Nov. 12, 1946. C. E. LANE 2,410,825

PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 1

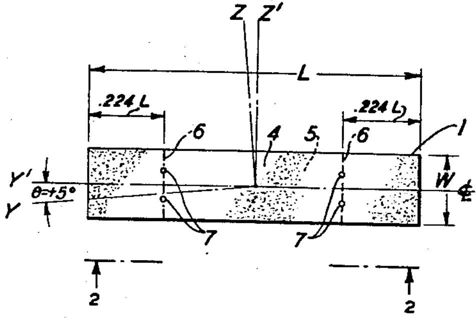

FIG. 5

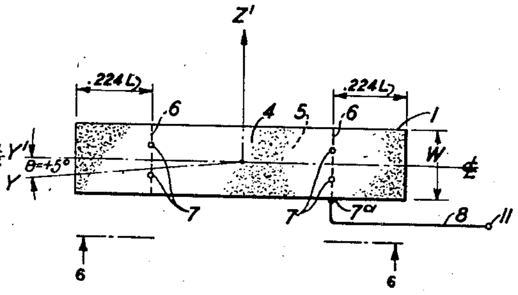

FIG. 2

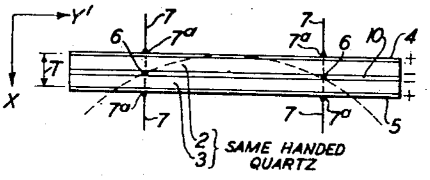

FIG. 6

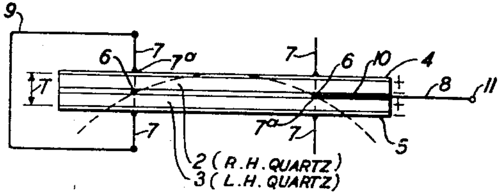

FIG. 3

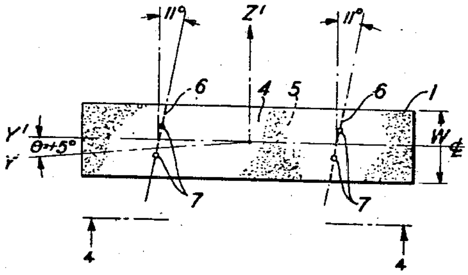

FIG. 7

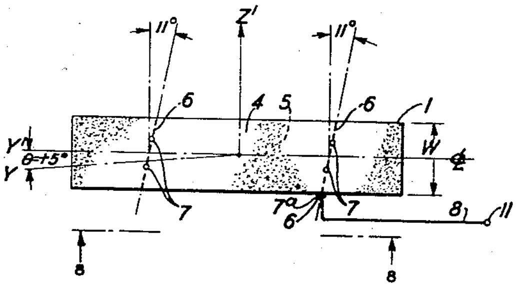

FIG. 4

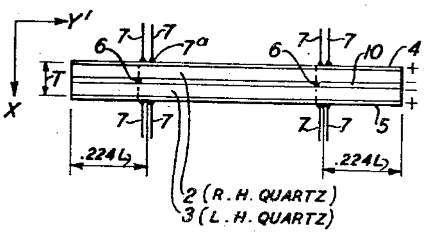

FIG. 8

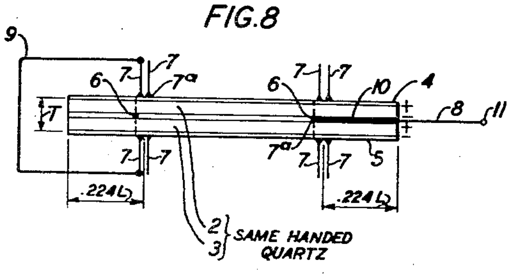

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FIG. 9

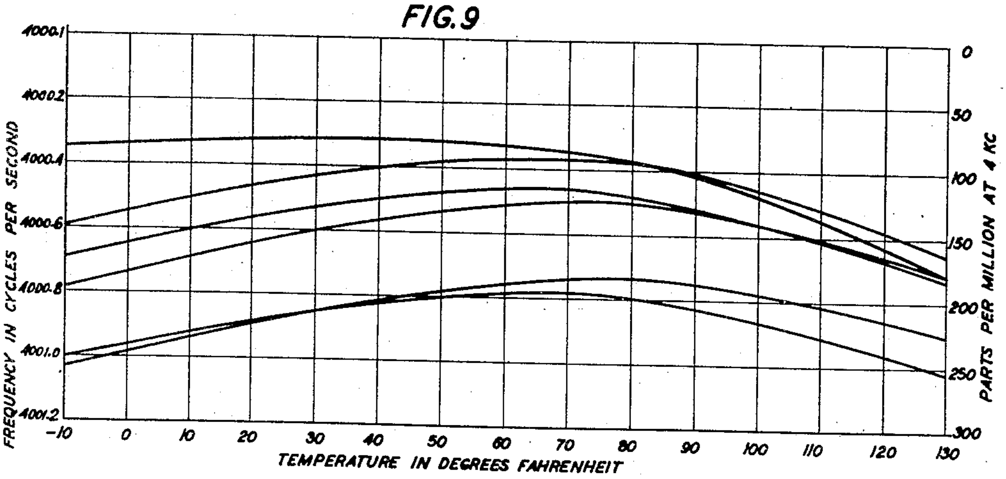


FIG. 10

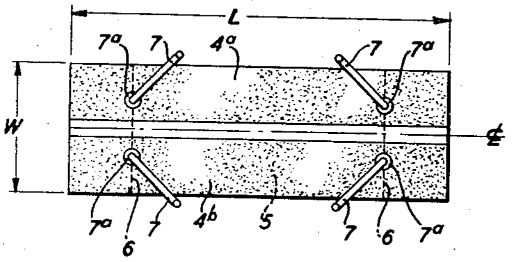


FIG. 11

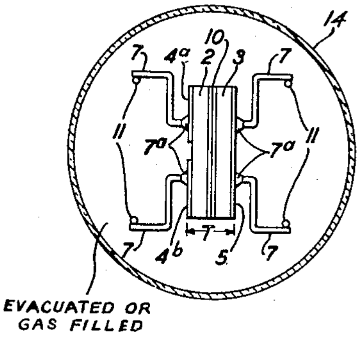


FIG. 12

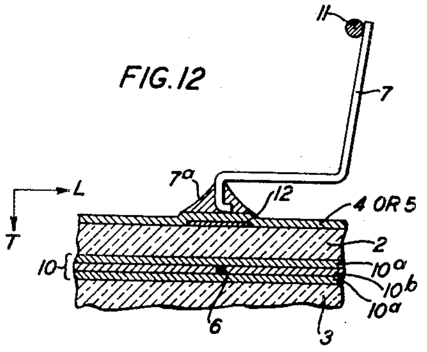
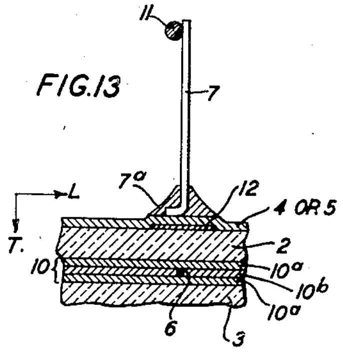


FIG. 13



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2,410,825

UNITED STATES PATENT OFFICE

2,410,825

PIEZOELECTRIC CRYSTAL APPARATUS

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Application March 4, 1943, Serial No. 477,915

21 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to low frequency flexure mode composite or duplex type quartz crystals, suitably bonded together and mounted for use as frequency control units in such systems as oscillation generator systems, electric wave filter systems, and in electromechanical vibratory systems generally.

One of the objects of this invention is to provide a composite or duplex type flexure mode piezoelectric crystal body of low temperature coefficient of frequency.

Another object of this invention is to provide a duplex type flexure mode piezoelectric crystal body with such nodes of motion that the body may be there supported and electrically connected with minimum interference with its desired frequency of vibration.

Another object of this invention is to provide a low temperature-frequency coefficient piezoelectric crystal body of relatively low impedance, and of relatively small and economical size at low frequencies such as, for example, frequencies below 5 or 10 kilocycles per second.

In such systems as low frequency electric wave filter systems and oscillation generator systems, for example, it is often desirable to utilize vibratory crystals which have a low temperature coefficient of frequency at a low frequency such as a frequency below 5 to 10 kilocycles per second, and which for many applications may have a relatively lower impedance than is usually attainable in former low frequency, low temperature coefficient crystals. It is also desirable that such crystals be of relatively small and convenient size in order to save quartz and to avoid the expense that is usually involved in crystals of the relatively larger sizes. Since the crystals provided in accordance with this invention may have a relatively small size at low frequencies, they may be constructed economically down to below 1 kilocycle 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 bonded piezoelectric quartz crystal plates of suitable handedness, orientation, electric poling, and dimensions may be subjected to a thickness direction electric field or fields and vibrated at a resonance frequency thereof dependent both upon the longest or length dimension and also upon the thickness dimension of the bonded crystal plates in a mode of vibration which may

be called a flexural mode bending in the thickness direction. To obtain a low temperature coefficient of frequency, the orientation of each of the bonded crystal plates may be that of an X-cut crystal element rotated in effect about +5 degrees about its X axis thickness dimension, which may be called a +5-degree X-cut crystal element. Examples of quartz crystal cuts, which may be utilized in the face-to-face bonded form of this invention to obtain a low frequency of low temperature coefficient, are disclosed in W. P. Mason Patent 2,259,317, dated October 14, 1941, which discloses the +5-degree X-cut crystal element, and in W. P. Mason Patent 2,268,413 dated December 30, 1941, which discloses a +5-degree X-cut type of crystal element that is in addition rotated in effect about its length or longest dimension L.

While the +5-degree X-cut crystal element gives a low temperature coefficient of frequency for any of the smaller dimensional ratios of the width W with respect to the length L thereof, certain ratios such as, for example, a width W to length L ratio of about from .20 to .35 may be utilized to obtain a low temperature-frequency coefficient over a quite wide temperature range.

The composite or duplex type piezoelectric crystal body may consist of two +5-degree X-cut type quartz crystal plates, or of other suitable cut of crystal plates which preferably have a low temperature coefficient of frequency for their length longitudinal mode of vibration. The two crystal plates may be soldered or otherwise securely bonded together in face-to-face relation to form the composite or duplex type piezoelectric crystal body and with a suitable electric field applied thereto, the composite crystal body is adapted for flexure mode vibrations bending in the thickness direction along two nodal regions located about .224 of the length dimension from each end thereof. The frequency of vibration may be a low frequency of the order of 1 to 10 kilocycles per second, more or less, dependent mainly upon the length and thickness dimensions selected for the composite body. With such a composite crystal body a low frequency may be obtained with a relatively small amount of quartz material and where the individual crystal elements thereof are made of a suitable cut such as +5-degree X-cut type crystal plates of suitable handedness and poling, a very low temperature coefficient of frequency of the order of 0.3 cycle per million per degree centigrade may be obtained for the composite flexure mode vibrator.

The two quartz crystal plates to be bonded may be made from quartz of the same handedness or one of them may be of left-handed quartz and the other of right-handed quartz. When the two bonded quartz crystal plates are made of the proper handedness and electric poling with respect to each other, the resultant nodal lines of the composite body may be perpendicular to the length dimension and the long edges thereof. The crystal body may be conveniently mounted at points on or as near as possible to such nodal lines with a minimum of interference with the desired vibration of the crystal body. The crystal mounting may consist of pressure type clamping pins or alternatively of fine spring wires soldered to the crystal major surface electrodes or to side surface coatings at any point or points on or as near as possible to such nodal lines.

Examples of crystal wire supporting systems that may be utilized are illustrated in A. W. Ziegler United States Patent 2,275,122, dated March 3, 1942. If desired, the crystal supporting wires may be provided with vibration damping means, or with nodal reflectors as disclosed in I. E. Fair United States Patent 2,371,613, dated March 20, 1945, granted on application Serial No. 470,759, filed December 31, 1942, in order to remove the adverse effects of undesired wire vibrations on the crystal frequency and activity. When provided with such nodal reflectors, the crystal supporting wires attached to the crystal body may have a natural frequency that is substantially equal to the frequency of the piezoelectric crystal body whereby the crystal body and its supporting spring wires secured thereto operate as a composite vibrator at a common natural frequency with minimum interference with the crystal frequency and activity.

For operation at the fundamental flexure mode frequency, the crystal electrodes may substantially wholly cover the two outside major faces of the bonded crystal plates. For operation at any overtone or harmonic frequency of the fundamental flexure mode, the crystal electrodes may consist of a plurality of pairs of interconnected platings to drive the bonded crystal at any selected overtone flexure mode frequency, as illustrated, for example, in W. G. Cady United State Patent 1,860,529, dated May 31, 1932. The crystal electrodes may fully, or may partially cover the outer major surfaces of the bonded crystal plates leaving in the latter case, the end areas thereof uncovered and the central areas covered, in order to obtain a desired value of capacitance, or an improved driving efficiency that may result from such partial electrodes.

To reduce or adjust the frequency of the duplex type flexure mode crystal unit, it may be loaded as by the addition of metal onto the major surfaces thereof. With such loading, bonded crystal plates of given dimensions may be used at a somewhat lower frequency than the unloaded crystal unit, a feature which is of special interest at the very low frequencies where the unloaded crystal plates may become too long and too thin for convenient use.

The crystal plates may be bonded by spraying the major surfaces to be bonded with a solution of Hanovia silver paste, baking the sprayed crytal plates at an elevated temperature in order to fix the silver paste coating firmly to the surface of the quartz, burnishing the baked silver layer and then tinning it, using a stearin flux and a solder to which is added silver sufficient for saturation at the melting temperature, placing the quartz plates to be bonded with the tinned surfaces together and applying sufficient pressure to force out the excess molten solder. The addition of silver to the solder discourages the molten solder from absorbing the thin film of silver which has been baked on the quartz plates. The baked silver film is of the order of 0.2 mil in thickness.

The bonding means between the two +5-degree X-cut type or other type crystal plates may include a thin metal plate secured between the two crystal plates and made of steel or other metal suitably proportioned with respect to the crystal plates in order to obtain a temperature coefficient of frequency of selected value for controlling the over-all temperature coefficient of frequency of the bonded crystal unit. If desired, one of the two bonded crystal plates could be made of non-piezoelectric material such as, for example, a metal plate secured thereto and made to have a temperature-frequency coefficient to balance that of the piezoelectric crystal plate secured thereto, thereby to obtain a low over-all temperature-frequency coefficient for the bonded unit.

The duplex type flexure mode crystal body supported at or as near as possible to its nodes by supporting wires or by other suitable supporting means may be mounted in an evacuated or sealed metal or glass tube or other suitable sealed container, as disclosed for example in the A. W. Ziegler Patent 2,275,122 hereinbefore referred to.

The sealed crystal container may be evacuated or alternatively, it may contain dry air or other inert gas which may be heavier or lighter than air and of suitable density or pressure which may be greater or less than atmospheric pressure, in order to suppress or damp out the weaker secondary resonances of the crystal body or to slightly damp the major or desired resonance thereof in case of excessive vibration and for other purposes such as to control or adjust the frequency of the desired resonance or resonances. Examples of gases which may be used to provide an inert atmosphere for control of the crystal resonances are helium, neon, hydrocarbons, carbon dioxide, argon, krypton, xenon.

For a clearer understanding of the nature of this invention and the additional 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 major face and a long side edge, respectively, of wire mounted, electroded and bonded fundamental flexure mode +5-degree X-cut quartz crystal plates which are constructed of the same handed quartz and poled oppositely;

Figs. 3 and 4 are, respectively, major face and long side edge views of bonded quartz crystal plates similar to those of Figs. 1 and 2 but constructed of opposite handed quartz;

Figs. 5 and 6 are, respectively, major face and long side edge views of bonded quartz crystal plates similar to those of Figs. 3 and 4 but provided additionally with an inner electrode connection;

Figs. 7 and 8 are, respectively, major face and long side edge views of bonded quartz crystal plates similar to those of Figs. 5 and 6 but constructed of the same handed quartz;

Fig. 9 is a graph illustrating the temperature-frequency characteristics of bonded +5-degree X-cut quartz crystal plates;

Figs. 10 and 11 are, respectively, enlarged views of a major face and the small end of a bonded crystal body that is provided with a longitudinally divided electrode coating and a wire supporting system;

Fig. 12 is a greatly enlarged view of details of the crystal unit, illustrated in Figs. 10 and 11; and

Fig. 13 is a greatly enlarged view illustrating a modification of the device shown in Fig. 12.

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 a single rotation of the quartz crystal element substantially about an electric axis X, as particularly illustrated in Figs. 1 to 8, the orientation angle θ designates in degrees the effective angular position of the crystal plate as measured from the optic axis Z and from the orthogonal mechanical axis Y.

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. 100, page 807 (1922). 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 2 or 3 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 Y′ makes with respect to the axis Y 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 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 2, illustrated in Figs. 1 to 8, is right-handed as the term is used herein. For either right-handed or left-handed quartz, a positive (+) angle θ rotation of the Y′ axis with respect to the Y 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 Y′ axis with respect to the Y axis is toward parallelism with the plane of a major apex face of the natural quartz crystal.

Referring to the drawings, Figs. 1 to 8 are major face and corresponding long side edge views of thin piezoelectric quartz crystal plates or elements 2 and 3 cut from crystal quartz free from twinning, veils or other inclusions and made into a bonded plate 1 of 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 major axis length dimension L of the bonded quartz crystal elements 2 and 3 of Figs. 1 to 8 is determined by and is made of a value according to the desired flexure mode resonant frequency. The thickness dimension T also is related to the desired flexure mode frequency. The width dimension W may be of the order of one-fifth or other suitable value relative to the length dimension L to suit the desired frequency of the bonded flexure mode crystal elements 2 and 3.

The length dimension L of each of the individual crystal plates or elements 2 and 3 of Figs. 1 to 8 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 elements 2 and 3 are cut, and is inclined at a positive (+) θ angle of degrees with respect to said Y axis, the angle θ being one of the values between about +4 and +6 degrees more or less, or substantially +5 degrees. The major surfaces and the major planes of the crystal elements 2 and 3 are disposed substantially in the plane of the Y and Z axes mentioned. The angle between the width dimension W, which lies along the Z′ axis in the plane of the Y and Z axes mentioned, and the Z axis is also inclined at the angle θ with respect to the optic axis Z. It will be noted that the individual crystal elements 2 and 3 of Figs. 1 to 8 are in effect X-cut crystals rotated θ=substantially +5 degrees about the X axis. At this angle of θ=+5 degrees, tests show that the first or fundamental flexural mode vibrational frequency has a low temperature coefficient of frequency. While the individual crystal plates 2 and 3 are shown in Figs. 1 to 8 as having their opposite major faces disposed perpendicular to the X axis, it will be understood that they may be positioned nearly perpendicular or within a few degrees of or considerably away from such perpendicular relationship with respect to the X axis.

As illustrated in Figs. 1 to 8, the low temperature-frequency coefficient fundamental flexure mode crystal body 1 comprising the two bonded crystal elements 2 and 3 has two nodal line regions 6 each extending from one side face to the opposite side face and disposed midway between the outside major surfaces of the bonded body 1. The nodal lines 6 intersect the center line length dimension L or Y′ axis of the duplex crystal element 1 at points spaced about 0.224 or less of the length dimension L from each end thereof, as shown in Figs. 1 to 8. At any point or points on or near to the two nodal lines 6, the duplex crystal body 1 may be mounted and electrically connected as by means of a supporting wire system 7, or by rigidly clamping it between one or more pairs of oppositely disposed pressure type clamping projections of small contact area which may, if desired, be inserted in small semispherical indentations or depressions provided at or as near as possible to the nodal points on the opposite major surfaces or on the side surfaces of the duplex crystal body 1. The nodal line regions 6 of the bonded flexure mode crystals 2 and 3 are shown in Figs. 1 to 8, and in addition, the integral electrode coatings 4 and 5 therefor, the bonding means 10 and the conductive projections 7 and 8 that may be utilized for mounting and establishing electrical connections with the flexure mode crystal body 1.

As illustrated in Figs. 1 to 8, suitable conductive electrodes, such as the two crystal electrodes 4 and 5, for example, may be placed on or adjacent to or formed integral with the opposite outside major surfaces of the bonded crystal plates 2 and 3 to apply electric field excitation to the duplex type quartz body 1 in the direction of the X 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 body 1 may be vibrated in the desired first or fundamental flexural mode of motion at a response frequency which varies inversely as square of the major axis length dimension L, and directly as the thickness T.

The fundamental flexure mode frequency of the bonded quartz crystal plates 2 and 3 of Figs. 1 to 8 is given approximately by the relation

$$f=\frac{KT}{L^2} \qquad (1)$$

where:

f=frequency in cycles per second;
L=length or longest dimension in millimeters of the bonded crystal unit;
T=thickness or thinnest dimension in millimeters of the composite crystal body;
K=a value which varies with the fabrication of the bonded quartz plates. For the +5-degree X-cut quartz crystal plates 2 and 3 when poled in opposite directions, as illustrated in Figs. 1 and 2 or poled in the same direction as shown in Figs. 5 and 6, the value of K is about 5.83×10^6, and when poled in the opposite direction, as illustrated in Figs. 3 and 4, or in the same direction as shown in Figs. 7 and 8, the value of K is about 5.65×10^6.

As an example, the dimensions for a fundamental flexure mode 4-kilocycle per second bonded crystal body 1 constructed from two +5-degree X-cut quartz crystal plates 2 and 3 may be about 1 millimeter in over-all thickness T, about 23 millimeters in length L, and about 11.5 millimeters more or less in width W, the bonded crystal body vibrating in the manner of a free-free bar bending about its two nodal lines 6 in the direction of the thickness T.

As another example, a bonded crystal unit 1 constructed following the arrangement illustrated in Figs. 1 and 2 and utilizing two +5-degree X-cut quartz crystal plates 2 and 3 each about 65 millimeters long, 13 millimeters wide and .832 millimeter thick has a fundamental flexure mode frequency of about 2.3 kilocycles per second, a temperature coefficient of frequency of about one part per million per degree Fahrenheit at ordinary room temperature, a ratio of capacities r of about 175, and a Q of about 30,000 when operated in a vacuum. As another example, two bonded +5-degree X-cut quartz plates 2 and 3 constructed as illustrated in Figs. 1 and 2 and each having a length L of about 60 millimeters, a width W of 10 millimeters and a thickness of about 0.390 millimeter give a first or fundamental flexure mode frequency of about 1250 cycles per second. A similar bonded crystal body 1 of the same length but constructed with plates 2 and 3 each of 0.427 millimeter thickness gives a fundamental flexure mode frequency of about 1400 cycles per second.

Small adjustments in the resonant frequency of the bonded crystal plates 2 and 3 of Figs. 1 to 8 may be made by grinding off or otherwise removing small amounts of quartz from either or both of the small ends of the bonded crystal plates 2 and 3, thereby shortening the over-all length L and slightly raising the frequency. To lower the frequency slightly, small and equal amounts of quartz may be removed from both of the lengthwise minor faces of the bonded crystal plates 2 and 3 at the ends of each of the two nodal lines 6 thereof.

The crystal electrodes 4 and 5 of Figs. 1 to 8 when formed integral with the outside major surfaces of the crystal body 1 may consist of thin coatings of silver, 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 4 located on one major surface of the crystal body 1 or the crystal electrode 5 located on the opposite major surface thereof may be longitudinally shortened, leaving the end portions of the crystal major surfaces equally uncovered. Also, the electrodes 4 or 5 may be centrally separated or split along the center line of the length dimension L, thereby forming two separate electrodes on each major surface in order to provide the crystal body 1 with additional connections to suit the oscillator or other circuit with which it may be connected. Figs. 10 and 11 illustrate such splits or separations in the crystal electrode 4. Where the electrodes 4 and 5 are shortened lengthwise to less than the distance between the two nodal lines 6, they may be provided with small ears extending over the mounting points 7a adjacent the nodal lines 6 of the crystal body 1 in order to make electrical contact with the ends of the conductive supporting wires 7 disposed at or near such nodal points. Where the electrodes 4 and 5 are split lengthwise, the lengthwise gap or separation of the electrode platings 4 and 5 on the outside major surfaces of the crystal body 1 may be about 0.365 millimeter, the center line of such splits in the platings on opposite sides of the bonded crystal body 1 being aligned with respect to each other. To drive the crystal body 1 in the desired first or fundamental flexure mode, the opposite outside electrodes 4 and 5, and in certain cases, the inner electrode 10 also, are utilized to apply a field or fields in the thickness direction T through the crystal body 1 in order to lengthen one crystal plate 2 or 3 and simultaneously shorten the other crystal plate, thus bending the composite crystal body 1 in the thickness direction about the two stationary nodal lines 6 in the desired first flexural mode of motion, as illustrated by the curved broken line in Figs. 2 and 6. Examples of crystal and electrode arrangements that may be utilized for operating the composite crystal body 1 in the fundamental flexure mode vibration are illustrated in Figs. 1 to 8 which show duplex type flexure mode crystal bodies 1 constructed in four different ways.

Referring particularly to Figs. 1 and 2, Figs. 1 and 2 are, respectively, major face and side views which illustrate one of several ways or methods in which the composite or duplex type fundamental flexure mode crystal body 1 may be made from two equal-sized bonded +5-degree X-cut quartz crystal plates 2 and 3. In Figs. 1 and 2, the latter being a view taken on the line 2—2 of Fig. 1, the crystal plates 2 and 3 are constructed of quartz of the same handedness poled in opposite ways, and are provided with outer electrodes 4 and 5 but have no inner electrode connection to the bonding means 10. As illustrated by the plus (+) and minus (—) signs in Fig. 2, the two bonded quartz crystal plates 2 and 3 are poled in opposite ways so that when voltage is applied to the outer electrodes 4 and 5, the electric field produced thereby transverses the thickness dimension T of both of the crystal plates 2 and 3 in the same direction with the result that one crystal plate will expand along its length L, while the other crystal plate simultaneously contracts along its length L, thereby causing the bonded plates 2 and 3 to curve or bend slightly as shown in exaggerated form by the curved dotted line in Fig. 2. The bending occurs in the thickness direction T about the two nodal lines 6 which are located at a region about .224 of the length dimension L from each end thereof and midway between the outside major surfaces. The quartz crystal plates 2 and 3 in Figs. 1 and 2 are both made of the same handed quartz, that is, both may be constructed of right-hand quartz or both may be constructed of left-hand quartz and the resultant two nodal lines 6 then occur at right angles or perpendicular to the side edge or length dimension L of the bonded crystals 2 and 3, as illustrated in Figs. 1 and 2. Such perpendicular nodal lines 6 are obtained in the bonded crystal body 1 of Figs. 1 and 2, although the individual +5-degree X-cut crystal plates 2 and 3 do not have such perpendicular nodal lines in themselves. The perpendicular arrangement of the nodal lines 6 resulting in the bonded crystal plates 2 and 3 of Figs. 1 and 2 is somewhat more convenient and easier to use in mounting and establishing electrical connections with the bonded crystal 1 by means of conductive clamping pins or supporting wires 7 that may be attached or soldered thereto at points on or as near as possible to the nodal lines 6, as illustrated in Figs. 1 and 2. In the individual length-mode +5-degree X-cut crystal plates 2 and 3, the nodal lines are inclined about 11 degrees to the perpendicular to the length dimension L. The nodal lines 6 in Figs. 1 and 2 illustrate the result of the 11-degree inclined nodal lines of the individual crystal plates 2 and 3 which become the perpendicular nodal lines 6 when the two +5-degree X-cut crystal plates 2 and 3 of Figs. 1 and 2 are bonded and operated in the flexure mode. It will be noted that no inner electrode connection is used for the inner plating or bonding means 10 in the arrangement illustrated in Figs. 1 and 2, and that the electric field supplied by the outside electrodes 4 and 5 transverses the thickness dimension T of both of the bonded crystals 2 and 3 resulting in a duplex crystal body of somewhat higher impedance level than that obtained when using an inner electrode connection of the type illustrated in Figs. 5 to 8.

To determine the plus (+) and minus (—) poling of the individual crystal plates 2 and 3, the two crystal plates 2 and 3 may be placed in major face to major face position one on top of the other in unbonded condition and driven at the frequency at which each individual plate would resonate longitudinally. If the two plates 2 and 3 are poled in the same direction, the two crystals will resonate longitudinally together and give approximately as good a "Q" or ratio of reactance to resistance as though each were driven individually; and if they are poled oppositely, no resonance will be observed. In this manner, the poling of the crystal plates 2 and 3 may be determined before bonding them together.

Secured together and suitably poled, one of the crystal plates 2 or 3 under the action of an electric field, will lengthen in the length direction L and the other will simultaneously shorten, thus causing the bonded plates 2 and 3 to curve slightly into a cylindrical major surface form as shown in greatly exaggerated form by the curved broken line in Fig. 2. In an alternating field, the bonded plates 2 and 3 will curve first in one direction and then in the other or opposite direction, producing flexural vibrations by bending in the thickness direction T about the nodal lines 6.

The flexural vibrations are of considerable amplitude and their frequency is much lower than that of the longitudinal or lengthwise vibration of one of the single crystal plates 2 or 3 thereof. A wide range of frequencies may be obtained by the proper choice of the length L and thickness T of the bonded crystal plates 2 and 3. The width dimension W is of little effect on the flexure mode frequency if not made too large and, as an example, may conveniently be about one-fifth of the length dimension L or other suitable value.

Figs. 3 and 4 are, respectively, major face and side views, the latter being a view taken on the line 4—4 of Fig. 3, and illustrate a second way in which a duplex or composite fundamental flexure mode crystal body 1 may be made from two bonded +5-degree X-cut quartz crystal plates 2 and 3. As illustrated by the plus (+) and minus (—) signs in Fig. 4, the two bonded crystal plates 2 and 3 are poled in opposite ways like the crystal plates 2 and 3 of Fig. 2 so that when the electric field produced by the electrodes 4 and 5 transverses both crystal plates 2 and 3 in the same direction, one crystal plate expands along the length L, while the other simultaneously contracts along its length L, thereby slightly bending the bonded crystal plates 2 and 3 in the thickness direction T about the two nodal lines 6, the inner major surface centers of which are located about .224 of the length L from each end thereof. It will be noted that the two crystal plates 2 and 3 of Figs. 3 and 4, unlike those of Figs. 1 and 2, are made of opposite handed quartz instead of the same handed quartz. By opposite handedness, it is meant that one crystal plate is constructed of right-handed quartz and the other crystal plate is constructed of left-handed quartz, as illustrated in Fig. 4. Being of opposite handedness, the bonded crystal plates 2 and 3 of Figs. 3 and 4 have resultant nodal lines 6 which may be inclined at an angle to the perpendicular to the length dimension L and which in the case of the +5-degree X-cut plates 2 and 3 particularly illustrated are inclined about 11 degrees, as shown in Fig. 3. As illustrated in Figs. 3 and 4, the 11-degree nodal lines 6 are both in one direction with reference to the perpendicular to the length dimension L. The proper direction of rotation may be located by test for minimum motion.

In Figs. 3 and 4, as in Figs. 1 and 2, no inner electrode connection is used and the electric field that is supplied by the outer electrode coatings **4** and **5** traverses the thickness dimension T of both crystal plates **2** and **3** therebetween, giving a duplex crystal unit that may have a relatively higher impedance level than that obtained from the two types of duplex crystal body **1** of Figs. 5 to 8, which utilize an inner electrode connection **8** that may be made by soldering to the bonding means **10**.

For high impedance level bonded crystal plates **2** and **3**, the construction illustrated in Figs. 3 and 4 using one crystal plate taken from right-handed quartz and the other crystal plate taken from left-handed quartz represents a desirable arrangement for +5-degree X-cut type quartz plates **2** and **3** from the standpoint of very low temperature coefficient of frequency, as illustrated by the curves of Fig. 9. It will be understood, however, that duplex flexure mode crystals made from bonded +5-degree X-cut type quartz plates generally as shown in Figs. 1 to 8, display very low frequency-temperature coefficients of the order of one part or less part per million per degree centigrade, a value which is less than that displayed by the individual plates when operated singly in unbonded condition.

Figs. 5 and 6 are, respectively, major face and side views illustrating a third way in which a duplex fundamental flexure mode crystal body **1** may be made from two +5-degree X-cut type quartz crystal plates **2** and **3** secured together by conductive bonding means **10**. In Figs. 5 and 6, the inner plating or bonding means **10** is used as one electrode for the crystal body **1**, the connection thereto being made by means of a fine lead wire **8** connected or soldered thereto at the node **6** or otherwise, and the two outer platings or coatings **4** and **5** being connected together by any suitable means such as a connector **9**, for example, and used as a second or outer electrode for the two crystal plates **2** and **3** connected in parallel. The arrangement shown in Figs. 5 and 6 provides a duplex crystal unit **1** which has about one-fourth of the impedance level provided by the connections used in the two arrangements shown in Figs. 1 to 4 where no outside connection to the inner electrode is utilized. The lower impedance level provided by the inner electrode connection **8** of Figs. 5 and 6 may be of advantage in certain applications. When using the inner electrode connection **8** of Figs. 5 and 6, the quartz crystal plates **2** and **3** are poled in the same way, as illustrated by the plus (+) and minus (−) signs in Fig. 6, in order to obtain an expansion of one plate along its length L and simultaneously a contraction of the other plate along its length L, thereby bending the bonded crystal plates **2** and **3** in the thickness direction T about the two nodal lines **6**, in the manner described hereinbefore in connection with Figs. 1 and 2. In Figs. 5 and 6, the bonded crystal plates **2** and **3** are of opposite handedness, that is, one plate is constructed from right-handed quartz, while the other plate is constructed of left-handed quartz, as illustrated in Fig. 6. The crystal plates **2** and **3** of Figs. 5 and 6 being of opposite handedness, poled in the same way and operated with fields in opposite directions, the two nodal lines **6** thereof are substantially at right angles to the length dimension L, as illustrated in Figs. 5 and 6. Accordingly, the bonded crystal plates **2** and **3** of Figs. 1, 2 and Figs. 5, 6 provide the same type of nodal lines **6** although constructed with different connections, poling and handedness. Also they have in general the same temperature coefficients of frequency.

Figs. 7 and 8 are, respectively, major face and side face views illustrating a fourth method by which a duplex fundamental flexure mode composite crystal unit **1** may be made from two +5-degree X-cut type quartz crystal plates **2** and **3**. In Figs. 7 and 8, the in-between plating or bonding means **10** is used as one externally connected electrode **8** and the two outer coatings **4** and **5** are connected together and used as a second electrode, as in the case of Figs. 5 and 6; and also, the crystal plates **2** and **3** are poled in the same way as illustrated by the plus (+) and minus (−) signs in Fig. 8. The crystal plates **2** and **3** of Figs. 7 and 8 are made however of the same handedness, that is, both of the crystal plates **2** and **3** are constructed either of right-handed quartz or of left-handed quarts, and the resulting nodal lines **6** are inclined at an angle of about 11 degrees with respect to the perpendicular to the length dimension L, as shown in Fig. 7, where the quartz plates are +5-degree X-cut type crystal plates **2** and **3**. The duplex crystal unit **1** of Figs. 7 and 8, like that of Figs. 5 and 6, has an impedance level about one-fourth of that given by the duplex crystals **1** of Figs. 1 to 4. The characteristics of the duplex crystals of Figs. 7 and 8 and Figs. 3 and 4 are similar, each having an 11-degree nodal line **6**, the same dimensions for a given frequency, and about the same temperature coefficients of frequency.

While the connections required to form the bonded crystal units of Figs. 5 to 8 require an inner electrode connection that is not required in those shown in Figs. 1 to 4, the inner electrode connection of Figs. 5 to 8 has the advantage that for the same crystal dimensions the impedance obtained is about one-fourth that obtained by the method used in Figs. 1 to 4 where no inner electrode connection is utilized. In Figs. 5 to 8, the inner electrode connection may be made by soldering a fine wire **8** which may be a supporting spring wire to the inner electrode **10** at a node end **6** thereof on the side surface thereof. It will be understood that the composite crystal unit **1** of Figs. 1 to 8 may be mounted and electrically connected if desired entirely at the side surface node ends **6** by means of four fine conductive spring wires **8** soldered to baked silver paste spots **12** placed at the four side surface nodes **6** or by pressure type conductive clamping pins, for example, the pins or wires **8** being individually connected to the electrodes **4** and **5** by integral crystal coatings that are separated from each other and from the inner coating **10**, the inner coating being removed at the ends only of the nodal lines **6** where connections are made to the outside coatings **4** and **5**.

It will be noted that in the flexure mode of motion, one of the bonded crystal plates **2** or **3** becomes shorter while the other crystal plate simultaneously becomes longer, thus throwing the bonded crystal plates **2** and **3** into the flexure mode vibration in the direction of their thinnest dimension T. To produce this vibration, the bonded crystal plates **2** and **3** are poled in opposite directions when voltage is applied only to the two outer major surfaces of the crystal plates as shown in Figs. 1 to 4, and are poled in the same direction when the electric field goes through them in opposite directions as shown in Figs. 5 to 8. To obtain the nodal lines **6** that run through the bonding means **10** of the crystal at right angles to the length dimension L, the bonded crystal plates **2** and **3** may be made of the same handedness, either right or left, as in Figs. 1 and 2, or of opposite handedness as in Figs. 5 and 6. To obtain the 11-degree nodal lines **6**, the poling and handedness may be as in Figs. 3 and 4 or 7 and 8. The temperature-frequency coefficient and the frequency constant that relates the crystal dimensions to the frequency are somewhat different for the 11-degree nodal line **6** construction as compared with the perpendicular nodal line **6** construction, the temperature coefficient being superior in the latter case.

While in Figs. 1 to 8, the +5-degree X-cut type crystal plates are particularly illustrated, it will be understood that other low temperature coefficient longitudinal mode crystal plates may also be used in the same manner of fabrication to obtain a low temperature coefficient of frequency for the flexure mode vibration of the bonded crystal body.

Fig. 9 is a graph showing the measured temperature-frequency coefficients of six duplex type fundamental flexure mode 4-kilocycle per second crystals **1** each composed of two bonded +5-degree X-cut crystal plates **2** and **3** made in accordance with the method illustrated in Figs. 3 and 4. The curves of Fig. 9 illustrate that maximum frequency stability with temperature change occurs in the region of 70° for bonded +5-degree X-cut type crystal plates **2** and **3** made in accordance with the method as illustrated in Figs. 3 and 4. Similar measurements made on bonded +5-degree X-cut type 4-kilocycle per second flexure mode crystal plates **2** and **3** but arranged in accordance with the method as illustrated in Figs. 1 and 2 show that maximum frequency stability occurs in the region of about 30° F. While either arrangement of the bonded crystals may be used at ordinary temperatures to obtain a good temperature coefficient of frequency, the curves of Fig. 9 show that between 64 and 91° F., for example, the frequency of the bonded crystal plates **2** and **3** made by the method of Figs. 3 and 4 shows a variation of only about nine parts per million at 4 kilocycles per second, whereas the same cut of composite crystal plates made by the method of Figs. 1 and 2 vary about eighteen parts per million. These figures correspond to about two parts per million per degree Fahrenheit and four parts per million per degree Fahrenheit, respectively, and represent a fairly high degree of frequency stability. In accordance with the foregoing illustration, and as illustrated by the curves of Fig. 9, the temperature at which the zero temperature coefficient of frequency occurs for a composite flexure mode crystal **1** may be varied by a suitable selection and arrangement of the proper crystal plates.

Figs. 10 and 11 are, respectively, major face and small end views of a duplex fundamental flexure mode crystal body **1** provided with longitudinally divided electrode coatings **4***a* and **4***b* on one outside major face thereof, a non-divided electrode coating **5** on the other outside major face thereof, and a wire support system comprising fine phosphor bronze spring wires **7** soldered by means of small solder cones **7***a* to the crystal coatings **4***a*, **4***b* and **5** at points over the two nodal lines **6** of the flexure mode bonded crystal plates **2** and **3** held securely together by the bonding means **10**. While in Figs. 10 and 11 the crystal wire supporting system **7** and the longitudinally divided electrode coatings **4***a* and **4***b* are shown particularly in connection with the bonded crystal construction of the type illustrated in Figs. 1 and 2, it will be understood that these features may be applied also to the other types of bonded crystal plates illustrated in Figs. 3 to 8. While in Figs. 10 and 11 the longitudinally divided system of electrodes **4***a* and **4***b* is shown as being applied only to the electrode **4** of Figs. 1 to 8, it may also be applied similarly to the crystal electrode **5**. The longitudinally divided electrode, such as the electrodes **4***a* and **4***b*, may be utilized for the purpose of providing connections to suit the particular circuit such as an oscillator circuit with which the duplex crystal unit may be connected.

As shown in Figs. 10 and 11, the crystal supporting fine spring wires **7** may extend a short distance from the solder dots or cones **7***a* in a direction perpendicular to the major faces of the bonded crystal body **1**, may then be bent at right angles and extend outwardly in the direction shown in Figs. 10 and 11 or in any direction, and may then be bent again at roughly right angles and attached to four larger supporting spring wires **11** as illustrated in Figs. 11 and 12. Alternatively, instead of being provided with multiple L-shaped bends as illustrated in Figs. 10, 11 and 12, the fine supporting spring wires **7** attached to the crystal body may extend directly to the support wires **11**, as illustrated in Fig. 13. The support wires **11** illustrated in Figs. 11, 12 and 13 may be, for example, four upright parallel wires extending through the press of an evacuated metal or glass tube **14** illustrated in Fig. 11 and may be of the type disclosed in A. W. Ziegler Patent 2,275,122, dated March 3, 1942. It will be understood that the crystal wire supporting system may be of any suitable form that is adapted to support and establish electrical connections with the bonded crystal body **1**, and that the wire supported crystal unit may be mounted in any suitable container such as a vacuum tube **14** of the type disclosed in the A. W. Ziegler Patent 2,275,122 mentioned, for example.

The sealed crystal container **14**, illustrated in cross-section in Fig. 11, may be evacuated or alternatively, it may contain dry air or other inert gas which may be heavier or lighter than air and of suitable density or pressure which may be greater or less than atmospheric pressure, in order to suppress or damp out the weaker secondary resonances of the crystal body or to slightly damp the major or desired resonance thereof in case of excessive vibration and for other purposes such as to control or adjust the frequency of the desired resonance or resonances. Examples of gases which may be used to provide an inert atmosphere for control of the crystal resonances are helium, neon, hydrocarbons, carbon dioxide, argon, krypton, xenon.

Fig. 12 is an enlarged detail view illustrating a crystal supporting wire **7** provided with multiple bends which may function to dampen or dissipate undesired wire vibrations and to absorb externally applied mechanical shock. Alternatively, as shown in Fig. 13, a straight wire **7** may be used extending perpendicularly from the major surface of the crystal body **1** to the slightly heavier support spring wire **11**. The fine crystal lead wire **7** may be attached to the support wire **11** by solder or other suitable means. The extreme end of the lead wire **7** that is adjacent the crystal body **1** may be bent at right angles as illustrated in Figs. 12 and 13 or may be bent in hook form or otherwise in order to retain it more firmly in the solder cone **7***a* in which it is embedded. The lead wire **7** may be firmly attached to the crystal surface at a node thereof by means of the solder joint 7a soldered to a baked silver paste spot 12 of circular shape formed on the bare quartz crystal, as illustrated in Figs. 12 and 13. The solder cone 7a may be formed from any suitable solder such as, for example, a solder of the type used for the bonding means 10 to be described. The small silver spots 12 on the outside major surfaces and on the nodes 6 of the side surfaces of the bonded crystal plates 2 and 3 may be formed there by applying to the bare quartz, spots 12 of silver paste and then baking in an oven at an elevated temperature.

As to the conductive crystal bonding means 10, the inside major surfaces of the quartz crystal plates 2 and 3 may be firmly bonded together by applying to one major face of each of the unbonded bare quartz plates 2 and 3 a coating 10a of silver paste covering substantially the whole surface, of each of the inside major surfaces which after baking thereon may be soldered together by a layer of solder 10b, as illustrated in Figs. 12 and 13. The silver paste coating 10a may be applied to each of the inside major surfaces of the unbonded crystal plates 2 and 3 by spraying it thereon with an air brush, for example, using a mixture of one part by volume of silver paste such as Hanovia silver paste and two parts by volume of distilled turpentine and an air pressure of approximately 25 pounds per square inch. The weight of the silver coatings 10a may be about 35 milligrams per square inch after final heat treatment. The silver paste coatings 10a may be baked firmly onto the quartz by baking the silver-coated crystal plates in separated form in an oven at a temperature of about 220 to 250° F. for about 15 minutes and then increasing the temperature approximately 350° F. per hour until the crystal plate reaches a temperature of about 950 to 1000° F. After maintaining this elevated temperature for a period of approximately 30 minutes, the crystal plates 2 and 3 may be allowed to cool gradually. The baked silver paste coatings 10a on the inside major surfaces of the crystal plates 2 and 3 to be bonded may then be burnished with a glass brush or other suitable means until a bright metallic lustre is obtained. The individual crystal plates 2 and 3 may then be placed on a hot platen with the burnished side up and heated to a temperature of about 315° F. At this point stearine soldering flux may be applied to the heated silvered surfaces and solder 10b evenly applied over these surfaces to be bonded. As an example, the solder 10b may be composed of about 32 per cent lead, 50 per cent tin, 18 per cent cadmium and a small quantity or sufficient silver for saturation at the melting point of the solder which is about 300° F. The purpose of using the silver in the solder composition 10b is to prevent the solder 10b from absorbing the silver from the silver coatings 10a on the crystal plates 2 and 3. The molten solder 10b may be distributed with a suitable spreader such as a piece of tinned copper wire. After the solder is molten and has been evenly distributed over the entire upper major surfaces of the crystal plates 2 and 3, one of the two crystal plates 2 and 3 to be bonded may be picked up and placed evenly on the other crystal plate with the major surfaces having the molten solder coating 10b facing each other. A pressure of about 4 pounds per square inch may be applied and the excess solder which is forced out from between the two crystal plates 2 and 3 may be removed. The pressure may then be released and the crystal plates 2 and 3 removed from the hot platen. Before the bonded crystal plates 2 and 3 have cooled below the melting point of the flux, the flux may be removed by wiping with a clean lintless cloth or other suitable means. The bonded crystal plates 2 and 3 may be cleaned by immersing and brushing in carbon tetrachloride and drying with clean warm air. The baked silver paste coatings 10a adhere firmly to the quartz and when soldered together at 10b form a strong bond 10 between the two crystal plates 2 and 3.

If desired, the bonding means 10 as illustrated in Figs. 2, 4, 6 and 8 for example, may comprise a thin metal plate 10 secured between the two crystal plates 2 and 3 and made of steel or other metal suitably proportioned with respect to the crystal plates 2 and 3 in order to obtain a temperature coefficient of frequency of selected value for controlling the over-all temperature coefficient of frequency of the bonded crystal unit 2, 3 and 10. If desired, one of the two bonded crystal plates 2 or 3, such as the plate 3 illustrated in Fig. 12 for example, may be made of non-piezoelectric material and made to have a temperature-frequency coefficient to balance that of the crystal plate 2 secured thereto, thereby to obtain a low over-all temperature coefficient of frequency for the bonded unit.

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 duplex type thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, means for driving said crystal body in said thickness flexure mode comprising electrodes formed integral with the outside major faces of said body, and means comprising four pairs of conductive bent spring wires soldered to said electrodes substantially at the nodes of motion of said body for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof.

2. A duplex type thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, electrodes on the outside major faces of said body, and means for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, said means comprising conductive spring wires soldered to said electrodes substantially at said nodes of motion of said body.

3. A duplex type thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of

values in accordance with the value of said flexure mode frequency, the dimensional ratio of the width of said major faces with respect to said length thereof being one of the values substantially from 0.20 to 0.35, means for driving said body in said thickness flexure mode comprising electrodes on the outside major faces of said body, and means comprising four pairs of wire-like conductive supports contacting said electrodes at points substantially along the lengths of two spaced nodal lines of said body for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, said crystal plates being poled in opposite ways and subjected to a thickness direction electric field produced by said outside electrodes only.

4. A duplex type fundamental thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, means for driving said crystal body in said thickness flexure mode comprising electrodes on the outside major faces of said body, and means including four pairs of wire-like conductive supports for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, said crystal plates being poled in opposite ways and subjected to a thickness direction electric field produced by said outside electrodes only, said crystal plates being constructed of crystal quartz of the same handedness, and said nodes being on nodal lines disposed substantially along said major faces substantially parallel to the width dimension and perpendicular to said length dimension of said body and spaced substantially .224 of said length dimension from each end thereof.

5. A duplex type fundamental thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, means for driving said body in said thickness flexure mode comprising electrodes on the outside major faces of said body, and means comprising a plurality of pairs of wire-like supports for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, said crystal plates being poled in opposite ways and subjected to a thickness direction electric field produced by said outside electrodes only, said crystal plates being constructed of crystal quartz of opposite handedness, and said nodes being on nodal lines of said major surfaces, said nodal lines being inclined substantially 11 degrees with respect to the perpendicular to said length dimension of said body, said perpendicular being spaced substantially .224 of said length dimension from each end thereof.

6. A duplex type thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of

values in accordance with the value of said flexure mode frequency, means for driving said body in said thickness flexure mode comprising electrodes on the outside major faces of said body, and means comprising conductive bent spring wires for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, said crystal plates being poled in the same way and subjected to opposite direction electric fields produced by said outside electrodes connected together and an inner electrode between said crystal plates.

7. A duplex type fundamental thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, means for driving said body in said thickness flexure mode comprising electrodes on the outside major faces of said body, and means comprising conductive bent spring wires for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, said crystal plates being poled in the same way and subjected to opposite direction electric fields produced by said outside electrodes connected together and an inner electrode between said crystal plates, said crystal plates being constructed of crystal quartz of opposite handedness, and said nodes being on nodal lines of said major surfaces, said nodal lines being substantially perpendicular to said length dimension of said body and spaced substantially .224 of said length dimension from each end thereof.

8. A duplex type thickness flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, electrodes on the outside major faces of said body, and means for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, one of the major faces electrodes being divided and separated substantially along its lengthwise center line.

9. A composite thickness flexure mode piezoelectric crystal body comprising two length-mode quartz crystal plates bonded together in major face to major face relation, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, means for driving said body in said thickness flexure mode comprising electrodes formed integral with the outside major faces of said body and a plurality of pairs of wire-like support members, said members having ends disposed in contact with said outside electrodes at a plurality of spaced points thereon, said points being substantially at each of the plurality of nodal lines extending midway between said outside major faces of said body, one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz.

10. A composite thickness flexure mode piezoelectric crystal body comprising two length-mode quartz crystal plates bonded together in major

face to major face relation, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, means for driving said body in said thickness flexure mode comprising electrodes formed integral with the outside major faces of said body and a plurality of pairs of wire-like support members, said members having ends disposed in contact with said outside electrodes at a plurality of spaced points thereon, said points being substantially at each of the plurality of nodal lines extending midway between said outside major faces of said body, one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz, said crystal plates being +5-degree X-cut type quartz crystal plates poled in opposite ways.

11. A composite thickness flexure mode piezoelectric crystal body comprising two length-mode quartz crystal plates bonded together in major face to major face relation, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, means for driving said body in said thickness flexure mode comprising electrodes formed integral with the outside major faces of said body and a plurality of pairs of wire-like support members, said members having ends disposed in contact with said outside electrodes at a plurality of spaced points thereon, said points being substantially at each of the plurality of nodal lines extending midway between said outside major faces of said body, one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz, said crystal plates being +5-degree X-cut type quartz crystal plates poled in the same way.

12. A low temperature-frequency coefficient composite piezoelectric crystal body adapted to vibrate flexurally by bending in its thickness dimension direction about its nodes of motion comprising two +5-degree X-cut type piezoelectric quartz crystal elements soldered together in major face to major face relation, the length and thickness dimensions of said crystal elements being made of values in accordance with the value of said flexure mode frequency, the dimensional ratio of the width of said major faces with respect to said length thereof being one of the values substantially from 0.20 to 0.35, electrodes formed integral with the outside major faces of said crystal body, and means comprising conductive spring wires secured to said electrodes substantially at said nodes of motion for supporting and establishing electrical connections with said composite body.

13. A low temperature-frequency coefficient composite piezoelectric crystal body adapted to vibrate flexurally by bending in its thickness dimension direction comprising two +5-degree X-cut type piezoelectric quartz crystal elements and means for bonding said crystal elements together in major face to major face relation, said bonding means comprising coatings of baked metallic paste formed integral with each of the inside or inner major faces of said crystal elements and a layer of solder disposed between and formed integral with said inner metallic coatings, one of said crystal elements being made from right-handed quartz and the other of said elements being made from left-handed quartz.

14. A low temperature-frequency coefficient composite piezoelectric crystal body adapted to vibrate flexurally by bending in its thickness dimension direction comprising two piezoelectric quartz crystal elements and means for bonding said crystal elements together in major face to major face relation, said bonding means comprising coatings of baked metallic paste formed integral with each of the inside or inner major faces of said crystal elements and a layer of solder disposed between and formed integral with said inner metallic coatings, one of said crystal elements being made from right-handed quartz and the other of said elements being made from left-handed quartz.

15. A duplex type flexure mode crystal body comprising two length-mode +5-degree X-cut type quartz crystal plates bonded together in major face to major face relation to obtain a low temperature coefficient for said flexure mode frequency of said body, the length and thickness dimensions of said crystal plates being made of values in accordance with the value of said flexure mode frequency, electrodes on the outside major faces of said body, and means for supporting and establishing electrical connections with said body substantially at the nodes of motion thereof, said bonding means comprising coatings of baked silver paste formed integral with each of the inside major surfaces of said crystal plates and a layer of solder disposed between and formed integral with said inside crystal coatings, said solder comprising silver as an element of its composition.

16. Piezoelectric crystal apparatus comprising a composite or duplex type crystal body adapted to bend in thickness flexure mode vibrations at a relatively low frequency determined mainly by the length and the thickness dimensions of said crystal body, said length and thickness dimensions of said crystal body being of values corresponding to the value of said thickness flexure mode frequency, conductive electrodes disposed on the outside major faces of said crystal body, and means for supporting and establishing electrical connections with said electroded crystal body substantially adjacent the nodes of motion thereof, said crystal body comprising two length-mode quartz crystal plates and means for bonding said crystal plates together in major face to major face relation, said crystal plates being +5 degree X-cut type quartz crystal plates constructed from crystal quartz of opposite handedness one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz whereby a very low temperature coefficient is obtained for said thickness flexure mode frequency.

17. Piezoelectric crystal apparatus comprising a composite or duplex type crystal body adapted to bend in thickness flexure mode vibrations at a relatively low frequency determined mainly by the length and the thickness dimensions of said crystal body, said length and thickness dimensions of said crystal body being of values corresponding to the value of said thickness flexure mode frequency, conductive electrodes disposed on the outside major faces of said crystal body, and means for supporting and establishing electrical connections with said electroded crystal body substantially adjacent the nodes of motion thereof, said crystal body comprising two length-mode quartz crystal plates and means for bonding said crystal plates together in major face to major face relation, said crystal plates being +5 degree X-cut type quartz crystal plates constructed from crystal quartz of opposite handed-

ness one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz whereby a very low temperature coefficient is obtained for said thickness flexure mode frequency, and the dimensional ratio of the width of said major faces with respect to said length thereof being one of the values substantially from 0.20 to 0.35.

18. Piezoelectric crystal apparatus comprising a composite or duplex type crystal body adapted to bend in thickness flexure mode vibrations at a relatively low frequency determined mainly by the length and the thickness dimensions of said crystal body, said length and thickness dimensions of said crystal body being of values corresponding to the value of said thickness flexure mode frequency, conductive electrodes disposed on the outside major faces of said crystal body, and means for supporting and establishing electrical connections with said electroded crystal body substantially adjacent the nodes of motion thereof, said crystal body comprising two length-mode quartz crystal plates and means including solder for bonding said crystal plates together in major face to major face relation, said crystal plates being +5 degree X-cut type quartz crystal plates constructed from crystal quartz of opposite handedness one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz whereby a very low temperature coefficient is obtained for said thickness flexure mode frequency.

19. Piezoelectric crystal apparatus comprising a composite or duplex type crystal body adapted to bend in thickness flexure mode vibrations at a relatively low frequency determined mainly by the length and the thickness dimensions of said crystal body, said length and thickness dimensions of said crystal body being of values corresponding to the value of said thickness flexure mode frequency, conductive electrodes disposed on the outside major faces of said crystal body, and means for supporting and establishing electrical connections with said electroded crystal body substantially adjacent the nodes of motion thereof, said crystal body comprising two length-mode quartz crystal plates and means for bonding said crystal plates together in major face to major face relation, said crystal plates being +5 degree X-cut type quartz crystal plates constructed from crystal quartz of opposite handedness one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz whereby a very low temperature coefficient is obtained for said thickness flexure mode frequency, said crystal plates being electrically poled in opposite ways and subjected to a thickness direction electric field produced by said outside electrodes, and said nodes being lines disposed midway between said outside major faces and extending from side edge to side edge of said body in a direction which is inclined substantially 11 degrees with respect to the perpendicular to said length dimension of said body.

20. Piezoelectric crystal apparatus comprising a composite or duplex type crystal body adapted to bend in thickness flexure mode vibrations at a relatively low frequency determined mainly by the length and the thickness dimensions of said crystal body, said length and thickness dimensions of said crystal body being of values corresponding to the value of said thickness flexure mode frequency, conductive electrodes disposed on the outside major faces of said crystal body, and means for supporting and establishing electrical connections with said electroded crystal body substantially adjacent the nodes of motion thereof, said crystal body comprising two length-node quartz crystal plates and means for bonding said crystal plates together in major face to major face relation, said crystal plates being +5 degree X-cut type quartz crystal plates constructed from crystal quartz of opposite handedness one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz whereby a very low temperature coefficient is obtained for said thickness flexure mode frequency, said crystal plates being electrically poled in opposite ways and subjected to a thickness direction electric field produced by said outside electrodes, and said nodes being lines disposed midway between said outside major faces and extending from side edge to side edge of said body in a direction which is inclined substantially 11 degrees with respect to the perpendicular to said length dimension of said body, and the dimensional ratio of the width of said major faces with respect to said length thereof being one of the values substantially from 0.20 to 0.35.

21. Piezoelectric crystal apparatus comprising a composite or duplex type crystal body adapted to bend in thickness flexure mode vibrations at a relatively low frequency determined mainly by the length and the thickness dimensions of said crystal body, said length and thickness dimensions of said crystal body being of values corresponding to the value of said thickness flexure mode frequency, conductive electrodes disposed on the outside major faces of said crystal body, and means for supporting and establishing electrical connections with said electroded crystal body substantially adjacent the nodes of motion thereof, said crystal body comprising two length-mode quartz crystal plates and means including solder for bonding said crystal plates together in major face to major face relation, said crystal plates being +5 degree X-cut type quartz crystal plates constructed from crystal quartz of opposite handedness one of said crystal plates being right-handed quartz and the other of said crystal plates being left-handed quartz whereby a very low temperature coefficient is obtained for said thickness flexure mode frequency, said crystal plates being electrically poled in opposite ways and subjected to a thickness direction electric field produced by said outside electrodes, and said nodes being lines disposed midway between said outside major faces and extending from side edge to side edge of said body in a direction which is inclined substantially 11 degrees with respect to the perpendicular to said length dimension of said body, and the dimensional ratio of the width of said major faces with respect to said length thereof being one of the values substantially from 0.20 to 0.35.

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