May 1, 1945.

W. R. LUNDRY

2,374,872

ATTENUATION EQUALIZER

Filed April 7, 1943

2 Sheets-Sheet 1

FIG. 1

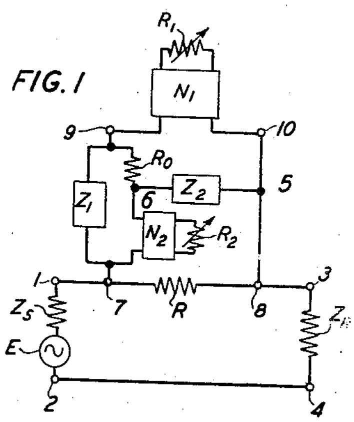


FIG. 2

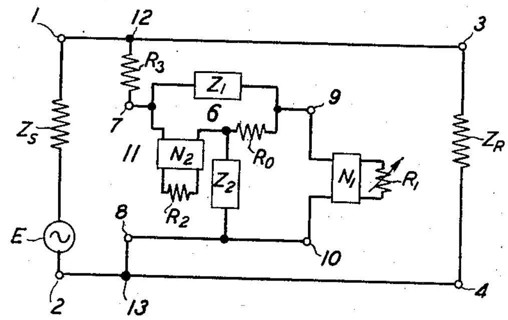


FIG. 3

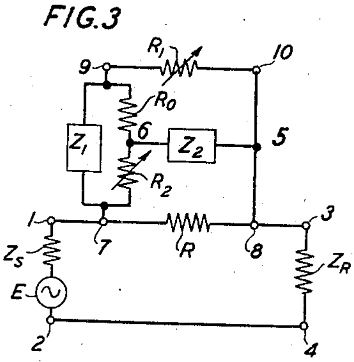


FIG. 4

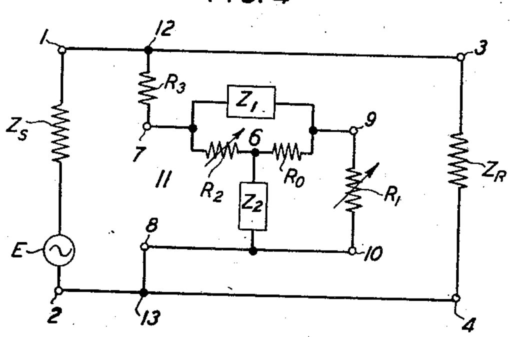


FIG. 5

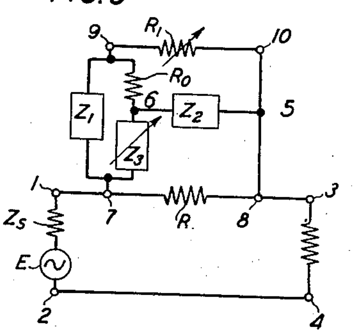
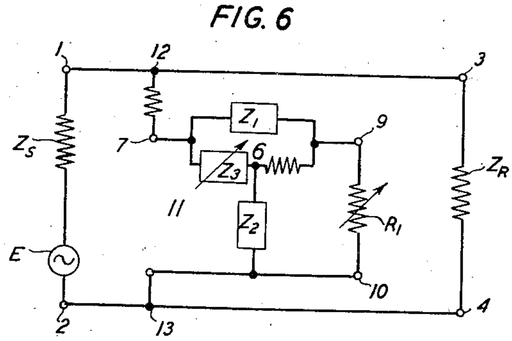


FIG. 6



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ATTENUATION EQUALIZER

Filed April 7, 1943 2 Sheets-Sheet 2

FIG. 7

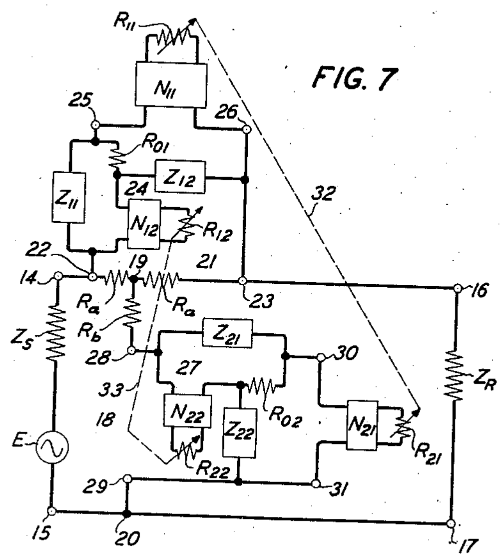


FIG. 8

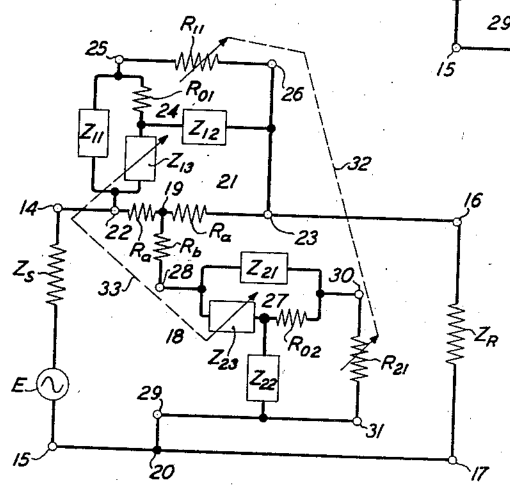
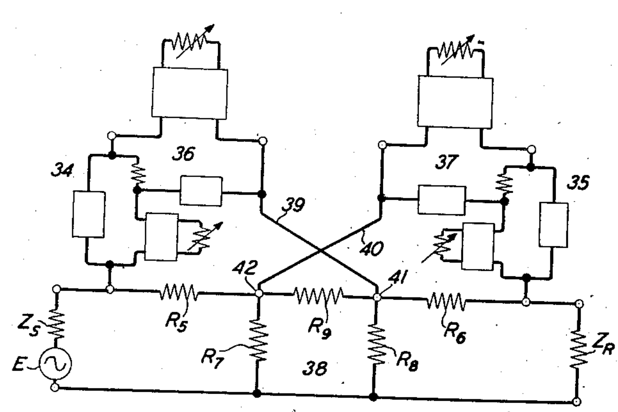


FIG. 9



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2,374,872

UNITED STATES PATENT OFFICE

2,374,872

ATTENUATION EQUALIZER

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Application April 7, 1943, Serial No. 482,081

28 Claims. (Cl. 178—44)

This invention relates to wave transmission networks and more particularly to variable attenuation equalizers for use as regulating networks.

The principal object of the invention is to compensate for changes in the attenuation distortion in a transmission line or the like caused, for example, by variations in temperature or humidity.

A feature of the invention is an attenuation equalizing network which operates over two separated frequency ranges and is independently variable over one or both of the ranges.

The attenuation distortion in a telephone circuit varies continually due to changes in temperature or humidity. Continuously variable attenuation equalizers which may be varied in either direction from a constant flat loss are employed to compensate for these variations. When such a circuit requires equalization over two separated frequency ranges the practice heretofore has been to use two equalizers, with a resistance pad between, thus more than doubling the flat loss of a single equalizer. By employing special coupling arrangements between the equalizers the over-all flat loss may be reduced somewhat, but in long circuits the total becomes very large.

The attenuation equalizer in accordance with the present invention operates over two separated frequency ranges but introduces only the flat loss of a single equalizer. By proper design the equalizer may be made independently variable over one or both of the ranges. The variable elements may, for example, be only two variable resistors which are readily adapted for automatic regulation.

The equalizer, which is of the general type disclosed in United States Patent 2,096,027, issued October 19, 1937, to H. W. Bode, comprises a variable impedance coupling branch connected in series or in parallel with the wave source impedance and the load impedance. The coupling branch comprises a fixed resistor connected at one end of a subsidiary four-terminal bridged-T network terminated at its other end in a variable impedance which may be either a variable resistor or a four-terminal constant resistance building-out network terminated in a variable resistor. The subsidiary network comprises a reactive bridging impedance branch and a reactive shunt impedance branch which are inversely related and two series branches, one of which may be either a variable resistor, a fixed frequency-dependent impedance or a variable frequency-dependent impedance. This last-mentioned impedance may include a second four-terminal constant resistance building-out network terminated by a variable resistor. When two variable controls are provided the equalizer may be designed to provide substantially independent regulation over two sufficiently widely separated frequency ranges.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings in which like reference characters refer to similar or corresponding parts and in which:

Fig. 1 is a schematic circuit showing one form of the two-range attenuation equalizer of the invention, employing a series coupling branch which comprises two building-out networks terminated in variable resistors;

Fig. 2 is a schematic circuit showing another form of the equalizer similar to one shown in Fig. 1 except that the coupling branch is connected in parallel;

Fig. 3 shows an equalizer circuit similar to the one of Fig. 1 except that the building-out networks are omitted;

Fig. 4 is a circuit similar to the one shown in Fig. 2 but with the building-out networks omitted;

Fig. 5 shows a circuit similar to the one of Fig. 3 except that one of the variable resistors is replaced by a frequency-dependent impedance;

Fig. 6 is a circuit similar to the one shown in Fig. 4 but with a frequency-dependent impedance substituted for one of the variable resistors;

Fig. 7 is a schematic circuit showing the structure of Figs. 1 and 2 formed into a bridged-T network;

Fig. 8 shows the structures of Figs. 5 and 6 formed into a bridged-T network; and

Fig. 9 shows two equalizers of the type shown in Fig. 1 coupled by resistors to provide a four-range network.

Taking up the figures in more detail, Fig. 1 shows a series type of two-range attenuation equalizer in accordance with the invention. The network, which is of the same general configuration as the one shown in Fig. 11 of the above-mentioned Bode patent, has a pair of input terminals 1, 2 to which is connected a wave source of impedance Z_S and voltage E and a pair of output terminals 3, 4 to which the load impedance Z_R is connected. Connected in series with the impedances Z_S and Z_L is a variable impedance coupling branch 5 which comprises a fixed resistor of value R and a four-terminal subsidiary network 6 of the bridged-T type having two pairs of terminals 7, 8 and 9, 10. The resistor R is connected between the terminals 1 and 3 of the load impedances and the terminals 7 and 8 of the network 6 are connected respectively, to the terminals of the resistor R. The network 6 is terminated at its other end in a variable impedance which comprises a four-terminal building-out network N_1 terminated in a variable resistor R_1. The subsidiary network 6 comprises a reactive bridging impedance Z_1 and a reactive shunt impedance Z_2, which are inversely related to each other with respect to R_0, and two series branches. One of the series branches is the fixed resistor of value R_0 and the other is constituted by a second four-terminal building-out network N_2 terminated in a second variable resistor R_2. The building-out networks N_1 and N_2 have image impedances equal to R_0, and when R_2 is equal to R_0 the subsidiary network 6 also has an image impedance of R_0.

The insertion factor ϵ^{θ_0} for the network of Fig. 1 operating between the terminal impedances Z_S and Z_R, as shown, with the variable resistors R_1 and R_2 set so that

$$R_1=R_2=R_0 \tag{1}$$

may be found from the expression

$$\epsilon^{\theta_0}=1+\frac{R\,R_0}{(R+R_0)\ (Z_S+Z_R)} \tag{2}$$

If α_0 is the real part of θ_0 the difference between α_0 and the insertion loss α, for any other settings of the resistors R_1 and R_2, may be found to a sufficient degree of accuracy for design purposes from the approximate expression

$$\alpha-\alpha_0\doteq-2Re\left[\left(\rho_1\epsilon^{-2(\varphi_1+\varphi_3)}+\rho_2\epsilon^{-2(\varphi_2+\varphi_4)}\right)\tanh\frac{\theta_0}{2}\right] \tag{3}$$

in which Re indicates that only the real part of the complex quantity in the brackets is to be use, φ_3 and φ_4 are the transfer constants of the networks N_1 and N_2 respectively,

$$\rho_1=\frac{R_0-R_1}{R_0+R_1} \tag{4}$$

$$\rho_2=\frac{R_0-R_2}{R_0+R_2} \tag{5}$$

$$\epsilon^{\varphi_1}=1+\frac{Z_1}{R_0} \tag{6}$$

and

$$\epsilon^{\varphi_2}=1+\frac{Z_2}{R_0} \tag{7}$$

An inspection of Equation 3 shows that, in general, the presence of the building-out networks N_1 and N_2 reduces the maximum loss swing that would be obtained if they were omitted. It follows, therefore, that the impedances Z_1 and Z_2, which are general in character, must be chosen to give a somewhat greater swing than is desired from the network as a whole. Furthermore, in order to insure substantial independence of regulation over two frequency ranges, Z_1 must be large compared to R_0 over the range in which ρ_2 is to control the regulation and Z_2 must be large compared to R_0 over the range where ρ_1 is to control.

It is usually desirable that the change in insertion loss $\alpha-\alpha_0$ be substantially proportional to ρ_1 in the one frequency range and to ρ_2 in the other range. From Equation 3 it is apparent that, in the range where ρ_1 controls, the desired result may be accomplished in one of the following ways: first, by setting R_2 equal to R_0; second, by making the real part of $(\varphi_2+\varphi_4)$ large compared to unity; or, third, by making the phase angle of $(\varphi_2+\varphi_4)$ equal to 45 degrees. Of course, any two or all three of these conditions may be approximated at the same time. On the other hand, in the range where ρ_2 controls either R_1 is set at the value R_0, the real part of $(\varphi_1+\varphi_3)$ is made large compared to unity or the phase angle of $(\varphi_1+\varphi_3)$ is made equal to 45 degrees.

The two-range attenuation equalizer shown schematically in Fig. 2 is of the shunt type, having the same general configuration as shown in Figs. 15 and 27 of the above-mentioned Bode patent. The variable impedance coupling branch 11, which is connected between the points 12 and 13 in parallel with the load impedances Z_S and Z_R, comprises a fixed resistor R_3 and a subsidiary bridged-T network 6 similar to the subsidiary network used in the equalizer of Fig. 1. One terminal of the resistor R_3 is connected to the point 12 and the other terminal is connected to terminal 7 of the network 6, terminal 8 of which is connected to the point 13.

The equalizer of Fig. 2 may be designed in accordance with the principles set forth above to give the same type of regulation under the control of the variable resistors R_1 and R_2 as is obtainable with the equalizer of Fig. 1. The insertion factor, for the condition that R_1 and R_2 are both set equal to R_0, is given by the expression

$$\epsilon^{\theta_0}=1+\frac{R_3R_0(Z_S+Z_R)}{Z_SZ_R(R_3+R_0)} \tag{8}$$

The regulation characteristic for other settings of R_1 and R_2 may be found from Equation 3 by multiplying either side by (-1).

In some cases the building-out networks N_1 and N_2 are not needed to give the desired regulation characteristic. Fig. 3, for example, shows the series type circuit of Fig. 1 modified by the omission of N_1 and N_2. The characteristic may be found from Equation 3 by setting

$$\varphi_3=\varphi_4=0 \tag{9}$$

Fig. 4 shows the alternative shunt type circuit of Fig. 2 with the networks N_1 and N_2 omitted.

A useful modification of the circuits of Figs. 3 and 4 is to replace one of the variable resistors by either a fixed or a variable frequency-dependent impedance. In Fig. 5 and Fig. 6, for example, the variable resistor R_2 is replaced by the frequency-dependent impedance Z_3, which may be either variable, as indicated by the arrow, or fixed. If Z_3 is fixed, the equalizer is, of course, variable over only one range.

A two-range equalizer having at each end an image impedance R_{03} which is a constant resistance may be provided by combining series and shunt type networks in a bridged-T structure. Fig. 7 shows such a bridged-T, with input terminals 14, 15 and output terminals 16, 17, comprising two equal series resistors R_a, R_a an interposed shunt branch 18 connected between the points 19, 20 and a bridging branch 21 connected to the terminals 22, 23. The bridging branch 21, which is similar to the series coupling branch 5 of Fig. 1, comprises a subsidiary bridged-T network 24 of constant resistance image impedance R_{01}, with terminals 22, 23 and 25, 26, similar to the network 6 of Fig. 1. The series arms of the network 24 are constituted by a fixed resistor of value R_{01} and a building-out network N_{12}, also of constant resistance image impedance R_{01}, terminated in a variable resistor R_{12}. The bridging impedance Z_{11} and the shunt impedance Z_{12} have the relationship

$$Z_{11}Z_{12}=R_{01}^2 \tag{10}$$

The network 24 is terminated at its terminals 25, 26 in a second building-out network N_{11} of constant resistance image impedance R_{01} which, in turn, is terminated in a variable resistor R_{11}. In the bridging branch 21 the resistor which corresponds to R in Fig. 1 has been incorporated in the T of resistances constituted by R_a, R_a and R_b, in order to save one element.

The shunt branch 18, which is similar to shunt coupling branch 11 of Fig. 2, comprises the fixed resistor R_b connected in series with a second subsidiary bridged-T network 27 of constant resistance image impedance R_{02}, with terminals 28, 29 and 30, 31 similar to the network 6 of Fig. 2. The series arms of the network 27 are constituted by a fixed resistor of value R_{02} and a third, building-out network N_{22}, also of constant resistance image impedance R_{02}, terminated in a variable resistor R_{22}. The bridging impedance Z_{21} and the shunt impedance Z_{22} have the relationship

$$Z_{21}Z_{22}=R_{02}^2 \qquad (11)$$

The network 27 is terminated at its terminals 30, 31 in a fourth building-out network N_{21} of constant resistance image impedance R_{02} which, in turn, is terminated in a variable resistor R_{21}.

In order to provide the constant resistance image impedance R_{03} looking in at the terminals 14, 15 and 16, 17 of the equalizer of Fig. 7, the image impedances R_{01} and R_{02} of the auxiliary and the building-out networks must have the relationship

$$R_{01}R_{02}=R_{03}^2 \qquad (12)$$

and for all settings the values of the variable resistors must have the relationship

$$R_{11}R_{21}=R_{12}R_{22}=R_{03}^2 \qquad (13)$$

In order to facilitate the maintenance of this relationship conveniently the resistors R_{11} and R_{21} may be placed under a unitary control, as indicated by the broken line 32, and the resistors R_{12} and R_{22} under a second unitary control, as indicated by the broken line 33.

The series type equalizer of Fig. 5 and the shunt type equalizer of Fig. 6 may also be combined in a constant resistance bridged-T structure, as shown in Fig. 8. The circuit of Fig. 8 is similar to the one shown in Fig. 7 except that the building-out networks N_{11}, N_{12}, N_{21} and N_{22} are omitted and the variable resistors R_{12} and R_{22} replaced respectively, by the general impedances Z_{13} and Z_{23} which correspond to the impedance Z_3 of Figs. 5 and 6 respectively, and have the relationship

$$Z_{13}Z_{23}=R_{03}^2 \qquad (14)$$

In order to provide an adjustment over the second frequency range the impedances Z_{13} and Z_{23} may be made adjustable as indicated by the arrows. If the constant resistance image impedance R_{03} is to be maintained the values of the impedances Z_{13} and Z_{23} must satisfy Equation 14 for all settings and, therefore, these impedances may conveniently be arranged for unitary control, as indicated. The impedances Z_{13} and Z_{23} may, of course, be simple variable resistors such as R_2 in Figs. 3 and 4.

Fig. 9 shows two networks 34 and 35 of the type shown in Fig. 1 connected in tandem between the terminal loads Z_S and Z_R to provide an equalizer which may be designed to give independent regulation over four frequency ranges. These ranges may, if desired, coincide in pairs to give in effect double regulation over two ranges. The resistors R_5 and R_6 correspond to the resistor R and the bridged-T auxiliary networks 36 and 37 to the network 6, of Fig. 1. The two equalizers 34 and 35 are coupled by means of a π type resistance pad 38 made up of the two shunt resistors R_7, R_8 and the interposed series resistor R_9. It will be noted that the leads 39 and 40 from the networks 36 and 37 respectively, cross each other as they go to the terminals 41 and 42 respectively, of the resistor R_9. With this configuration and proper design the over-all flat loss may be reduced from the value it would have if the leads 39 and 40 were connected respectively, to the terminals 42 and 41. This type of coupling is more fully described in the copending United States patent application, Serial No. 461,171, filed October 7, 1942.

What is claimed is:

1. A variable attenuation equalizer comprising in combination with a wave source impedance and a load impedance a coupling branch interposed between said impedances, said coupling branch comprising a subsidiary four-terminal bridged-T network, a resistor connected at one end of said subsidiary network and a variable impedance terminating said network at its other end, said network comprising two series branches, an interposed reactive shunt impedance and a reactive bridging impedance, said shunt impedance and said bridging impedance being inversely related to each other and one of said series branches having a frequency-dependent impedance characteristic.

2. An equalizer in accordance with claim 1 in which said interposed coupling branch is connected in series with said wave source impedance and said load impedance.

3. An equalizer in accordance with claim 1 in which said interposed coupling branch is connected in parallel with said wave source impedance and said load impedance.

4. An equalizer in accordance with claim 1 in which said resistor is connected in series with said wave source impedance and said load impedance and a pair of terminals of said subsidiary network are connected respectively to the terminals of said resistor.

5. An equalizer in accordance with claim 1 in which one terminal of said resistor is connected to one terminal of said wave source impedance and one terminal of said load impedance, the other terminal of said resistor is connected to one terminal of said subsidiary network and another terminal of said subsidiary network is connected to the other terminal of said wave source impedance and the other terminal of said load impedance.

6. An equalizer in accordance with claim 1 in which said one series branch is variable in impedance.

7. An equalizer in accordance with claim 1 in which said one series branch comprises a four-terminal building-out network.

8. An equalizer in accordance with claim 1 in which said one series branch comprises a four-terminal building-out network terminated by a variable impedance.

9. An equalizer in accordance with claim 1 in which said one series branch comprises a four-terminal building-out network of constant resistance image impedance terminated by a variable resistor.

10. An equalizer in accordance with claim 1 in which said variable impedance comprises a four-terminal building-out network.

11. An equalizer in accordance with claim 1 in which said variable impedance comprises a four-terminal building-out network of constant re-

sistance image impedance terminated by a variable resistor.

12. An equalizer in accordance with claim 1 in which said one series branch and said variable impedance each comprises a four-terminal building-out network.

13. An equalizer in accordance with claim 1 in which said one series branch and said variable impedance each comprises a four-terminal building-out network of constant resistance image impedance terminated by a variable resistor.

14. An equalizer in accordance with claim 1 in which the other of said series branches is a resistor of value R_0 and said shunt and bridging impedances are inversely related with respect to R_0.

15. An equalizer in accordance with claim 1 in which said variable impedance comprises a four-terminal building-out network of constant resistance image impedance R_0 terminated by a variable resistor and the other of said series branches is a resistor of value R_0.

16. An equalizer in accordance with claim 1 in which said one series branch comprises a four-terminal building-out network of constant resistance image impedance R_0 terminated by a variable resistor and the other of said series branches is a resistor of value R_0.

17. An equalizer in accordance with claim 1 in which said one series branch and said variable impedance each comprises a four-terminal building-out network of constant resistance image impedance R_0 terminated by a variable resistor and the other of said series branches is a resistor of value R_0.

18. An equalizer in accordance with claim 1 in which said one series branch and said variable impedance each comprises a four-terminal building-out network of constant resistance image impedance R_0 terminated by a variable resistor, the other of said series branches is a resistor of value R_0 and said shunt and bridging impedances are inversely related with respect to R_0.

19. An equalizer in accordance with claim 1 in which said one series branch is variable in impedance, said subsidiary network has a constant resistance image impedance R_0 when said one series branch is set equal to R_0, said bridging impedance has a value which is large compared to R_0 over one frequency range and said shunt impedance has a value which is large compared to R_0 over a second frequency range.

20. A bridged-T attenuation equalizer of constant resistance image impedance R_{03} comprising a bridging branch and a shunt branch, each of said branches comprising a subsidiary four-terminal bridged-T network and a variable impedance terminating said network, each of said networks comprising two series branches, an interposed reactive shunt impedance and a reactive bridging impedance, said shunt impedance and said bridging impedance being inversely related to each other and one of said series branches having a frequency-dependent impedance characteristic.

21. An equalizer in accordance with claim 20 in which said subsidiary networks have image impedances inversely related with respect to R_{03}.

22. An equalizer in accordance with claim 20 in which said one series branch is variable in impedance.

23. An equalizer in accordance with claim 20 in which said one series branch comprises a four-terminal building-out network.

24. An equalizer in accordance with claim 20 in which said one series branch comprises a four-terminal building-out network of constant resistance image impedance terminated by a variable resistor.

25. An equalizer in accordance with claim 20 in which said variable impedance comprises a four-terminal building-out network.

26. An equalizer in accordance with claim 20 in which said variable impedance comprises a four-terminal building-out network of constant resistance image impedance terminated by a variable resistor.

27. An equalizer in accordance with claim 20 in which said one series branch and said variable impedance each comprises a four-terminal building-out network.

28. An equalizer in accordance with claim 20 in which said one series branch and said variable impedance each comprises a four-terminal building-out network of constant resistance image impedance terminated by a variable resistor.

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