Recent Developments in Telephone Train Dispatching Circuits*

First of Three Installments Including History, Transmission Theory, Line Conditions and Cable Factors

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THE telephone as a means of communication for the dispatching of trains came into use in the United States about 1907. Various telephone sets and calling equipment have been developed for this purpose and used extensively until the telephone has become recognized as the most suitable means for dispatching work.

The first equipment which was developed met the requirements as then existing. Just previous to our entry into the World War, another change of conditions made it necessary to develop still more efficient train dispatching equipment to replace that which was no longer entirely satisfactory.

At this time a fundamental study of existing conditions and requirements was undertaken. This investigation has continued until apparatus has been developed which takes care of the greatly increased traffic conditions, meets higher standards of service, and includes equipment for the present types of line or those likely to be used in the future, that is, open wire copper lines, non-loaded and loaded cable. The increasing desire of certain railroads for satisfactory loud speaking equipment for use at both dispatchers' officers and waystations has led to the development of efficient circuits and vacuum tube amplifiers to meet these needs, replacing the former mechanical type which has inherent limitations.

The object of this paper, therefore, is to consider the transmission features of train dispatching circuits in general, and to discuss the solution of the problems involved in the design of the most recent apparatus.

General Transmission Theory

The problem of telephone transmission, as here presented, consists in the establishment of a system between two or more parties by means of which intelligible speech may be interchanged. In ordinary telephone communication it is generally required to transmit as much as possible of the electrical power generated by the transmitter at one end of the system to the receiver at the other end. Like the ordinary telephone system, the train dispatching circuit must be a two-way system and transmission in either direction must be approximately the same. Not only must the amount of power generated by the action of the sound waves on the transmitter be adequate to actuate the receiver at the distant end sufficiently to produce clearly audible sounds, but these sounds must bear enough resemblance to the original ones to produce intelligible speech. The frequencies of the sounds in the human voice that are necessary for satisfactory transmission vary from perhaps 200 cycles to 2,000 cycles per second. Since the loss of power in the connecting telephone lines may be over 99 per cent in ordinary two-party service, it is obvious that we have a very nice problem to solve when the requirements make it necessary for a considerable number of parties to listen simultaneously to one talker using a standard type of microphone with its limited power output.

It is evident that in a dispatching line which may be upwards of 300 miles in length and on which there may be 50 or 60 waystations simultaneously listening, the stations nearest to the talker will absorb most of the power and the distant stations will therefore be inoperative if the usual method of designing these sets to absorb maximum power is used.

There is no inherent reason why the waystations could not be inserted in series in the line, and it may be of interest to cite briefly the reasons why the bridged type has been adopted as the best. In the first place, precedent favors this type. Among the objections to the series set are the following:

(1) For installation reasons it appears better to bridge the stations than to loop the circuit through each, since the station may be located at some distance from the main line.

(2) Any open in the local circuit would put entirely out of commission that part of the circuit beyond the affected station, some transmission being likely up to this point. With the bridged type an open in the local circuit would only cut off that one station. On the other hand, a short in a series set would cut out the one station, and in a bridged type set would cut out a part of the line and would probably still permit some transmission over the majority of the line between the shorted station and the dispatcher. Even if there is no actual open, poor contacts or connections are liable to occur and with the series set these would impair the transmission on the entire system. It would appear that there is considerably greater probability of having an open in the local circuit than of having a short.

(3) If the dispatching circuit is to be used as one side of a phantom it will, of course, be necessary to insure that it be balanced, and when a system is equipped with a series type set the balancing can be obtained only by dividing the impedance of the set equally between the two line wires. Such a requirement would, therefore, necessitate four wires from the main line to the sub-set as compared to two wires when the bridged type set is used. These station leads are often of considerable length and an appreciable additional expense would be incurred, therefore, in connection with the installation of the series type set. Even if the dispatching circuit were not used as one side of a phantom the great unbalance introduced by use of the series type set would greatly increase the susceptibility of the system to inductive interference, necessitating the balancing method in most cases.

(4) The present standard selector apparatus is of the bridged type, and would, therefore, require at least three wires between the main line and the waystation set if the series type is used, as compared with two wires when the bridged type is employed.

Consideration of the above facts seems to leave little question as to the greater desirability of the bridged type.

As has been recognized for many years, it is neces-

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sary to increase the impedance[1] of the nearby bridged stations sufficiently so that the power absorbed by each will not be a large proportion of the total at that point and yet sufficient will be available at each station to give a satisfactory volume of sound in the associated receivers along the line.

In order to obtain the most ideal results with bridged stations it is more or less evident that the waystations nearest the dispatcher should have a high impedance, gradually decreasing for the more distant stations. This method has, in fact, been tried[1] and various patents covering the circuits have been taken out. Such a scheme, however, not only complicates the design and the installation of the set, but would give unsatisfactory transmission from distant stations towards the dispatcher. As will be shown later, satisfactory results can be obtained with properly designed sets having the same characteristic at each waystation.

It is readily seen that simply because a waystation has high impedance it does not signify that it will be satisfactory, since it is possible to bridge a station of such high impedance that the voltage across the telephone line will be insufficient to produce enough current flow through the station for conversion to adequate volume of sound. Furthermore, consideration will show that the amount of current flowing through the waystation will not determine the power available in that station for the production of sound, since a pure inductance or a pure capacitance will have no resistance component to absorb the power which is the product of the resistance and the square of the current $(I^2 R)$. It is quite obvious, then, that the satisfactory solution of the problems involved in train dispatching systems depends, among other things, upon the proper proportion of resistance for a given impedance. It may be added that the angle of the waystation impedance for most efficient results is also greatly affected by the characteristics of the line connecting the stations.

Although the method of setting up an artificial line and actually testing the efficiency with waystations of different impedances was used in some preliminary investigations, it was believed that the more complete solution lay in determining the best impedance values by computing methods which had already been highly developed in the solution of other telephone problems. These solutions could be checked by actual test of the adopted design. By using the computation method it was possible to obtain a very thorough understanding of the relations of the variables involved and certain interesting facts were brought to light which it would probably have taken a much longer time to discover had the testing method alone been used.

Consideration of Line Conditions

It is evident that the solution of the problem will depend largely on the type and length of line, the number of sets in simultaneous use, and the grade of transmission required. It was, therefore, necessary to survey the dispatching field thoroughly in order to determine the variations in the above-mentioned conditions as found in actual service.

The great majority of dispatching lines in this country are of open wire copper, usually No. 9 A. W. G. Iron wire has been and is, unfortunately, still used in some cases, but is so rapidly being discarded that it was left out of consideration. Besides the open wire lines there are some paper cable dispatching lines in the East. At present there are non-loaded, but some consideration has been given to the extension of these cable facilities by means of loading coils. In some cases, of course, dispatching lines are a mixture of open wire and cable and in the East there are a number of open wire circuits terminated at the dispatcher's end in 7 or 8 miles of underground cable where the circuit passes through a city to the railroad terminal, as at New York and Chicago.

A complete solution of the problem, then, appears to divide itself into the solution of three problems, namely, those of open wire lines, non-loaded cable and loaded cable, since the characteristics of these three types of lines are so different that the waystations for each must be of widely different impedances.

The grade of transmission generally acceptable as satisfactory for regular telephone service, namely a 30-mile equivalent,[2] was formerly considered adequate for dispatching service. With this value and the maximum length of lines in use at that time, some 25 to 30 stations could be simultaneously receiving messages from the dispatcher.

This was also approximately the maximum number of waystations expected to be simultaneously in use. As traffic conditions increased it was found that not more than about 10 to 15 stations could be simultaneously in use and still obtain satisfactory results. Investigation has since shown that the grade of transmission now thought satisfactory requires an equivalent of not more than 20 miles.

The typical dispatching lines in the United States and Canada were studied to secure the data here given which is representative of the existing conditions at the time this investigation was undertaken. Subsequent changes quite likely may have modified the conditions to some extent.

Investigations have shown the advisability of assuming that under the most severe conditions all of the stations on a line would be simultaneously in service for receiving. In order that any equipment may meet all conditions arising in practice it is necessary to consider the most severe ones likely to exist. From the data given in the table and from a consideration of the probable future growth of dispatching systems it was felt that No. 9 A. W. G. copper could be considered representative of that type of line and that an average maximum length of 250 miles with 40 stations would be a reasonable assumption. For loaded cable two typical conditions were considered: 100 miles of No. 13 A. W. G. with 25 stations, and 30 miles of No. 16 A. W. G. with 15 stations were assumed representative conditions for design purposes. There appears to be little likelihood of much non-loaded cable being used in the future, as the distances over which such circuits can be worked are rather limited except by the use of so large a gage that the cost of the copper would be excessive. No special consideration is therefore given to non-loaded cable circuits in this paper, although information is available regarding the impedance requirements, etc., for

[1]Throughout this paper the impedance of a piece of equipment is under stood to be the vectorial sum of the alternating current resistance and reactance at the frequency under consideration. If R is the resistance and X the reactance (either positive for inductance or negative for capacitance), the i pedance Z of the apparatus is $Z = \sqrt{R^2+X^2}$. Since the absolute value of the impedance is not always sufficient, it is often desirable to indicate the angular relation of the total impedance to its resistance component. The resistance and reactance components are always in quadrature (90° apart) and therefore $Z/\theta = R + jX$ in which θ signifies the angle between the vectors Z and R, or the angle of the impedance, and j indicates the 90° relation between R and X.

[2] The transmission equivalent of a system is defined as the number miles of standard cable required in the standard reference circuit to give the same volume of sound from the receivers of the reference and compared systems for the same loudness of speech in the transmitters of both systems. The standard reference circuit is generally accepted and has been standard for many years with the Bell Telephone System, and has been adopted by the Independent Telephone Association of America —Ref., "Tentative Stds. of Transmission," Bulletin No. 1, Dec., 1915, Independent Telephone Association of America. "Some Facts Concerning Telephone Transmission," Elam Miller and C. A. Robinson, Proceedings of Association of Railway Telegraph Superintendents, Annual Meeting. St. Louis, May, 1913.

sets for use with these circuits, should the need for such sets arise.

Detailed Design Considerations

In order to simplify the preliminary investigation is was assumed:

1. That a typical line could be used.
2. That if the power in the last station on the line were sufficient, the intermediate stations would receive sufficient power.
3. That the power consumed in the way-station impedance could be satisfactorily converted into sound.
4. That the stations were equally spaced along the line.
5. That the transmission from the dispatcher to the way-stations was of primary importance and that if this were satisfactory, transmission from the waystations to the dispatcher would be satisfactory.
6. That the loss introduced by the selectors was negligible.
7. That single frequency computations would give satisfactory results.

required in series with the set in order to keep down the loss of the low frequency selector currents. The curves substantiate what has already been said regarding the absolute value of the way-station impedance and its angle. As the absolute value of the impedance is increased above a certain amount, the loss increases. As the impedance angle approaches 90°, that is, as the resistance component approaches zero, the loss approaches infinity, since no power can be consumed by the station in the limiting condition. Fig. 1 also shows that for the impedances considered the best value for the way-station is about 5,000 ohms having an angle of 86°. Considerations, which will be discussed later, made it impracticable to obtain an impedance with as high an angle as 86°, so the value of 7,500 ohms with a positive angle of 75°, was tentatively adopted.

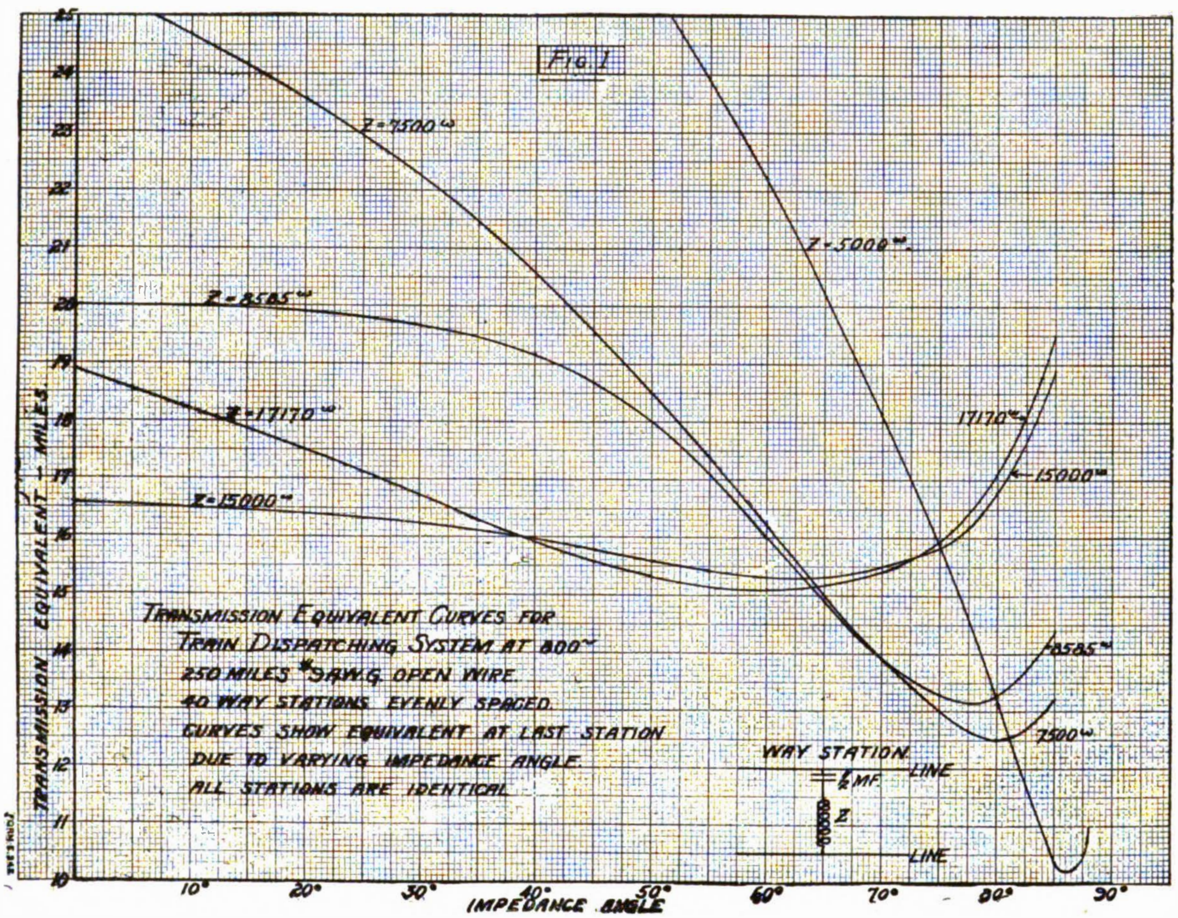

Fig. 1—Transmission Equivalent Curves for Train Dispatching

Having obtained a value for the best impedance based on the above assumptions, further investigation was made in order to determine whether with this waystation impedance satisfactory transmission could be obtained for the other conditions, such as unequally spaced stations, transmission from the waystation to the dispatcher, etc. In all cases this was found to be so and no modifications in the waystation impedance were required. The investigation was undertaken in two parts: (1) Open wire lines; (2) Loaded cable. These conditions will be considered in the above order.

For the assumed typical open wire condition Fig. 1 gives the transmission equivalent at the last station on the line with various values of impedance and impedance angle. These curves are plotted for the impedance of the waystation exclusive of the 1/2 mf. condenser

Figure 2 shows the variation of transmission equivalent at the last station on a 250-mile line for different impedances and numbers of waystations. The curve marked 2000/47° is that for the type of waystation formerly in use. It is seen that with the present desired equivalent of 20 miles it will not be possible to use more than 12 stations simultaneously. It is also seen that with stations having the proposed value, the equivalent is considerably below the limit, and changes very little with a variation of stations from 1 to 45. This is quite an important point since any considerable change in the transmission efficiency as the number of stations on the circuit varies is not at all desirable. Not only is the change very large with the old type station, but when a few stations are in service the equivalent is small, making the volume of sound uncomfortably loud.

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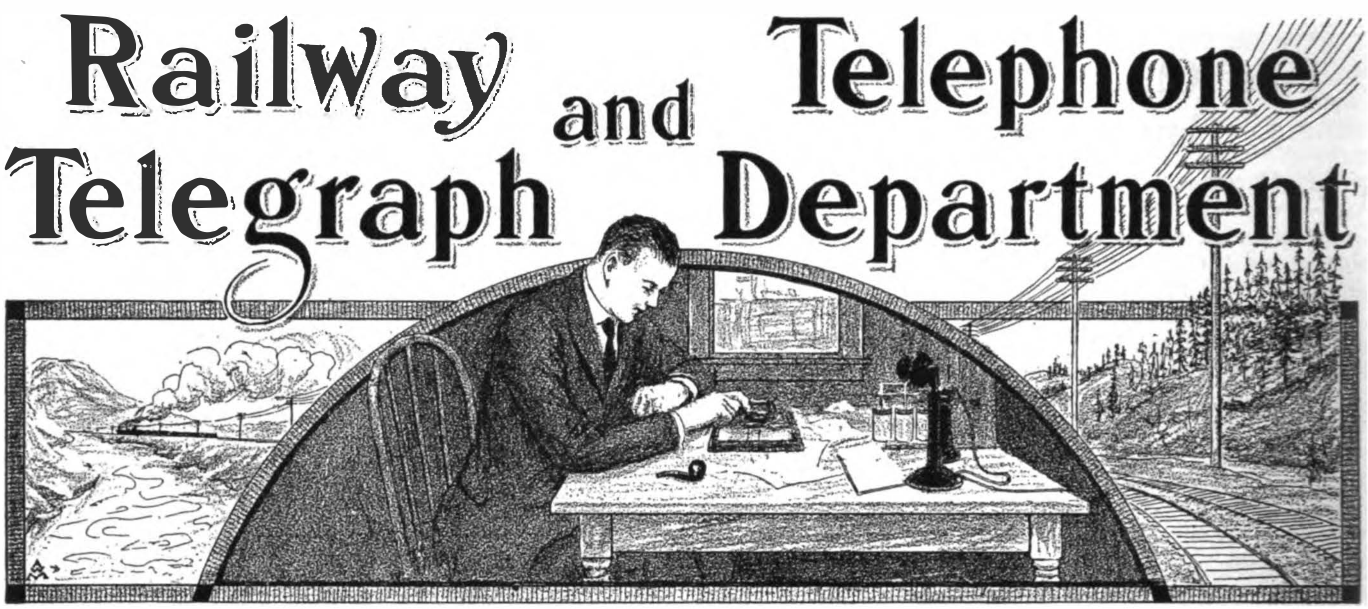

Recent Developments in Telephone Train Dispatching Circuits*

Second Installment Including Line Transmission and Cable Factors, of Outside Plant

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THE variation in equivalent at the stations along the typical line when all are in service is shown in Fig. 3. Each station has a total bridging impedance of 7500/70°, which includes the condenser, and is the value of impedance actually obtained on the final design of the set. Two curves are shown, one obtained by computation and the other by test in the laboratory with an artificial line of No. 9 A. W. G. copper equipped with actual sets. The curves of Fig. 3 bring out a condition which was expected to exist, namely, that the farthest station on the line does not necessarily receive

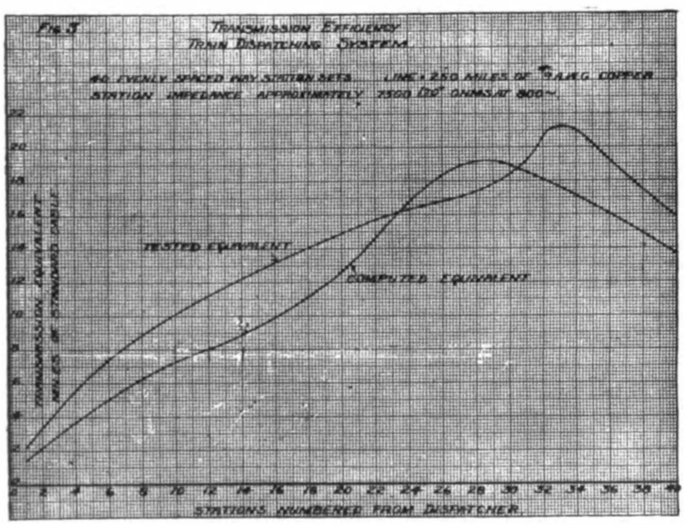

Fig. 3.—Transmission Efficiency Curves

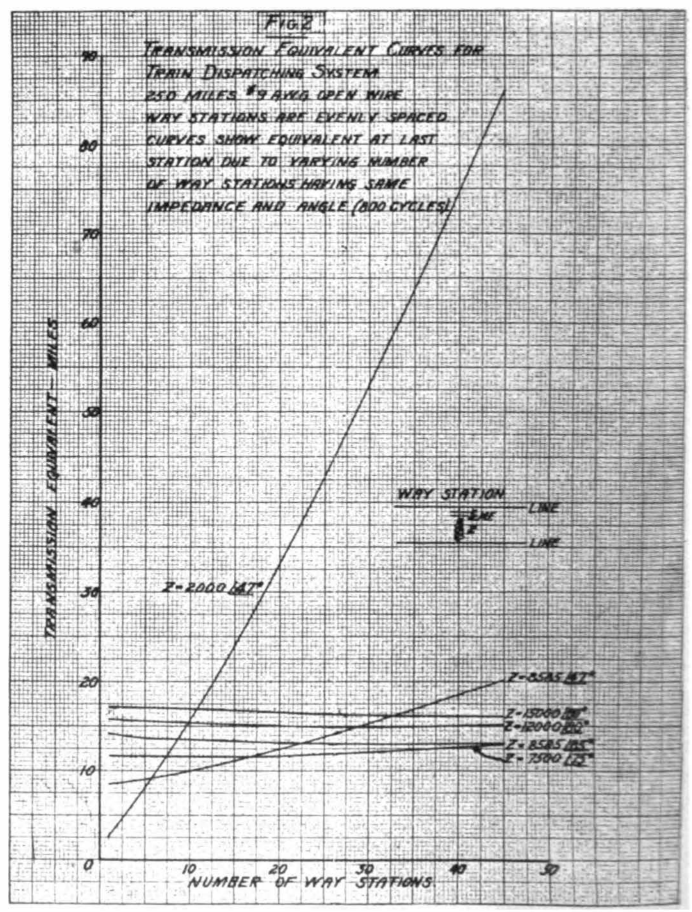

Fig. 2—Transmission Equivalent Curves

*Abstract of paper presented before the 1923 annual convention of the Telegraph & Telephone Section, A. R. A.

the smallest amount of power. The condition is due to the so-called "standing wave" effect and is much more pronounced on loaded cable, under which heading it will be more fully discussed. It is seen that although this effect causes an equivalent at a station 4 or 5 from the end of the line to be about 5 miles greater than at the last station, the equivalent is still sufficiently low to be satisfactory.

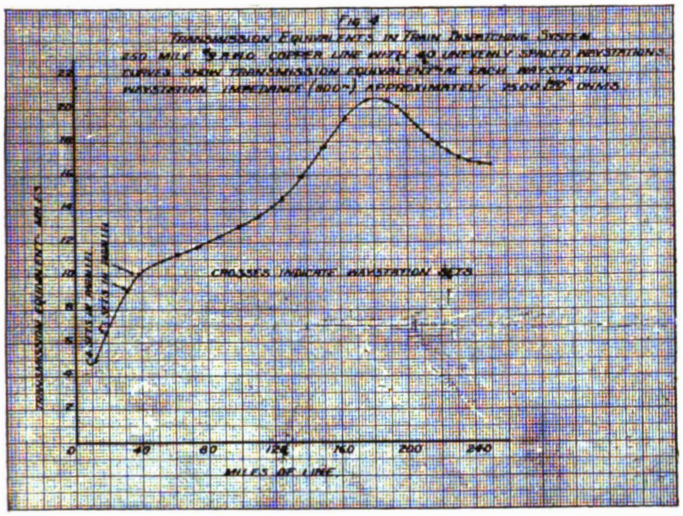

Fig. 4—Effect of Spacing Stations Irregularly

Some investigation was made in order to determine whether very irregular spacing of stations would greatly increase the equivalent at any point. Figure 4 shows the results of such a computation, and although the equivalent at the worst point was slightly increased, it is believed that the conditions assumed were much more severe than would probably be found in any actual circuit.

When the laboratory tests were completed an installation of the sets was made in October, 1917, on the dispatching line of the Seaboard Air Line Railroad between Columbia, S. C., and Jacksonville, Fla. This line consists of 283 miles of No. 9 A. W. G. open wire copper circuit with 34 waystations. The results of this installation were entirely satisfactory and the equipment has been in continuous use ever since.

On Fig. 5 are shown several curves for circuit loss[3] vs. length of line with different numbers of waystations having an impedance of 7500/70°. The losses are those at the last station on the line. It is safe to assume that the maximum loss at any other station on the line will not be more than about 5 miles greater than these values. The actual equivalents for the conditions shown in this figure will be about 2 miles greater than the losses indicated. The shape of the curves is interesting and may at first seem inexplicable. The fact is that this type of waystation causes a slight loading effect on the line which actually tends to reduce the attenuation of the line. It is, of course, possible to load a line by means of shunt inductances as well as the more usual method of series inductances. Examination shows that the minimum loss occurs in each case when the stations are approximately 4 miles apart. Under these conditions it is found by computation that this is the spacing for which the loading effect is a maximum. The curve for 10 stations crosses that for 20 stations at about 95 miles for the length of line, and for longer lengths gives

[3] In order to avoid confusion in regard to negative equivalents, these curves and certain of those following are plotted in terms of circuit loss, giving the miles of standard cable corresponding to the difference in the power consumed at a given station and that in the receiver of the reference circuit with zero trunk. These loss values do not include corrections for the differences in the efficiency of the receivers and transmitters used in the two systems.

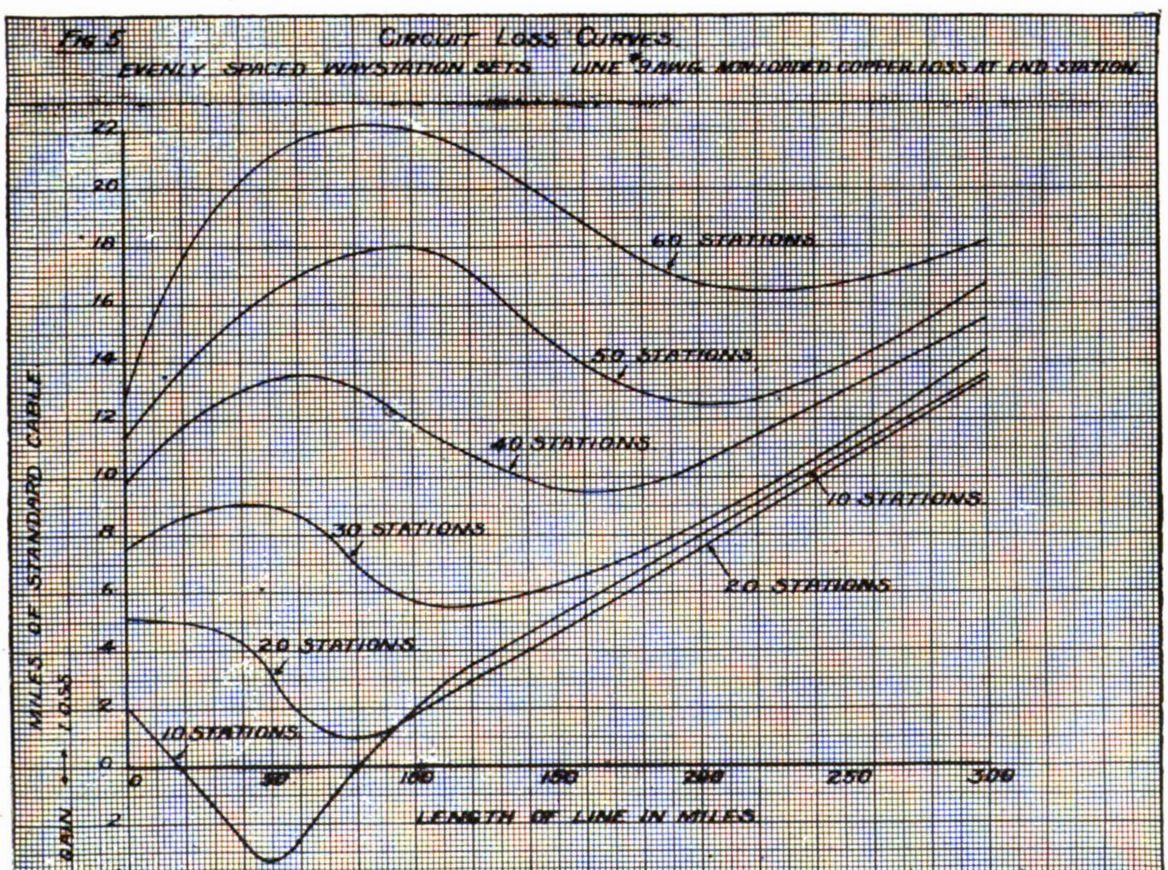

Fig. 5—Circuit Loss Curves, for Last Station on the Line

slightly greater losses. This is due to the fact that on the longer lengths the advantage of the shunt loading effect is not obtained with so few stations as 10, and that the gain from this cause with the 20 stations offsets the increased loss of this larger number of stations.

Loaded Cable

As in the case of the open wire circuits certain assumptions were made for the loaded cable condition in regard to the typical lines, number of stations, etc.

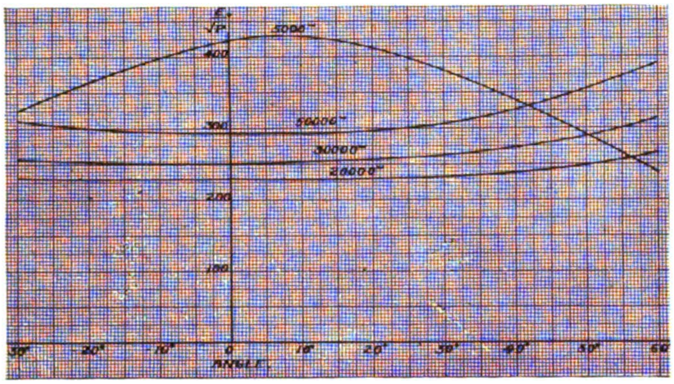

Fig. 6—Computation for Proper Wayside Impedance

The problem was, however, not so simple as for the open wire case since there is not the uniformity of practice in the use of a particular gage. Indications are that Nos. 10, 13, 16 and 19 A. W. G. may be used. It was already mentioned that 100 miles of 13 A. W. G. cable and 30 miles of 16 A. W. G. cable, with 25 waystations and 15 waystations, respectively, were considered representative, the preliminary investigation being based on these two conditions. The two weights of loading assumed in this work were 0.175 henry coils on

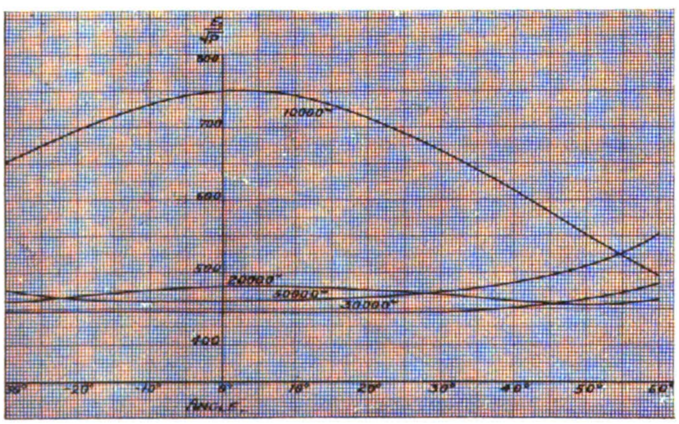

Fig. 7—Curves Showing Wayside Impedance

1⅔ miles spacing, and 0.205 henry coils on 1.4 miles spacing, as those most likely to be used.

Although the detrimental effect of "standing waves" was appreciated early in the investigation, and the final solution eliminates them, it is felt that the phenomenon is of sufficient interest to justify a somewhat detailed discussion of it, since such a consideration brings forth certain important facts.

Preliminary computations showed that the best value of waystation impedance at 800 cycles was 20,000 ohms or more at a small angle, although the values were not at all critical, as may be seen from Figs. 6 and 7, which show the variation in the ratio of voltage impressed on the sending end of the line to the square root of the power consumed in the last station. The curves are shown in this form since, as explained in the appendix, they are more simple to determine than the actual equivalents or losses, a minimum value for this ratio, of course, corresponding to minimum loss.

Using impedances actually obtained with an experimental set, some computations were made to determine the change in efficiency at the different stations along the line, the results being shown on Fig. 8 and 9. As shown on these figures the values of station impedance at 800 cycles and 1,500 cycles were $20{,}000\underline{/0°}$ and $34{,}000\underline{/61°}$ respectively. In both Fig. 8 and 9 the 800 cycle efficiencies, and on Fig. 8 the 1,500 cycle also, pass through maxima and minima at approximately regular intervals. Further investigation showed that these maxima and minima occur at approximately one-half wave-lengths[4] points, the greatest loss being at one-quarter wave-length from the distant end of the line. The sudden changes in efficiency are due to the interference phenomenon known as "standing waves."

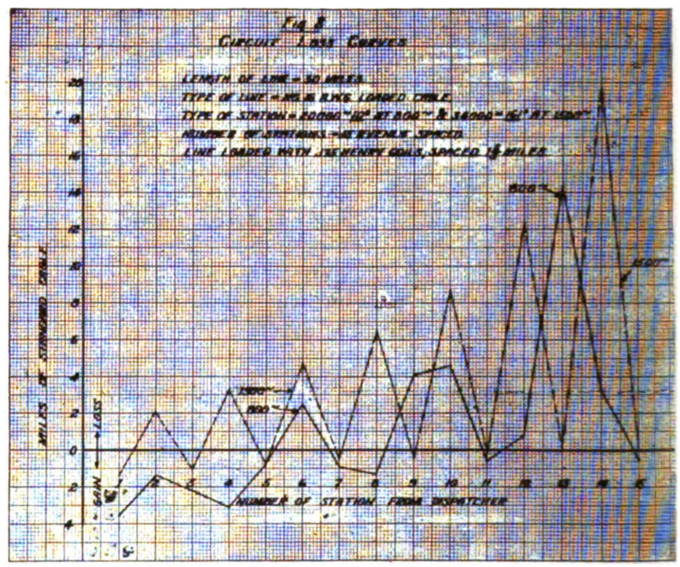

Fig. 8—Curves of Circuit Losses

When a voltage wave is propagated along a line of uniform structure the changes in phase and magnitude are uniform. If, however, a sudden change in the character of the line occurs, the voltage wave will be more or less reflected from this discontinuity and a reflected wave will start back along the line. This reflected wave will also follow the law of uniform change in magnitude and phase until a discontinuity is again encountered, with consequent reflection. The shift in phase of the reflected wave at a junction depends upon the nature[5] of this discontinuity.

It can easily be seen, therefore, that with stations of as high an impedance as here assumed the terminal of the line is in effect approximating an open circuit which is, of course, the maximum discontinuity and gives total reflection. A large reflected wave would, therefore, be expected. The combined effect of the original and reflected waves on the voltage at any point on the line will depend upon the relative magnitudes and phases of

[4] A current or voltage wave propagated along a line of uniform construction is shifted in phase as well as reduced in magnitude. The actual velocity of propagation is a function of the frequency of the impressed wave as well as the line characteristics, and the length of line required to produce a 360° or 2 π radians shift in the phase is called the wave-length for that frequency.

the two waves. This phenomenon results in maxima and minima voltages along the line, although the voltage at any one point remains constant since the phase relation at any point between the advancing and reflected waves does not change. This causes the so-called "standing wave."

From the above it is clear that the irregularities in efficiency at the several stations on the line are due to standing waves; i.e., the voltage wave which is reflected from the end of the line meets the advancing waves in opposite phase at a quarter wave-length from the end of the line and at each succeeding odd multiple thereof, namely, 1-4, 3-4, 5-4, etc., or in Fig. 8 at the 13th, 10th and 9th, 6th and 2nd stations for 800 cycles.[6] It becomes apparent that at these points the voltage across the line will be the difference between the amplitudes of

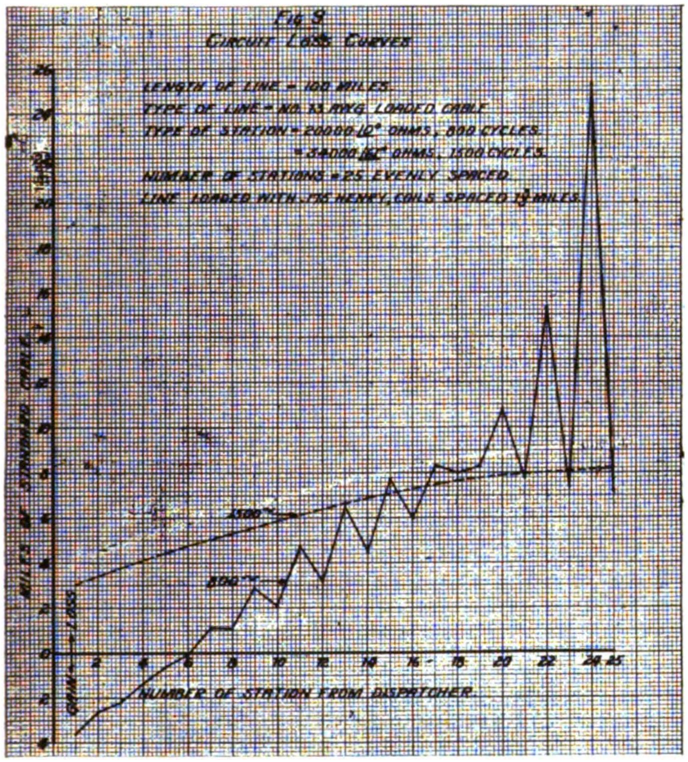

Fig. 9—Curve of Losses on a 100-Mile Line

the direct and reflected waves, this difference in amplitude being due to the greater attenuation of the reflected wave. If, therefore, there happens to be a station at or near one of these null points, the current through it must consequently be small and a considerable loss will occur. From this reasoning it would be expected that the greatest loss would occur at the interference point nearest the end of the line and show a gradual decrease towards the sending end, since the difference in the amplitude of the two waves will be greater as the sending end of the line is reached. This tendency is borne out by the curves which show that these excessive losses diminish towards the dispatcher's end of the line.

From the above consideration one would not expect to find these maxima if the stations occurred at points on the line even multiples of 1-4 wave-length from the end, since at such points the two waves will be in phase giving minimum losses. Since the wave-length is approximately inversely proportional to the frequency, it is obvious that for 1,500 cycles the stations will be electrically at nearly twice the 800 cycles spacing. Therefore, if at 800 cycles the stations are at odd multiples of 1-4 wave-length, at 1,500 cycles they will be approximately at even multiples of a quarter wave-length. Hence those stations having the greatest losses at 800 cycles will have minimum losses at 1,500 cycles. This theory is upheld by the data on Fig. 8. Furthermore, for 1,500 cycles there are twice as many maxima and minima points, and those stations, which for 800-cycle computations are at approximately the mid points between the poor stations, or at 1-8, 3-8, 5-8, etc., of a wave-length from the end of the line, come at approximately 1-4, 3-4, 5-4, etc., of a wave-length for 1,500 cycles, which are the minimum voltage points giving high losses. On the particular line of Fig. 8, as is indicated by the curves, the 1,500-cycle computations bring the poor stations more nearly at the exact 1-4 wave-length points, and hence the maximum losses for this frequency are considerably greater than for 800 cycles.

In Fig. 9 the 800 cycle curve shows maxima and minima, but the losses at 1,500 cycles vary uniformly. On this line the stations are so spaced that at 800 cycles each is approximately at either a maximum or a minimum point. As shown above, the maximum losses at 800 cycles become minimum at 1,500. The stations which at 800 cycles have minimum losses are at approximately 2-4, 4-4, 6-4, etc., of a wave-length from the end of the line, will be, as previously shown, at 4-4, 8-4, 12-4, for 1,500 cycles. These are also even multiples of a quarter wave-length and hence are still at minimum loss points. Therefore, it follows that for 1,500 cycles all the stations will have minimum losses, which explains the curve.

In passing it is well to note that the effect of standing waves is not serious on the open wire lines because the reflected wave is not so large, due to the fact that the lower impedance of the end stations does not so nearly approximate the open circuit condition. Only one maximum is found, the longest line considered being less than one wave-length. The speed of propagation on open wire is very much greater than on loaded cable.

Not only will the efficiency at these maximum loss points on such lines be low for actual voice currents as talking tests on artificial cable have shown, but even more important is the effect on the quality. As the curves indicate, there is a great difference in the efficiency of some of the stations between 800 and 1,500 cycles. The efficiencies will vary materially at other frequencies in the voice currents, and may be greater or less than those shown, so that at all stations distortion of the voice waves results due to the standing wave effect. The distortion is so serious that means were sought to avoid it.

Since the reflected waves are caused by a discontinuity at the line terminal, it was decided that the best way to avoid the trouble was to so terminate the line that no reflection occurs, which would be the case if the line continued indefinitely beyond the last station, for no discontinuity would exist. As applied to the case under consideration, the elimination of the reflected wave may be accomplished by terminating the line in its own impedance.[6] Practically, this can be done by shunting the last station with a resistance of approximately 1,260 ohms, since the characteristic impedance of the lines here considered is about this value.

(Continued in an early issue)

[6] The portion of a voltage wave reflected at a discontinuity in a uniform line is given by the formula $\frac{Z_L - Z_R}{Z_L + Z_R}$ in which Z_L is the characteristic impedance of the line and Z_R is the impedance of the termination. The characteristic impedance of any line is the impedance of an infinitely long line of uniform structure. (See Appendix.)

[6] Due to the lumping of the loading coil inductance at definite points instead of being uniformly distributed as assumed in the computations (see appendix), the stations having maxima and minima losses on the actual line will not in general be geographically located just as shown on the attached curves.

Recent Developments in Telephone Train Dispatching Circuits*

Third Installment, Including Line Transmission Equipment, Train Dispatching Circuits and Location of Apparatus

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THE curves on Fig. 10 show the results of computations on the typical 100-mile line when the terminal is shunted with an impedance equal to the characteristic impedance of the line. It may be observed that the efficiency varies proportionally to the attenuation of the length of line and that the difference between 800 and 1,500 cycles is not great.

Having determined upon the method of eliminating the standing waves, the impedance to be used for the waystation was considered. The shunting of the line changes the condition sufficiently to make it advisable to redetermine the most desirable impedance values.

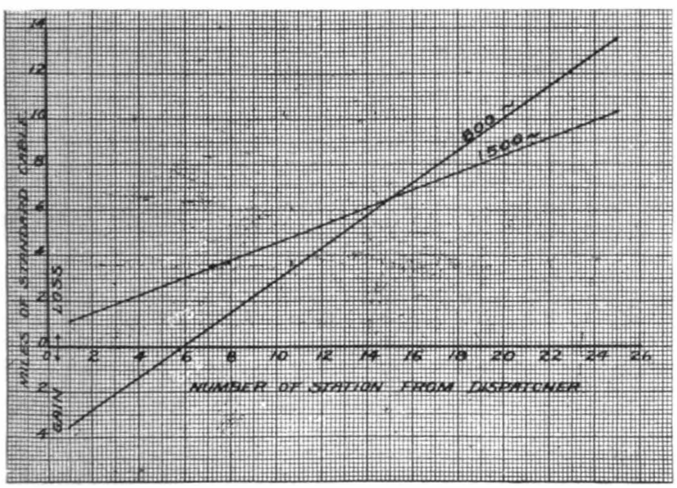


Fig. 10—Circuit Loss Curves for a 100-Mile Line

Numerous computations were made on the typical lines and 35,000 ohms /20° at 800 cycles, and 20,000 ohms at 1,500 with as low a positive angle as possible were considered the best compromise values.

It may be remarked that our final computations covered a rather wide range of conditions and brought out several interesting points, one of which was that the most desirable angle at either 800 cycles or 1,500 cycles was 30°, irrespective of whether it was negative or positive. This is due to the fact that the line impedance of the loaded cable is practically pure resistance, so that there is no loading effect obtained from the waystations; or, in other words, the maximum efficiency is obtained when the ratio of the resistance of the station to its total impedance is cosine 30°. The change in angle from —30° to +30° caused only a small change in efficiency. The optiumum impedance at 1,500 cycles was considerably lower than that at 800 cycles.

Computations further showed that there was practically no advantage in using a heavier weight of loading than 0.175 henry on 1⅔ miles spacing. For example, computations were made with 0.205 henry coils on 1.4 miles spacing. With 13 gage cable the respective attenuations per mile without the bridged stations were 0.01 and 0.0085 respectively, but with the bridged stations, located every 4 miles, the attenuations were approximately 0.019 in each case. The latter is due to the greater effect of leakage when the heavier weights of loading are used and has been known to be so serious that on certain lines with high leakage the loaded lines may be less efficient than the nonloaded lines.[9] The waystation has the effect of increasing leakage.

Figure 11 gives the results of computations for a wide range of line conditions and shows the equivalent at the last station on the line when the stations are all the same and have the impedance above determined. The end of the line is shunted with an impedance equal to the characteristic impedance of the line. The equivalent at the last station is in this case greatest since the effect of standing waves has been eliminated.

Waystation Set Design

Having determined upon the impedances for the waystations, it next became necessary to design a set which would have the desired operating features as well as the proper impedance relations. After careful consideration of the requirements, the following were agreed upon as desirable:

1. The set must have a condenser in series to reduce losses to selector currents.
2. The set should have a key to be operated for talking; the transmitter to be open during listening.
3. There should be sufficient "break-in" efficiency during talking to attract the operator's attention.
4. Transmitting efficiency should be a maximum.
5. The receiver and the transmitter should be insulated from the line by an induction coil.
6. The impedence in the receiving condition must be as close to the desired theoretical values chosen as practicable.

These conditions are met by the circuit shown in Fig. 12 for the open wire set.

In the receiving condition the low impedance receiver is connected to an induction coil, the secondary winding of which is in series with the ¼ mf. condenser and bridged across the line. The number of turns on the coil is such that the combined impedances of the coil, receiver and condenser give approximately 7500/70° as required. The ¼ mf. condenser is required to reduce the losses at the low frequencies of the selector currents. It was found desirable to use this value of condenser in place of the original ½ mf. condenser since the increased efficiency of selector operation was considerable. Besides providing suitable insulation between the receiver and the line the use of the induction coil makes it possible to obtain a higher positive impedance angle than could be obtained by use of a receiver alone. Referring back

*Abstract of paper presented before convention of Telegraph and Telephone Section, A. R. A.

[9] Bancroft Gheardi, "Some Recent Advances in Transmission Efficiency of Long Distance Circuits" (Address), New York Telephone Society, April 18, 1911.

to the original curves it will be seen that the efficiency decreases rapidly as the impedance angle is reduced.

In order to obtain a high transmission efficiency in the line, it is necessary to change the ratio of the turns on the coil when used to connect the transmitter in the circuit. This is accomplished by depressing the key which also closes the transmitter circuit. To give satisfactory "break-in" efficiency the receiver is bridged directly across the transmitter winding of the coil. The impedance of the receiver is relatively high compared to that of the coil winding so that no great loss in efficiency of transmission occurs from high frequency losses. The desk stand contacts operate to open the receiver and transmitter circuits in the normal way. With the receiver on the hook, only the secondary of the coil in series with the condenser is bridged across the line. In this condition the impedance of the set is somewhat higher than in the normal receiving condition, giving rather lower losses to the other stations. The insulation between the primary and secondary windings of the induction coil is tested with 1,000 volts, as is also that between the contacts of the key. This insures adequate protection to the operator from induced voltages between the line and ground.

Because of the more difficult impedance conditions to be met by the loaded cable set, two additional condensers are required. Figure 13 shows the circuit. Figure 14 shows the impedance of the set for different frequencies. It will be noted from this figure that the impedance of the set varies considerably for different frequencies, although at the two computed values is close to that desired. A study of all the data obtained by computation, together with the results of certain talking tests on artificial loaded cable circuits, showed that throughout the range of important frequencies the impedance of this set would be satisfactory, and that detailed computations at other frequencies than 800 and 1,500 cycles were not justified.

The operating features of the set are the same as those of the open wire set. In the receiving condition the secondary series condenser is of a small value, .0125 mf., and is required primarily to obtain the desired impedance; a larger one would, of course, be satisfactory for selector operation, as in the case of the open wire set. The 0.68 mf. condenser in series with the low impedance receiver is also required to give the proper impedance and slightly increases the receiving efficiency of the set itself. The small condenser in the line side would offer such a high impedance in the transmitting condition that the efficiency would be greatly impaired. For this reason it was necessary to use a third condenser of ¼ mf., as shown when the circuit is switched to the transmitting condition.

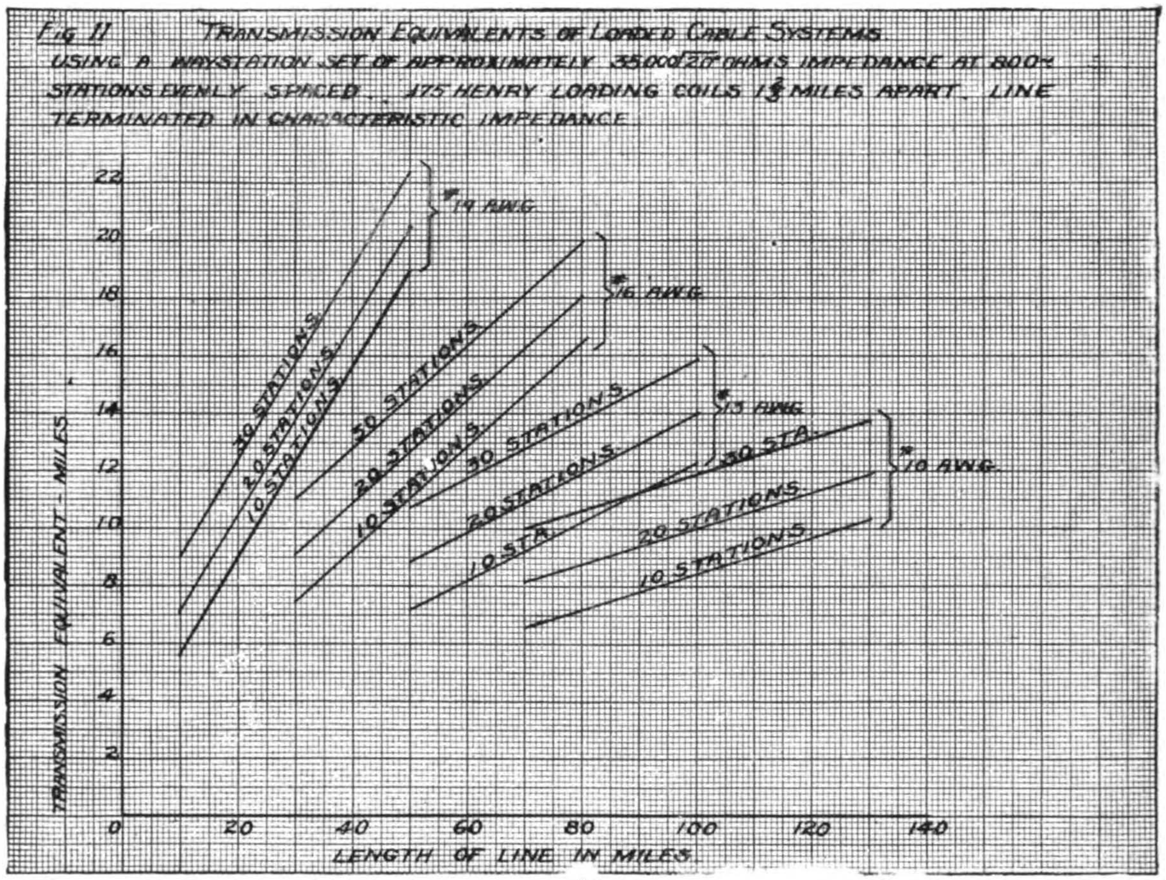


Fig. 11—Transmission Equivalents of a Loaded Cable System

The shunt at the end of the line could, from a transmission standpoint only, be a pure resistance of 1,250 to 1,300 ohms, but because of losses to selector currents it is necessary to use a one or two mf. condenser in series with this resistance.

Dispatcher's Equipment

The requirements for a dispatcher's set are, of course, different from those of a way-station set. The dispatcher is required to listen on his set practically continuously for 8-hour periods. It is necessary that in addition to high receiving efficiency, the "break-in" efficiency as well as the transmitting efficiency be as high as possible. In order to save the transmitter batteries a foot switch is usually provided, which, when depressed, closes the transmitter battery circuit for talking.

In the usual type of set the power from the transmitter is divided between the line and the receiver, and often the energy into the receiver approximates that into the line. This, of course, means that the talker's voice sounds very loud in his own receiver and that while listening any room noise will appear as a disturbing sound in the local receiver tending to obscure the received voice sounds, thus effectively decreasing the efficiency of reception. Not only because this "side tone" may be loud enough during transmitting to be decidedly annoying to the dispatcher, but because of the effect on the reception it was believed that an anti-side tone set was advisable for this class of service.

A set which is variable between the receiving and transmitting conditions, and in which only the receiver is in circuit in the receiving condition and only the transmitter while talking, is inherently about 3 miles more efficient than an invariable set in which both receiver and transmitter are in circuit in the same relation during both transmitting and receiving. In the practical case of the waystation set, where the receiver actually obtains a certain amount of energy from the transmitter during transmitting, the transmitting efficiency will be about 2 miles greater than in the case of an invariable set where only approximately half of the energy is delivered to the line. Even at the sacrifice of these 2 miles in transmission efficiency of the dispatcher's circuit it seemed advisable to use the invariable type of set in order to obtain the maximum "break-in" efficiency.

Since there is only one dispatcher on the line it is required that the dispatcher's set be designed to transmit and receive most efficiently when connected to an impedance equal to that of the lines occurring in practice. It was found that the impedance of the open wire lines for the most severe conditions, as regards length and number of stations, was approximately 925 to 1,265 ohms, with impedance angles varying from negative 6° to positive 15°; similarly for loaded cable circuits the impedances vary from about 1,250 to 1,300 ohms, with small negative angles of not more than about 2°. The impedances of the two types of line are sufficiently alike to make it advisable to design one dispatcher's set for use with both. The gain in efficiency by using two sets would, at best, be only a fraction of a mile, and the decrease in side tone not very large. The circuit of the set finally adopted is shown in Fig. 15.

A brief discussion of the action of an anti-side tone set may be advisable at this point. The operation of the anti-side tone circuit is based on the Wheatstone bridge principle, in which a balance is obtained between the line and a network having the same impedance as that of the line. Referring to Fig. 15, the analogous Wheatstone bridge circuit indicates the relation between the various elements. It is obvious from this that when the network *N* has the same impedance as that of the line *L*, no current will flow in the receiver from an electromotive force connected across the bridge since a balance exists. On the other hand, any electromotive force in the line *L* will cause current to flow through the receiver. The first mentioned arrangement corresponds to the transmitting condition of the set, and the second to the receiving condition. In the actual circuit the transmitting voltage is applied to the bridge network through the coil, the two windings *C* and *B* of which are balanced; but this does not alter the bridge analogy. This arrangement also makes it possible to include the resistance component of the network as a part of the resistance of the winding *C*. This may be accomplished by either using a small gage wire for winding *C* or adding some high resistance wire.

As has been pointed out before,[10] the impedances of telephone lines vary considerably over the range of tele-

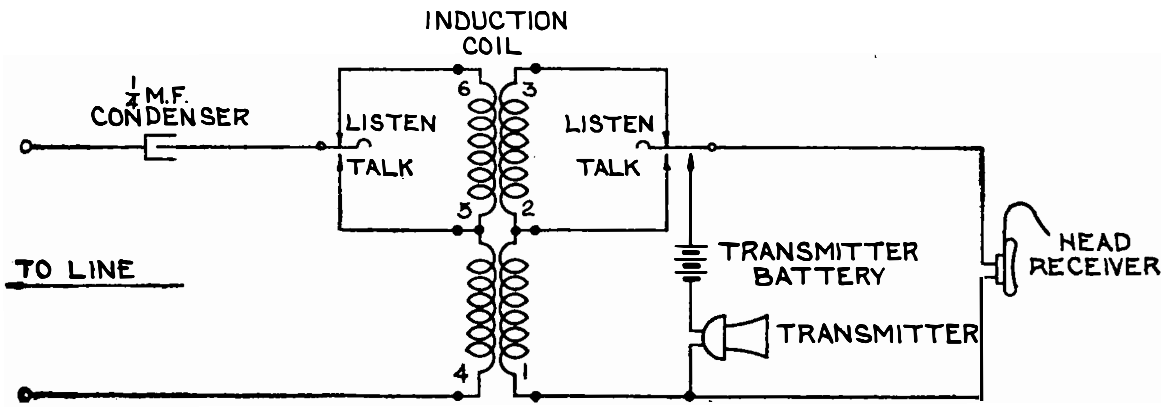


Fig. 12—Circuit Diagram for a Way Station Set for Open Wire Lines

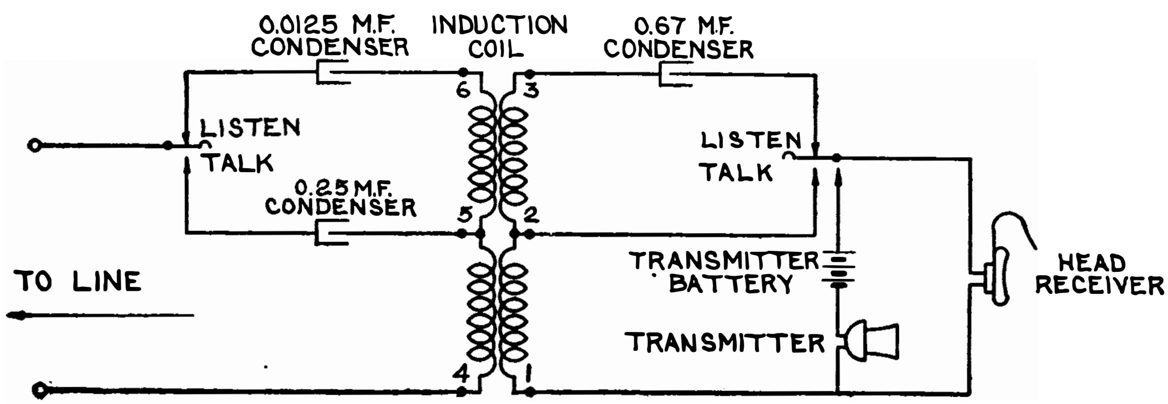


Fig. 13—Wiring Diagram for Way Station Set for Loaded Cable Dispatching Circuit

[10] Gherardi and Jewett, "Telephone Repeaters." Paper before joint meeting of American Institute of Electrical Engineers and the Institute of Radio Engineers, New York, Oct. 1, 1919.

phone frequencies. Furthermore, different lines, such as those generally used in dispatching work, may differ appreciably. It is, therefore, not possible nor practical to design a single balancing network to exactly equal the impedance of different lines at all frequencies of interest. A compromise must be used, but it is possible to obtain sufficient balance by this means to produce a considerable reduction in the current flowing in the receiver circuit while transmitting. In the case of the dispatcher's equipment a simple resistance and a condenser are sufficient. A line condenser is required to keep selector currents from being shunted through the set as in the case of the waystation set. This condenser must be balanced by a similar one in the network side.

The coil in the receiver circuit is used to insulate the receiver from the line and afford the same protection as in the waystation set. The condenser in series with the receiver increases the receiving efficiency.

A set of the type just described will have a transmitting efficiency about two miles less than that of the waystation set, but a receiving efficiency about six miles better. The side tone will be in the neighborhood of 15 miles less. The "break-in" efficiency of the dispatcher's set is the same as its receiving efficiency.

The possibility of using the waystation set for a dispatcher has been considered. In certain cases, of course, it may give satisfactory service, but since the requirements for a waystation and a dispatcher's set are different, it does not seem advisable in general to use a waystation set for a dispatcher. The anti-side tone feature alone would seem to justify the more complicated set.

Loud Speaking Equipment

Even with the improved anti-side tone dispatcher sets, the necessity for the dispatcher to wear a head receiver for a considerable period of time has developed the need for satisfactory loud speaking equipment. Although in a few special cases loud speakers with mechanical amplifiers have been in use for some years, it has only been since the development of the vacuum tube amplifier that the demand for such apparatus could be satisfactorily met. As previously mentioned, the mechanical amplifier has inherent characteristics which limit its usefulness.

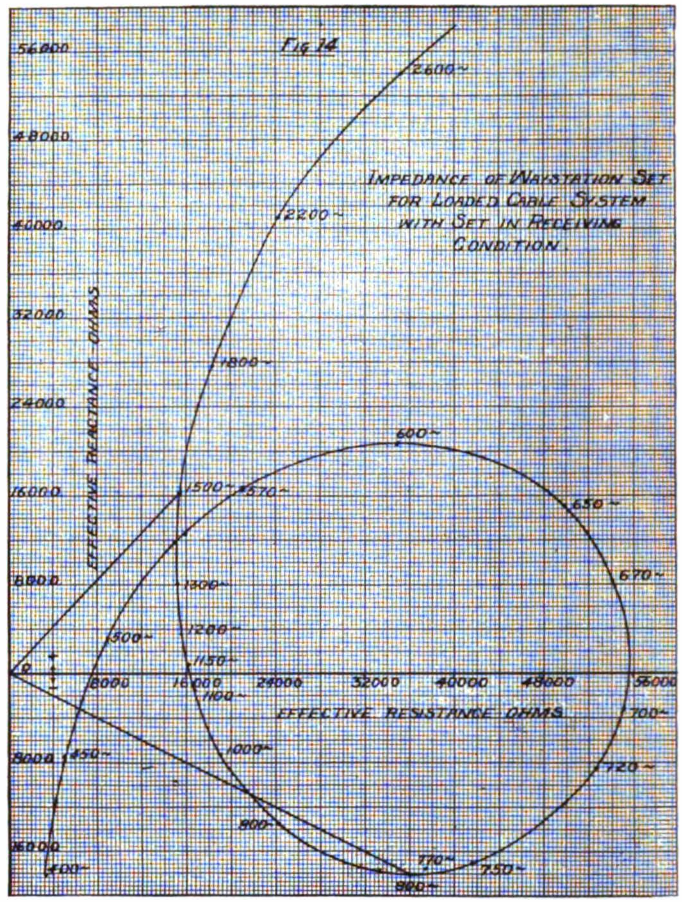
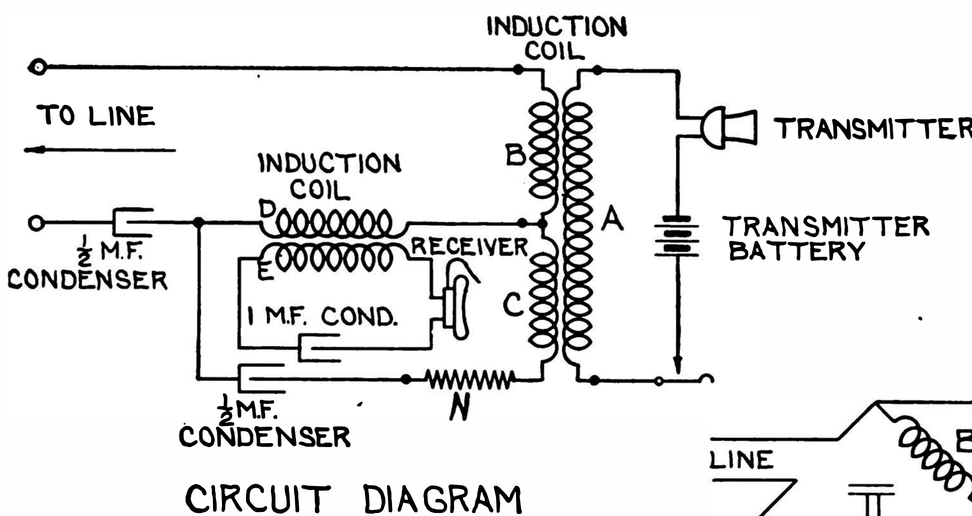


Fig. 14—Impedance Curve for Way Stations Set on Loaded Cable

The greater stability and freedom from distortion of the present day vacuum-tube amplifier make its general use much more certain. The perfecting of loud speaking equipment for dispatcher's use was undertaken first, and later similar equipment for use at waystations was developed.



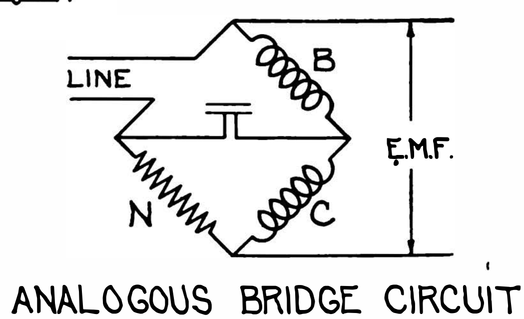


Fig. 15—Dispatcher's Set for Non-Loaded Open Wire Metallic Lines and Loaded Cable Circuits

(To be continued in an early issue)