

Oct. 8, 1940.

D. F. CICCOLELLA

2,216,937

WAVE FILTER

Filed Nov. 5, 1938

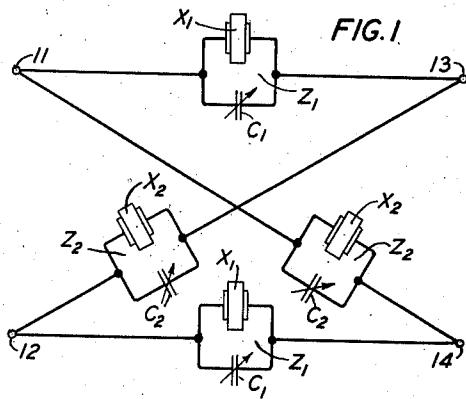


FIG. 1

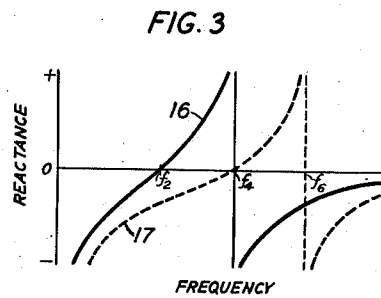


FIG. 3

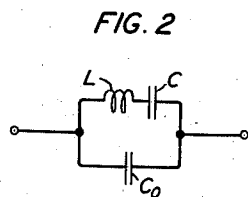


FIG. 2

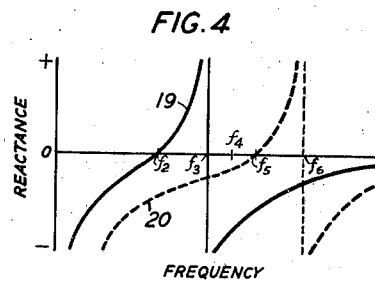


FIG. 4

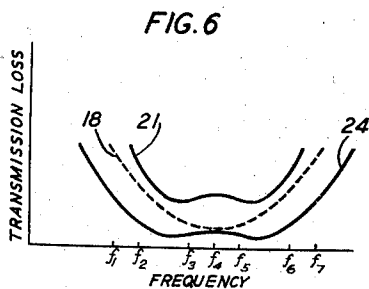


FIG. 6

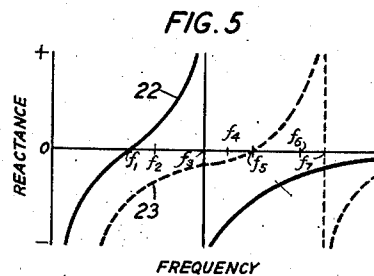


FIG. 5

INVENTOR
D.F. CICCOLELLA
BY
Ralph P. Holcomb
ATTORNEY

UNITED STATES PATENT OFFICE

2,216,937

WAVE FILTER

David F. Ciccolella, Forest Hills, N. Y., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application November 5, 1938, Serial No. 238,991

19 Claims. (Cl. 178—44)

This invention relates to wave transmission networks and more particularly to wave filters in which piezoelectric crystals are used as impedance elements.

5 An object of the invention is to decrease the distortion in a wave filter using piezoelectric crystal elements.

Another object is to increase the width of the transmission band in such a filter.

10 Other objects are to increase the discrimination between the transmitted and the attenuated waves and to sharpen the cut-off in filters of this type.

In a wave filter of the lattice type employing 15 piezoelectric crystals as reactance elements the reactance characteristics of the series and diagonal impedance branches may be proportioned to provide a band of free transmission bounded on either side by attenuation regions. Due to energy dissipation in the component elements the transmission loss characteristic of such a filter is rounded at the edges of the band. This rounding at the edges gives rise to undesirable attenuation distortion within the transmission band.

20 In accordance with the present invention this distortion is greatly reduced by a redistribution of the critical frequencies of the impedance branches. Ordinarily, one of the branches has a resonance and the other branch has an anti-resonance both located at the mid-band frequency. If these critical frequencies are spaced 25 apart, according to filter theory there would appear an additional attenuation band extending between them because in this region the reactances of the two branches are of the same sign. It has been found, however, that if the separation of the frequencies, on a percentage basis, is not too great only a rudimentary attenuation band will develop. Due to the narrowness of the band 30 and to the dissipation in the filter elements only a small hump of loss, in the mid-band region, will materialize. Since this hump occurs in the region of minimum loss it provides a means of reducing the attenuation distortion within the transmission band. As the spacing between the non-coincident critical frequencies is increased the height of the hump is increased, and it is possible to choose a spacing such that the loss at mid-band is approximately equal to the loss at the edges of the band. 35 By this method not only will the attenuation distortion be greatly reduced but at the same time the cut-offs will be sharpened and the difference between the loss in the transmission band and the loss outside of the band will be increased.

40 The invention may also be utilized to widen the

transmission band. This is done by separating the critical frequencies which ordinarily occur at the mid-band frequency, as explained, and at the same time moving outward the critical frequencies which determined the cut-offs of the filter. If all of the critical frequencies in any one pair of impedance branches are moved in the same direction and by approximately the same amount the discrimination of the filter will be unaffected but the band will be widened and the distortion in the band reduced. If the cut-offs are moved less than the normally coincident critical frequencies the discrimination may be actually increased. The ability to increase the band width is of special importance when it is necessary to provide a wider band than can be obtained in previously known crystal filters without the addition of inductance elements.

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 is a schematic circuit of a lattice-type crystal filter to which the invention is applicable;

Fig. 2 is an equivalent electrical circuit for a 25 piezoelectric crystal;

Fig. 3 represents the reactance characteristics of the impedance branches of the filter of Fig. 1 with the critical frequencies distributed according to former practice;

Figs. 4 and 5 show the distribution of the critical frequencies in the component impedance branches in accordance with the present invention; and

Fig. 6 shows typical transmission loss characteristics obtainable with the filter of Fig. 1.

Fig. 1 is a schematic circuit of a lattice-type crystal wave filter to which the invention is applicable. The filter comprises a pair of similar series impedance branches Z_1 and a pair of similar diagonal impedance branches Z_2 connected between two pairs of terminals 11, 12 and 13, 14 to form a symmetrical lattice network. A wave source of electromotive force may be connected to one pair of the terminals and a utilization circuit to the other terminals. To avoid reflection effects these terminal loads should match the characteristic impedance of the filter at one or more frequencies within the transmission band.

Each series impedance branch Z_1 comprises as 50 a reactance element a piezoelectric crystal X_1 and a capacitance C_1 connected in parallel. Each diagonal branch Z_2 includes a piezoelectric crystal X_2 shunted by a capacitance C_2 . As shown in Fig. 2 an equivalent electrical circuit representing a 55

piezoelectric crystal consists of a capacitance C_0 shunted by an arm made up of an inductance L in series with a second capacitance C . The capacitance C_0 represents the simple electrostatic capacitance between the electrodes associated with the crystal, and the values of the inductance L and the capacitance C depend upon the dimensions of the crystal and also upon its piezoelectric and elastic constants.

The reactance characteristic for such a piezoelectric crystal will have two critical frequencies, a resonance determined by the values of L and C and an anti-resonance occurring at a higher frequency. The interval between these two frequencies may be decreased by the addition of a shunting capacitance, such as C_1 or C_2 in Fig. 1. The maximum interval is obtained when the value of the shunting capacitance is zero. These capacitances may be made variable, as indicated by the arrows, to facilitate the adjustment of the frequencies of anti-resonance. In accordance with filter theory a transmission band will occur when the reactances of the series and the diagonal impedance branches are of opposite sign, and there will be attenuation in the regions where the branches are of the same sign. Therefore, in order to provide a transmission band for the filter of Fig. 1 the anti-resonance in one of the branches, the reactance of which is represented by the solid-line curve 16 of Fig. 3, is made to coincide at some frequency f_4 with the resonance in the other branch, the reactance of which is represented by the dotted-line curve 17. The resonance of the one branch, occurring at f_2 , and the anti-resonance of the other branch, occurring at f_6 , determine the theoretical cut-offs of the filter. Due to the energy dissipation in the elements the transmission loss in the band, as shown by the dotted-line curve 18 of Fig. 6, will not be uniform but will increase toward the edges of the band, with a minimum loss in the neighborhood of the mid-band frequency f_4 . This non-uniformity of the loss in the band will cause a distortion of the waves as they pass through the filter.

In accordance with the invention this attenuation distortion in the band is reduced by spacing apart the critical frequencies which normally occur coincidentally at the mid-band frequency. As shown by the solid-line reactance characteristic 19 of Fig. 4 the anti-resonance of the one branch may be moved from the frequency f_4 to a lower frequency f_3 . This may be done by increasing the value of the capacitance shunting the crystal. At the same time the resonance of the other branch is moved from f_4 to a higher frequency f_5 , as shown by the dotted-line reactance characteristic 20. This may be done by substituting a slightly longer crystal and by increasing the value of the associated shunt capacitance. Ordinarily, the one frequency will be moved down by approximately the same number of cycles as the other frequency is moved up.

According to filter theory it would be expected that an attenuation band would develop between the frequencies f_3 and f_5 because the reactance characteristics of the series and the diagonal impedance branches are of the same sign in this region. However, due to the dissipation in the component elements only a small hump appears in this region, provided the space between the frequencies is not too great on a percentage basis. As is apparent from the curve 21 of Fig. 6 the transmission loss is made more uniform within the band. There are now two minimum points

and an intermediate maximum point. For the most uniform characteristic the frequencies are spaced apart to such an extent that the loss at this maximum point is approximately equal to the loss at the edges of the useful band. Of course, the frequencies may be further spread to further increase the loss in the region of the mid-band so that the filter is made to equalize to a certain extent for other associated apparatus which may have a deficiency of loss in the region. Although the loss throughout the band has been slightly increased the attenuation outside of the band has been considerably increased, thereby increasing the discrimination. Also, the cut-offs have been sharpened.

If it is desired to widen the transmission band of the filter the resonance of the one branch is moved from f_2 to a lower frequency f_1 and the anti-resonance of the other branch is moved by approximately the same number of cycles from f_6 to a higher frequency f_7 . The resulting reactance characteristics of the branches will now be as shown, respectively, by the solid-line curve 22 and the dotted-line curve 23 of Fig. 5. It may be necessary to relocate the frequencies f_3 and f_5 , but in any event the separation of these frequencies may be so chosen that the transmission loss within the practical band, as shown by the curve 24 of Fig. 6, is substantially uniform. It is apparent that the band has been widened, the distortion reduced and the loss in the band decreased.

The expedient just described may be applied to a crystal filter of the type shown in Fig. 1 to widen the band beyond the maximum limits heretofore attainable. If the impedance branches have the reactance characteristics shown in Fig. 3 it is evident that maximum band is obtained when the resonance and the anti-resonance in each branch have the greatest separation. As already pointed out this corresponds to the case where the capacitances shunting the crystals are omitted. In order to extend the band further it has formerly been necessary to add inductances to the circuit. However, by moving both the resonance and the anti-resonance to lower frequencies in the one branch and to higher frequencies in the other branch the band may be widened beyond these former limits without adding any more reactance elements. Furthermore, the distortion in the band is thereby reduced.

The filter of Fig. 1 may, of course, be built in an equivalent form in which capacitances are connected in shunt at the ends of the network. If each of these end capacitances is given a value equal to the smaller of the capacitances C_1 and C_2 then the smaller of the capacitances may be omitted from the impedance branch with which it was formerly associated, and at the same time the larger of the capacitances is reduced in value by the value of each end capacitance. For example, if the capacitance C_1 has a value A and the capacitance C_2 has a value equal to A plus B each end capacitance will have the value A , each capacitance C_2 is replaced by a capacitance having the value B and the capacitances C_1 are omitted. If the capacitances C_1 and C_2 have the same value each of the end capacitances will have this value and both of the capacitances C_1 and C_2 may be omitted.

What is claimed is:

1. A wave filter comprising two pairs of similar impedance branches disposed between two pairs of terminals to form a lattice network, each

of said branches including a piezoelectric crystal, said pairs of branches having different reactance-frequency characteristics proportioned with respect to each other to provide a transmission

5 band, one of said pairs of branches having a resonance, the other of said pairs of branches having an anti-resonance, said resonance and said anti-resonance being located in said band and normally being coincident in frequency, but
10 said filter being modified by moving said resonance to a higher frequency and said anti-resonance to a lower frequency in order to increase the transmission loss of said filter in the frequency interval between said resonance and
15 said anti-resonance, and said frequency interval being so chosen that the maximum transmission loss therein is approximately equal to the loss at the edges of the effective transmission band of the modified filter.

20 2. A wave filter in accordance with claim 1 in which the frequency interval between said resonance and said anti-resonance includes the frequency of minimum transmission loss in the unmodified filter.

25 3. A wave filter in accordance with claim 1 in which the frequency interval between said resonance and said anti-resonance includes the mid-band frequency.

30 4. A wave filter in accordance with claim 1 in which said resonance and said anti-resonance are each moved by approximately the same number of cycles.

35 5. A wave filter comprising two pairs of similar impedance branches disposed between two pairs of terminals to form a lattice network, each of said branches including a piezoelectric crystal, said pairs of branches having different reactance-frequency characteristics proportioned with respect to each other to provide a transmission
40 band, one of said pairs of branches having a resonance, the other of said pairs of branches having an anti-resonance, said resonance and said anti-resonance being located in said band and normally being coincident in frequency, said one
45 pair of branches having an anti-resonance and said other pair of branches having a resonance which determine the limits of said band, and said filter being modified by separating said normally coincident resonance and anti-resonance, moving
50 said band-limiting resonance to a lower frequency and moving said band-limiting anti-resonance to a higher frequency, whereby the transmission loss in the frequency interval between said normally coincident resonance and anti-resonance is
55 increased and said band is widened, said normally coincident resonance and anti-resonance being separated by a frequency interval so chosen that the maximum transmission loss in said interval is approximately equal to the loss at the edges of the effective transmission band of the modified filter.

60 6. A wave filter in accordance with claim 5 in which said normally coincident resonance and anti-resonance are moved by approximately the same number of cycles.

65 7. A wave filter in accordance with claim 5 in which said band-limiting resonance and anti-resonance are moved by approximately the same number of cycles.

70 8. A wave filter in accordance with claim 5 in which each of said resonances and anti-resonances is moved by approximately the same number of cycles.

75 9. A wave filter in accordance with claim 5 in which said band-limiting resonance and anti-

resonance are each moved by a number of cycles approximately equal to half the distance in cycles between said normally coincident resonance and anti-resonance.

10. A wave filter in accordance with claim 5 in which the frequency interval between said normally coincident resonance and anti-resonance includes the frequency of minimum transmission loss in the unmodified filter.

11. A wave filter in accordance with claim 5 in which the frequency interval between said normally coincident resonance and anti-resonance includes the mid-band frequency.

12. A wave filter comprising two pairs of impedance branches disposed between two pairs of terminals to form a lattice network, each of said branches including a piezoelectric crystal, said pairs of branches having different reactance-frequency characteristics proportioned with respect to each other to provide a transmission band, one of said pairs of branches having a resonance which determines the lower cut-off of said band and an anti-resonance at a higher frequency, the other of said pairs of branches having an anti-resonance which determines the upper cut-off of said band and a resonance at a lower frequency, and said anti-resonance in said one pair of branches and said resonance in said other pair of branches being separated by a frequency interval so chosen that the maximum transmission loss in said interval is approximately equal to the loss at the edges of said transmission band.

13. In a wave filter comprising two pairs of impedance branches disposed between two pairs of terminals to form a lattice network in which each of said branches includes a piezoelectric crystal, said pairs of branches have different reactance-frequency characteristics proportioned with respect to each other to provide a transmission band, and one of said pairs of branches has a resonance and the other of said pairs of branches has an anti-resonance both normally located at the mid-band frequency, the method of reducing the attenuation distortion within the band of the filter which comprises moving the resonance to a frequency above the mid-band frequency, moving the anti-resonance by approximately the same number of cycles to a frequency below said mid-band frequency, and so choosing the frequency interval between said resonance and said anti-resonance that the maximum transmission loss in said interval is approximately equal to the loss at the edges of said band.

14. In a wave filter comprising two pairs of impedance branches disposed between two pairs of terminals to form a lattice network in which each of said branches includes a piezoelectric crystal, said pairs of branches have different reactance-frequency characteristics proportioned with respect to each other to provide a transmission band, one of said pairs of branches has a resonance and the other of said pairs of branches has an anti-resonance both normally located at the mid-band frequency, and said one pair of branches has an anti-resonance and said other pair of branches has a resonance which determine the limits of said band, the method of reducing the attenuation distortion within said band and widening said band which comprises separating said normally coincident resonance and anti-resonance, by a certain frequency interval, further separating said band-limiting resonance and anti-resonance by approximately the same frequency interval, and so choosing said certain frequency interval that

the maximum transmission loss therein is approximately equal to the loss at the edges of the band of the modified filter.

15. A wave filter comprising two pairs of
5 similar impedance branches disposed between two pairs of terminals to form a lattice network, each of said branches including a piezoelectric crystal, said pairs of branches having different
10 reactance - frequency characteristics proportioned with respect to each other to provide a transmission band, one of said pairs of branches having a resonance, the other of said pairs of branches having an anti-resonance, said reso-
15 nance and said anti-resonance being located in said band and normally being coincident in frequency, but said filter being modified by moving said resonance to a higher frequency and said anti-resonance by approximately the same number of cycles to a lower frequency in order to
20 increase the transmission loss of said filter in the frequency interval between said resonance and anti-resonance.

16. A wave filter comprising two pairs of
25 similar impedance branches disposed between two pairs of terminals to form a lattice network, each of said branches including a piezoelectric crystal, said pairs of branches having different
30 reactance - frequency characteristics proportioned with respect to each other to provide a transmission band, one of said pairs of branches having a resonance, the other of said pairs of branches having an anti-resonance, said reso-
35 nance and said anti-resonance being located in said band and normally being coincident in frequency, said one pair of branches having an anti-resonance and said other pair of branches having a resonance which determine the limits
40 of said band, and said filter being modified by separating said normally coincident resonance and anti-resonance by moving each approximately the same number of cycles, moving said
45 band limiting resonance to a lower frequency and moving said band limiting anti-resonance to a higher frequency whereby the transmission loss in the frequency interval between said normally coincident resonance and anti-resonance is increased and said band is widened.

17. A wave filter comprising two pairs of
50 similar impedance branches disposed between two pairs of terminals to form a lattice network, each of said branches including a piezoelectric crystal, said pairs of branches having different reactance - frequency characteristics propor-

tioned with respect to each other to provide a transmission band, one of said pairs of branches having a resonance, the other of said pairs of branches having an anti-resonance, said reso-
5 nance and said anti-resonance being located in said band and normally being coincident in frequency, said one pair of branches having an anti-resonance and said other pair of branches having a resonance which determine the limits
10 of said band, and said filter being modified by separating said normally coincident resonance and anti-resonance, moving said band limiting resonance by a certain number of cycles to a lower frequency and moving said band limiting
15 anti-resonance by approximately said same certain number of cycles to a higher frequency, whereby the transmission loss in the frequency interval between said normally coincident resonance and anti-resonance is increased and said
20 band is widened.

18. A wave filter in accordance with claim 17 in which each of said resonances and anti-resonances is moved by approximately the same number of cycles.

19. A wave filter comprising two pairs of
25 similar impedance branches disposed between two pairs of terminals to form a lattice network, each of said branches including a piezoelectric crystal, said pairs of branches having different
30 reactance - frequency characteristics proportioned with respect to each other to provide a transmission band, one of said pairs of branches having a resonance, the other of said pairs of branches having an anti-resonance, said reso-
35 nance and said anti-resonance being located in said band and normally being coincident in frequency, said one pair of branches having an anti-resonance and said other pair of branches having a resonance which determine the limits
40 of said band, and said filter being modified by separating said normally coincident resonance and anti-resonance, moving said band limiting resonance to a lower frequency and moving said
45 band limiting resonance to a higher frequency, said band limiting resonance and anti-resonance each being moved by a number of cycles approximately equal to half the distance in cycles between said normally coincident resonance and anti-resonance whereby the transmission loss in the frequency interval between said normally
50 coincident resonance and anti-resonance is increased and said band is widened.

DAVID F. CICCOLELLA.