May 14, 1957 S. BOBIS 2,792,552

ATTENUATION EQUALIZER

Filed Nov. 27, 1953

FIG. 1

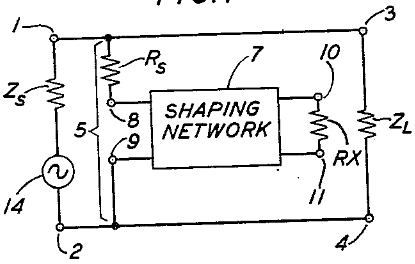


FIG. 3

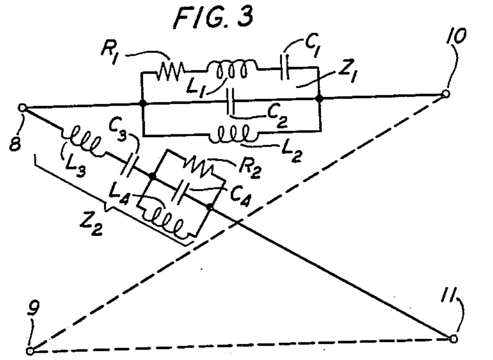


FIG. 2

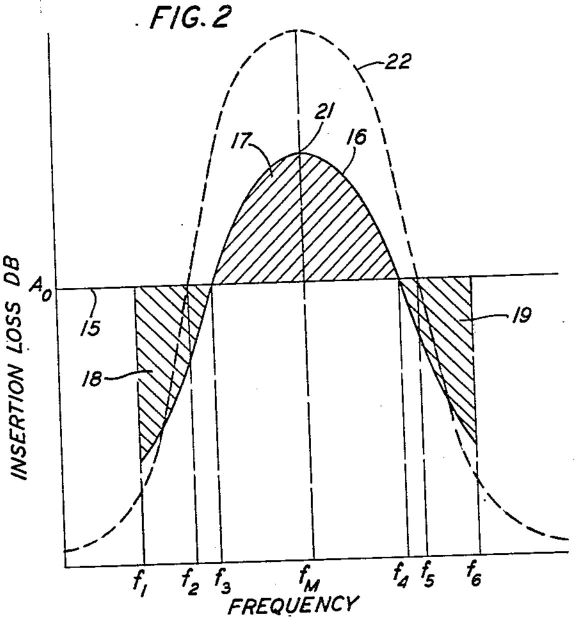


FIG. 4

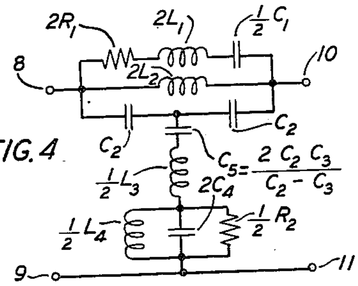


FIG. 5

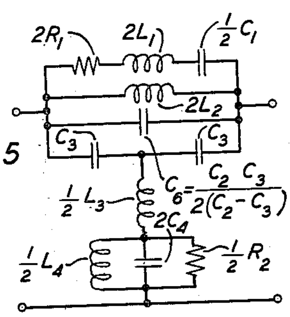


FIG. 7

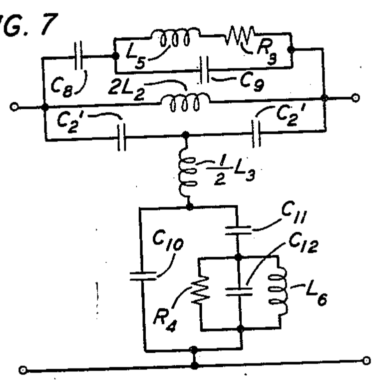
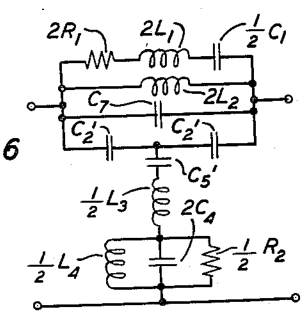


FIG. 6



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ATTENUATION EQUALIZER

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7 Claims. (Cl. 333—28)

This invention relates to wave transmission networks and more particularly to adjustable attenuation equalizers.

An object of the invention is to provide an adjustable attenuation equalizer whose deviation characteristics is a parabola. A more specific object is to provide an adjustable equalizer which, over the operating frequency range, has a flat insertion loss characteristic for the normal setting of the control element and, for any other setting, has a deviation characteristic of such a shape that the area between the characteristics and above the normal characteristic is equal to the area between the characteristics and below the normal characteristic.

In long signal circuits the transmission loss varies with changes in temperature or humidity, or for other reasons. It is customary to compensate for these transmission variations by means of an automatic attenuation regulator which comprises a number of independently adjustable equalizer shapes. Interaction or hunting between the equalizers can be avoided if the shapes are orthogonal to each other. One such orthogonal shape found very useful is a parabola.

The adjustable attenuation equalizer in accordance with the present invention has such a parabolic deviation characteristic. The equalizer comprises an adjustable impedance adapted for insertion between a wave source impedance and a load impedance. The adjustable impedance includes a shaping network terminated in an adjustable resistor. The shaping network is an all-pass structure having an image impedance which is a constant resistance. The network includes a series impedance branch which is resonant at approximately the midband frequency f_M of the operating range and antiresonant at two frequencies on opposite sides of f_M. This branch includes a resistive element which affects the impedance thereof primarily in the neighborhood of f_M. The shaping network may be a lattice, bridged-T, or other equivalent structure.

The component elements of the equalizer are so proportioned that one setting of the adjustable resistor produces a normal insertion loss-frequency characteristic which is substantially flat over the operating range. Any other setting produces a deviation characteristic which over this range, is essentially a parabola having its apex at approximately f_M. The parabola crosses the normal characteristic at two points approximately equally spaced from f_M. These are pivot points for the parabola and remain substantially fixed for all adjustments. The apex of the parabola may be either above or below the normal characteristic and its distance therefrom depends upon the setting. An important feature is that within the operating range, for every setting the area between the parabola and the normal characteristic and above the normal characteristic is approximately equal to the area between these characteristics and below the normal characteristic.

The nature of the invention and its various objects, features, and advantages will appear more fully in the following detailed description of preferred embodiments illustrated in the accompanying drawing, of which:

Fig. 1 is a schematic circuit of an adjustable attenuation equalizer in accordance with the invention;

Fig. 2 shows the normal and one extreme insertion loss-frequency characteristic obtainable with the equalizer of Fig. 1, and also a reference characteristic;

Fig. 3 is a schematic circuit of a lattice structure suitable for the shaping network in Fig. 1; and

Figs. 4, 5, 6, and 7 are schematic circuits of equivalent, unbalanced, bridged-T structures suitable for the shaping network.

The adjustable attenuation equalizer in accordance with the present invention is of the general type disclosed in Patent 2,096,027, issued October 19, 1937, to H. W. Bode. The embodiment shown in Fig. 1 is a modification of the circuits shown in Figs. 12, 15, and 27 of the Bode patent. The equalizer comprises a pair of input terminals **1**, **2**, a pair of output terminals **3**, **4**, and an interposed adjustable impedance **5**. The impedance **5** comprises a four-terminal shaping network **7** having input terminals **8**, **9** and output terminals **10**, **11**, a symmetry resistance R_S, and an adjustable terminating resistance of value R_X. The resistance R_S is connected between the input network terminal **8** and the equalizer terminals **1** and **3**. The other input network terminal **9** is connected to the equalizer terminals **2** and **4**. The resistor R_X is connected between the output network terminals **10** and **11**. A wave source **14** of impedance Z_S is connected between the input terminals **1**, **2** of the equalizer and a load of impedance Z_L is connected between the output terminals **3**, **4**. Thus, the impedance **5** is connected in parallel with the source and the load.

Fig. 2 shows two insertion loss-frequency characteristics obtainable with the equalizer of Fig. 1. The straight line **15**, of zero slope, represents the substantially flat loss A_O obtainable for the normal setting of the terminating resistance R_X. The curve **16**, over the operating frequency range f_1 to f_6, is an acceptably close approximation to the desired parabolic characteristic. The solid-line curve **16** represents one extreme adjustment limit of the loss and is obtained when R_X has the minimum value. For other values of R_X, the curve will pivot about the crossing points at the frequencies f_2 and f_4. When R_X has its maximum value, the characteristic will be substantially a mirror image of the curve **16**, with respect to the line **15**. Any desired loss characteristic between these extremes may be obtained by properly setting R_X. For the curve to be orthogonal, the cross-hatched area **17** between the curves **15** and **16** and above the curve **15** must be equal to the sum of the oppositely cross-hatched areas **18** and **19** between the curves **15** and **16** and below the curve **15**. Also, for symmetry, the apex **21** should be located at the frequency f_M midway between f_1 and f_6 and the areas **18** and **19** should be equal.

Fig. 3 is a schematic circuit of a constant-resistance, lattice-type network suitable for the shaping network **7** of Fig. 1. The input terminals **8**, **9** and the output terminals **10**, **11** have the same designations as are used in Fig. 1. The network comprises a pair of equal series impedance branches Z_1 and a pair of equal diagonal impedance branches Z_2. For simplicity, only one series branch and one diagonal branch are shown in detail. The other two branches are indicated in the usual manner by broken lines connecting the terminal **9** with the terminals **10** and **11**. Each of the branches Z_1 consists of an inductance L_2 and a capacitance C_2 connected in parallel with an arm comprising the series combination of a resistance R_1, an inductance L_1, and a capacitance C_1. Each of the branches Z_2 is made up of an inductance L_3 and a capacitance C_3 connected in series with the parallel combination of an inductance L_4, a capacitance C_4, and a resistance R_2. In order to make the image impedance of the network a constant resistance R_0, the branches have the relationship

$$Z_1 Z_2 = R_0^2 \tag{1}$$

A suggested procedure for designing the shaping network of Fig. 3 is as follows:

First, assume that each series branch Z_1 comprises only C_2 and L_2 and each diagonal branch Z_2 comprises only C_3 and L_3. This lattice is then designed as an all-pass structure having an image impedance R_0 chosen to provide the desired extreme deviation swings. Therefore, C_2 and L_2 will be antiresonant, and C_3 and L_3 resonant, at approximately f_M. The stiffness of each branch, which is dependent upon the ratio C_2/L_2 or the ratio L_3/C_3, determines the frequencies at which the extreme deviation characteristic crosses the normal characteristic **15**. This stiffness is so chosen that, when the network is used as the shaping network **7** in the equalizer of Fig. 1, an extreme deviation characteristic shown by the broken-line curve **22** in Fig. 2 is obtained. This is essentially a sinusoidal shape, with a maximum at f_M and crossings of the normal curve **15** at the frequencies f_2 and f_5, which are the pivot points. The frequencies f_2, f_M, and f_5 approximately correspond, respectively, to the frequencies at which the phase shift in the shaping network **7** is 135 degrees, 180 degrees and 225 degrees. It will be noted that the pivot point f_2 is somewhat lower than f_3 and the pivot point f_5 is somewhat higher than f_4. The value of the symmetry resistance R_S is so chosen that the inverse extreme deviation characteristic is the mirror image of the curve **22** with respect to the normal characteristic **15**.

As compared to the desired parabolic characteristic **16**, the sinusoidal curve **22** is too low at the limiting frequencies f_1 and f_6 of the operating range and too high at the midband frequency f_M. In accordance with the present invention, the shape **16** is obtained by adding the arm comprising L_1, C_1, and the damping resistance R_1 to each series impedance branch Z_1 and the corresponding inverse combination of L_4, C_4, and a damping resistance R_2 to each diagonal branch Z_2. The elements L_1 and C_1 are resonant, and L_4 and C_4 are antiresonant, at approximately f_M. Therefore, the modified series branch Z_1 is resonant at f_M and antiresonant at two frequencies substantially equally spaced above and below f_M. The inverse diagonal branch Z_2 is antiresonant at f_M and resonant at the two antiresonant frequencies of Z_1. The main effect of adding the elements L_1, C_1, R_1, L_4, C_4, and R_2 is to lower the curve **22** at f_M and raise it at f_1 and f_6. Incidentally, the addition of these elements also raises the pivot point f_2 to f_3 and lowers the pivot point f_5 to f_4. The amount by which the curve **22** is lowered at f_M is determined by the magnitudes of the added resistances R_1 and R_2. The width of the frequency range affected is determined by the stiffness of the added arms, that is, by the ratios C_1/L_1 and L_4/C_4. After a few trials, a value of R_1 and a ratio C_1/L_1 can ordinarily be found which will give a sufficiently close approximation to the desired parabolic characteristic **16**. The elements in the series branch are thus determined. The values of the corresponding elements in the inverse diagonal branch Z_2 may be found from the relationship given in Equation 1.

As an illustrative example only, the element values will be given for an adjustable equalizer of the type shown in Fig. 1 in which the shaping network **7** is a lattice structure of the type shown in Fig. 3. It is assumed that the source impedance Z_S and the load impedance Z_L are each 2830 ohms, the operating range extends from a frequency f_1 of 176 kilocycles to a frequency f_6 of 264 kilocycles, the pivot frequencies f_3 and f_4 are approximately 191 and 247 kilocycles, respectively, the midband frequency f_M is 217 kilocycles, and the permissible flat loss A_0 is 6.82 decibels. The symmetry resistance R_S has a value of 373 ohms, the image impedance R_0 of the shaping network **7** is 818 ohms, and terminating resistance R_X is adjustable between 134 and 5000 ohms. The component elements of the network **7** have approximately the following values:

$C_1=63$	$L_2=300$
$C_2=17{,}915$	$L_3=1{,}200$
$C_3=448$	$L_4=42.22$
$C_4=12{,}742$	$R_1=4{,}910$
$L_1=8{,}532$	$R_2=136.4$

The capacitances are given in micromicrofarads, the inductances in microhenries, and the resistances in ohms. The chracteristic **16** shown in Fig. 2 is obtained when the terminating resistance R_X is set at its minimum value of 134 ohms. The maximum swing of the equalization characteristic, which is the difference between the insertion loss at f_M and at f_1, is five decibels. The equalizer is thus adapted to equalize a maximum parabolic bump or dip of five decibels. The swing could be increased somewhat by extending the adjustment range of R_X.

In order to save elements and avoid providing pairs of equal impedance branches such as Z_1, Z_1 and Z_2, Z_2, it is desirable to transform the symmetrical lattice network of Fig. 3 into an equivalent unbalanced structure. For example, Fig. 4 shows an equivalent unbalanced bridged-T network into which the lattice of Fig. 3 may be transformed when C_2 is larger than C_3. In Fig. 4, the values of the component elements are given in terms of the elements appearing in Fig. 3. Fig. 5 shows another equivalent bridged-T structure, obtained by transforming the T of capacitances C_2, C_2, C_5 into the equivalent π arrangement C_3, C_3, C_6.

Fig. 6 shows a third equivalent bridged-T network. It is obtained by adding the redundant capacitance C_7 to the bridging branch of Fig. 4 and changing the values of the capacitances C_2, C_2, and C_5 to C_2', C_2', and C_5', determined by the choice of C_7. The capacitance C_7 is added to permit further transformations which will result in more convenient element sizes. Fig. 7 shows the final circuit. The component elements have approximately the following values:

$C_2'=1{,}556$	$2L_2=600$
$C_8=149$	$L_3/2=600$
$C_9=555$	$L_5=764$
$C_{10}=1{,}021$	$L_6=1{,}000$
$C_{11}=173.6$	$R_3=439.6$
$C_{12}=389.5$	$R_4=3{,}230$

The capacitances are given in micromicrofarads, the inductances in microhenries, and the resistances in ohms.

It will be noted that the inductance L_5 has a value of only 764, whereas the corresponding inductance $2L_1$ has a value of 17,064. Also, the inductance L_6 has a value of 1,000, which is much more easily obtained within close limits than is the value 21.11 of the corresponding inductance $L_4/2$. The other component elements also have values which are readily obtainable in standard designs.

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. An adjustable attenuation equalizer for operation over a range of frequencies comprising an adjustable impedance adapted for insertion between a wave source and a load, said adjustable impedance comprising an all-pass, four-terminal, shaping network having an image impedance which is a constant resistance R_0 and a phase shift which continuously increases over said range and is equal to at least 180 degrees at the midband frequency f_M of said range, a symmetry resistor connected to the input thereof, and an adjustable resistor of value R_X connected to the output terminals thereof, said network

comprising a series impedance connected between an input terminal and the corresponding output terminal, said series impedance comprising a damping resistance and being resonant at approximately f_M and antiresonant at two frequencies substantially equally spaced above and below f_M, the component elements of said adjustable impedance being so proportioned that, over said range, when R_X is equal to R_D the insertion loss-frequency characteristic of the equalizer is a first curve substantially flat, when R_X has a value other than R_D said characteristic is essentially a parabolic curve having its apex at f_M and crossing said first curve at two frequencies within said range approximately equally spaced from f_M, and the area between said curves and above said one curve is approximately equal to the area between said curves and below said one curve.

2. An equalizer in accordance with claim 1 in which said shaping network is of the lattice type.

3. An equalizer in accordance with claim 1 in which said shaping network is of the bridged-T type.

4. An equalizer in accordance with claim 1 in which said shaping network is an unbalanced structure.

5. An equalizer in accordance with claim 1 in which said shaping network is an unbalanced, bridged-T structure.

6. An equalizer in accordance with claim 1 in which said adjustable impedance is adapted to be connected in parallel with said source and said load.

7. An equalizer in accordance with claim 6 in which said symmetry resistor is connected at one end to an input terminal of said shaping network and adapted for connection at the other end to said source and said load.

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