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S. T. MEYERS

2,817,822

NEGATIVE IMPEDANCE CONVERTER

Filed March 22, 1954

2 Sheets-Sheet 1

FIG. 1

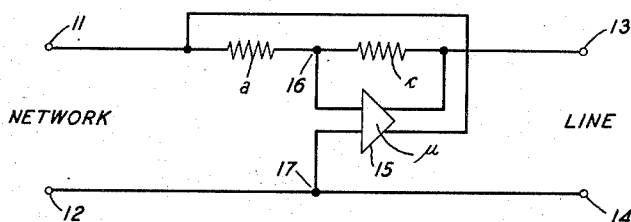


FIG. 2

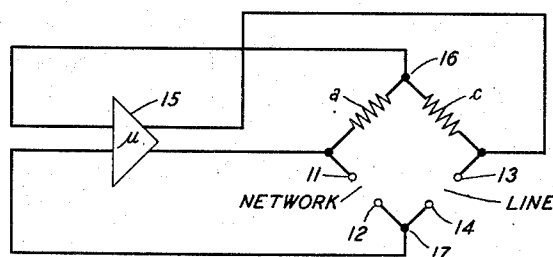


FIG. 3

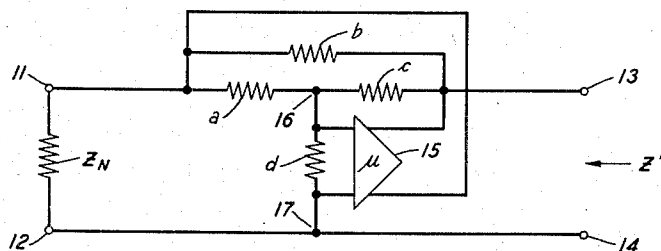
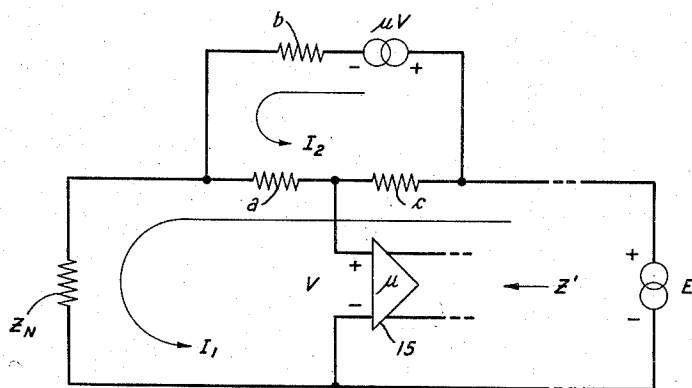


FIG. 4



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2 Sheets-Sheet 2

FIG. 5

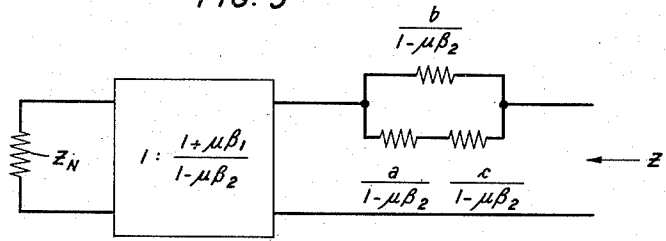
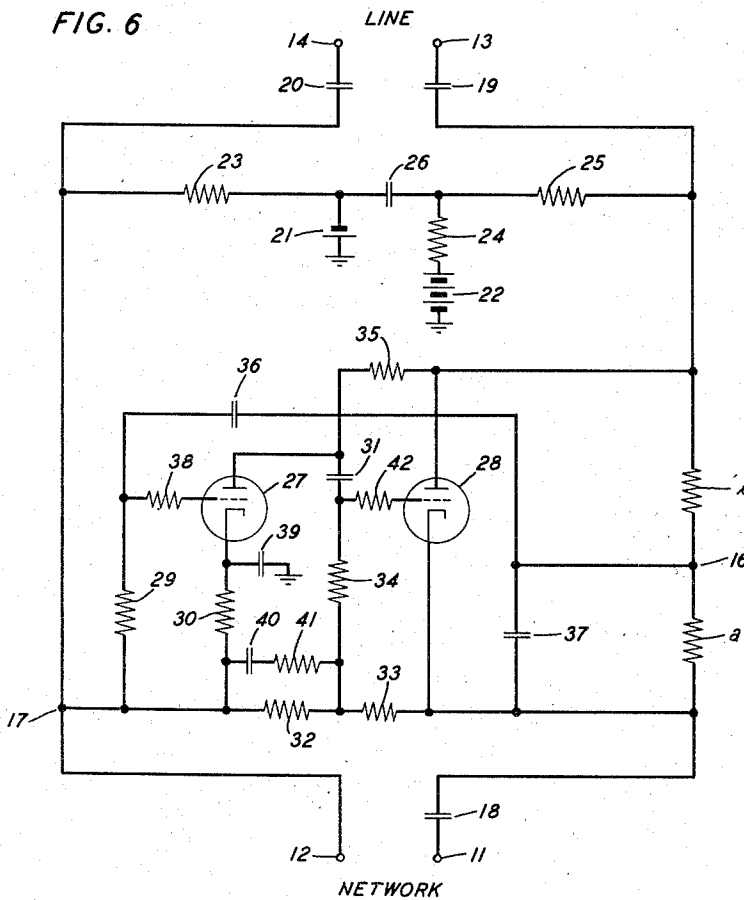


FIG. 6



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1

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NEGATIVE IMPEDANCE CONVERTER

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3 Claims. (Cl. 333—80)

This invention relates generally to negative impedance circuits and more particularly to four-terminal negative impedance converters, which over a prescribed frequency range present at one pair of terminals an impedance which is substantially a negative multiple of any passive impedance connected to its other pair of terminals.

One object of the invention is to produce a stable negative impedance of the shunt or reversed-current type.

Another object is to produce a stable negative impedance of the shunt type without using transformers or inductance coils.

Still another object is to minimize the power requirements of a stable negative impedance of the shunt type.

A further object of the invention is to avoid disturbing the longitudinal balance of a transmission line across which a negative impedance of the shunt type is connected.

As outlined by George Crisson in his article on "Negative impedances and the twin 21-type repeater," appearing at page 485 of the July 1931 issue of the Bell System Technical Journal, negative impedances may be classified in two categories. The first of these includes negative impedances of the series or reversed-voltage type. Such negative impedances are open-circuit stable and can be connected in series in a transmission line, without singing, to produce amplification. The second group includes negative impedances of the shunt or reversed-current type. Such negative impedances are short-circuit stable and can be connected in shunt across a transmission line, without singing, to produce amplification. One or more negative impedances of each type may be associated with each other to reduce the loss of a transmission line below the level which would be made possible through the use of negative impedances of one type alone.

One of the best circuits for producing negative impedances of both the series type and the shunt type is disclosed by J. L. Merrill, Jr., in his article, "Theory of the negative impedance converter," appearing at page 88 of the January 1951 issue of the Bell System Technical Journal and in his United States Patent 2,582,498, issued January 15, 1952. Fig. 6 of the article and Fig. 7 of the patent illustrate a four-terminal negative impedance converter which, when an impedance Z is connected across one pair of terminals, presents an impedance of substantially $-kZ$ at its other pair of terminals and, when an impedance Z is connected across the other pair of terminals, presents an impedance of substantially

$$\frac{Z}{-k}$$

at the first pair of terminals. In these impedance expressions, $-kZ$ represents a negative impedance of the series type

$$\frac{Z}{-k}$$

2

represents a negative impedance of the shunt type, and k is substantially a real number over a prescribed operating frequency range.

The above-mentioned negative impedance converter has been found very useful in the production of negative impedances of the series type. In addition to the actual negative impedance produced by this converter, there is a spurious series impedance component substantially proportional to the plate resistances of the vacuum tubes forming the active elements of the converter. However, because the negative impedance is generated at a relatively high level with respect to the vacuum tube resistances, this spurious component is of negligible importance. Coupling to a low impedance line is made through a step-down transformer to bring the negative impedance down to its proper relation with respect to the line.

When a negative impedance of the shunt type is bridged across a transmission line to provide amplification, however, it is sometimes not possible to use a transformer as a coupling element between the converter impedance and the low impedance line. In such cases, the generation of the negative impedance cannot be made at a favorably high level with respect to vacuum tube resistances in order to eliminate the effects of variations in this spurious impedance component from consideration. If, for example, it is necessary to avoid providing a D.-C. path across the line, blocking condensers must be connected in series with any transformer used and the resulting combination is likely not only to have unwanted resonances but also to interfere with the designed frequency response of the converter. When the above-mentioned converter is used without a transformer to provide the negative impedance in shunt across the line, the spurious series impedance component proportional to plate resistance is large enough to be a substantial percentage of the converted impedance. Under such conditions, variations in the magnitude of this resistance can have an adverse effect on the impedance stability of the converter. The percentage level of this series resistance may be reduced by adding additional push-pull stages of amplification to the converter, but such a solution to the difficulty tends not only to be expensive but also to increase power and space requirements and create problems of heat dissipation.

The present invention overcomes this difficulty by permitting a shunt type of negative impedance to be produced with a much smaller spurious impedance component. Converters embodying the invention require no transformer to achieve impedance stability and require no increase in the total number of active devices used to produce amplification.

In its principal aspect, the present invention takes the form of a negative impedance converter having two pair of terminals, a pair of resistances connected from a common point to respective ones of each pair of terminals, connections from another common point to the respective remaining ones of each pair of terminals, and a single-sided two-stage amplifier the input terminals of which are connected to the two common points and the output terminals of which are connected to the sides of the respective resistances remote from the common point between them.

Negative impedance converters embodying the invention resemble the prior art converter disclosed in the Merrill article and patent in that an impedance Z connected across one pair of terminals causes an impedance of substantially $-kZ$ to be presented at its other pair of terminals, and an impedance connected across the

other pair of terminals causes an impedance of substantially

$$\frac{Z}{-k}$$

to be presented at the first pair of terminals. They differ from the prior art converter in, among other things, their circuit configuration, the lower spurious impedance component they produce, and their lack of transformers and inductance coils. They tend, therefore, in their shunt type negative impedance applications to be much more suitable than prior art converters for connection in shunt across a transmission line to reduce loss, either alone or in association with series type negative impedances connected in series with the line.

An important feature of the invention permits a negative impedance of the shunt type to be connected across a balanced two-wire transmission line without disturbing the longitudinal balance of the line. In a number of important embodiments of the present invention, the D.-C. power supply for the two-stage amplifier is effectively connected between the line terminals of the negative impedance converter. The anode and cathode potentials of the amplifier tubes are thereby permitted to rise and fall together with signal variations on the balanced transmission line and a substantially constant D.-C. potential is maintained between them. As a result, any tendency for an unbalanced signal to be introduced into the amplifier and reinserted by it onto the line is eliminated.

A more complete understanding of the present invention may be secured by a study of the following detailed analysis and explanation of a specific embodiment. In the drawings:

Fig. 1 is a block diagram of a four-terminal negative impedance converter embodying the invention;

Fig. 2 is a block diagram like that of Fig. 1, redrawn to illustrate further the general nature of circuits embodying the invention;

Figs. 3 and 4 are block diagrams which are used in the explanation of the mode of operation of negative impedance converters embodying the present invention;

Fig. 5 is an equivalent circuit of the embodiments of the invention shown in Figs. 1 and 2; and

Fig. 6 is a schematic diagram of a specific negative impedance converter embodying the invention.

The embodiment of the invention illustrated in Fig. 1 includes a first pair of terminals 11 and 12, a second pair of terminals 13 and 14, an amplifier 15, and a pair of resistances a and c . Resistances a and c are connected between a common point 16 and terminals 11 and 13, respectively, while terminals 12 and 14 are both connected to a common point 17. The input terminals of amplifier 15, which has substantially no phase shift over a prescribed operating frequency range, are connected to common points 16 and 17, respectively, while the output terminals are connected to terminals 13 and 11, respectively.

In the operation of the four-terminal negative impedance converter shown in Fig. 1, if an impedance Z is connected across terminals 11 and 12, an impedance substantially equal to

$$\frac{Z}{-k}$$

is presented at terminals 13 and 14, while if an impedance Z is connected across terminals 13 and 14, an impedance substantially equal to $-kZ$ is presented at terminals 11 and 12. The first of these impedances presented by the converter is a negative impedance of the shunt or reversed-current type, and the second is a negative impedance of the series or reversed-voltage type. In both instances, k is substantially a real num-

ber (i. e., has no phase angle) over the frequency range of interest.

In Fig. 1, as well as in succeeding figures, terminals 11 and 12 have been labelled "network" and terminals 13 and 14 "line" to indicate the proper converter orientation for the production of a shunt negative impedance to be bridged across a transmission line. For any passive impedance connected across the "network" terminals 11 and 12, a negative impedance of the shunt type, related to the network impedance by the impedance transformation ratio of the converter, appears at the "line" terminals 13 and 14. As mentioned above, there is, in addition to this, a series component of spurious negative impedance which the present invention reduces almost to the vanishing point. It is to be understood that the invention is not limited to the production of negative impedances of the shunt type and that the converter orientation may be reversed to provide a negative impedance of the series type. Since the present invention was approached from the standpoint of shunt negative impedances, however, subsequent analyses of the mode of operation of the converter will be devoted largely to the production of negative impedances of that type.

Broadly, both the "line" and the "network" connected to the respective terminals of the embodiment of the invention illustrated in Fig. 1 may be looked upon as terminating circuits. Thus, the converter presents to one "terminating circuit" an impedance which is substantially a negative multiple of the impedance presented to the converter by the other "terminating circuit." Conversion in one direction yields a negative impedance of the shunt type and conversion in the other a negative impedance of the series type.

In Fig. 2, the embodiment of the invention shown in Fig. 1 is rearranged to demonstrate more clearly certain aspects of the circuit configuration. As shown in Fig. 2, resistances a and c actually constitute two adjacent arms of a four-terminal bridge circuit, the other two arms of which are formed by "network" terminals 11 and 12 and "line" terminals 13 and 14. The input and output terminals of amplifier 15 are connected to conjugate terminals of the bridge circuit.

Fig. 3 represents the embodiment of the invention illustrated in Fig. 1 connected to produce a negative impedance of the shunt type and with the input and output impedances of amplifier 15 shown. Resistance d , the input resistance of amplifier 15, is shown connected across the amplifier input terminals between common points 16 and 17, while resistance b , the amplifier output resistance, is connected across the amplifier output terminals between terminals 11 and 13. Z_N is the network impedance presented to the converter at terminals 11 and 12, and Z' is the impedance seen looking in at terminals 13 and 14.

For purposes of analysis, the circuit of Fig. 3 can be redrawn as shown in Fig. 4. For simplification, amplifier input resistance d is assumed to be infinite. In specific embodiments of the invention, d is usually of the order of a megohm or more, making this a reasonable assumption. V is the voltage appearing across the input terminals of amplifier 15, and μ is the amplifier gain. E is a voltage across "line" terminals 13 and 14, and μV is the output voltage of amplifier 15. In Fig. 4, μV is shown as a separate generator appearing in series with amplifier output resistance b . I_1 is the current flowing around the loop formed by E , c , a , and Z_N , while I_2 is the current in the loop formed by μV , b , a , and c . The current and voltage polarities are assumed to be those shown in Fig. 4, although these are arbitrary and do not influence the end results of the analysis. The only requisite is that the polarities of voltages V and μV be the same.

The circuit equations for the converter shown in Fig. 4 are as follows:

$$E = (a + c + Z_N)I_1 - (a + c)I_2 \quad (1)$$

$$-\mu V = -(a + c)I_1 + (a + b + c)I_2 \quad (2)$$

$$V = (a + Z_N)I_1 - aI_2 \quad (3)$$

Substitution of the value for V given in Equation 3 into Equation 2 and solving for I_2 gives

$$I_2 = \frac{[a(1 - \mu) + c - \mu Z_N]I_1}{a(1 - \mu) + b + c} \quad (4)$$

Substitution of the value for I_2 given by Equation 4 into Equation 1 and solving for

$$\frac{E}{I_1}$$

which is Z' , then yields the following:

$$Z' = \frac{E}{I_1} = \frac{(a + c + Z_N)[a(1 - \mu) + b + c] - (a + c)[a(1 - \mu) + c - \mu Z_N]}{a(1 - \mu) + b + c} \quad (5)$$

Simplified, Equation 5 reduces to

$$Z' = \frac{Z_N[a + b + c(1 + \mu)] + b(a + c)}{a(1 - \mu) + b + c} \quad (6)$$

The negative impedance conversion properties of embodiments of the present invention may be shown by dividing both the numerator and the denominator of the expression on the right-hand side of Equation 6 by $(a + b + c)$. The resulting expression for Z' is

$$Z' = Z_N \left[\frac{1 + \frac{\mu c}{a + b + c}}{1 - \frac{\mu a}{a + b + c}} \right] + \frac{b(a + c)}{a + b + c} \quad (7)$$

This may be simplified still further by making the following substitutions:

$$\beta_1 = \frac{c}{a + b + c}$$

$$\beta_2 = \frac{a}{a + b + c}$$

The resulting expression is:

$$Z' = Z_N \left[\frac{1 + \mu\beta_1}{1 - \mu\beta_2} \right] + \frac{b(a + c)}{a + b + c} \quad (8)$$

If $\mu\beta_1$ and $\mu\beta_2$ are both very large in comparison with unity and are both substantially real numbers over the prescribed operating frequency range, the impedance presented at the "line" terminals 13 and 14 of the converter is, therefore, equal to a negative multiple of the network impedance Z_N plus a spurious negative component represented by the right-hand expression on the right side of Equation 8.

Fig. 5 is an equivalent circuit of the negative impedance converter analyzed in connection with Fig. 4 and illustrates the meaning of Equation 8. As shown in Fig. 5, the negative impedance converter embodying the present invention is electrically equivalent to an ideal converter having a conversion ratio of

$$1 : \frac{1 + \mu\beta_1}{1 - \mu\beta_2}$$

plus a spurious series resistance composed of a resistance

$$\frac{b}{1 - \mu\beta_2}$$

connected in parallel with the series combination of a resistance

$$\frac{a}{1 - \mu\beta_2}$$

and a resistance

$$\frac{c}{1 - \mu\beta_2}$$

If this series resistance component of the impedance presented by such a converter is small in comparison with the impedance level of the line to which the converter is connected, the impedance presented to the line by the converter is substantially equal to a negative multiple of the network impedance Z_N .

The negative impedance component on the right-hand side of Equation 8 is immediately recognizable as a negative impedance of the shunt or reversed-current type. The negative impedance component is

$$-\frac{Z_N}{k}$$

where k is substantially equal to the ratio of $\mu\beta_2$ to $\mu\beta_1$, still assuming that both $\mu\beta_1$ and $\mu\beta_2$ are very large in comparison with unity.

It should be noted again at this point that a negative impedance of the series type may be obtained from converters embodying the present invention by connecting the passive impedance network to the opposite set of terminals from those used to produce a negative impedance of the shunt type. It can readily be shown that the conversion ratio of the ideal converter in the equivalent circuit would then be

$$\frac{1 - \mu\beta_2}{1 + \mu\beta_1} : 1$$

With both $\mu\beta_1$ and $\mu\beta_2$ very large in comparison with unity, the negative impedance component would be $-kZ_N$, where k is substantially equal to the ratio of $\mu\beta_2$ to $\mu\beta_1$.

The equivalent circuit shown in Fig. 5 illustrates the importance of the feature of the invention relating to the improvement of the impedance stability of the converter. As stated above, the spurious series resistance component produced by the converter may be considered as being made up of three resistances

$$\frac{a}{1 - \mu\beta_2}, \frac{b}{1 - \mu\beta_2}, \text{ and } \frac{c}{1 - \mu\beta_2}$$

All three of these resistances are reduced to a low value by the presence of the $(1 - \mu\beta_2)$ term in the denominator. Amplifier 15 is preferably a two-stage single-sided amplifier, making the $\mu\beta_2$ term very large in comparison with unity. As a result, the spurious resistance component produced by the converter is very small in comparison with the impedance of the line to which the converter is connected, and variations in its magnitude are of little consequence. In addition, it should be noted that b , the output resistance of amplifier 15, may itself be reduced and stabilized through the application of negative feedback to amplifier 15.

A full schematic diagram of a specific embodiment of the invention appears in Fig. 6. There, terminals 11 through 14, resistances a and c , and common points 16 and 17 are the same as in the preceding figures, but instead of a block diagram the complete circuit details of the amplifier are shown. As before, terminals 11 and 12 are labelled the "network" terminals and terminals 13 and 14 the "line" terminals. As has already been pointed out, such an arrangement produces a negative impedance of the so-called shunt or reversed-current type at the "line" terminals 13 and 14. It should be remembered, however, that these connections may be reversed to produce a negative impedance of the series or reversed-voltage type at terminals 11 and 12, which would then be the "line" terminals.

In Fig. 6, resistances *a* and *c* are connected in series between terminals 11 and 12, with a coupling condenser 18 connected between terminal 11 and resistance *a* and a coupling condenser 19 connected between terminal 13 and resistance *c*. Terminal 12 is connected directly to common point 17, while a coupling condenser 20 is connected between there and terminal 14.

D.-C. power is supplied to the negative impedance converter illustrated in Fig. 6 by a pair of potential sources 21 and 22. Source 21, which supplies a small negative potential, has its positive terminal grounded and its negative terminal connected through a resistance 23 to common point 17. Source 22, which supplies a larger positive potential, has its negative terminal grounded and its positive terminal connected through the series combination of resistances 24 and 25 to the junction between resistance *c* and condenser 19. A condenser 26 is connected from the negative terminal of source 21 to the junction between resistances 24 and 25.

The amplifier in the negative impedance converter shown in Fig. 6 is a two-stage single-sided amplifier composed of a pair of triodes 27 and 28. If desired, these two tubes may be within a single envelope. The grid of the first tube 27 is connected to common point 17 through the series combination of a small protective resistance 38 and a large grid biasing resistance 29, while the cathode of the same tube is connected to the same point through a smaller cathode resistance 30. The cathode of tube 27 is also returned to ground through a small balancing condenser 39. The anode of tube 27 is connected to the grid of the second tube 28 through a coupling condenser 31 and a small protective resistance 42. A pair of resistances 32 and 33 are connected in series between common point 17 and the junction between resistance *a* and condenser 18. The grid of the tube 28 is returned to the junction between resistances 32 and 33 through a large grid biasing resistance 34, and a condenser 40 and a resistance 41 are connected in series across resistance 32.

The cathode of tube 28 is connected to the junction between resistance 33 and resistance *a*, while the anode of the same tube is connected to the junction between resistance 25 and resistance *c*. Resistance 35 is coupled between the anode of tube 27 and the anode of tube 28. A coupling condenser 36 is connected between the grid of tube 27 and common point 16, while a condenser 37 is returned from that point to the junction between resistance 33 and resistance *a*.

By way of example, the following elements may be used in the embodiment of the invention illustrated in Fig. 6:

Resistance <i>a</i>	ohms...	100,000
Resistance <i>c</i>	do.....	84,500
Condenser 18.....	microfarads...	0.5
Condenser 19.....	do.....	1
Condenser 20.....	do.....	1
Potential source 21.....	volts...	-24
Potential source 22.....	do.....	+130
Resistance 23.....	ohms...	3010
Resistance 24.....	do.....	1000
Resistance 25.....	do.....	3010
Condenser 26.....	microfarads...	20
Tube 27.....		407A
Resistance 29.....	megohms...	1
Resistance 30.....	ohms...	681
Condenser 31.....	microfarads...	0.1
Resistance 32.....	ohms...	5000
Resistance 33.....	do.....	221
Resistance 34.....	megohms...	1
Resistance 35.....	ohms...	33,200
Condenser 36.....	microfarads...	0.022
Condenser 37.....	micromicrofarads...	47
Resistance 38.....	ohms...	470
Condenser 39.....	micromicrofarads...	270

Condenser 40.....	microfarads...	0.027
Resistance 41.....	ohms...	24,900
Resistance 42.....	do.....	470

When the embodiment of the invention shown in Fig. 6 is connected across a transmission line, care should generally be taken to avoid disturbing the longitudinal balance of the line. In other words, it is important that the same currents flow on both sides of the line. To accomplish this, anode power is supplied to tubes 27 and 28 through resistances 23 and 25, which are paired to close limitations. The line coupling condensers 19 and 20 are closely paired for the same reasons, and balancing condenser 39 is returned to ground from the cathode of tube 27. Battery noise is reduced by the filter composed of resistance 24 and condenser 26 in the D.-C. supply circuit, and the anode supply resistance 35 for the first stage is returned to the anode of tube 28 to eliminate a longitudinal path that would exist if it were returned to potential source 22.

For conversion of the network impedance with the minimum number of spurious components shown in Fig. 5, it is generally necessary to balance out, as nearly as possible, all converted circuit elements associated with the bridge formed by resistances *a* and *c* and the "network" and "line" terminals 11 through 14. For this reason, the "line" condensers 19 and 20 are balanced by condenser 18 at "network" terminal 11, while D.-C. supply resistances 23 through 25, condenser 26, and resistance 35 are all balanced out by the combination of resistances 32, 33, and 41 and condenser 40 in the cathode circuit of the second amplifier stage.

While an ideal converter would convert faithfully any impedance over the entire frequency spectrum, it is usually desirable to limit the conversion bandwidth so that the line and network impedances do not have to be controlled over an unlimited frequency band. The conversion bandwidth of the converter illustrated in Fig. 6 is limited at low frequencies by the resistance-capacitance coupling provided by resistance 29 and capacitance 36 between the bridge and the grid of tube 27 and at high frequencies by the condenser 37 connected across resistance *a*.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a two-wire transmission line which is balanced with respect to ground potential, a two-terminal terminating network of passive impedance elements, and a negative impedance converter which comprises a first pair of terminals connected to opposite sides of said transmission line; a second pair of terminals connected to opposite sides of said terminating network, first and second resistances connected in series between one of said first pair of terminals and one of said second pair of terminals, the others of said first and second pairs of terminals being connected directly together with respect to A.-C., first and second amplifying devices each having a current-emissive electrode, a current-receiving electrode, and a control electrode for current passing between said current-emissive and current-receiving electrodes, the control electrode of said first device being connected to the junction between said first and said second resistances, the current-emissive electrode of said first device being connected to the junction between said other terminals, the current-receiving electrode of said first device being connected to the control electrode of said second device with respect to A.-C. and to the end of said first resistance electrically remote from said second resistance with respect to D.-C., the current-emissive electrode of said second device being connected to both the end of said second resistance electrically remote from said first resistance and the junction between said other terminals, and the current-receiving electrode of said second device being connected

9

to the end of said first resistance electrically remote from said second resistance, and a D.-C. power supply for both of said amplifying devices connected across said first pair of terminals between the current-emissive electrode of said first device and the end of said first resistance electrically remote from said second resistance to avoid disturbing the longitudinal balance of said line, the impedance presented to said transmission line by said converter being related to the impedance presented to said converter by said terminating network by factor

$$\frac{1}{-k}$$

where k is substantially a real number over a predetermined operating frequency range.

2. In combination, a two-wire transmission line which is balanced with respect to ground potential, a two-terminal terminating network of passive impedance elements, and a negative impedance converter which comprises a first pair of terminals connected to opposite sides of said transmission line, a second pair of terminals connected to opposite sides of said terminating network, first and second resistances connected in series between one of said first pair of terminals and one of said second pair of terminals, the others of said first and second pairs of terminals being connected directly together with respect to A.-C., first and second amplifying devices each having an anode, a cathode, and a control grid, the control grid of said first device being connected to the junction between said first and second resistances, the cathode of said first device being connected to the junction between said other terminals, the anode of said first device being connected to the control grid of said second device with respect to A.-C. and to the end of said first resistance electrically remote from said second resistance with respect to D.-C., the cathode of said second device being connected to both the end of said second resistance electrically remote from said first resistance and the junction between said other terminals, and the anode of said second device being connected to the end of said first resistance electrically remote from said second resistance, and a D.-C. power supply for both of said amplifying devices connected across said first pair of terminals between the cathode of said first device and the end of said first resistance electrically remote from said second resistance to avoid disturbing the longitudinal balance of said line, the impedance presented to said transmission line by said converter being related to the impedance presented to said converter by said terminating network by the factor

$$\frac{1}{-k}$$

10

where k is substantially a real number over a predetermined operating frequency range.

3. In combination, a two-wire transmission line which is balanced with respect to ground potential, a two-terminal terminating network of passive impedance elements, and a negative impedance converter which comprises first, second, third, and fourth terminals, said first and second terminals being connected to opposite sides of said transmission line and said third and fourth terminals being connected to opposite sides of said terminating network, first and second resistances connected from a first common point to said first and third terminals respectively, connections from a second common point to said second and fourth terminals respectively, first and second amplifying devices each having an anode, a cathode, and a control grid, the control grid of said first device being connected to said first common point, the cathode of said first device being connected to said second common point, the anode of said first device being connected to the control grid of said second device with respect to A.-C. and to the end of said first resistance electrically nearest said first terminal with respect to D.-C., the cathode of said second device being connected to both the end of said second resistance electrically nearest said third terminal and said second common point and the anode of said second device being connected to the end of said first resistance electrically nearest said first terminal, and a D.-C. power supply for both of said amplifying devices connected across said first and second terminals between said second common point and the end of said first resistance electrically nearest said first terminal to avoid disturbing the longitudinal balance of said line, the impedance presented to said transmission line by said converter being related to the impedance presented to said converter by said terminating network by the factor

$$\frac{1}{-k}$$

where k is substantially a real number over a predetermined operating frequency range.

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