Dec. 30, 1941.

W. P. MASON

2,268,413

PIEZOELECTRIC CRYSTAL APPARATUS

Filed March 29, 1940

2 Sheets-Sheet 1

FIG. 1

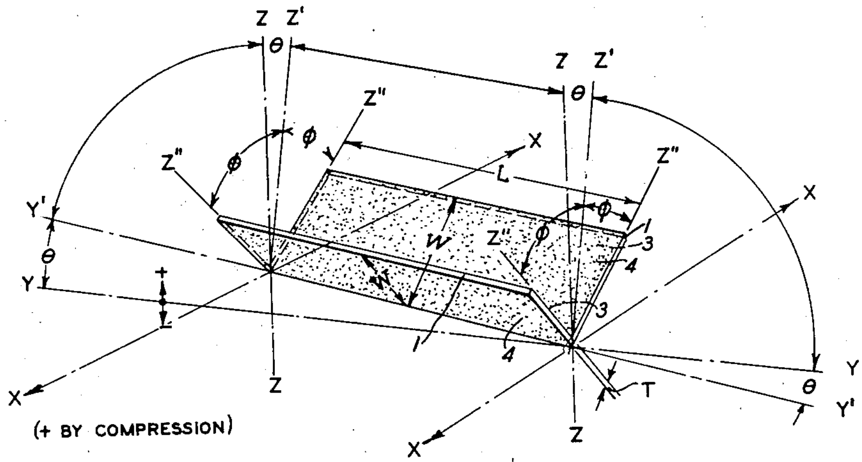


FIG. 2

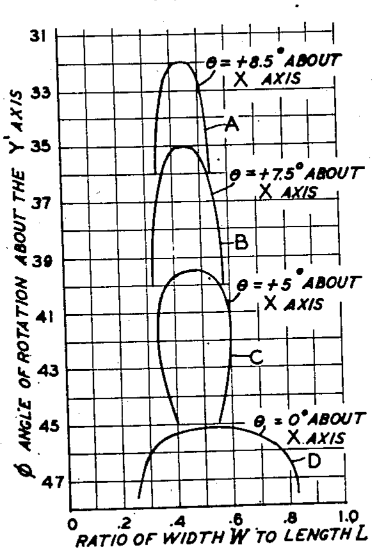
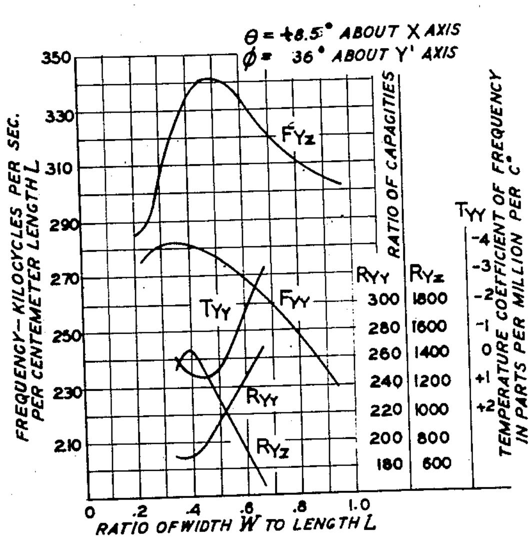


FIG. 3



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PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 4

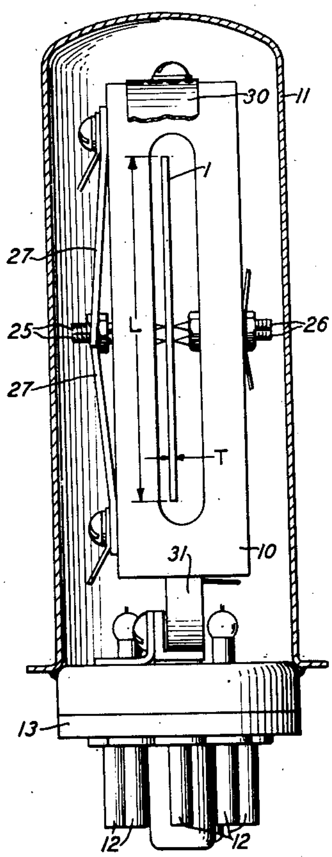


FIG. 5

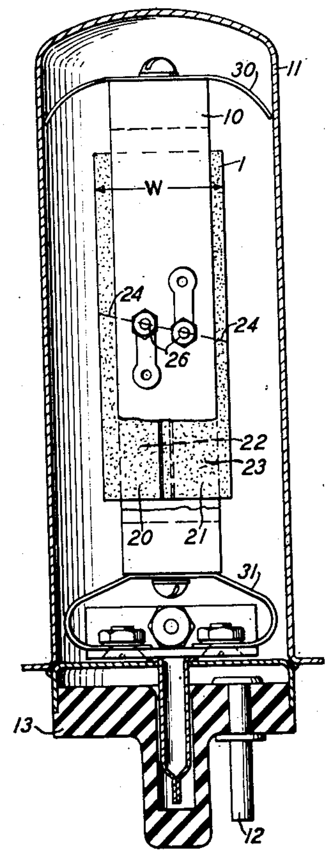
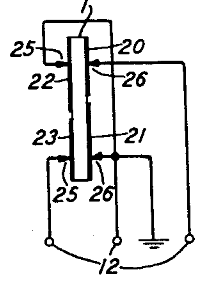


FIG. 6



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UNITED STATES PATENT OFFICE

2,268,413

PIEZOELECTRIC CRYSTAL APPARATUS

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Application March 29, 1940, Serial No. 326,764

16 Claims. (Cl. 171—327)

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

One of the objects of this invention is to provide piezoelectric crystals having a low or substantially zero temperature coefficient of frequency.

Another object of this invention is to provide relatively low frequency piezoelectric crystals having a very constant vibrational frequency throughout a wide range of temperatures.

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

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

Another object of this invention is to provide piezoelectric crystal elements having a small variation in temperature coefficient of frequency over a wide range of dimensional ratios.

In such systems as electric wave filter systems or oscillation generator systems, for example, it is often desirable to utilize longitudinally vibrating crystals which have a low temperature coefficient of frequency over wide range of temperatures and which are so constructed that any undesired prominent secondary resonances therein may be moved or 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, 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.

The piezoelectric crystal elements provided in accordance with this invention may have a low temperature coefficient of frequency over a wide range of dimensional ratios, and on account of this feature, they are advantageous for use in filter systems since any undesired secondary resonance frequency therein may, by adjustment of the dimensional ratio, be placed at a remote position where it will cause no harm, without disturbing the temperature coefficient of the desired resonant frequency. Also 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 50 kilocycles per second or less, and accordingly are advantageous for use in low frequency oscillators, filters and other low frequency systems.

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 ratios may be subjected to a thickness direction 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 motion which is herein called a longitudinal mode. The orientation angles and the dimensional ratios of the crystal plate may be any of several to produce for the longitudinal mode of motion a low or substantially zero temperature coefficient of frequency at temperatures within a range between about 0 and +80 degrees centigrade over a wide ratio of the width to length dimensions of its major faces, the frequency of the fundamental mode vibration along the length or longest dimension of the crystal element being approximately or roughly 275 kilocycles per second per centimeter of the length or longest dimension. In a particular embodiment, the ratio of the width dimension W with respect to length dimension L of the major surfaces may range from about 0.35 to 0.57 and the orientation may be that of an X cut crystal element rotated in effect about +8.5 degrees about its X axis or thickness dimension and then rotated from about 32 to 40 degrees about the major axis Y′ or length dimension L.

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:

Fig. 1 is a perspective view showing the orientation of piezoelectric quartz crystal elements cut in accordance with this invention;

Fig. 2 is a graph illustrating some preferred orientation angles and dimensional ratios of crystal elements in accordance with this invention;

Fig. 3 is a graph illustrating the characteristics of a typical crystal element in accordance with this invention;

Figs. 4 and 5 are front and side elevation views of a holder which may be used for mounting the crystal element; and

Fig. 6 is a schematic diagram of the electrical connections of the crystal unit shown in Figs. 4 and 5.

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 Y' of the piezoelectric body 1, as illustrated in Fig. 1, the orientation angles θ and φ respectively, designate in degrees the effective angular position of the crystal plate 1 as measured from the optic axis Z to the axis Z' and from the axis Z' to the axis Z'', respectively. The axis Z'' shown in Fig. 1 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-handed 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 θ 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 X 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 θ with respect to the Y axis or 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 Fig. 1 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, Fig. 1 is a perspective view showing a thin piezoelectric quartz crystal element 1 cut from crystal quartz free of twinning, veils or other inclusions and made into a substantially rectangular parallelepiped shape having a 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 other two dimensions L and W.

The final length dimension L of the crystal element 1 is determined by and is made of a value according to the desired resonant frequency. The width dimension W is preferably related to the length dimension L in accordance with the values of dimensional ratios as given herein. 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 is utilized.

The length dimension L of the crystal element 1 lies along a Y' axis in the plane of a mechanical axis Y and the optic axis Z of the quartz crystal material from which the element 1 is cut and is inclined at an angle of $+\theta$ degrees with respect to said Y axis, the angle θ being one of the values between substantially 0 and +10 degrees.

The major surfaces and the major plane of the crystal element 1 are disposed or inclined at an angle φ with respect to the plane of the Y and Z axes mentioned, the angle φ being the angle between the width dimension W lying along the Z'' axis and the Z' axis which lies in the plane of the Y and Z axes mentioned, the Z' axis being inclined at the angle θ with respect to the optic axis Z. The axis Z'' is accordingly the result of a double rotation of the width dimension W first about the X axis $+\theta$ degrees, and then φ degrees about the length dimension L or Y' axis. It will be noted that the crystal element 1 is in effect an X cut crystal rotated $+\theta$ degrees about the X axis and then rotated φ degrees about the Y' axis length dimension L.

The crystal plate 1 is shown in Fig. 1 as being inclined at a φ angle on opposite sides of the Z axis. It will be understood that either of these positions for the φ angle may be used alternatively with any φ angle disclosed herein.

Suitable conductive electrodes, such as the electrodes 3 and 4 of Fig. 1 or the electrodes **20**, **21**, **22** and **23** of Figs. 4 to 6, for example, may be placed on or adjacent to or formed integral with the opposite major surfaces of the crystal plate 1 in order to apply electric field excitation to the quartz plate 1 in the direction of the thickness dimension T, and by means of 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 mode of motion at a resonant response frequency which depends mainly upon and varies inversely as the major axis length dimension L, the frequency being a value within a range roughly from about 250 to 280 kilocycles per second per centimeter of the length dimension L, the particular value depending upon the orientation angles θ and φ of the crystal element 1.

The crystal electrodes 3 and 4 when formed integral with the major surfaces of the crystal element 1 may consist of thin coatings of silver, aluminum or other suitable metal deposited upon the bare quartz by evaporation in vacuum or by other suitable process, and may wholly or partially cover the major surfaces of the crystal element 1. Examples of partial electrodes for driving the crystal element 1 in the fundamental or harmonic longitudinal mode of motion along the length dimension L are illustrated in application Serial No. 219,325 filed July 15, 1938, by R. A. Sykes now United States Patent No. 2,223,537, dated December 3, 1940.

The crystal electrodes 3 and 4 may be longitudinally centrally divided or split along the length dimension L to form four separate electrodes in order to obtain two separate circuits of equal frequency from the single crystal element 1 or for other purposes. Figs. 4 to 6 illustrate such a division of the electrodes but with the two larger electrodes overlapping and interconnected to reduce the capacity of the electrode crystal element 1. The bare crystal element 1 may be etched in a solution of commercial hydrofluoric acid for a period of approximately 20 minutes before applying the electrode coatings thereto.

The crystal element 1 may be supported by any suitable means such as, for example, by clamping or otherwise supporting it along the nodal line which is located centrally midway between the small ends of the crystal element 1 and inclined about 11 degrees more or less with respect to the width dimension W. The sense of the direction of such 11-degree inclination with respect to the width dimension W may be easily determined by trial, the position giving the minimum resistance or damping being the correct one.

When the relatively thin longitudinally vibrated quartz crystal element 1 has a φ angle of substantially zero degrees and any θ angle between about 0 and +10 degrees, and the dimensional ratio of the width dimension W with respect to the length dimension L is relatively small as, for example, about 0.15. the temperature coefficient of the longitudinal mode vibrational frequency along the length dimension L is low or less than 0.7 part per million per degree centigrade at a temperature of about 30 degrees centigrade for all of such angles of φ up to about +10 degrees and where such angle of θ is substantially or very slightly greater than +8 degrees, the temperature coefficient of such longitudinal mode vibrational frequency is only about 0.2 part per million per degree centigrade over a wide range of ordinary temperatures. Such crystals and particularly the one having the θ angle of substantially +8.5 degrees, the φ angle being roughly zero degrees, are useful as oscillators or in other circuit element applications where a very low temperature coefficient of frequency is desired with a relatively high impedance in a long, thin and very narrow width form of crystal element.

If the width dimension W relative to the length dimension L of such crystal elements having a φ angle of substantially zero degrees and a θ angle within the range from about 0 to +10 degrees, be increased to values between 0.3 and 0.5, the temperature coefficient of the length or longitudinal mode frequency becomes of the order of about −4 up to −10 parts per million per degree centigrade at a temperature of about 30 degrees centigrade and for dimensional ratios of width W to length L about 0.5, the temperature coefficient of the longitudinal mode becomes more highly negative.

When the longitudinally vibrated crystal element 1 of Fig. 1 has a θ angle between about 0 and +10 degrees, and a φ angle between about 30 and 50 degrees, the crystals may have a low or substantially zero temperature coefficient of frequency over a wide range of dimensional ratios of the width W with respect to the length L thereof as illustrated by the curves A, B, C and D of Fig. 2.

Fig. 2 is a graph showing the relation between some of the θ and φ angles of cut and the corresponding values of the dimensional ratios of the width W with respect to the length L that may be utilized in connection with the crystal element 1 of Fig. 1 in order to obtain a substantially zero temperature coefficient of frequency for the longitudinal mode vibration thereof, the fundamental mode frequency being a value within the range between about 250 and 280 kilocycles per centimeter of the length dimension L. In Fig. 2, it will be noted that the φ angles illustrated range from about 32 to 47 degrees for θ angles from 0 to +8.5 degrees with dimensional ratios within a range from about 0.25 to 0.85 according to the θ and φ angles selected.

For example, when the θ angle is substantially +8.5 degrees as shown in the curve A of Fig. 2, the ratio of the width dimension W with respect to the length dimension L of the crystal element 1 may be between 0.33 and 0.52 for a φ angle from 32 to 36 degrees.

When the θ angle is substantially +7.5 degrees as shown in the curve B of Fig. 2, the ratio of the width dimension W with respect to the length dimension L of the crystal element 1 may be within a range from about 0.32 to 0.56 for a φ angle from 35 to 40 degrees.

Similarly, as shown by the curve C of Fig. 3 when the θ angle is substantially +5 degrees, the ratio of the width dimension W with respect to the length dimension L of the crystal element 1 may be within the range from about 0.33 to 0.60 for φ angles between about 39.5 degrees and 45 degrees.

When the θ angle is substantially 0 degrees as shown in the curve D of Fig. 2, the ratio of the width dimension W with respect to the length dimension L of the crystal element 1 may be within a range from about 0.25 to 0.85 for a φ angle from 45 to 47.5 degrees.

It will be noted that the curves A, B, C and length L dimensional ratios corresponding to certain θ and φ angles for which the crystal element will have substantially zero temperature coefficient of frequency for longitudinal mode vibrations.

While the curves A, B, C, and D of Fig. 2 illustrate the corresponding values of φ angles and dimensional ratios of width W to length L that may be used with crystal elements 1 having θ angles of substantially +8.5, +7.5, +5.0 and 0 degrees respectively, it will be understood that the corresponding values of φ angles and dimensional ratios for θ angles intermediate the values given or from 0 to about +10 degrees may also be obtained from the curves A, B, C and D of Fig. 2 by interpolation. For example, when the θ angle is about +8.0 degrees and the φ angle about 36 degrees the dimensional ratio of the width W with respect to the length L of the crystal element may be any value near to or between 0.33 and 0.52.

It will be noted from the curves of Fig. 2 that for any θ angle between about 0 and +10 degrees the dimensional ratio of the width W with respect to the length L may be between about 0.35 and 0.50 with a wide range of suitable φ angles as indicated by the ordinate values given in Fig. 2. It will be understood that the longitudinal mode resonant frequency hereinbefore referred to of all of such crystals will have a low temperature coefficient at one or more temperatures within a wide range of temperatures between roughly 0 and 80° centigrade.

Fig. 3 is a graph showing the characteristics of a quartz crystal element 1 having a θ angle of substantially +8.5 degrees and a φ angle of substantially 36 degrees and having various values for the ratio of its width dimension W with respect to its length dimension L, as given by the curve A of Fig. 2. The curve labeled Fy_y of Fig. 3 shows the relation between the desired fundamental longitudinal mode resonant frequency Fy_y thereof, expressed in kilocycles per second per centimeter of the length dimension L, and the ratio of the width dimension W with respect to the length dimension L. For example, when the dimensional ratio of the width W to the length L is about 0.38, the longitudinal mode resonant frequency Fy_y of a crystal element 1 having a length dimension L of one centimeter and having θ and φ angles of substantially +8.5 and 36 degrees respectively, is about 282 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 four centimeters for example will have a longitudinal mode resonant frequency Fy_y of one-fourth this value or about 70.5 kilocycles per second. Similarly, the frequency and the corresponding length dimension L may be obtained for any other size of crystal element.

The curve Ty_y of Fig. 3 shows the relation between the temperature coefficient of the longitudinal mode resonant frequency Fy_y and the ratio of the width dimension W with respect to the length dimension L. It will be noted that for all of the dimensional ratios of W to L between about 0.33 and 0.52, as shown by the curve labeled Ty_y of Fig. 3 and somewhat beyond these values as is shown by the curve Ty_y of Fig. 3, the crystal element 1 having a θ angle of substantially +8.5 degrees and a φ angle of substantially 36 degrees has a low or substantially zero temperature coefficient of frequency Ty_y over a wide range of ordinary temperatures above and below 30° centigrade. As shown by the curve Ty_y of Fig. 3, this crystal element has a maximum positive temperature coefficient of frequency of about +0.6 part per million per degree centigrade within the range of dimensional ratios between about 0.34 and 0.52, the zero temperature coefficient of frequency occurring at the dimensional ratio values of about 0.34 and 0.52.

As shown in Fig. 3, in addition to the resonant frequency labeled Fy_y, there is also another prominent resonant frequency labeled Fy_z, the former being the longitudinal mode vibration along the length dimension L of the crystal element 1 and the latter being the face shear mode which may be coupled to a flexural mode for certain dimensional ratios of width W to length L. These two prominent resonant frequencies labeled Fy_y and Fy_z are very similar to those occurring in an X cut crystal as described in a former paper by the applicant entitled "Electrical Wave Filters Employing Quartz Crystals as Elements," Bell System Technical Journal, July 1934, pages 405 to 452.

The ratios of capacities for the two modes Fy_y and Fy_z are given by the curves Ry_y and Ry_z respectively of Fig. 3. When the dimensional ratio of width W to length L is within the preferred ranges as given by the curves of Fig. 2, the lower frequency longitudinal mode Fy_y is considerably stronger than that of the higher frequency mode Fy_z. Where the secondary resonant frequency Fy_z has a frequency value and a ratio of capacities relatively high with respect to those of the desired resonance Fy_y, the importance of the former is decreased.

As another example from curve A of Fig. 2, a crystal element 1 having a θ angle of substantially +8.5 degrees and a φ angle of substantially 34 degrees has a maximum positive temperature coefficient for its longitudinal mode vibrational frequency along the length dimension L of about +.4 part per million per degrees centigrade and a zero temperature coefficient at the dimensional ratios of about 0.36 and 0.51. Where crystals having the lowest temperature coefficient over the widest temperature range are desired, those selected from the curve A of Fig. 2 may be used, the θ angle thereof being about +8.5 degrees, the φ angle being between 32 and 36 degrees, and the dimensional ratio being a value within the ranges given by the curve A of Fig. 2.

As an example from the curve C of Fig. 2, a crystal element 1 having a θ angle of substantially +5 degrees and a φ angle of about 40 degrees has a temperature coefficient for its longitudinal mode resonant frequency of less than 0.2 part per million per degree centigrade for dimensional ratios of width W to length L between about 0.35 and 0.57. Over this ratio, the secondary resonant frequency Fy_z changes by a considerable amount and hence it can be placed in a favorable position where it can do no harm to the desired longitudinal mode frequency Fy_y which has the low temperature coefficient.

As another example from the curve C of Fig. 2, a crystal element 1 having a θ angle of substantially +5 degrees and a φ angle of substantially 45 degrees has a temperature coefficient for its longitudinal mode frequency of less than one part per million per degree centigrade over a dimensional ratio of width W to length L from about 0.40 to 0.55.

In these longitudinally vibrated crystals and especially in those having the orientation angles and dimensional ratios as given by the curve A of Fig. 2, the first derivative a_1 and also the second derivative a_2 of the frequency with temperature may be zero—similar to the crystal designated GT in my application Serial No. 180,921 filed December 21, 1937, now United States Patent 2,204,762 dated June 18, 1940, and hence they may have a very small frequency variation throughout a wide temperature range. At the same time, they are relatively small in size for a given frequency and can be economically made for operation considerably below 100 kilocycles per second at the fundamental mode longitudinal vibration frequency which is dependent mainly on the length dimension L lying along the Y' axis of the quartz. Also the dimensional ratio of axes W to L can be varied over a wide range without affecting the desired low temperature coefficient of frequency and hence the one prominent undesired secondary resonance therein may be changed or moved to any convenient position without affecting the temperature coefficient of the desired frequency.

The crystal elements described herein 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 electroded crystal plate 1 at opposite points of very small area along the nodal line of the crystal element 1. Figs. 4 and 5 illustrate a suitable holder of this type.

Figs. 4 and 5 are front and side elevation views of a crystal holder unit which consists of an electroded quartz crystal plate 1 mounted by clamping means in an Isolantite or other insulating mounting block 10 and assembled inside an evacuated metal bulb 11 which is equipped with at least three external conductive pin terminals 12 arranged for mounting in a suitable socket (not shown). As shown in Figs. 4 to 6, the quartz crystal plate 1 is provided with four separate electrodes 20, 21, 22 and 23 which are formed integral with the opposite major surfaces of the crystal element 1 by depositing thereon thin films of metal, such as thin films of silver or aluminum deposited by evaporation in vacuum, or by any other suitable process.

As shown in Figs. 4 and 5, the electroded crystal element 1 is clamped along its nodal line 24 between four conductive contact clamping pins 25 and 26 which may be composed of gold-plated brass, the clamping points thereof being individually in contact with the four electrodes 20, 21, 22 and 23 of the crystal element 1. The two clamping contact pins 26 which are disposed on one side of the crystal element 1 are fixed in the "Isolantite" mounting block 10 while the oppositely disposed clamping contact pins 25 located on the opposite side of the crystal element 1 are slidable in suitable brass bushings placed in openings in the mounting block 10. The clamping members 25 are pressed against the electroded crystal element 1 by means of two separate springs 27 which are secured to the outer surface of the mounting block 10. The pressure exerted by each of the springs 27 on the movable contacts 25 may be about 1 to 3 pounds or sufficient to hold the clamped crystal element 1 against bodily movement out of a predetermined position when placed between the two pairs of clamping points 25 and 26.

The two pairs of clamping points 25 and 26 are oppositely disposed with respect to each other and axially disposed perpendicular to the major surfaces of the crystal element 1 and since they make contact only along the nodal line 24 of the crystal element 1, there is a minimum of damping of the vibratory motion of the crystal element 1. The nodal line 24 is inclined roughly 11 degrees with respect to the width dimension W of the crystal element 1 as illustrated in Fig. 5. The crystal plate 1 is preferably clamped only along the nodal line 24 in order to obtain the minimum effective resistance at resonance. The mounting block 10 is resiliently supported within the metal bulb 11 at or near its opposite ends by two phosphor bronze springs 30 and 31. The metal bulb 11 may be soldered vacuum tight to the header assembly 13. The vacuum within the tube 11 may be made about 0.1 millimeter of mercury absolute. The crystal plate 1 is adjusted to the desired series resonance frequency by reducing the length dimension L of the crystal plate 1. 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.

Fig. 6 is a schematic diagram showing the electrical connections between the crystal electrodes 20, 21, 22 and 23 and three of the pin terminals 12 which extend from the base or header assembly 13 of the bulb or tube 11. As shown in Fig. 6, the electrode 20 is connected with one of the pin terminals 12, the crystal electrode 23 is connected with another of the pin terminals 12, and the crystal electrodes 21 and 22 are interconnected and connected with a third pin terminal 12 which is grounded. The two larger crystal electrodes 21 and 22 may overlap as illustrated in Fig. 6 in order to reduce the capacity of the electroded crystal element 1. The interconnection between the electrodes 21 and 22 may be made by extending the integral metal plating around the top or bottom edge of the crystal element 1 or by a flexible insulated wire within the tube 11 extending around the top of the mounting block 10 and connected with the proper terminals of the clamping points 25 and 26. The two pairs of clamping projections 25 and 26 serve not only to clamp the crystal element 1 to hold it in position but also to establish the individual electrical connections with its electrodes 20 to 23 of the crystal element 1.

Since the crystal electrodes 21 and 22 of Fig. 6 are interconnected, a continuous conductive clamping spring surrounding the crystal element 1 may be utilized for clamping the crystal element 1 between one or more pairs of clamping projections extending from the opposite sides thereof and also contacting the electrodes 21 and 22 for simultaneously providing the interconnection between the two larger crystal electrodes 21 and 22 of Fig. 6. At points where such projections may contact the high potential electrodes 20 and 23, they may be insulated therefrom by removing the plating 20 and 23 directly under the points of contact. Such a spring arrangement may be of the type shown in application Serial No. 248,437 filed December 30, 1938, by W. L. Bond, now United States Patent 2,203,486 dated June 4, 1940, but free of insulation between the spring parts. The electrical connections for the two remaining crystal electrodes 20 and 23 may then be established by means of two separate wires soldered thereto preferably along the nodal line 24 of the crystal element 1.

Alternatively instead of being mounted by clamping as illustrated in Figs. 4 to 6, 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 along its nodal line 24 or along its central width dimension line W. The fine supporting wires referred to may be conveniently soldered to four narrow stripes of baked silver paste or other metallic paste which has been previously applied along the central width dimension line W either directly on the bare quartz or on top of the field producing crystal electrodes 20 to 23 which may consist of pure silver applied by the known evaporation in vacuum process. Such fine supporting wires secured to the electroded crystal element 1 may extend horizontally from the vertical major surfaces of the crystal element 1 and at their opposite ends be attached by solder, for example, to four vertical spring conductive wires carried by the press or other part of an evacuated glass tube 11. The spring wires may have one or more bends therein to resiliently absorb mechanical vibrations. Also, bumpers or stops of soft resilient material may be spaced adjacent the edges or other parts of the crystal element 1 to limit the bodily displacement thereof when the device is subjected to mechanical shock. It will be understood that any holder 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 element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined or disposed at an angle within the range from substantially +5 to +8.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 48 degrees with respect to said YZ plane, said length dimension being a value in accordance with the value of said frequency, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.25 to 0.85.

2. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined or disposed at an angle within the range from substantially +5 to +8.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 48 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.25 to 0.85, said length dimension expressed in centimeters being a value within the range from substantially 250 to 280 divided by said frequency expressed in kilocycles per second.

3. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined or disposed at an angle within the range from substantially 0 to +10.0 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 48 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.25 to 0.85, said angles and said dimensional ratio being values as given by the curves of Fig. 2.

4. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined or disposed at an angle within the range from substantially 0 to +10.0 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 48 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.25 to 0.85, said length dimension expressed in centimeters being a value within the range from substantially 250 to 280 divided by said frequency expressed in kilocycles per second, said angles and said dimensional ratio being values as given by the curves of Fig. 2.

5. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +8.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 40 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.56.

6. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +8.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 40 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.56, said length dimension expressed in centimeters being substantially 280 divided by said frequency expressed in kilocycles per second.

7. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +8.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 40 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.56, said angle and said dimensional ratio being values as given by the curve A of Fig. 2.

8. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature

coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +8.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 30 to 40 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.56, said length dimension expressed in centimeters being substantially 280 divided by said frequency expressed in kilocycles per second, said angle and said dimensional ratio being values as given by the curve A of Fig. 2.

9. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +8.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 34 to 36 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.33 to 0.52, said length dimension expressed in centimeters being substantially 280 divided by said frequency expressed in kilocycles per second.

10. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +7.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 35 to 40 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.56.

11. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +7.5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 35 to 40 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.56, said angle and said dimensional ratio being values as given by the curve B of Fig. 2.

12. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 39 to 45 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.60.

13. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined substantially +5 degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 39 to 45 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.30 to 0.60, said angle and said dimensional ratio being values as given by the curve C of Fig. 2.

14. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and disposed substantially zero degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 45 to 50 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.25 to 0.85.

15. A piezoelectric quartz crystal element adapted to vibrate at a frequency of low temperature coefficient dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and disposed substantially zero degrees with respect to said Y axis, said major surfaces being inclined at an angle within the range from substantially 45 to 50 degrees with respect to said YZ plane, the ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.25 to 0.85, said angle and said dimensional ratio being values as given by the curve D of Fig. 2.

16. A quartz piezoelectric crystal element of low temperature coefficient adapted to vibrate at a frequency dependent mainly upon the length or longest dimension of its major surfaces, said length dimension being a value in accordance with the value of said frequency, said major surfaces being substantially parallel to the plane of a Y axis and the Z axis, said length dimension being inclined substantially +8 degrees with respect to said Y axis, and the ratio of the width dimension of said major surfaces with respect to said length dimension being substantially 0.15.

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