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2,153,743

ATTENUATION EQUALIZER

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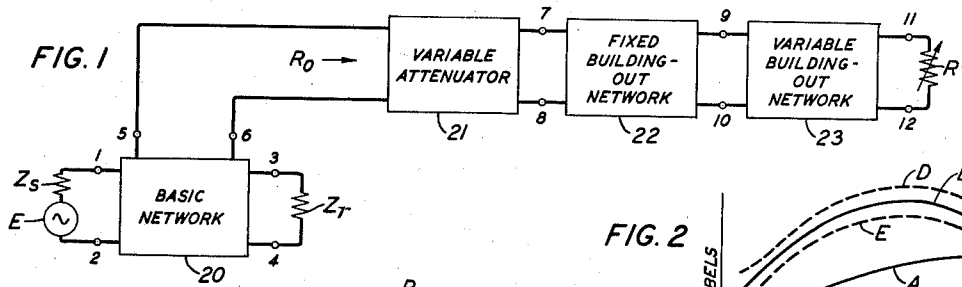


FIG. 2

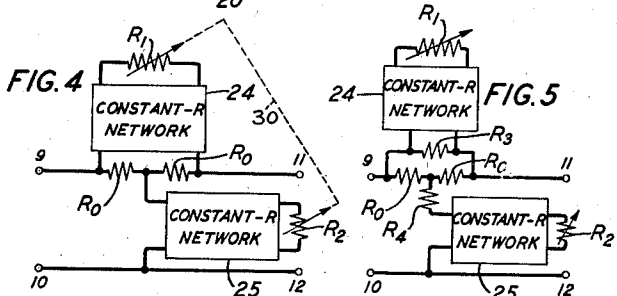
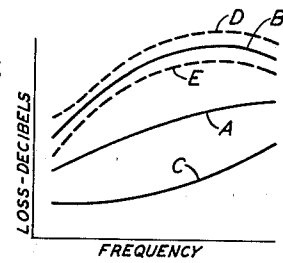


FIG. 3

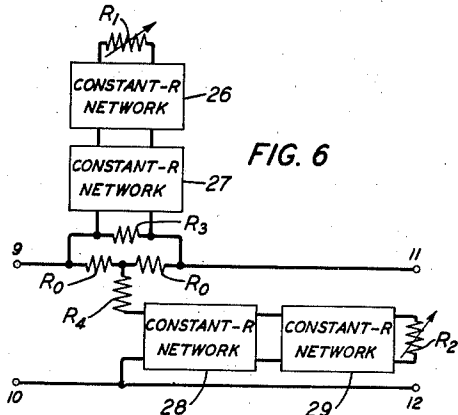
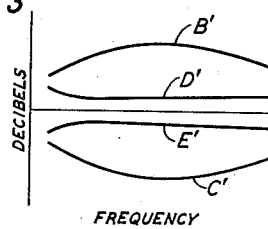


FIG. 7

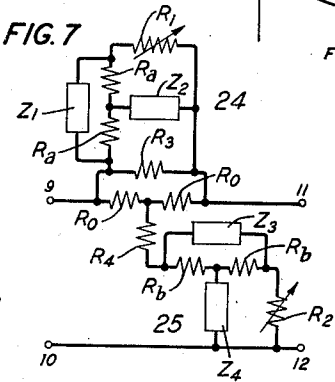
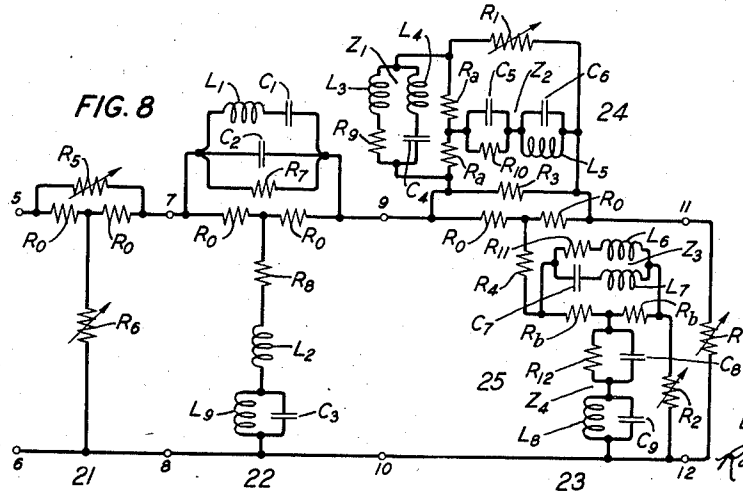


FIG. 8



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ATTENUATION EQUALIZER

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14 Claims. (Cl. 178-44)

This invention relates to attenuation equalizing networks and more particularly to adjustable variable equalizers for the equalization of transmission lines and associated networks the attenuation of which is subject to variation.

An object of the invention is to equalize the changes in the attenuation distortion in transmission lines or the like due, for example, to changes in temperature or humidity.

Another object is to adapt a variable attenuation equalizer for use with transmission lines having different transmission characteristics.

A further object is to adapt an adjustable variable equalizer for use with sections of line which differ in length.

A feature of the invention is an adjustable variable attenuation equalizer having a single variable impedance for controlling the fractional part of a compensation characteristic which is added to or subtracted from the normal insertion loss characteristic of the equalizer, an additional pair of variable impedances for adjusting the shape of the compensation characteristic, and a second pair of variable impedances for adjusting the maximum amplitude of the compensation characteristic.

In long telephone circuits involving a large number of repeaters it is necessary for high quality transmission not only that the over-all attenuation distortion be held within close limits, but also that each line section be accurately equalized. This equalization is usually accomplished by means of individual attenuation equalizing networks associated with the sections of line. The attenuation in a line section tends to vary continually due to temperature changes, and in order to compensate for these variations the equalizer is provided with a single variable impedance under automatic temperature control. It has been found that the changes in line loss are functions of frequency and are proportional to the temperature changes. The equalizer is therefore so designed that it will have a certain normal insertion loss characteristic for a chosen normal setting of the variable impedance, while changes in this setting serve to add to or subtract from the normal characteristic fractional parts of a predetermined frequency-variable loss characteristic. A variable equalizer of this type is disclosed in H. W. Bode's copending application Serial No. 61,497, filed January 30, 1936, which was patented October 19, 1937 as United States Patent No. 2,096,027. By means of such an equalizer each line section and the entire cir-

cuit may be kept automatically equalized at all temperatures.

The loss in a transmission line may vary widely from section to section due to differences in the type of facility or in the length of section. The equalizer is therefore designed to compensate the average line section and, in accordance with the present invention, auxiliary adjustments are provided for adapting or adjusting the equalizer to the particular section of line with which it is to be used. A variable equalizer having this feature of adjustment may be called an adjustable variable equalizer. In general, two types of adjustment are required, one for changing the shape, and another for controlling the maximum amplitude, of the compensation characteristic. In the preferred embodiment two variable building-out sections are provided for this purpose.

One of these building-out sections is a variable attenuator having a pair of variable impedances by means of which the amplitude, or maximum value, of the compensation characteristic may be controlled. This adjustment is useful in adapting the equalizer to any length of line section without the necessity of recalibrating the temperature-controlled variable impedance. Its use may also be required in fitting the equalizer characteristic to that of a particular section of line.

Another building-out section having a second pair of variable impedances is provided for adjusting the shape of the compensation characteristic. With these impedances set at chosen normal values the section acts as a pad of constant attenuation, which merely reduces the amplitude of the compensation characteristic and may be compensated for by an adjustment of the variable attenuator. At other settings of the impedances the section serves to adjust the compensation characteristic by adding thereto or subtracting therefrom fractional parts of an auxiliary frequency-variable loss characteristic. This auxiliary characteristic is so chosen that the equalizer may be adapted to the maximum percentage of the types of line sections to be encountered in the field.

In physical form the equalizer of the invention comprises a 6-terminal fixed-impedance basic network, a single variable impedance which is usually a variable resistor under temperature control, and a number of 4-terminal building-out networks connected in tandem between the basic network and the variable impedance. In one embodiment the building-out networks include a variable attenuator, a fixed-impedance equal-

izer and a variable equalizer having associated therewith a pair of variable impedances which are preferably resistances. The present invention is directed more particularly to the design of the building-out networks to provide the auxiliary adjustments mentioned above so that the insertion loss characteristic of the variable equalizer may be so adjusted that it will compensate more exactly for the attenuation distortion of the particular section of line with which it is to be used.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing, of which:

Fig. 1 shows the general schematic arrangement of the adjustable variable attenuation equalizers of the invention;

Fig. 2 illustrates typical insertion loss characteristics obtainable at certain chosen settings of the variable impedances;

Fig. 3 shows the changes in loss represented by the curves of Fig. 2;

Fig. 4 shows schematically in more detail one form of the variable building-out network consisting of a bridged-T structure in which the bridging impedance branch and the shunt impedance branch comprise subsidiary 4-terminal constant-resistance networks;

Fig. 5 shows the schematic arrangement of a modification of the network of Fig. 4 in which a resistance is added in shunt with the bridging branch and a second resistance is added in series with the shunt branch;

Fig. 6 is a schematic showing of a modification of the network of Fig. 5 in which the bridging branch comprises two 4-terminal constant-resistance networks and the shunt branch comprises two other 4-terminal constant-resistance networks;

Fig. 7 shows schematically in more detail the network of Fig. 5 in which each subsidiary 4-terminal network is of the bridged-T type; and

Fig. 8 shows the detailed configuration of a particular network of the invention in accordance with Figs. 1 and 7.

Fig. 1 shows schematically the arrangement of the adjustable variable equalizer of the invention comprising a basic network 20, a variable resistance R under automatic temperature control, and interposed in tandem therebetween three 4-terminal building-out networks having image impedances R_0 which are equal constant resistances. The building-out networks include a variable attenuator 21, a fixed-impedance equalizer 22 and a variable equalizer 23. The basic network 20 has a pair of input terminals 1, 2 to which is connected a wave source of impedance Z_s and voltage E , a pair of output terminals 3, 4 leading to a load of impedance Z_r , and a third pair of terminals 5, 6 to which are connected the building-out sections 21, 22 and 23 and the variable resistance R . The equalizer is basically of the same form as that shown in Fig. 3 of the above-mentioned Bode patent except that the building-out network is divided into three sections, two of which are variable. The basic network 20 may take any of the several forms shown in the Bode patent, and reference is made thereto for detailed design formulas.

The function of the variable attenuator 21 is to control the amplitude or range of the compensation characteristic, and it may be of any suitable type having the proper image impedance R_0 . In general, two inversely related vari-

able impedances are needed to meet this requirement.

The fixed building-out network 22 may consist of one or more sections, all having matching image impedances R_0 . The function of this network is to correct for changes in attenuation distortion in the average line caused by changing temperature. With the variable resistance R set at R_0 the equalizer will equalize the associated line at some reference temperature. As the temperature varies the setting of R is automatically changed and proportional parts of a frequency-variable loss characteristic are added to or subtracted from the normal characteristic. The variable characteristic thus introduced depends upon the transfer constant of the fixed building-out network, and this network is designed to compensate as nearly as possible for the change in loss in the average line due to the corresponding change in temperature. Extra amplitude in the swing of the correction characteristic introduced by the network 22 is required in order to allow for the effect of the variable attenuator 21 and the variable building-out section 23, as explained below.

Any line section may therefore be compensated to a first approximation by means of the variable characteristic introduced by the equalizer section 22. When more exact equalization is required, however, it is necessary that this variable characteristic be independently adjustable. In accordance with the invention this is accomplished by means of the variable attenuator 21 together with the variable equalizer 23. This equalizer is a symmetrical 4-terminal network having a constant-resistance image impedance R_0 and having a pair of variable impedances by means of which the transfer constant may be adjusted. The equalizer 23 is preferably of the bridged-T type and may take any of the forms shown schematically in Figs. 4, 5, 6 and 7. As shown in Fig. 4, the bridging branch is a symmetrical 4-terminal constant resistance subsidiary network 24 terminated in a variable resistance R_1 , and the shunt branch is another network 25 of similar type terminated in another variable resistance R_2 . The two networks 24 and 25 have image impedances R_a and R_b which are inversely related with respect to the square of the image impedance R_0 , and the resistances R_1 and R_2 also have the same inverse relationship at all settings. When the resistances R_1 and R_2 have reference settings equal to the image impedances of the networks 24 and 25, respectively, the equalizer 23 simply acts as an attenuation pad and restricts the swing in the same manner as does the attenuator 21. If, in addition, R is set at the reference value R_0 an adjustment of the resistances R_1 and R_2 has no effect on the insertion loss of the network as a whole. For other than the reference settings of R_1 , R_2 and R , an auxiliary characteristic approximating any desired part of a frequency-variable loss curve may be added to or subtracted from the over-all characteristic obtained with the above-specified reference settings of R_1 and R_2 . As a matter of convenience the variable resistances R_1 and R_2 may, if desired, be arranged for unitary control as indicated in Fig. 4 by the dotted line 30.

Fig. 2 shows typical insertion loss characteristics obtainable with the adjustable variable equalizer of Fig. 1 when the variable resistances have certain chosen values. The ordinates of the curves represent the over-all insertion loss in decibels and the abscissas represent frequency.

Curve A is the normal characteristic when R is set at R_0 . This normal characteristic may vary with frequency, as shown, or it may be constant with frequency, depending upon the type of basic network employed. When R is set at R_0 all of the building-out networks 21, 22 and 23 are terminated in their image impedance and changing the settings of R_1 and R_2 has no effect on the insertion loss. With R_1 and R_2 set at the reference values R_a and R_b , respectively, a setting of R at some value R' will give the curve B which depends only upon the transfer constant of the fixed building-out network 22 and the constant loss which represents the transfer constant of the variable building-out network 23 with these reference settings. The difference between the ordinates of curves A and B, represented by curve B' of Fig. 3, is approximately proportional to a reference characteristic, the factor of proportionality being determined by the setting of R and the setting of the variable attenuator 21. There is also another setting R'' for the resistance R such that

$$R'' = \frac{R_0^2}{R'} \quad (1)$$

which will give the curve C of Fig. 2. The difference between the ordinates of curves A and C is given by curve C' of Fig. 3. It will be seen that at every frequency the ordinates of curves B' and C' are equal in magnitude but of opposite sign. Curves B' and C' may therefore be called mirror images with respect to curve A. Other curves, approximately proportional at every frequency to B and C, are obtainable with other settings of R.

Now, with the resistance R set at R' , if the resistances R_1 and R_2 are reset at a different pair of values, curve B will be adjusted to a different characteristic, represented by dotted curve D, and there is another set of values for R_1 and R_2 which will give the curve E. The difference between the ordinates of curves B and D is shown by curve D' of Fig. 3, and the difference between the ordinates of curves B and E is given by curve E'. The curves D' and E' are very nearly mirror images with respect to curve B. With other settings of R_1 and R_2 other curves, approximately proportional to D' and E', may be obtained. In this way any desired fractional part of an auxiliary characteristic may be added or subtracted, the fraction in any case depending only upon the setting of the resistances R_1 and R_2 . By means of this adjustment and, when required, an adjustment of the attenuator 21, the over-all insertion loss of the network may be very exactly fitted to the requirements of the particular line section with which it is to be associated. This auxiliary adjustment may conveniently be made in the field, with the equalizer connected into the circuit.

The variable building-out network of Fig. 4 is adequate to provide the mirror image curves D' and E' when the required auxiliary adjustment is comparatively small in magnitude. When larger adjustments are required the network shown in Fig. 5 will give better results. The network of Fig. 5 differs from the network of Fig. 4 only by the addition of the resistance R_3 in shunt with the bridging branch and the resistance R_4 in series with the shunt branch. The magnitudes of the resistances R_3 and R_4 may be found from Equations (18) and (20) given hereinafter.

Fig. 6 shows a further modification of the variable building-out network of Fig. 5 in which the subsidiary constant-resistance network 24 in the

bridging branch is divided into two symmetrical constant-resistance sections 26 and 27, having the same image impedance R_a but different transfer constants, and likewise the network 25 in the shunt branch is divided into two sections 28 and 29 having the same transfer constants respectively as the networks 26 and 27 but a different image impedance R_b . If one of the sections in each branch, say sections 27 and 28, has a transfer constant which is complementary to that of the fixed building-out network 22, the effect of varying the resistances R_1 and R_2 will be very nearly independent of this transfer constant. This facilitates the design of networks in which the adjustment of R_1 and R_2 is to have a prescribed effect.

The network of Fig. 5 is shown in more detail in Fig. 7 wherein the constant-resistance network 24 in the bridging branch is itself a bridged-T structure of image impedance R_a , and the network 25 in the shunt branch is another bridged-T structure of image impedance R_b . The network 24 has a bridging branch of impedance Z_1 and a shunt branch of impedance Z_2 related by

$$Z_1 Z_2 = R_a^2 \quad (2)$$

and the network 25 has corresponding bridging and shunt impedances Z_3 and Z_4 related by

$$Z_3 Z_4 = R_b^2 \quad (3)$$

The mathematical theory on which the invention is based will now be considered in more detail. In the above-mentioned Bode patent the following relation is set forth as Equation (24)

$$e^{-\theta} = e^{-\theta_0} \frac{x + e^{\phi'}}{1 + x e^{\phi'}} \quad (4)$$

in which θ is a quantity from which the over-all insertion loss and insertion phase can be computed by determining the real and imaginary parts of the right-hand side of the equation

$$\alpha_I + j\beta_I = \theta + \log_e \frac{R_0}{Z_s + Z_r} \quad (5)$$

where

α_I = over-all insertion loss in nepers

β_I = over-all insertion phase in radians

R_0 = image impedance of building-out networks

Z_s = impedance of the wave source

Z_r = impedance of the load.

The quantities R_0 , Z_s and Z_r are independent of the settings of the variable resistances R, R_1 and R_2 . The other symbols used in Equation (4) represent the following:

θ_0 = value assumed by θ when $R = R_0$

$$x = \frac{R}{R_0} \quad (5)$$

ϕ' = some function of frequency depending upon the specific network considered.

Equation (4) can be shown to be exactly equivalent to the expression

$$\tanh \frac{\theta - \theta_0}{2} = \frac{x - 1}{x + 1} \tanh \frac{\phi'}{2} \quad (6)$$

in which the real part of the quantity $(\theta - \theta_0)$ represents the variation of the insertion loss from its value when the resistance R is set at R_0 , in accordance with Equation (5), the definition of θ_0 , and the fact that

$$\log_e \frac{R_0}{Z_s + Z_r}$$

is independent of R and the other variable impedances.

When a building-out network is included ϕ' in

Equation (4) can be replaced by ϕ and ψ in accordance with the relation

$$e^{\phi} = \frac{e^{\psi} + \tanh \psi}{1 + e^{\psi} \tanh \psi} \quad (7)$$

where

$\phi = \phi'$ function that would be obtained without the building-out network

ψ = transfer constant of the building-out network.

Combining Equations (6) and (7) gives

$$\tanh \frac{\theta - \theta_0}{2} = \frac{x-1}{x+1} e^{-2\psi} \tanh \frac{\phi}{2} \quad (8)$$

Fig. 15 of the Bode patent shows a variable equalizer comprising two series impedance branches and an interposed shunt impedance branch. The shunt branch consists of a fixed resistance equal to R_0/a connected in series with one end of a building-out network M which is terminated at its other end in the variable resistance R. If ψ is the transfer constant of the network M it is found that

$$e^{-\phi} = a \quad (9)$$

and, from Equation (8), in this special case

$$\tanh \frac{\theta - \theta_0}{2} = \frac{x-1}{x+1} \frac{1-a}{1+a} e^{-2\psi} \quad (10)$$

Now, if the building-out network comprises three tandem-connected sections having individual transfer constants α_1 , ψ_2 and ψ_3 defined as follows:

α_1 = variable attenuation, constant with frequency

ψ_2 = transfer constant of the fixed building-out section

$\psi_3 = \alpha_{30} + \psi_{3a}$ = transfer constant of the variable building-out section

wherein

α_{30} = constant attenuation of the variable section at the reference settings of R_1 and R_2

ψ_{3a} = departure of the transfer constant of the variable section from α_{30}

then Equation (10) becomes

$$\tanh \frac{\theta - \theta_0}{2} = \frac{x-1}{a+1} \frac{a-1}{a+1} e^{-2\alpha_{30}} e^{-2\alpha_1} e^{-2\psi_2} e^{-2\psi_{3a}} \quad (11)$$

From the above rigorous formulas there may be derived approximate formulas which are sometimes more convenient to use for design purposes. From Equation (11) a series expansion for θ can be obtained in the form

$$\theta - \theta_0 = \theta' + \frac{1}{12} \theta'^3 + \frac{1}{80} \theta'^5 + \dots \quad (12)$$

To a first approximation, therefore,

$$\theta - \theta_0 \doteq \theta' \quad (13)$$

and, from Equation (11)

$$\theta' = 2 \frac{x-1}{x+1} \frac{a-1}{a+1} e^{-2\alpha_{30}} e^{-2\alpha_1} e^{-2\psi_2} e^{-2\psi_{3a}} \quad (14)$$

The term

$$e^{-2\psi_{3a}}$$

in Equation (14) may be replaced by a series in

$$\frac{y-1}{y+1}$$

where y is the ratio of the image impedance R_a of network 24 to the value of its variable terminating resistance R_1 . In general, this series will be of the form

$$e^{-2\psi_{3a}} = 1 + \frac{y-1}{y+1} F_1 + \left(\frac{y-1}{y+1} \right)^2 F_2 + \dots \quad (15)$$

where F_1 , F_2 , etc. are functions of the transfer

constant ψ_3 of the variable building-out network 24, of its image impedance R_a and of any associated resistances, such as R_3 . If the square term and higher terms are neglected in Equation (15), approximate equation (13) becomes

$$\theta - \theta_0 \doteq 2 \frac{x-1}{x+1} \frac{a-1}{a+1} e^{-2\alpha_{30}} \left(e^{-2\alpha_1} e^{-2\psi_2} + \frac{y-1}{y+1} e^{-2\alpha_1} F_1 e^{-2\psi_2} \right) \quad (16)$$

Equation (16) involves two approximations, first the neglect of terms θ'^3 and higher order terms in obtaining Equation (13) from Equation (12), and second the neglect of the term

$$\left(\frac{y-1}{y+1} \right)^2 F_2$$

and higher order terms in evaluating the term

$$e^{-2\psi_{3a}}$$

by Equation (15). If large adjustments in the over-all insertion loss θ are to be made by means of the variable section 23 neglect of the term

$$\left(\frac{y-1}{y+1} \right)^2$$

and higher order terms will in general lead to large errors, while if these are included the adjustments will not be proportional to the reference characteristic to a good approximation. However, if a network of the type shown in Fig. 5, 6 or 7 is used and a proper choice of the added resistances R_3 and R_4 is made, the square term in Equation (15) will not appear because the function F_2 will be identically zero. Since the neglected cube and higher power terms have a relatively small effect, the desired type of adjustment can therefore be obtained over a much wider range.

In demonstrating how to choose the values of the added resistances R_3 and R_4 in order to eliminate the square term in Equation (15) it is found convenient to set up Equations for the image impedance R_a of network 24 and also for the value of the shunt resistance R_3 in terms of an additional parameter. The simplest parameter is the attenuation α_{30} representing the transfer constant of the variable network 23 with the resistances R_1 and R_2 at the reference settings R_a and R_b . In terms of this parameter the image impedance R_a of network 24 is

$$R_a = R_0 \frac{(e^{\alpha_{30}} - 1)(3 - e^{\alpha_{30}})}{e^{\alpha_{30}}} \quad (17)$$

and the value of the shunting resistance R_3 is

$$R_3 = R_0 \frac{(e^{\alpha_{30}} - 1)(3 - e^{\alpha_{30}})}{3 - 2e^{\alpha_{30}}} \quad (18)$$

The image impedance R_b of the constant-resistance network 25 in the shunt branch is

$$R_b = \frac{R_0^2}{R_a} \quad (19)$$

and the value of the associated series resistance R_4 is

$$R_4 = \frac{R_0^2}{R_3} \quad (20)$$

If the above conditions are satisfied the term

$$e^{-2\psi_{3a}}$$

of Equations (14) and (15) is given by

$$e^{-2\psi_{3a}} = \left[\frac{1 + 3 \frac{y-1}{y+1} \frac{e^{\alpha_{30}} - 1}{3 - e^{\alpha_{30}}} e^{-2\alpha}}{1 + \frac{y-1}{y+1} \frac{e^{\alpha_{30}} - 1}{3 - e^{\alpha_{30}}} e^{-2\alpha}} \right]^2 \quad (21)$$

where α is the transfer constant of the network 24. Equation (15) then becomes

$$e^{-2\psi_{30}} = 1 + \frac{y-1}{y+1} \frac{4(e^{\alpha_{30}}-1)}{3-e^{\alpha_{30}}} e^{-2\alpha} - \frac{1}{16} \left(\frac{y-1}{y+1} \right)^3 \left[\frac{4(e^{\alpha_{30}}-1)}{3-e^{\alpha_{30}}} \right]^3 e^{-6\alpha} + \dots \quad (22)$$

and approximate Equation (16) becomes

$$\theta - \theta_0 \div 2 \frac{x-1}{x+1} \frac{a-1}{a+1} e^{-2\alpha_{30}} \left[e^{-2\alpha_1} e^{-2\psi_2} + \frac{y-1}{y+1} e^{-2\alpha_1} K e^{-2(\alpha+\psi_2)} \right] \quad (23)$$

where

$$K = \frac{4(e^{\alpha_{30}}-1)}{3-e^{\alpha_{30}}} \quad (24)$$

In Equation (23) the portion in brackets represents the reference characteristic, and the terms

$$\frac{y-1}{y+1} e^{-2\alpha} K e^{-2(\alpha+\psi_2)}$$

represent the adjustment. As pointed out above, it is sometimes advantageous to divide the constant-resistance network 24 into two sections, such as 26 and 27 of Fig. 6, having transfer constants γ_1 and γ_2 the sum of which is α . Now if γ_1 is made complementary to the transfer constant ψ_2 of the fixed building-out network 22, so that their sum is equal to a constant attenuation α_k , the adjustment part of the reference characteristic becomes

$$\frac{y-1}{y+1} e^{-2\alpha_1} K e^{-2\alpha_1} e^{-2\gamma_1}$$

The shape of this adjustment characteristic, it will be noted, depends only upon γ_2 and is independent of the function ψ_2 determining the mean reference characteristic obtained with the resistances R_1 and R_2 set at reference positions. The networks 28 and 29 also have transfer constants γ_1 and γ_2 .

Fig. 8 shows an actual example of an adjustable variable equalizer of the type of Fig. 1 with a variable building-out network 23 of the type shown in Fig. 7. The equalizer is designed for the compensation of changes in the attenuation distortion in 100 miles of overhead 19 gauge cable due to temperature variations over the range of zero to 110° Fahrenheit. A 24.43 ohm resistance is connected in series with the equalizer at terminal 5 to form a variable 2-terminal impedance branch which is shunted across a transmission line having impedances Z_s and Z_r each equal to 2400 ohms. The normal insertion loss of the equalizer, with all of the variable resistances set at their reference values, is constant with frequency.

The equalizer shown in Fig. 8 comprises a variable attenuator 21, a fixed building-out network 22 and a variable building-out network 23 connected in tandem and terminated in a variable resistance R . All of the networks are of the bridged-T type and all have image impedances R_0 equal to 173.4 ohms. The attenuator 21 has a pair of variable resistances R_5 and R_6 for adjusting its attenuation. The bridging branch of the variable network 23 comprises a resistance R_3 shunted across a pair of terminals of the bridged-T network 24 which has an image impedance R_a of 42.28 ohms and is terminated in a variable resistance R_1 . The shunt branch of network 23 comprises a resistance R_4 in series with the bridged-T network 25 which has an image impedance R_b of 711.12 ohms and is terminated in a variable resistance R_2 . As explained above the resistances R_1 , R_2 , R_3 , R_4 , R_5 and R_6 and the

image impedances R_a and R_b are related to the image impedance R_0 as follows:

$$R_1 R_2 = R_3 R_4 = R_5 R_6 = R_a R_b = R_0^2 = 30000 \quad (25)$$

The values of the elements shown in Fig. 8 are given in the following table:

R	=10.8 to 2067 ohms	
R_0	=173.4 ohms	
R_1	=0 to 15000 ohms	10
R_2	=2 to ∞ ohms	
R_3	=69.98 ohms	
R_4	=429.6 ohms	
R_5	=0 to 130 ohms	
R_6	=232 to ∞ ohms	15
R_7	=188.0 ohms	
R_8	=159.9 ohms	
R_9	=5.285 ohms	
R_{10}	=338.2 ohms	
R_{11}	=88.89 ohms	20
R_{12}	=5689 ohms	
L_1	=0.9510 millihenry	
L_2	=1.214 millihenries	
L_3	=0.2879 millihenry	
L_4	=0.06378 millihenry	25
L_5	=0.4916 millihenry	
L_6	=4.843 millihenries	
L_7	=1.073 millihenries	
L_8	=8.268 millihenries	
L_9	=13.870 millihenries	30
C_1	=188.05 microfarads	
C_2	=0.4614 microfarad	
C_3	=0.03163 microfarad	
C_4	=0.2750 microfarad	
C_5	=0.1602 microfarad	35
C_6	=0.03568 microfarad	
C_7	=0.01635 microfarad	
C_8	=0.009576 microfarad	
C_9	=0.002121 microfarad	

The normal or reference setting of the resistance R is 173.4 ohms, and the reference values of R_1 and R_2 are 42.28 ohms and 711.12 ohms, respectively. The equalizer is so designed that, in combination with an auxiliary fixed equalizer not shown, it will compensate an average length of average cable at a reference temperature of 56.2° Fahrenheit. Differences in lengths or in the temperature coefficients of the various sections of line are allowed for by adjusting the resistances R_1 , R_2 , R_5 and R_6 to adapt the equalizer to the particular line section with which it is to be used. After this line-up the regulation of the characteristic is made automatically by means of a pilot wire regulator which changes the value of the single terminating resistance R in accordance with the variations in temperature. A pilot wire regulator system suitable for this purpose is disclosed in the United States patent of F. A. Brooks, No. 2,075,975, issued April 6, 1937.

What is claimed is:

1. An adjustable variable attenuation equalizer for transmission lines comprising a basic network, a single variable impedance, a variable attenuator and a variable building-out network connected between said variable impedance and said basic network, and a pair of inversely related variable impedances under unitary control associated with said building-out section for adjusting its transfer constant, said equalizer having a preassigned normal insertion loss characteristic for assigned normal values of said variable impedances, variations of said single impedance from its normal value serving to add to or subtract from said normal characteristic proportional parts of a preassigned frequency-variable loss charac-

teristic, variations of said inversely related impedances from their normal values serving to adjust said frequency-variable characteristic by adding thereto or subtracting therefrom proportional parts of another preassigned frequency-variable loss characteristic, and adjustment of said variable attenuator serving to adjust the maximum values of the parts of said preassigned frequency-variable loss characteristics produced by the variations of said adjustable impedances.

2. An adjustable variable attenuation equalizer comprising a fixed-impedance basic network, a single variable impedance, a building-out network having a transfer constant which is a function of frequency, and a pair of inversely related variable impedances for adjusting said transfer constant, said basic network and said building-out network being proportioned to have a preassigned normal insertion loss characteristic for assigned normal values of said variable impedances, variations of said single impedance from its normal value serving to add to or subtract from said normal characteristic proportional parts of a preassigned frequency-variable loss characteristic, and variations of said inversely related impedances from their normal values serving to adjust said frequency-variable characteristic by adding thereto or subtracting therefrom proportional parts of a second preassigned frequency-variable loss characteristic.

3. An adjustable variable attenuation equalizer in accordance with claim 2 comprising means independent of said adjustable impedances for varying the maximum values of the parts of said preassigned frequency-variable loss characteristics produced by the variations of said adjustable impedances.

4. An adjustable variable attenuation equalizer in accordance with claim 2 in which said variable impedances are variable resistors.

5. An adjustable variable attenuation equalizer in accordance with claim 2 in which said building-out network is a constant-resistance bridged-T structure comprising a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a subsidiary 4-terminal network, said shunt branch comprising another subsidiary 4-terminal network, and each of said subsidiary networks having an image impedance which is a constant resistance and a transfer constant which is a function of frequency.

6. An adjustable variable attenuation equalizer in accordance with claim 2 in which said building-out network is a constant-resistance bridged-T structure comprising a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a subsidiary 4-terminal constant-resistance network terminated by one of said pair of inversely related variable impedances, and said shunt branch comprising another subsidiary 4-terminal constant-resistance network terminated by the other of said pair of variable impedances.

7. An adjustable variable attenuation equalizer in accordance with claim 2 in which said building-out network is a constant-resistance bridged-T structure having a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a resistance in shunt with a subsidiary 4-terminal constant-resistance network, and said shunt branch comprising another resistance in series with another subsidiary 4-terminal constant-resistance network.

8. An adjustable variable attenuation equalizer in accordance with claim 2 in which said

building-out network is a constant-resistance bridged-T structure having a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a subsidiary 4-terminal constant-resistance network shunted at one end by a resistance and terminated at the other end by one of said pair of variable impedances, and said shunt branch comprising another resistance in series with another subsidiary 4-terminal constant-resistance network terminated by the other of said pair of variable impedances.

9. An adjustable variable attenuation equalizer in accordance with claim 2 in which said building-out network is a constant-resistance bridged-T structure having a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a fixed resistance in shunt with a subsidiary 4-terminal constant-resistance network, and said shunt branch comprising another fixed resistance in series with another subsidiary 4-terminal constant-resistance network, said fixed resistances being so proportioned that the adjustment characteristic controlled by said inversely related impedances is proportional to said second preassigned loss characteristic over a wide range of adjustments.

10. An adjustable variable attenuation equalizer in accordance with claim 2 in which said building-out network is a constant-resistance bridged-T structure having a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a resistance in combination with a plurality of subsidiary 4-terminal constant-resistance networks, and said shunt branch comprising another resistance in combination with a plurality of other subsidiary 4-terminal constant-resistance networks.

11. An adjustable variable attenuation equalizer comprising a basic network, a single variable impedance and a plurality of building-out sections with matched constant-resistance image impedances connected in tandem between said variable impedance and said basic network, two of said building-out sections having transfer constants which are functions of frequency and one of said two building-out sections having a pair of inversely related variable impedances for adjusting its transfer constant, said basic network and said building-out sections being proportioned to have a preassigned normal insertion loss characteristic for assigned normal values of said variable impedances, variations of said single impedance from its normal value serving to add to or subtract from said normal characteristics proportional parts of a preassigned frequency-variable loss characteristic, and variations of said inversely related impedances from their normal values serving to adjust said frequency-variable characteristic by adding thereto or subtracting therefrom proportional parts of a second preassigned frequency-variable loss characteristic.

12. An adjustable variable attenuation equalizer for compensating the changes in attenuation distortion in a transmission line due to temperature variations comprising a basic network, a single variable impedance, a plurality of building-out sections with matched constant-resistance image impedances connected in tandem between said variable impedance and said basic network, and a plurality of pairs of auxiliary impedances associated with said building-out sections, one of said building-out sections having a fixed transfer constant which is a function of frequency, another of said sections having an adjustable transfer constant which is a function of frequency,

still another of said sections having an adjustable transfer constant which is a constant attenuation independent of frequency for every adjustment, said equalizer being designed to compensate an average length of average transmission line at a reference temperature when all of said variable impedances are set at normal values, adjustments of said auxiliary variable impedances serving to adapt the equalizer for use with a particular line section which differs from the average, and variation of said single variable impedance serving to maintain equalization over a temperature range.

13. An adjustable variable attenuation equalizer comprising a plurality of tandem-connected building-out sections with matched constant-resistance image impedances, one of said sections having a fixed transfer constant which is a function of frequency, and another of said sections having an adjustable transfer constant and being of the bridged-T type with a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a plurality of subsidiary 4-terminal networks and said shunt branch comprising a plurality of other subsidiary 4-terminal networks, one of said networks in said

bridging branch and one of said networks in said shunt branch having transfer constants which are equal to each other and each of which is complementary to the transfer constant of said fixed building-out section.

14. An adjustable variable attenuation equalizer for compensating the changes in attenuation distortion in a transmission line section due to temperature variations comprising a basic network, a single variable impedance, a plurality of building-out sections interposed between said variable impedance and said basic network, and a plurality of pairs of auxiliary variable impedances associated with said building-out sections, said equalizer being designed to compensate an average length of average transmission line at a reference temperature when all of said variable impedances are set at normal values, adjustments of said auxiliary variable impedances serving to adapt the equalizer for use with a particular line section which differs from the average, and variation of said single variable impedance serving to maintain equalization over a temperature range.

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