April 29, 1930. M. M. DOLMAGE 1,756,816

IMPEDANCE VARIATION COMPENSATOR CIRCUITS

Filed Feb. 13, 1920 2 Sheets-Sheet 1

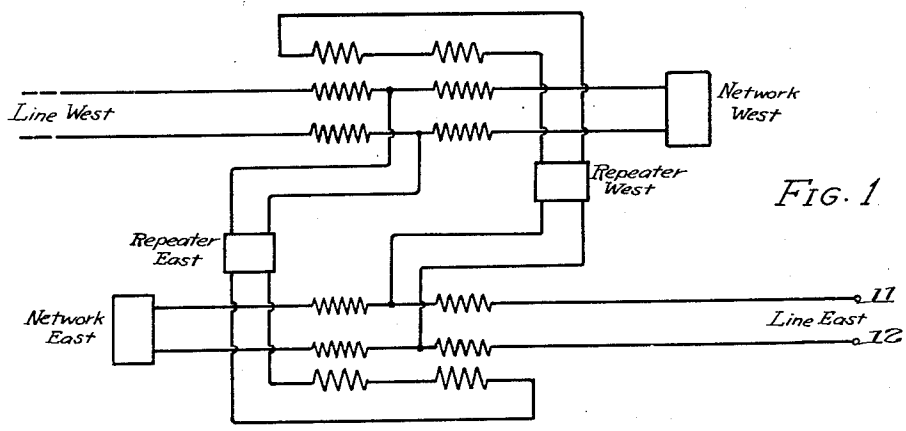



FIG. 1

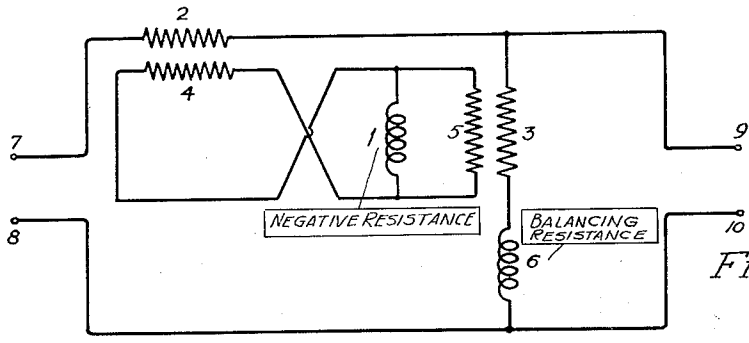



FIG. 2

IMPEDANCES 6 AND 1 TO BE OF OPPOSITE SIGN.

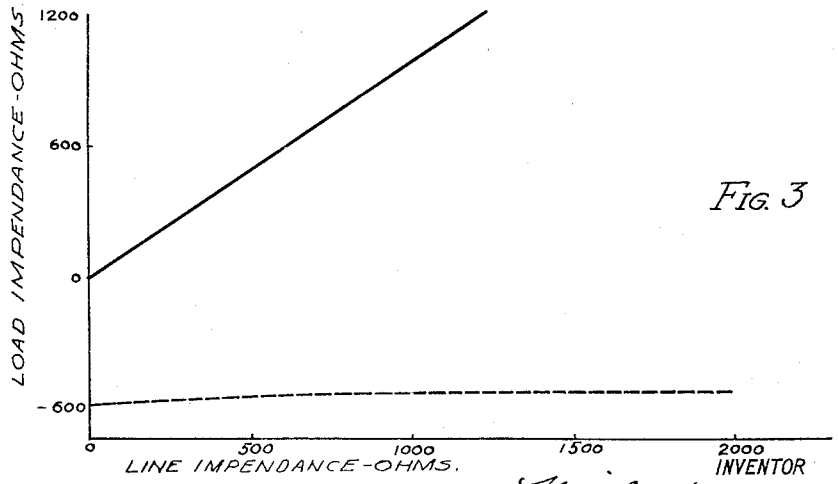



FIG. 3

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IMPEDANCE VARIATION COMPENSATOR CIRCUITS

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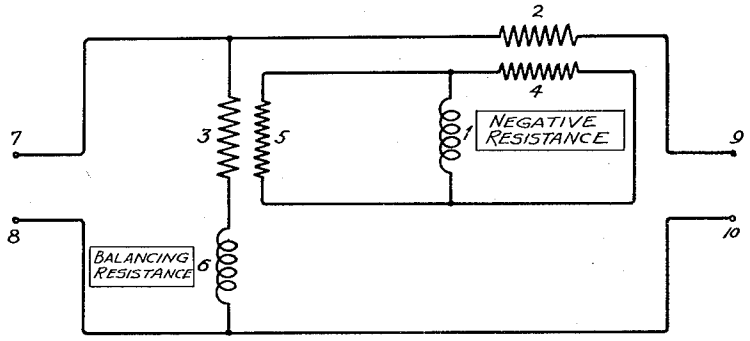



FIG. 4

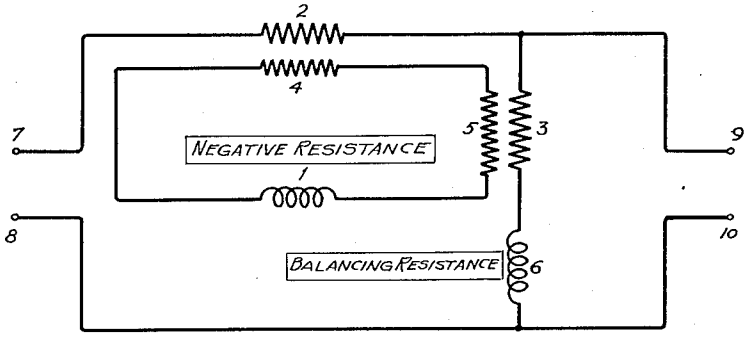
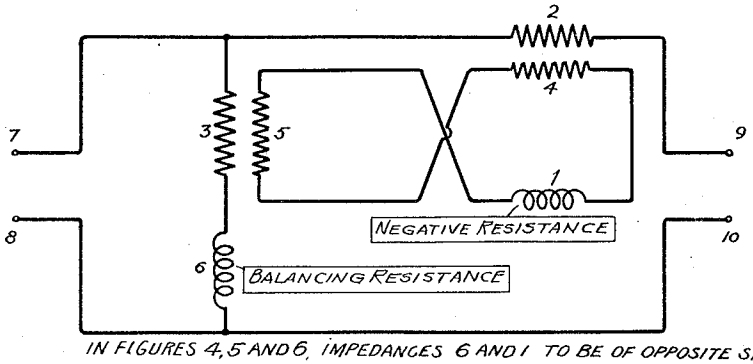



FIG. 5




IN FIGURES 4, 5 AND 6, IMPEDANCES 6 AND 1 TO BE OF OPPOSITE SIGN.

FIG. 6

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## IMPEDANCE VARIATION COMPENSATOR CIRCUITS

Application filed February 13, 1920. Serial No. 358,370.

This invention has for its main object the amplification and transmission of speech currents in both directions. Where only two wires are utilized to secure telephonic transmission between any two points and a repeater is associated with the transmission line, the repeater circuit which finds the most successful application in practice is known as the "22" type. In a circuit of this type, which essentially consists in a duplex Wheatstone bridge arrangement, the telephone line is balanced by the inclusion in the opposite arm of the bridge of an artificial line of similar impedance — frequency characteristics. The two sections of the telephone transmission line or the two telephone transmission lines, between which the telephone repeating equipment is interposed, are each terminated by bridge circuits, an artificial line in each case balancing its corresponding telephone line. A "22" type repeater circuit is diagrammatically illustrated in Fig. 1. As will be evident by reference to this diagram, such a circuit will operate satisfactorily without "singing" provided the telephone line and its corresponding artificial line have approximately equal impedance characteristics, or have impedances which are not widely different. This limitation is described by Gherardi and Jewett in the November 1919 issue of the "Proceedings of the American Institute of Electrical Engineers", (vol. 38, page 1296) wherein it is stated:

"It is then the line conditions, rather than the repeater element or its circuits which finally limit in every practical case the amplification which can be obtained with a repeater."

If some way could be found to limit the variation in the impedance of the telephone lines that may be connected to a repeater station of the "22" type, the range of usefulness of the telephone repeater could be very widely extended, and its operation made more certain under all conditions.

This invention consists essentially in the discovery of a method for automatically limiting the impedance of all telephone lines within predetermined values and in the disclosure of the practical means required to accomplish such a purpose.

In general, the impedance of telephone lines will have a resistance component and a reactive component. The resistance component may vary between zero ohms and infinity ohms, the reactive component between minus infinity and plus infinity, depending upon the length of the telephone line and its termination. Furthermore, any given line will have characteristics which change with temperature, humidity and the frequency of the speech currents transmitted over this line so that it is not possible to secure a balance by means of an artificial line except under certain limiting conditions. One object of this invention is to secure greater amplifications at each repeating station than is now possible. It can be applied to any two-way repeater circuit wherein freedom from "singing" is obtained by the use of artificial lines balancing telephone lines, also where freedom from "singing" is obtained by the use of telephone lines balancing each other without the interposition of any artificial lines. While a particular type of two-way repeater circuit is shown on the drawings and described in these specifications, it will be clear at once to any one who is familiar with the electrical art that its application is not limited to any particular two-way repeater circuit. The invention will be more fully described in connection with the accompanying drawings, in which Fig. 1 represents the well-known "22" type telephone repeater circuit. Fig. 2 illustrates diagrammatically one embodiment of my invention. Fig. 3 shows a set of telephone line impedance curves obtained after the interposition of the circuit of Fig. 2 between a two-way repeater circuit and telephone lines of various impedances. Fig. 4 indicates a modification of the arrangement shown in Fig. 2. Fig. 5 indicates a still further embodiment of my invention. Fig. 6 shows a modification of the arrangement shown on Fig. 5.

The arrangement of Fig. 1 illustrating a "22" type telephone repeater circuit is too well known to require description. In the arrangement shown in Fig. 2, terminals 7—8

connect to any two-way repeater circuit at the points where a telephone line would normally terminate. The telephone line itself would be connected to terminals 9—10 of the same figure. As an illustration, if the two-way repeater circuit is of the type shown in Figure 1, then terminals 7—8 of Figure 2 would be connected to terminals 11—12 of Figure 1, and the telephone line to terminals 9—10 of Fig. 2. In this same Fig. 2, 1 is an impedance, 2 is the primary winding of a telephone transformer wired in series relation with the telephone line, 4 is the secondary winding of this same transformer. In parallel with the telephone line is wired the primary 3 of a second transformer and an impedance 6. Secondary winding 5 of this second transformer and secondary winding 4 are wired in parallel with impedance 1, in the manner shown. The mode of operation of this circuit will be clear if it is stated that amplified speech currents reaching terminals 7 and 8 from a two-way repeater circuit flow through winding 2 and divide into two paths—part of these currents is sent over the telephone line connected to terminals 9 and 10 and part is sent through winding 3 and impedance 6. Electromotive forces are thereby induced in windings 4 and 5. The aforesaid windings are so associated that the electromotive forces induced in these windings tend to force currents in the same direction through 1. As will also be evident by inspection, attenuated speech currents from distant points reaching the circuit of Fig. 2 via terminals 9—10 divide in two paths, a path through winding 2 and a second path through winding 3. The electromotive forces induced in windings 4 and 5 tend, in this case, to force currents in opposite directions through 1, and if the windings have been properly proportioned the resulting current through 1 may be made nil in value. In Fig. 3 two curves are shown, one in full line and the other in dotted line. The full line curve which is a straight line, shows in ordinate the impedances as seen from the two-way repeater circuit, when various telephone lines having the impedances indicated in abscissæ are directly connected to the two-way repeater circuit. The curve shown in dotted line indicates the same impedances as seen again from the same two-way repeater circuit, when the same telephone lines instead of being directly connected to the two-way repeater circuit, are connected to terminals 9 and 10 of Fig. 2 of the drawings. This last curve shows in a very clear way the effectiveness of the circuit of Fig. 2 in flattening out the impedances.

In Fig. 4 the elements are exactly the same as indicated on Fig. 2. 1 is an impedance, 2 and 4 represent the primary and secondary windings respectively of a transformer, 3 and 5 the primary and secondary windings respectively of a second transformer, 6 is an impedance. The only difference between the arrangements of Fig. 2 and Fig. 4 consists in the fact that in addition to the current transmitted over the telephone line, all of the locally utilized current finds a path through winding 2 of Fig. 2, while the transmission current only is allowed to flow through winding 2 of Fig. 4. The transformer secondaries 4 and 5 are associated exactly as before, viz, in such a manner that while receiving from a distant point, the electromotive forces induced in windings 4 and 5 tend to force currents in opposite directions through element 1.

In Fig. 5 the circuit arrangement is similar to the arrangement shown in Fig. 2 except that secondary windings 4 and 5 are in series with each other and with element 6, instead of being in parallel. The secondary windings 4 and 5, as heretofore, are associated in such a manner that the electromotive forces induced in these windings will be in opposition when receiving from a distant point.

In Fig. 6 the circuit arrangement is similar to the arrangement shown in Fig. 4, except that secondary windings 4 and 5 are in series with each other and with element 6, instead of being in parallel. In this case also these windings are so associated that, when receiving from a distant point, the electromotive forces induced in 4 and 5 would be in opposition to each other.

In the arrangement shown on Fig. 2 we may assume that the telephone repeater impedance has only a resistance component and no reactive component. This is usually the case with two-way repeater circuits, using vacuum tubes of a modern type as repeater elements. With the arrangement described, the impedance range as measured between terminals 7 and 8 and with this telephone line connected to terminals 9 and 10, can be made not to exceed a predetermined value, even though the impedance range of the telephone line itself may vary between 0 and infinity ohms. In fact the impedance measured between terminals 7 and 8 can be made a non-varying quantity, if desired, though the impedance of the telephone line itself may vary between 0 and infinity ohms. It will be shown, however, that this last arrangement though possible is not a desirable one.

A complete mathematical demonstration of my method as illustrated in Fig. 2 is furnished hereunder.

The following is the notation used:

E—Electromotive force of telephone repeater output circuit.

X—Resistance of telephone repeater output circuit, through which is acting electromotive force E.

Y—Resistance of element 6 of Figure 2.
A—Resistance of element 1 of Figure 2.

Z—Impedance of line as measured from terminals 9 and 10—Figure 2 of the drawings.

L—Impedance as measured from terminals 7 and 8 when impedance Z is connected to terminals 9 and 10.

N—Impedance as measured from terminals 9 and 10 when resistance X is connected to terminals 7 and 8.

$I_1$—Current transmitted to line connected to terminals 9 and 10 when the repeater equipment is connected to terminals 7 and 8.

$I_2$—Current through resistance 6 when the repeater equipment is connected to terminals 7 and 8.

$I_3$—Current in winding 4 when the repeater equipment is connected to terminals 7 and 8.

$I_4$—Current in winding 5 when the repeater equipment is connected to terminals 7 and 8.

If, for the sake of simplicity, we make the number of turns in windings 2 and 4 the same, and correspondingly the number of turns in windings 3 and 5 the same, then the difference of potential across the resistance A will be equal to

$$A(I_1+I_2)+AI_2=A(I_1+2I_2).$$

The transmitting equations, with the repeater connected to terminals 7 and 8, can then be written very simply as follows:

(1) $E=X(I_1+I_2)+A(I_1+2I_2)+A(I_1+2I_2)+YI_2$

(2) $E=X(I_1+I_2)+A(I_1+2I_2)+ZI_1$

Combining together all terms in ($I_1$) and ($I_2$) the above equations can be written as shown below:

(3) $E=(X+2A)I_1+(X+4A+Y)I_2$

(4) $E=(X+A+Z)I_1+(X+2A)I_2$

The solution of the above equations by means of ordinary algebra leads to:

(5) $$I_1=E\frac{2A+Y}{(X+4A+Y)(X+A+Z)-(X+2A)^2}$$

(6) $$I_2=E\frac{Z-A}{(X+4A+Y)(X+A+Z)-(X+2A)^2}$$

The accuracy of the above can be readily checked by substitution of $I_1$ and $I_2$ into Equations (3) and (4), which then become identities. The denominator in equations (5) and (6) can be further simplified and written in the following form:

(7) $$I_1=E\frac{2A+Y}{AX+YX+AY+Z(X+4A+Y)}$$

(8) $$I_2=E\frac{Z-A}{AX+YX+AY+Z(X+4A+Y)}$$

The total output current $(I_1+I_2)$ of the repeater circuit is given by:

(9) $$I_1+I_2=E\frac{A+Y+Z}{AX+YX+AY+Z(X+4A+Y)}$$

The total impedance in the circuit, including the output resistance X of the repeater is obtained directly from Equation (9) and is given by:

$$\frac{AX+YX+AY+Z(X+4A+Y)}{A+Y+Z}$$

If we subtract from the above the output resistance X of the repeater, we obtain the impedance of the outside load on the repeater, as follows:

(10) $$\frac{AX+YX+AY+Z(X+4A+Y)}{A+Y+Z}-X=\frac{AY+Z(4A+Y)}{A+Y+Z}$$

The impedance of the repeater load, as given by the foregoing equation, evidently depends upon Z, and it is my primary object to have this impedance vary as little as possible when Z varies. It may be shown very easily that when:

(11) $AY=(4A+Y)(A+Y)$

the load impedance, as given by Equation (10), is independent of the variable line impedance Z. For proof, replace in the numerator of the fraction in Equation (10), AY by the value given in Equation (11) for AY. This substitution results in the following value for the load impedance:

(12) $$L=\frac{(4A+Y)(A+Y)+Z(4A+Y)}{A+Y+Z}=4A+Y$$

The value of the load impedance, as given by Equation (12), namely $4A+Y$, does not contain Z, the variable line impedance, and, therefore, the repeater would be working

under the ideal condition of constant impedance, if A is so chosen that Equation (11) is satisfied. This equation, relating together just the two quantities A and Y, both of which we may choose at will, can be further simplified into the following relation, when the common term AY is cancelled from both sides of conditional Equation (11), which then becomes:

$$(13)\quad 4A^2+4AY+Y^2=(2A+Y)^2=0$$

Hence, to obtain the condition sought for, it is sufficient to make:

$$(14)\quad 2A+Y=0$$

It is important to note that when relation (14) is satisfied, the load impedance will have a numerical value equal to:

$$(15)\quad L=4A+Y=-Y$$

It is also important to note that if Y is taken as a positive resistance, then A as obtained from Equation (14), is a negative resistance equal to $-\frac{Y}{2}$.

The transmitting conditions in the reverse direction, when an electromotive force E is acting through impedance Z, connected to terminals 9 and 10, with a resistance X, connected to terminals 7 and 8, are given by the following set of equations.

If we call:

E—Electromotive force acting through the impedance Z of the line.

$I_5$—Received current into repeater circuit.

$I_6$—Current through balancing resistance 6 (designated as Y).

$$(16)\quad E=Z(I_5+I_6)-A(I_5-I_6)+YI_6$$

$$(17)\quad E=Z(I_5+I_6)+A(I_5-I_6)+XI_5$$

Rearranging the above in terms of $I_5$ and $I_6$, we get:

$$E=(Z-A)I_5-(Z+A+Y)I_6$$

$$E=(Z+A+X)I_5-(Z-A)I_6$$

The solution of the above simple set of equations is given by ordinary algebra as follows:

$$I_5=E\frac{2A+Y}{(Z+A+Y)(Z+A+X)-(Z-A)^2}$$

$$I_6=E\frac{2A+X}{(Z+A+Y)(Z+A+X)-(Z-A)^2}$$

It will be noted that if conditional Equation (14) is satisfied, which results in the ideal condition of constant load upon the repeater, then the receiving into the repeater is nil, in view of the numerator of I being equal to $(2A+Y)$, unless the denominator is also equal to 0. We can write this denominator (D), as follows:

$$D=(Z+A+X+Y-X)(Z+A+X)-(Z-A)^2$$

$$D=(2A+X)(2Z+X)-(Y-X)(Z+A+X)$$

Using the last expression for D given above, in connection with $I_5$ and $I_6$, we obtain:

$$(18)\quad I_5=E\frac{2A+Y}{(2A+X)(2Z+X)+(Y-X)(Z+A+X)}$$

$$(19)\quad I_6=E\frac{2A+X}{(2A+X)(2Z+X)+(Y-X)(Z+A+X)}$$

It is evident immediately that if $2A+Y=0$, in order for the received current to be different from 0, we must have:

$$2A+X=0$$
$$Y-X=0$$

If the conditions just outlined are satisfied, then we may divide the numerator and denominator of Equation (18) by $2A+Y$, which is also equal to $2A+X$, and by so doing we obtain—

$$(20)\quad I_5=\frac{E}{2Z+X}$$

We may here observe that regardless of the fact whether $2A+Y$ is chosen equal to 0 or given some value different from 0, if $Y=X$, then Equation (20) is always satisfied.

The total impedance to currents received from the line through terminals 9 and 10 is given by:

$$(21)\quad \frac{E}{I_5+I_6}-Z=\frac{AX+AY+XY}{4A+Y+X}$$

We can now show that the above impedance varies but little with X, and, therefore, the impedance variation compensator circuit, as shown on Figure 2 of the drawings will also work effectively if a variable load is connected to its terminals 7 and 8 instead of to the terminals 9 and 10. For proof, assume again A is an impedance which we can choose at will. Then, if—

$$(22)\quad AY=(A+Y)(4A+Y)$$

the total impedance as measured from the terminals 9 and 10, with a variable load X connected to terminals 7 and 8 is independent of the variable load X. To prove this point, substitute AY as given in Equation (22) into the numerator of Equation (21), then this last equation becomes equal to $A+Y$, as shown hereunder:

$$(23)\quad N=\frac{AX+(4A+Y)(A+Y)+XY}{4A+Y+X}=A+Y$$

Conditional Equation (22) relating together A and Y is exactly the same as conditional Equation (11), which we showed resulted in a constant impedance $4A+Y$, when the variable load Z was connected to terminals 9 and 10 and the impedance was meas-

ured from terminals 7 and 8. This conditional equation, as already shown, is equivalent to the simpler equation $2A+Y=0$, as shown in Equation (13). The constant impedance obtained in this case, as given by Equation (23) is equal to $A+Y$, which shows that when conditional Equation (22) is satisfied, this impedance is very simply given by $+\frac{Y}{2}$.

Summarizing the analysis of the performance characteristics of the circuit arrangement shown on Figure 2 of the drawings, we may state that if the critical condition $2A+Y=0$ is satisfied, a variable load Z, connected to the terminals 9 and 10, will be completely compensated and become a constant fixed load equal to $-Y$ ohms, when seen from terminals 7 and 8. Correspondingly, if the situation is reversed and the variable load is connected to the terminals 7 and 8, complete compensation is again obtained, and the load when measured from terminals 9 and 10 will be a constant fixed load equal to $+\frac{Y}{2}$.

If the variable load is connected to terminals 9 and 10 and the generator or repeater (such as illustrated in Figure 1 of the drawings) is connected to terminals 7 and 8, and further A is so chosen that the critical condition as given by Equation (14) is satisfied, then Y must be taken equal to X and the total impedance in the circuit, including that of the repeator X and the impedance as seen from terminals 7 and 8 is equal to $X-Y=0$. The operation of the circuit will require infinite energy since the current delivered by the repeator is equal to infinity under the conditions stated hereinabove.

I have discovered, however, that a value may be chosen for A which will result in limiting the circuit impedance variations as seen from terminals 7 and 8 within any limits that may be desired, without requiring the expenditure of infinite energy in the circuit. Additional amplification without "singing" reactions, over and above what is now possible to obtain with two way repeater systems, may be secured through the use of the method illustrated in Figure 2, if, instead of A being given its critical value as indicated by Equation (14), it is given some value included between ½ and 1 of its critical value.

As a specific example, by giving A a value equal to ¾ of its critical value:

$$(24)\quad A=-\frac{3}{4}\left(\frac{Y}{2}\right)=-\frac{3}{8}Y$$

and substituting this value into Equation (10), gives for the load impedance a value equal to:

$$(25)\quad L=-Y\frac{3Y+4Z}{5Y+8Z}$$

It will be noted that if the actual variable load Z varies between 0 ohms and infinity ohms, the corresponding impedance L will vary between $\frac{-6}{10}$ Y and $\frac{-5}{10}$ Y, respectively. If then Y is 1000 ohms, the impedance affecting the telephone repeater balance varies only between −600 and −500 ohms. Since the impedance of the repeater itself was assumed equal to 1000 ohms, the total impedance of the circuit varies only between +400 and +500 ohms, so that reasonably low energy consumption will be sufficient to secure the excellent results indicated. The variation of L as a function of Z is shown graphically in Figure 3 of the drawings. In this drawing, the abscissæ indicate the line impedance as seen from terminals (9, 10), the ordinates indicate the impedance as seen from the repeater terminals (7, 8). The curve shown on the drawing is a graphical representation of the relation between L and Z given by Equation (25), for Y=1000 ohms, and A=−375 ohms.

If we take a more conservative range of variation for the line impedance, say between 500 ohms and 1,000 ohms, with an average or normal line impedance of 500 ohms, then the following table is obtained (still retaining A=−375 ohms and Y=1,000 ohms):

| Line impedance (terminals 9, 10) | Load impedance (terminals 7,8) |
|---|---|
| 500 ohms | −555 ohms |
| 1000 ohms | −540 ohms |

When the line impedance varies 500 ohms, as shown in the above table, the load impedance is varying only 15 ohms, which is only 3% of the line variation of 500 ohms. It is thus seen how effective is the arrangement shown in Fig. 2 of the drawings in reducing the load impedance variations.

A still more important application may be here referred to. The impedance compensator circuit when interposed at the two ends of a telephone toll line between such toll line and the exchange lines connected to the terminals of said toll line, will act as an effective "echo suppressor". This application can be made both on two wire as well as four wire toll lines. The necessity of some method for compensating the impedances of exchange lines as seen from the toll line will be evident, if it is borne in mind that exchange lines vary greatly in impedance and an electrical speech wave incoming to the exchange system over the toll line will be reflected back (thus producing an echo and resulting in poor quality) if the toll line impedance and the exchange line impedance are not equal in impedance. To secure effective compensation or in this case we might say effective echo suppression, it is necessary to wire the circuit shown in Fig. 2 with terminals (7, 8) connected to the exchange system and terminals (9, 10) to the toll line system. So

far as the toll line is concerned, formulas 18 and 19 will apply. The current into the exchange system will be given by formula 18 and the current into balancing element 6 by formula 19. For normal operation, the impedance Y would be chosen so that the impedance of the circuit, as given by formula 21 would equal the line impedance. The choice of A in the same formula would be governed by the effectiveness with which it is desired to suppress echoes or reflections. To illustrate the extremely valuable application that can be made, assume as stated above, the toll line to be connected to terminals (9, 10) of the circuit shown on Fig. 2, and the toll office connected to terminals (7, 8). For an incoming wave over the toll line, the impedance (M) offered to the wave is given by formula 21 and is equal to

$$M=\frac{AX+AY+XY}{4A+X+Y}$$

Assuming the toll line impedance (X), as seen from terminals (7, 8), to be equal to 1000 ohms and the average exchange line impedance to be equal to 1000 ohms, and taking

$$Y=-1500 \text{ ohms}$$

$$A=-\frac{3}{8}Y=562 \text{ ohms}$$

the value of the impedance M of the exchange line as seen from terminals (9, 10) will be equal to

$$M=Y\frac{5X-3Y}{8X-4Y}$$

When X varies between 0 ohms and infinity ohms, the impedance M varies between −1125 ohms and −937 ohms. Where the average impedance of the exchange line connected to terminals (7, 8) is 1000 ohms, the corresponding impedance M is −1018 ohms. We must therefore wire an impedance equal to 2018 ohms between terminals (9, 10) and the toll line.

With this arrangement in effect, the impedance of the entire combination just described, as seen from the toll line, will be just 1000 ohms.

We can now show the effectiveness of the proposed arrangement as a reflection reducing device by reference to the well known relation giving the ratio ($r$) of the amplitude of the reflected wave to the incoming wave, which is given by—

$$r=\frac{X-X_0}{X+X_0}$$

where

X=impedance of exchange line.

$X_0$=normal impedance of toll line.

Where, for instance, the exchange line has a minimum impedance of 0 ohms and the toll line an impedance of 1000 ohms, the ratio referred to becomes—

$$r=\frac{0-1000}{0+1000}=-1$$

The reflected wave in this case is equal in amplitude to the incoming wave. If, however, the arrangement shown in Fig. 2 is used under the conditions outlined above, the impedance of the exchange line of 0 ohms, as seen from the toll line will be equal to (2018−1125)=893 ohms. In this case, therefore, the corresponding ratio ($r$) will become

$$r=\frac{893-1000}{893+1000}=-\frac{56}{1000}$$

It is thus seen that the amplitude of the reflected wave will be less than 6% of the amplitude of the incoming wave, when the circuit arrangement of Fig. 2 of the drawings is used, while without the interposition of this circuit, the reflected wave, as shown above, is equal to 100% of the amplitude of the incoming wave.

I have therefore succeeded in discovering a method of associating a negative resistance in such a manner with a telephone line or a two-way repeater circuit that this negative resistance will compensate to a large extent the variations in the impedance of a given telephone line for its varying impedance—frequency characteristics, and also any other changes that may be brought about in this impedance by varying temperature or humidity conditions. As a special case, I have also shown that, if desired, the constants of the balancing equipment 6 may be so chosen that the negative resistance itself will work under constant impedance conditions. The arrangement of apparatus I have described may be used either in association with through line repeaters or cord circuit repeaters. In the first case the telephone repeater is associated with a given telephone line. In this case the use of my method will enable the securing of higher amplifications than now possible. In the case of cord circuit repeaters a number of different telephone lines may be connected together by means of this cord circuit. In this case the use of the arrangement I have disclosed, associated with the cord circuit, will make it possible to extend the use of the cord circuit repeater. A proper understanding of this subject may be reached by reference to the paper by Gherardi and Jewett, in the November issue of the "Proceedings of the American Institute of Electrical Engineers", (vol. 38, number 11, page 1308).

I have shown, in the analytical section of these specifications the fundamental requirements that must be satisfied to obtain successful results. It was assumed in this section that the impedance of the telephone repeater circuit could be represented by a

simple resistance. This is actually the case where use is made of vacuum tube repeaters of modern type. The application of my method is not, however, limited to association with repeater circuits having no reactive components in their impedance. If the repeater element in addition to a resistance component has also a reactive component then a balancing equipment having an equal resistance and an equal reactance, instead of a simple resistance, may be substituted in place of resistance element 6. In such a case element 1 must also be chosen, as definitely indicated in the analytical section of these specifications, with proper values for the negative resistance and the negative reactance components. The values will be chosen by reference to Equation (10) giving to both the resistance and reactance components values included between ½ and 1 of the critical value for A derived from Equation (10). It is to be understood that any value whatever between ½ and 1 of the critical or limiting value as derived from Equation (10) may be chosen for A, values nearer unity resulting in larger amplifications but also in correspondingly greater energy consumptions in the special circuit of Fig. 2 of my drawings. To correctly understand the practical significance of my invention it is necessary to revert to the limiting conditions now permissible with "22" type circuits such as illustrated diagrammatically in Fig. 1 of my drawings.

The arrangements shown on Fig. 2, Fig. 4, Fig. 5 and Fig. 6 of the drawings are alike in their operating characteristics. Since the design of the various component parts of Fig. 2 has been very completely dealt with, it is not necessary to indicate in detail here the designing of the circuit arrangements of Fig. 4, Fig. 5 and Fig. 6, as any one familiar with the art can readily do this with the indications given in connection with the design of the circuit shown on Fig. 2 of the drawings. The arrangements shown on Fig. 5 and Fig. 6 are not quite as advantageous to use as those illustrated on Fig. 2 and Fig. 4, on account of the frequency discriminating characteristics of the first mentioned arrangements, but may prove useful in special cases.

I find that I can also use a number of circuits, each wired as shown on Fig. 2, in tandem association with any given two-way repeater circuit.

I have indicated carefully the application of my method to the two-way repeater problem. Numerous other electrical applications can be made of the method outlined in these specifications as this method is applicable in all cases where it is necessary to compensate for varying load conditions. It will apply therefore where it is necessary to secure freedom from "side tone" with telephone substation equipment and in all cases where it is extremely important to maintain a constant impedance for the output circuit of any electrical generating unit, though it is not likely to replace any of the modern voltage regulating methods since this method cannot be recommended from the standpoint of low consumption of energy in securing regulation.

The essential object of the present invention is to show a method of so combining impedances in association with a generating source and a variable load that the total load on the generator itself is substantially constant or is maintained constant within narrow limits. This is equivalent to stating that the outgoing impedance, as seen from the generating source, varies within narrow limits though the load itself may vary within wide limits. Hence, therefore, the effect of the use of the combination of impedances is to limit the variation of the load impedance or perhaps we might be justified to create, for convenience, a new term and state that this effect is "to compensate" for these variations. As impedance 1, due to the particular manner in which it is associated with the load, is to a large extent responsible for the "compensating" effect obtained, I have designated element 1 throughout the claims by its functional property through the new term "compensating impedance."

I claim:

1. Means for compensating varying loads comprising a local circuit, a constant compensating impedance therein having resistance and reactance components of opposite sign to the corresponding impedance components of the generating source, and means for connecting said local circuit to the varying load and to the generating source.

2. Means for compensating varying loads comprising two transformers with primary windings wired respectively in series and in parallel with the load, a negative resistance in the secondary circuit of the two transformers, and means for connecting said primary windings to the generating source.

3. Means for compensating varying loads comprising two transformers with primary windings wired respectively in series and in parallel with the load, a compensating impedance in the secondary circuit of the transformers having resistance and reactance components opposite in sign to the corresponding components of the generating source, and means for connecting said primary windings to the generating source.

4. Means for compensating varying loads comprising two transformers with primary windings wired respectively in series and in parallel with the load, an impedance in series with the winding wired in parallel, a negative resistance in the secondary circuit of the transformers and means to connect said primary windings to the generating source.

5. Means for compensating varying loads comprising two transformers with primary windings wired respectively in series and in parallel with the load, an impedance in series with the winding wired in parallel, a compensating impedance in the secondary circuit of the transformers having resistance and reactance components opposite in sign to the corresponding components of the generating source, and means for connecting said primar windings to the generating source.

6. Means for compensating varying loads comprising two tarnsformers with primary windings wired respectively in series and in parallel with the load, a balancing impedance in series with the winding in parallel equal to the impedance of the generating source, a compensating impedance in the secondary circuit of the transformers having resistance and reactance components of opposite sign to the corresponding components of the generating source, and means for connecting said primary windings to the generating source.

7. Means for compensating varying loads comprising two transformers of identical construction with primary windings wired respectively in series and in parallel with the load, a balancing impedance in series with the winding wired in parallel equal to the impedance of the generating source, a compensating impedance in the secondary circuit of the transformers having resistance and reactive components of opposite sign to the corresponding components of the generating source, and means for connecting said primary windings to the generating source.

8. In a two way repeater system, means for compensating the differences in the impedance of telephone lines, comprising two local circuits, a constant compensating impedance in each local circuit, and means for connecting said local circuits to the telephone lines and to the two way repeater system.

9. In a two way repeater system, means for compensating the differences in the impedance of telephone lines, comprising two local circuits, a compensating impedance in each local circuit having resistance and reactive components of opposite sign to the corresponding components of the generating source, and means for connecting said local circuits to the telephone lines and to the two way repeater circuit.

10. In a two way repeater system connecting two telephone lines, means for compensating the difference in the impedance of telephone lines, comprising for each telephone line two transformers with primary windings wired respectively in series and in parallel with the telephone line, a negative resistance in the secondary circuit of the two transformers, and means for connecting said primary windings to the two way repeater system.

11. In a two way repeater system connecting two telephone lines, means for compensating the differences in the impedance of telephone lines, comprising for each telephone line two transformers with primary windings wired respectively in series and in parallel with the telephone line, compensating equipment in the secondary circuit of the transformers having an impedance opposite in sign to the impedance of the two way repeater system, and means for connecting said primary windings to the two way repeater system.

12. In a two way repeater system connecting two telephone lines, means for compensating the differences in the impedance of telephone lines, comprising for each telephone line two transformers with primary windings wired respectively in series and in parallel with the telephone line, an impedance in series with the winding wired in parallel, a negative resistance in the secondary circuit of the transformers, and means to connect said primary windings to the two way repeater system.

13. In a two way repeater system between two telephone lines, means for compensating the differences in the impedance of telephone lines, comprising for each telephone line two transformers with primary windings wired respectively in series and in parallel with the telephone line, an impedance in series with the winding in parallel, compensating equipment in the secondary circuit of the transformers having an impedance opposite in sign to the impedance of the two way repeating system, and means for connecting said primary windings to the repeater system.

14. In a two way repeater system between two telephone lines, means for compensating the differences in the impedance of telephone lines comprising for each telephone line, two transformers with primary windings respectively in series and in parallel with the telephone line, an impedance in series with the winding in parallel, compensating equipment in the secondary circuit of the transformers having an impedance opposite in sign to the impedance of the two way repeater system, and means for connecting said primary windings to the two way repeater system.

15. An echo suppressor system between a transmission line and a system of telephone lines of varying impedance, which consists of two electrical networks of opposite sign to each other, associated with the transmission line and with said system of telephone lines, the impedances of the two networks being so proportioned with respect to each other, as described, that electrical waves coming over the transmission line will suffer substantially no reflection in reaching the combination of the lines of varying impedance and of the two fixed networks.

In testimony whereof I affix my signature.

MIHRAN M. DOLMAGE.