

Jan. 27, 1942.

H. J. McSKIMIN

2,270,906

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Nov. 16, 1940

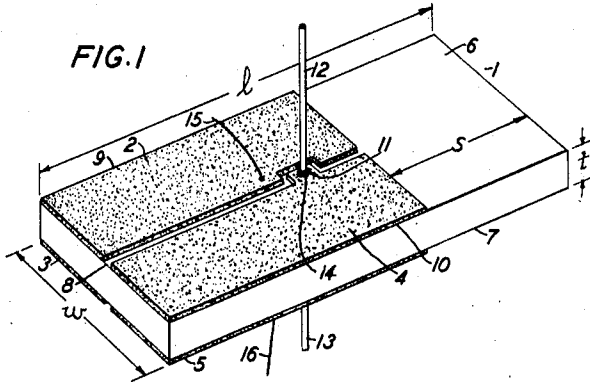


FIG. 1

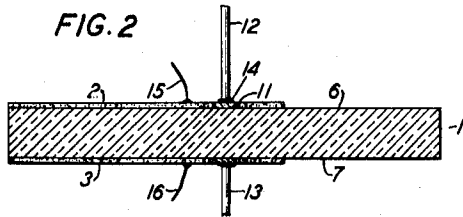


FIG. 2

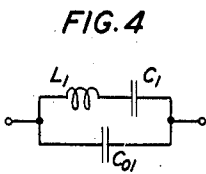


FIG. 4

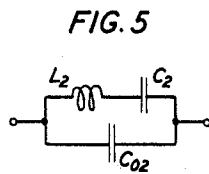


FIG. 5

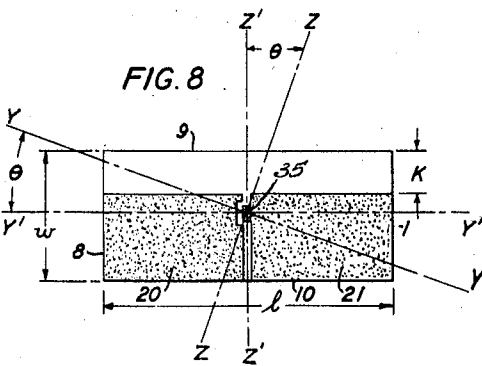


FIG. 8

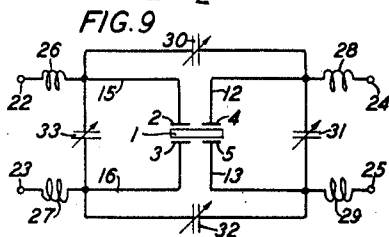


FIG. 9

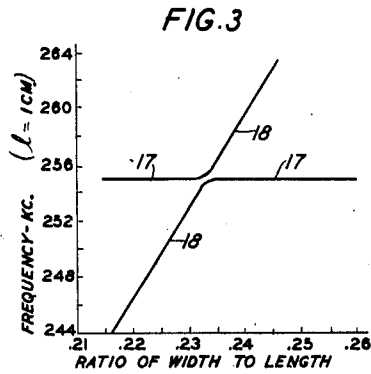


FIG. 3

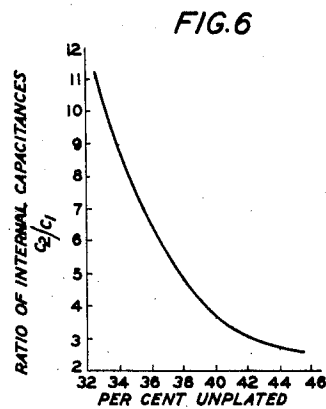


FIG. 6

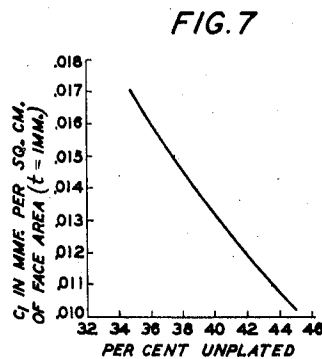


FIG. 7

INVENTOR
H. J. McSKIMIN
BY
Ralph T. Holcomb
ATTORNEY

UNITED STATES PATENT OFFICE

2,270,906

PIEZOELECTRIC CRYSTAL APPARATUS

Herbert J. McSkimin, Lynhurst, N. J., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application November 16, 1940, Serial No. 365,910

20 Claims. (Cl. 171-327)

This invention relates to piezoelectric crystal apparatus and more particularly to means for simultaneously driving a piezoelectric crystal in two substantially uncoupled and independently controlled modes of motion.

Objects of the invention are to simplify the electrode arrangement, facilitate the adjustment and reduce the cost of a piezoelectric crystal adapted for simultaneous operation in two uncoupled and independently controlled modes of motion.

In general, a piezoelectric crystal plate is capable of vibrating in a number of different modes of motion. If the resonant frequencies of two of these modes can be controlled independently a single crystal will provide, in effect, two separate impedances which may be used as component elements in wave filters or other transmission networks.

In accordance with the present invention a piezoelectric crystal plate is provided with a simple electrode arrangement which is adapted to excite the crystal simultaneously in two substantially uncoupled modes of motion. The crystal plate is preferably made of quartz. One of the modes is preferably the fundamental longitudinal or extensional mode and the other may be the second flexural mode in the major plane parallel to a major face. For certain specified orientations of the crystal plate the mechanical coupling between the two modes may be reduced to a minimum. The resonant frequencies of the two modes are dependent upon different sets of dimensions of the crystal plate and these frequencies may, therefore, be independently controlled by properly choosing these dimensions. Associated with one major face of the crystal are two equal or nearly equal electrodes, adjacent to one edge of the face and adjacent to each other, which cover only a portion of the area of the face, leaving the remainder uncovered. The relative level of the two impedances is dependent upon the ratio of the area covered by the electrodes to the entire area of the crystal face. By properly selecting this ratio the desired relative impedance level may be obtained. Two other electrodes, similar to the ones just described, are associated with the opposite face of the crystal. In some cases the electrodes on one of the faces may be replaced by a single electrode. By way of example, the crystal is shown used in a wave filter circuit.

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 perspective view of a piezoelectric crystal device in accordance with the invention;

Fig. 2 shows a vertical longitudinal section of the crystal device of Fig. 1;

Fig. 3 presents curves giving the frequencies of resonance for the two desired modes of motion of the crystal plotted against the ratio of width to length;

Figs. 4 and 5 are equivalent electrical circuits for the two desired modes of the crystal;

Figs. 6 and 7 give, respectively, the ratio of internal capacitances for the two desired modes and the internal capacitance for the desired extensional mode plotted against the per cent of the area of the crystal face left unplated;

Fig. 8 shows an alternative electrode arrangement that may be used for the crystal device of Fig. 1; and

Fig. 9 is a schematic circuit of a wave filter using the crystal device of the invention.

As shown in the enlarged perspective view of Fig. 1 the piezoelectric crystal device of the invention comprises a piezoelectric plate 1 and associated electrodes 2, 3, 4 and 5. The plate 1 is a rectangular parallelepiped of length l , width w and thickness t having two parallel or nearly parallel major faces 6 and 7. The plate 1 is preferably made of quartz and is so oriented with respect to the principal axes of the mother crystal that, with the aid of the proper electrode arrangement, it can be made to vibrate simultaneously in two different modes, one of which is generally the fundamental longitudinal or extensional mode in the direction of the length l or the width w . A quartz plate having its major faces 6 and 7 perpendicular to an electric or X axis of the mother crystal meets this requirement. In this case the other utilized mode is the second flexural vibration in the major plane parallel to the faces 6 and 7.

For many applications of the invention it is desirable that the mechanical coupling between the two modes of motion be kept to a minimum. This may be done by properly choosing the angle θ between the optical or Z axis of the mother crystal and minor axis Z' of the plate 1, which is parallel to the width dimension w . The nearest mechanical or Y axis of the mother crystal makes this same angle θ with the major axis Y' of the plate 1, which is parallel to the length dimension l . These relationships between the various axes are clearly shown in Fig. 8 where a diagram of axes, in dot and dash lines, is

superimposed upon a plan view of the positive face of the crystal plate 1. In the case where the fundamental extensional mode in the direction of the longest dimension l is to be utilized the angle θ should have one of the values -19.5 degrees or $+42$ degrees for minimum coupling. The orientation of this type of crystal cut is described more fully in U. S. Patent 2,173,589 to W. P. Mason and R. A. Sykes, dated September 19, 1939. In this patent, however, the angle -19.5 degrees is referred to as being substantially -18.5 degrees.

Fig. 1 shows how the electrodes may be applied to drive the crystal plate 1 simultaneously in the fundamental extensional mode in the direction of the length l and in the second flexural mode in the major plane parallel to the faces 6 and 7. As shown, the electrodes 2 and 4, associated with the major face 6, cover only a portion of the area, leaving uncovered the area proportional to the distance S . The electrodes are adjacent to the end 8 of the face 6 and extend from one side 9 to the opposite side 10. The electrodes are substantially equal in area and are separated by a dividing line which is perpendicular to the end 8 and centrally located between the sides 9 and 10. The electrodes 3 and 5 associated with the opposite major face 7 are similar, respectively, to the electrodes 2 and 4 and are oppositely disposed with respect to them. For some uses of the crystal element the dividing line between the two electrodes on one of the faces may be dispensed with, leaving a single electrode on that face. The electrodes are preferably of aluminum, platinum, silver or other suitable metallic material, formed integral with the bare quartz surfaces.

The crystal is preferably supported at its center because this is the only common nodal point for the two desired modes of motion. To facilitate central support each of the opposite electrodes 4 and 5 is extended in the form of a metallic tongue such as 11 to cover a small area at the center of a major face. The crystal is supported by a wire or rod 12 soldered to the tongue 11 as shown at 14 and a second wire 13 soldered to the tongue extending from the electrode 5. The wires 12 and 13 may be of phosphor-bronze with a diameter of from 5 to 10 mils. The outer ends of the wires 12 and 13 may be supported by any suitable mounting arrangement. Electrical connections to electrodes 4 and 5 may be made by soldering wires to the supports 12 and 13. Connections to electrodes 2 and 3 may be made by means of flexible wires, such as 15 and 16, having a diameter of 1.5 mils or less. The details just described are shown in Fig. 1 and more clearly in Fig. 2, which is a vertical section taken along a center line midway between the sides 9 and 10.

The curves of Fig. 3 give the frequencies of resonance in kilocycles per second for the two desired modes of motion of a crystal plate in which θ is equal to -19.5 degrees plotted against the ratio of width w to length l . The fundamental extensional mode in the direction of the length has a frequency constant of about 255 kilocycles regardless of the width of the crystal, as shown by the two branches of curve 17. The frequency of the second flexural vibration in the major plane parallel to the faces 6 and 7, however, is dependent upon the ratio of the width w to the length l , as shown by the two branches of curve 18. The curves of Fig. 3 are for a crystal plate having a length l of one centimeter. The frequencies of both modes for a crystal of any other length will be inversely proportional to

the length l . A similar set of curves may be prepared for a crystal plate in which the angle θ is equal to $+42$ degrees.

Fig. 4 represents the equivalent electrical circuit for the piezoelectric element of Figs. 1 and 2 vibrating in the fundamental longitudinal mode in the direction of the length l . The circuit is made up of two parallel arms, one including in series the inductance L_1 and the capacitance C_1 representing, respectively, the inductance and internal capacitance of the crystal, and the other consisting of the capacitance C_0 representing the electrostatic capacitance effective between the electrodes. The circuit of Fig. 5 is similar to that of Fig. 4 and represents the equivalent electrical circuit for the crystal vibrating in the second flexural mode in the major plane parallel to the faces 6 and 7. The reactances L_2 , C_2 and C_{02} represent, for this mode, the same quantities as do the corresponding reactances in Fig. 4.

The required frequency of resonance of the L_1 , C_1 arm of Fig. 4 determines the length l of the crystal plate 1 and the required frequency of resonance of the L_2 , C_2 arm of Fig. 5 determines the ratio of the length to the width and thus fixes the width w . The impedance level is dependent upon the thickness t of the crystal, and, therefore, this dimension is chosen to give the level desired. In this way all of the crystal dimensions l , w , and t are determined.

The only factor left to be selected is the per cent of the crystal face to be left unplated. On the choice of this factor depends the ratio of internal capacitances C_2/C_1 which, in turn, determines the ratio of impedance levels for the two modes. The required ratio of C_2/C_1 will be known from design considerations of the circuit in which the crystal is to be used. The per cent of the face to be left unplated is then found from the curve of Fig. 6 which is a plot of the ratio of internal capacitances against the per cent of area unplated for a typical crystal having a length l of 3.908 centimeters, a width w of 0.896 centimeters and a thickness t of 0.100 centimeter. For a crystal having different dimensional ratios the curve may be somewhat different but will be of the same general shape as the one given. The value of the internal capacitance for the fundamental extensional mode is found from the curve of Fig. 7 which is a plot of C_1 in micro-microfarads per square centimeter of face area against the per cent of area unplated for a crystal having the dimensions given above. The value of C_1 is inversely proportional to the thickness t , and from this relationship the internal capacitance of a crystal having a different thickness may be found. Varying the ratio l to w may change the curve somewhat but it will be of the form shown. In most practical cases the area covered by the electrodes will fall within the range of 50 to 70 per cent of the entire area of the major face of the crystal.

Fig. 8 shows an alternative electrode arrangement for the major face 6 of the crystal plate 1 of Figs. 1 and 2. Here the two equal electrodes 20 and 21 are adjacent to the side 10 of the face 6 and extend from one end 8 to the opposite end. The electrodes are separated by a centrally located dividing line which is perpendicular to the side 10. In this case the electrodes cover only a portion of the width w of the face, leaving the portion K uncovered. Electrode 21 has a tongue 25 extended to cover a small area at the center of the face 6. On the other major face 7 are two other electrodes similar to 20

and 21 and oppositely disposed with respect to them. The crystal may be supported at its center by stiff wires or rods and electrical connections may be made in the same manner as explained above in connection with Figs. 1 and 2. The plating arrangement of Fig. 8 may be used to excite the crystal in the two modes described above and the per cent of area unplated may be chosen to provide the desired ratio of internal capacitances as explained above in connection with Fig. 6.

Fig. 9 shows how the crystal 1 of Fig. 1 may be used in a wave filter circuit. The filter has a pair of input terminals 22, 23, a pair of output terminals 24, 25, and four equal series end inductances 26, 27, 28 and 29. Electrode 2 is connected through inductance 26 to terminal 22, electrode 3 is connected through inductance 27 to terminal 23, electrode 4 is connected through inductance 28 to terminal 24 and electrode 5 is connected through inductance 29 to terminal 25. The filter also includes the four capacitances 30, 31, 32 and 33. Capacitance 30 is connected between electrodes 2 and 4, capacitance 31 is connected between electrodes 4 and 5, capacitance 32 is connected between electrodes 3 and 5 and capacitance 33 is connected between electrodes 2 and 3. The component elements may be so designed that the filter will have a band-pass transmission characteristic. The capacitors may be made variable, as indicated by the arrows, to facilitate adjustment of the characteristic. The crystal of Fig. 8 may be substituted for the one used in Fig. 9. In this case the electrodes 20 and 21 on face 6 and the corresponding ones on the opposite face 7 are connected into the filter circuit in the same way as are electrodes 2, 4, 3 and 5.

The single crystal element used in the filter of Fig. 9 furnishes two impedances of the type shown in Fig. 4 which represent the fundamental extensional vibration and are effective in the diagonal branches of the equivalent lattice network and two other impedances of the type shown in Fig. 5 which represent the second flexural vibration and are effective in the series branches of the equivalent lattice. For a more detailed description of the circuit shown in Fig. 9 and other filter circuits using doubly resonant crystals to which the crystal element of the present invention is applicable, reference is made to application Serial No. 303,757, filed November 10, 1939.

What is claimed is:

1. A piezoelectric crystal plate having a substantially rectangular major face and means for simultaneously driving said plate in two substantially uncoupled modes of motion, one of which is the extensional mode and the resonant frequencies of which are independently controlled by different dimensions of said face, said means including two substantially equal electrodes covering only a portion of the area of said face leaving the remaining area uncovered, said electrodes being adjacent to one edge of said face and adjacent to each other, and the ratio of said covered area to the whole area of said face being chosen between the limits of 50 and 70 per cent to provide a desired predetermined ratio between the internal capacitances associated with said two modes of motion.

2. A crystal device in accordance with claim 1 in which said electrodes are adjacent to an end of said face.

3. A crystal device in accordance with claim 75

1 in which said electrodes are adjacent to a side of said face.

4. A crystal device in accordance with claim 1 in which said electrodes extend substantially from a second edge of said face to the opposite edge.

5. A crystal device in accordance with claim 1 in which said electrodes are of equal width.

6. A crystal device in accordance with claim 1 in which said electrodes are separated by a dividing line which is substantially perpendicular to said one edge.

7. A crystal device in accordance with claim 1 in which said electrodes are separated by a dividing line which is midway between two edges of said major face.

8. A crystal device in accordance with claim 1 in which said electrodes are separated by a dividing line which is midway between the sides of said major face.

9. A crystal device in accordance with claim 1 in which said electrodes are separated by a dividing line which is midway between the ends of said major face.

10. A crystal device in accordance with claim 1 in which said extensional mode of motion is in the direction of the longest dimension of said major face and the second of said modes of motion is the flexural mode in the major plane parallel to said major face.

11. A crystal device in accordance with claim 1 in which said plate is made of quartz.

12. A crystal device in accordance with claim 1 in which said plate is made of quartz and said major face is disposed substantially perpendicular to an electric or X axis and has a length dimensioned inclined substantially -19.5 degrees with respect to the nearest mechanical or Y axis.

13. A crystal device in accordance with claim 1 in which said plate is made of quartz and said major face is disposed substantially perpendicular to an electric or X axis and has a length dimension inclined substantially $+42$ degrees with respect to the nearest mechanical or Y axis.

14. A crystal device in accordance with claim 1 having a second major face substantially parallel to said first-mentioned major face, said driving means including at least one electrode on said second major face disposed opposite said pair of electrodes.

15. A crystal device in accordance with claim 1 having a second major face substantially parallel to said first-mentioned major face, said driving means including two other electrodes on said second face, said other electrodes being oppositely disposed with respect to said first-mentioned electrodes.

16. A piezoelectric quartz crystal plate having two substantially rectangular major faces disposed substantially perpendicular to an X axis and a pair of electrodes of substantially equal area disposed adjacent to each other on one of said faces adjacent one edge thereof, the length and width dimensions of said faces being inclined substantially -19.5 degrees with respect to the nearest Y axis and the Z axis, respectively, said length dimension and the ratio of said width dimension to said length dimension having values determined by the curves of Fig. 3 and said pair of electrodes covering an area which is from 50 to 70 per cent of the total area of said one face, leaving uncovered the remaining area of said one face.

17. A crystal device in accordance with claim

16 which includes at least one electrode on the other of said major faces disposed opposite said pair of electrodes.

18. A crystal device in accordance with claim 16 which includes a pair of electrodes on the other of said major faces, said last-mentioned pair of electrodes being disposed opposite said first-mentioned pair of electrodes.

19. A crystal device in accordance with claim 16 which includes at least one electrode on the other of said major faces disposed opposite said pair of electrodes, said electrodes being formed integral with said faces.

20. A quartz crystal having a substantially rectangular major face disposed substantially perpendicular to an electric or X axis and a length dimension inclined at one of the angles -19.5 de-

grees and $+42$ degrees with respect to the nearest mechanical or Y axis, and means for simultaneously driving said crystal in two substantially uncoupled modes of motion one of which is the extensional mode and the resonant frequencies of which are independently controlled by different dimensions of said face, said means including two equal electrodes covering only a portion of the area of said face leaving the remaining area uncovered, said electrodes being adjacent to one edge of said face and adjacent to each other, and the ratio of said covered area to the whole area of said face being chosen between the limits of 50 to 70 per cent to provide a desired predetermined ratio between the internal capacitances associated with said two modes of motion.

HERBERT J. McSKIMIN.