March 7, 1933. G. CRISSON 1,900,045

TWO-WAY NEGATIVE RESISTANCE REPEATER

Filed May 13, 1931

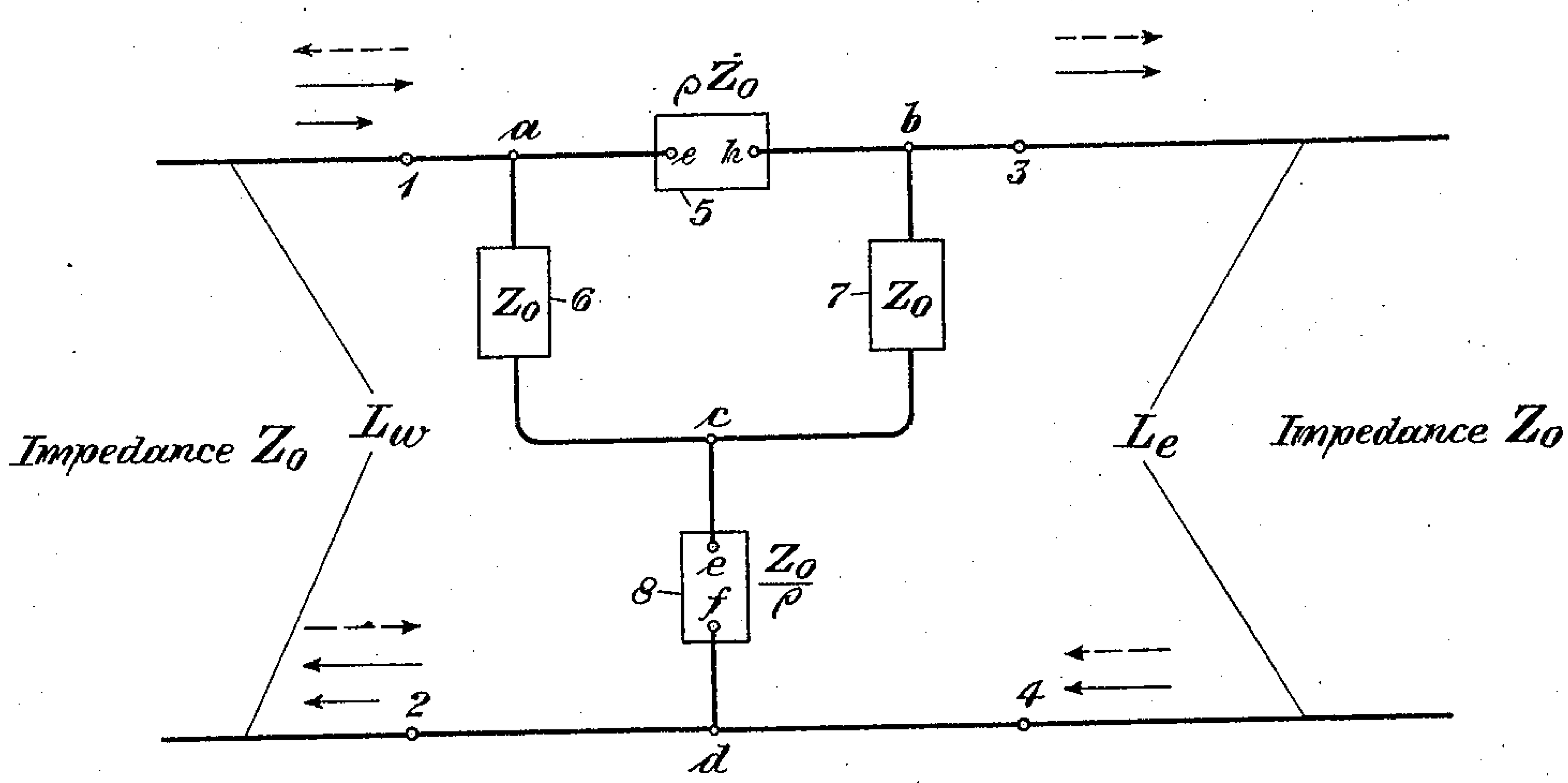

Fig. 1

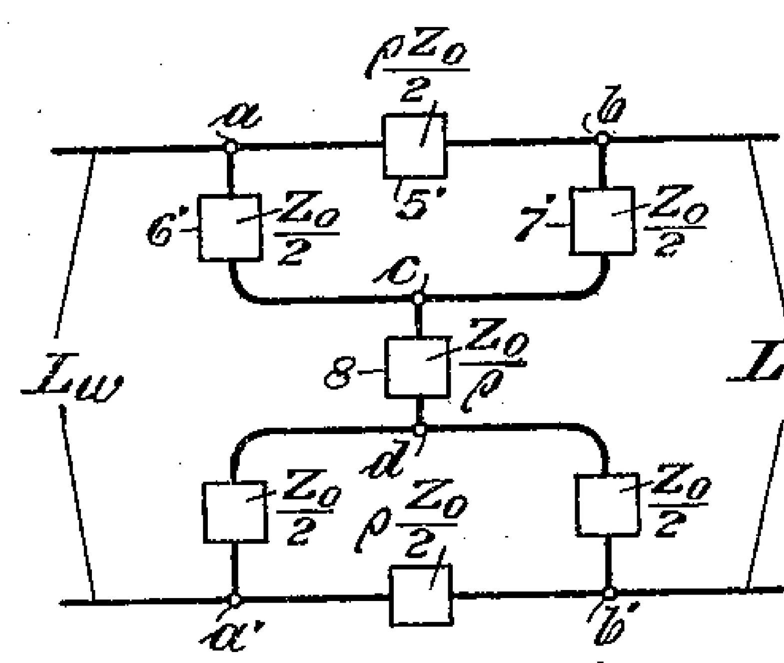

Fig. 4

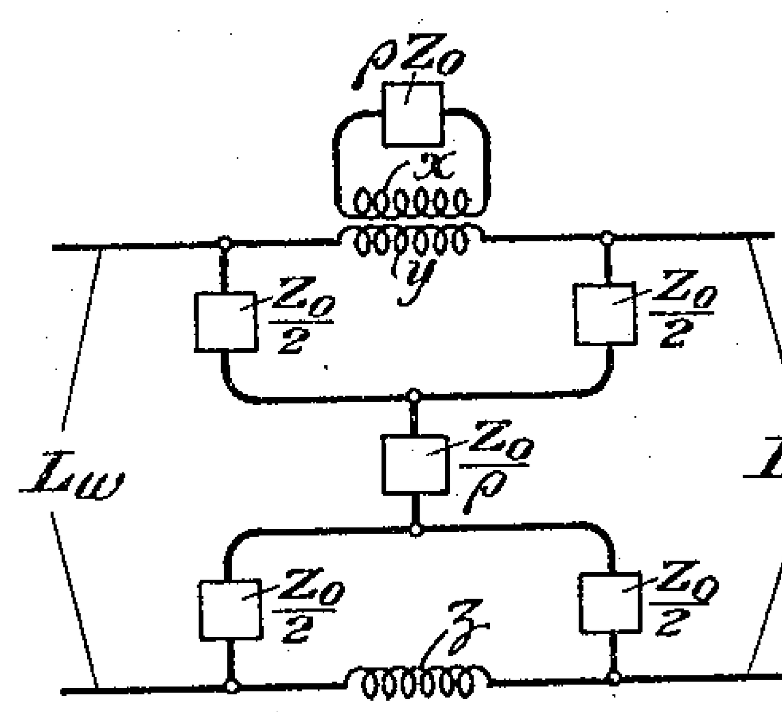

Fig. 5

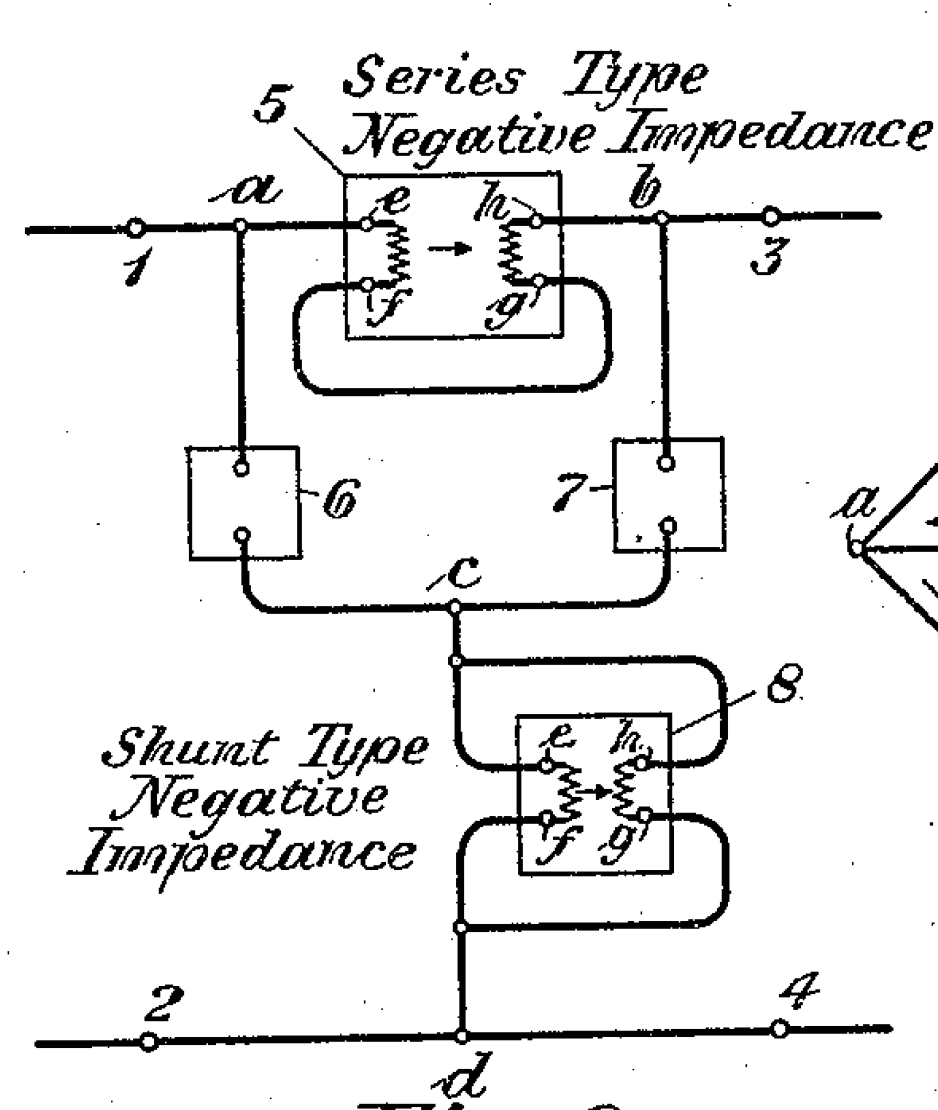

Fig. 2

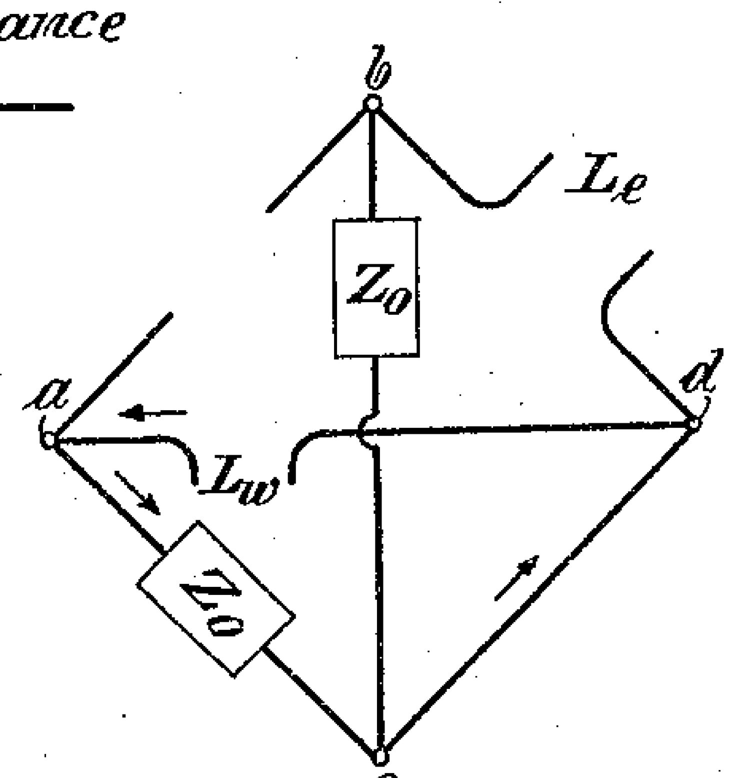

Fig. 3

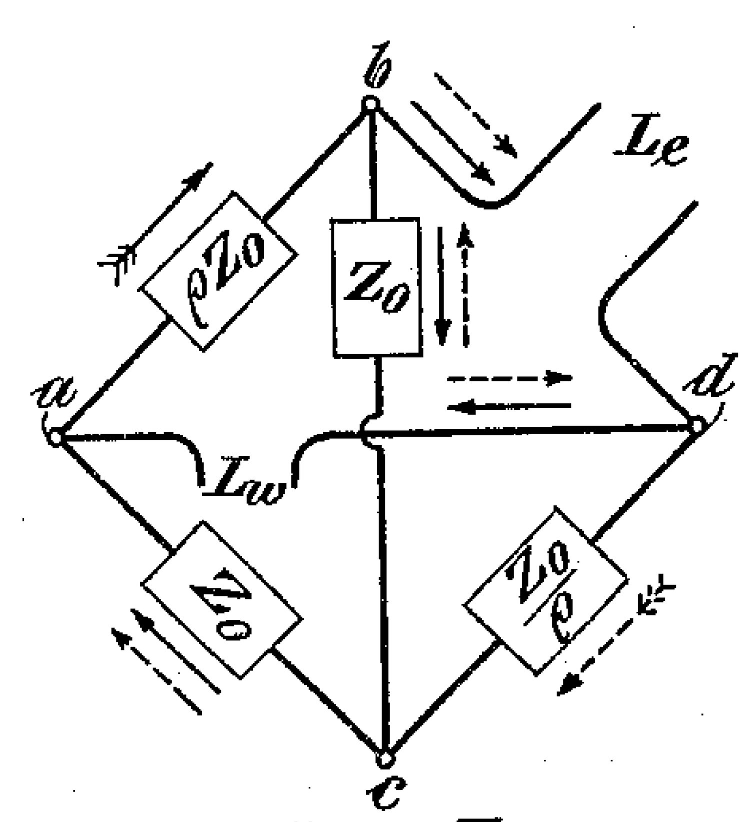

Fig. 3a

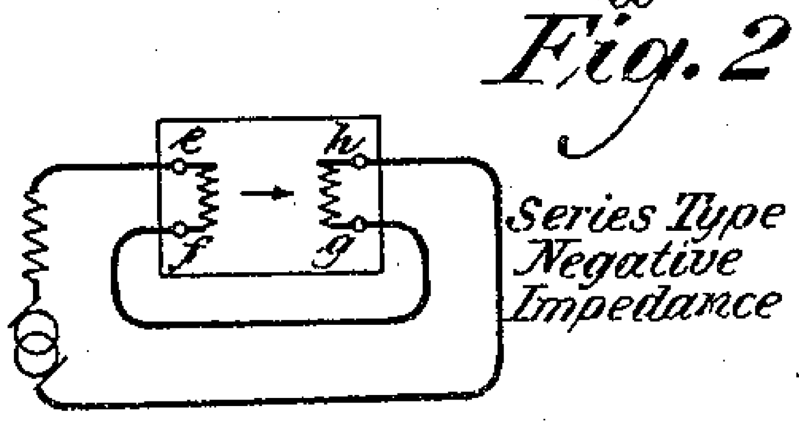

Fig. 1a

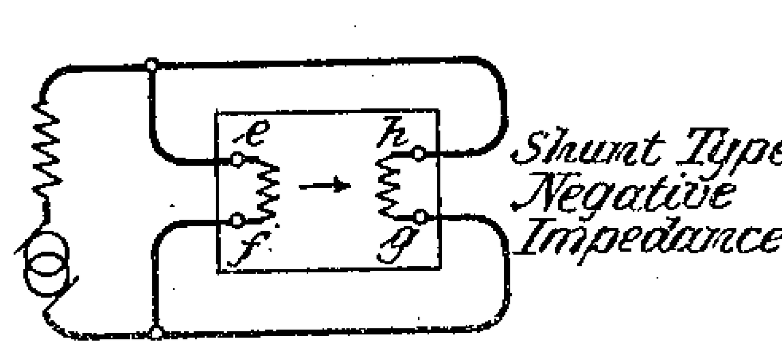

Fig. 1b

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UNITED STATES PATENT OFFICE

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TWO-WAY NEGATIVE RESISTANCE REPEATER

Application filed May 13, 1931. Serial No. 537,146.

This invention relates to repeater systems and particularly to one characterized by the use of two negative impedances.

In the patent to George H. Stevenson, No. 1,606,817, that issued on November 16, 1926, there is described a form of electrical network whose object is to provide a specified attenuation correction, said network being distinguished from the prior art by a reduction in the number of elements required in a net work having symmetrical structure and characteristics.

I have found that by giving a negative value to certain of the impedances shown in Stevenson's network, the said network will function as a repeater which will return no energy toward the transmitting station as an echo except that reflected by irregularities of the line.

This invention will be clearly understood from the following description when read in connection with the attached drawing of which Figure 1 shows schematically the arrangement of the impedances forming the repeater; Figs. 1*a* and 1*b* represent the series type negative impedance and the shunt type negative impedance, respectively; Fig. 2 shows the manner in which the negative impedances of Figs. 1*a* and 1*b* may be connected to the circuit shown in Fig. 1; Figs. 3 and 3*a* show in the form of the Wheatstone bridge network the circuit shown in Fig. 1, and illustrate the description of the manner in which the invention functions; and Figs. 4 and 5 represent arrangements in which the impedances are divided symmetrically with respect to the sides of the line, Fig. 5 differing from Fig. 4 in that a single impedance ρZ_o coupled to both sides of the line performs the function of the two impedances $\frac{\rho Z_o}{2}$ shown in Fig. 4.

In Fig. 1, 1 and 2 represent a pair of terminals for connecting the conductors of one section of a line to the repeater network and 3 and 4 represent another pair of terminals for similarly connecting the other section of the line.

As will be seen from the drawing the network provides an electrical path between the corresponding terminals of each pair. Thus between the terminals 1 and 3 an impedance 5 is connected. Between the points *a* and *c* and *b* and *c* are connected the impedances 6 and 7 that are equal in magnitude. Between the junction point *c* and the point *d* of the connection between the terminals 2 and 4 there is connected another impedance 8. The sections of the line connected to the said terminals are assumed to be free from irregularities and to have the characteristic impedance Z_o. Each of the impedances 6 and 7 also has the value Z_o. The impedances 5 and 8 are designed to be varied reciprocally from the value Z_o, that is, if one impedance is multiplied by a factor ρ the other is divided by the same factor. The factor ρ may be positive or negative and may be complex. The impedances 5, 6 and 8 and the section L_e of the line, shown in Fig. 1, may be considered as forming the arms of a Wheatstone bridge as shown in Fig. 3*a* of which the impedance 7 forms one diagonal and the section L_W, the other diagonal. That bridge is balanced, consequently the impedance connected to the section L_w consists of two parallel circuits, one comprising the impedance 5 in series with the line section L_e and the other comprising the impedance 6 in series with the impedance 8. The impedance of that network is independent of ρ, being equal to Z_o. By symmetry, the impedance connected to the line section L_e is also equal to Z_o so that no reflection occurs at the terminals of the network.

Assume that a wave arrives, for example, over the line section L_W and is transmitted by the repeater to the section L_e. The ratio of the voltage across the points *a*—*d* to that impressed by the repeater on the section L_e, is

$$\frac{(1+\rho)}{1}$$

and the transmission loss through the network, assuming that impedances 5 and 8 are positive, is $L=20 \log_{10} (1+\rho)$.

It will be apparent that when ρ becomes negative the loss L is negative, that is, the network produces a gain and thereby acts as an amplifier. That result may be attained by substituting for the impedances 5 and 8, the arrangements shown in Figs. 1*a* and 1*b*, respectively. Those arrangements are forms of negative impedances that are fully described in my Patent 1,776,310 that issued on September 23, 1930, and are designated therein as the series type and the shunt type negative impedances. The manner in which those negative impedances may be connected into the schematic circuit of Fig. 1 is shown clearly in Fig. 2. If ρ lies between zero and -1 the negative impedance 5 must be of the series type and the negative impedance 8 of the shunt type. If ρ lies between -1 and $-\infty$, those types must be interchanged.

The manner in which the repeater apparatus functions is as follows: Let it be assumed that a wave arrives over the section L_w and is impressed across the terminals of the repeater to which it is connected. At a given instant it tends to cause current to flow in the upper conductor in the direction indicated by the short, solid arrow. The series type negative impedance 5 tends to increase this current to a larger value. The additional current due to the series negative impedance is indicated by the long solid arrows. The shunt type negative impedance 8 tends to produce currents having the directions indicated by the dotted arrows. By choosing the proper values for the negative impedances, as indicated above, the additional currents due to each will be equal. It will be seen that the effect produced by those negative impedances of dissimilar types is to increase the current in the line leading toward the receiver, and at the same time to substantially produce no change in the current in the line extending toward the transmitter.

This will perhaps be more clearly seen by considering Figs. 3 and 3*a* in connection with Fig. 2. First as a reference condition, let it be assumed that ρ is made infinite so that the impedance 5 of Fig. 1 becomes infinite and the impedance 8 becomes zero. This condition is illustrated by Fig. 3. Next let it be assumed that a wave reaches the terminals *a—d* over the line L_w. At a given instant this wave will cause a current to flow in the arms *a—d*, *a—c*, and *c—d* in the direction shown by the small solid arrows. The current will not flow in the arms *b—c* or *b—d* because these are short-circuited through the arm *c—d*. Next let it be assumed that ρ is made negative and less than unity and that the impedance 5 in the arm *a—b* is of the series-type and that the impedance 8 in the arm *c—d* is of the shunt-type. The impedance 5 in the arm *a—b* causes a flow of currents represented by the large solid arrows in Fig. 3*a*. The current in the arm *a—b* represented by the arrow with a tail is equal to twice the current in the arms *b—d*, *a—d*, *b—c*, or *a—c* represented by the arrows without tails. Similarly the impedance 8 in the arm *c—d* causes a flow of current in the network represented by the dotted arrows. The current in the arm *c—d* represented by the arrow with a tail is twice the current produced in the arm *a—c*, *a—d*, *b—c*, or *b—d* represented by the arrows without tails. From this diagram it will be seen that the currents introduced into the network by the two negative impedances cancel each other in the arm *a—d* representing line L_w so that no echoes are returned towards the talker while these currents reinforce each other in the arm *b—d* connected with the line L_e, thus causing an amplified wave to travel towards the receiver.

If it is assumed that the wave is coming from section L_e and after amplification is to be impressed from section L_w it will be found that the action of the repeater is similar to that described above, that is, the current is increased toward the receiver and the tendency of the repeater to send waves toward the transmitter is substantially suppressed. If the shunt type of impedance, such for example as that shown in Fig. 1*b*, is substituted for impedance 5 of Fig. 1 and the series type such as shown in Fig. 1*a* is substituted for impedance 8 of Fig. 1, it would cause a reversal of the sign of the amplified wave.

For such network to function as described above it is not necessary for the ratio ρ to be independent of frequency. Phase shifts in the negative impedances are permissible provided they are kept equal so that echos will be eliminated. It is therefore possible to use filters and other apparatus to cause the gain to vary with frequency in a desired manner without encountering the troubles that occur when a single negative impedance is employed as a booster.

It is also desirable to point out that the negative impedance 5 may be connected to the line by means of a transformer as shown in my patent mentioned above; and furthermore the branch *cd* may have therein a condenser without destroying the reciprocal relation of those negative impedances. The provision of the transformer and condenser provides means for permitting low frequency signals to pass over the conductors of the said line without interference from the network constituting the repeater.

Fig. 4 shows a form of embodiment of the invention in which a balanced relationship has been obtained by dividing the impedances and symmetrically arranging them with respect to the sides of the line. Thus the series negative impedance having the value ρZ_0 in Fig. 1 has been divided, and one-half has been placed in one side of the line and the other half in the other side. Similarly, the positive impedances 6 and 7 of Fig. 1, having values therein of Z_0, have been divided into equal parts and those parts have been symmetrically connected with the line.

The arrangement shown in Fig. 5 differs from that shown in Fig. 4 in that a series negative impedance having the value ρZ_0 is inductively connected to both sides of the line by means of the windings of a coupling transformer, thus rendering unnecessary a division of that negative impedance between the two sides of the line.

While this invention has been disclosed in certain forms it is to be understood that it is capable of embodiment in other and different forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. The combination with a line of a repeater connected between sections thereof, each of which sections has the characteristic impedance Z_0, the said line sections and said repeater forming a Wheatstone bridge network, one of said line sections forming one arm, an impedance Z_0 forming the opposite arm, and negative impedances ρZ_0 and Z_0/ρ forming the other arms, the other section of said line forming one diagonal and an impedance Z_0 forming the other diagonal.

2. A repeater adapted to be connected between adjacent sections of a transmission line comprising a negative impedance ρZ_0 adapted to be connected in series with a line each of the sections of which has an impedance of value Z_0, and a network bridge across the line, the said network comprising another negative impedance $\frac{Z_0}{\rho}$ in series with a positive impedance Z_0, the said positive impedance being shunted by another positive impedance Z_0 in series with said first mentioned negative impedance.

3. A repeater adapted for connection between sections of a line, the said repeater having a pair of terminals for connecting to the said repeater one section of said line having an impedance Z_0, another pair of terminals for connecting to the said repeater the other section of said line also having an impedance Z_0, a pair of positive impedances, each of value Z_0 connected in series between one terminal of one pair and the corresponding terminal of the other pair, a negative impedance connected in parallel with said positive impedances between the outer terminals thereof, and a second negative impedance connected between the junction point of said impedances and the connection between the other corresponding terminals, one of the said negative impedances being of the series type and the other being of the shunt type, and both negative impedances varying reciprocally from the value Z_0.

4. A balanced repeater adapted for connection between sections of a line, each section having the value Z_0, said repeater having a pair of terminals for connecting one section of said line to the said repeater, another pair of terminals for connecting the other section of said line to said repeater, a pair of equal impedances, each of value $\frac{Z_0}{2}$ connected in series between one terminal of one pair and the corresponding terminal of the other pair, a negative impedance of value ρZ_0 connected in parallel with the said impedances between the outer terminals thereof, another pair of equal impedances, each of value $\frac{Z_0}{2}$ connected in series between the other terminal of one pair of terminals and the correponding other terminal of the other pair of terminals which impedances are equal to each other and also to the impedances of the said first mentioned pair, a second negative impedance of value $\frac{\rho Z_0}{2}$ connected in parallel with the said last mentioned pair of impedances between the outer terminals thereof, and a third negative impedance of value $\frac{Z_0}{\rho}$ connected between the junction point of the first mentioned pair of impedances and the junction point of the last mentioned pair of impedances, the first two negative impedances being of the same type, and the third negative impedance being opposite in type to the other negative impedances.

5. A repeater designed for connection between adjacent sections of a transmission line, each section having the impedance Z_0, comprising a negative impedance ρZ_0 to be connected serially between a conductor of one section and that of another section, forming one side of the line, the said negative impedance being shunted by two positive impedances, serially connected, having the value Z_0, and another negative impedance $\frac{Z_0}{\rho}$ connected between the junction of the positive impedances and the other side of the said line.

6. The combination with a negative impedance connected serially between sections of a transmission line of a positive impedance in series with another negative impedance connected between one terminal of said first-mentioned negative impedance and the other side of said line and another positive impedance connected between the other terminal of said first-mentioned negative impedance and the junction between the first-mentioned positive impedance and the second negative impedance, the impedance of the line sections being equal to each other and to the said positive impedances, and the negative impedances varying reciprocally from the value Z_0.

7. A three-terminal network having a negative impedance connected between the first and second terminals of said network, a positive impedance in series with another negative impedance connected between the first and third terminals thereof and another posi-

tive impedance connected between the second terminal and the junction of the first positive impedance with the said other negative impedance, the values being so chosen that the network shall have the value Z_0 when viewed from the first and third terminals of said network provided an impedance Z_0 is connected across the second and third terminals thereof, and likewise shall have an impedance Z_0 when viewed from the second and third terminals of the network provided an impedance Z_0 is connected across the first and third terminals.

8. A three-terminal network having a negative impedance connected between the first and second terminals of said network, a positive impedance in series with another negative impedance connected between the first and third terminals thereof and another positive impedance connected between the second terminal and the junction of the first positive impedance with the said other negative impedance, in which network each of the positive impedances equals Z_0 and the negative impedances vary in value reciprocally from Z_0.

In testimony whereof, I have signed my name to this specification this 12th day of May, 1931.

GEORGE CRISSON.