

Feb. 19, 1929.

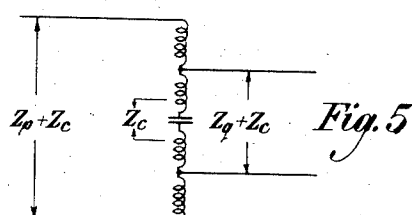
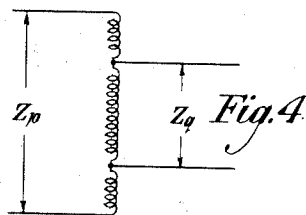
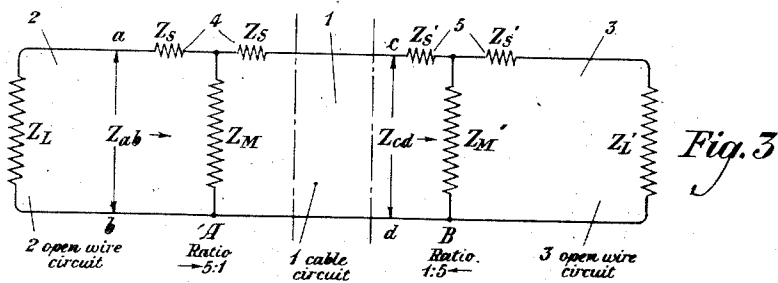
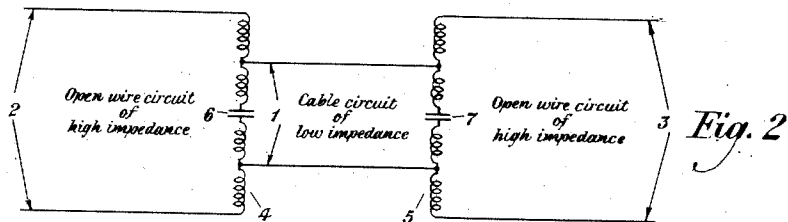
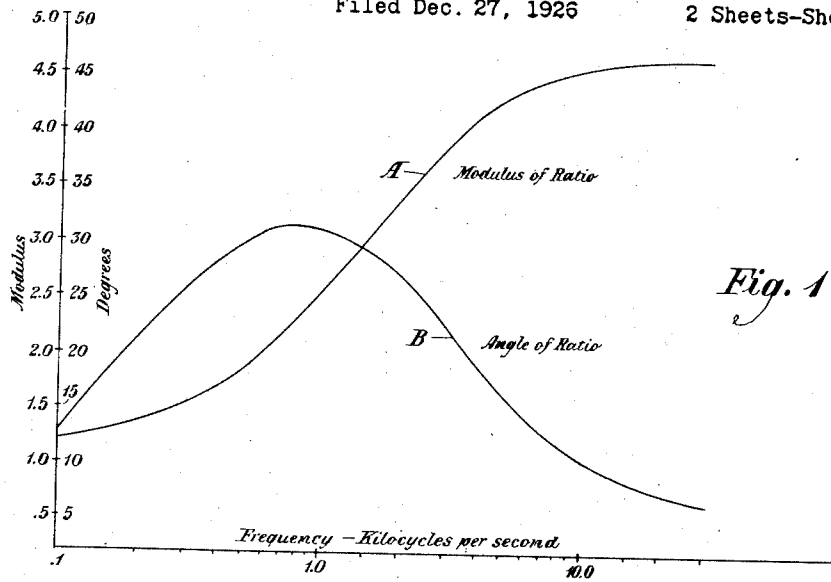
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1,702,305

IMPEDANCE MODIFYING DEVICE

Filed Dec. 27, 1926

2 Sheets-Sheet 1



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IMPEDANCE MODIFYING DEVICE

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2 Sheets-Sheet 2

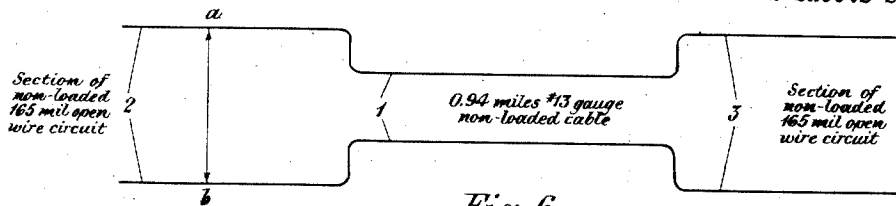


Fig. 6

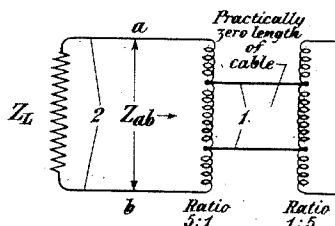


Fig. 7

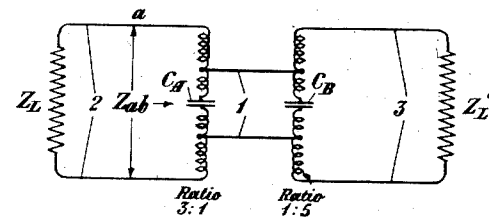


Fig. 8

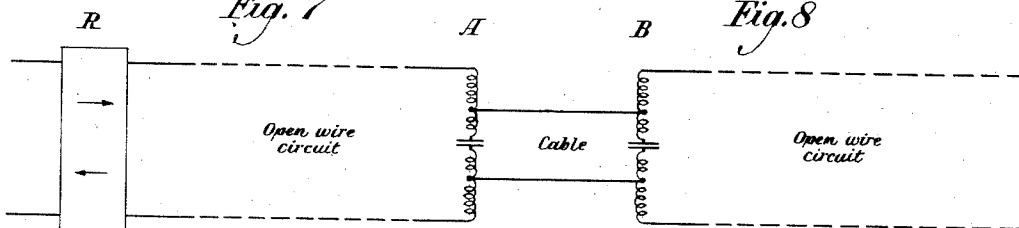


Fig. 9

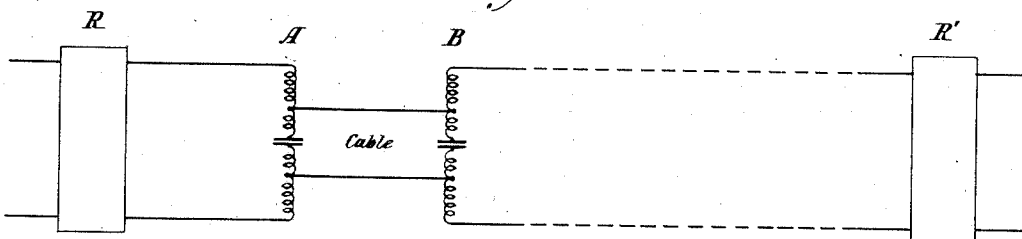


Fig. 10

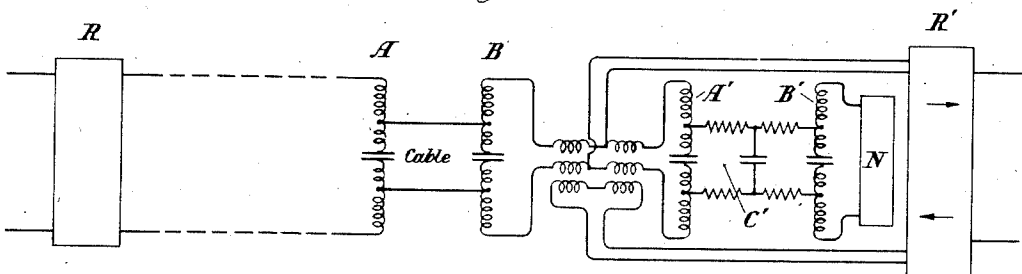


Fig. 11

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UNITED STATES PATENT OFFICE.

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IMPEDANCE-MODIFYING DEVICE.

Application filed December 27, 1926. Serial No. 157,269.

This invention relates to the application of impedance modifying devices to lines transmitting a voice-frequency telephone system and high-frequency carrier telephone or carrier telegraph system, and particularly to transmission lines composed of a plurality of line sections having different electrical characteristics.

An illustration of one type of transmission line to which the application of impedance modifying means in accordance with this invention would be desirable would be a line, composed of two sections of non-loaded open wire circuit inter-connected by a non-loaded cable circuit, and transmitting a repeated voice frequency system, involving frequencies, say from about 300 to 3,000 cycles, and one or more carrier systems involving frequencies from about 3,000 cycles upward to about 30,000 cycles, depending on the number and type of carrier systems. Due to the differing electrical characteristics or impedances of the cable and open wire circuits, considerable transmission loss results at carrier frequencies due to the reflection effects introduced by the irregularity at the junction points of the incidental cable circuit and the open wire circuits. This reflection loss at carrier frequencies might be reduced to a considerable extent by the insertion at the ends of the incidental cable circuit of impedance modifying transformers each having an impedance ratio equal to the ratio between the open wire circuit and cable circuit characteristic impedances at the carrier frequencies. However, the use of transformers which will accomplish this purpose is limited by the fact that their insertion in the transmission line produces an impedance irregularity in the line at voice frequencies which will tend to materially increase the unbalance of the voice frequency repeaters in the line. Accordingly, the present invention provides a method of and arrangements for so modifying the impedance in a transmission line of the above type that the reflection losses at carrier frequencies may be reduced without any material detrimental effect on the balance of the

voice-frequency repeaters included in the line. The method and arrangements of the invention together with other features and purposes thereof will appear more fully from the detailed description hereinafter given.

The invention may be more fully understood from the following description together with the accompanying drawing in the Figures 1 to 11 of which the invention and the principles of its operation are illustrated. Fig. 1 illustrates the variation with frequency of the ratio of the characteristic impedance of a typical non-loaded open wire line to the characteristic impedance of a typical non-loaded cable. Fig. 2 is a schematic showing of a cable circuit interconnecting two open wire circuits. Fig. 3 is the equivalent of Fig. 2. Figs. 4 and 5 are schematic showings of connections between a single open wire circuit and a cable circuit. Figs. 6, 7, and 8 are schematic showings of connections between two open wire circuits and a cable circuit. Figs. 9, 10, and 11 are schematic showings of practical embodiments of the invention.

In Fig. 2 is illustrated a transmission line composed of two non-loaded open wire line sections 2 and 3 interconnected by a non-loaded cable circuit of relatively low impedance as compared to the impedance of the open wire line. These sections are interconnected by the auto-transformers 4 and 5 which have at their midpoints the condensers 6 and 7. As has been previously pointed out, in a transmission line of the above mentioned type the reflection loss at carrier frequencies may be reduced to a considerable extent by the insertion at the ends of the cable of the impedance modifying transformers such as 4 and 5, each having an impedance ratio equal to the ratio between the open wire circuit and cable circuit characteristic impedances at carrier frequencies. However, in the voice frequency range this impedance ratio varies considerably from the value for the carrier frequency range both in modulus and in angle. This variation is illustrated graphically by the curves of Fig. 1.

In order to understand what these curves

signify, a few words of explanation will be given as to what is meant by the modulus and angle of the impedance of a circuit. As is well known, the impedance of a circuit has two components, resistance and reactance. If these components be represented by a vector diagram, in which the vector representing the magnitude of the reactance is drawn at right angle to the vector representing the resistance, these vectors may be resolved into an equivalent vector drawn at an angle to the resistance vector. The length or magnitude of the equivalent vector is known as the modulus of the impedance. The angle between the equivalent vector and the resistance component is known as the angle of the impedance. If now we measure the reactance and resistance components of each of two circuits at a given frequency, the ratio of the impedance of the two circuits may be expressed in terms of the impedance moduli of the two circuits and the impedance angles of the two circuits. This is done by dividing the modulus of one circuit by that of the other to obtain the "modulus of the impedance ratio" and by subtracting the corresponding angles to obtain the "angle of the impedance ratio". The curves A and B of Fig. 1 are obtained by plotting the "modulus of the impedance ratio" and the "angle of the impedance ratio" for the entire range of voice and carrier frequencies to be transmitted over an open wire circuit and a cable circuit to which it is joined.

Curve A represents values for the modulus of the ratio and curve B represents values for the angle of the ratio at various frequencies plotted logarithmically. It will be seen that at the upper carrier frequencies illustrated, such as at 30,000 cycles, the impedance ratio has a modulus of about 4.6 with a 6° angle, while at the low voice frequencies, such as 300 cycles, the impedance ratio has a modulus of only 1.5 but with a 25° angle. Due to this variation in impedance ratio the use of a transformer having the impedance ratio of the circuits at carrier frequencies would increase the impedance irregularity at voice frequencies at the junction of a non-loaded cable circuit and a non-loaded open wire circuit to such an extent that it would be very objectionable from the repeater balance standpoint when the circuit is used to transmit a repeated voice frequency system.

If the incidental cable circuit is electrically short at voice frequencies and is equipped at each end with properly designed transformers, this variation in the ratio between the impedances of the open wire circuit and cable circuit may be unimportant, since the length of the cable makes its effect small, and the transformers work practically back to back. Assuming the use of two equal ideal transformers, i. e., transformers which have

perfect transformer action without any impedance distortion effects, the impedance of the open wire line at the voice frequencies would be reduced by the ratio of the first transformer and, then, little distortion being introduced by the short cable circuit, would be stepped back by the second transformer to practically the impedance of the open wire line so that the irregularity introduced by the cable and transformers would be very nearly equal to zero. However, in actual practice it is not possible to design transformers which have this ideal performance, i. e., the energy losses in the practical (non-ideal) transformers cause impedance distortion effects which must be taken into consideration. These effects consist of an addition to the resistance and reactive component to the impedance at voice frequencies looking into the high side of one transformer. Thus, in the practical case, under the ordinary assumptions made above, there results an impedance irregularity at this point which may be great enough to make the use of the transformer mentioned very objectionable on voice frequency repeated circuits.

Accordingly, it will be seen that the use of impedance modifying transformers to correct for reflection losses at carrier frequencies may be objectionable from the transmission standpoint, with respect to voice frequency repeated channels for two reasons,—first, because of the variation with frequency of the impedance ratio of the two circuits, and secondly, because of the impedance irregularities introduced by the inherent impedance distortion effect of the transformers themselves. It is these two objectionable features to the use of transformers that the present arrangement and application of transformers in the transmission line will substantially overcome, as will appear more fully hereinafter.

The effect of the inherent impedance distortion of the transformer at voice frequencies may be more fully understood with reference to Fig. 3 which is a schematic showing of the two line sections 2 and 3 interconnected through the transformers 4 and 5 and the cable circuit 1. The transformers have been represented by equivalent T networks of impedances having the series components Z_s and Z_s' . These components Z_s and Z_s' are equivalent to the copper resistance of the coils and the leakage reactance. Z_M and Z_M' represent the transformer mutual impedance. At carrier frequencies this mutual impedance factor would be very large. However, at voice frequencies, it might be small enough to be comparable to the line impedances which are termed Z_L and Z_L' . Let it be assumed that the auto-transformers have equal ratios at voice frequencies of 5:1, that the line impedance, such as Z_L or Z_L' is equal to 650

ohms, that Z_s and Z_s' are negligibly small and equal to $+j 3,000$, this being a value consistent with good design for the conditions noted.

(In parallel with)
Then $Z_L' // Z_M'$ is equivalent to $\frac{650/0^\circ \times 3000/90^\circ}{650 + j 3000} = 635/12.2^\circ$

The impedance at points cd , or

$$Z_{cd} = 635/12.2 \div 5 = 127/12.2$$

Z_{cd} as seen through the transformer at

$$A = 127/12.2 \times 5 = 635/12.2$$

The impedance at points ab or

$$Z_{ab} = Z_M // 635/12.2 = j 3000 // 635/12.2 = 597/23.4 \text{ or } 548 + j 237$$

5 Hence it will be seen that as impedance $Z_{ab} = 597 + j 237$ and as the line impedance $Z_L = 650$, that there is a considerable irregularity between these impedances. Accordingly, it will be seen that at voice frequencies the inherent distortion effect of the transformers, assuming well designed transformers of equal ratio, will introduce an objectionable impedance irregularity in the line.

10 In actual practice the auto-transformers, as shown in Fig. 2, will have condensers at their midpoints for circuit operation reasons,—i. e., to prevent the existence of a direct-current shunt across the line which would prevent superposed telegraph operation by the usual composite method. These condensers would normally be of equal values in both transformers and would ordinarily have a capacity of 2 mf. or lower, in order to keep cross-fire between superposed telegraph circuits low. The effect of inserting a condenser at the midpoints of the windings of the auto-transformers is to increase the effective transformer ratio above the nominal ratio at voice frequencies. This will appear more fully from the following discussion, together with Figs. 4 and 5. For an auto-transformer, as shown in Fig. 4, by suitably proportioning the windings, the nominal impedance ratio would be made the same as the ratio of the impedances of the lines which it interconnects, since this is the condition of maximum energy transfer. In the case illustrated, the

nominal impedance ratio would be $\frac{Z_p}{Z_q}$. The transformer ratio would, as a first degree approximation, be independent of frequency. Now, after setting the transformer ratio as $\frac{Z_p}{Z_q}$, if a condenser is added at midpoint, as illustrated in Fig. 5, the effective impedance ratio becomes

$$\frac{Z_p + Z_c}{Z_q + Z_c}$$

50 This effective ratio is not materially greater than the nominal ratio at carrier frequencies,

since the impedance of the condenser is negligible at high frequencies. The difference is quite material at voice frequencies, however, and the larger the impedance of the condenser, the larger will be its effect in changing the effective transformer ratio, particularly at voice frequencies. For a transformer having a high side inductance of 3 henries, a 2 mf. condenser would raise the impedance ratio from a nominal value of 5 to 1 to an effective ratio of about 6 to 1. Similarly, a 3 to 1 nominal ratio would be raised to about 3.5 to 1. The insertion of a midpoint condenser also affects the series arms of the transformer equivalent network so that besides representing the copper loss and the leakage impedance, these arms also represent some of the condenser reactance.

Hence, at voice frequencies, taking into consideration all the impedance components of the auto-transformers, Z_L' in combination with Z_M' and Z_s' = an impedance having a magnitude of about 875. With a 5:1 nominal ratio, which, as has been seen, is equivalent to an effective ratio of 6:1

$$Z_{cd} = 145\omega$$

$$Z_{cd} \text{ seen through transformer at } A = 875\omega$$

$$Z_{cd} \text{ in combination } Z_M \text{ and } Z_s = 1000\omega$$

$$\therefore Z_{ab} = 1000.$$

It will be seen that when Z_{ab} is compared with the line impedance Z_L that the match is very poor. It, in fact, amounts to an impedance irregularity introduced by the transformers of 55%, which would make it exceedingly difficult to balance voice frequency repeater apparatus in the line.

At carrier frequencies the effect of the transformer is that of a shunt capacity reactance and a series inductance. The shunting impedance of the capacity reactance is generally high enough for the range of frequencies involved so that at carrier frequencies, the auto-transformers are equivalent to a T network having series arms of small impedance and a shunt arm having an impedance which is very large as compared

with the impedance of the open wire line. The resultant impedance equivalent to the shunt arm in parallel to the line impedance with the series arms, will therefore not be greatly different from the impedance of the open wire line, which at carrier frequencies may be assumed to be 600 ohms. Hence, at carrier frequencies of 30,000 cycles we have from Fig. 3

$$Z_L = Z_L' = 600\omega$$

$$Z_M' // Z_L' = 600\omega +$$

$Z_{ed} = 120\omega +$ (the effective ratio being substantially the same at carrier frequencies as the nominal ratio of 5:1)

$$Z_{ed} \text{ seen through transformer at } A = 600\omega + Z_{ab} = Z_M // 600\omega + = 600\omega +$$

Obviously in view of the matching of impedances Z_L and Z_{ab} , there would be only a small reflection loss at carrier frequencies under these conditions.

Owing to the bad irregularity at voice frequencies, it might be desirable in accordance with this invention to change the ratio of the transformer at A to make the impedance Z_{ab} a substantial match to the impedance Z_L at voice frequencies. This would, of course, cause reflection loss at the carrier frequency. For purposes of illustration, let us change the nominal ratio of the transformer at A from 5:1 to 3:1. Due to the midpoint condenser, the effective ratio, as has been pointed out under such conditions, would become 3.5:1. Under these conditions

$$Z_{ed} = 145\omega$$

Z_{ed} seen through transformer at A with ratio 3.5:1 = 510ω

$$Z_{ab} = Z_M + Z_s \text{ in combination with } 510\omega = 850\omega$$

Compared to the line impedance Z_L' it will be seen that this gives an impedance irregularity of only 33% at voice frequencies instead of 55% for the case previously pointed out.

While this impedance irregularity of 33% is greater than would be desired at voice frequencies, it may be reduced by further change in the nominal transformer ratio. Before considering this possibility, let us see what the use of a 3:1 nominal ratio for the transformer at A does at carrier frequencies. As previously explained, the effective ratio with a 2 mf. midpoint condenser will be approximately 3:1 at carrier frequencies. As has been shown previously at carrier frequencies

$$Z_{ed} = 120\omega +$$

Z_{ed} at 3:1 ratio seen through transformer at A = $360\omega +$

As Z_M at carrier frequencies is very high as compared to $360\omega +$

$$Z_{ab} = Z_M // 360\omega + = 360\omega +$$

This loss involved by the use of a 3:1 and a 5:1 nominal ratio at A and B, respectively, would therefore be allowable at carrier frequencies. Hence, we might further reduce

the nominal ratio of the transformer at A to get smaller irregularity at voice frequencies. The same effect at voice frequencies can be produced, however, by changing the values of the midpoint condensers without causing further loss at carrier frequencies. In other words, by proportioning the condensers we can reduce the effective transformer impedance ratio at voice frequencies without reducing the ratio at carrier frequencies. This is evident from the fact previously noted that the nearer Z_c approaches zero, the nearer will the effective ratio at voice frequencies approach the nominal ratio. Hence, if we increase the size of the midpoint capacities (thus decreasing their impedance) we may reduce the effective ratio at voice frequencies without reducing the effective ratio of the transformer at carrier frequencies. For example, if we use a 3 mf. condenser at the midpoint of the transformer at A, its effective ratio at 300 cycles will be approximately 3.2 to 1. Now referring again to Fig. 3,

$$Z_{ed} = 145\omega$$

Z_{ed} seen through transformer at A with ratio of 3.2 to 1 = 460ω

$$Z_{ab} = Z_M \text{ and } Z_s \text{ in combination with } 460\omega = 750\omega$$

It will be seen that, as compared with the line impedance, this results in an irregularity at voice frequencies of only 19%. The irregularity at carrier frequencies is not materially changed. It will therefore be apparent that in accordance with this invention by reducing the nominal ratio of the transformer and by adjusting its midpoint capacity, the irregularity at voice frequencies may be brought to an allowable value at the expense of some increase in the reflection loss at carrier frequencies as compared with the ideal condition involving an exact matching of impedances at carrier frequencies.

In order to more clearly understand how the impedance irregularities at voice frequencies may be brought within allowable limits at only a small increase in the reflection loss at carrier frequencies in accordance with the principles of this invention, there is presented a series of calculations based on conditions met in actual practice. These may more readily be understood from reference to Figs. 6, 7 and 8.

In Fig. 6 are shown two line sections 2 and 3 interconnected by the cable 1 without the use of auto-transformers. Line sections 2 and 3 are non-loaded 165 mil open wire circuits. The cable section consists of 0.94 miles of #13 gauge non-loaded cable. The cable equivalent at carrier frequencies of 25 kilocycles is 1.2 T. U. At this carrier frequency the overall transmission loss due to the insertion of this cable in the transmission line was 8 T. U. At voice frequencies the cable circuit is short electrically, so the total loss

due the cable is about the same as the cable equivalent, which is about .4 T. U. Accordingly, the presence of the cable introduces an irregularity at voice frequencies of about 28% which in this particular case is allowable.

In Fig. 7 auto-transformers have been inserted at the junction points of the cable and the open wire circuits. These transformers have the same nominal ratio of 5:1. The voice frequency case may be considered first with a frequency of 300 cycles. The line impedance $Z_L = 635 - j190$. If the transformers are ideal, then $Z_L = Z_{ab}$, and the impedance irregularity at $ab = 0$. However, if real transformers used in practice are utilized, then $Z_{ab} = 950 - j490$, and the impedance irregularity at $ab =$

$$\frac{950 - j490 - (635 - j190)}{635 - j190} = 66\%$$

At carrier frequencies of 25 kilocycles, due to the effect of the transformer ratio, the overall loss due to the cable plus the two transformers is 2 T. U. Therefore, the net gain at carrier frequencies is $8 - 2 = 6$ T. U.

In Fig. 8 the transformers at the junction points of the cable and open wire circuits have inserted at their midpoints the condensers C_a and C_b . Let it be assumed that the values of these condensers are the same and are 2 mf. each. The transformers have different ratios, the transformer at ab having a 3:1 ratio and the other transformer having a 5:1 ratio. Under these conditions at a voice frequency of 300 cycles $Z_{ab} = 750 - j380$ and the impedance irregularity at $ab = 33\%$. This irregularity is slightly higher than the value 28% given above as allowable. As has been previously pointed out in the theoretical case the impedance irregularity at ab can be further reduced by further lowering of the nominal ratio of the transformer at ab . Doing this, however, would sacrifice transmission at carrier frequencies, since the reflection loss would be increased at such a point. As has been previously pointed out, the same effect at voice frequencies may be accomplished by increasing the capacity of the condenser at the midpoint of the transformer at ab . This would not sacrifice any transmission at carrier frequencies, since the effect of the condenser is negligible in that range. Accordingly, let us change the value to 3 mf. Then $Z_{ab} = 700 - j300$, and the impedance irregularity at $ab = 19\%$. At carrier frequencies the loss due to the reduction of the nominal ratio of the transformer at ab from 5:1 to 3:1 is only about .2 T. U.

Hence by applying the principles of this invention to the above discussed case, we find that the net gain at carrier frequencies due to the transformers will be about 5.8 T. U. Or, in other words, the total loss due to the

insertion of the cable circuit and transformers in the line is 2.2 T. U. as compared to a condition when the line is open wire throughout. At the same time the impedance irregularity at voice frequency is only 19% which is well within allowable limits from a voice frequency repeater balance standpoint in this particular case.

The utilization in accordance with the principles of this invention of transformer units having different ratios at the ends of a non-loaded cable circuit is applicable in actual telephone practice in cases where the impedance irregularity at voice frequencies is important from the voice frequency repeater standpoint at only one end of the cable. In Figs. 9, 10 and 11 are illustrated three different service conditions found in actual practice in transmission lines to which the transformer units of this invention are applicable.

In Fig. 9 are shown two open wire circuits interconnected by a cable with transformers at A and B, and only one voice frequency repeater located at R, no voice frequency repeater being involved beyond B. It will be seen that the impedance irregularity at voice frequencies will be important only at the end of the cable circuit at A, and hence the ratio of the transformer thereat will be adjusted in accordance with this invention to correct for this irregularity. There would be no voice frequency repeater apparatus in the open wire circuit connected to the cable at B and hence any impedance irregularity at B would be unimportant. In other words, the invention is applicable when the distance R-A is short enough so that the impedance irregularity at voice frequencies at A due to correcting for reflection losses at carrier frequencies is great enough to effect the repeater balance at R.

In Figure 10 is shown a line in which voice frequency repeater apparatus is included in both of the open wire lines, as at R and R'. The repeater at R is quite close to the cable, and is effected by impedance irregularities at A. Hence the different ratio transformer unit of this invention may be utilized to correct for the effect of this impedance irregularity at A on the repeater at R. The irregularity at B will not affect the repeater at R' as it will be located at such a distance from B that the effect of the irregularity introduced at B will be small at R' due to the attenuation of the line B-R'.

In Fig. 11 is illustrated a line having a repeater at R close enough to A to be affected by irregularities thereat and also having a repeater at R' close enough to B to be affected by irregularities thereat. Under these conditions the transformer unit of this invention may be utilized to correct for the effect on R of irregularities at A as heretofore. To correct for the effect of irregularities at B on R' the repeater at R' would have a balancing net-

work N adapted to simulate that section of the open wire line between R and A and would also be provided with an additional network A', B', C' to simulate the transformer unit (including cable) utilized at A B.

While the invention has been disclosed as embodied in certain specific forms and as applicable to certain specific types of lines, it is understood that this has been done for purposes of illustration only, and that the invention may be embodied in many other forms and circuits without departing from the spirit of the appended claims.

What is claimed is:

1. A transmission line over which currents of carrier frequencies and currents of voice frequencies are transmitted, said transmission line comprising two open wire circuits of relatively high impedance interconnected by a cable circuit of relatively low impedance, balanced voice frequency repeater apparatus in one of said open wire circuits, and impedance modifying means at the junction points of said cable and open wire circuits, said impedance modifying means comprising auto-transformers having condensers at the midpoints of their windings, the constants of each of said impedance modifying means being so adjusted with respect to the characteristics of said individual open wire circuits, which differ due to the inclusion of said balanced repeater apparatus in only one thereof, that the variation in impedance distortion at different transmitted frequencies introduced

thereby in said line will be reduced to a minimum.

2. A transmission line over which currents of carrier frequencies and currents of voice frequencies are transmitted, said transmission line comprising two open wire circuits of relatively high impedance interconnected by a cable circuit of relatively low impedance, voice frequency repeater apparatus in one of said open wire circuits, and impedance modifying means at the junction points of said cable and open wire circuits, said impedance modifying means comprising auto-transformers having condensers at the midpoints of their windings, the auto-transformer interconnecting the cable circuit and the open wire circuit without said voice frequency repeater apparatus having an impedance ratio equal to the nominal impedance ratio between said circuits at carrier frequencies and the midpoint condenser associated therewith being of a fixed capacity value, the auto-transformer interconnecting the cable circuit and the open wire circuit including said voice frequency repeater apparatus having an impedance ratio smaller than the nominal impedance ratio between said circuits at carrier frequencies and the midpoint condenser associated therewith being of greater capacity value than said other condenser.

In testimony whereof, I have signed my name to this specification this 22nd day of December, 1926.

BENJAMIN F. LEWIS