

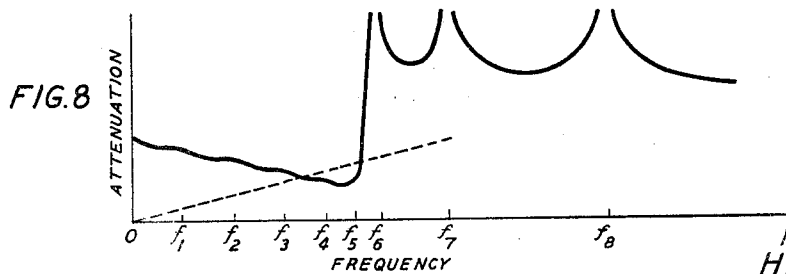
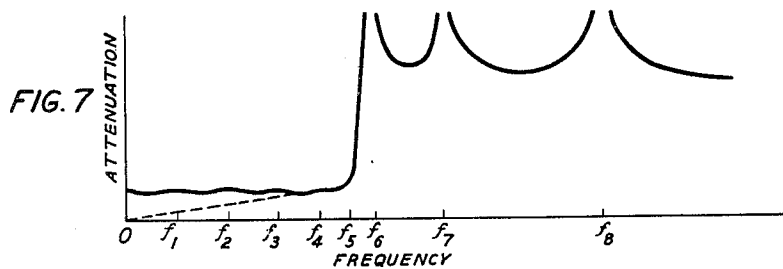
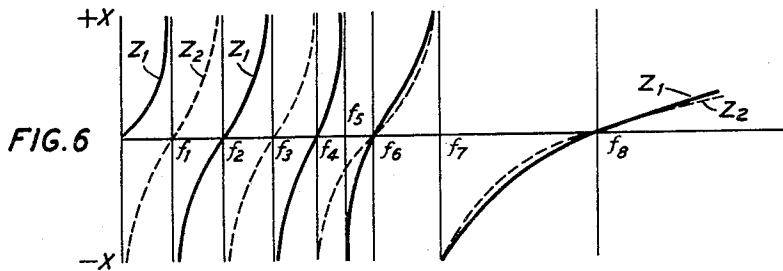
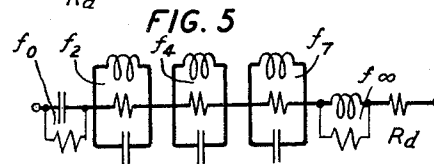
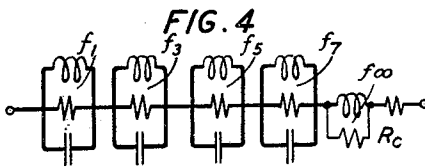
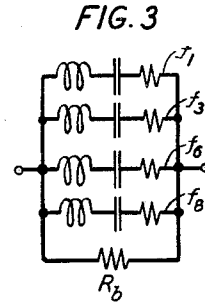
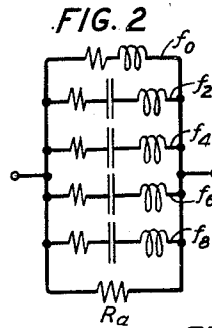
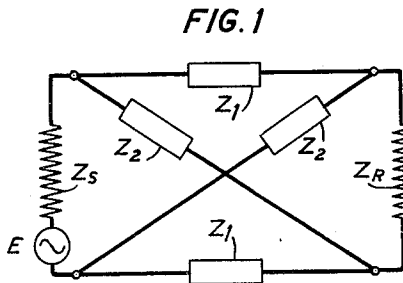
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H. W. BODE

1,955,788

TRANSMISSION NETWORK

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INVENTOR
H. W. BODE
BY
G. H. Stevenson
ATTORNEY

UNITED STATES PATENT OFFICE

1,955,788

TRANSMISSION NETWORK

Hendrik W. Bode, New York, N. Y., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

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This invention relates to electrical transmission networks of the types known as wave filters, phase correctors and delay networks and more particularly to a method of and means for regulating the attenuation of such networks in the transmitted frequency band.

The principal object of the invention is to control the frequency variation of the attenuation in the transmission range of a network. Another object is to provide uniform attenuation in the band. A further object is to effect the compensation of attenuation distortion due to associated apparatus or lines by means within the network.

It is well known that in wave filters, phase correctors and delay networks the attenuation over the band of frequencies transmitted is not zero. This attenuation is due in part to energy dissipation in the component inductances and capacitances and, as a rule, is not uniform over the pass-band. In my prior Patent No. 1,828,454, dated October 20, 1931, it is shown that wave filters and delay networks having any desired characteristic may be constructed in the form of a symmetrical lattice or bridge the branches of which are constituted by multiple resonant reactances of any degree of complexity. The most convenient forms of the branches comprise either a parallel connected system of simple resonant combinations or a series connected chain of anti-resonant loops. In accordance with this invention the networks are preferably of the type described in my aforementioned Patent 1,828,454. The transmission characteristic of the network in its range of free transmission is controlled by the addition of properly chosen ohmic resistances in series with the resonant combinations or in parallel with the anti-resonant loops. The energy dissipation in these added resistances increases the attenuation of the network, with maximum effect at the resonant or anti-resonant frequency of the branch to which the resistance has been added. By properly proportioning the resistance values the points of low attenuation may be built up and the characteristic thereby made substantially flat, or it may be given some other desired shape. In certain cases these resistances can be incorporated in the inductances themselves so that no additional elements are required in order to provide the desired control.

In the following detailed description the application of the invention to a broad band filter is described. It is to be understood, however, that the invention is not limited in its application to this type of transmission network, but only in accordance with the appended claims.

Referring to the drawing:

Fig. 1 represents the general schematic form of the networks of the invention;

Figs. 2, 3, 4 and 5 show typical forms of the network branch impedances;

Fig. 6 gives symbolically the reactance characteristics of the branch impedances of Figs. 2, 3, 4 and 5; and

Figs. 7 and 8 shows typical transmission characteristics obtained by the invention.

The network of Fig. 1 is of the lattice or bridge type, comprising two equal line impedances Z_1 and two equal impedances Z_2 connected diagonally between the input and output terminals. It is shown connected between terminal impedances Z_s and Z_R which may represent, for example, portions of a telephone system or other apparatus, a wave source of electromotive force E being included in series with one of the terminal impedances Z_s . The impedances Z_1 and Z_2 are primarily reactances and may have any degree of complexity and any of a wide variety of schematic forms. Preferred forms of the branch impedances are those illustrated in Figs. 2 to 5 inclusive, the type illustrated in Figs. 2 and 3 comprising a plurality of resonant circuits connected in parallel and the type shown in Figs. 4 and 5 comprising a plurality of anti-resonant circuits connected in series. In the former type a small resistance is included in each resonant circuit and the whole impedance may be shunted by a high resistance. In the latter type each anti-resonant circuit is shunted by a high resistance and a small resistance may be included in series with the whole impedance.

The principles of the invention will be explained in connection with their application to a low-pass filter having branch impedances Z_1 and Z_2 corresponding to Figs. 2 and 3 respectively. In this case the impedance Z_1 comprises a parallel connected system of five resonant circuits, shunted by a resistance R_a and having an ohmic resistance in series with each resonant circuit. In the figure each resonant branch is designated by its frequency of resonance, f_0, f_2, f_4 , etc. The variation of the reactance of Z_1 is shown symbolically by the solid-line curve of Fig. 6 in which abscissae represent frequency, and the ordinates the values of the reactance. The reactance is zero at zero frequency, is alternately infinite and zero at the successive frequencies $f_1, f_2, f_3, \dots, f_5$, and is infinite at infinite frequency.

If it is desired that the network shall have a single pass-band extending from zero to f_5 , the necessary variation of Z_2 follows readily from the

requirement that Z_1 and Z_2 shall have opposite signs everywhere throughout the band and shall have the same sign everywhere outside the band. The dotted curve of Fig. 6 shows the reactance characteristic required for Z_2 , having infinite values at zero frequency, f_2 , f_4 , f_7 and infinity, and zero values at f_1 , f_3 , f_6 and f_8 . Fig. 3 shows a suitable structure for Z_2 , composed of four resonant circuits connected in parallel, a shunting resistance R_b and an ohmic resistance in series with each resonant circuit being added for attenuation control purposes. Each resonant branch is designed by its frequency of resonance.

The resistances shown in series with the resonant branches of Figs. 2 and 3 cause a certain amount of energy dissipation which serves to increase the attenuation of the filter in the pass-band. The increase in attenuation due to any particular resistance is greatest at the resonance frequency of the circuit in which the resistance is located, because at that frequency the current through that branch is a maximum and the energy dissipation in the resistance is also a maximum. The resistance R_a shunting impedance Z_1 has its maximum effect in increasing the attenuation of the network at the anti-resonant frequencies of Z_1 , and, similarly, R_b has its maximum effect at the anti-resonant frequencies of Z_2 . It will be seen, therefore, that in the pass-band there are five frequencies, namely, zero, f_1 , f_2 , f_3 and f_4 , at which control of the attenuation of the network is provided. By proper choice of the individual resistances the attenuation characteristics of the network may be given any desired shape, within wide limits. For example, the attenuation of the filter of Fig. 1, which, without added resistances, is shown symbolically by the dotted curve of Fig. 7, can, by the addition of the proper resistances, be leveled out in the pass-band as shown by the solid-line curve of Fig. 7. Where the attenuation is low it is built up by the addition of resistances which have their greatest effect over that frequency range. As a concrete illustration it will be assumed that the filter is to have a constant attenuation within the transmission band equal in magnitude to four decibels, the attenuation of the unequalized filter at some particular frequency near its cut-off. It will be further assumed that the attenuation of the unequalized filter at the frequency f_1 is one decibel, which value has been determined by measurement or by well known methods of computation, taking into account the dissipation in the reactive elements. It is necessary, therefore, to increase the attenuation of the filter at f_1 from one decibel to four decibels. In accordance with the invention this is accomplished by increasing by a factor of four the resistance effectively in series with the resonant f_1 arm of the Z_2 impedance branch, shown in Fig. 3. If the uncorrected resistance component of the f_1 arm at resonance is two ohms, as measured on an impedance bridge or as calculated, then this resistance must be increased to eight ohms, by the addition of a six ohm resistance in series with the f_1 arm. Similarly, if the attenuation at the frequency f_2 is to be increased from say two decibels to the required four decibels, then it is necessary to increase the effective resistance of the resonant f_2 arm of the Z_1 impedance branch, shown in Fig. 2, to twice its former value. If the effective resistance of this arm before correction is three ohms at the resonant frequency, then a three ohm resistance must be added in series with the f_2 arm. In the same way, the at-

tenuation of the filter is built up to four decibels at the other critical frequencies within the pass-band, namely, zero, f_3 and f_4 , by the addition of an ohmic resistance in series with the arm of the impedance branch which is resonant at the particular frequency.

In a similar manner the attenuation of the filter in its transmission range may be given a downward slope with increasing frequency, as shown by the solid-line curve of Fig. 8. Such an attenuation characteristic would be useful, for example, in compensating the attenuation distortion of an associated transmission line or other apparatus having attenuation which increases with frequency in a complementary manner as indicated by the dotted-line curve of Fig. 8.

In certain cases the resistances R_a and R_b may be omitted without serious detriment to the control of attenuation. In addition each of the resistances in the resonant circuits of Z_1 and Z_2 may, if desired, be combined with the inductance with which it is in series by proper choice of the size of the wire with which the coil is wound and of the coil dimensions.

Fig. 4 shows an alternative form for Z_1 consisting of a chain of anti-resonant loops with a resistance shunting each loop and a resistance R_c in series with the chain. In the figure each anti-resonant loop is designated by its frequency of anti-resonance, f_1 , f_3 etc. Each shunting resistance has its maximum effect in increasing the attenuation of the filter at the anti-resonant frequency of the loop which the resistance shunts. The series resistance R_c is most effective in increasing the filter attenuation at the resonant frequencies of Z_1 . In certain cases this resistance may be omitted and, if desired, each of the shunting resistances may be replaced by a small resistance in series with the inductance of the anti-resonant loop so chosen as to give at the anti-resonance frequency of the loop the same effective resistance as the shunting resistance. This resistance in series with the inductance can then be incorporated into the effective resistance of the inductance. In this way no additional resistance elements are required in order to provide effective attenuation control for the filter. An alternative form for Z_2 comprising a chain of anti-resonant loops is shown in Fig. 5. The above discussion of the resistances of Fig. 4 applies with equal force to the resistances of Fig. 5.

In order to avoid a duplication of the impedances Z_1 and Z_2 the networks of the invention may, of course, be converted from the lattice form shown in Fig. 1 to a bridged-T form, as described in my aforementioned Patent 1,828,454. The latter form comprises a bridging branch having the impedance

$$\frac{Z_1}{2}$$

and a central branch having the impedance $2Z_2$, connected by means of a unity ratio transformer. Whether the network is of the lattice or the bridged-T form, its transmission characteristics are determined by the impedances of two of its branches.

In the appended claims the term critical frequency as applied to the branch impedances of the network is used to denote either a resonant or an anti-resonant frequency of the impedance as a whole.

What is claimed is:

1. A four-terminal transmission network comprising a plurality of branches, the impedances

of two of said branches being adapted to determine the transmission characteristics of said network, said impedances each having a plurality of critical frequencies defining resonances and anti-resonances and being proportioned to provide a free transmission band, and a resistance included in one of said branches, said resistance being so disposed in said branch that its value determines the magnitude of the impedance of said branch at one of said critical frequencies, and the value of said resistance being so chosen that said network has a predetermined attenuation at said one critical frequency.

2. A wave transmission network comprising a plurality of branch impedances, two of said impedances being adapted to determine the transmission characteristics of said network, said two impedances each having a plurality of critical frequencies and being proportioned to provide a free transmission band, and a resistance included in at least one of said impedances for controlling the effective resistance of said impedance at one of said critical frequencies, whereby said network is given a predetermined attenuation at said one critical frequency.

3. A four-terminal transmission network comprising a plurality of branch impedances, two of said impedances being adapted to determine the transmission characteristics of said network, said two impedances each having a plurality of critical frequencies and being proportioned to provide a free transmission band, and the effective resistance of said impedances being given predetermined values at said critical frequencies whereby the attenuation characteristic of the network is made to follow a desired curve throughout the transmission band of said network.

4. A wave transmission network comprising a plurality of multiple resonant branch impedances having a plurality of critical frequencies of resonance and anti-resonance, two of said impedances being adapted to determine the transmission characteristics of said network, the attenuation of said network being determined at a certain frequency within said transmission band by providing a predetermined effective resistance for at least one of said branch impedances at a critical frequency near said certain frequency, whereby the attenuation of said network is made to coincide at said certain frequency, with an arbitrarily chosen attenuation curve.

5. A wave transmission network comprising two pairs of equal impedances arranged to form a symmetrical lattice structure, said impedances comprising multiple resonant reactances, the resonances of the one pair coinciding with the anti-resonances of the other pair in a preassigned broad frequency range to provide free transmission, and the effective resistance of said impedances being controlled at the resonant and anti-resonant frequencies by energy-dissipating means within said impedances whereby the attenuation of said network in the transmitting range is made substantially uniform.

6. A four-terminal transmission network comprising two pairs of equal impedances arranged to form a symmetrical lattice structure, each of said impedances having a plurality of critical frequencies, the resonances of the one pair coinciding with the anti-resonances of the other pair in a preassigned broad frequency range to provide free transmission, and energy dissipating means within at least one of said impedances for controlling the effective resistance of said impedance at one of said critical frequencies, whereby the attenuation of said network is made substantially uniform throughout its transmission range.

7. A wave transmission network comprising two pairs of equal impedances arranged to form a symmetrical lattice structure, at least one pair of said impedances each comprising a resistance in parallel with a plurality of resonant branches, each of said branches comprising an inductance, a capacitance and a resistance in series relation, the attenuation of said network being determined at the critical frequencies of said impedances by the individual values of said resistances and said values being so chosen that the curve of said attenuation conforms to a desired shape in the transmission range of said network.

8. A four-terminal transmission network comprising two pairs of equal impedances arranged to form a symmetrical lattice structure, at least one pair of said impedances each comprising a resistance in series with a chain of anti-resonant loops, with a separate resistance shunting each of said loops, the attenuation of said network being determined at the critical frequencies of said impedances by the individual values of said resistances and said values being so chosen that the curve of said attenuation conforms to a desired shape in the transmission range of said network.

9. In combination a network in accordance with claim 3 and associated apparatus, said associated apparatus having an attenuation characteristic which is not uniform in the transmission band of said network, and the effective resistance of the branch impedances of said network being so chosen that the attenuation characteristic of the network substantially compensates the attenuation distortion of said associated apparatus.

10. A wave transmission network comprising a plurality of branch impedances, two of said impedances being adapted to determine the transmission characteristics of said network, said two impedances each having a plurality of critical frequencies and being proportioned to provide a free transmission band, and the effective resistance of said two impedances being given predetermined values at said critical frequencies whereby the attenuation of said network is made substantially uniform throughout said transmission band.

HENDRIK W. BODE.