

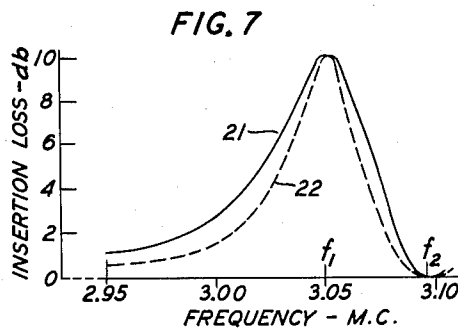
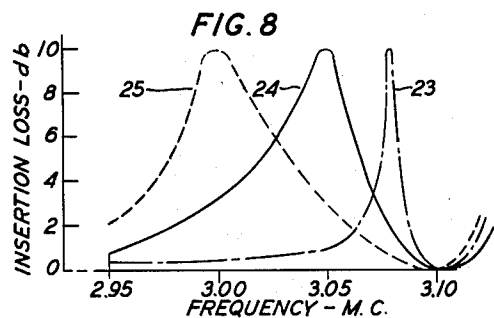
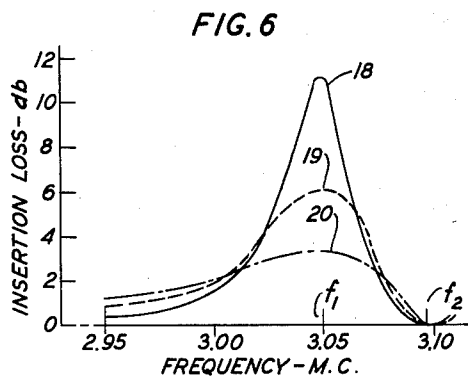
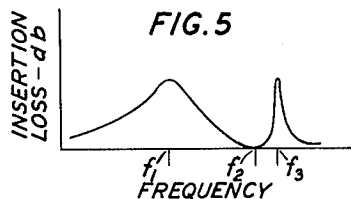
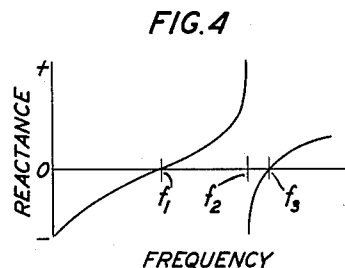
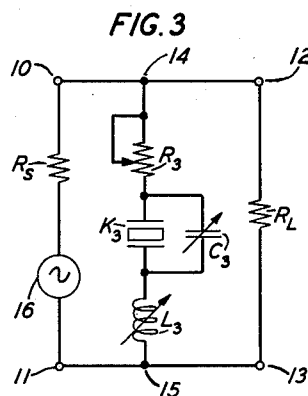
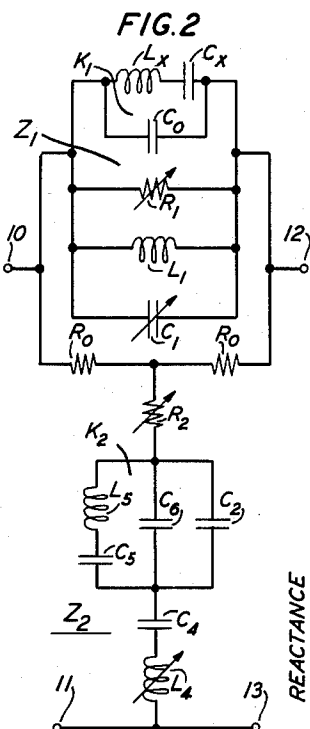
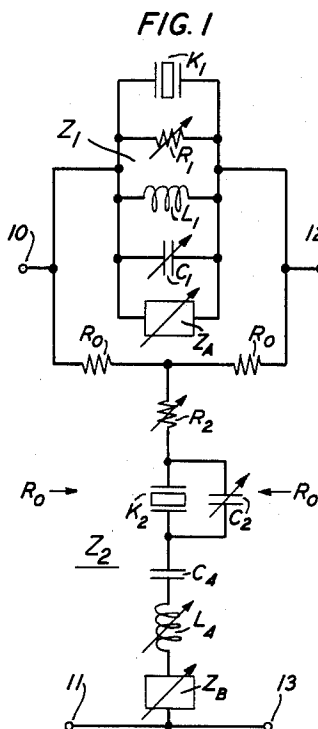
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2,738,465

EQUALIZER

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2,738,465

EQUALIZER

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

The object of the invention is to introduce a peak of loss which can be independently adjusted in height, sharpness, and frequency, while the loss at another selected frequency remains substantially zero.

If sufficiently long, telephone and television circuits of the type employing coaxial lines, even though equipped with basic equalizers under the automatic control of a pilot frequency, often show gain distortion in the form of a comparatively sharp peak, which may reach a height of as much as 10 decibels or more, located in the neighborhood of the pilot frequency. Equalizers heretofore available for removing such a peak have the serious shortcoming that they introduce a loss of between 1.5 and 3 or more decibels at the pilot frequency, thus greatly reducing the effectiveness of the automatic gain regulation provided for the system.

The equalizer in accordance with the present invention reduces the loss at the pilot frequency to substantially zero by employing a shunt impedance branch which includes the series combination of a resistor, an inductor, and a piezoelectric crystal which is parallel resonant at or near the pilot frequency. The equalizer will have peaks of loss at the resonant frequencies of the shunt branch. Means may be provided for adjusting the resistance of the resistor, in order to vary the heights of these peaks, and the inductor may be made adjustable for shifting the frequencies at which the peaks occur. The lower peak becomes broader as it is moved farther from the parallel-resonant frequency of the crystal. However, the sharpness of the peak may be adjusted by adding an adjustable capacitor in shunt with the crystal. If the product of the inductance and the capacitance is kept constant, the sharpness of the peak may be adjusted, without changing its height or frequency, by adjusting both the inductor and capacitor. Also, the peak may be shifted in frequency by adjusting only the capacitor, if a change in sharpness is permissible. It is apparent that a great variety of shapes, heights, and frequency locations of the loss peaks may thus be provided by the equalizer. However, for all settings of the adjustable elements, the loss of the equalizer is substantially zero at the parallel-resonant frequency of the crystal, because at this frequency the equalizer presents a very high shunt impedance to the transmission line with which it is associated. One or more additional impellers, either resistors, inductors, or capacitors, may be added in series or in shunt with one or more of the elements already mentioned to provide special shapes of the loss peak, if desired.

If a constant-resistance image impedance is required for the equalizer, it may be constructed as a bridged-T network comprising two equal resistors connected in series, a shunt branch of the type described above connected to the common terminal of the resistors, and a bridging branch, which also includes a piezoelectric crystal, having an impedance inverse to that of the shunt branch,

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connected between the outer terminals of the resistors. In many cases it is found that one of the crystals is not physically realizable. However, in accordance with a design technic herein presented, involving the addition of one or more redundant capacitors to one of the branches, both crystals can always be realized physically. As a special case, it is shown how to design the equalizer to use identical crystals in both the bridging branch and the shunt branch. A resulting advantage is that one of the branches can be designed to use an available standard crystal, and the same type of crystal can be used also in the other branch, thus often avoiding the design of a special crystal. The manufacture of the equalizer is thus simplified and the cost reduced.

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

Fig. 1 is a schematic circuit of one embodiment of an equalizer in accordance with the invention, in the form of a bridged-T network;

Fig. 2 is an equivalent circuit of a network of the type shown in Fig. 1;

Fig. 3 shows a simplified equalizer in accordance with the invention, connected between a source and a load;

Figs. 4 and 5 show, respectively, typical reactance-frequency and insertion loss-frequency characteristics for the equalizer of Fig. 3; and

Figs. 6, 7, and 8 show a variety of other possible insertion loss-frequency characteristics of the equalizer, obtainable by adjusting one or more of the component impellers.

The equalizer in accordance with the invention shown in Fig. 1 is a bridged-T network comprising a pair of input terminals 10, 11, upon which are impressed the alternating current signals to be equalized, and a pair of output terminals 12, 13, to which a suitable load circuit may be connected. The network is a constant-resistance structure, with an image impedance R_0 , of the general type disclosed in United States Patent No. 1,606,817, granted to G. H. Stevenson on November 16, 1926. The circuit comprises a pair of series resistors each having a resistance equal to R_0 , an interposed shunt branch of impedance Z_2 , and a bridging branch of impedance Z_1 , so related to Z_2 that

$$Z_1 Z_2 = R_0^2 \quad (1)$$

The branch Z_1 comprises the parallel combination of a piezoelectric crystal K_1 , a resistor having a resistance R_1 , an inductor of inductance L_1 , and a capacitor of capacitance C_1 . The branch Z_2 consists of the series combination of a resistor having a resistance R_2 , a piezoelectric crystal K_2 , a capacitor having a capacitance C_4 , and an inductor of inductance L_4 , with a capacitor of capacitance C_2 shunted across the crystal K_2 . Additional general impedances comprising any desired combination of resistance, inductance, and capacitance may be connected in series or in shunt with any of the elements in the bridging branch or the shunt branch already described. For example, as shown, a general impedance Z_A may be connected in shunt in the bridging branch Z_1 and a second general impedance Z_B in series in the shunt branch Z_2 . The equalizer will introduce substantially zero insertion loss at the series-resonant frequency of the crystal K_1 . The other elements, R_1 , L_1 , C_1 , and Z_A , in the bridging branch are designed to give the desired loss characteristic at other frequencies of interest.

How to find the required values of the component elements in the shunt branch Z_2 may be explained more easily by referring to the circuit shown in Fig. 2, which is equivalent to Fig. 1 if the impedance Z_A is infinite and the impedance Z_B is zero. The crystal K_1 has been re-

placed by its equivalent circuit comprising a capacitance C_0 , representing the interelectrode capacitance, shunted by the series combination of an inductance L_x and a second capacitance C_x . In like manner, the crystal K_2 has been replaced by the inductance L_5 and the capacitances C_5 and C_6 .

Assuming that the capacitance C_2 is zero, or an open circuit, and the capacitance C_4 is infinite, or a short circuit, the elements in the shunt branch Z_2 will have the following values, in terms of the image impedance R_0 and the known values of the elements in the bridging branch Z_1 :

$$R_2 = \frac{R_0^2}{R_1} \quad (2)$$

$$L_4 = R_0^2 (C_1 + C_0) \quad (3)$$

$$L_5 = R_0^2 C_x (1 + L_x/L_1)^2 \quad (4)$$

$$C_5 = \frac{L_1}{R_0^2 (1 + L_x/L_1)} \quad (5)$$

$$C_6 = \frac{L_x}{R_0^2 (1 + L_x/L_1)} \quad (6)$$

As indicated by the arrows, certain of the elements may be made adjustable for changing the insertion loss characteristic of the equalizer. For example, means may be provided for adjusting R_1 , C_1 , Z_A , R_2 , C_2 , L_4 , and Z_B . The height of a loss peak may be changed, without altering the image impedance R_0 , by adjusting both R_1 and R_2 while maintaining the inverse relationship given by Equation 2. Also, the frequency at which the peak occurs may be shifted by adjusting both C_1 and L_4 , and R_0 will be unchanged if the relationship given by Equation 3 is maintained.

In some cases, however, no crystal K_2 can be found for which the elements L_5 , C_5 , and C_6 in its equivalent circuit will have the values given, respectively, by Equations 4, 5, and 6. In accordance with the invention this difficulty is overcome by adding a capacitance C_2 in shunt with K_2 and a capacitance C_4 in series with the combination, as shown in Figs. 1 and 2. These capacitances may then be adjusted so that the crystal K_2 will always be physically realizable. In particular, if the added capacitances have the following values, the crystal K_2 will be identical in all respects with the crystal K_1 :

$$C_2 = \sqrt{\frac{L_x C_x}{R_0}} - C_0 \quad (7)$$

$$C_4 = \frac{L_1}{R_0^2 \left[1 - \frac{L_1}{L_x} \left(\sqrt{\frac{L_x}{R_0^2 C_x}} - 1 \right) \right]} \quad (8)$$

Thus, it is often possible to design the bridging branch Z_1 around a standard crystal K_1 and use a second identical crystal K_1 in the shunt branch Z_2 , thereby simplifying the manufacture and reducing the cost of the equalizer. The values of R_2 and L_4 , given by Equations 2 and 3, respectively, will remain unchanged.

If it is unnecessary to provide an image impedance which is a constant resistance, the equalizer may take the form of a single shunt impedance branch such as is shown in Fig. 3 between the points 14 and 15. A suitable source 16 of impedance R_s may be connected to the input terminals 10, 11, and a suitable load impedance R_L to the output terminals 12, 13. As shown, by way of example only, the equalizer comprises the series combination of a resistance R_3 , a piezoelectric crystal K_3 , and an inductance L_3 , with a capacitance C_3 shunting the crystal.

Fig. 4 shows a typical reactance-frequency characteristic for the equalizer of Fig. 3, with zeros at the frequencies f_1 and f_3 and a pole at the intermediate frequency f_2 . Fig. 5 shows a typical insertion loss-frequency characteristic for this equalizer. The loss is substantially

zero at the frequency f_2 , corresponding to the antiresonance of the parallel combination C_3 , K_3 , and peaks occur at the resonant frequencies f_1 and f_3 . Any one or all of the elements R_3 , C_3 , and L_3 may be made adjustable, as indicated by the arrows, to permit changing the loss characteristic.

Typical insertion loss-frequency characteristics obtainable by adjusting the elements R_3 , C_3 , and L_3 are shown in Figs. 6, 7, and 8. Only the peak of loss occurring at the lower resonant frequency f_1 is shown. In the equalizer for which these characteristics were taken, the crystal K_3 , which is made of quartz, has a series resonance at 3.095 megacycles per second and a parallel resonance at 3.100 megacycles, approximately coinciding with the anti-resonant frequency f_2 . The resistance R_3 is adjustable between zero and 100 ohms, the capacitance C_3 , between 15 and 45 micromicrofarads, and the inductance L_3 , between 73 and 95 microhenries. The source impedance R_s and the load impedance R_L are each equal to 75 ohms.

Fig. 6 shows how the height of the lower insertion loss peak, which has its maximum value at the resonant frequency f_1 , may be varied by adjusting the resistance R_3 while holding the elements C_3 and L_3 constant. The solid-line curve 18 corresponds to the minimum value of R_3 , the curve 20, to the maximum value of 100 ohms, and the curve 19, to an intermediate value. Although not shown in Fig. 6, the upper insertion loss peak, which occurs at the resonant frequency f_3 , will respond in a similar manner to an adjustment of the resistance R_3 . It will be noted that the loss at the frequency f_2 remains substantially zero for all settings of R_3 .

Fig. 7 shows how the sharpness of the loss peak at the frequency f_1 may be changed by adjusting both L_3 and C_3 while keeping their product, and also R_3 , constant. The broader peak 21 corresponds to a small value of L_3 and a large value of C_3 , while the narrower peak 22 corresponds to the reverse condition. Here, also, the loss at the frequency f_2 remains substantially zero.

Fig. 8 shows how the lower peak may be shifted in frequency by adjusting C_3 while keeping R_3 and L_3 fixed. The curve 23 corresponds to a small value of C_3 , the curve 24, to a larger value, and the curve 25, to a still larger value. The frequency f_1 at which this loss peak occurs is thus lowered as C_3 is increased. At the same time, the antiresonant frequency f_2 is lowered only slightly since it cannot fall below 3.095 megacycles, the series-resonant frequency of K_3 , regardless of how large C_3 becomes. Therefore, the frequency of substantially zero loss remains essentially constant as C_3 is varied. A similar family of curves may be obtained by adjusting L_3 while keeping C_3 and R_3 fixed. The frequency f_1 of the peak will decrease as L_3 is increased, but the frequency f_2 will not change, and the loss at f_2 will remain substantially zero. Of course, both C_3 and L_3 may be increased to lower the frequency of the peak loss, or both may be decreased to raise its frequency. It is seen that the peak becomes broader as its frequency is lowered. Its sharpness may be adjusted as desired, however, by adjusting both L_3 and C_3 while keeping their product constant, as explained above in the discussion of Fig. 7.

What is claimed is:

1. An adjustable equalizer having a peak of insertion loss which may be adjusted while maintaining a substantially zero loss at a selected frequency comprising a pair of input terminals, a pair of output terminals, and a branch connected at one end to one of said input terminals and one of said output terminals and at its other end to the other two of said terminals, said branch including the series combination of an adjustable resistor, an inductor, and an impedance comprising a piezoelectric crystal which is parallel resonant approximately at said frequency.

2. An equalizer in accordance with claim 1 in which said inductor is adjustable.

3. An equalizer in accordance with claim 1 in which

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said impedance includes an adjustable capacitor connected in parallel with said crystal.

4. An equalizer in accordance with claim 3 in which said inductor is adjustable.

5. An adjustable equalizer of the bridged-T type having a peak of insertion loss which may be adjusted while maintaining a substantially zero loss at a selected frequency comprising two resistors each of value R_0 connected in series, a bridging branch of impedance Z_1 connected between the outer terminals of said resistors, and a shunt branch of impedance Z_2 connected to the common terminal of said resistors, the product of Z_1 and Z_2 being equal to R_0^2 , said bridging branch including the parallel combination of a first piezoelectric crystal which is series resonant at said frequency, a third adjustable resistor, an inductor of value L_1 , and an adjustable capacitor, said shunt branch including the series combination of a fourth adjustable resistor, a second capacitor of value C_4 , a second adjustable inductor, and an impedance comprising a third capacitor of value C_2 in parallel with a second piezoelectric crystal which is identical with said first crystal, and said first crystal having an equivalent circuit comprising a capacitance C_0 shunted by the series combination of an inductance L_x and a capacitance C_x , wherein

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$$C_2 = \sqrt{\frac{L_x C_x}{R_0}} - C_0$$

$$C_4 = \frac{L_1}{R_0^2 \left[1 - \frac{L_1}{L_x} \left(\sqrt{\frac{L_x}{R_0^2 C_x}} - 1 \right) \right]}$$

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