

Feb. 24, 1942.

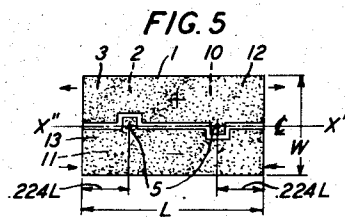
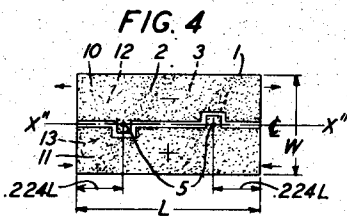
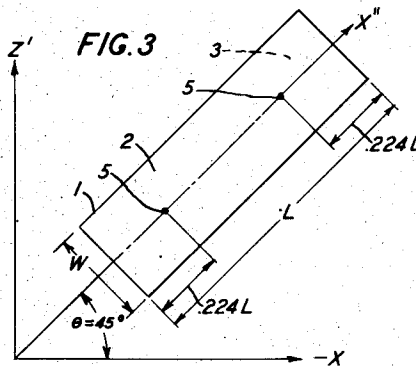
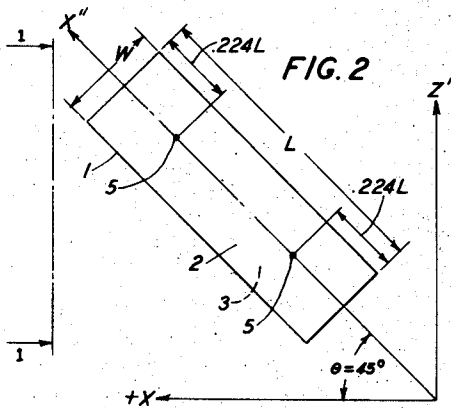
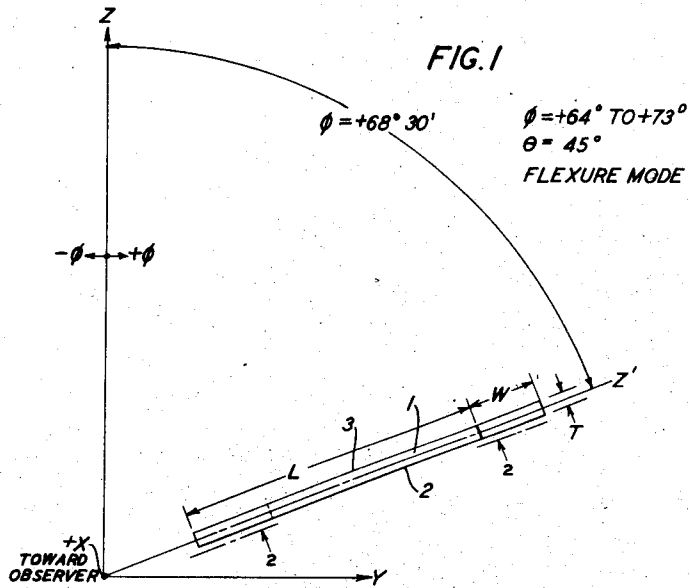
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2,274,079

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Sept. 18, 1940

2 Sheets-Sheet 1



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PIEZOELECTRIC CRYSTAL APPARATUS

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2 Sheets-Sheet 2

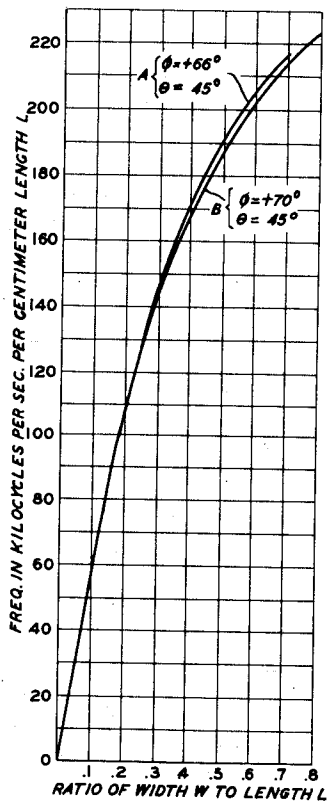


FIG. 6

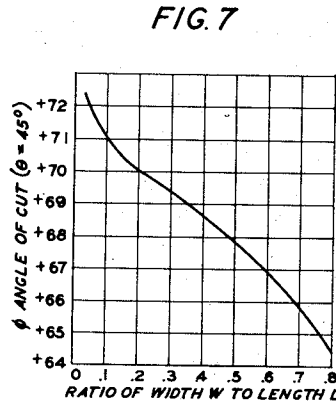


FIG. 7

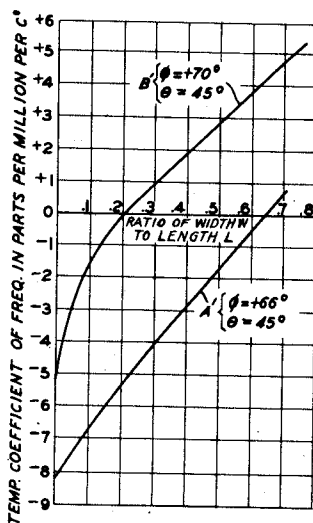


FIG. 8

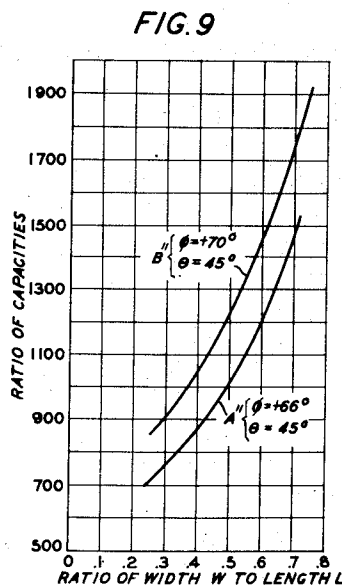


FIG. 9

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UNITED STATES PATENT OFFICE

2,274,079

PIEZOELECTRIC CRYSTAL APPARATUS

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Application September 18, 1940, Serial No. 357,252

12 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to flexure mode piezoelectric quartz crystal elements adapted for use as circuit elements in such systems as electric wave filter systems and oscillation generator systems, for example.

In my United States Patent No. 2,204,762, granted June 18, 1940, on application Serial No. 180,921, filed December 21, 1937, longitudinal mode quartz crystal elements of low or substantially zero temperature coefficient of frequency are described. In the present application, flexure mode quartz crystal elements are described which have similar low temperature coefficient of frequency but differ therefrom in orientation angle, dimensional ratio, and vibrational frequency characteristics.

One of the objects of this invention is to provide piezoelectric crystal elements having a low temperature coefficient of frequency.

Another object of this invention is to provide relatively low frequency piezoelectric crystal elements having a nearly constant vibrational frequency throughout a range of ordinary temperatures.

Another object of this invention is to provide piezoelectric crystals substantially free from undesired interfering vibrational modes or other undesired frequencies near to the desired frequency.

Another object of this invention is to provide piezoelectric crystal elements that may be of relatively small and economical sizes at relatively low frequencies.

In such systems as electric wave filter systems or oscillation generator systems, for example, it is often desirable to utilize vibrating crystals which have a low temperature coefficient of frequency over a range of temperatures and which are so constructed that any undesired prominent secondary resonances therein may be remote or at convenient ratios from the desired main mode of vibration where they will cause no harm. It is also desirable that such crystal elements, when utilized at the relatively lower frequencies such as, for example, below about 100 kilocycles per second, be of relatively small and convenient size in order to avoid the expense that is usually involved in crystal elements of the relatively larger sizes.

Since the crystal elements provided in accordance with this invention may have a relatively small size at low frequencies, they may be constructed economically down to considerably below 50 kilocycles per second, and, accordingly,

are advantageous for use in low frequency oscillators, filters and other low frequency systems where a low frequency of low temperature coefficient is desired.

In accordance with this invention, relatively thin piezoelectric quartz crystal plates of suitable orientation with respect to the X, Y and Z axes of the quartz material and of suitable dimensional ratio, may be subjected to a thickness direction or Y' electric field and vibrated at a resonance frequency dependent mainly upon the longest or major axis length dimension and the width dimension of the crystal plate in a mode of vibration which may be called a flexural mode. The orientation angles and the related dimensional ratios of the crystal plate may be any of several in order to produce, for the first flexural mode of motion, a low or substantially zero temperature coefficient of frequency, at temperatures within a range between about 0 and +80° C. over a wide ratio of the width to length dimension of its major faces, the frequency of the flexural mode vibration being dependent upon such dimensional ratio and the length or longest dimension of the crystal element. In particular embodiments the ratio of the width dimension with respect to length dimension of the major surfaces may conveniently range from about 0.05 to 0.8. The orientation of the crystal plate may be any of several, the major axis length dimension of the crystal plate being in every such case inclined either about 45, or alternatively about 135 degrees, with respect to an electric axis X, and the major plane being in every case parallel or nearly parallel to such X axis and inclined with respect to the optic axis Z at any angle between +64 and +73 degrees. Such quartz crystal plates when suitably proportioned as to relative width and length dimensions produce, for the flexure mode resonant frequency mentioned, a low or substantially zero temperature coefficient of frequency at temperatures within a temperature range between -40 and +100° C. In a particular species where the major plane of the crystal plate is inclined about +68 degrees 30 minutes with respect to the Z axis and the width dimension of the crystal plate is related to the length dimension in the ratio of about 0.42, the flexure mode resonant frequency referred to has a nearly constant frequency characteristic throughout a range of ordinary temperatures.

Cut in the form of a bar, these crystal elements may be conveniently made to have a frequency within the range from about 15 or less to 60 kilo-

cycles per second or more; and cut in the form of a tuning fork they may have a low temperature coefficient frequency within the range from about 4 to 15 kilocycles per second or more. Such crystal elements in the form of a bar or tuning fork may be usefully employed in pilot channel filters, oscillation generators, and in secondary frequency standards, for example.

For a clearer understanding of the nature of this invention and the additional advantages, features and objects thereof, reference is made to the following description taken in connection with the accompanying drawings, in which like reference characters represent like or similar parts and in which:

Figs. 1 and 2 are enlarged views of a flexure mode piezoelectric quartz crystal plate embodying this invention, Fig. 1 being a projected edge view taken in the horizontal direction indicated by the arrows 1—1 of Fig. 2 and Fig. 2 being a major face view taken in the direction indicated by the arrows 2—2 of Fig. 1;

Fig. 3 is a major face view of a quartz plate similar to that of Fig. 2 but having an alternative 45 degree orientation angle with respect to the X axis;

Figs. 4 and 5 are views of electrodes that may be used on the opposite major surfaces of the flexure mode crystal element of Fig. 1, Fig. 4 being a view looking toward one of the major surfaces of the crystal element and Fig. 5 being a view looking in the opposite direction toward the opposite major surface of the crystal element;

Fig. 6 is a graph showing the relation between the dimensional ratio and the resonant frequency of typical flexure mode quartz crystal elements in accordance with this invention;

Fig. 7 is a graph showing the relation between the orientation angle and the dimensional ratio of flexure mode quartz crystal elements in accordance with this invention;

Fig. 8 is a graph illustrating the relation between the dimensional ratio and the temperature coefficient of frequency of typical quartz crystal elements in accordance with this invention for ϕ angles in the region of substantially +66 and +70 degrees; and

Fig. 9 is a graph illustrating the relation between the dimensional ratio and the ratio of capacities of quartz crystal elements embodying this invention for ϕ angles in the region of substantially +66 and +70 degrees.

This specification follows the conventional terminology as applied to crystalline quartz which employs three orthogonal or mutually perpendicular X, Y and Z axes, as shown in the drawings, to designate an electric, a mechanical and the optic axes, respectively, of piezoelectric quartz crystal material, and which employs three orthogonal axes X', Y' and Z' to designate the directions of axes of a piezoelectric body angularly oriented with respect to such X, Y and Z axes thereof. Where the orientation is obtained by double rotations of the quartz crystal element 1, one rotation being in effect substantially about an electric axis X, and the other about another axis of the piezoelectric body as illustrated in Figs. 1 and 2, the orientation angles ϕ and θ , respectively, designate in degrees the effective angular position of the crystal plate 1 as measured from the optic axis Z and from the orthogonal electric axis X, respectively. The length axis X'' shown in Figs. 2 and 3 indicates the result of a second rotation.

Quartz crystals may occur in two forms, namely, right-handed and left-handed. A right-handed quartz crystal is one in which the plane of polarization of a plane polarized light ray traveling along the optic axis Z in the crystal is rotated in a right-hand direction, or clockwise as viewed by an observer located at the light source and facing the crystal. This definition of right-hand quartz follows the convention which originated with Herschel, Trans. Cam. Phil. Soc. vol. 1, page 43 (1821); Nature vol. 110, page 807 (1922); Quartz Resonators and Oscillators, P. Vigoureux, page 12 (1931). Conversely, a quartz crystal is designated as left-handed if it rotates such plane of polarization referred to in the left-handed or counter-clockwise direction, namely, in the direction opposite to that given hereinbefore for the right-handed crystal.

If a compressional stress or a squeeze be applied to the ends of an electric axis X of a quartz body 1 and not removed, a charge will be developed which is positive at the positive end (+) of the X axis and negative at the negative end (—) of such electric axis X, for either right-handed or left-handed crystals. The magnitude and sign of the charge may be measured in a known manner with a vacuum tube electrometer, for example. In specifying the orientation of a right-handed crystal, the sense of the angle ϕ which the new axis Z' makes with respect to the optic axis Z as the crystal plate is rotated in effect about the X axis is deemed positive (+) when, with the compression positive end (+) of the axis pointed toward the observer, the rotation is in a clockwise direction as illustrated in Fig. 1. A counter-clockwise rotation of such a right-handed crystal about the X axis gives rise to a negative orientation angle ϕ with respect to the Z axis. Conversely, the orientation angle of a left-handed crystal is positive when, with the compression positive end (+) of the electric axis X pointed toward the observer, the rotation is counter-clockwise, and is negative when the rotation is clockwise. The crystal material illustrated in Figs. 1 to 3 is right-handed as the term is used herein. For either right-handed or left-handed quartz, a positive (+) angle ϕ rotation of the Z' axis with respect to the Z axis is illustrated in Fig. 1 is toward parallelism with the plane of a minor apex face of the natural quartz crystal, and a negative (—) ϕ angle rotation of the Z' axis with respect to the Z axis is toward parallelism with the plane of a major apex face of the natural quartz crystal.

Referring to the drawings, Figs. 1 and 2 are respectively an edge view and a major face view of a right-handed relatively thin piezoelectric quartz crystal plate 1 of substantially rectangular parallelepiped shape having an over-all length or longest dimension L, a width dimension W which is perpendicular to the length dimension L, and a thickness or thin dimension T which is perpendicular to the length dimension L and the width dimension W. As shown in Fig. 1, the major plane and the opposite major faces 2 and 3 of the crystal plate 1 may be parallel or nearly parallel to an electric or X axis of the quartz material and inclined with respect to the optic axis Z at a ϕ angle of about +68 degrees 30 minutes as measured between the Z and Z' axes in a plane which is perpendicular to the X axis and to the major plane of the crystal plate 1. Small angle departures up to 5 degrees or more, for example of the major faces 2 and 3, from parallelism with respect to the X axis do not greatly

alter the corresponding ϕ angle required to obtain the low or substantially zero temperature coefficient of frequency. Since the minor apex faces of the natural quartz crystal from which the quartz plate 1 is cut occur at a ϕ angle of about $+38$ degrees with respect to the optic axis Z, the positive (+) sense for the ϕ angle is equivalent to a rotation about the X axis from the Z axis toward parallelism with the plane of a minor apex face for either right-handed or left-handed quartz.

In Fig. 1, the X axis is perpendicular to the plane of the drawing with the compression positive end (+) of the X axis pointed towards the observer, and is also perpendicular to both the Y and Z axes. The over-all length dimension L of the crystal plate 1 lying along the major axis X' as shown in Figs. 2 and 3 may be inclined at an angle θ of about 45 degrees with respect to the above-mentioned X axis in either direction as illustrated by the alternative θ angle orientations shown in Figs. 2 and 3. While the major axis length dimension L of the crystal plate 1 of Fig. 2 is inclined at a different 45 degree θ angle with respect to the X axis than that of Fig. 3, it will be understood that either of these 45 degree positions for the angle θ may be used alternatively with any of the ϕ angles disclosed herein.

The final major axis length dimension L of the quartz crystal element 1 is determined by and is made of a value according to the desired resonant frequency. The width dimension W also is related to the frequency and to the length dimension L in accordance with the values of dimensional ratios as given herein in Fig. 6. The thickness dimension T may be of the order of one millimeter or other suitable value to suit the impedance of the circuit in which the crystal element 1 may be utilized.

As illustrated in Figs. 2 to 5, the low temperature coefficient flexure mode crystal element 1 has two nodal point regions 5 on each of its major surfaces 2 and 3. These nodal points are located on the center line length dimension L or X' axis of the crystal element 1 at points spaced about 0.224 of the length dimension L from each end thereof, as shown in Figs. 2 to 5. At these nodal points 5, the crystal element 1 may be mounted as by rigidly clamping it between two pairs of oppositely disposed clamping projections of small contact area which may be inserted in small semispherical indentations or depressions provided at the four nodal points 5 on the opposite major surfaces 2 and 3 of the crystal element 1. The small circular depressions cut in the major surfaces 2 and 3 of the crystal element 1 at the nodal points 5 thereof may have a depth of about 0.05 millimeter and a diameter of about 0.4 millimeter as measured on the surfaces 2 and 3.

As illustrated in Figs. 4 and 5, suitable conductive electrodes, such as the four crystal electrodes 10, 11, 12 and 13, for example, may be placed on or adjacent to or formed integral with the opposite major surfaces 2 and 3 of the crystal plate 1 to apply electric field excitation to the quartz plate 1 in the direction of the Y' axis thickness dimension T, and by means of suitable electrode interconnections and any suitable circuit, such as for example, a filter or an oscillator circuit, the quartz plate 1 may be vibrated in the desired first flexural mode of motion at a response frequency which depends mainly upon and varies inversely as the major axis length dimension L,

and which also depends upon the dimensional ratio of the width W with respect to the length L, the frequency being a value within a range roughly from about 5 to 230 kilocycles per second per centimeter of the length dimension L, the value depending somewhat upon the value of the angle ϕ of the crystal element 1, and largely upon the dimensional ratio of the width W with respect to length L thereof, as illustrated in Fig. 6.

The crystal electrodes 10 to 13 of Figs. 4 and 5 when formed integral with the major surfaces 2 and 3 of the crystal element 1 may consist of thin coatings of silver, aluminum or other suitable metallic or conductive material deposited upon the bare quartz by evaporation in vacuum or by other suitable process. The crystal electrodes 10 and 11 located on one major surface 2 of the crystal element 1 and the crystal electrodes 12 and 13 located on the opposite major surface 3 thereof are longitudinally centrally separated or split along the center line of the X' axis length dimension L, thereby forming four separate electrodes 10, 11, 12 and 13 in order to operate the crystal element 1 in the desired flexural mode of motion. Figs. 4 and 5 illustrate such splits or separations in the crystal electrodes, the electrodes 10 to 13 being provided with ears extending over the nodal points 5 of the crystal element 1 in order to make contact with the points of the conductive clamping projections that may be disposed at such nodal points. The gap or separation between the electrode platings 10 and 11 and also between the platings 12 and 13 on the major surfaces 2 and 3, respectively, of the crystal element 1 may be about 0.365 millimeter, the center line of such splits in the platings on opposite sides of the crystal plates being aligned with respect to each other. To drive the crystal element 1 in the desired first flexure mode, one pair of opposite electrodes, such as the crystal electrodes 10 and 12, apply a field in one direction through the crystal element 1 in order to lengthen one long edge L thereof while the other pair of opposite electrodes 11 and 13 simultaneously apply a field in the opposite direction in order to simultaneously shorten the opposite long edge L thereof, thus bending the long axis L of the crystal element 1 about the stationary nodal points 5 in the desired first flexural mode of motion. The + and - signs of Figs. 4 and 5 illustrate instantaneous values of polarities for the electrodes 10 to 13, and the arrows of Figs. 4 and 5 illustrate the resulting force system. Examples of crystal electrode arrangements that may be utilized for operating the crystal element 1 in flexure mode vibrations are illustrated in W. A. Marrison U. S. Patent 1,823,329 dated September 15, 1931, Figs. 5 to 8, and C. A. Bieling U. S. Patent 2,155,035, April 18, 1939, Fig. 7.

Fig. 6 is a graph showing the flexure mode frequency characteristics of quartz crystal element 1 having a θ angle of 45 degrees and ϕ angles of substantially $+66$ and $+70$ degrees and having various values of ratio of the width dimension W with respect to the length dimension L, as given by the curves A and B of Fig. 6. The curves labeled A and B in Fig. 6 show the relation between the desired first flexural mode resonant frequency thereof, expressed in kilocycles per second per centimeter of the length dimension L for given ratios of the width dimension W with respect to the length dimension L. For example, when the dimensional ratio of the

width W with respect to the length L is about 0.50, the flexural mode frequency of a crystal element l having a length dimension L of 1 centimeter and having a ϕ angle of substantially $+66$ degrees, is about 190 kilocycles per second. Since the frequency is inversely proportional to the length dimension L , a crystal element of the same orientation and dimensional ratio but having a length dimension L of 4 centimeters will have a flexural mode frequency of one-fourth this value or about 47.5 kilocycles per second. Similarly, the approximate frequency, the corresponding length dimension L and dimensional ratio may be obtained for any other size of crystal element l from the curves A or B of Fig. 6, when the ϕ angle is a value from about $+64$ to $+73$ degrees, the θ angle always being substantially 45 for every angle of ϕ .

As an example, a substantially $+68.5$ degree ϕ angle crystal element l having a thickness dimension T of 1.662 millimeters, a length dimension L of 29.91 millimeters, and a width dimension W of 11.96 millimeters, has a dimensional ratio of width W with respect to length L of about 0.4 and, as shown by curve A or B of Fig. 6, has a low temperature coefficient first flexural mode frequency of about 170 kilocycles per second per centimeter of length dimension L or about 57 kilocycles per second for the given length dimension L of 29.91 millimeters.

As another example, a substantially $+73$ degree ϕ angle crystal element l having a thickness dimension T of 0.800 millimeter, a length dimension L of 65.0 millimeters and a width dimension W of 9.35 millimeters, has a dimensional ratio of width W with respect to length L of about 0.145 and, as shown by curve A or B of Fig. 6, has a low temperature coefficient first flexural mode frequency of about 80 kilocycles per second per centimeter of length dimension L or about 12 kilocycles per second for the given length dimension L of 65.0 millimeters.

When the crystal bar l vibrating in flexure has a relatively wide width dimension W as compared to its length dimension L , the frequency and the temperature coefficient of frequency thereof are controlled mainly by the shearing modulus of elasticity. And when the crystal element l is made of a relatively long length L and a narrow width W , the flexure mode frequency and temperature coefficient are controlled mainly by Young's modulus of elasticity which also controls the longitudinal vibrations. Young's modulus gives a negative temperature coefficient of frequency whereas the shear modulus may result in either a positive or a negative temperature coefficient of frequency. By selecting a crystal cut in which the shear modulus has a positive temperature coefficient, the resultant temperature coefficient of frequency may be negative when the crystal element l is long and narrow and positive when it is as wide or wider than it is long. As a result, it may have a zero temperature coefficient of frequency at some intermediate ratio of axes of width W with respect to length L . The crystal element l has a positive shear modulus of elasticity when the ϕ angle is relatively large, as in the region of $+64$ to $+73$ degrees, and consequently, when it is driven in flexure mode by the two sets of electrodes 10 to 13 of opposite polarity, one set causing the crystal element to expand and the other to contract, thus setting up a flexure vibration, it may have a zero temperature coefficient of frequency at some se-

lected dimensional ratio of width W to length L according to the value of the ϕ angle selected.

The curve of Fig. 7 gives the orientation angles of ϕ and the corresponding dimensional ratios that may be used to construct quartz plates l to obtain a low or substantially zero temperature coefficient of flexure mode frequency. The dimensional ratios are therein given in terms of the width dimension W with respect to the length dimension L of the crystal plate l , for all of the corresponding positive angles of ϕ between about $+64$ and $+73$ degrees, the angle θ in every case being about 45 degrees as illustrated in either Fig. 2 or Fig. 3. The angles of ϕ outside of these ranges as given in Fig. 7 do not produce the substantially zero temperature coefficient of flexure mode frequency but may be otherwise utilized if desired.

The corresponding frequency constants for the quartz plates l , oriented and dimensioned in accordance with the values given by the curve of Fig. 7, are substantially given by the curves of Fig. 6 at the intercept of the particular value of dimensional ratio selected. For example, when ϕ is substantially $+70$ degrees, θ being substantially 45 degrees, and the dimensional ratio of the width W with respect to the length L of the quartz plate l is substantially .2 as indicated by the curves of Figs. 6 and 7, the frequency constant is about 105 kilocycles per second per centimeter of length dimension L .

Other values of corresponding orientation, dimensional ratio and frequency for crystal plates l that give a low or substantially zero temperature coefficient of frequency may be obtained from the curves of Figs. 6 and 7 for any angle of ϕ selected between about $+64$ and $+73$ degrees.

It will be noted that these crystal elements l cut at definite orientation angles of ϕ varying between about $+64$ and $+73$ degrees have a substantially zero temperature coefficient of frequency at a definite ratio of axes of width W with respect to length L . The dimensional ratio of the width W with respect to the length L may be varied from 0 to 1.0 by changing the ϕ angle of cut so that the zero temperature coefficient frequency of the crystal elements l may be conveniently placed in a range from about 15 kilocycles per second or less to 60 kilocycles per second or more by utilizing crystal elements of dimensions that are easily obtainable. By cutting from the plate form of the crystal element l , a crystal element in the form of a tuning fork, frequencies as low as 4 kilocycles per second and of low temperature coefficients may be obtained.

Fig. 8 is a graph illustrating the relation between the temperature coefficient of frequency and the dimensional ratio of width W to length L for two flexure mode crystal elements l , one of which has a ϕ angle of $+66$ degrees and a θ angle of 45 degrees as shown by the curve A'' of Fig. 8, and the other of which has a ϕ angle of $+70$ degrees and a θ angle of 45 degrees as shown by the curve B'' of Fig. 8. The corresponding frequency constants and ratios of capacities for these two crystal orientations are given by the curves of Figs. 6 and 9, respectively. In Fig. 9, the curves A'' and B'' give the measured values of the ratio of capacities for the crystal elements l , one having a ϕ angle of $+66$ and a θ angle of 45 degrees, corresponding to the curve A of Fig. 6, and the other having a ϕ angle of $+70$ degrees and a θ angle of 45 degrees, corresponding to the curve B of Fig. 6. As shown by the curves A'' and B'' of Fig. 9, the ratio of capacities for these

two crystal orientations run from about 700 to 2000 for dimensional ratios of width W to length L between 0.2 and 0.8. The term ratio of capacities refers to the ratio of the internal or series capacity C_1 with respect to the shunt capacity C_2 as explained in a paper entitled Electrical Wave Filters Employing Quartz Crystals as Elements, Bell System Technical Journal, July 1934, pages 409, 410, 411, published by the applicant.

The crystal elements described herein and illustrated in Figs. 1 to 5, may be mounted in any suitable manner, such as for example, by rigidly clamping the electroded crystal plate 1 between one or more pairs of opposite conductive clamping projections which may contact the integral electrodes 10 to 13 of the crystal plate 1 at opposite points of very small area at the nodal points 5 only of the crystal element 1. The pairs of clamping points may be oppositely disposed with respect to each other and axially disposed perpendicular to the major surfaces 2 and 3 of the crystal element 1 and since they make contact only at the nodal points 5 of the crystal element 1, there is a minimum of damping of the flexural vibratory motion of the crystal element 1. The nodal points 5 are located as illustrated in Figs. 2 to 5. The crystal plate 1 is preferably clamped only at the nodal points 5 in order to obtain the minimum effective resistance at resonance. The crystal plate 1 may be adjusted to its desired resonance frequency by reducing the length dimension L thereof. The mounted crystal plate 1 will be found to age over a period of as much as seven days after so adjusting it. During this aging period, the resonance frequency rises and the effective resistance decreases. Suitable allowance for this aging may be made so that the crystal element 1 will meet the requirements after it has become stable.

Particular forms of mountings that may be utilized for clamping the crystal element 1 are illustrated, for example in C. A. Bieling U. S. Patent 2,155,035, dated April 18, 1939, and R. A. Sykes U. S. Patent 2,124,596, dated July 26, 1938, the clamping projections thereof being spaced and shaped to suit the nodal points 5 of the flexure mode crystal element 1.

Alternatively, instead of being mounted by clamping, the electroded crystal plate 1 may be mounted and electrically connected by soldering, cementing or otherwise attaching four fine conductive supporting wires directly to the bare quartz or to a thickened part of the electroded crystal element 1 at its nodal points 5. The fine supporting wires referred to may be conveniently soldered to four small spots or stripes of baked silver paste or other metallic paste which has been previously applied at the nodal points 5 only on the length dimension L center line either directly on the bare quartz or on top of the field producing crystal electrodes 10 to 13 which may consist of pure silver applied by the known evaporation in vacuum process. Such fine supporting wires may extend perpendicularly from major surfaces 2 and 3 of the crystal element 1 and be attached by solder, for example to conductive spring wires or rods carried by the press or other part of an evacuated glass tube. If desired, the support wires and rods may have one or more bends therein to better absorb mechanical vibrations originating outside the device. Also, bumpers or stops of soft or resilient material may be spaced adjacent the edges, sides, ends or other parts of the crystal element 1 to

limit the endwise and sidewise bodily displacement thereof when the device is subjected to externally applied mechanical shock. It will be understood that any holder and mounting which will give stability and a relatively high Q or reactance-resistance ratio for the crystal element 1 may be utilized for mounting the crystal element 1.

Although this invention has been described and illustrated in relation to specific arrangements, it is to be understood that it is capable of application in other organizations and is therefore not to be limited to the particular embodiments disclosed, but only by the scope of the appended claims and the state of the prior art.

What is claimed is:

1. A piezoelectric quartz crystal vibratory body having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined substantially $+68.5$ degrees with respect to the Z axis as measured in a plane substantially perpendicular to said major faces, the major axis length dimension and the width dimension of said major faces being inclined substantially 45 degrees with respect to said X axis, said width dimension having a ratio of substantially 0.42 with respect to said length dimension.
2. A piezoelectric quartz crystal vibratory body having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined substantially $+66$ degrees with respect to the Z axis as measured in a plane substantially perpendicular to said major faces, the major axis length dimension and the width dimension of said major faces being inclined substantially 45 degrees with respect to said X axis, said width dimension having a ratio of substantially 0.67 with respect to said length dimension.
3. A piezoelectric quartz crystal vibratory body having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined substantially $+70$ degrees with respect to the Z axis as measured in a plane substantially perpendicular to said major faces, the major axis length dimension and the width dimension of said major faces being inclined substantially 45 degrees with respect to said X axis, said width dimension having a ratio of substantially 0.2 with respect to said length dimension.
4. A piezoelectric quartz crystal vibratory body of substantially zero temperature coefficient of flexure mode frequency having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined at one of the angles from substantially $+66$ to $+70$ degrees with respect to the Z axis as measured in a plane substantially perpendicular to said major faces, the major axis length dimension and the width dimension of said major faces being inclined substantially 45 degrees with respect to said X axis, said width dimension having a ratio of one of the values from substantially 0.2 to 0.67 with respect to said length dimension.
5. A piezoelectric quartz crystal vibratory body having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined at one of the angles from substantially $+64$ to $+73$ degrees with respect to the Z axis as measured in a plane substantially perpendicular to said major faces, the major axis length dimension and the width dimension of said major faces being inclined substantially 45 degrees with respect to said X axis, the dimensional ratio of said width dimension with respect to said length dimension being a value given by

the curve of Fig. 7 at a point corresponding to the value of said angle.

6. A quartz piezoelectric body adapted to vibrate at a flexure mode frequency of low temperature coefficient dependent mainly upon the length and width dimensions of its major surfaces, said major surfaces being of substantially rectangular shape, disposed substantially parallel to an X axis and inclined with respect to the Z axis at one of the angles from substantially +64 to +73 degrees as measured in a plane perpendicular to said major surfaces, said length dimension and said width dimension being inclined substantially 45 degrees with respect to said X axis, said width dimension being related to said length dimension in the ratio given substantially by the curve of Fig. 7 at a point thereon corresponding to the value of said angle.

7. A piezoelectric quartz crystal body adapted to vibrate at a flexure mode frequency dependent mainly upon its major surface length and width dimensions, said major surface of said body being substantially parallel to an X axis and inclined substantially +68.5 degrees with respect to the Z axis as measured in a plane perpendicular to said major surface, said length dimension and said width dimension being inclined substantially 45 degrees with respect to said X axis, said width dimension being substantially 0.42 of said length dimension, said length dimension expressed in centimeters being substantially 172 divided by said frequency expressed in kilocycles per second.

8. A piezoelectric quartz crystal body of low or substantially zero temperature coefficient of frequency adapted to vibrate at a flexure mode frequency dependent mainly upon the length and width dimensions of the major surfaces of said body, said major surfaces being substantially rectangular, disposed substantially parallel to an X axis and inclined at an angle between +64 and +73 degrees with respect to the Z axis, said length dimension axis of said major surfaces being inclined substantially 45 degrees with respect to said X axis, said angle and the corresponding dimensional ratio of said width dimension with respect to said length dimension being substantially a set of those corresponding values given by one of the points on the curve of Fig. 7, and said frequency being a value between 20 and 225 kilocycles per second per centimeter of said length dimension in accordance with the value of said dimensional ratio.

9. A piezoelectric quartz crystal body of low temperature coefficient of frequency adapted to vibrate in a flexure mode of motion and at a frequency dependent upon the length and width dimensions of its major surfaces, said frequency being a value between 110 and 215 kilocycles per second per centimeter of said length dimension according to the value of the dimensional ratio of said width dimension with respect to said length dimension, said major surfaces being of

substantially rectangular shape, disposed substantially parallel with respect to an X axis and inclined at an angle between +66 and +70 degrees with respect to the Z axis, said length dimension of said major surfaces being inclined substantially 45 degrees with respect to said X axis, said angle and the dimensional relation between said width dimension and said length dimension being substantially a set of those corresponding values given by one of the points on the curve of Fig. 7 between the points thereon corresponding to said angles of +66 and +70 degrees.

10. A piezoelectric quartz crystal body adapted for flexure mode vibrations at a frequency dependent mainly upon the length and width dimensions of its substantially rectangular major surfaces, said major surfaces being substantially parallel to an X axis and inclined at an angle between substantially +64 and +73 degrees with respect to the Z axis as measured in a plane perpendicular to said major surfaces, said major axis length dimension being inclined substantially 45 degrees with respect to said X axis, the dimensional ratio of said width dimension with respect to said length dimension of said major surfaces being a value between 0.05 and 1.0, said angle and said dimensional ratio having such relative values as to provide a low or substantially zero temperature coefficient for said frequency.

11. A piezoelectric quartz crystal body adapted for flexure mode vibrations at a frequency dependent mainly upon the length and width dimensions of its substantially rectangular major surfaces, said major surfaces being substantially parallel to an X axis and inclined at an angle between +66 and +70 degrees with respect to the Z axis as measured in a plane perpendicular to said major surfaces, said major axis length dimension being inclined substantially 45 degrees with respect to said X axis, the dimensional ratio of said width dimension of said major surfaces with respect to said length dimension being a value between substantially 0.2 and 0.7, said angle and said dimensional ratio having such relative values as to produce a low or substantially zero temperature coefficient for said frequency.

12. A piezoelectric quartz crystal element having its major surfaces substantially parallel to an X axis and inclined at an angle between +64 and +73 degrees with respect to the Z axis, the length dimension of said major surfaces being inclined substantially 45 degrees with respect to said X axis, two pairs of opposite electrodes formed integral with said major surfaces, said electroded crystal element having nodes of motion, said nodes being along the center line of said length dimension at points located from the ends thereof a distance substantially 0.224 of said length dimension.

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