfarad. This measurement, originally possible only under carefully controlled conditions, is, by the use of the capacity unbalance testing set, reduced to a routine part of the work of the construction and cable splicing forces.

Another interesting kind of measurement bearing in a very important way on the maintenance of the efficiency of telephone toll circuits is measurements of transmission efficiency, that is, of the power output of the telephone circuit in proportion to the power input of alternating current at the distant end. In order that such a measurement may represent the efficiency of the circuit for the transmission of telephone currents, it is necessary not only that the frequency of the testing current correspond to one of the important frequencies of telephone currents (1,000 cycles is ordinarily used when only one frequency is necessary) but also that the amount of power transmitted correspond approximately to the average power of telephone currents. For this reason the standard input power for such tests is one milliwatt and the power received at the other end of the telephone circuit is often one-tenth of that or less.

When tests of this sort were first made as a part of the routine work of maintaining telephone toll circuits the only available instrument sufficiently sensitive to measure the received power and practical for use under field conditions was the combination of the telephone receiver and the ear. In making such a measurement power was transmitted alternately over the circuit to be tested and over an artificial circuit whose efficiency was known and adjustable, the adjustment being made until the received sound was equally loud in the two cases. Then with the further development of the art sensitive receiving instruments became available which were substituted for the telephone receiver and the ear, the adjustment then being made of the artificial telphone line until the received power as indicated by the sensitive meter was equal to that received over the circuit under test. The perfection of instruments of sufficient sensitivity for this measurement and yet sufficiently rugged to be practicable for use by the regular telephone maintenance forces constituted a great advance in the development of measuring systems for telephone transmission. The most satisfactory instruments of this type made use of vacuum tubes to provide the necessary sensitiveness.

A still further improvement has been made by development of instruments which within a limited range showed directly by their amplitude of deflection the amount of power loss in the telephone circuit. With this latter development the artificial circuit is entirely dispensed with, the standard amount of alternating current power applied to the circuit at one end and the meter connected to the other end. These great advances in the technique of measuring instruments provided an ease of measurement almost comparable to the ease of the measurements commonly made in power transmission systems where the large amounts of power available made the development of satisfactory instruments very much less difficult. Now a still further advance in these methods of measurement has been made by devising arrangements such that the deflection of the instrument is indicated in an enlarged scale on an illuminated screen. This makes it unnecessary to transport the instrument to the terminal of the circuit and makes it possible in a repeater office, by making connections in one part of the room so that the circuit is connected to the receiving instrument, for the maintenance man to read the deflection of the meter at a distance thus further cutting down the time required for tests of this nature.

Other types of tests on telephone toll circuits for which special measuring apparatus and measuring methods have been devised include measurements of the crosstalk between circuits, measurements of the noise currents induced in circuits by other electrical circuits, such as electric power circuits, measurements of the uniformity of electrical impedance from the standpoint of suitability for operation with repeaters, measurements of the amplification of telephone repeaters and measurements of the thermionic activity of the vacuum tubes.

While the above discussion refers to instruments for the measurement of alternating currents in what is called the voice-frequency range, that is, up to about 3,000 cycles per second, the introduction of carrier telephone and telegraph systems made necessary the development of similar measuring instruments for the higher frequency currents used in carrier, namely, up to about 30,000 cycles per second. With the expected use in the future of currents up to frequencies of 100,000 or 1,000,000 cycles or more the range of field measuring apparatus will, of course, have to be greatly increased.

The use of these special types of apparatus for making necessary electrical measurements has required a large amount of instruction of the maintenance forces. Also, it was necessary to devise systems of test and adjustment using these measuring methods by means of which the transmission performance of toll circuits of the new types can best be maintained at the desired standards. This involves a determination of the kind of tests and the limits of adjustment necessary for the different types of apparatus included in these circuits, the frequency of tests and the desirable range of performance results for the maintenance of a high quality of service over these circuits, with the least practicable expense for their maintenance. Maintenance routines of this sort are developed from time to time with each new type of circuit and amended to accord with modifications in the details of the circuits or to take advantage of the results of field experience.

Special Services

With a nation-wide network of poles, wires and circuits available for telephone message purposes, and with its accumulated knowledge concerning technical communication problems the Bell System, as the demand has arisen, has naturally been in a position to analyze the technical requirements of the special communication services and to provide suitable facilities for them. The earliest demand for intercity circuits for special services were for private telephone circuits between telephones in different cities and for private line telegraph circuits. Since that time developments in the communication art, such as radio broadcasting and the transmission of pictures over wires, have created additional demands.

The toll wire plant of the Bell System can be used either interchangeably or simultaneously for telephone message service and many of the special services. In addition, the telephone message service and practically all the special services make common use of many other parts of the toll plant, such as poles, conduits, buildings and power plants.

Some of the special services which make use of telephone circuits or of circuits similar to telephone circuits involve special requirements for satisfactory transmission. This is best illustrated by the transmission of programs for radio broadcast stations, a service which is given on a nation-wide basis over the toll plant of the Bell System. The principal reason for the wide difference in technical requirements of program transmission circuits and of telephone message circuits is that, unlike the message circuits, program transmission circuits are required to transmit music as well as speech. The satisfactory reception of transmitted music requires the transmission of a broader band of frequencies than is necessary for speech alone. The national program transmission networks of the country at the present time, consistent with the requirements of radio broadcast art, transmit a band of frequencies of from about 50 to about 5,000 cycles compared with a band of frequencies of 250 to 2,750 cycles commonly transmitted by message circuits, and means by which a broader band of frequencies can be transmitted over program transmission circuits have been developed. Another important requirement of program transmission circuits is that they shall be able to handle a wide range of input power. Generally speaking, the power may be varied over a range of 10,000 to 1, without the overloading of the amplifiers or other apparatus on the circuit at the highest levels or interference with the program by extraneous noises at the lowest levels.

Because of these and other special requirements a large part of the telephone plant devoted to program transmission is designed specifically for that service. In the toll cables special 16-gauge pairs have been placed and these pairs are equipped with loading and with amplifiers designed to produce satisfactory transmission circuits. The equalization for variations in attenuation, the regulating arrangements to assure constant efficiency, and the compensators for the difference in the velocity of transmission of currents of different frequencies present special problems.

On open-wire lines the conductors used are generally of the same type as those provided for telephone message circuits. On the other hand, it is necessary to give up the use of direct current telegraph and generally necessary to give up the use of phantoms on circuits used for program transmission. Also, in some cases the number of carrier channels which can be superposed upon the conductors is reduced. The amplifiers and other equipment used in connection with these conductors for program transmission are of special design.

Not only is the plant for program transmission of special design but even to a greater extent the operating features are special to this type of service. For many conditions continuous monitoring is necessary during the transmission of the program. Special switching arrangements are required to make possible rapid changes in the connection of program transmission networks at the moment of a change in program.

At the present time there are about 60,000 miles of program transmission circuit maintained for full-time and recurring program service, of which about 40,000 miles are in daily service in the Bell System on full-time networks. The extent of the network devoted regularly to this purpose is indicated in Fig. 19.

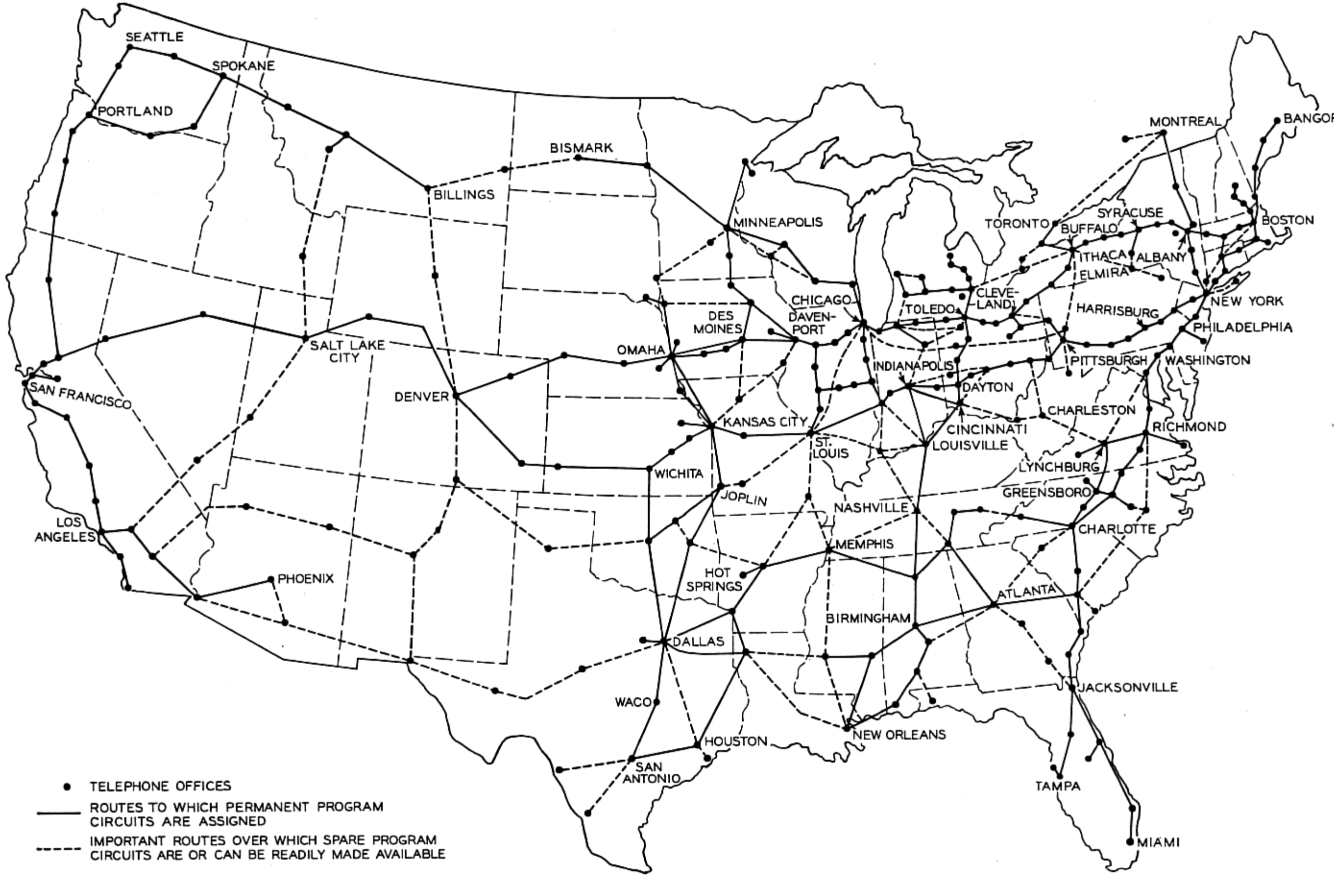


Fig. 19—Routes of the American Telephone and Telegraph Company and Associated Companies in the United States used for radio program transmission.

Telephotography

In 1925 the Bell System inaugurated between a limited number of points a service for the transmission of photographs by wire. Such a system involved the use of telephone circuits, the band of frequencies required for successful transmission being approximately 800–1,800 cycles. This service was discontinued in 1933 because of lack of commercial demand.

At the present time the Bell System is providing to one of the press associations special circuits for their use in transmitting photographs with apparatus owned by them. The type of apparatus used for this circuit is a Bell System development, and represents a marked advance over the earlier apparatus, transmitting pictures at a higher speed and requiring a band of frequencies of approximately 1,200–2,600 cycles. Within the band of frequencies used for the picture transmission a very high degree of equalization of attenuation and velocity of transmission is required. This involves the use of apparatus designed specifically for this service which is associated with regular telephone repeaters. It also requires special attention on the part of the operating forces.

Other Special Services

The Bell System gives an extensive private line telephone service. The requirements for circuits for this service are similar to those for telephone message service and do not require any special discussion.

Also, the toll plant of the Bell System is from time to time used in a limited way for other special services. The private line telegraph service and teletypewriter exchange service are not discussed here, being outside the scope of this statement.

Toll Operating Methods

Operating Method Defined

By "toll operating method" is meant the process by which a toll call is received, recorded, completed and timed. This process is referred to as "handling the call." It relates, for the most part, to the routine and procedure of handling the call, although it must conform to the type of equipment provided, the trunking method involved and the arrangement of the plant. During the development of the telephone business many different toll operating methods have been used, but in the following only the five are described which at various times have come into general use and by which the vast majority of all toll calls have been handled. Such questions as the following are involved in the toll operating method:

How shall the customer's order be received and recorded?

How shall the operator reach the called place?

What combination of plant and method will result in the best service at least cost?

Interrelation of Method and Equipment Design

The operating method and the design of the equipment must be considered together. In many cases the design of the equipment must be changed to permit the use of an improved operating method. In other cases redesign of the equipment is not essential to the improvement of an operating method but in nearly all cases some change in equipment design or arrangement is desirable to permit the best service and the most economical operation of the method. In the normal evolution of the business, improvements in methods and equipment design follow along concurrently. It is not unusual that the greatest amount of work in connection with the improvement of a method has to do with the study and design or redesign of equipment rather than with the study of the operating method alone.

Rearrangement of Plant Brought About by Changes in Method

Various types of switchboard equipment are designed to serve specialized functions in the toll operating room. These various types of equipment must be arranged so that the toll calls can be handled most speedily and economically. Most of the equipment used by operators is provided to make possible the interconnection of a telephone with any other telephone within the exchange or toll network. In addition, however, certain auxiliary equipment is provided which facilitates such interconnection. At information desks no connection is made between telephones but this equipment is provided to make available to operators and subscribers the telephone numbers required in completing connections. In the long distance office the route desk is provided to perform a similar function in connection with the routing of calls. The various operating methods are designed to use these auxiliary equipments to best advantage and the various items of equipment must, therefore, be arranged in such a manner as to meet different operating conditions as methods are changed. Occasionally an improvement in method makes it possible to eliminate one of these auxiliary equipments. An example of this will be shown below in connection with the combined line and recording method. The manner in which various types of equipment are arranged in the operating room, their proximity to each other, their relative locations on different floors of the building, the arrangement of the trunks that tie them together, the arrangement of the ticket distributing apparatus, all have important effects upon the service rendered by and the efficiency of the operating method. Changes in method, therefore, frequently call for rearrangement of equipment.

Trunking Methods Distinguished from Operating Methods

As soon as the telephone business developed to the point where it became necessary to connect together two telephones not served by the same central office, the arrangements for interconnection between the two offices became an important consideration. Offices are connected together by trunks or toll lines and there must be arrangements for operators to get into communication with each other promptly. In general this is accomplished by signals transmitted over the circuit which later is used for conversation, but sometimes a separate circuit, known as a call-circuit, is used. The manner in which trunks are arranged and used is known as trunking method, as distinguished from operating method which has to do with the manner in which calls are handled. Much of the trunking methods experience gained in handling local traffic has been applied to the handling of toll calls. The more important trunking methods are call-circuits, straightforward, ringdown and dialing. Any of these trunking methods may be used with the various toll operating methods.

Description of Trunking Methods

Call-Circuit Trunking Method

Under this method a call-circuit was provided between the two offices. The terminating end was connected to an operator's receiver and at the originating end, any one of a number of operators could connect her telephone set to this circuit merely by depressing a key. Let us assume, for example, that a call from New York to Philadelphia is being handled by this trunking method. The customer in New York has given the Philadelphia number to the New York operator. The latter depresses a key which connects her telephone set to the call-circuit which at Philadelphia is connected to the receiver of an operator who handles only inward connections from New York. The New York operator listens for a moment, to determine that no one else is speaking on the call circuit, and then passes the Philadelphia number over the circuit. Let us also assume that there are 50 toll circuits between New York and Philadelphia, numbered 1 to 50. At the moment that the New York operator passes the number to the Philadelphia operator, some of these circuits are in use. By glancing at her switchboard the Philadelphia operator determines that circuit No.

13, for example, is not in use. In response to the number passed by the New York operator, she says "one-three." This notifies the New York operator that she is going to connect the required telephone number at Philadelphia to circuit No. 13. The New York operator connects her calling party to this circuit and conversation begins as soon as the Philadelphia subscriber answers his telephone. As on any local call the removal or hanging up of the receiver at the called telephone is indicated to the New York operator by appropriate signal lights.

Straightforward Trunking Method

As improvements in equipment and operating methods were made, the call-circuit trunking method gradually was replaced by the straightforward trunking method. Let us assume that a call is being handled by the straightforward method from office A to office B. The calling party gives the called number to the operator in office A who then makes connection to a trunk to office B. The trunk is connected to apparatus at office B in such a way that when the operator at A makes connection to it she is connected automatically to the receiver of an operator at B and a momentary audible tone indicates to her that the operator at B is ready to receive the call. Upon hearing the tone the operator at A passes the called number to the operator at B who then connects the trunk to the called telephone line. It will be noted that the selection of the trunk or circuit between the calling and the called offices is made by the originating operator under the straightforward trunking method, whereas under the call-circuit trunking method the selection of the trunk is made by the operator at the terminating office.

Ringdown Trunking Method

The ringdown trunking method was the first to come into use and is still used where it is uneconomical to provide the equipment necessary to straightforward or dial operation. Under this method the operator at office A signals the operator at office B by making connection to a trunk or circuit between A and B and by depressing a key which operates a signal associated with the circuit at office B. The operator answers this signal by connecting her telephone set to the circuit and announcing the name of her office. The operator at A then passes the number of the called telephone to the operator at B who makes connection to the called number.

Dial Trunking Method

Under some conditions it is feasible to arrange for the originating toll operator to dial the called number without the assistance of an inward operator at the called place. By this trunking method the calling party reaches the operator and gives her his call in the usual way. She then makes connection to a trunk or circuit to the called place and upon receipt of the proper automatic signal, indicating that the apparatus at the terminating office is ready to receive the call, she dials the called number. Under this method, as with the call-circuit and straightforward trunking methods, switchboard lamp signals indicate to the originating operator whether the receiver at the called telephone is on or off its hook.

Description of Toll Operating Methods

General Characteristics of Toll Calls and Operating Methods

The percentage of toll calls handled by the various toll operating methods has varied from year to year, as shown in Fig. 20, until at

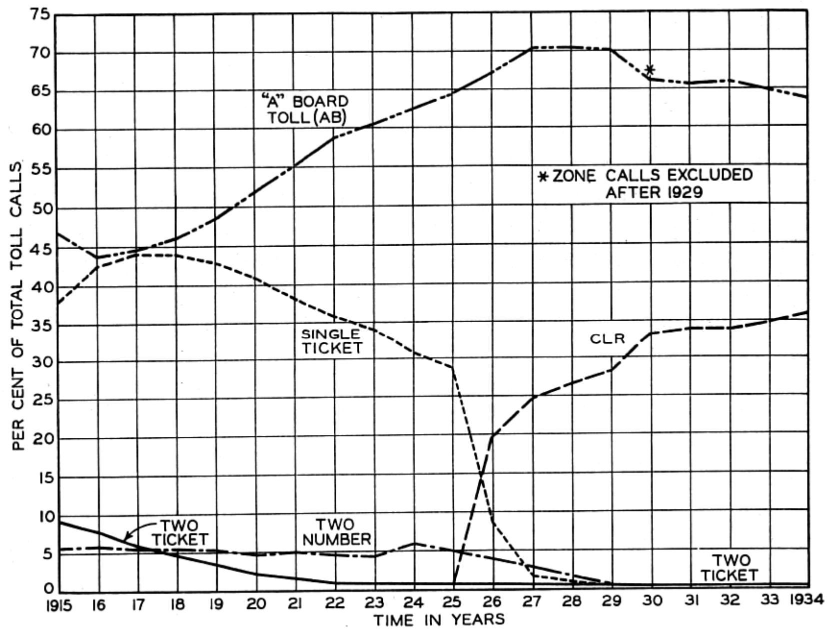


Fig. 20—Distribution of toll calls by operating methods at Bell operated offices in the United States.

present about 99 per cent are handled by the A-Board Toll and Combined Line and Recording methods. A large percentage of toll calls involve short distances and are of a simple type that may readily be handled at local switchboards. The remaining toll calls are handled at separate long distance offices where equipment especially designed for the handling of long distance calls is provided. In addition to the switchboard positions at which the operators work who handle the long distance calls, there are certain auxiliary positions where operators supply information to other operators with regard to routes, rates and charges. Whether the toll call is handled at the local office or at the long distance office the operator who handles the call and deals with the customers must have access to the toll lines and means of communication with the auxiliary operators. Under any toll operating method the operator who handles the call must make a record from which the customer is billed. This is done on a small ticket which also serves other supervisory purposes. There must be timing devices by which the operator may time the length of conversation and facilities for sending the ticket to file or to other operators if additional or special work is to be done in connection with it.

A-Board Toll Operating Method

On the toll calls handled at local A boards, the subscriber reaches his local operator (by dialing the code "0" in dial areas) and gives his call to her. If she does not know the route to the called place from memory, she obtains it either from a bulletin at her position or by inquiry of the route operator. She reaches the called place by whatever trunking method is in use over the route in question. Most such calls today are completed by the straightforward or dialing methods over direct trunks. If direct circuits to the called place are not provided and the straightforward method is used, the operator selects a trunk to an intermediate or tandem office and upon receipt of proper signal passes the proper order to the tandem or intermediate operator who connects the trunk on which the order was received to a trunk to the called office. Upon receipt of the order at the called office, the terminating operator makes connection to the called line. If the dialing method is involved, the originating operator dials the called number over tandem trunks to the called place. When the called telephone answers, the operator enters the connect time on the ticket. When both parties hang up the receivers this action operates signals before the operator which indicate to her that the customers have finished talking. When these signals appear, the operator enters the disconnect time on the ticket above the time previously shown and the duration of the connection then may be obtained simply by subtracting the connect time from the disconnect time. If the calling party requests the charge for the call, the operator makes this subtraction, obtains the rate to the called place either from her bulletin or from the rate operator, computes the charge and advises the customer.

Two-Number Toll Operating Method

For transmission reasons it was found desirable in large metropolitan areas to provide a separate trunk plant and a separate toll switchboard for handling calls between widely separated central offices. This separate office became known as the "two-number" office and the traffic was handled by the "two-number" method. This method was used for a number of years before the present tandem systems came into service.

Under the two-number operating method the subscriber gave the called number to his local operator as on a local call. The local operator, over a trunk to the two-number board, passed the called number and then the calling number to the two-number operator. The two-number operator then obtained connection to the calling number over another trunk which afforded better transmission than that of the first trunk, and disconnected from the trunk over which the call was received. This disconnection caused a signal to light before the local operator who originally received the call, whereupon the local operator took down the connection she had made between the calling party and the two-number operator. The two-number operator then proceeded to establish connection with the called telephone over a trunk of proper transmission design by whatever trunking method was in use. At the time the two-number toll operating method was in greatest use, the usual trunking method was call-circuit although much of this business was handled by the ringdown method. Tickets were written, connections timed, and routes and rates were obtained in much the same manner that they are obtained with the A board toll operating method. The two-number method acquired its name through the fact that the local operator passed two numbers on each call to the so-called two-number operator.

Two-Ticket Toll Operating Method

For that portion of the toll business on which the customer reaches and gives his call to the long distance operator, three important toll operating methods have been used. One of the important early toll operating methods involved the writing of a ticket by the operators at both ends of the connection and became known as the "two-ticket" method.

In each long distance office where the two-ticket operating method was in use, there was provided a recording board at which long distance calls were recorded by a special group of recording operators; there was an arrangement for sending the tickets either by mechanical device or by messenger from the recording board to other positions as required. There was a directory desk where the directory operator wrote on the ticket the telephone number of the called person. Usually associated with the directory desk was an arrangement for filing completed tickets such that should any customer wish to inquire the charge on his call after it had been filed, it might be located quickly. There was a route and rate desk to which the ticket was then sent and where the operator recorded upon it the route and the rate to the called place. There was an outward or line board where operators established connection between the calling and called telephones. There was a special board known as an inward board where operators established connections to local offices for operators at distant offices. There was a through board where operators connected toll circuits together, end to end, on calls coming from a distant city and going to another city via this office. Each pair of line positions was equipped with a device for timing calls, the calculagraph.

With two-ticket operation, a customer wishing to place a long distance call reached his local operator and asked her to connect him with long distance. The local operator complied with this request by making connection to a trunk to long distance which appeared for answering before a special group of operators trained only to record the customer's order. The recording operator answered the signal on this trunk by saying "Long Distance." The customer told the recording operator whom he wished to reach and where he might be found. He was then told by the recorder that the operator would call him and he hung up his receiver. After recording the information supplied by the customer on an "outward" ticket form, the ticket was sent to other operators for further handling. If the customer had not supplied the number of the called telephone, the ticket was sent to a directory operator who looked up in the directory of the called place the telephone number of the called person. Each toll office did not then, nor does it now, have direct circuits to all other toll offices. It was necessary, therefore, in many cases, to determine the route to the called place. After the telephone number had been supplied to the ticket by the directory operator, the ticket next went to the routing operator who indicated on the ticket the route to the called place. The ticket was then sent to the particular line operator who handled calls to the desired place. The line operator obtained connection with the calling subscriber's telephone and to a circuit to, or in the direction of, the called place. Having reached the inward operator at the called place, she passed the details of the call to her. The inward operator recorded them on an "inward" ticket form and proceeded to obtain connection with the called telephone or party or to find out where or when the called person might be reached. Having reached the called station or party she notified the originating operator who then rang the calling party. When both the calling and called parties answered their telephones, the operator inserted the ticket in the calculagraph and stamped the time. When the calling party hung up his receiver, the originating operator received a disconnect signal on his line, stamped the time on the ticket by means of the calculagraph and took down the connection. The ticket was then sent to the ticket filing desk where it was filed in the numerical order of the calling number. The inward operator also took down the connection upon receipt of a signal indicating that the called party had hung up his receiver.

Single-Ticket Operating Method

Before the single-ticket method came into use operating methods and practices, as well as accounting methods, varied from place to place. This made it necessary for a considerable part of the operating work on toll calls to be done by the operator at the called place. The first step in passing from the two-ticket to the single-ticket method was to eliminate the ticket at the inward end, and to place the responsibility for all work in connection with handling the call, except the purely mechanical operation of making physical connection to the called telephone, upon the outward operator at the calling place. The elimination of this work made possible also the elimination of a large amount of equipment at the terminating place, avoided the duplication of operator time at both ends of the circuit and saved circuit time. It required standardization throughout the System in equipment, local and toll practices, and auditing methods.

Under the single-ticket method the customer reached long distance just as he did with the two-ticket method and the preliminary work of finding the called number and the route for the call remained unchanged. When the ticket reached the line operator, however, she took up a circuit to the called place and merely passed an order to the inward operator for connection to the called number. When the called telephone answered, the originating operator announced the call, arranged for the called party to come to the telephone and connected the calling party to the circuit when the person at the called station was ready to talk. The connection was timed and the ticket filed in the same way as under the two-ticket method.

Combined Line and Recording (CLR) Method

Experience with the single-ticket operating method had suggested the possibility of having the line operator receive and record the call as well as perform the work of reaching the called telephone or party and of establishing the connection. Improvements in toll plant contributed to the feasibility of this type of operation. Such a plan would eliminate the need for a separate recording board but would increase the number of outward line positions required. It also would bring in new problems of training and supervision. With the proposed method it appeared that the speed of service on long distance calls might be considerably improved by virtue of the fact that it would no longer be necessary to send tickets from one position to another within the office. Furthermore, with this method it would be unnecessary for the operator to dismiss the customer after he had given her his call and to recall him when ready with the connection. Instead the customer could remain at the telephone while the line operator attempted to complete his call.

Under the CLR method of operating, now in use, the customer dials or asks for long distance in the usual way. The signal at the long distance board appears before the line operator who answers with the words "Long Distance." The line operator records the call in the usual way except that when the customer gives the name of the called place and the number of the called telephone she takes up a circuit to the called place and records the information on the ticket while waiting for the inward operator at the called place to answer. After passing the called number to the inward operator and while waiting for the called telephone to answer, she asks the calling party for his telephone number. Conversation is timed and the ticket disposed of in the usual way.

Under the single-ticket method calls to or via a given city are always handled by the same group of operators. Under the CLR method any line operator may handle a call to any place in the toll system. If the call is not completed on the first attempt, the ticket is sent to the so-called point-to-point positions where calls to a given city are assigned to positions designated to handle calls only to that city. This assures prompt and careful handling of those calls which have encountered delay and the handling of such calls does not interfere with the handling of work on new calls at the CLR position.

It may be of interest to follow the handling of a call by the CLR method. Figure 21 shows schematically the route of a long distance call through the telephone plant, and the functions performed by the various operators along the route while handling the call by the CLR method. Let us assume that the call in question is a station-to-station paid call from an individual line dial telephone in New York to an individual line telephone in Chicago. The New York subscriber removes the receiver from its hook, listens for dial tone and dials a code for the long distance operator (in New York "211"). A signal appears before the line operator at the long distance switchboard and the customer hears the ringing signal. The line operator plugs into the trunk on which the customer's signal has appeared and indicates her readiness to receive the call by saying "Long Distance." The customer gives his order by saying "Chicago, Harrison 1234." The long distance operator plugs into a Chicago circuit with the other end of the cord pair used in answering the subscriber and rings. While

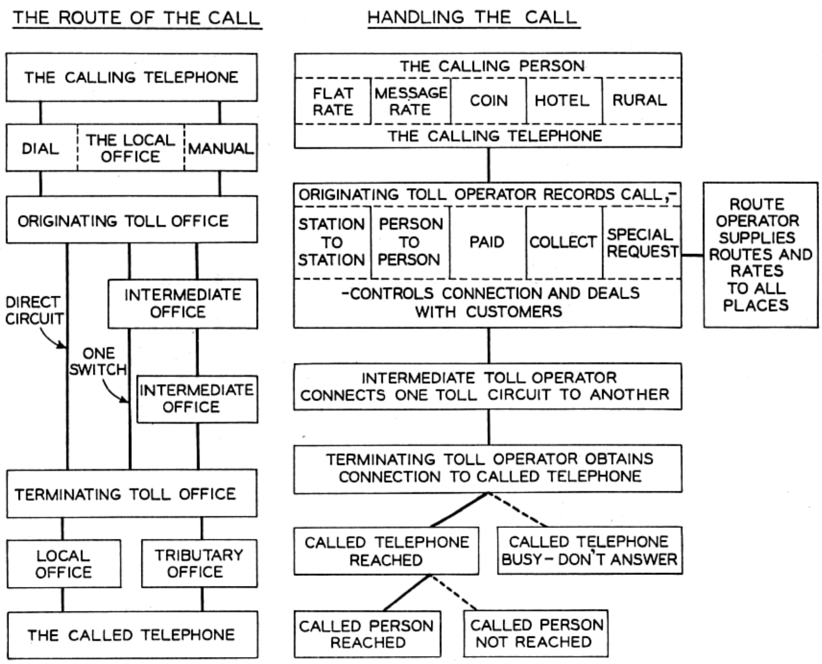


Fig. 21—The long distance call.

the customer was speaking and while performing these operations and waiting for the Chicago inward operator to answer, she has recorded the abbreviation for Chicago and the Chicago telephone number on a toll ticket. The Chicago inward operator answers by saying "Chicago." The New York operator responds with "Harrison 1234" and while waiting for the Chicago inward operator to obtain connection to this number, she asks the New York subscriber for his telephone number. The subscriber at Harrison 1234 answers and conversation begins. After recording the New York number on the toll ticket, the

New York operator inserts the ticket in the calculagraph in readiness to stamp the start of conversation. When she hears the party at Chicago speak to the New York party, she cuts out of the connection, stamps the start of conversation on the ticket and places the ticket in a clip associated with the pair of cords on which the conversation is taking place. When the parties have finished speaking, the New York party hangs up his receiver which lights a signal associated with this pair of cords, whereupon the operator inserts the ticket in the calculagraph and stamps the finish of conversation. She then takes down the connection and sends the ticket to file. When the Chicago party hangs up his receiver, the inward operator at Chicago receives a disconnect signal and likewise takes down the connection.

The above describes the steps in the handling of the simplest type of long distance call. There are many variations from this. The process varies with the type of telephone at which the call originates and at which it terminates. Person-to-person calls involve reaching particular persons and introduce additional variations in handling. Calls may be placed either paid or collect and the routine is different in each case. Direct circuits are not provided to all places and intermediate operators are involved in handling switched calls. The called telephone sometimes is busy or does not answer or the called person may not be available and additional attempts must be made to complete the call. All of these conditions call for variations in the process of handling the call, yet the operating method and the operating rules or practices which describe it must cover all of these situations.

Evolution of Toll Operating Methods

It may be seen from the above that toll operating methods have grown and developed along with the business to meet the changing requirements. As each new method came into use the quality and usefulness of the toll service has steadily improved and the way has been cleared for a better operating job and improved supervision. High grade operating and supervision broaden the possibilities in methods betterment work and may well be the controlling factors in the success of improved plans. The operating method is influenced by features of plant design such as transmission requirements and improvements in switchboard equipment. Conversely, the design and arrangement of plant is influenced by changes in operating method made to improve the quality of the service. Through the toll system the telephone service of the country as a whole is tied together as one great network and the coordination and standardization of the plant and methods make possible universal service.

General Toll Switching Plan

The technical developments which are outlined in the preceding sections of this account made possible continued improvement in the range and quality of telephone conversations over long distances and economies in the costs of providing long distance circuits. As a result, long distance telephone service grew rapidly, both in volume and in extent, and by 1915 service was established between the Atlantic and the Pacific Coasts. The application of technical developments continued, increasing the transmission efficiency not only of the very long telephone circuits which technical developments have recently made possible but also of shorter toll circuits of all lengths.

Although the opening of the transcontinental line showed the possibility of establishing direct telephone service between any two points in the country, a great deal more had to be done in order to closely realize the Bell System ideal of universal service, that is, good service between any two points in the country. While a large proportion of the toll board messages (at present 80 per cent) is handled by direct circuits between the two terminal points, there is naturally a very large number of combinations of cities and towns in the country between which the telephone business is too light to justify direct circuits—in fact, these constitute a large percentage of all the combinations of places in the country. For these conditions, when a telephone connection is required, it must be established by switching together two or more telephone circuits. Some cases might require switching together a considerable number of telephone circuits, this sometimes involving difficulty and delay in establishing the connection. Also, while the telephone circuits may be so designed that, individually or in combinations of two, they provide very satisfactory transmission, in some of these cases requiring a number of switches, the combination of circuits might result in unsatisfactory transmission.

In order that universal service for the nation might practically be realized, it was necessary to provide an underlying plan for the routing of telephone calls between any two places such that the maximum number of switches necessary for building up the connection would be as low as practicable. This must apply to connections between any two points in an operating area, or other natural subdivision of the country, and also to the country as a whole. Furthermore, the plan should provide for a transmission design of toll circuits such that transmission conditions will be satisfactory on individual circuits when used for direct traffic between their terminals, and also for any combination of circuits which may be connected together in establishing a connection between any two points. It is the purpose of the General Toll Switching Plan to provide a general design of the toll plant which meets these requirements and which, therefore, when fully effective, provides for satisfactory service between any two points in the continental United States. The Plan also covers that part of Canada served by the Bell Telephone Company of Canada. For most of the messages, where volume of business and other conditions justify, the telephone service is of course better than the minimum contemplated by the Plan as, for example, by the provision of direct circuits.

In addition, trends in the construction of toll circuits were such that there was a growing need for an underlying plan for routing toll circuits in such a way as to provide for the most economical plant design. Large numbers of additional toll circuits were required and the types of new telephone plant were such as to trend increasingly toward the concentration of large numbers of telephone circuits on a single route. This is illustrated best by the telephone cable, making possible the installation of many hundreds of circuits along the same route and in a smaller way by the application of carrier telephone systems to open-wire lines, doubling or trebling the number of circuits which could be carried by each such line. Satisfactory operation over connections built up by switching together several toll circuits (multi-switch connections as they are called) requires the insertion of transmission gain at the switching points. Developments in methods of providing such transmission gain by the proper manipulation of repeaters were of such nature that increasing economies could be realized by concentrating through switching as far as possible at a small number of points. Also, this concentration could result in operating economies. A General Toll Switching Plan lends itself naturally to concentrations of circuits on important routes, and in the development of the plan, account was taken of this trend. It therefore forms a background for realizing in future plant extensions the maximum economies from these concentrations of route and of through switching.

These considerations led to the development in 1928 and 1929 of a General Toll Switching Plan. The general features of this Plan may be understood by referring to Figs. 22 and 23. Figure 22 shows how the Plan applies within a given operating area such as an operating unit of an Associate Company. Within such an area there were selected a few important switching points and these were designated as "primary outlets." Each toll center in the area is directly connected to at least one primary outlet and each primary outlet is directly connected to every other primary outlet in the area. There-

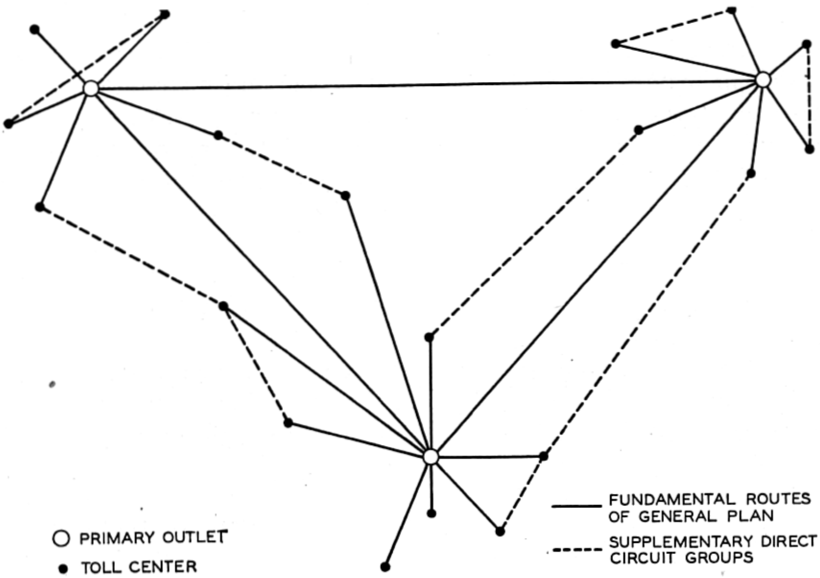


Fig. 22—Application of the toll switching plan to an operating area.

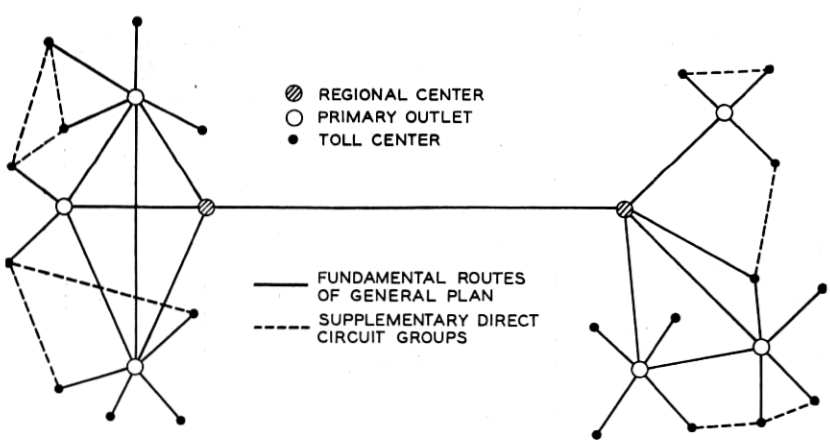


Fig. 23—Application of the toll switching plan to the country as a whole.

fore, any two toll centers in the area can be connected together with a maximum of two intermediate switches. The primary outlets for each area were selected after a careful study of present switching and operating conditions. Due weight also was given to the probable future trends. The number and location of primary outlets selected for each operating area were designed to give maximum economy considering both present and future conditions. This naturally resulted in many cases in the selection of the larger cities of a given operating area although in some cases other points were chosen as primary outlets due to their advantageous location, for example, at the point of intersection of a number of important toll routes. The routings provided by the Plan are supplemented by direct routes or other routings where the volume of traffic or other conditions made this desirable. These other routings, however, are designed to provide service conditions at least as good as those provided by the General Toll Switching Plan.

Figure 23 shows the application of the General Toll Switching Plan to the country as a whole. In order to tie together with a minimum number of switches the interconnected groups of primary outlets, each one of these primary outlets has direct connection to at least one very important switching point designated as a "regional center," and each regional center has direct connection to every other regional center in the country. This means that any two primary outlets in the country are connected together with a maximum of two intermediate switches. The numbers of switches between telephone points of different classifications are shown by Fig. 24. It will be noted that in the limiting

	Same Regional Area				Another Regional Area			
To— From	Regional Center	Primary Outlet	Toll Center Directly Connected to Regional Center	Toll Center Directly Connected to Primary Outlet	Regional Center	Primary Outlet	Toll Center Directly Connected to Regional Center	Toll Center Directly Connected to Primary Outlet
REGIONAL CENTER	0	0	0	1	0	1	1	2
PRIMARY OUTLET	0	1	1	2	1	2	2	3
TOLL CENTER (directly connected to Regional Center)	0	1	1	2	1	2	2	3
TOLL CENTER (directly connected to Primary Outlet)	1	2	2	3	2	3	3	4

Fig. 24—Numbers of switches between telephone points of different classifications.

case of toll centers in different regional areas and not connected directly to any regional center, the maximum number of intermediate switches is four.

The present location of regional centers and primary outlets in the General Toll Switching Plan is shown in Fig. 25. There are, as will

Fig. 25—Locations of primary outlets and regional centers.

be noted, eight regional centers in the United States, and 143 primary outlets including three in the eastern part of Canada.

While a regional center has direct circuits to all of the primary outlets tributary to it, it also has direct circuits to many other primary outlets. This is illustrated by Fig. 26 showing for the case of the Chicago regional center the direct circuits to a large number of primary outlets throughout the country. In addition, Chicago has, of course, direct circuits to many toll centers which are not primary outlets where the volume of traffic is sufficient to justify such direct circuits. The same is true also of other regional centers and of primary outlets.

In order that the transmission between any two points in the country over a circuit routed in accordance with the General Toll Switching Plan should be satisfactory, standards were established for each class of toll circuit, that is, for toll circuits between toll centers and primary outlets, between primary outlets and regional centers, etc. These standards provide satisfactory overall transmission for connections between any two points in an operating area, with an economical division of the total transmission loss between the different toll circuits entering into the connection. Generally speaking, these same circuits form parts also of very long connections, switching at primary outlets or regional centers to long circuits running to other parts of the country. In order that satisfactory transmission may be given under these conditions, it is necessary that severe requirements be applied to the very long circuits with the result that they must be designed and maintained with great care and coordination throughout their entire length. It is also necessary that transmission gain be inserted at points where circuits are connected together, and therefore that the characteristics of the shorter circuits be such that they do not limit the possibilities of inserting such transmission gains. The application of these various complex requirements for toll circuits, in order that they may form satisfactory links in any connection, short or long, in the nation-wide toll telephone network, is greatly facilitated by the systematic character of the General Toll Switching Plan, and by the recommendations as to minimum performance standards which that plan contains.

Until recently, the method generally used for inserting transmission gain on through connections of toll circuits was by means of repeaters associated with the cord circuits at the intermediate switching points. About the time that the Toll Switching Plan was established, there was made available an improved method by which the gain of repeaters permanently inserted in the toll line is automatically adjusted at the switching point when the toll circuits are connected together. These

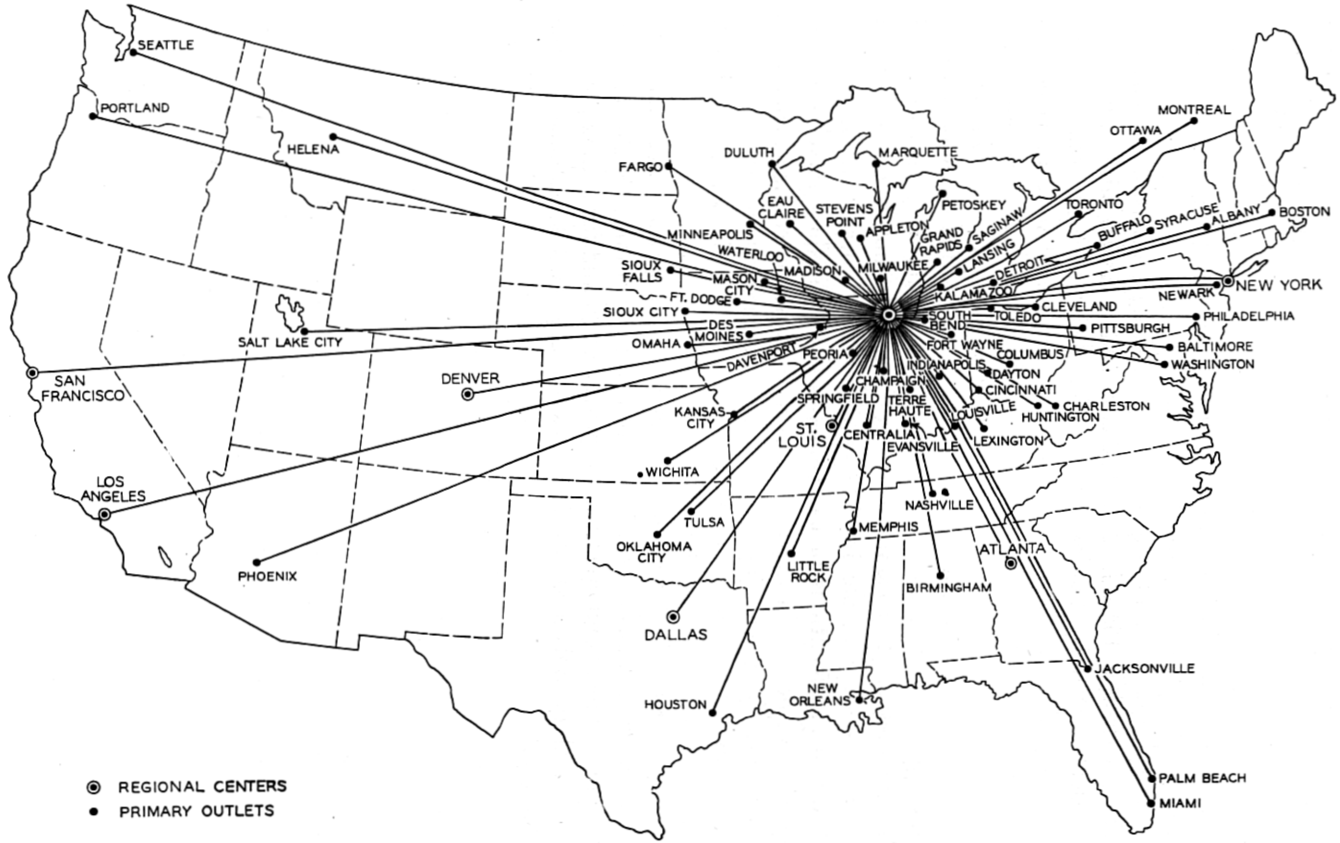


Fig. 26—Direct circuits from Chicago to primary outlets and regional centers.

improved arrangements were scheduled for application as circumstances warranted to the regional centers and primary outlets. At the present time they have been applied to all of the regional centers and about half of the primary outlets and about 95 per cent of the switched connections requiring gain at the switching centers make use entirely of this improved method.

As the Bell System is a living and growing organism, the General Toll Switching Plan is continuously under review and frequently revised in detail. For example, while there are now four primary outlets in the territory of the New England Telephone and Telegraph Company, it seems probable that future developments in concentration of circuits on cable routes will result in reducing these in number.

The transmission requirements applied to the different classifications of circuit for best results vary with the availability of further technical developments. For example, in the future the improved high-speed circuits made possible by the application of carrier to cables will result in modifications of the General Toll Switching Plan, resulting in improvements of transmission over all switched connections and in economies in circuit design through liberalizing the transmission requirements for certain routes, particularly the circuits between toll centers and primary outlets.

The General Toll Switching Plan is an important instrument in systematizing plans for the design of plant extensions, for the application of technical and operating improvements, and for realizing in fact the ideal of universal service between any two telephones in the country.

The Joint Occupancy Of Plant

The Bell System organizations involved directly in the giving of telephone service include regional companies (known as the Associate Companies), operating in various areas throughout the United States, who are responsible for the exchange service and for toll service within their areas,* and the American Telephone and Telegraph Company, responsible for the long distance toll service between points in the areas of different regional companies.

As a result, it is a common situation to have inter-area toll plant of one company terminating in towns and cities where the exchange plant is owned and operated by another company, and sometimes extending for considerable distances along the same general routes as the intra-area toll plant of that company. In a great many cases

* There are a few companies in which certain interstate items of traffic within the company area are handled by the American Telephone and Telegraph Company.

there are economic and service advantages in the consolidated construction of plant used by the two companies involved and, for such situations, this is the common practice. This involves the joint use of land, buildings, right of way, pole lines, conduits, etc.

The economic advantages of such joint use of plant are obvious. For example, one duct run with a sufficient number of ducts for both companies can be built more cheaply than two separate duct runs, and the same is true of pole lines. When toll cable is installed, it is an economy, when practicable, to place within one sheath sufficient circuits to take care of the requirements of both companies. The same is true for other parts of the telephone plant. Furthermore, there are advantages in having the toll switchboard in a building used for exchange service and often in having inter-area and intra-area toll circuits terminate at the same switchboards and use the same groups of trunk to the local exchange plant.

Other things being equal, there is an advantage in each company owning the plant required for its service, and this is the basis generally followed. This leads to a large extent to the joint ownership of jointly used plant, particularly of outside plant. This includes joint conduit runs, joint pole lines, and jointly owned toll cables.

In some cases, rather than joint ownership of jointly used plant, there are advantages in a single ownership by one of the companies, generally the company having the largest requirements, which leases some of the plant to the other company. This applies, for example, to land and buildings where, because of the greater ease and simplicity of transactions of various sorts, a single ownership is preferable. This is also often true where the requirements of one company are small or where, as a result of growth, the division of ownership of jointly occupied plant no longer corresponds exactly to the relative needs of the two companies for the use of the plant. It applies also to the temporary use by one company of spare plant owned by another which will later be required for the owner's use.

Rental Arrangements

To meet the varying conditions, two general bases of rental are in use: (1) the "reserved plant" basis, and (2) the "spare plant" basis.

On the reserved plant basis, rentals cover plant designed and constructed by the owning company for joint use with the renting company or for the sole use of the renting company under a specific plan mutually agreed upon, usually in advance of construction. Existing plant may also be put on a reserved basis by specific agreement. The plant reserved for the lessee provides not only for its present needs, but usually for growth as well. A good example of this type of arrangement is a jointly occupied building which is designed to meet the present and expected future requirements of both companies and in which certain designated space is reserved for the lessee company.

The spare plant basis applies to plant which, in general, the owning company has provided for its own use in anticipation of its own future requirements, or to plant which is spare because of fluctuating load demands and can be temporarily placed at the disposal of the renting company. Such plant may be released by the lessee at any time or may be taken back by the lessor company at any time upon reasonable notice to the other company.

Illustrations of both these bases of rental where the American Telephone and Telegraph Company and an Associate Company are involved are given below.

(*a*) *Buildings*

In providing building space, it is the general practice for one company to own the building used jointly by both companies. This arrangement is advantageous, particularly in the larger cities, since it permits one company to deal with taxing authorities, zoning commissions, public works authorities, and the public generally. Where space for a local central office is required, it is the general practice for the Associate Company to own the building. The American Telephone Company's ownership in buildings is accordingly largely confined to intermediate repeater stations. The owning company generally furnishes space to the other company on a reserved plant basis.

(*b*) *Equipment*

In the case of toll equipment, one of several arrangements is followed, depending in part upon local conditions, such as local operating or maintenance conditions, and in part upon the relative amount of equipment required by the two companies involved. In some cases where one company requires a relatively large part of the total equipment used, that company owns all equipment and furnishes equipment for the other company's needs on a reserved rental basis. Thus, on some of the long through routes where the American Telephone and Telegraph Company uses the majority of the equipment in the intermediate repeater stations, it owns all equipment and rents such portion as required to meet the other company's needs on a reserved rental basis. In many other cases where both the American Telephone and Telegraph Company and the Associate Company have considerable toll equipment requirements and these can best be provided in joint installation, each company will own the equipment provided for its use. If there is any sudden peak in the equipment requirements of one company, the other company will usually temporarily furnish spare equipment from its own reservation on a rental basis to aid in meeting the peak demands.

(*c*) *Outside Plant*

Where both companies' use is substantial, arrangements are usually made for the joint ownership of the common items of plant. In underground conduit, the ownership is usually divided on the basis of number of ducts required by each company, except that if one company's requirements are less than one-half of one duct (occupied by a jointly owned cable), it is customary for that company to rent duct space from the other company. Open-wire pole lines are generally jointly owned where each company has a requirement of one crossarm or more, the cost of the pole line being divided in proportion to the numbers of crossarms required by each company. In cases where the requirements of one company are minor, it may lease space from the other company on an attachment rental basis, using a reciprocal rental rate for the use of the supporting structure which reflects the average carrying charges on both line and right of way. In the case of toll cables, the ownership of certain wires in the cable is generally held by each company, the cost of the cable being divided in proportion to the copper cross-section of the wires owned by each of the companies.

In the open-wire plant, each pair or phantom group is generally owned by one company and located in the crossarm space reserved on the pole line for that company.

Emergency situations arise from time to time in which service may be restored most quickly by a temporary use of spare facilities of the other company or by a temporary pooling of the circuits of both companies which remain in service and applying them most equitably to the service demands of both companies. The work of restoring service in such cases is handled without the execution of any formal agreements between the companies involved, and such adjustments as are necessary are worked out later.

Joint Maintenance Arrangements

The joint maintenance arrangements are based on the principle of providing the most economical procedure in each case. This results, generally speaking, in the maintenance by employees of one company of all jointly occupied outside plant on a single route. It is obviously economical, for example, to have such an arrangement for the maintenance of pole lines, conduit, and cables which are jointly owned by the two companies.

In the case of central office equipment, it is generally desirable in large cities where a large amount of equipment is owned by each company to have separate maintenance staffs, particularly for the service maintenance work performed by the toll test room forces. At smaller points, a single maintenance force is generally provided by the company having the greater amount of work.

The division of maintenance costs between the two companies is based upon the same principles of equitable allocation as applied to the division of ownership and to rental charges. For example, the cost of maintaining toll cables is divided between the companies in proportion to their ownership interest in the cable. Another example is the cost of pole replacement, which is one of the large items of pole line costs. Replacements are made upon the basis of periodic inspections of the pole line, the first inspection being made about ten years after the new line is built and subsequent inspections approximately every four years. These inspections determine the poles which are in such deteriorated condition as to require replacement. Where the replacements consist of substituting the same size of pole for the existing pole, the charges are borne by the companies concerned on the basis of their assignments on the old pole.

General

The above indicates briefly the types of arrangements for the usual case. No attempt has been made, however, to indicate all of the variations in these arrangements applying to the extensive plant of the Bell System covering the entire country and sometimes requiring modifications of these arrangements or some other special provisions. However, the general principle outlined above is followed, namely, that of providing the most economical overall result with an equitable division of costs and responsibility between the companies involved in each case.

Standardization

The electrical design of telephone toll circuits is necessarily complicated, as the overall electrical characteristics on which the efficiency of the circuits depends are the result of the composite effect of many different electrical phenomena. Also, the overall characteristics of a toll circuit are the composite resultant of the characteristics of a large number of individual pieces of apparatus and sections of circuit. The construction of the plant at such times and in such quantities as to produce most economic results involves many considerations. In many cases, as for example, in the construction of pole lines and of toll cables, it is necessary for greatest economy to provide plant to meet the estimated requirements for a considerable period ahead. Furthermore, the maintenance of this plant at a higher degree of efficiency and its operation to connect together quickly and accurately any two of the fourteen million telephones in the Bell System involve a good deal of complication in routines and procedures. In view of these considerations, the telephone toll plant and service offer very good examples of the advantages of standardization in plant and in operating methods.

The complexity of the toll plant and the number of types of apparatus and material which would be required would be greatly multiplied if it were not for the high degree of standardization in the Bell System telephone plant. In fact, it is not an exaggeration to say that the telephone toll service of today could not be given had not effective steps been taken from the beginning looking to this high degree of standardization and simplification.

Plant Design

It is evident that if each toll circuit were designed individually to meet exactly the requirements for that circuit as regards efficiency for good transmission and other requirements, the result would be, in general, that each small group of toll circuits between two points would differ in electrical design from every other group of toll circuits between any other two points. This would result in many thousands of different kinds of toll facilities, each designed for a specific use only, and would result in endless confusion and lack of practicability. However, the standardization of the apparatus and materials forming the toll telephone plant has been carried on since the beginning of toll service and has resulted in a simplification of practice and the general use of the same types of apparatus and material throughout the country. For example, there has been a high degree of standardization of the sizes of copper wire used for open-wire telephone conductors. A very large percentage of the wire used in the plant for this purpose is made up of three sizes, respectively, 104, 128, and 168 mils in diameter. In toll cables, practically all conductors are made up entirely of two gauges, 16 and 19 B & S gauge. With few exceptions, repeaters for telephone message circuits are of either one of two basic types, one for two-wire circuits and one for four-wire circuits, with such modifications in balancing arrangements, signaling arrangements, etc., as are necessary to adapt them to the different types of circuit. Carrier systems are one of two general types, a three-channel system for long distances and a single-channel system for shorter distances, although additional types of system for other types of circuit condition are now under development. In the design of any given circuit, choice is made from this limited number of types of facilities, selecting the one which will give not less than the required transmission efficiency in the given case with maximum economy and other advantages. This procedure results in great advantages in simplicity of plant design and in the flexibility with which sections of toll circuit can be transferred from one use to another as occasion requires.

Construction, Maintenance, and Operation

The advantages of standardization apply to the operating field as well as to the engineering design. Standard construction practices are based upon the use of standard types of construction material all over the country. This standardization of materials makes it possible for the purchasing organization to buy large quantities of a relatively small number of types of material with a resulting saving in cost. Also, the standard construction practices facilitate the training of men and the transfer of men from one part of the System to another with shifting needs.

Similar advantages result from the standardization of maintenance practices. The Bell System maintenance practices make use of the maintenance experiences of the operating companies and of general investigations of the relative advantages of different practices and methods. These practices are generally used throughout the country with advantages from the standpoints both of economy and of service. Men at widely separated points and sometimes employed by different companies can cooperate closely in the maintenance of telephone circuits which have been or may be connected together in the toll service. Also, at times of emergency, men and materials from various parts of the country, wherever available, may be concentrated on the emergency job, and the men, applying standard methods to standard materials with which they are familiar, can work most effectively in the quick restoration of service.

It is perhaps in considering traffic operation practices that the advantages and, indeed, the necessity of standardization in relation to operation is most evident. The toll operators must constantly deal with other operators in distant cities, and it is obviously essential that the operating practices should be alike in order to avoid extreme difficulties and reaction on the speed and quality of service. The standard Bell System operating practices provide in detail the standard procedures to be followed by operators in handling the various types of toll call and, in general, specify also the phraseology to be used by operators with a view to insuring maximum accuracy, clearness, and convenience to subscribers.

General

While, as pointed out in the above paragraphs, standardization in the Bell System is a means of obtaining economy and efficiency, it is more than that. It is essential to the best service and the most rapid progress. The conditions bearing on the telephone toll plant and toll service are constantly changing through growth, shifting demands, the development of new needs of customers for telephone service. Also, the best means and methods available for giving service are constantly developing as a result of the experience of the various operating companies and through the development of new instrumentalities and operating methods by the headquarters forces of the Bell System. These types of apparatus and of communication systems, and methods and practices for construction, maintenance or operation represent the outcome of careful consideration of the best way to meet a type of situation. Through the headquarters organization their availability is made known at once to the operating telephone companies of the Bell System throughout the country with information regarding their desirable field of use. This greatly facilitates their adoption and application by these Companies.

In some cases, such new standards present means for doing something which could not be done before. In many cases, such new standards replace existing standards due to advances in the art, improvements in methods or technique, or changes in operating requirements. Standardization in the Bell System, therefore, involves a continuous procession of new standards to meet new conditions or to meet old conditions better than was heretofore possible, and the subsequent dropping of old standards. Such standardization is based not only upon the present needs of the telephone system, but also upon the best picture which can be formed of future trends. It is essential to the rapid and satisfactory development of telephone toll service.

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