

June 7, 1949.

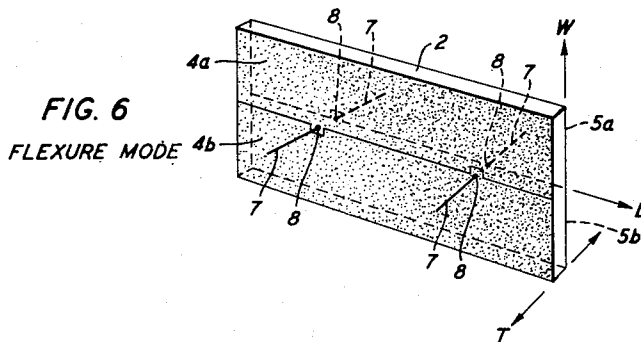
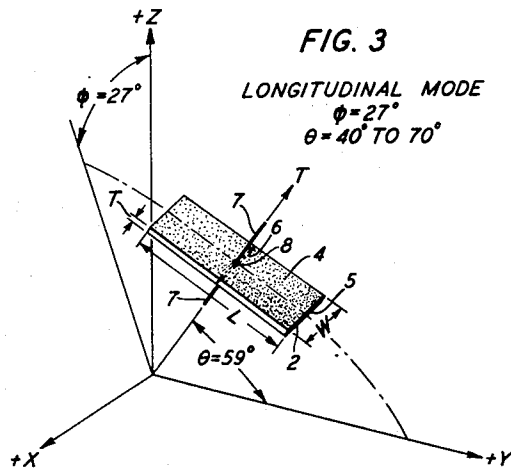
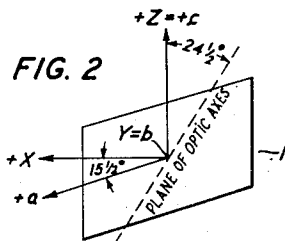
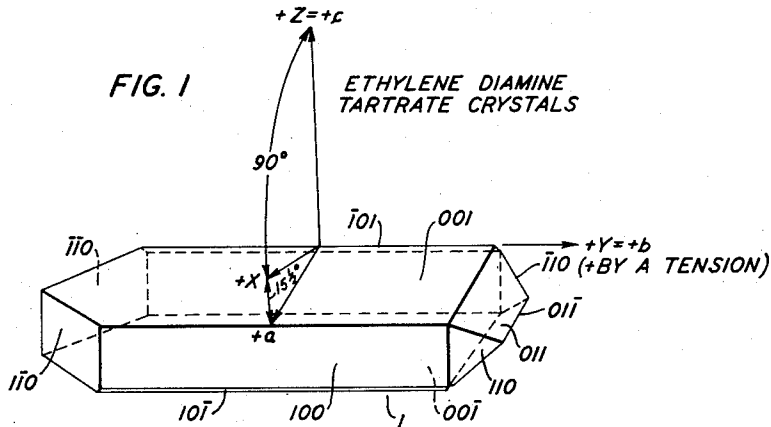
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2,472,691

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Aug. 16, 1946

2 Sheets-Sheet 1



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PIEZOELECTRIC CRYSTAL APPARATUS

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2 Sheets-Sheet 2

FIG. 4

LONGITUDINAL MODE

$\phi = 27^\circ$

$\theta = 59^\circ$

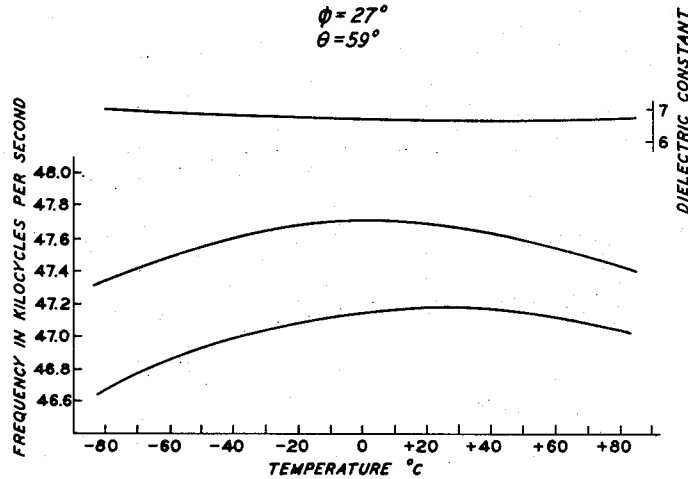
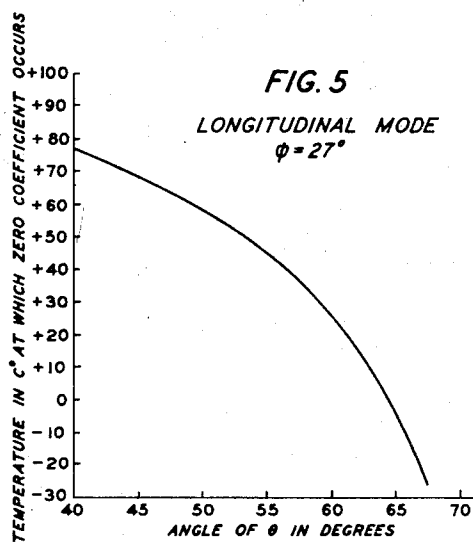


FIG. 5

LONGITUDINAL MODE

$\phi = 27^\circ$



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2,472,691

PIEZOELECTRIC CRYSTAL APPARATUS

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Application August 16, 1946, Serial No. 690,987

11 Claims. (Cl. 171-327)

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This invention relates to crystal apparatus and particularly to longitudinal mode piezoelectric crystal elements comprising ethylene diamine tartrate ($C_6H_{14}N_2O_8$). Such crystal elements may be used as frequency controlling circuit elements in electric wave filter systems, oscillation generator systems and amplifier systems. Also, they may be utilized as modulators, or as harmonic producers, or as electromechanical transducers in sonic or supersonic projectors, microphones, pick-up devices and detectors.

One of the objects of this invention is to provide advantageous orientations in longitudinal mode crystal elements made from synthetic crystalline ethylene diamine tartrate.

Another object of this invention is to take advantage of the high piezoelectric coupling, the low ratio of capacities, the low cost and other advantages of crystalline ethylene diamine tartrate.

Other objects of this invention are to provide crystal elements comprising ethylene diamine tartrate that may possess useful characteristics, such as effective piezoelectric constants, minimum or low coupling of the desired mode of motion to undesired modes of motion therein, and low or zero temperature coefficient of frequency.

A particular object of this invention is to provide synthetic ethylene diamine tartrate crystal elements having a zero temperature coefficient of frequency.

Other objects of this invention are to provide cuts of the double orientation type in ethylene diamine tartrate crystals which may have a flatter temperature-frequency characteristic curve, which may have a higher impedance or greater ratio of capacities, and which may have mechanically stronger surfaces for purposes of cementing or otherwise securing supporting wires thereto.

Ethylene diamine tartrate is a salt of tartaric acid having a molecule which lacks symmetry elements. In its crystalline form, it lacks a center of symmetry and belongs to a crystal class which is piezoelectric and which is the monoclinic sphenoidal crystal class. By virtue of its structure, ethylene diamine tartrate will form crystals offering relatively high piezoelectric constants. In addition, the crystalline material affords certain cuts with low or zero temperature coefficient of vibrational frequency and low coupling to other modes of motion therein, and fairly high Q or low dielectric loss and mechanical dissipation. Also crystalline ethylene diamine tartrate has no water of crystallization and hence will not dehydrate when used in air or in vacuum.

Crystal elements of suitable orientation cut from crystalline ethylene diamine tartrate may be excited in different modes of motion such as the longitudinal length or the longitudinal width modes of motion. Also, low frequency flexural

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modes of motion of either the width bending flexure type or the thickness bending flexure duplex type may be obtained. These various modes of motion are similar in the general form of their motion to those of similar or corresponding names that are already known in connection with crystal elements cut from other crystalline substances such as quartz, Rochelle salt and ammonium dihydrogen phosphate crystals, for example.

It is useful to have a synthetic type of piezoelectric crystal element having a low or zero temperature coefficient of frequency, and having a low coupling to other modes of motion therein. In accordance with this invention, such synthetic type crystal cuts may be provided in the form of ethylene diamine tartrate crystals and such tartrate crystals may be suitable cuts taken from crystalline ethylene diamine tartrate adapted to operate in a suitable longitudinal mode of motion. Such zero temperature coefficient ethylene diamine tartrate crystal elements may be used as acceptable substitutes for quartz crystal elements in oscillator, filter and other crystal systems.

The longitudinal mode ethylene diamine tartrate crystal cuts provided in accordance with the present invention have relatively flatter temperature-frequency characteristics, less variation of inductance with temperature change, and higher impedance, and may be used as a direct replacement of quartz filter crystals in carrier systems utilizing filters such as channel filters and pilot pick-off filters. Moreover, due to freedom from fracture or cleavage plane effect along the mounting surfaces, the cuts provided in accordance with this invention, may have stronger surfaces for cementing purposes. The crystal elements may be defined as to orientation by the double orientation angles ϕ and θ . The temperature at which the zero temperature coefficient of frequency occurs varies with the value of the angle θ and occurs at about 27.5 degrees centigrade when the angle θ is about 59 degrees, the angle ϕ being 27 degrees or in the region of 27 degrees. The frequency spectrum is such that all prominent resonances may be separated from the main longitudinal mode along the length axis dimension by a factor of about 2 to 1 when the dimensional ratio of the width with respect to the length is less than about 0.3 to 0.5.

The crystal elements provided in accordance with the present invention have a somewhat larger impedance and a smaller thermal expansion coefficient along the width axis dimension, and accordingly may withstand a somewhat faster temperature change without danger of cracking and will put less strain on the glued or cemented joints to the crystal mounting wires when the unit is taken over a temperature range. For this

purpose, the ϕ angle may be 27 degrees or in the region of 27 degrees, which lies near to an X-ray plane that may be used for orienting purposes.

The synthetic tartrate crystal elements provided in accordance with this invention have a high electromechanical coupling of the order of 20 to 25 per cent, a high reactance-resistance ratio Q at resonance, and a small change in frequency over a wide temperature range. These advantageous properties together with the low cost and freedom from supply troubles indicate that these crystal elements may be used in place of quartz as circuit elements in crystal filters and oscillators. Moreover, since the high electromechanical coupling existing in these crystals allows the circuit frequency to be varied in much larger amounts by a reactance tube, than can be done for the frequency of crystal quartz, such tartrate crystal cuts may be advantageously used for frequency modulating an oscillation generator.

The tartrate crystal elements provided in accordance with this invention may be especially useful in filter systems, for example. When used in channel filters, for example, the electromechanical coupling in these crystal elements is so high that regular channel widths of about 3600 cycles per second, for example, may be obtained without the use of auxiliary coils for frequencies as low as 60 to 100 kilocycles per second, for example. Accordingly, such a crystal channel filter may be produced more cheaply and put into a smaller space than one which is used with bulky and expensive coils and condensers. When such crystal filters are to be paralleled, a terminating network comprising coils and condensers may be used therewith in order to obtain no paralleling loss; or terminating resistances may be used therewith and the paralleling loss made up for by an added stage of amplification. The tartrate crystal elements in accordance with this invention have a low ratio of capacities and accordingly may be used in wide band filters, such as, for example, in program filters where the tartrate type crystal element may be used to control the loss peaks located at some distance from the pass-band, while using quartz crystals if desired for the sharpest peaks nearest the pass-band. The tartrate crystal elements in accordance with this invention have high piezoelectric coupling and accordingly may be used to extend the range of crystal filters to lower frequencies than have been obtained in the past. For example, voice channels down to about 12 kilocycles per second or less may be obtained using a flexure mode tartrate crystal element, the flexure modes of motion being obtained by methods presently used in connection with flexure mode quartz crystal elements. The tartrate crystal elements in accordance with this invention may also be used for control of frequency modulation in oscillators. On account of the large electromechanical coupling, the frequency variation and shift may be of large value and may be controlled by an applied direct current voltage or by a suitable reactance tube, for example.

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

Fig. 1 is a perspective view illustrating the form

and growth habit in which a monoclinic crystal of ethylene diamine tartrate may crystallize; and also illustrating the relation of the surfaces of the mother crystal with respect to the mutually perpendicular X, Y and Z axes, and with respect to the crystallographic a , b and c axes;

Fig. 2 is an edge view illustrating the rectangular X, Y and Z and crystallographic a , b and c systems of axes for monoclinic crystals, and also illustrating the plane of the optic axes of ethylene diamine tartrate crystals;

Fig. 3 is a perspective view illustrating longitudinal mode ethylene diamine tartrate crystal elements rotated in effect to a position corresponding to a ϕ angle in the region of 27 degrees, and a θ angle of substantially 59 degrees or more broadly from 40 to 70 degrees;

Fig. 4 is a graph illustrating the resonance and antiresonance frequencies and the dielectric constant characteristics of a longitudinal mode ethylene diamine tartrate crystal element as a function of temperature, the angle ϕ being about 27 degrees and the angle θ being about 59 degrees;

Fig. 5 is a graph illustrating the relation between the temperature at which zero temperature coefficient of frequency occurs in length longitudinal mode ethylene diamine tartrate crystal elements having a ϕ angle of about 27 degrees and θ angles varying from 40 to 68 degrees; and

Fig. 6 is a perspective view illustrating a width bending flexure mode type ethylene diamine tartrate crystal element.

This specification follows the conventional terminology, as applied to piezoelectric crystalline substances, which employs a system of three mutually perpendicular X, Y and Z axes as reference axes for defining the angular orientation of a crystal element. As used in this specification and as shown in the drawing, the Z axis corresponds to the c axis, the Y axis corresponds to the b axis, and the X axis is inclined at an angle with respect to the a axis which, in the case of ethylene diamine tartrate, is an angle of about $15\frac{1}{2}$ degrees. The crystallographic a , b and c axes represent conventional terminology as used by crystallographers.

Referring to the drawing, Fig. 1 is a perspective view illustrating the general form and growth habit in which ethylene diamine tartrate may crystallize, the natural faces of the ethylene diamine tartrate mother crystal 1 being designated in Fig. 1 in terms of conventional terminology as used by crystallographers. For example, the top surface of the crystal body 1 is designated as a 001 plane, and the bottom surface thereof as a $00\bar{1}$ plane, and other surfaces and facets thereof are as shown in Fig. 1.

The mother crystal 1, as illustrated in Fig. 1, may be grown from any suitable nutrient solution by any suitable crystallizer apparatus or method, the nutrient solution used for growing the crystal 1 being prepared from any suitable chemical substances and the crystal 1 being grown from such nutrient solution in any suitable manner to obtain a mother crystal 1 of a size and shape that is suitable for cutting therefrom piezoelectric crystal elements in accordance with this invention. The mother crystal 1, from which the crystal elements 2 are to be cut, is relatively easy to grow in shapes and sizes that are suitable for cutting useful crystal plates or elements 2 therefrom. Such mother crystals 1 may be conveniently grown to sizes around two inches or more for any of the X, Y and Z dimen-

alons or of any sufficient size to suit the desired size for the piezoelectric circuit elements 2 that are to be cut therefrom. It will be understood that the mother crystal 1 may be grown to size by any suitable crystallizer apparatus such as, for example, by a rocking tank type crystallizer or by a reciprocating rotary gyrator type crystallizer.

Crystals 1 comprising ethylene diamine tartrate have no water of crystallization and hence no vapor pressure, and may be put in an evacuated container without change, and may be held in temperatures as high as 100 degrees centigrade. At a temperature of about 130 degrees centigrade, some surface decomposition may start. A crystal 1 comprising crystalline ethylene diamine tartrate has only one cleavage plane which lies perpendicular to the Y axis. While cleavage planes may make the crystal 1 somewhat more difficult to cut and process, nevertheless, satisfactory processing may be done by any suitable means such as, for example, by using an abrading belt or a sanding belt cooled by oil or by a solution of water and ethylene glycol, for example. It will be noted that the crystal elements 2 oriented in accordance with this invention have major faces which do not coincide with the cleavage plane lying perpendicular to the Y axis, and hence have mechanically stronger surfaces for mounting purposes.

Crystals 1 comprising ethylene diamine tartrate ($C_6H_{14}N_2O_8$) have three dielectric constants, eight piezoelectric constants, and thirteen elastic constants, and form in the monoclinic sphenoidal class of crystals which has as its element of symmetry the b axis, the b axis being an axis of binary symmetry. As shown in Fig. 1, monoclinic crystals 1 comprising ethylene diamine tartrate are characterized by having two crystallographic axes b and c, which are disposed at right angles with respect to each other, and a third crystallographic axis a which makes a right angle with the b axis but an angle different than 90 degrees from the other crystallographic axis c. The c axis is the shortest axis and lies along the longest direction of the unit cell of the crystalline material. The b axis is an axis of two-fold or binary symmetry. In dealing with the axes and the properties of such a monoclinic crystal 1, it is convenient and simpler to use a right-angled or mutually perpendicular system of X, Y and Z coordinates. Accordingly, as illustrated in Fig. 1, the method chosen for relating the conventional right-angled X, Y and Z system of axes to the a, b and c system of crystallographic axes of the crystallographer, is to make the Z axis coincide with the c axis and the Y axis coincide with the b axis, and to have the X axis lie in the plane of the a and c crystallographic axes at an angle with respect to the a axis, the X axis angle being about 15 degrees 30 minutes above the a axis for ethylene diamine tartrate, as shown in Figs. 1 and 2.

The X, Y and Z axes form a mutually perpendicular system of axes, the Y axis being a polar axis which is positive, (+) by a tension at one of its ends, as shown in Fig. 1. In order to specify which end of the Y axis is the positive end, the plane of the optic axes of the crystal 1 may be located. A monoclinic crystal 1 is an optically biaxial crystal and for crystalline ethylene diamine tartrate, the plane that contains these optic axes is found to be parallel to the b or Y crystallographic axis and inclined

at an angle of about $24\frac{1}{2}$ degrees with respect to the +Z axis, as illustrated in Fig. 2.

Fig. 2 is a diagram illustrating the plane of the optic axes for crystals 1 comprising ethylene diamine tartrate. As shown in Fig. 2, the plane of the optic axes of an ethylene diamine tartrate crystal 1 is parallel to the Y or b axis, which in Fig. 2 is perpendicular to the surface of the drawing; and is inclined in a clockwise direction at an angle of about $24\frac{1}{2}$ degrees from the +Z or +c crystallographic axis. Since the +X axis lies at a counter-clockwise angle of 90 degrees from the +c or +Z axis, and the +b = +Y axis makes a right angle system of coordinates with the X and Z axes, the system illustrated in Fig. 2 determines the positive (+) directions of all three of the X, Y and Z axes. Hence, the positive directions of all three X, Y and Z axes may be specified with reference to the plane of the optic axes of the crystal 1. A similar optical method of procedure may be used for orienting and specifying the direction of the three mutually perpendicular X, Y and Z axes of other types of monoclinic crystals. Oriented crystal cuts are usually specified in practice by known X-ray orientation procedures.

Fig. 3 is a perspective view illustrating a crystal element 2 comprising ethylene diamine tartrate that has been cut from a suitable mother crystal 1 as shown in Fig. 1. The crystal element 2 as shown in Fig. 3 may be made into the form of an elongated plate of substantially rectangular parallelepiped shape having a longest or length axis dimension L, a breadth or width axis dimension W, and a thickness or thin dimension T, the directions of the dimensions L, W and T being mutually perpendicular, and the thin or thickness axis dimension T being measured between the opposite parallel major or electrode faces of the crystal element 2. The length axis dimension L and the width axis dimension W of the crystal element 2 may be made of values to suit the desired frequency thereof. The thickness axis or thin dimension axis T may be made of a value to suit the impedance of the system in which the crystal element 2 may be utilized as a circuit element; and also it may be made of a suitable value to avoid nearby spurious modes of motion which, by proper dimensioning of the thickness axis dimension T relative to the larger length and width dimensions L and W, may be placed in a location that is relatively remote from the desired longitudinal mode of motion along the length axis dimension L.

Suitable conductive electrodes 4 and 5 may be provided adjacent the two opposite major or electrode faces of the crystal element 2 in order to apply electric field excitation thereto. The electrodes 4 and 5 when formed integral with the faces of the crystal element 2 may consist of gold, platinum, silver, aluminum or other suitable conductive material deposited upon surfaces of the crystal element 2 by evaporation in vacuum or by other suitable process. The electrodes 4 and 5 may be electrodes wholly or partially covering the major faces of the crystal element 2, and may be provided in divided or non-divided form as already known in connection with quartz crystals. Accordingly, it will be understood that the crystal element 2 disclosed in this specification may be provided with conductive electrodes or coatings 4 and 5 on their faces of any suitable composition, shape and arrangement, such as those already known in connection with Rochelle salt or quartz crystals, for example; and that they may

be nodally mounted and electrically connected by any suitable means, such as, for example, by pressure type clamping pins or by one or more pairs of opposite conductive supporting spring wires 7 disposed along the nodal line 6 and cemented by conductive cement or glued to the crystal element or to the metallic coatings 4 and 5 deposited on the crystal element 2, as already known in connection with quartz, Rochelle salt and other crystals having similar or corresponding longitudinal modes of motion. Each of the supporting wires 7 may be provided with a small flat-headed end portion, the outer surface of which may be cemented directly to the major face of the crystal element 2 adjacent a node 6 thereof by a spot of any suitable adhesive cement 8. The electrical connection from each support wire 7 to the associated crystal coating 4 or 5 may be established by extending the respective conductive coating 4 or 5 onto the associated supporting wire 7. By utilizing a good conductive cement spot 8, the electrical connection may be established directly with the associated coating 4 or 5. Examples of support wires adapted for mounting crystal elements are illustrated in United States Patents No. 2,371,613, granted March 20, 1945, to I. E. Fair and No. 2,275,122, granted March 3, 1942, to A. W. Ziegler, for example.

As illustrated in Fig. 3, the thin or thickness axis dimension T of the crystal element 2 lies in a plane which contains the Y axis and which makes an angle ϕ of about 27 degrees or in the region of 27 degrees with respect to the +Z axis as measured from the +Z axis. The direction of the thickness axis dimension T lying in that plane makes an angle θ of about 59 degrees with respect to the +Y axis as measured from the +Y axis. The length axis dimension L of the crystal element 2 which is disposed normal to the thickness axis dimension T, as illustrated in Fig. 3, lies in or nearly in the plane which is determined by the Y axis and the value of the angle ϕ , which is in the region of 27 degrees. It will be noted that the angles ϕ and θ are measured in the quadrant comprising the +X, the +Y and the +Z axes, the angle ϕ being 27 degrees or in the region of 27 degrees as measured from the +Z axis toward the +X axis in the plane of the X and Z axes, and the θ angle being in the region of 59 degrees or more broadly one of the angles from 40 to 70 degrees as measured from the +Y axis in the plane containing the Y axis, as illustrated in Fig. 3.

At the θ angle of about 59 degrees with respect to the +Y axis, the angle ϕ being about 27 degrees, the ethylene diamine tartrate crystal plate 2 of Fig. 3 has a zero temperature coefficient of frequency at about +27.5 degrees centigrade for its longitudinal mode of motion along the length axis dimension L. At angles of θ above and below the θ angle of about 59 degrees referred to, the value of the temperature at which the zero temperature coefficient of frequency occurs for the longitudinal length L mode of motion is raised or lowered from the +27.5 degrees centigrade value referred to, according to the angle of θ selected, as illustrated by the curve in Fig. 5. Accordingly, the crystal element 2 of Fig. 3 may be selectively oriented for best use with the prevailing ambient temperature. The electrodes 4 and 5 disposed adjacent the major faces of the crystal element 2 provide an electric field in the direction of the thickness axis dimension T of the crystal element 2 thereby producing a useful

longitudinal mode of motion along the length dimension L of the crystal element 2 with high electromechanical coupling and a low temperature coefficient of frequency over a temperature range in the region above and below about +27 degrees centigrade, when the angle θ is about 59 degrees, the angle ϕ being about 27 degrees.

The dimensional ratio of the width dimension W with respect to the length dimension L of the crystal element 2 may be made of any suitable value in the region less than 0.7 for example, and as particularly described herein is less than about 0.5 for longitudinal length mode crystal elements 2. The smaller values of dimensional ratios of the width W with respect to the length L, as of the order of 0.5 or less, have the effect of spacing the width W mode of motion at a frequency which is remote from the fundamental longitudinal mode of motion along the length dimension L.

When the crystal element 2 is operated in the fundamental longitudinal mode of motion along the length dimension L thereof, the nodal line 6 occurs at the center of and transverse to the length dimension L of the crystal element 2 about midway between the opposite small ends thereof and the crystal element 2 may be there nodally mounted and electrically connected by any suitable means such as by one or more pairs of opposite spring wires 7 cemented to the crystal element 2 by spots of cement 8 at the nodal region 6 of the crystal element 2.

While the crystal element 2 is particularly described herein as being operated in the fundamental longitudinal mode of motion along its length axis dimension L, it will be understood that it may be operated in any even or odd order harmonic thereof in a known manner or by means of a plurality of pairs of opposite interconnected electrodes spaced along the length L thereof, as in a known manner in connection with harmonic longitudinal mode quartz crystal elements. Also, if desired, the crystal element 2 may be operated simultaneously in the longitudinal length L and width W modes of motion by arrangements as disclosed, for example, in W. P. Mason Patent 2,292,885, dated August 11, 1942; or simultaneously in the longitudinal length L mode of motion and the width W flexure mode of motion by arrangements as disclosed, for example, in W. P. Mason Patent 2,292,886, dated August 11, 1942.

Fig. 4 is a graph illustrating an example of the variation, with temperature change, in the frequency and dielectric characteristics of a longitudinal-mode ethylene diamine tartrate crystal element 2 of the type illustrated in Fig. 3, the crystal element 2 having a ϕ angle of about 27 degrees, a θ angle of about 59 degrees, a thickness axis dimension T of about 0.93 millimeter, a width axis dimension W of about 9.13 millimeters and length axis dimension L of about 35.8 millimeters, thus giving a dimensional ratio of about 0.255 for the ratio of the width axis dimension W with respect to the length axis dimension L. As illustrated by the top curve in Fig. 4, the longitudinally clamped dielectric constant of such a crystal plate 2 of Fig. 3 is of the order of about 6.5, expressed in centimeter-gram-seconds (c. g. s.) units, over a temperature range from about -90 degrees to +90 degrees centigrade. Over the same temperature range, the variation in the anti-resonance frequency is given by the middle curve in Fig. 4, and the variation in the resonance frequency is given by the bottom curve. As shown by the bottom curve in Fig. 4, the reso-

nant frequency has a zero temperature coefficient at about +27.5 degrees centigrade, and from about 0 degrees to +50 degrees centigrade the total variation in frequency is small enough for use at all ordinary temperatures. As shown by the bottom curve of Fig. 4, the frequency constant at about 27 degrees centigrade is about 168 kilocycles per second per centimeter of the length axis dimension L for the fundamental longitudinal mode of motion along the length axis dimension L.

It will be understood that the frequency of the main mode of motion, which is the fundamental longitudinal mode of motion along the length axis dimension L, varies inversely as the value of the length axis dimension L. Thus, as an example a crystal element 2 having a ϕ angle of about 27 degrees, a θ angle of about 59 degrees, a length axis dimension L of about one centimeter and a dimensional ratio of width W to length L of about 0.255 will have a frequency of about 168 kilocycles per second for its fundamental longitudinal mode of motion along the length axis dimension L. Also, the frequency will vary with the value of the dimensional ratio of width W to length L that is selected. At the smaller values of dimensional ratio of width W to length L, as around 0.3 or less for example, the effects of secondary modes of motion upon the main length longitudinal mode of motion along the length axis dimension L are comparatively negligible and do not produce any troublesome interference therewith. The ratio of capacities is also a function of the dimensional ratio of the width W with respect to the length L and is lowest in value in the region of dimensional ratios below about 0.4.

As an illustrative example, the constants at a temperature of about 25 degrees centigrade of an ethylene diamine tartrate crystal plate 2 having a longitudinal mode frequency of about 100 kilocycles per second, a ϕ angle of about 27 degrees, a θ angle of about 59 degrees, a length axis dimension L of about 1.69 centimeters, a width axis dimension W of about 0.42 centimeter, and a thickness axis dimension T of about 0.1 centimeter are approximately as follows: The dielectric constant k —about 6.4 as expressed in centimeter-gram-seconds units, the ratio of capacitance r or C_0/C_1 —about 50.0, the capacitance C_0 —about 4.02 micromicrofarads, the capacitance C_1 —about .0805 micromicrofarad, and the inductance L_1 —about 31.6 henries, the elements C_0 , C_1 and L_1 being elements in the conventional equivalent circuit of the electroded crystal plate 2. It will be noted that this crystal plate 2 has an inductance sufficiently comparable with that of quartz for a similar thickness T to enable it to be used as a direct replacement of quartz without many changes.

It will be noted that by cutting the crystal element 2 of Fig. 3 at θ angle values above and below 59 degrees, the angle ϕ being about 27 degrees in all cases, the position of the zero coefficient temperature may be lowered below or raised above the +27.5 degrees centigrade value which obtains at a θ angle of about 59 degrees. Accordingly, the crystal element 2 of Fig. 3 may be oriented for use with the prevailing ambient temperature.

Fig. 5 is a graph showing a plot of the temperature at which the zero temperature coefficient of frequency occurs in longitudinal mode ethylene diamine tartrate crystal elements 2 of Fig. 3, when the orientation angle θ is varied from about 40 to 68 degrees, the angle ϕ being substantially 27 degrees in all cases. As shown by the curve in

Fig. 5, when the crystal element 2 of Fig. 3 has a θ angle of about 59 degrees and a ϕ angle of about 27 degrees, the temperature at which its zero temperature coefficient of longitudinal mode frequency occurs is about +27.5 degrees centigrade; and when it has a θ angle of about 45 degrees, the angle ϕ being about 27 degrees, the temperature at which its zero temperature coefficient of longitudinal mode frequency occurs is about +68 degrees centigrade. Similarly, for other angles of θ between 40 and 68 degrees, the temperature at which the zero temperature coefficient occurs for crystal elements 2 of Fig. 3 operating in the fundamental longitudinal mode of motion along the length axis dimension L may be obtained from the curve of Fig. 5.

Fig. 6 is a perspective view of the elongated crystal plate 2 of Fig. 3 provided with two separate pairs of opposite electrodes 4a, 4b, 5a and 5b, instead of a single pair of electrodes 4 and 5, in order to operate it in a width flexure mode of motion at a lower frequency having at the same time a low temperature coefficient of frequency. For frequencies below about 40 kilocycles per second for example, the size of the crystal plate 2 may become inconveniently large when it is operated in the straight longitudinal length mode of motion as illustrated in Fig. 3, and it may then become desirable to provide for operation in a width bending type of flexure mode of motion by providing the crystal element 2 of Fig. 3 with the divided type of integral electrodes 4a, 4b, 5a and 5b, as illustrated in Fig. 6. For this purpose, the electrodes 4a, 4b, 5a and 5b may be metal coatings similar to those shown in Fig. 3 but arranged as shown in Fig. 6, the electrode arrangement and connections to produce the flexure motion being of the type described in United States Patent No. 2,259,317, granted October 14, 1941, to W. P. Mason, for example.

While in Fig. 6 an arrangement is disclosed for operating the crystal plate 2 in the width bending mode of flexure motion, two of such crystal elements 2 may be cemented or bonded together in face-to-face relation in order to form a duplex type crystal unit for operation at a still lower frequency in a thickness bending type of flexure motion. For this purpose, the crystal poling, electrode arrangement and electrode connections may be of the form disclosed for example in application Serial No. 477,915, filed March 4, 1943, by C. E. Lane, now United States Patent No. 2,410,825, dated November 12, 1946.

The crystal elements provided in accordance with this invention may be protected from moisture by mounting in a suitable sealed container containing dry air or evacuated, or if desired by coating the crystal surfaces with plastic films or shellac films deposited from butanol or ethanol. It will be noted that the crystal bodies provided in accordance with this invention may have per se a low or zero temperature coefficient of frequency, and hence do not require an added bar of material of equal and opposite temperature coefficient of frequency secured thereto in order to obtain an overall low temperature coefficient of frequency, as for example in the case of a half-wave 45-degree Z-cut longitudinal mode ammonium dihydrogen phosphate crystal element which has a high negative temperature coefficient and may be cemented to a half-wave 38 per cent nickel-62 per cent iron alloy bar having a high positive temperature coefficient in order to obtain for the wire supported composite longitudinal vibrator an overall low or zero temperature coefficient.

cient of frequency by proportioning the relative cross-sectional areas of the crystal and the metal bar.

It will be noted that among the advantageous cuts of ethylene diamine tartrate illustrated and described in this specification are orientations for which the temperature frequency coefficient may be zero at a specified temperature T_0 , the frequency variation being sufficiently small over ordinary temperature ranges to be useful, for example, in filter systems. The low temperature coefficient of frequency together with the high electromechanical coupling, the high Q , the ease of procurement, the low cost of production and the freedom from water of crystallization are advantages of interest for use as circuit elements in electrical systems generally.

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.

What is claimed is:

1. An elongated ethylene diamine tartrate piezoelectric crystal plate having its thickness or thinnest axis dimension disposed in a plane containing the Y axis and inclined at an angle of substantially 59 degrees with respect to the +Y axis as measured from said +Y axis toward the plane of the +X and +Z axes, said plane containing said Y axis being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in said plane of said +X and +Z axes, the lengthwise or longest axis dimension of said crystal plate lying substantially in said plane containing said Y axis.

2. An elongated ethylene diamine tartrate piezoelectric crystal plate having its thickness or thinnest axis dimension disposed in a plane containing the Y axis and inclined at one of the angles in the range from 45 to 68 degrees with respect to the +Y axis as measured from said +Y axis toward the plane of the +X and +Z axes, said plane containing said Y axis being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in said plane of said +X and +Z axes, the lengthwise or longest axis dimension of said crystal plate lying substantially in said plane containing said Y axis.

3. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said lengthwise axis dimension being made of a value corresponding to the value of said frequency and being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at an angle of substantially 59 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes.

4. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said length-

wise axis dimension being made of a value corresponding to the value of said frequency and being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at an angle of substantially 59 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes, said body having a width axis dimension perpendicular to said said lengthwise and thickness axes, the dimensional ratio of said width axis dimension with respect to said lengthwise axis dimension being a value less than 0.5.

5. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said lengthwise axis dimension being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at an angle of substantially 59 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes, and means producing an electric field in the direction of said thickness axis dimension for operating said crystal body in a mode of motion controlled by said lengthwise axis dimension at said frequency having said low temperature coefficient.

6. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said lengthwise axis dimension being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at an angle of substantially 59 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes, said body having a width axis dimension perpendicular to said lengthwise and thickness axes, the dimensional ratio of said width axis dimension with respect to said lengthwise axis dimension being a value less than 0.5, and means producing an electric field in the direction of said thickness axis dimension for operating said crystal body in a mode of motion controlled by said lengthwise axis dimension at said frequency having said low temperature coefficient.

7. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said lengthwise axis dimension being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined

at an angle of substantially 59 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes, said body having a width axis dimension perpendicular to said lengthwise and thickness axes, the dimensional ratio of said width axis dimension with respect to said lengthwise axis dimension being a value less than 0.5, and means comprising electrodes disposed adjacent said major faces and producing an electric field in the direction of said thickness axis dimension for operating said crystal body in a longitudinal mode of motion along said lengthwise axis dimension at said frequency having said low temperature coefficient, said lengthwise axis dimension expressed in centimeters being a value in the region of substantially 168 divided by the value of said frequency expressed in kilocycles per second.

8. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said lengthwise axis dimension being made of a value corresponding to the value of said frequency and being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at one of the angles within the range of angles from 40 to 68 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes.

9. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said lengthwise axis dimension being made of a value corresponding to the value of said frequency and being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at one of the angles within the range of angles from 45 to 68 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes, said body having a width axis dimension perpendicular to said lengthwise and thickness axes, the dimensional ratio of said width axis dimension with respect to said lengthwise axis dimension being a value less than 0.5.

10. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said

lengthwise axis dimension being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at one of the angles within the range of angles from 40 to 68 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes, said body having a width axis dimension perpendicular to said lengthwise and thickness axes, the dimensional ratio of said width axis dimension with respect to said lengthwise axis dimension being a value less than 0.5, and means producing an electric field in the direction of said thickness axis dimension for operating said crystal body in a mode of motion controlled by said lengthwise axis dimension at said frequency having said low temperature coefficient.

11. An ethylene diamine tartrate piezoelectric crystal body of low temperature coefficient of frequency having a thickness axis dimension perpendicular to its major faces and a lengthwise axis dimension along said major faces, said lengthwise axis dimension being made of a value corresponding to the value of said frequency and being disposed substantially in a plane containing the Y axis, said thickness axis dimension being disposed in said plane containing said Y axis and being inclined at one of the angles within the range of angles from 50 to 68 degrees with respect to the +Y axis as measured from said +Y axis into the quadrant comprising the +X, +Y and +Z axes, said plane being inclined at an angle of substantially 27 degrees with respect to said +Z axis as measured from said +Z axis toward said +X axis in a plane determined by said +X and +Z axes, said body having a width axis dimension perpendicular to said lengthwise and thickness axes, the dimensional ratio of said width axis dimension with respect to said lengthwise axis dimension being a value less than 0.5, and means comprising electrodes disposed adjacent said major faces and producing an electric field in the direction of said thickness axis dimension for operating said crystal body in a longitudinal mode of motion along said lengthwise axis dimension at said frequency having said low temperature coefficient, said lengthwise axis dimension expressed in centimeters being a value in the region of substantially 168 divided by the value of said frequency expressed in kilocycles per second.

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