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W. P. MASON

2,081,405

WAVE FILTER

Filed July 27, 1935

FIG. 1

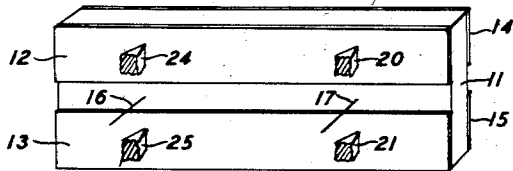


FIG. 2

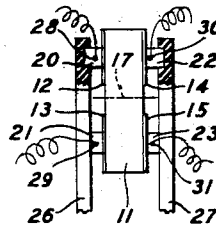


FIG. 3

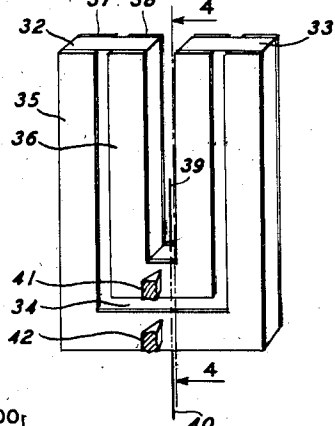


FIG. 4

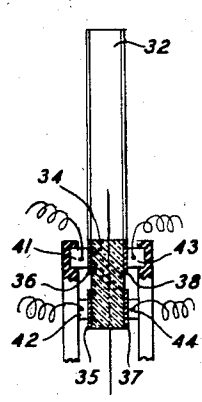


FIG. 5

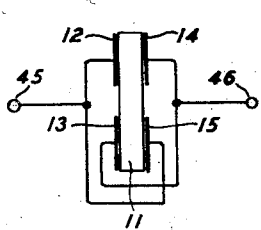


FIG. 8

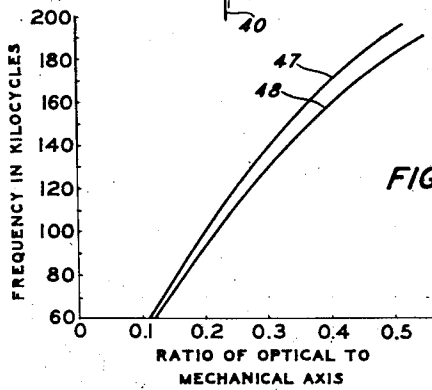
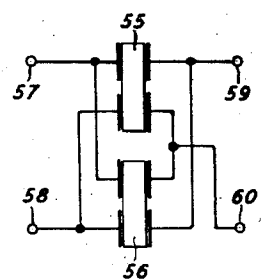
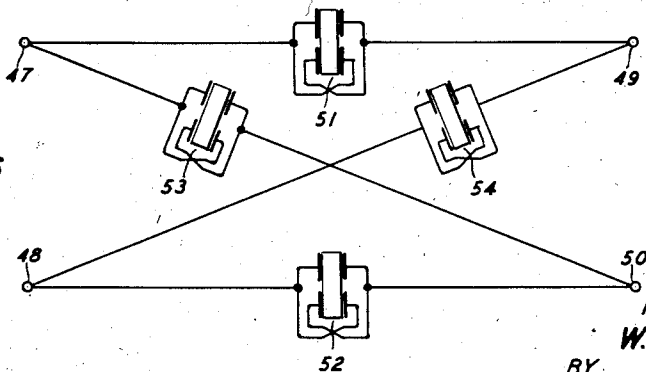


FIG. 7

FIG. 6



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2,081,405

WAVE FILTER

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Application July 27, 1935, Serial No. 33,511

13 Claims. (Cl. 178—44)

This invention relates to wave filters of the type employing piezoelectric crystals as reactance elements.

An object of the invention is to extend the frequency range of such wave filters.

Another object is to reduce the cost of filters of this type.

A further object is to reduce the number of piezoelectric elements required in the construction of such crystal filters.

Still further objects of the invention are to support a piezoelectric element for unrestricted vibration and to simplify the making of electrical contact with a plurality of electrodes associated with each major face of the element.

A feature of the invention is a wave filter employing as a reactance element a piezoelectric crystal adapted to vibrate in the flexural mode.

Another feature is the use in such a filter of a piezoelectric crystal cut in the form of a tuning fork.

Another feature is a piezoelectric crystal adapted to vibrate in flexure and serving to take the place of two crystal elements ordinarily required.

Still another feature of the invention is a piezoelectric crystal having a plurality of electrodes associated with each major face supported at a nodal region by a plurality of pair of clamps which are utilized to make electrical contact with the electrodes.

Heretofore piezoelectric crystals have been used as reactance elements in the construction of wave filters but difficulty has been encountered in obtaining crystals which will vibrate at a sufficiently low frequency that the transmission bands may be located at comparatively low frequencies. In accordance with the present invention piezoelectric crystals adapted to vibrate in the flexural mode are employed in the construction of such filters and the frequency range is thereby considerably extended. Crystal elements cut either in the form of a bar or in the form of a tuning fork may be used for this purpose, and the elements are preferably supported at or near their nodal points. As an extension of the invention a single crystal element is made to take the place of two elements ordinarily required in the construction of such a filter. In one form of the invention the supports which hold the crystal element are utilized for the purpose of making electrical connections to the electrodes of the crystal.

The nature of the invention will be more fully understood from the following description, of which reference to the accompanying drawing, of which:

Fig. 1 shows a piezoelectric crystal element cut in the form of a bar and adapted to vibrate in the flexural mode;

Fig. 2 is an end view of the crystal element of

Fig. 1 showing how it may be supported by clamps which are used to make electrical contact with the individual electrodes;

Fig. 3 shows a piezoelectric crystal element cut in the form of a tuning fork, with its associated electrodes and clamping members;

Fig. 4 is a sectional view of the crystal element of Fig. 3 taken along the line 4, 4;

Fig. 5 shows how the electrodes of the elements shown in Figs. 1 and 3 may be connected so that the crystal will vibrate in the flexural mode;

Fig. 6 shows how four of the elements of Figs. 1 or 3 may be arranged in the form of a lattice-type wave filter;

Fig. 7 represents a graph of data useful in the design of such filters; and

Fig. 8 is a schematic representation of a lattice-type wave filter in which two piezoelectric elements take the place of four such elements.

One form of the piezoelectric crystal element used in the invention is shown in Fig. 1 which is a parallelepiped 11 having a pair of electrodes 12 and 13 associated with one major face and a second pair of electrodes 14 and 15 associated with the opposite face. When such a bar is set into vibration in the flexural mode as explained hereinafter it will vibrate about two nodal lines represented by 16 and 17, located approximately 0.224 of the length of the bar from its ends. In order that the least damping of the vibrations will be introduced by the holder, it is preferable to support the bar at or near these points. This may be done, for example, by means of the clamps 20 and 21 which engage the electrodes 12 and 13, respectively, on one side of the crystal, and an oppositely disposed pair of clamps 22 and 23 which engage the electrodes 14 and 15 on the other side of the crystal near the line 17. A third pair of clamps 24 and 25, and a fourth oppositely disposed pair of clamps engage the crystal electrodes in the region of the nodal line 16.

As shown in Fig. 2, the clamps described above may, for example, be metal inserts inlaid into the supporting members 26 and 27 which are made of insulating material. Electrical connectors may be soldered or otherwise secured to the clamps as indicated at the points 28, 29, 30 and 31, for the purpose of interconnecting the various electrodes or for connecting the crystal element into an external circuit.

Fig. 3 shows a second form of the crystal element, cut in the form of a tuning fork having two prongs 32 and 33, and a butt part 34. On one side of the tuning fork is an electrode 35 extending along the outer edges of the prongs and along the lower portion of the butt. A second electrode 36 extends along the inner edges of the prongs and across the upper portion of the butt. A similar pair of electrodes 37 and 38 are associated with the opposite side of the tuning

fork. Such a tuning fork will have a nodal region which follows a perpendicular line, such as the one shown at 39, 40 bisecting the butt part. The fork is preferably supported along this nodal line, which may be done, for example, by means of a pair of clamps 41 and 42 on one side, and an oppositely disposed pair of clamps 43 and 44 on the other side. As shown in Fig. 4 these clamps may be metal inserts set into a pair of supporting members made of insulating material, and electrical connections to the electrodes may be made by soldering connectors to these clamps, as explained above in connection with Fig. 2.

Fig. 5 is a schematic diagram showing how the electrodes of the crystal element of Fig. 1 may be connected together in order to set up a flexural vibration in the bar. The electrode 12 and the diagonally opposite electrode 15 are connected to one terminal 45 and the two remaining electrodes are connected to the other terminal 46. These connections may be made by means of the connectors and conducting clamps, as explained above. When an alternating electromotive force is impressed upon terminals 45 and 46 the element 11 will be set into vibration in the flexural mode. Piezoelectric elements of this type adapted to vibrate flexurally are disclosed in greater detail in U. S. Patent 1,823,329 issued September 15, 1931 to W. A. Marrison to which reference is hereby made.

The frequency of vibration in the flexural mode for a zero degree, X-cut crystal having a mechanical axis one centimeter in length is shown in curve 47 of Fig. 7, which gives the frequency in kilocycles per second plotted against the ratio of optical to mechanical axis. By a zero degree, X-cut crystal is meant one cut from a mother crystal having a principal face which is perpendicular to a face of the mother crystal and having a width dimension which makes a zero angle with the optical axis. Curve 48 of the figure presents the same data for a -18 degree, X-cut crystal, that is, one having a width dimension which makes an angle of -18 degrees with the optical axis. The thickness of the electrical axis plays no part in the determination of the frequency. For a crystal of any other length the frequency can be determined from the principal of similitude which states that for a crystal of a given shape the resonant frequency of any mode is inversely proportional to the magnitude of any dimension. For a zero degree crystal five centimeters long, for example, with the ratio of optical to mechanical axis of 0.2 it will be seen from curve 47 that the frequency is about 20 kilocycles. This is only about one-third of the frequency for the same crystal when vibrating in the longitudinal mode. For a -18 degree cut crystal the frequency will be somewhat less, as shown by curve 48, due to the fact that Young's modulus is less for this cut.

A well known representation of the equivalent electrical circuit of a piezoelectric crystal is a capacitance C_1 shunted by an arm comprising a second capacitance C_2 in series with an inductance. The value of the ratio

$$\frac{C_1}{C_2}$$

for a crystal in which the electrodes on one side cover from two-thirds to four-fifths of the surface is about 180 for the -18 degree cut crystal and about 150 for the zero degree cut crystal. The shunt capacitance C_1 of the equivalent net-

work will be the electrostatic capacitance between the two sets of plates. From this data the values of the reactances in the equivalent circuit may be determined for a bar vibrating in flexure.

Fig. 6 shows how two pairs of crystal elements adapted to vibrate in flexure may be arranged to form a lattice-type wave filter. The network has a pair of input terminals 47, 48 and a pair of output terminals 49, 50, with one pair of the elements 51, 52 connected in the series branches and the other pair 53, 54 connected diagonally between the two sets of terminals. The electrodes of the crystal are connected as indicated in Fig. 5.

With crystal elements cut in the form of a bar and vibrating in the flexural mode, frequencies as low as 16 or 17 kilocycles may be obtained. In accordance with the invention still lower frequencies may be obtained by the use of a piezoelectric crystal element cut in the form of a tuning fork as shown in Fig. 3. In order to cause the tuning fork to vibrate the electrodes are connected as shown in Fig. 5, in this case the electrodes 12, 13, 14 and 15 representing the electrodes 35, 36, 37 and 38 of the tuning fork crystal. The two outside electrodes 35 and 37 for a certain voltage polarity will cause the outside of the two prongs to expand, while at the same time the voltage applied to the two inside electrodes 36 and 38 will cause the inside parts of the two prongs to contract, thus forcing the prongs inward and making them vibrate in the form of a tuning fork.

The frequency f of a tuning fork in cycles per second is given by the formula

$$f = \frac{KW}{l^2} \quad (1)$$

where K is a constant, W is the width of one prong of the tuning fork and l is the length of the prong. This formula assumes that the length of the butt part is comparatively large, and if this is made small a correction should be made. From measurements on a zero degree, X-cut crystal the constant K has been evaluated as 65,000. Applying the above formula to a concrete example, a crystal in the form of a fork 6 centimeters in length, three-quarters of which is included in the prong, having an individual prong width of 0.4 centimeter will vibrate at the frequency

$$f = \frac{65000 \times 0.4}{(4.5)^2} = 1284 \text{ cycles} \quad (2)$$

With a crystal 6 centimeters in length and of reasonable width it is possible, therefore, to get down to a frequency of the order of 1 kilocycle. This type of element, with a reasonable size, can also be made to work as high as 16 kilocycles. Thus, by the use of piezoelectric elements in the form of a bar supplemented by those in the form of a tuning fork, it is possible to cover the frequency range extending from 1 to 50 kilocycles without using a crystal larger than is required for vibrations in the longitudinal mode at 50 kilocycles.

The ratio C_1 to C_2 for the zero degree cut crystal in the form of a tuning fork is about 300. By means of the above data the reactances in the equivalent circuit for the tuning fork crystal may be evaluated. Two pairs of such tuning fork crystals may be arranged in the form of a lattice-type filter, the schematic diagram being the same as that shown in Fig. 6.

Fig. 3 shows how in accordance with an extension of the invention two piezoelectric crystal elements are made to take the place of four such elements in the construction of a wave filter. As shown in the figure, two crystal elements 55 and 56, either of the type shown in Fig. 1 or the type shown in Fig. 3, are arranged between a pair of input terminals 57, 58 and a pair of output terminals 59, 60 to form a lattice-type network. One set of oppositely disposed electrodes associated with crystal 55 are connected between input terminal 57 and the corresponding output terminal 59, while the other set of electrodes is connected between the other two terminals 58 and 60. This single element thus effectively furnishes the two impedance branches connected in series with the line. The diagonal impedance branches are furnished by the other crystal element 56, one set of electrodes being connected between terminals 58 and 59 while the other set of electrodes is connected between terminals 57 and 60. When two elements are made to take the place of four as shown in Fig. 3 the transmission characteristics of the resulting filter will be the same as when individual elements are used in each impedance branch, but the characteristic impedance of the network will be doubled.

What is claimed is:

1. A wave filter comprising as a reactance element a piezoelectric crystal in the form of a tuning fork having two prongs connected by a butt part, each of two opposite faces of said crystal having an electrode extending along the outer edges of said prongs and along said butt, and a second electrode of opposite polarity extending along the inner edges of said prongs, and said electrodes being connected into the filter circuit in such a way that the applied electrical stresses cause the outside parts of said prongs alternately to expand and contract and the inner parts of said prongs alternately to contract and expand.

2. A wave filter having a plurality of pairs of impedance branches connected between a pair of input terminals and a pair of output terminals to form a lattice network, said filter comprising a piezoelectric crystal adapted to vibrate in the flexural mode, and said crystal taking the place of a plurality of separate crystal elements.

3. In a wave filter comprising a plurality of impedance branches equal in pairs connected between two input terminals and two output terminals, a piezoelectric crystal adapted to vibrate in the flexural mode, said crystal providing reactances which are effective in a plurality of said branches and taking the place of two separate crystal elements.

4. In a wave filter of the lattice type comprising a plurality of impedance branches equal in pairs, two piezoelectric crystals adapted to vibrate in the flexural mode, each of said crystals providing reactances which are effective in a plurality of said branches, and said two crystals serving to take the place of four separate crystal elements.

5. In 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, a piezoelectric crystal in the form of a tuning fork, said crystal providing reactances which are effective in a plurality of said branch impedances and taking the place of a plurality of separate crystal elements.

6. In 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, a piezoelectric crystal adapted to vibrate in the flexural mode, said crystal providing reactances which are effective in a plurality of said impedances and taking the place of a plurality of separate crystal elements.

7. In a four-terminal transmission network comprising two pairs of equal impedances arranged to form a symmetrical lattice, a piezoelectric crystal in the form of a tuning fork, said crystal providing reactances which are effective in each of the branches forming one of said pairs.

8. In a four-terminal transmission network comprising two pairs of equal impedance branches arranged to form a symmetrical lattice, a piezoelectric crystal adapted to vibrate in the flexural mode, said crystal providing reactances which are effective in each of the branches forming one of said pairs.

9. A wave filter comprising two pairs of equal impedance branches connected between two input terminals and two output terminals to form a symmetrical lattice network, said filter comprising as a reactance element a piezoelectric crystal having a pair of electrodes placed adjacent corresponding portions of opposite sides of said crystal parallel to its longest axis and unsymmetrically with respect to said axis, a second pair of electrodes associated with said opposite sides and interconnections between said electrodes, whereby said crystal tends to vibrate in the flexural mode to provide reactances which are effective in each of the branches forming one of said pairs.

10. A piezoelectric crystal element in the form of a tuning fork, two electrodes associated with one side of said element, two other electrodes associated with the opposite side of said element, and two pairs of conducting clamps for supporting said element along a nodal line and for making electrical contact with each of said electrodes.

11. In a wave filter of the lattice type comprising a pair of equal series impedance branches and a pair of equal diagonal impedance branches, two piezoelectric crystals adapted to vibrate in the flexural mode, one of said crystals providing reactances which are effective in each of said series branches, and the other of said crystals providing reactances which are effective in each of said diagonal branches.

12. In a wave filter of the lattice type comprising a pair of equal series impedance branches and a pair of equal diagonal impedance branches, two piezoelectric crystal elements in the form of tuning forks, one of said elements providing reactances which are effective in each of said series branches, and the other of said elements providing reactances which are effective in each of said diagonal branches.

13. A wave filter comprising as a reactance a piezoelectric crystal element in the form of a tuning fork, said element having two electrodes associated with one face, two other electrodes associated with the opposite face, two pairs of conducting clamps for supporting said element along a nodal line and for making electrical contact with each of said electrodes, and connectors for interconnecting said electrodes.