

Nov. 5, 1935.

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2,019,624

ATTENUATION EQUALIZER

Filed May 19, 1934

2 Sheets-Sheet 1

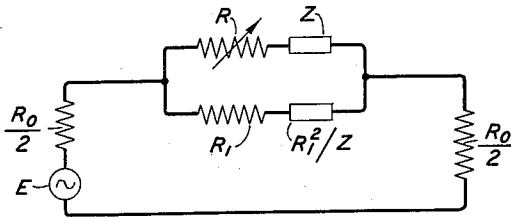


FIG. 1

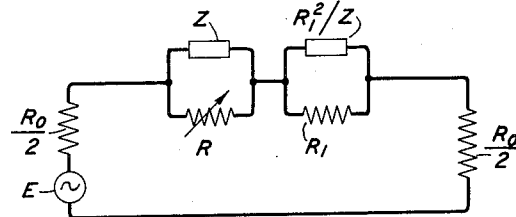


FIG. 2

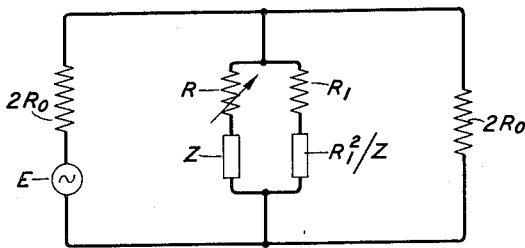


FIG. 3

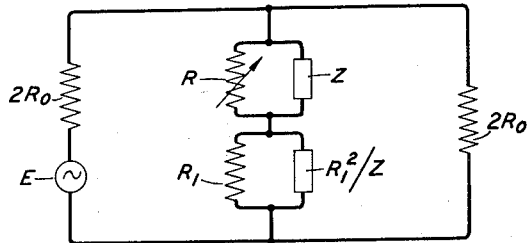


FIG. 4

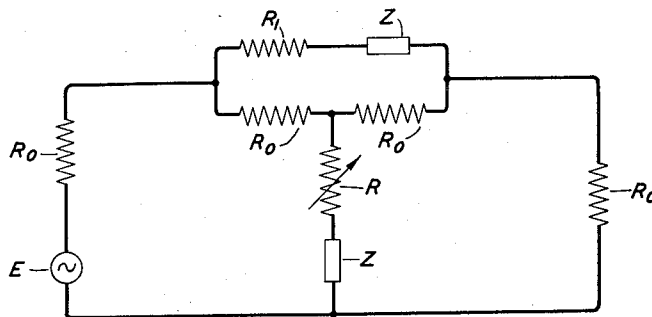


FIG. 5

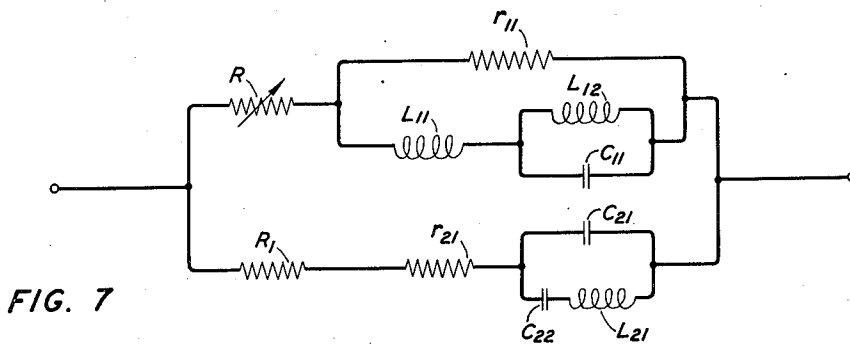


FIG. 7

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2 Sheets-Sheet 2

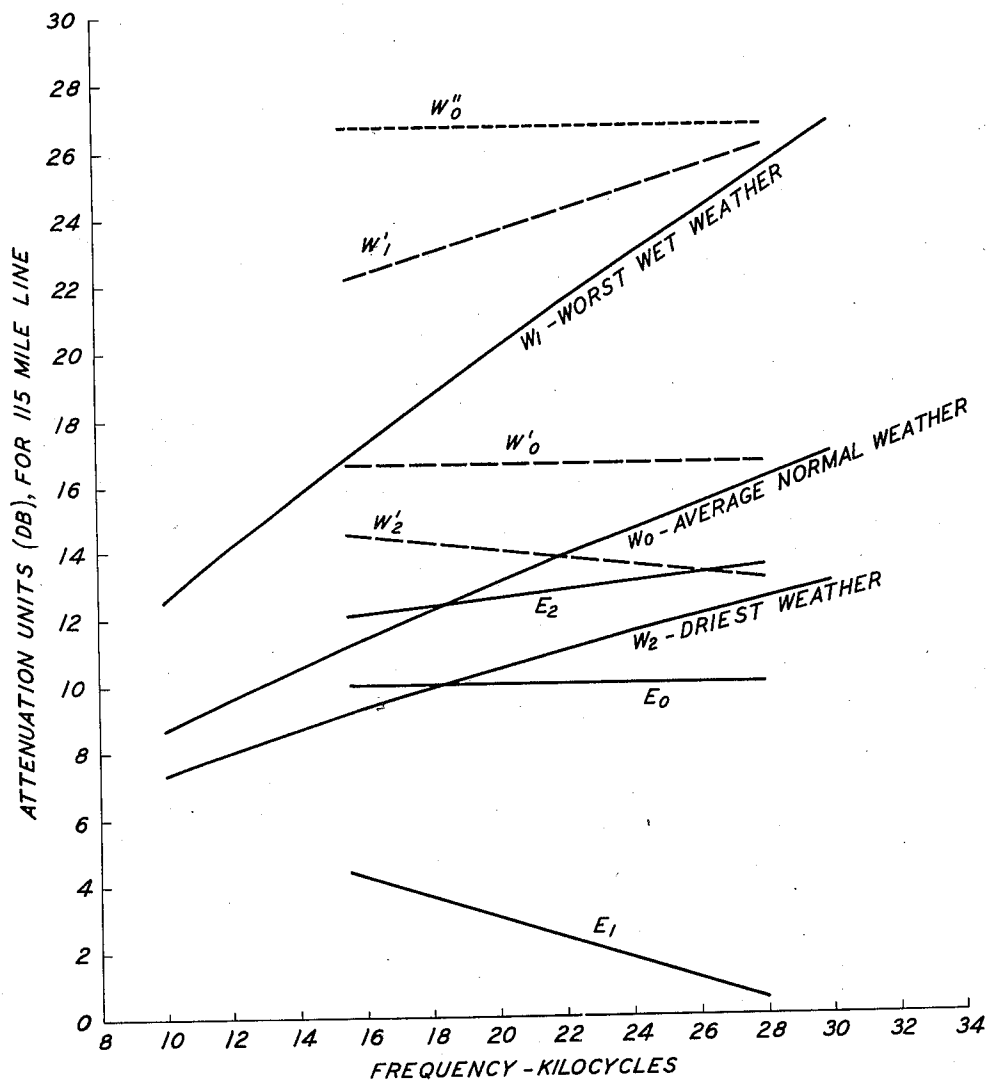


FIG. 6

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UNITED STATES PATENT OFFICE

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ATTENUATION EQUALIZER

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8 Claims. (Cl. 178-44)

This invention relates to transmission equalizing networks and more particularly to adjustable equalizers for compensating the variations of the attenuation in a transmission line due to changes in temperature and humidity.

The normal transmission loss characteristic of a uniform line, or of a loaded line below the cut-off, is an approximately linear function of frequency, the loss in decibels increasing more or less uniformly with frequency. As the temperature or the humidity varies, the slope of the characteristic changes, the result being that the increment of loss likewise increases with frequency. In consequence of this, if a line is compensated for a given set of conditions, departures from these conditions may result either in an increase or a decrease of attenuation which must be compensated by appropriate adjustments of the compensating networks to change the slope of their attenuation characteristics.

Heretofore this adjustment has usually been effected by the addition to or the removal from the line of equalizer sections of small attenuation or by the adjustment of a plurality of the impedance elements of a given network. These arrangements, however, tend to be expensive and complicated.

By the present invention an equalizer network is provided in which the adjustment of a single impedance element serves to increase or decrease the attenuation as desired, the increment of attenuation for each step of the adjustment retaining the necessary relationship to frequency. By proper proportioning, in the manner hereinafter described, the networks of the invention may be made to cover a range of attenuation adjustments at the upper frequency limit of approximately 14 decibels.

Of the attached drawings;

Figs. 1, 2, 3, 4 and 5 are diagrams of various schematic forms of the network of the invention, of which Figs. 1 and 2 show a series connection;

Figs. 3 and 4 a shunt connection; and

Fig. 5 a bridged-T connection;

Fig. 6 is a diagram showing attenuation characteristics of a certain non-loaded open-wire line, together with the characteristic curves of an equalizer to be used therewith; and Fig. 7 is a diagram of a specific design of the invention having the equalizer characteristics referred to in Fig. 6.

In Figs. 1 to 5, inclusive, the various forms of the network comprising the invention are shown each connected in a circuit between terminal resistances of equal value. In each figure, the driv-

ing electromotive force is represented by the generator E, the resistance of the sending end by the resistance at the left, and that of the receiving end by the equal resistance at the right. Referring now specifically to Fig. 1, the network therein shown is composed of two parallel branches, one branch consisting of a variable resistance R in series with an impedance Z and the other branch of a fixed resistance R₁ in series with an inverse impedance R₁²/Z, the network being connected in series between terminal resistances each equal to R₀/2. The structure of the inverse impedance may be arrived at from that of the impedance Z in accordance with United States Patent 1,603,305 to O. J. Zobel, issued October 19, 1926.

When the network is used as a compensator for a transmission line one or other of the terminal resistances may be provided by the line itself, the impedance of which is usually a substantially constant resistance, or by the line in combination with terminating networks such as fixed attenuation equalizers and phase correctors. Alternatively, the variable compensator may be used between amplifier stages of a vacuum tube repeater in the line, in which case the terminal resistances may represent the output and the input impedances of the successive amplifiers.

The insertion loss θ due to connecting the network in the circuit is given by

$$e^{\theta} = \frac{I_1}{I_2}$$

where e is the base of natural logarithms, I_1 is the current through the receiving-end resistance with the network absent and I_2 is the corresponding current with the network in the circuit. We have therefore

$$I_1 = \frac{E}{R_0}$$

$$I_2 = \frac{E}{R_0 + \frac{(R+Z)(R_1+R_1^2/Z)}{R+Z+R_1+R_1^2/Z}}$$

and, after substituting and simplifying,

$$e^{\theta} = 1 + \frac{1}{R_0} \frac{(R+Z)(R_1+R_1^2/Z)}{R+Z+R_1+R_1^2/Z} \quad (1)$$

Now when $R=R_1$, the network has a constant resistance equal to R_1 , independent of the value of Z and consequently independent of frequency. For this condition the insertion loss has a fixed value θ_0 given by

$$e^{\theta_0} = 1 + \frac{R_1}{R_0} \quad (2)$$

The change in the insertion loss from this con-

stant value, $\theta - \theta_0$, due to a departure of R from the value R_1 , will be given by

$$e^{\theta - \theta_0} = \frac{e^\theta}{e^{\theta_0}} = \frac{(R + Z + R_1 + R_1^2/Z) + \frac{1}{R_0}(R + Z)(R_1 + R_1^2/Z)}{(1 + R_1/R_0)(R + Z + R_1 + R_1^2/Z)} \quad (3)$$

which may be simplified to

$$e^{\theta - \theta_0} = 1 + \frac{\frac{R - R_1}{R_0 + R_1}}{1 + \frac{Z}{R_1} \left(1 + \frac{R}{R_1}\right) + \left(\frac{Z}{R_1}\right)^2} \quad (4)$$

When R is not greatly different from R_1 (i. e., for small departures), the change in loss may be represented by the approximate formula,

$$e^{\theta - \theta_0} \doteq 1 + \frac{(R - R_1)/(R_0 + R_1)}{(1 + Z/R_1)^2} \quad (5)$$

or,

$$e^{\theta - \theta_0} \doteq 1 + \frac{R_1}{R_0 + R_1} \frac{(R - R_1)/R_1}{\left(1 + \frac{Z}{R_1}\right)^2} \quad (6)$$

It is to be noted that the second term of the right-hand side of Equation 6 changes sign as R passes through the value R_1 , thus corresponding to a change from a positive to a negative slope of the frequency characteristic.

In Fig. 2 the network of the equalizer, which again is connected in series between terminal resistances each equal to $R_0/2$, consists of two parts in series, a variable resistance R in shunt with an impedance Z , and a fixed resistance R_1 in shunt with the inverse impedance R_1^2/Z . In a manner similar to the above it can be shown that the insertion loss θ is given by

$$e^\theta = 1 + \frac{1}{R_0} \left(\frac{RZ}{R + Z} + \frac{R_1^2}{R_1 + Z} \right) \quad (7)$$

When $R = R_1$, the constant loss θ_0 will be given by

$$e^{\theta_0} = 1 + \frac{R_1}{R_0} \quad (8)$$

and the change in loss, $\theta - \theta_0$, when R is varied, by

$$e^{\theta - \theta_0} = 1 + \frac{(R - R_1)/(R_0 + R_1)}{\left(1 + \frac{R}{R_1}\right) \left(1 + \frac{R_1}{Z}\right)} \quad (9)$$

which, when R is not greatly different from R_1 , gives the approximate formula,

$$e^{\theta - \theta_0} \doteq 1 + \frac{R_1}{R_0 + R_1} \frac{(R - R_1)/R_1}{\left(1 + \frac{R_1}{Z}\right)^2} \quad (10)$$

In Fig. 3 the network is the same as that of Fig. 1 but connected in shunt between terminal resistances each equal to $2R_0$. For this case we will have

$$e^\theta = 1 + R_0 \frac{\left(1 + \frac{Z}{R}\right) \frac{Z}{R_1^2} + \left(1 + \frac{Z}{R_1}\right) \frac{1}{R}}{\left(1 + \frac{Z}{R_1}\right) \left(1 + \frac{Z}{R}\right)} \quad (11)$$

$$e^{\theta_0} = 1 + \frac{R_0}{R_1} \quad (12)$$

$$e^{\theta - \theta_0} = 1 + \frac{R_0}{R_0 + R_1} \frac{(R_1 - R)/R}{\left(1 + \frac{Z}{R}\right) \left(1 + \frac{Z}{R_1}\right)} \quad (13)$$

or

$$e^{\theta - \theta_0} \doteq 1 + \frac{R_0}{R_0 + R_1} \frac{(R_1 - R)/R}{\left(1 + \frac{Z}{R_1}\right)^2} \quad (14)$$

In Fig. 4 the network is exactly similar to that of Fig. 2 but connected in shunt between ter-

minal resistances each equal to $2R_0$. Following the same steps as in the preceding examples it can be shown that;

$$e^\theta = 1 + R_0 \frac{\left(\frac{1}{R} + \frac{1}{Z}\right) \left(\frac{1}{R_1} + \frac{Z}{R_1^2}\right)}{\frac{1}{R} + \frac{1}{Z} + \frac{1}{R_1} + \frac{Z}{R_1^2}} \quad (15)$$

$$e^{\theta_0} = 1 + \frac{R_0}{R_1} \quad (16)$$

$$e^{\theta - \theta_0} = 1 + \frac{R_0}{R_1 + R_0} \frac{(R_1 - R)/R}{1 + \frac{R_1}{Z} \left(1 + \frac{R_1}{R}\right) + \left(\frac{R_1}{Z}\right)^2} \quad (17)$$

or,

$$e^{\theta - \theta_0} \doteq 1 + \frac{R_0}{R_1 + R_0} \frac{(R_1 - R)/R}{\left(1 + \frac{R_1}{Z}\right)^2} \quad (18)$$

For the bridged-T form of the invention as illustrated in Fig. 5, if we write Z_1 for $R_1 + Z$ and Z_2 for $R + Z$, it can be readily shown that the insertion loss will be given by

$$e^{-\theta} = \frac{1}{2} \left[1 + \frac{\frac{1}{R_0} (Z_2 - Z_1)}{\left(1 + \frac{Z_1}{R_0}\right) \left(1 + \frac{Z_2}{R_0}\right)} \right] \quad (19)$$

which, when $Z_1 = Z_2$ (i. e., when $R_1 = R$), gives a fixed loss θ_0 determined by

$$e^{-\theta_0} = \frac{1}{2}$$

For the change in loss we will therefore have

$$e^{-(\theta - \theta_0)} = 1 + \frac{(R - R_1)/R_0}{1 + \frac{R_1}{R_0} + \frac{Z}{R_0} \left(1 + \frac{R}{R_0} + \frac{Z}{R_0}\right)} \quad (20)$$

and when R is not greatly different from R_1 ,

$$e^{-(\theta - \theta_0)} \doteq 1 + \frac{R_0}{R_0 + R_1} \frac{(R - R_1)/R_0}{\left(1 + \frac{Z}{R_0 + R_1}\right)^2} \quad (21)$$

It will be noted that in each case the insertion loss is constant for one particular value of R (equal to R_1) and that the change in the insertion loss from this value is positive or negative depending upon whether R is increased or decreased; and that when R differs from R_1 the loss is variable with the impedance, and hence with frequency. Also, in each case the change in loss is expressed by a formula of the type,

$$e^{-(\theta - \theta_0)} \doteq 1 + \frac{(R - R_1)/R_a}{\left[1 + \left(\frac{Z}{R_b}\right)^{n+1}\right]^2} \quad (22)$$

in which R_a and R_b are resistances the values of which are indicated in the equations for the several circuits.

When $R - R_1$ is small compared with R_a the loss increment, $\theta - \theta_0$, may be computed directly from the formula,

$$-(\theta - \theta_0) \doteq \frac{(R - R_1)/R_a}{\left[1 + \left(\frac{Z}{R_b}\right)^{n+1}\right]^2} \quad (23)$$

The requirements of an ideal equalizer of the type described above, by means of which the loss is adjustable by the variation of a single resist-

ance, may be stated as follows: If L is the change in the insertion loss of the equalizer from the constant value when $R=R_1$, then $L=KL_0$, where K is a function of the variable resistance alone and is independent of frequency, and L_0 is a function of frequency. In other words, if a change in resistance is made in the adjustable element which doubles the change in loss at some particular frequency, then the change in loss must be doubled at all other frequencies within the band that is to be equalized.

From Equations 2, 8, 12 and 16, giving the fixed loss ϕ_0 for the networks of Figs. 1, 2, 3 and 4, respectively, it is seen that the fixed loss in these cases depends upon the ratio of R_1 to R_0 , and since R_1 is arbitrary and R_0 a constant it is evident that ϕ_0 may be given any value desired. However, in order for the equalizer to approximate the ideal characteristic specified above with simple structures for the impedances Z and R_1^2/Z it has been found that the fixed loss should have a value of approximately 10 decibels. This provides also for a relatively large range of compensation in both positive and negative directions. For the bridged-T network of Fig. 5, on the other hand, it is seen from Equation 21 that the fixed loss is independent of the resistances and is equal to 6 decibels in all cases.

As an illustration of a use for my invention I will show how, in combination with a fixed equalizer, it can be used to compensate for the changes in the attenuation of a transmission line due to such causes as changes in weather conditions. In Fig. 6 the curves W_1 , W_2 and W_0 represent the variation of attenuation with frequency of a certain line 115 miles long for two extremes of humidity, and for an average condition. It is desired to connect in the line an equalizer such that as the weather conditions change the equalizer may be adjusted to compensate for this change over a range of frequency from 15.5 to 28 kilocycles. It is assumed that the impedance of the line is equivalent to a resistance of 600 ohms and that the line is to be connected to a terminal resistance of equal value.

In order to accomplish this object most conveniently, there is first provided a fixed equalizer of the type shown in United States Patent 1,603,305, to Zobel, which is so designed as to equalize the attenuation for a chosen mean weather condition, as represented, for example, by the curve W_0 . This equalizer will have an attenuation-frequency characteristic such that the sum of its ordinates and those of curve W_0 will give a constant attenuation within the chosen frequency limits, as represented by the horizontal line W_0' ; while for the extreme conditions represented by the curves W_1 and W_2 the insertion of the fixed equalizer will result in attenuations as shown by the sloping lines W_1' and W_2' .

It will be seen that the over-all attenuation characteristic with the fixed equalizer may have either a positive or a negative slope depending upon weather conditions. To connect these varying slopes a single adjustment variable equalizer of the invention may be used. If this is designed for a fixed loss of 10 decibels, represented by straight line E_0 , the characteristics required for the compensation of the curves W_1' and W_2' will be represented by the oppositely sloping lines E_1 and E_2 , respectively, the resultant over-all characteristic of the line and the two equalizers being represented by the horizontal line W_0'' .

The two characteristics E_1 and E_2 and proportionally related intermediate characteristics are

obtained by the adjustment of a single resistance element so that all proper compensation of the line under all conditions may readily be accomplished.

An equalizer network of the series type of Fig. 1 which will substantially accomplish the above desired results is shown in Fig. 7 where the elements have the following values:

$R_1=2592$ ohms
 $r_{11}=1073$ ohms
 $L_{11}=3.49$ millihenries
 $L_{12}=39.7$ millihenries
 $C_{11}=.00772$ microfarad
 $r_{21}=6260$ ohms
 $C_{21}=.00052$ microfarad
 $C_{22}=.00592$ microfarad
 $L_{21}=51.8$ millihenries

With this design the characteristic E_0 is obtained when $R=R_1=2592$ ohms, the characteristic E_1 when $R=0$, and the characteristic E_2 when $R=3120$ ohms. Assuming now that for intermediate weather conditions the law of variation of line attenuation with frequency is of the same form as that for the curves W_0 , W_1 and W_2 , which experience shows to be the case, it follows that for any condition whatever between the extremes here shown the over-all attenuation may be made substantially constant throughout the chosen frequency range by merely adjusting the single resistance R .

Although the equalizer selected for this illustration is the series type shown in Fig. 1, it is to be understood that equally good results could be obtained by the use of either of the arrangements shown in Figs. 2, 3, 4 and 5. In each case the design procedure involves the selection of an impedance Z_1 , such that its ratio to the resistance R_1 when inserted in the appropriate formula gives the required type of characteristic. In this respect the design follows the conventional methods of equalizer design, the selection being largely a matter of successive approximations.

What is claimed is:

1. A variable attenuation network comprising in combination with two fixed terminal resistances a composite impedance connected between said resistances, said composite impedance comprising two portions, one of said portions consisting of a fixed resistance in combination with a reactive impedance and the other of said portions consisting of a variable resistance in combination with a second reactive impedance inversely related to said first mentioned reactive impedance, said two portions together being proportioned to have a constant resistance impedance for one value of the variable resistance of the second portion.

2. A variable attenuator in accordance with claim 1 in which the constant resistance of the composite impedance is proportioned with respect to the terminal resistances to produce an insertion loss of substantially 10 decibels.

3. In combination with a transmission line having an attenuation characteristic subject to variations, a variable attenuation equalizer comprising a composite impedance having two portions, one of said portions consisting of a fixed resistance in combination with a reactive impedance and the other of said portions consisting of a variable resistance in combination with a second reactive impedance of inverse character to said first reactive impedance, said two portions together being proportioned to have a constant resistance impedance for one value of said variable resistance, and said reactive impedances being proportioned

with respect to the resistances associated therewith and to the attenuation characteristic of the transmission line whereby for adjustments of the variable resistance to other values than that giving constant resistive impedance, the equalizer provides an attenuation of complementary character to that of the line.

4. In combination, a transmission line having an attenuation characteristic subject to variations, a fixed attenuation equalizer therefor adapted to compensate the average attenuation characteristic of the line, and a variable equalizer for compensating variations of the line attenuation from the average, said variable equalizer comprising a fixed resistance and a reactive impedance, a variable resistance and a second reactive impedance of inverse character to said first mentioned reactive impedance, and being proportioned to have a constant resistance impedance for one value of said variable resistance.

5. In combination, a transmission line having an attenuation variable with frequency and subject to variations from a mean characteristic with time, and a variable equalizer adapted to compensate the variations of the line attenuation from the mean, said equalizer comprising a combination of resistances, including a variable resistance, and reactive impedances, said resistances and reactive impedances being proportioned and arranged to provide a constant resistance impedance for one value of said variable resistance and to provide attenuation characteristics complementary to the variations of the line attenuation from its mean for other values of said variable resistance.

6. A variable attenuation equalizer for operation between resistive terminal impedances comprising a fixed resistance in combination with a

reactive impedance, a variable resistance in combination with a second reactive impedance of inverse character to said first mentioned reactive impedance, said resistances and said reactive impedances being proportioned and arranged to provide a constant resistance impedance for one value of said variable resistance and to provide an attenuation, measured in decibels, which varies linearly with frequency for other values of the variable resistance.

7. A variable attenuation equalizer for operation between resistive terminal impedances comprising a fixed resistance in series with a reactive impedance, and, in parallel with said combination a variable resistance in series with a second reactive impedance of inverse character to said first mentioned reactive impedance, said parallel combination being proportioned to have a constant resistance impedance for one value of said variable resistance and to provide an attenuation, measured in decibels, which varies linearly with frequency for other values of said variable resistance.

8. A variable attenuation equalizer for operation between resistive terminal impedances comprising a fixed resistance in parallel with a reactive impedance and in series therewith a variable resistance in parallel with a second reactive impedance of inverse character to said first mentioned reactive impedance, said series combination being proportioned to have a constant resistance impedance for one value of said variable resistance and to provide an attenuation, measured in decibels, which varies linearly with frequency for other values of said variable resistance.

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