

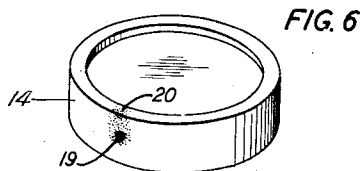
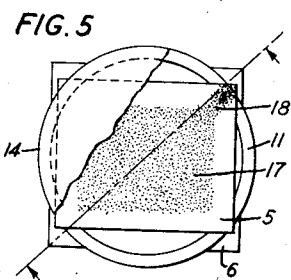
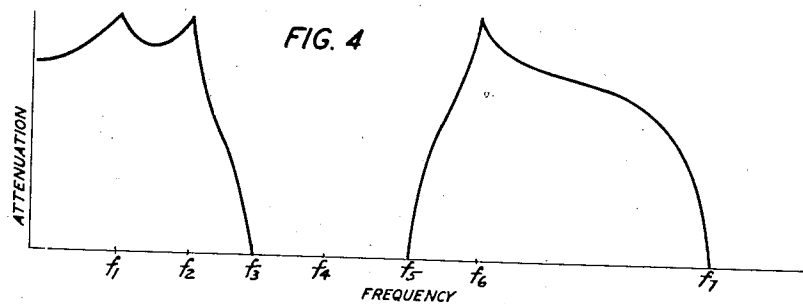
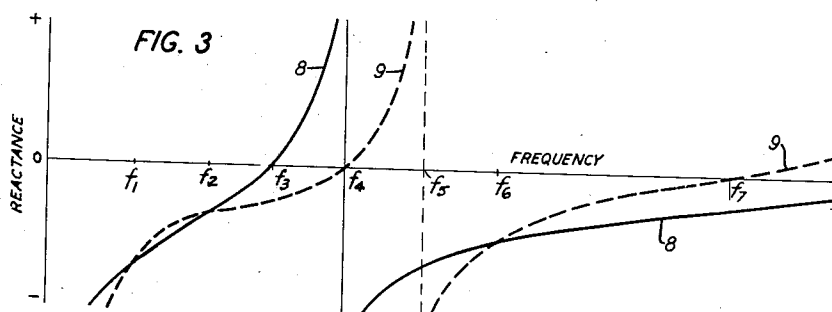
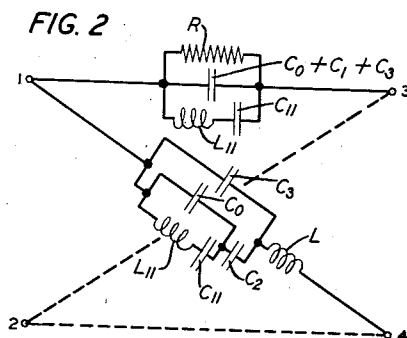
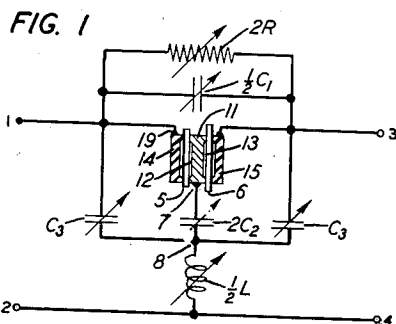
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WAVE FILTER

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WAVE FILTER

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20 Claims. (Cl. 178-44)

This invention relates to wave filters and more particularly to filters using piezoelectric crystals as impedance elements.

The principal object of the invention is to improve the attenuation characteristics of crystal filters, especially those of the unbalanced type intended for use at high frequencies.

My United States Patent 2,169,301, issued August 15, 1939, discloses a band-pass wave filter comprising a number of tandem sections of the differential transformer type in which each of the sections includes a piezoelectric crystal. Each crystal is designed to have its principal resonance at a common frequency, but its dimensions are so proportioned that its secondary resonances occur at frequencies different from those of the other crystals. In this way the formation of undesired subsidiary transmission bands in the attenuation range of the filter is prevented.

The present invention is an improvement on the filter of my prior patent in that the three-winding transformers are not required and the attenuation in the suppression ranges of the filter is improved.

In circuit arrangement the filter takes the form of a modified bridged-T in which the series arms of the T are constituted by two separate crystal elements having the same fundamental frequency but so proportioned that the secondary resonances of the one differ from the secondary resonances of the other. The shunt branch of the T includes an inductor and the bridging impedance branch includes a capacitor. A resistor connected in parallel with the bridging branch may be included to increase the attenuation at the peaks. The circuit is completed by two capacitors having a common terminal connected to a point in the shunt impedance branch and being connected at their other terminals to the ends of the bridging branch.

The crystal elements are preferably of the AT type described in the above-mentioned patent and more fully disclosed in my copending application Serial No. 278,237, filed June 9, 1939. In crystals of this type the principal resonance corresponds to a shear mode of vibration and its frequency is determined mainly by the thickness of the plate. An integral electrode is therefore applied to only one major face of the crystal and the other major face is left unplated so that the frequency may be finally adjusted by grinding down the unplated face.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing in which like reference characters represent like or similar parts and in which:

Fig. 1 is a schematic representation of a wave filter circuit in accordance with the invention;

Fig. 2 is the equivalent lattice network for the filter of Fig. 1;

Fig. 3 gives the reactance characteristics for the series and the diagonal impedance branches of the lattice network of Fig. 2;

Fig. 4 shows symbolically a typical attenuation characteristic for the filters of Figs. 1 and 2.

Fig. 5 is an elevation, partly broken away, of the crystal and holder assembly used in the filter; and,

Fig. 6 is a perspective view of one of the insulating members used in the crystal holder.

The circuit of a wave filter in accordance with the invention is shown schematically in Fig. 1. The circuit is of the modified bridged-T type and has a pair of input terminals 1, 2 and a pair of output terminals 3, 4 by means of which the filter may be connected to suitable load impedances. The series arms of the T are constituted by the two piezoelectric crystal elements 5 and 6 connected in series between the input terminal 1 and the associated output terminal 3. The bridging impedance branch, also connected between terminals 1 and 3, includes a capacitor $\frac{1}{2}C_1$, designated by its capacitance, in parallel with a resistor $2R$, designated by its resistance. The shunt branch of the T includes a second capacitor $2C_2$ and an inductor $\frac{1}{2}L$ connected in series between the junction point 7 between the two crystals and the remaining filter terminals 2 and 4. The filter is completed by the two equal capacitors C_3 and C_3 having a common terminal connected to the junction point 8 between the capacitor and the inductor in the shunt impedance branch and being connected at their other terminals respectively to the filter terminals 1 and 3. The component filter elements $\frac{1}{2}C_1$, $2C_2$, C_3 , $2R$ and $\frac{1}{2}L$ may be made variable, as indicated by the arrows, to facilitate the adjustment of the attenuation characteristic, as explained more fully hereinafter. The network is shown in its unbalanced form in which the path between terminals 2 and 4 may be grounded or otherwise fixed in potential. The filter may, of course, also be built as a balanced structure.

An application of Bartlett's bisection theorem gives the circuit of Fig. 2 as the lattice equivalent of the filter of Fig. 1. In Fig. 2 each of the piezoelectric crystals 5 and 6 has been represented by its equivalent electrical circuit consisting of a capacitance C_0 shunted by a path made up of a second capacitance C_{11} and an inductance L_{11} connected in series. In Fig. 2 only one series impedance branch and one diagonal impedance branch of the lattice are shown in detail. The other corresponding branches are represented by the dotted lines connecting the appropriate terminals. It is seen that the crystal impedance appears in each branch of the lattice.

Fig. 3 represents the reactance-frequency characteristics of the impedance branches of the lattice network of Fig. 2. The solid line curve 8 gives the reactance of the series branch, which has a zero at the frequency f_3 and a pole at f_4 . The diagonal branch has a zero at f_4 , corresponding to the pole of the series branch, a pole at f_5 and a second zero at f_7 , as shown by the dotted line curve 9.

Fig. 4 gives, symbolically, a typical attenuation characteristic for the filter. There will be a transmission band between the frequencies f_3 and f_5 , and a second transmission band extending above f_7 , where the two reactance curves 8 and 9 are of opposite sign. The attenuation regions extend from zero frequency to f_3 and from f_5 to f_7 , with peaks occurring at the frequencies f_1 , f_2 and f_6 where the reactance curves cross. A particularly desirable characteristic is obtained when the peaks occurring at f_2 and f_6 are symmetrically placed with respect to the mid-band frequency f_4 .

If the inductance $\frac{1}{2}L$ is kept sufficiently small the upper transmission band extending above f_7 will be relegated to such a high frequency range, compared to the mid-band frequency f_4 , that it will not interfere unduly with the proper functioning of the filter. The effects of this upper band may easily be overcome by operating the filter between a pair of tuned transformers.

Some design considerations of interest will now be set forth, on the assumption that a comparatively narrow band is desired between the frequencies f_3 and f_5 . In each of the crystals 5 and 6 the principal resonance occurs approximately at the lower cut-off frequency f_3 . The approximate value of the capacitance C_{11} associated with each crystal is found from the formula

$$C_{11} = \frac{f_5 - f_3}{2\pi f_4^2 Z_0} \text{ farads} \quad (1)$$

where Z_0 represents the image impedance in ohms of the filter at the mid-band frequency f_4 . With the resonant frequency and the value of C_{11} determined the dimensions of the two crystals may be computed. As already pointed out above, the crystals are preferably designed in accordance with the teachings of my aforementioned patent and application so that they will have the same fundamental frequencies but different extraneous resonances. The two crystal plates will, therefore, have approximately the same thicknesses but will differ from each other in one or both of their other dimensions. When the dimensions of the crystals have been determined then the value of the electrostatic capacitance C_0 for each plate may be calculated. The approximate value of each capacitance C_3 may now be found from the formula

$$C_3 = \frac{1}{2\pi f_4 Z_0} - C_0 \quad (2)$$

The capacitance $2C_2$ is equal approximately to $2C_3$.

The elements are now assembled to form the circuit shown in Fig. 1. If the capacitance $\frac{1}{2}C_1$ and the inductance $\frac{1}{2}L$ are both made zero, the filter will be found to have two peaks of attenuation occurring at the antiresonant frequencies of the two crystals. If, now, the inductance $\frac{1}{2}L$ is given a small value the effect will be to produce a single peak above the pass-band and two peaks below, as shown in Fig. 4. Introducing the bridging capacitance $\frac{1}{2}C_1$ causes the peaks at f_2 and f_6 to move apart. The preferred character-

istic is obtained when these two peaks are approximately equally spaced from the mid-band frequency f_4 . It may be found, however, that before this condition can be established a further increase in the bridging capacitance causes the two peaks at f_1 and f_2 below the band to merge and then disappear. Such an occurrence indicates that the shunt inductance $\frac{1}{2}L$ was set at too small a value. This inductance is, therefore, increased by a small amount and then the capacitance $\frac{1}{2}C_1$ adjusted from a small value to one which will provide a symmetrical characteristic, or to one which causes the lower peaks to disappear. If the inductance is increased by small increments and at each adjustment the bridging capacitance is varied through a range of values, the proper settings may be found for the desired attenuation characteristic. Of course, many useful characteristics other than the symmetrical one described above may be obtained.

The width of the transmission band between f_3 and f_5 is proportional to the ratio

$$\frac{C_{11}}{C_0 + C_1 + C_3}$$

Since C_3 is usually much larger than either C_0 or C_1 the value of C_3 determines to a large extent the width of the band. By making the capacitors C_3 variable there are provided convenient means of adjusting the band width. The larger the value of C_3 the narrower the band will be.

The capacitor $2C_2$ is made variable to facilitate the adjustment of the lower resonant frequency of the diagonal impedance branch of the equivalent lattice to bring it into coincidence with the antiresonant frequency of the series impedance branch, as shown at f_4 in Fig. 3.

The variable resistor $2R$ is included in the bridging branch to compensate for the effective resistance associated with the inductor $\frac{1}{2}L$. The resistance $2R$ is adjusted to such a value that the resistive components of the series and diagonal impedance branches of the lattice of Fig. 2 will balance as nearly as possible at the peak frequencies f_2 and f_6 . The proper adjustment of this resistance will materially increase the attenuation at these frequencies and thereby improve the discrimination provided by the filter.

The two crystals used in the filter are preferably mounted as shown schematically in Fig. 1 and in more detail in Fig. 5, which is an elevation partly broken away. The showing in Fig. 1 may be considered a sectional view along a diagonal of the crystals in the direction indicated by the arrows in Fig. 5. The surfaces of the crystals 5 and 6 which face each other are left unplated but have a common electrode 11 which may be made from a cold-rolled steel disk bored on each side to a depth of not more than 0.001 inch to provide the air-gaps 12 and 13. The disk is of such a diameter that the rim contacts the crystals only at the corners.

The other major faces of the crystals are partially plated, as shown on crystal 5 at 17 in Fig. 5, with a strip of plating 18 extending to one corner. The crystals are clamped on their outer faces by two insulating members 14 and 15. These may be made of ceramic material and are bored on one side to a depth of 0.01 inch to provide a rim for contacting the corners of the crystal. All of the surfaces that bear on the crystals should be plane and it is therefore recommended that these surfaces be lapped on a flat plate with 600 grain carborundum.

A perspective view of the member 14 with its

rim turned up is shown in Fig. 6. To provide an electrical connection to the plated area 17 of the crystal a small quantity of silver paste is placed on the side of the member 14 and baked to form the silver globule 19 as shown in Fig. 6, and a strip of plating 20 is run from this globule over the edge of the rim. The member 14 is so oriented in the assembly shown in Fig. 5 that the strip of plating 20 comes in contact with the strip 18 on the crystal 5. Connection to the plating on crystal 6 is made through a similar silver globule and a strip of plating on the member 15. The connecting wires are soldered directly to the silver globule. Electrical connection may be made to the common electrode 11 by soldering the wire directly thereto as indicated at 7 in Fig. 1.

The crystal and holder assembly of Fig. 5 may be held together by metal or other suitable clamping means, not shown. When the filter is designed for use at high frequencies the inductor $\frac{1}{2}$ L may take the form of a short length of wire coiled into a helix to reduce its field. The required component elements making up the filter are small enough in size so that they may conveniently be mounted within a metal vacuum tube which may be evacuated, if desired, to improve the operation and the stability of the filter.

What is claimed is:

1. A wave filter comprising a pair of input terminals, a pair of output terminals, two piezoelectric crystals connected in series between one input terminal and an associated output terminal, a bridging impedance branch including a capacitor also connected between said one input terminal and said associated output terminal, a shunt impedance branch including an inductor connected at one end to the junction point between said crystals and at the other end to the remaining filter terminals, and two equal capacitors having a common terminal connected to a point in said shunt impedance branch and being connected at their other terminals respectively to said one input terminal and said associated output terminal.
2. A filter in accordance with claim 1 in which said capacitor in said bridging branch is variable.
3. A wave filter in accordance with claim 1 in which said inductor is variable.
4. A wave filter in accordance with claim 1 in which said two equal capacitors are variable.
5. A wave filter in accordance with claim 1 in which said capacitor in said bridging branch and said inductor are variable.
6. A wave filter in accordance with claim 1 in which said shunt impedance branch includes a fourth capacitor connected in series with said inductor.
7. A wave filter in accordance with claim 1 in which the component impedance elements are so proportioned that the attenuation characteristic of the filter has a transmission band with peaks of attenuation on each side thereof which are symmetrically located with respect to the mid-band frequency.
8. A wave filter in accordance with claim 1 in which said piezoelectric crystals are rectangular plates each being proportioned to have a principal shear vibration resonance at a common frequency and the individual plates having different rectangular shapes whereby their secondary resonances occur at respectively different frequencies for each plate.

9. A wave filter in accordance with claim 1 in which said piezoelectric crystals are plates each having a principal shear vibration resonance at a frequency which defines one limit of a transmission band of the filter and each having an integral electrode on one principal face only, the other principal faces being left unplated to allow final frequency adjustments by grinding down the unplated faces.

10. A wave filter comprising a pair of input terminals, a pair of output terminals, two piezoelectric crystals connected in series between one input terminal and an associated output terminal, a bridging impedance branch including a capacitor also connected between said one input terminal and said associated output terminal, a shunt impedance branch including a series-connected second capacitor and an inductor connected at one end to the junction point between said crystals and at the other end to the remaining filter terminals, and two equal capacitors having a common terminal connected to the junction point between said second capacitor and inductor in said shunt branch and being connected at their other terminals respectively to said one input terminal and said associated output terminal.

11. A wave filter in accordance with claim 10 in which said capacitor in said bridging impedance branch is variable.

12. A wave filter in accordance with claim 10 in which said inductor is variable.

13. A wave filter in accordance with claim 10 in which said capacitor in said bridging impedance branch and said inductor are variable.

14. A wave filter in accordance with claim 10 in which said two equal capacitors are made variable to provide an adjustment of the width of a transmission band of the filter.

15. A wave filter in accordance with claim 10 in which said second capacitor is variable.

16. A wave filter in accordance with claim 10 in which all of said capacitors and said inductor are variable.

17. A wave filter in accordance with claim 10 in which the component impedance elements are so proportioned that the attenuation characteristic of the filter has a transmission band with peaks of attenuation on each side thereof which are symmetrically located with respect to the mid-band frequency.

18. A wave filter in accordance with claim 10 in which said piezoelectric crystals are rectangular plates each being proportioned to have a principal shear vibration resonance at a common frequency and the individual plates have different rectangular shapes whereby their secondary resonances occur at respectively different frequencies for each plate.

19. A wave filter in accordance with claim 10 in which said crystals are plates each having a principal shear vibration resonance at a frequency which defines one limit of a transmission band of the filter and each having an integral electrode on one principal face only, the other principal faces being left unplated in order that final frequency adjustments may be made by grinding down the unplated faces.

20. A wave filter in accordance with claim 10 in which said second capacitor is connected to the junction point between said crystals.

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