

Feb. 10, 1942.

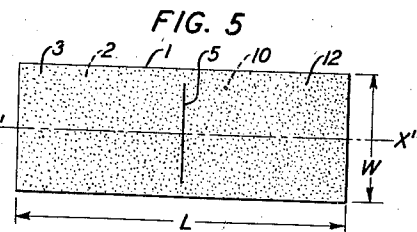
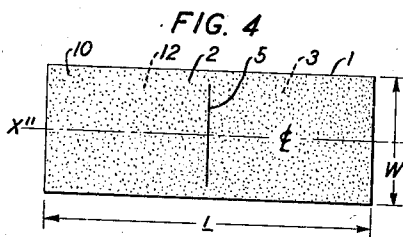
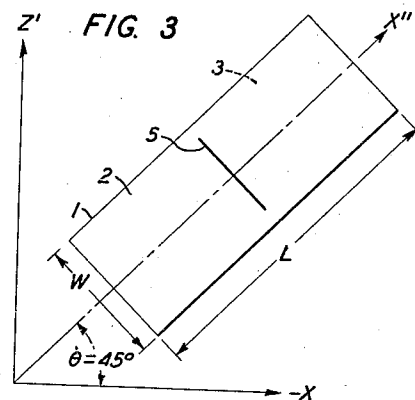
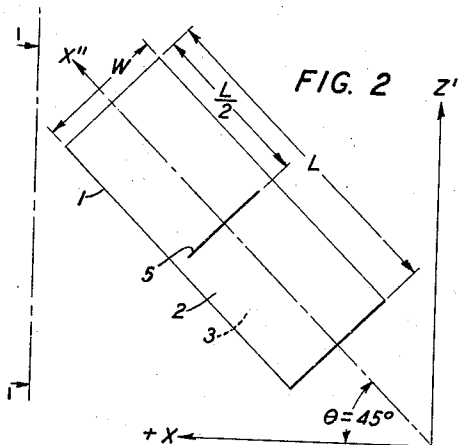
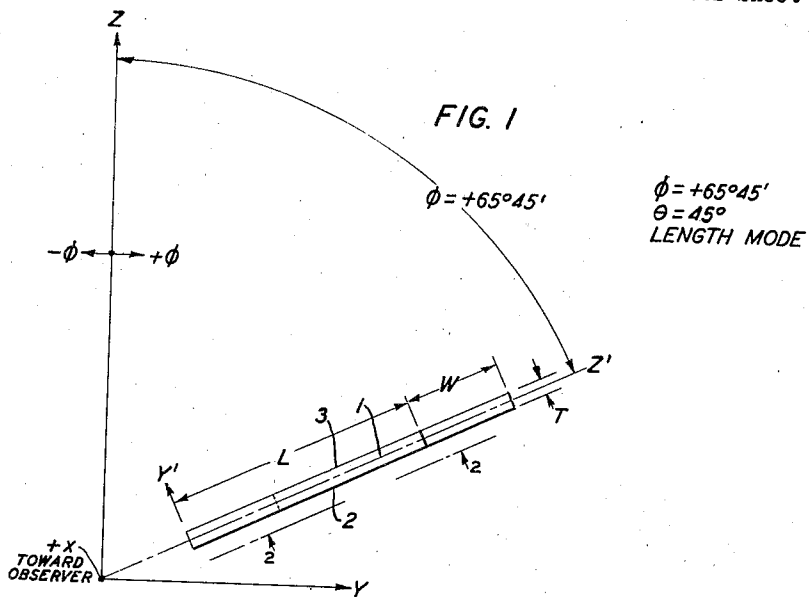
W. P. MASON

2,272,994

PIEZOELECTRIC CRYSTAL ELEMENT

Filed Dec. 14, 1940

2 Sheets-Sheet 1



INVENTOR
W. P. MASON
BY
W. J. O'Neill
ATTORNEY

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W. P. MASON

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PIEZOELECTRIC CRYSTAL ELEMENT

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2 Sheets-Sheet 2

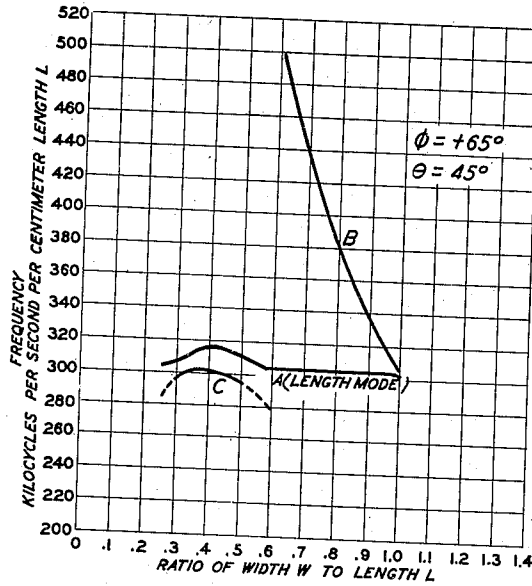


FIG. 6

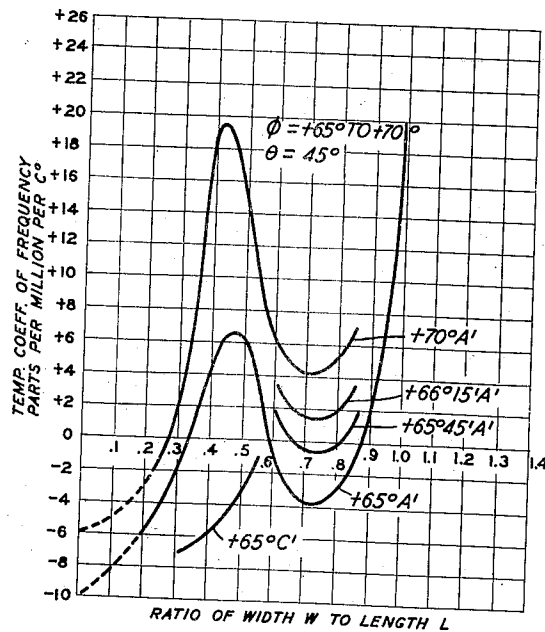


FIG. 7

INVENTOR
W. P. MASON
BY
W. J. O'Neill
ATTORNEY

UNITED STATES PATENT OFFICE

2,272,994

PIEZOELECTRIC CRYSTAL ELEMENT

Warren P. Mason, West Orange, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application December 14, 1940, Serial No. 370,127

12 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to length 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 width and length mode quartz crystal elements of low or substantially zero temperature coefficient of frequency are described. In the present application, length mode quartz crystal elements are described which also have a low temperature coefficient of frequency but differ therefrom in orientation angle, dimensional ratio values, and vibrational frequency characteristics.

One of the objects of this invention is to provide piezoelectric crystal elements having a low temperature coefficient of frequency over a wide range in the ratio of dimensions thereof.

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 secondary or extraneous frequencies near to the desired frequency.

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

In such systems as electric wave pilot channel filter systems and other filter 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 placed remotely 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, about 60 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.

The crystal elements provided in accordance with this invention may be constructed economically down to below 60 kilocycles per second, and

accordingly, are advantageous for use in low frequency 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 of the crystal plate in a mode of vibration which may be called a longitudinal or extensional mode. The orientation angles and the dimensional ratios of the crystal plate may be any of several in order to produce, for the desired length mode of motion, a low or substantially zero temperature coefficient of frequency, at temperatures within a range in the region of about 30° C. and over a wide ratio of the width to length dimensions of its major faces, the frequency of the desired length mode vibration being dependent mainly upon 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 0.64 to 0.83. 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 in the region between about +64 and +70 degrees. Such quartz crystal plates when suitably proportioned as to relative width and length dimensions exhibit for the length mode resonant frequency mentioned, a low or substantially zero temperature coefficient of frequency at ordinary room temperatures within a temperature range in the region of 30° C. In a particular species where the major plane of the crystal plate is inclined about +65 degrees 45 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 any value between about 0.64 and 0.83, the major axis length mode resonant frequency referred to has a nearly constant frequency value throughout a range of ordinary temperatures. Cut in the form of a plate, these crystal elements may be conveniently made to have a frequency within the range from about

60, or less, to 300, or more, kilocycles per second with a low temperature coefficient of frequency. Such crystal elements in the form of a plate 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 length 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 θ with respect to the X axis;

Figs. 4 and 5 are views of one form of electrode arrangement that may be used on the opposite major surfaces of the length 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 frequency spectrum of a typical length mode quartz crystal element in accordance with this invention; and

Fig. 7 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 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 the thickness dimension Y' 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 θ rotation of the Z' axis with respect to the Z axis as illustrated in Fig. 1 is toward parallelism with the plane of a minor apex face of the natural quartz crystal, and a negative (-) θ 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 +65 degrees 45 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 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 length dimension L in accordance with the preferred values of dimensional ratios as given herein in Figs. 6 and 7. The thickness dimension T may be of the order of 1 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 length mode crystal element 1 has nodal line regions 5 on each of its major surfaces 2 and 3. The nodal lines 5 are located transversely of and nearly perpendicular to the center line length dimension L or X' axis of the crystal element 1 at points spaced about 0.5 of the length dimension L from each end thereof, as shown in Figs. 2 to 5. At points on the nodal lines 5, the crystal element 1 may be mounted as by rigidly clamping it between one or more pairs of oppositely disposed clamping projections of small contact area which may, if desired, be inserted in small semispherical indentations or depressions provided in the quartz at opposite points on the nodal lines 5 on the opposite major surfaces 2 and 3 of the crystal element 1. Such small depressions cut in the major surfaces 2 and 3 of the crystal element 1 on or along the nodal lines 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 crystal electrodes 10 and 12 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 fundamental longitudinal length mode of motion at a response frequency which depends mainly upon and varies inversely as the major axis length dimension L, the desired frequency being a value of about 304 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 also upon the length L thereof, as illustrated in Fig. 6.

The crystal electrodes 10 and 12 of Figs. 4 and

5 when formed integral with the major surfaces 2 and 3 of the crystal element 1 may consist of thin conductive coatings of finely divided silver, aluminum, platinum or other suitable metallic or conductive material deposited upon the bare quartz by evaporation in vacuum or by other suitable process.

If desired, the crystal electrode 10 located on one major surface 2 of the crystal element 1 and the crystal electrode 12 located on the opposite major surface 3 thereof may be longitudinally centrally separated or split along the center line of the X' axis length dimension L, thereby forming four separate electrodes in order to obtain from the crystal element 1 two separate circuits of equal frequency and impedance. With such splits or separations in the crystal electrodes, the electrodes extend over the nodal points on the nodal lines 5 of the crystal element 1 and there may make individual electric contacts with the points of conductive clamping projections that may be disposed at such nodal points. The gap or separation in the electrode platings 10 and 12, if so split, may be about 0.365 millimeter, the center line of such splits in the platings on the opposite sides 2 and 3 of the crystal plate being aligned with respect to each other.

To drive the crystal element 1 in the desired length mode, the opposite electrodes, such as the crystal electrodes 10 and 12, apply a field in the thickness direction through the crystal element 1 in order to lengthen and shorten alternately the length dimension L, thus extending and contracting the long axis L of the crystal element 1 about the stationary nodal lines 5 in the desired longitudinal length mode of motion.

Fig. 6 is a graph showing the frequency characteristics of a quartz crystal element 1 having a θ angle of 45 degrees and a ϕ angle of substantially +65 degrees and having various values of ratio of the width dimension W with respect to the length dimension L. The curve labeled A in Fig. 6 shows the relation between the desired length 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 any value between about 0.56 and 0.9, the length mode frequency of a crystal element 1 having length dimension L of 1 centimeter and having a ϕ angle of substantially +65 degrees, is about 304 kilocycles per second. Since the frequency is inversely proportional to the length dimension L, a crystal element 1 of the same orientation and dimensional ratio but having a length dimension L of 5 centimeters will have a length mode frequency of one-fifth this value or about 60.8 kilocycles per second. As another example, a substantially +65 degrees 40 minutes ϕ angle crystal element 1 having a thickness dimension T of the order of 1 millimeter more or less, a length dimension L of 30.40 millimeters, and a width dimension W of from 19.45 to 25.23 millimeters, has a dimensional ratio of width W with respect to length L ranging from about 0.64 to 0.83 and, as shown by curve A of Fig. 6, has a low temperature coefficient length mode frequency of about 304 kilocycles per second per centimeter of length dimension L or about 100 kilocycles per second for the given length dimension L of 30.40 millimeters. 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 curve A of Fig. 6, when the ϕ angle is a value in the region from about $+64$ to $+70$ degrees, the θ angle always being substantially 45 degrees for every angle of ϕ .

In Fig. 6, it will be noted that the frequency spectrum of crystal element l having a ϕ angle in the region of $+65$ degrees 45 minutes is plotted as a function of the ratio of the width dimension W with respect to the length dimension L , the principal mode as represented by the curve A being the desired longitudinal vibration along the length dimension L of the crystal element l and having a frequency of about 304 kilocycles per second per centimeter of length dimension L when the dimensional ratio of axes W to L is between 0.56 and 0.9. Below the dimensional ratio of width W to length L of 0.56, the coupled shear and flexure mode, represented by the curve C of Fig. 6, becomes high enough in frequency to cross the main length mode represented by the curve A of Fig. 6 and cause a coupled circuit effect. Above the dimensional ratio of width W to length L of 0.9, the width mode represented by the curve B becomes prominent and affects the frequency of the main desired length mode represented by the curve A of Fig. 6. In the region about the dimensional ratio of width W to length L of 0.6, the only prominent extraneous frequency is the width mode which is considerably higher in frequency than the fundamental length mode, as shown by the curves B and A respectively of Fig. 6.

When the crystal plate l has a relatively wide width dimension W as compared to its length dimension L , the motion thereof is not exactly along the principal length dimension L and some shear motion exists. Hence the frequency and the temperature coefficient of frequency thereof may partake of that of 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 motion therein is essentially perpendicular to the width W and the frequency and the temperature coefficient of frequency are controlled mainly by Young's modulus of elasticity which controls the longitudinal vibrations along the length dimension L . 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 or ratios 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 $+70$ degrees, and consequently, when it is driven in the length mode by the electrodes 10 and 12 of opposite polarity, causing the crystal element l to expand and to contract mainly in longitudinal motion and partly in shearing motion, it may have a zero temperature coefficient of frequency at some selected dimensional ratio or ratios of width W to length L according to the value of the ϕ angle selected.

The curves of Fig. 7 give some orientation angles of ϕ , θ being 45 degrees, and the corre-

sponding dimensional ratios that may be used to construct quartz plates l to obtain a low or substantially zero temperature coefficient of length 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 positive angles of ϕ between about $+65$ and $+70$ degrees, the angle θ in every case being about 45 degrees as illustrated in either Fig. 2 or Fig. 3. While the angles of ϕ substantially within the range as given in Fig. 7 produce the substantially zero temperature coefficient of length mode frequency the angles of ϕ outside these values 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 curves of Fig. 7, are substantially given by the curve A of Fig. 6 at the intercept of the particular value of dimensional ratio selected. For example, when ϕ is substantially $+65$ degrees 45 minutes, 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 0.67 as indicated by the curves of Figs. 6 and 7, the frequency constant is about 304 kilocycles per second per centimeter of length dimension L .

In Fig. 7, the temperature coefficient of the length mode resonance frequency, represented by the curve A of Fig. 6, is illustrated by the curve $+65$ degrees A' of Fig. 7 and the temperature coefficient of the lower resonance, represented by the curve C of Fig. 6, is illustrated by the curve $+65$ degrees C' of Fig. 7. As shown by the curve $+65$ degrees A' of Fig. 7, when the width dimension W of the $+65$ degree ϕ angle crystal element l is nearly as large as the length dimension L thereof, the temperature coefficient of the length mode vibration is highly positive, but goes through zero at dimensional ratios of width W to length L of 0.372, 0.585, and 0.33, the last two ratios involving the presence of other strong modes.

The temperature coefficient of the length mode frequency of a $+70$ degree ϕ angle crystal element l , represented by the curve $+70$ degrees A' of Fig. 7, has a positive value in the useful dimensional ratio region of width W to length L from 0.6 to 0.85. In this same range of dimensional ratios, the temperature coefficient of the length mode frequency of a 66 degree 15 minute ϕ angle crystal element l has a still smaller positive value, as shown by the curve $+66$ degrees 15 minutes A' of Fig. 7.

When the ϕ angle is $+65$ degrees 45 minutes, the θ angle being 45 degrees, as illustrated by the curve labeled $+66^{\circ}45'$ A' of Fig. 7, the desired longitudinal vibration along the length dimension L of the crystal element l has a very low temperature coefficient of frequency over a wide dimensional ratio of width W to length L and over a wide temperature range, the temperature coefficient of frequency being less than one part in a million per degree centigrade throughout a ratio of width W to length L ranging from about 0.64 to 0.83. This wide range of permissible dimensional ratios is particularly advantageous for filter use in pilot channel filters, frequency suppression filters, and for other uses, since it allows any unwanted frequency to be put between channels where it will not change the temperature coefficient or cause difficulty or interference with the desired length mode longitudinal vibration.

Other values of corresponding orientation, di-

mensional ratio and frequency for crystal plates 1 that give a low 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 +70 degrees. In particular, it will be noted that the crystal elements 1 cut at the definite orientation angle of ϕ in the region of +65 degrees 45 minutes have a zero temperature coefficient of frequency when the ratio of axes of the width W with respect to the length L is about 0.67 or 0.81; and when the dimensional ratio of the width W with respect to the length L is any value from about 0.64 to 0.83, the ϕ angle of cut being +65 degrees 45 minutes, the temperature coefficient of frequency of the crystal element 1 is always less than 1 part per million per degree centigrade and may be conveniently placed in a range from about 60 kilocycles per second or less to 300 kilocycles per second or more by utilizing crystal elements of dimensions that are easily obtainable.

In the crystal element 1 having a ϕ angle of substantially +65 degrees 45 minutes, over a wide temperature range, the usual parabolic temperature-frequency curve obtains, the frequency being a maximum at about 30° C. and decreasing about 3 cycles in a million for a $\pm 10^\circ$ C. change from 30° C.

The only extraneous prominent resonance within this range of dimensional ratios from 0.64 to 0.83 is a width mode vibration illustrated by the curve B of Fig. 6 which in this range of dimensional ratio from 0.64 to 0.83 is from 20 to 56 per cent higher in frequency than the desired longitudinal mode along the length dimension L illustrated by the curve A of Fig. 6 and by the curve labeled +65°45'A' of Fig. 7.

The ratio of capacities for the +65 degree 45 minute ϕ angle crystal element 1 is of the order of about 670 throughout the dimensional ratio of width W to length L from 0.64 to 0.83, and the frequency constant is very nearly 303 kilocycles per second per centimeter of length dimension L throughout this range of dimensional ratios. The term ratio of capacities refers to the ratio of the internal or series capacity C_i with respect to the shunt capacity C_o 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 and 12 of the crystal plate 1 at opposite points of small area in the nodal region 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 region 5 of the crystal element 1, there is a minimum of damping of the vibratory motion of the crystal element 1. The nodal lines 5 are located as illustrated in Figs. 2 to 5. The crystal plate 1 is preferably clamped only at the nodal lines 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 lines 5 of the length 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. The fine supporting wires referred to may be conveniently soldered to four small spots or stripes, of "Hanovia" baked silver paste or other metallic paste, which have been previously applied at the nodal points only, either directly on the bare quartz or on top of the field producing crystal electrodes 10 and 12 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 or sealed glass or metal 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 length mode piezoelectric quartz crystal vibratory body having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined substantially +65 degrees 45 minutes 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.

2. A length mode piezoelectric quartz crystal vibratory body having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined substantially +65 degrees 45 minutes with respect to the Z axis as measured in a plane substantially perpendicular to said major faces, the major axis length di-

mension 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 0.81 with respect to said length dimension.

3. A length mode piezoelectric quartz crystal vibratory body having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined substantially +65 degrees 45 minutes 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 selected ratio with respect to said length dimension, said ratio being one of the values from substantially 0.64 to 0.83, said length dimension being of a value in accordance with the frequency of said length mode vibration.

4. A piezoelectric quartz crystal vibratory body of substantially zero temperature coefficient of length mode frequency having its opposite substantially rectangular major faces substantially parallel to an X axis and inclined at an angle of substantially +65 degrees 45 minutes 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 0.6 to 0.9 with respect to said length dimension.

5. A length mode 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 +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, the dimensional ratio of said width dimension with respect to said length dimension being a value substantially as given by one of the A' curves of Fig. 7 at a point thereon where the value of the temperature coefficient of frequency is less than 5 parts per million per degree centigrade.

6. A quartz piezoelectric body adapted to vibrate at a length mode frequency of low temperature coefficient dependent mainly upon the length or longest dimension 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 +65 to +70 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 of one of the values substantially from 0.6 to 0.9.

7. A piezoelectric quartz crystal body adapted to vibrate at a length mode frequency dependent mainly upon its major surface length dimension, the major surfaces of said body being substantially rectangular, disposed substantially parallel to an X axis and inclined substantially +65 degrees 45 minutes with respect to the Z axis 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 having a ratio of one of the values substantially from 0.6 to 0.9 with respect to said length dimension, said length dimension expressed in centimeters being substantially 304 divided by said frequency expressed in kilocycles per second.

8. A piezoelectric quartz crystal body of low temperature coefficient of frequency adapted to vibrate at a length mode frequency dependent mainly upon the length dimension 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 +70 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, the dimensional ratio of said width dimension with respect to said length dimension being substantially a value between 0.2 and 1.0, and said frequency being a value given by the curve A of Fig. 6 at the intercept thereon for said dimensional ratio.

9. A piezoelectric quartz crystal body of low temperature coefficient of frequency adapted to vibrate in a length mode of motion at a frequency dependent mainly upon the length dimension of its major surfaces, said frequency being a value given by the curve A of Fig. 6 for the dimensional ratio corresponding to a value of the dimensional ratios given by the curves A' of Fig. 7, said major surfaces being of substantially rectangular shape, disposed substantially parallel with respect to an X axis and inclined at an angle between +65 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 values given by the curves A' of Fig. 7.

10. A piezoelectric quartz crystal body adapted for length mode vibrations at a frequency dependent mainly upon the length dimension 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 +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 with respect to said length dimension of said major surfaces being a value between 0.6 and 0.9, said angle and said dimensional ratio having such relative values as to provide a low temperature coefficient for said frequency.

11. A piezoelectric quartz crystal body adapted for length mode vibrations at a frequency dependent mainly upon the length dimension of its substantially rectangular major surfaces, said major surfaces being substantially parallel to an X axis and inclined at an angle between +65 and +66 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 one of the values between substantially 0.6 and 0.9, said angle and said dimensional ratio being such relative values as to produce a low or substantially zero temperature coefficient for said frequency.

12. A length mode piezoelectric quartz crystal

element of low temperature coefficient of frequency having its major surfaces substantially parallel to an X axis and inclined at an angle between +65 and +66 degrees with respect to the Z axis, the length and width dimensions of said major surfaces being inclined substantially 45 degrees with respect to said X axis, the ratio of said width dimension with respect to said length dimension being a value between 0.6 and

0.9, opposite electrodes formed integral with said major surfaces, said electroded crystal element having nodes of motion, said nodes being transversely of the center line of said length dimension at points located from the ends thereof a distance substantially 0.5 of said length dimension.

WARREN P. MASON.