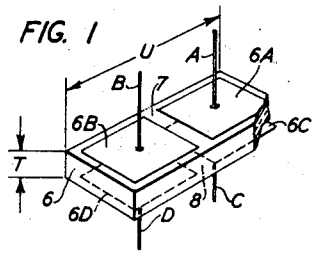
Oct. 28, 1947. H. J. McSKIMIN 2,429,639

WAVE FILTER

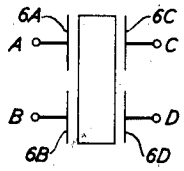
Filed June 14, 1945

FIG. 1




EVEN ORDER HARMONIC CRYSTAL

FIG. 2



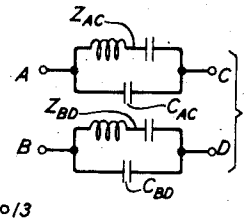




FIG. 3

FIG. 4

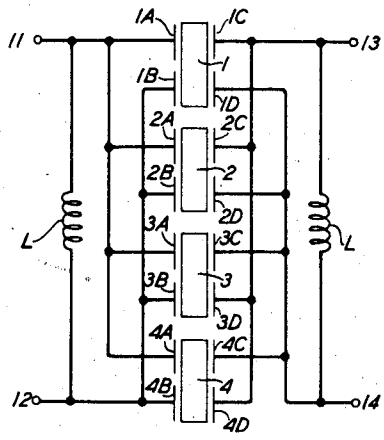
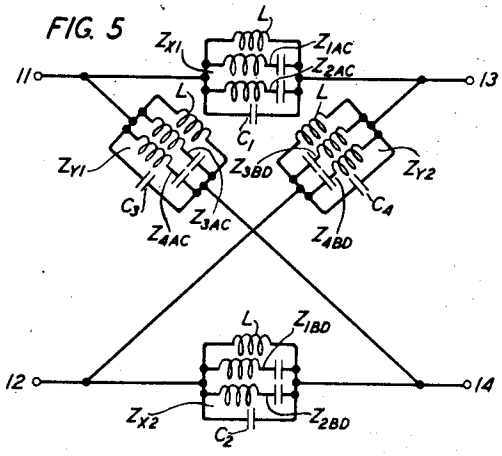



FIG. 5




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## WAVE FILTER

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Application June 14, 1945, Serial No. 599,340

23 Claims. (Cl. 178—44)

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

An object of the invention is to simplify the design of wave filters which use piezoelectric crystals operating at an even order harmonic frequency. Another object is to increase the maximum width of transmission band obtainable in such a filter.

When used in a wave filter of the lattice-type, a piezoelectric crystal element operating at an even order harmonic frequency has the advantage that it can be made to provide two equal crystal impedances without requiring more electrodes than for a single impedance. These impedances may be made to appear in either the series branches or the diagonal branches of the lattice. However, with the type of connections heretofore employed the crystal also introduces capacitances into the other pair of branches. These capacitances add complexity to the design of the filter and limit the width of band obtainable.

In accordance with the present invention the electrodes of an even order harmonic crystal are so connected into the filter circuit that each crystal furnishes only two impedances, which are effective in either the series or the diagonal branches of the lattice network. The crystals may, for example, operate in the extensional, the shear or some other mode, depending upon the crystal cut employed. For the second harmonic the crystal is provided with two input electrodes on one side and two output electrodes on the opposite side and the electrodes on the same side are separated by a transverse dividing line. The filter ordinarily includes two or more such crystals. The input electrodes of the crystals are connected to the input terminals of the filter and the output electrodes to the output terminals. In order to make the crystal impedances appear in the series branches of the lattice, the input electrodes are connected respectively to the input terminals of the filter and the corresponding output electrodes are connected respectively to the corresponding output terminals. For the crystal impedances to appear in the diagonal branches of the lattice, the input electrodes are connected in the same way but the connections from the output electrodes to the output terminals are reversed. When the crystals are connected into the filter circuit in this manner no capacitances are introduced into the other branches of the lattice. The design of the filter is, therefore, simplified. Furthermore, by avoiding the introduction of these undesired capacitances, the maximum obtainable width of transmission band is increased. Additional impedance elements may be added to the filter circuit if required. For example, equal inductances may be connected at the ends of the lattice.

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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 refer to similar or corresponding parts, and in which:

Fig. 1 is a perspective view, partly cut away, of a piezoelectric crystal element provided with two pairs of electrodes for operation at a second harmonic frequency;

Fig. 2 is a schematic side view of the crystal of Fig. 1;

Fig. 3 shows an equivalent electrical circuit for the crystal of Figs. 1 and 2;

Fig. 4 is a schematic circuit of a lattice-type wave filter in accordance with the invention employing four crystals of the type shown in Figs. 1 and 2; and

Fig. 5 shows an equivalent electrical circuit for the filter of Fig. 4.

Fig. 1 shows a piezoelectric crystal element with its associated electrodes suitable for use in the filter of the invention. The element comprises a rectangular parallelepiped 6 of piezoelectric material suitably oriented with respect to the X, Y and Z axes of the mother crystal for operation at an even harmonic frequency of the desired mode of motion when a suitable electric field is applied in the direction of the thickness dimension T. Piezoelectric crystals adaptable for operation at harmonic frequencies of various modes are disclosed, for example, in the following United States Patents: 2,157,701, to S. C. Hight, issued May 9, 1939; 2,173,589, to W. P. Mason and R. A. Sykes, issued September 19, 1939; 2,185,599, to W. P. Mason, issued January 2, 1940; 2,277,709, to H. J. McSkimin and R. A. Sykes, issued March 31, 1942; and 2,284,753, to W. P. Mason, issued June 2, 1942. For utilization of the second harmonic of the extensional mode in the direction of the length dimension U or the double shear major face mode, one side 7 of the crystal 6 is provided with two input electrodes 6A and 6B and the opposite side 8 is provided with two output electrodes 6C and 6D, positioned respectively opposite to the electrodes 6A and 6B. The electrodes 6A and 6B are separated by a transverse dividing line and the electrodes 6C and 6D are similarly separated. At the center of each half of the crystal 6 there will be a node of motion and the

crystal is preferably supported at these nodal points. Thus, the wires A, B, C and D are soldered respectively to the electrodes 6A, 6B, 6C and 6D at the nodal points. These wires may also serve as terminals for making electrical connections to the electrodes. Fig. 2 is a schematic side view of the crystal element of Fig. 1.

Fig. 3 shows schematically an equivalent electrical circuit for the crystal element of Figs. 1 and 2 when all of the electrodes are equal. Between the electrode terminals A and C there appears a resonant arm $Z_{AC}$, representing the crystal impedance, in parallel with a capacitance $C_{AC}$, representing the electrostatic capacitance effective between the electrodes 6A and 6C. Between the terminals B and D are the parallel impedance arms $Z_{BD}$ and $C_{BD}$, equal respectively to the arms $Z_{AC}$ and $C_{AC}$.

It will be noted that in Fig. 3 there are no diagonal impedances effective between the terminals A and D or B and C. This feature is of special importance when a number of crystals such as 6 are used in a lattice-type wave filter. Each crystal element will furnish two equal impedances which may be placed in either the series branches or the diagonal branches of the lattice, but there will be no undesired impedances introduced into the other branches. This simplifies the design and, due to the elimination of undesired shunting capacitances in the branches, permits the provision of a wider transmission band.

Fig. 4 shows four crystals 1, 2, 3 and 4, similar to the element 6, connected between a pair of input terminals 11 and 12 and a pair of output terminals 13 and 14 to form a lattice-type wave filter in accordance with the invention. The input electrodes 1A, 2A, 3A and 4A of the crystals 1, 2, 3 and 4 are connected to the filter input terminal 11 and the input electrodes 1B, 2B, 3B and 4B on the same sides are connected to the input terminal 12. The output electrodes 1C and 2C opposite respectively to the electrodes 1A and 2A, and the output electrodes 3D and 4D diagonally opposite respectively to the electrodes 3A and 4A, are connected to the filter output terminal 13, corresponding to the input terminal 11. The remaining output electrodes 1D, 2D, 3C and 4C are connected to the output terminal 14 corresponding to the input terminal 12. A shunt inductance L is connected between the input terminals 11 and 12 and a second shunt inductance L of the same value is connected between the output terminals 13 and 14, if required to widen the transmission band of the filter or for some other reason.

Fig. 5 shows schematically the equivalent lattice network for the filter of Fig. 4 comprising a pair of equal series impedance branches $Z_{X1}$ and $Z_{X2}$ and a pair of equal diagonal impedance branches $Z_{Y1}$ and $Z_{Y2}$ connected between input terminals 11 and 12 and output terminals 13 and 14. The crystals 1 and 2 furnish the resonant arms and the capacitances in the series branches and the crystals 3 and 4 provide those in the diagonal branches. Each of the branches $Z_{X1}$, $Z_{X2}$, $Z_{Y1}$ and $Z_{Y2}$ comprises four parallel arms. In each branch one of the arms is an inductance L, which is the same as one of the end shunt inductances L shown in Fig. 4. In addition to L, $Z_{X1}$ comprises the arms $Z_{1AC}$, $Z_{2AC}$ and $C_1$, $Z_{X2}$ includes $Z_{1BD}$, $Z_{2BD}$ and $C_2$, $Z_{Y1}$ includes $Z_{3AC}$, $Z_{4AC}$ and $C_3$, and $Z_{Y2}$ comprises $Z_{3BD}$, $Z_{4BD}$ and $C_4$. The capacitance $C_1$ is the sum of the electrostatic capacitance between the electrodes 1A and 1C



and that between the electrodes 2A and 2C, $C_2$ is the sum of that between 1B and 1D and between 2B and 2D, C3 is the sum of that between 3A and 3C and between 4A and 4C, and C4 is the sum of that between 3B and 3D and between 4B and 4D. The scheme of notation used for the crystal impedances will be apparent from a consideration of the equivalent circuit shown in Fig. 3. Thus, $Z_{1AC}$ and $Z_{1BD}$ represent the two equal crystal impedances associated with the crystal 1, $Z_{2AC}$ and $Z_{2BD}$ are furnished by the crystal 2, $Z_{3AC}$ and $Z_{3BD}$ by the crystal 3, and $Z_{4AC}$ and $Z_{4BD}$ by the crystal 4.

The filter circuit of Fig. 5 will be recognized as the one designated filter number 5 in Fig. 8.21 of W. P. Mason's "Electromechanical Transducers and Wave Filters," published by D. Van Nostrand Company, Inc., to which reference is made for details of the design procedure to be followed. It is to be understood that additional series branch crystals, such as 1 and 2, or additional lattice branch crystals, such as 3 and 4, may be added if more attenuation peaks and greater discrimination are required. On the other hand, if the attenuation requirements permit, one of the series branch crystals 1 or 2 and one of the diagonal branch crystals 3 or 4 may be omitted.

What is claimed is:

1. A wave filter comprising a piezoelectric crystal connected between a pair of input terminals and a pair of output terminals, said crystal being adapted to vibrate at an even order harmonic frequency and having on one side two electrodes separated by a transverse dividing line and on the opposite side two electrodes separated by a transverse dividing line, the electrodes on the one side being connected respectively to the input terminals and the electrodes on the opposite side being connected respectively to the output terminals.

2. A filter in accordance with claim 1 in which said crystal is adapted to vibrate in the extensional mode in the direction of its length.

3. A filter in accordance with claim 1 in which said crystal is adapted to vibrate in the extensional mode in the direction of its length at the second harmonic frequency.

4. A filter in accordance with claim 1 in which said crystal is adapted to vibrate in a major face shear mode.

5. A filter in accordance with claim 1 in which said crystal is adapted to vibrate in the double shear major face mode.

6. A wave filter comprising a piezoelectric crystal connected between a pair of input terminals and a pair of output terminals, said crystal being adapted to vibrate in the extensional mode in the direction of its length at an even harmonic frequency and having two electrodes on one side and two electrodes on the opposite side, the electrodes on the one side being connected respectively to the input terminals and the electrodes on the opposite side being connected respectively to the output terminals.

7. A wave filter comprising a piezoelectric crystal connected between a pair of input load terminals and a pair of output load terminals, said crystal being adapted to vibrate in an even order major face shear mode and having two electrodes on one side and two electrodes on the opposite side, the electrodes on the one side being connected respectively to the input terminals and the electrodes on the opposite side being connected respectively to the output terminals.

8. A wave filter comprising two piezoelectric crystals connected between a pair of input terminals and a pair of output terminals to form a lattice network, each of said crystals being adapted to vibrate at an even order harmonic frequency and having on one side two input electrodes separated by a transverse dividing line and on the opposite side two output electrodes separated by a transverse dividing line, the input electrodes being connected to the input terminals and the output electrodes being connected to the output terminals.

9. A filter in accordance with claim 8 in which each crystal is adapted to vibrate in the extensional mode in the direction of its length.

10. A filter in accordance with claim 8 in which each crystal is adapted to vibrate in the extensional mode in the direction of its length at the second harmonic frequency.

11. A filter in accordance with claim 8 in which each crystal is adapted to vibrate in a major face shear mode.

12. A filter in accordance with claim 8 in which each crystal is adapted to vibrate in the double shear major face mode.

13. A wave filter comprising two piezoelectric crystals adapted to vibrate at an even order harmonic frequency connected between a pair of input terminals and a pair of output terminals, each of said crystals having on one side two input electrodes separated by a transverse dividing line and on the opposite side two output electrodes separated by a transverse dividing line and oppositely disposed with respect to the input electrodes, one crystal having its input electrodes connected to the input terminals and its corresponding output electrodes connected to the corresponding output terminals and the other crystal having its input electrodes connected to the input terminals and its corresponding output electrodes connected to diagonally opposite output terminals.

14. A filter in accordance with claim 13 in which each crystal is adapted to vibrate in the extensional mode in the direction of its length.

15. A filter in accordance with claim 13 in which each crystal is adapted to vibrate in a major face shear mode.

16. A wave filter comprising two piezoelectric crystals adapted to vibrate at an even order harmonic frequency connected between a pair of input terminals and a pair of output terminals, each of said crystals having on one side two input electrodes separated by a transverse dividing line and on the opposite side two output electrodes separated by a transverse dividing line and oppositely disposed with respect to the input electrodes, one input terminal being connected to one input electrode on each crystal, the other input terminal being connected to the other input electrodes, one output terminal being connected to an output electrode of one crystal opposite said one input electrode and to an output electrode of the other crystal opposite said other input electrode, and the other output terminal being connected to the other output electrodes.



17. A filter in accordance with claim 16 in which each crystal is adapted to vibrate in the extensional mode in the direction of its length.

18. A filter in accordance with claim 16 in which each crystal is adapted to vibrate in a major face shear mode.

19. A wave filter comprising two pairs of impedance branches connected between a pair of input terminals and a pair of output terminals to form a lattice network, each pair of branches comprising a piezoelectric crystal adapted to vibrate at an even order harmonic frequency and having on one side two input electrodes separated by a transverse dividing line and on the opposite side two output electrodes separated by a transverse dividing line and oppositely disposed with respect to the input electrodes, one crystal having its input electrodes connected respectively to the input terminals and its corresponding output electrodes connected respectively to the corresponding output terminals and the other crystal having its input electrodes connected respectively to the input terminals and its corresponding output electrodes connected respectively to diagonally opposite output terminals.

20. A filter in accordance with claim 19 in which each crystal is adapted to vibrate in the extensional mode in the direction of its length.

21. A filter in accordance with claim 19 in which each crystal is adapted to vibrate in a major face shear mode.

22. A filter in accordance with claim 19 which includes equal inductances connected at the ends of the lattice network.

23. A filter in accordance with claim 19 which includes equal inductances connected in shunt at the ends of the lattice network.

HERBERT J. McSKIMIN.


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