

April 29, 1941.

G. H. LOVELL

2,240,142

WAVE FILTER

Filed June 7, 1938

FIG. 1

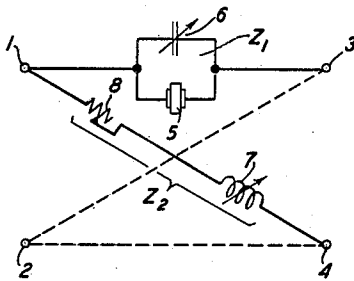


FIG. 2

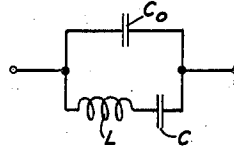


FIG. 3

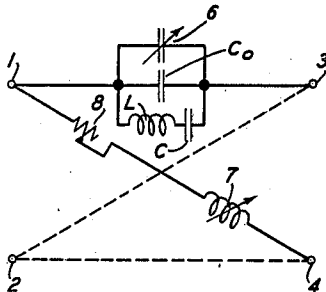


FIG. 4

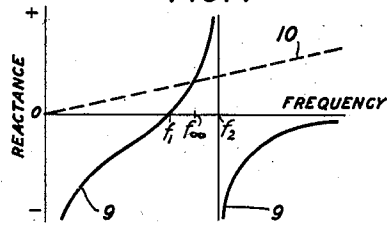


FIG. 5

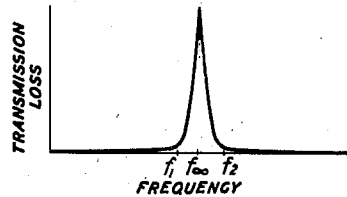


FIG. 7

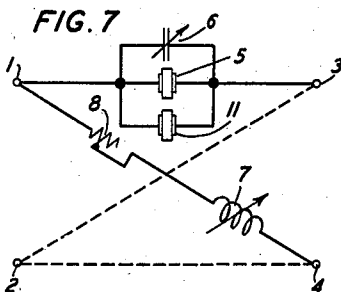
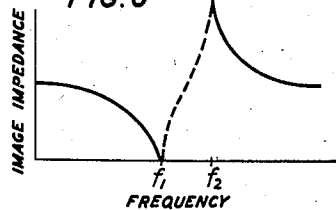


FIG. 6



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2,240,142

WAVE FILTER

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Application June 7, 1938, Serial No. 212,246

19 Claims. (Cl. 173-44)

This invention relates to wave filters in which piezoelectric crystals are used as impedance elements and more particularly to crystal filters of the band elimination type.

The principal object of the invention is to suppress one or more bands of frequencies while freely transmitting other frequencies. A further object is to provide means for adjusting the width of the band and the location of the attenuation peak in band elimination filters. Other objects are to improve the attenuation characteristics, simplify the structure and reduce the cost of filters of this type.

There is often required a frequency selective wave transmission network which will effectively suppress one or more comparatively narrow bands and will have very sharp cut-offs between the attenuation and transmission bands. Piezoelectric crystals, because of their low energy dissipation, have been found to be well adapted for use as impedance elements in such networks.

In accordance with the present invention there is provided a crystal band elimination wave filter of simple but efficient structure which will satisfactorily meet these requirements. The preferred embodiment is a symmetrical lattice type structure in which piezoelectric crystals are employed in only one pair of the impedance branches, and each of the other pair of branches comprises an inductance as the only reactance element. If two or more separate elimination bands or a wider single band is desired, a plurality of crystals, connected in series or in parallel, are used. In order to regulate the width of the band and the location of the attenuation peak, a variable capacitance may be added in shunt with each crystal. Also, the inductances may be made variable for the purpose of adjusting the characteristic impedance of the filter and the location of the peak of attenuation. An added resistance may be associated with each branch of one pair of the impedances in order to balance the resistive as well as the reactive components of the different impedance branches at the peak of attenuation and thereby increase the transmission loss of the filter at that frequency.

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 schematically one embodiment of the invention in a lattice type network;

Fig. 2 shows an equivalent electrical circuit of the piezoelectric crystal;

Fig. 3 shows an equivalent electrical circuit for the network of Fig. 1;

Fig. 4 gives the reactance characteristics of the different impedance branches shown in Figs. 1 and 3;

Fig. 5 shows a typical transmission loss characteristic obtainable with the filter of Figs. 1 and 3;

Fig. 6 represents the type of image impedance characteristic for the filter of Figs. 1 and 3; and

Fig. 7 shows another embodiment of the invention in which each of a pair of the impedance branches comprises a plurality of piezoelectric crystals.

A wave filter in accordance with the invention having a single elimination band is shown schematically in Fig. 1. The filter is of the symmetrical lattice type comprising two similar line impedance branches Z_1 and two similar lattice impedance branches Z_2 connected between input terminals 1, 2 and output terminals 3, 4. In this and in subsequent figures, for the sake of clarity, only one line branch and one lattice branch are shown in detail. The other corresponding impedance branches have identical elements. Each line branch comprises a piezoelectric crystal 5 shunted by a small capacitance 6 which is preferably an adjustable air condenser. Each lattice branch consists of a variable inductance 7 connected in series with a variable resistance 8.

The crystals are preferably rectangular quartz plates cut with the plane of the rectangle perpendicular to the electric axis of the crystal and with the longer edge of the rectangle parallel to the mechanical axis of the crystal. The larger faces of the crystal are provided with electrodes applied preferably by the electrical deposition of a layer of aluminum, silver or other metal to secure an intimate contact over the whole surface. Crystals of this type when subjected to an alternating potential difference between the electrodes vibrate mainly by expansion and contraction in the direction of the mechanical axis. The crystals should therefore be supported between points or knife edge clamps located close to the center of the crystal along the optical axis. Other well-known types of crystal cuts may also be used and under certain conditions these may be preferred.

For frequencies up to and well above the first resonance the electrical impedance of a crystal of the type described above is of a simple character corresponding to that of an electrical circuit of the type shown in Fig. 2. Other reso-

nances representing changes in the mode of vibration are practically eliminated so long as the length of the crystal is greater than its width and the thickness is relatively small. As shown in Fig. 2, the equivalent circuit consists of a capacitance C_0 connected in parallel with a branch comprising an inductance L in series with a second capacitance C . The series resonant combination consisting of L and C represents the piezoelectric properties of the crystal and C_0 represents the electrode capacity which has a minimum value of approximately 125 times the capacity C . The equivalent electrical elements may be evaluated in terms of the dimensions of the crystal plate by the following formulas:

$$L = \frac{106.1lt}{w} \text{ henries} \quad (1)$$

$$C = \frac{0.322wl}{t10^{14}} \text{ farads} \quad (2)$$

$$C_0 = \frac{40.2wl}{t10^{14}} \text{ farads} \quad (3)$$

in which l , w and t are respectively the length, width and thickness of the crystal measured in centimeters.

A single crystal may be made to provide the piezoelectric impedances in both series branches of the filter by dividing the plating and coupling each half of the crystal to one of the impedance branches as described in United States Patent 2,094,044, issued September 28, 1937, to W. P. Mason. Also the two inductances in the lattice branches may be furnished by a single coil having two equal windings inductively coupled. If this construction is employed, the filter circuit shown in Fig. 1 will require only one crystal and one coil and is, therefore, very economical of elements.

Fig. 3 shows a circuit which is electrically equivalent to that shown in Fig. 1 and in which the crystal 5 has been replaced by its equivalent circuit as shown in Fig. 2. The reactance characteristics of the series and lattice impedance branches of Figs. 1 and 3 are shown in Fig. 4. The reactance of the series impedance branch Z_1 is given by curve 9 and the reactance of the lattice branch is given by curve 10. The series branch has a resonance frequency f_1 , corresponding to the resonance of L and C , and an anti-resonance frequency f_2 . This frequency of anti-resonance is determined by the loop resonance of L and C connected in series with the parallel combination of C_0 and the capacitance 6. Extending between the frequencies f_1 and f_2 is a narrow region in which the reactance is inductive or positive. An adjustment of the capacitance 6 has no effect on the resonance frequency, but it does provide a means for adjusting the anti-resonance frequency. The frequencies f_1 and f_2 will have the widest spacing when the capacitance 6 is zero in magnitude. As the capacitance 6 is increased in value, the anti-resonance frequency f_2 will be moved closer and closer to the resonance frequency f_1 .

The propagation constant P of the filter is given by the expression

$$\tanh \frac{P}{2} = \sqrt{\frac{Z_1}{Z_2}} \quad (4)$$

from which it follows that the filter will have transmission bands in the regions where Z_1 and Z_2 are of opposite sign, and will have an attenuation band where these impedances are of

the same sign. The attenuation will be infinite when Z_1 is equal to Z_2 . Referring to the reactance characteristics of Fig. 4, it is apparent that the filter will have a transmission band from zero to f_1 , an attenuation band extending from f_1 to f_2 , and a second transmission band extending upward from f_2 . At the frequency f_∞ where curve 9 crosses curve 10 a peak of attenuation will occur. A typical transmission loss characteristic obtainable with the filter shown in Fig. 1 is given in Fig. 5. The cut-off frequencies are f_1 and f_2 and an attenuation peak occurs at the frequency f_∞ . The filter will have a maximum attenuation band of approximately 0.35 per cent of the mid-band frequency. The upper cut-off frequency f_2 can be moved closer to the lower cut-off frequency f_1 by the adjustment of the variable capacitance 6, as explained above.

As the value of the capacitance 6 is increased, the attenuation peak is also slightly displaced to a lower frequency. By adjusting the inductance 7 to the required value, the peak of attenuation can be located at any desired frequency between the two cut-offs. For a given band width the nearer the lower cut-off the peak of attenuation is placed, the smaller will be the required inductance and the lower the image impedance of the filter. The image impedance K is found from the expression

$$K = \sqrt{Z_1 Z_2} \quad (5)$$

and for the filter of Fig. 3 the characteristic is of the type shown in Fig. 6.

Since the attenuation at the peak frequency f_∞ is dependent upon the impedance balance between the series and lattice branches of the filter, its magnitude can be increased by balancing the resistive as well as the reactive components of these impedances. This may be done by adding a resistance to the branch which has the smaller resistive component. In Figs. 1 and 3, this has been done by the addition of resistance 8 in series with the inductance 7, on the assumption that the resistive component of the lattice branch is less than that of the series branch at the frequency f_∞ . If the contrary condition prevails, the resistance is added to the series branch instead of the lattice branch. The resistance 8 may be made variable in order to obtain a precise adjustment and in order to allow a readjustment, if required, in case the attenuation peak is moved by an adjustment of the variable capacitance 6 or the variable inductance 7, as explained above.

The band elimination filter described above has the advantages that a minimum number of elements are required in its construction, the attenuation in the transmission bands is low because a minimum number of inductance coils are used, a high attenuation peak is obtained because of the small number of inductances and by virtue of the balancing of the resistive components, the location of the peak of attenuation can be adjusted by means of the variable capacitance 6 or the variable inductance 7, and the width of the suppression band can be regulated by adjusting the variable capacitance. The filter has a further advantage that the location of the attenuation peak is only slightly affected by temperature changes. This is due to the facts that no inductance coils are used in the impedance branch which includes the crystal and that a small change in the magnitude of the inductance 7 will change only slightly the frequency at which the curve 10 crosses the curve 9. The

resonance frequency f_1 of the crystal will be only slightly affected by temperature changes if a crystal having a low temperature coefficient is used and the filter will have an attenuation characteristic which is extremely stable.

Fig. 7 shows a filter in accordance with the invention which will have a plurality of elimination bands or a widened single band. The structure is the same as that shown in Fig. 1, except that an additional crystal 11 is included in each series impedance branch. The figure shows the addition of only one more crystal, but it is to be understood that any number of crystals may be added. The crystal 11 is shown connected in parallel with the crystal 5, but the crystals may be connected in series if desired. The addition of each crystal adds another frequency of resonance and another frequency of anti-resonance to the reactance characteristic of the series impedance branch. It is apparent from a consideration of the curves of Fig. 4 that each added crystal will provide an additional region of positive reactance and therefore will introduce an additional elimination band. Ordinarily these elimination bands will be spaced apart by intervening transmission bands and they may be located at any desired frequencies. If the crystals are so selected that the resonance frequencies fall close together, the intervening transmission bands will tend to be wiped out due to dissipation in the elements, and the resulting insertion loss characteristics will merely show dips in the regions where the transmission bands would ordinarily occur. In this way there may be provided a filter with a single elimination band which may be widened as desired by the addition of more crystals.

As is well understood, the series impedance branches in Figs. 1 and 7 may be interchanged with the lattice branches without affecting the attenuation characteristics of the filters. This change will, however, alter the image impedance and the phase characteristics of the filter.

What is claimed is:

1. A wave filter for suppressing a narrow band of frequencies while freely transmitting frequencies on either side thereof comprising two pairs of similar impedance branches disposed between a pair of input terminals and a pair of output terminals to form a symmetrical lattice network, each of one pair only of said branches including a piezoelectric crystal having a region of positive reactance which coincides with and limits the band of frequencies to be suppressed, and each of the other pair of said branches comprising an inductance as the only reactance element.

2. A band elimination wave filter for eliminating a narrow band of frequencies while freely transmitting frequencies on either side thereof comprising four impedance branches equal in pairs and disposed to form a symmetrical lattice network, one only of said pairs of branches including similar piezoelectric crystal elements having a region of positive reactance which is co-extensive in frequency with the band to be eliminated, and the other of said branches comprising equal inductances as the only reactance elements.

3. A wave filter in accordance with claim 1 in which an added capacitance is connected in parallel with each of said crystals in order to control the width of the suppression band.

4. A wave filter in accordance with claim 1 in which an added resistance is included in each of one of said pairs of impedance branches in

order to increase the maximum attenuation of the filter.

5. A wave filter in accordance with claim 1 in which an added capacitance is connected in parallel with each of said crystals to control the width of the suppression band and an added resistance is included in each of a pair of said impedance branches in order to balance the resistive components of said two pairs of branches at the frequency of maximum attenuation.

6. A band elimination wave filter comprising four impedance branches equal in pairs and disposed between a pair of input terminals and a pair of output terminals to form a symmetrical lattice network, each of one pair of said branches comprising a piezoelectric crystal shunted by an added capacitance for the purpose of regulating the width of the suppression band, and each of the other pair of said branches consisting only of an inductance and a resistance, said resistance being added for the purpose of balancing the resistive components of said two pairs of branches at the frequency of maximum attenuation of the filter.

7. A wave filter for suppressing a plurality of separated bands of frequencies while freely transmitting frequencies on either side of said bands comprising four impedance branches equal in pairs and arranged between a pair of input terminals and a pair of output terminals to form a symmetrical lattice network, each of one of said pairs of branches comprising a plurality of piezoelectric crystals, each having a region of positive reactance which coincides with and limits one of said bands of frequencies to be eliminated, and each of the other pair of said branches comprising an inductance.

8. A wave filter in accordance with claim 7 in which all of said crystals in any one branch are connected in parallel.

9. A wave filter in accordance with claim 7 in which at least one crystal in each of said pair of branches has an added capacitance connected in shunt therewith for the purpose of regulating the width of one of said suppression bands.

10. A wave filter in accordance with claim 7 in which an added resistance is included in each branch of one of said pairs of impedances in order to balance the resistive components of the impedances of the pairs of branches at a peak of attenuation.

11. A band elimination wave filter comprising four impedance branches equal in pairs and disposed between input terminals and output terminals to form a symmetrical lattice network, each of one pair of said branches comprising an inductance as the only reactive element, and each of the other pair of said branches comprising a plurality of piezoelectric crystals having regions of positive reactance so closely spaced that the filter has a single continuous elimination band bounded on either side by free transmission bands.

12. A wave filter in accordance with claim 1 in which said inductances are made variable for the purpose of adjusting the location of the frequency of maximum attenuation.

13. A wave filter in accordance with claim 1 in which said inductances are made variable for the purpose of adjusting the characteristic impedance of the filter.

14. A wave filter in accordance with claim 6 in which said inductance and said resistance are connected in series.

15. A wave filter in accordance with claim 6 in which said capacitance is variable. in which all of said crystals in any one branch are connected in parallel.
16. A wave filter in accordance with claim 6 in which said resistance is variable. 19. A wave filter in accordance with claim 11 in which a resistance is included in each of one of said pairs of impedance branches.
17. A wave filter in accordance with claim 6 in which said inductance is variable.
18. A wave filter in accordance with claim 11.

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