

June 7, 1949.

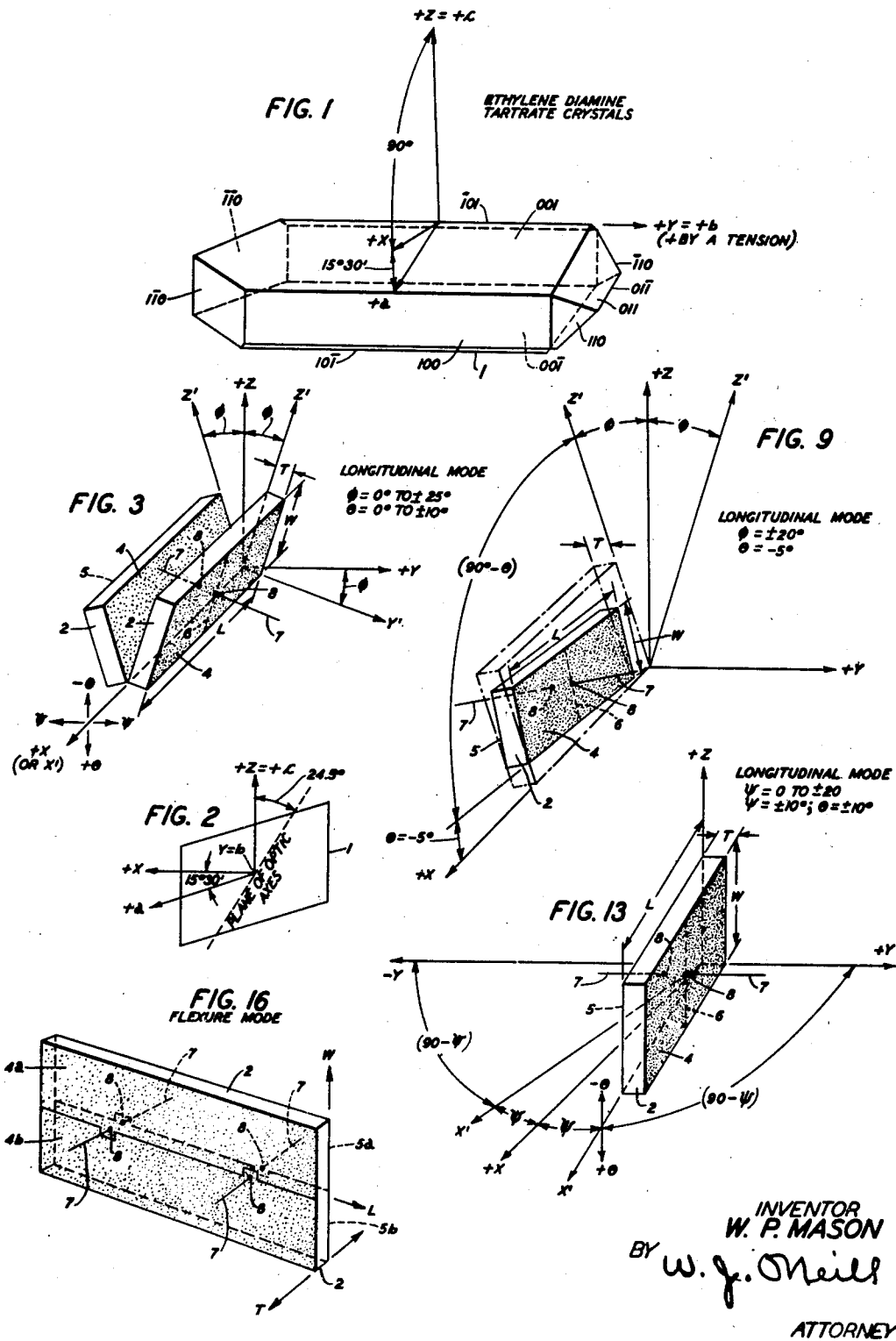
W. P. MASON

2,472,715

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Jan. 21, 1947

4 Sheets-Sheet 1



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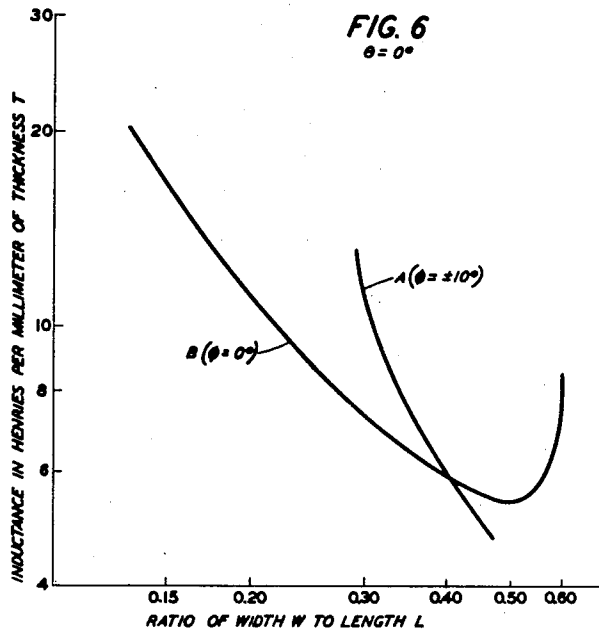
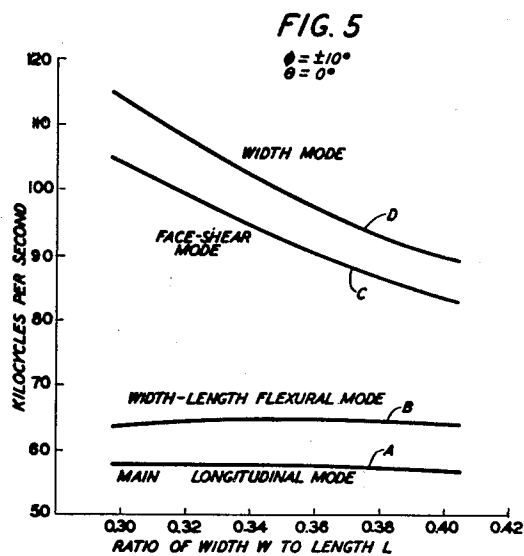
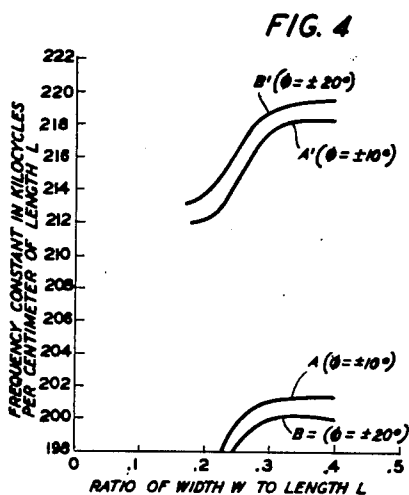
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PIEZOELECTRIC CRYSTAL APPARATUS

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4 Sheets-Sheet 2



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PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 7

$\phi = \pm 10^\circ$
 $\theta = 0^\circ$

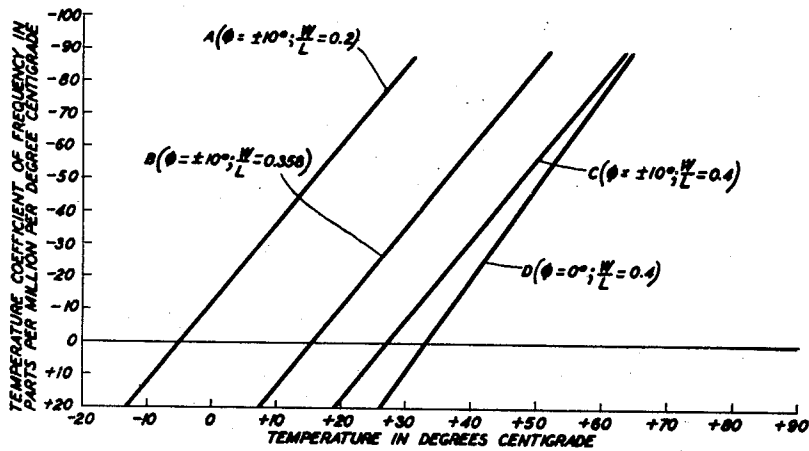
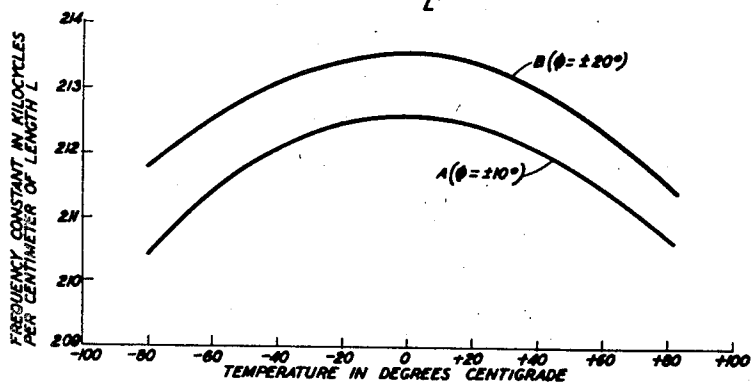


FIG. 8

$\phi = 0^\circ$
 $\frac{W}{L} = 0.2$



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PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 10

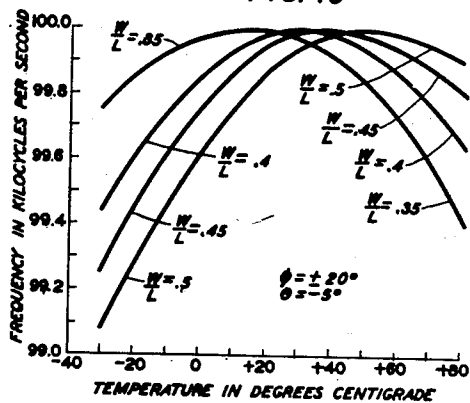


FIG. 11

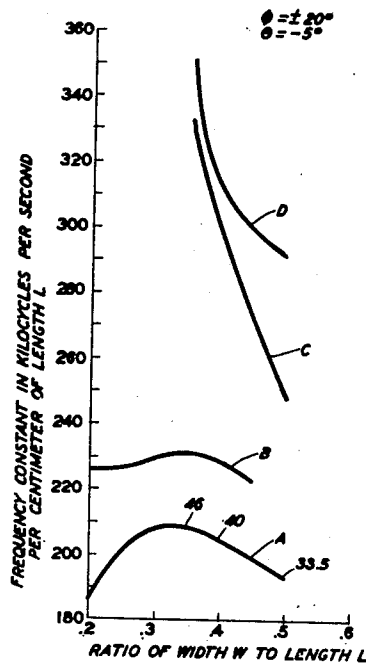


FIG. 12

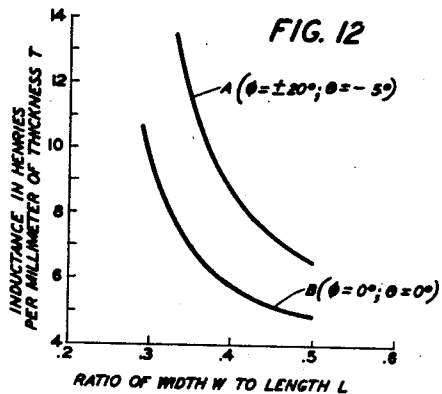


FIG. 14

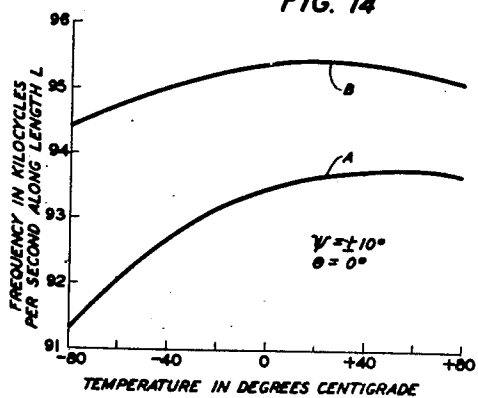
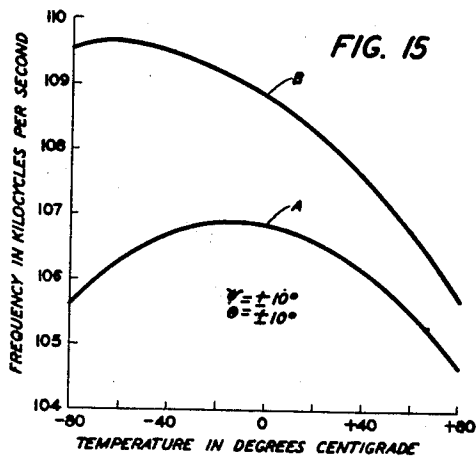


FIG. 15



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PIEZOELECTRIC CRYSTAL APPARATUS

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Application January 21, 1947, Serial No. 723,264

17 Claims. (Cl. 171—327)

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This invention relates to piezoelectric crystal apparatus and particularly to rotated Y-cut type, length-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 electro-mechanical transducers in supersonic projectors, microphones, pick-up devices and detectors.

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

Another object of this invention is to take advantage of the high piezoelectric coupling, the favorable 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 coupling of the desired mode of motion to undesired modes of motion therein, favorable inductance values and a 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 rotated Y-cut type in ethylene diamine tartrate crystals which may have a favorable 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 vibration frequency and favorable inductance values, and fairly high Q or low dielectric loss and mechanical dissipation. Also crystalline ethylene diamine tartrate has no water of crystallization

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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 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 relatively high piezoelectric coupling. In accordance with this invention, such synthetic type crystal cuts may be suitable rotated Y cuts taken from crystalline ethylene diamine tartrate and adapted to operate in a so-called longitudinal mode of motion substantially along the lengthwise axis dimension thereof. 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.

As disclosed and claimed in an earlier application for patent, Serial No. 657,886, filed March 28, 1946 by W. P. Mason, now Patent No. 2,458,615, crystal elements cut from crystalline ethylene diamine tartrate may be Y-cut type crystal elements having their major faces and major plane section disposed perpendicular or nearly perpendicular with respect to the Y or b axis of the crystal material and operating in the longitudinal mode of motion along the longest or lengthwise axis dimension thereof, the lengthwise axis dimension being disposed or inclined at an angle in the region from 0 to ± 25 degrees with respect to the +X axis; or in the region of 0 degrees where a zero temperature coefficient of frequency is desired at ordinary room temperatures in the region of about +27 degrees centigrade. The temperature at which the zero temperature coefficient occurs for the longitudinal length axis mode of motion varies according to the value of the angle selected, and for a dimensional ratio of width to length of about 0.4 in such a Y-cut crystal plate is at about +27 degrees centigrade for an angle of about 0 degrees, and at values between -10 degrees and +50 degrees centigrade for values of

angles of length from the X axis between +15 and -15 degrees. The coupling of the longitudinal length axis mode of motion to other modes of motion therein is small, and at the angle of about 0 degrees, there is no face shear mode of motion in the crystal element. That Y-cut longitudinal mode crystal element, when its length axis dimension is disposed along the X axis, has a ratio of capacities of about 27, a frequency-curvature constant α_2 of about 1.4×10^{-6} , and a change of inductance of about ± 8 per cent from 55 degrees Fahrenheit to 110 degrees Fahrenheit, which is the usual ambient temperature range that crystal filters have to meet in practice.

As compared with such Y-cut longitudinal mode crystal elements disclosed and claimed in the earlier Mason application Serial No. 657,886 referred to, the longitudinal mode ethylene diamine tartrate crystal cuts provided in accordance with the present invention are also Y-cut type but rotated in effect around the lengthwise axis dimension, or around the width axis dimension, or additionally around the thickness axis dimension of the crystal plate. Accordingly, there is obtained a series of additional crystal cuts in ethylene diamine tartrate crystals having a low or substantially zero temperature coefficient of frequency, and having orientations, more or less roughly speaking, in the general neighborhood of the unrotated or 0-degree Y-cut orientation, but actually rotated in effect about the length, thickness and width dimensions of the crystal plate for obtaining length-mode crystal cuts having favorable inductance values and resonances, a low temperature coefficient of frequency, and a high electromechanical coupling.

The synthetic tartrate crystal elements provided in accordance with this invention have a relatively high electromechanical coupling which is of the order of 20 per cent, a high reactance-resistance ratio Q at resonance, and a small change in frequency over a relatively wide temperature range. These advantageous properties together with the low cost and freedom from supply trouble 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 3,600 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 accord-

ingly 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 electrode arrangements 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 a sectional edge view of Fig. 1 illustrating the rectangular X, Y and Z and the 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 cuts of length or longitudinal mode ethylene diamine tartrate crystal elements of the Y-cut type rotated in effect around the lengthwise axis dimension to positions corresponding to ϕ angles ranging from 0 to ± 25 degrees, and which may be additionally rotated in effect around the thickness axis to positions corresponding to θ angles, ranging from 0 to ± 10 degrees;

Figs. 4 to 8 are graphs illustrating the characteristics of crystal plates oriented as illustrated in Fig. 3;

Fig. 9 is a perspective view illustrating a rotated Y-cut type length-mode ethylene diamine tartrate crystal plate rotated in effect to a position corresponding to a ϕ angle in the region of plus or minus ($\pm$) 20 degrees, and a θ angle in the region of minus ($-$) 5 degrees;

Figs. 10 to 12 are graphs illustrating characteristics of crystal plates oriented as illustrated in Fig. 9;

Fig. 13 is a perspective view illustrating rotated Y-cut type length-mode ethylene diamine tartrate crystal plates rotated in effect around the width axis thereof, and also around the thickness axis thereof;

Figs. 14 and 15 are graphs illustrating characteristics of crystal plates oriented as illustrated in Fig. 13;

Fig. 16 is a perspective view illustrating a

length-width or face flexure mode crystal plate which may be constructed from crystal plates oriented as illustrated in Figs. 3, 9 and 13;

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 crystalline 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 mother 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 2 in accordance with this invention. The ethylene diamine tartrate solution may be made up from its known ingredients comprising tartaric acid salt and ethylene diamine solution, the tartaric acid salt being dissolved in the liquid ethylene diamine solution. 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 the X, Y and Z dimensions 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 or fracture 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 ($C_4H_{14}N_2O_6$) have four 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 an angle different than 90 degrees from the other two crystallographic axes b and c. The c axis 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-angle 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 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 counterclockwise 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 crystal elements 2 comprising ethylene diamine tartrate that have been cut from a suitable mother crystal

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as shown in Fig. 1. The crystal elements 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 or nearly 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 or thin dimension 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 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 at 8, 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 or resin 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.

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.

The adhesive spots 8 may comprise any suitable cement or resin such as "Bakelite" cement capable of securing the headed ends of the support wires 7 directly to the faces of the crystal plate 2. While the support wire 7 can, if desired, be secured by cement placed in small holes provided in the crystal plate 2 along the surface nodal line 6, or the small wires 7 when heated sufficiently at their ends to melt a very small contiguous portion of the crystal plate 2, can be directly pressed into and embedded in the body of the crystal plate 2, the preferred method is to glue the headed wire 7 with cement to the flat crystal plate 2, and then evaporate gold over the glued joint 8. Suitable bumpers of plastic or other soft material, similar to the crystal bumper arrangements disclosed, for example, in United States Patent 2,275,122, dated March 3, 1942, to A. W. Ziegler, may be employed to prevent excessive bodily displacement of the wire-mounted crystal plate 2 when subjected to externally applied mechanical shock.

The dimensional ratio of the width axis dimension W with respect to the length axis dimension L of the crystal element 2 may be made of suitable value in the region less than 0.7 for example, and as particularly described herein is made 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 more 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. 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 axis 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.

As illustrated in Fig. 3, the orientation of the elongated crystal plate 2 with respect to the mutually perpendicular X, Y and Z axes of the crystalline material is that of a Y-cut crystal plate rotated in effect around the X axis lengthwise or longest axis dimension L to a position corresponding to a ϕ angle within the range from 0 to about ± 25 degrees on either side of the +Z axis, the ϕ angle being measured in a plane perpendicular to the X axis and to the major faces of the crystal plate 2. The θ angle may be taken to represent an additional rotation around the thickness axis dimension T of the crystal plate 2. Where the θ angle is zero and the ϕ angle is zero, the crystal plate 2 is an unrotated or 0-degree Y-cut ethylene diamine tartrate crystal element 2 with its length or longest axis disposed along the X axis. Such a crystal plate has a low temperature coefficient of frequency as well

As a high electromechanical coupling of the order of 21 per cent corresponding to a ratio of capacities of about 27.

By rotating such a Y-cut crystal element 2 in effect around the X axis length dimension L, in either ϕ direction of rotation, additional crystal elements 2 may be obtained that also have a low temperature coefficient of frequency and a high electromechanical coupling, and in addition major surfaces which is not parallel to a fracture or cleavage plane thereof and which accordingly may be glued to, for mounting purposes, to thereby result in a stronger glued or cemented joint capable of withstanding stronger forces that may have to be met in practice by wire mounted crystals.

Where the angle ϕ is an angle greater than zero degrees, such as an angle up to ± 20 degrees for example, and the main mode of vibration is substantially along the X-axis length dimension L, the temperature coefficient of frequency of the elongated thin crystal plate 2 operated in such a longitudinal mode of vibration depends mainly on the direction of the length axis dimension L and is preserved at a comparatively low value for the various angles of $\pm \phi$ while at the same time giving major surfaces inclined at an angle ϕ to the fracture or cleavage plane of the crystalline material. Also the piezoelectric constant and the electromechanical coupling for the rotated crystal bar 2 is not decreased very materially for a $\pm \phi$ angle variation up to 20 degrees or more such as from 10 to 20 degrees, for example.

Where the major plane section and major surfaces of the rotated Y-cut crystal plate 2 of Fig. 3 are rotated in effect to a ϕ angle of about ± 10 degrees around the X axis, with the lengthwise axis dimension L disposed substantially along the X axis, the crystal element 2 has an electromechanical coupling of the order of 19.8 per cent corresponding to a ratio of capacities of about 30, has a low temperature coefficient of longitudinal mode frequency, and a comparatively strong mounting surface that will stand pull tests well. The characteristics of such a $\phi = \pm 10$ degree Y-cut type ethylene diamine tartrate crystal element 2 of Fig. 3 are such that it may be used for filter purposes such as, for example, in channel filters in the frequency region from 60 to 90 kilocycles per second more or less. The secondary width-length flexure mode introduced in such a $\phi = \pm 10$ degree Y-cut crystal element 2 of Fig. 3 is usually not prominent enough to cause trouble.

Fig. 4 is a graph illustrating values of the frequency constants of length-mode ethylene diamine tartrate crystal plates 2 oriented as illustrated in Fig. 3, the lengthwise axis dimension L being disposed along or nearly along the X axis giving a θ angle of 0 degrees, the major faces being rotated to a ϕ angle position of about ± 10 degrees, and also about ± 20 degrees, from the +Z axis, and the dimensional ratio of width W to length L being a value varying from around 0.2 to 0.4. The curves labeled A and A' in Fig. 4 represent the ± 10 degree ϕ angle orientation, and the curves labeled B and B' in Fig. 4 represent the ± 20 degree ϕ angle orientation. The lower curves A and B may be taken to represent the main fundamental longitudinal or lengthwise mode of motion, and the upper curve A' and B' the secondary mode of motion of the coupled width-length flexure type. As illustrated by the curve A in Fig. 4, the frequency constant of the

fundamental longitudinal or lengthwise mode of motion of the $\phi = \pm 10$ degree crystal bar 2 of Fig. 3, as expressed in kilocycles per second per centimeter of the lengthwise dimension L, has values roughly between 197 and 202 for width W to length L dimensional ratios between about 0.2 and 0.4, as shown by the curve A in Fig. 4. As illustrated by the curve B in Fig. 4, the frequency constant of the fundamental longitudinal or lengthwise mode of motion of the $\phi = \pm 20$ degree crystal bar 2 of Fig. 3, expressed in same units, has values slightly less and roughly between 195 and 200 for width W to length L dimensional ratios roughly between 0.2 and 0.4, as shown by the curve B in Fig. 4. As illustrated by the curves A' and B' in Fig. 4, there is a secondary coupled width-length flexure mode present in the $\phi = \pm 10$ degree and the $\phi = \pm 20$ degree crystal bars 2 of Fig. 3, which coupled mode is quite weak for the dimensional ratios of width W to length L below about 0.2. For the range of dimensional ratios of width W to length L from about 0.23 to 0.4, the main resonances represented by the curves in Fig. 4 have two parts, the upper part being the coupled flexure mode referred to, and the lower part being the coupled longitudinal mode.

Fig. 5 is a graph illustrating an example of the frequency spectrum of an ethylene drawing tartrate crystal plate 2 of Fig. 3 having a ϕ angle orientation of about ± 10 degrees, a θ angle orientation of about 0 degrees, a length dimension L of about 35.08 millimeters, a thickness dimension T of about 1.43 millimeters, thus giving a length L to thickness T dimensional ratio of about 24.55, and a width W to length L dimensional ratio varying from about 0.3 to 0.4. The main longitudinal or lengthwise mode of motion as represented by the curve A in Fig. 5, has a frequency of about 58 kilocycles per second with a low temperature coefficient, and the secondary width-length flexural mode as represented by the curve B in Fig. 5 has a frequency of about 64 kilocycles per second with a negative temperature coefficient of about 200 parts per million per degree centigrade. The curves C and D in Fig. 5 represent the more remote face shear and width modes, respectively.

Fig. 6 is a graph illustrating an example of the inductance level values of crystal plates 2 of Fig. 3 having a ϕ angle orientation of about ± 10 degrees, as compared with a ϕ angle orientation of 0 degrees, for dimensional ratios of width W to length L between about 0.15 and 0.6. The curve A in Fig. 6 illustrates such inductance level values for the $\phi = \pm 10$ degree crystal plate 2 of Fig. 3, and the curve B in Fig. 6 illustrates the inductance values for the $\phi = 0$ degree crystal plate of Fig. 3, the latter being an unrotated Y-cut crystal plate with its length axis dimension L along the X axis.

Fig. 7 is a graph illustrating values of the temperature coefficient of frequency, as a function of the temperature and of the dimensional ratio of width W to length L, for length longitudinal mode ethylene diamine tartrate crystal plates 2 of Fig. 3 having a ϕ angle orientation of about ± 10 degrees and a θ angle orientation of about 0 degrees. As illustrated by the curve A in Fig. 7, the zero coefficient of frequency occurs at a temperature a little below 0 degrees centigrade when the dimensional ratio of width W to length L is about 0.2 for a crystal plate 2 of Fig. 3 having a ϕ angle orientation of about ± 10 degrees. As illustrated by the curve B in Fig. 7,

the zero coefficient of frequency occurs at a temperature of about +15 degrees centigrade when the dimensional ratio of width W to length L is about 0.358 for a crystal plate 2 of Fig. 3 having a ϕ angle orientation of about ± 10 degrees. As illustrated by the curve C in Fig. 7, the zero coefficient of frequency occurs at a temperature of about +26 degrees centigrade when the dimensional ratio of width W to length L is about 0.4 for a crystal plate 2 of Fig. 3 having a ϕ angle orientation of about ± 10 degrees. As illustrated by the curve D in Fig. 7, the zero coefficient of frequency occurs at a temperature of about +33 degrees centigrade when the dimensional ratio of width W to length L is about 0.4 for a crystal plate 2 of Fig. 3 having a ϕ angle orientation of about zero degrees, which corresponds to an unrotated Y-cut crystal plate with its length axis dimension L along the X axis. It will be noted from the curves A, B and C of Fig. 7 that the temperature of zero coefficient of frequency may be varied considerably in accordance with the value of the dimensional ratio of width W to length L selected.

Fig. 8 is a graph illustrating an example of the variation in frequency with change in temperature of two differently oriented ethylene diamine tartrate elongated crystal plates 2 of Fig. 3, both having their lengthwise axis dimension L disposed along or nearly along the X axis and their major faces inclined at ϕ angles, one ϕ angle being a value of about ± 10 degrees and the other about ± 20 degrees, and the dimensional ratio of width W to length L being a value of about 0.2 in both cases. The curve A in Fig. 8 represents the $\phi = \pm 10$ degree orientation, and the curve B in Fig. 8 represents the ± 20 degree orientation. As shown in Fig. 8, the curvature is about the same for both of these orientations and the temperature at which the zero coefficient of frequency occurs is about 0 degree centigrade. By making these crystals of larger W/L dimensional ratios, the temperature of zero coefficient may be raised to around ordinary room temperature, as illustrated in Fig. 7.

As illustrated by the curves in Fig. 4, there is a coupling of the main lengthwise mode of motion with the face shear or width-length flexure mode of motion for all dimensional ratios of width W to length L from about 0.2 to 0.5. By rotating the lengthwise axis L around the thickness axis dimension T and away from the X axis, as illustrated by the θ angle rotation in Fig. 3 and Fig. 9, for example, the position of the main lengthwise longitudinal mode of motion with respect to the coupled secondary flexure mode may be changed. For example, where the ϕ angle orientation is about ± 20 degrees, and the θ angle is made about minus ($-$) 5 degrees, as illustrated in Fig. 9, the coupled secondary flexure mode of motion referred to may be made of relatively smaller coupling effect upon the main length longitudinal mode of motion.

Fig. 9 is a perspective view of a length-mode ethylene diamine tartrate crystal plate 2, similar to that illustrated in Fig. 3, but provided with a particular orientation comprising an angle ϕ in the region of either +20 or -20 degrees with respect to the + Z axis, and an angle θ in the region of -5 degrees with respect to the + X axis. As in Fig. 3, the ϕ angle orientation illustrated in Fig. 9 represents a rotation in effect around the lengthwise axis dimension L , and the θ angle orientation represents a rotation in effect around the thickness axis dimension T . Fig. 9

accordingly illustrates a particular doubly rotated orientation among those generally illustrated in Fig. 3. The ϕ angle may be measured at either of the two opposite sides of the + Z axis as illustrated in Figs. 3 and 9.

Fig. 10 is a graph illustrating an example of the variation in the frequency of the main lengthwise mode of motion which occurs with a variation in temperature, for various dimensional ratios of width W to length L in ethylene diamine tartrate crystal plates 2 of Fig. 9 having a ϕ angle orientation of about ± 20 degrees and a θ angle orientation of about -5 degrees, as illustrated in Fig. 9. As shown in Fig. 10 the temperature at which the zero temperature coefficient of frequency occurs varies with the value of the dimensional ratio of width W to length L , and for dimensional ratios of about 0.35, 0.4, 0.45 and 0.5 occurs at temperatures of about +15, +30, +40 and +50 degrees centigrade, respectively, as shown by the curves in Fig. 10.

Fig. 11 is a graph illustrating an example of the frequency spectrum of length-mode ethylene diamine tartrate crystal plates 2 of Fig. 9 having a ϕ angle orientation of about ± 20 degrees and a θ angle orientation of about -5 degrees, for varying dimensional ratios of width W to length L from about 0.2 to 0.5. As illustrated in Fig. 11, the curve A represents the main length L mode of motion having a frequency constant varying roughly from 180 to 210 as expressed in kilocycles per second per centimeter of the length axis dimension L , for dimensional ratios of width W to length L from about 0.2 to 0.5. The curve B in Fig. 11 represents the secondary width-length flexure mode of motion, and the curves C and D in Fig. 11 represent other more remote face modes of motion related to the width dimension W of the crystal plate 2 of Fig. 9. The numbers placed alongside the curve A in Fig. 11 represent the corresponding value of ratio of capacities at the measured points. For example, the ratio of capacities is about 40 for a dimensional ratio of width W to length L of about 0.4, as illustrated by the curve A in Fig. 11. The ratio of capacities of 40 gives an inductance value useful for filter purposes, for example. From the values of the ratios of capacities, and the dielectric constant of about 7.8 expressed in centimeter-gram-second (C. G. S.) units, the inductance per millimeter of thickness dimension T for the main lengthwise or longitudinal mode of motion represented by the curve A of Fig. 11 may be calculated and is plotted in Fig. 12.

Fig. 12 is a graph illustrating an example of the inductance in henries per millimeter of thickness dimension T for the main lengthwise longitudinal mode of motion in an ethylene diamine tartrate crystal plate 2 having a ϕ angle orientation of about ± 20 degrees and a θ angle orientation of about -5 degrees, as illustrated in Fig. 9 and in curve A of Fig. 12. These inductance values may be compared with the lower inductance values of an unrotated Y-cut plate illustrated in curve B of Fig. 12, the latter giving lower values of inductance than the former for the same dimensions. As an illustrative example from curve A in Fig. 12, to obtain an inductance of about 9.39 henries, the crystal plate 2 illustrated in Fig. 9 having a ϕ angle orientation of about ± 20 degrees and a θ angle orientation of about -5 degrees may have a length dimension L of about 3.26 centimeters, a width dimension W of about 1.46 centimeters and a thickness dimension T of about 0.126 centimeter, giving a

dimensional ratio of width W to length L of about 0.45, and a resonant lengthwise longitudinal mode frequency of about 61,165 cycles per second, with an inductance of about 9.39 henries. Similarly, as an illustrative example, to obtain a lengthwise longitudinal mode resonance frequency of about 104,923 cycles per second with an inductance of about 32.01 henries, the crystal plate 2 of Fig. 9 may have a length dimension L of about 1.96 centimeters, a width dimension W of about 0.784 centimeter and a thickness dimension T of about 0.368 centimeter giving a dimensional ratio of width W to length L of about 0.4; or to obtain the same frequency and inductance but with a width W to length L dimensional ratio of 0.35, the length dimension L may be about 1.99 centimeters, the width dimension W about 0.695 centimeter and the thickness dimension T about 0.269 centimeter.

Fig. 13 is a perspective view of a length mode rotated Y-cut type ethylene diamine tartrate crystal plate 2 rotated in effect around the Z axis width dimension W to a position where the major faces of the crystal plate 2 are inclined at an angle ψ which may be measured with respect to either of the two opposite sides of the $+X$ axis, as illustrated in Fig. 13. As in Figs. 3 and 9, the θ angle rotation in Fig. 13 may represent an additional rotation in effect around the thickness axis dimension T , in either or both of the two opposite directions with respect to the X or X' axis, as indicated by the $+\theta$ and $-\theta$ angles in Fig. 13.

Fig. 14 is a graph illustrating an example of the frequency characteristics with change in temperature for a lengthwise mode ethylene diamine tartrate crystal plate 2 of Fig. 13 of the Y-cut type rotated in effect about ± 10 degrees around the Z axis width dimension W giving a ψ angle orientation of ± 10 degrees and a θ angle orientation of about 0 degrees. The curves as illustrated in Fig. 14 are from a crystal plate 2 having a length dimension L of about 1.991 centimeters, a width dimension W of about 1.001 centimeters thus giving a dimensional ratio of width W to length L of about 0.5, and a thickness axis dimension T of about 1.035 millimeters. The curves A and B in Fig. 14 represent the main length L mode resonance and antiresonance frequencies, respectively. The ratio of capacities is about 27, and the temperature coefficient of frequency has a zero value in the region around $+40$ degrees centigrade, as illustrated by the curve A in Fig. 14.

Fig. 15 is a graph illustrating an example of the frequency characteristics with change in temperature for a length-mode ethylene diamine tartrate crystal plate 2 of Fig. 13 of the Y-cut type rotated in effect first around the Z axis width dimension W giving a ψ angle orientation of ± 10 degrees and then rotated in effect around the thickness axis dimension T about ± 10 degrees, thus giving a θ angle orientation of ± 10 degrees. The curves as illustrated in Fig. 15 are taken from a crystal plate 2 having a length axis dimension L of about 1.7025 centimeters, a width axis dimension W of about 0.8515 centimeter thus giving a dimensional ratio of width W to length L of about 0.5, and a thickness axis dimension T of about 1.025 millimeters. The curves A and B in Fig. 15 represent the main length L mode resonance and antiresonance frequencies, respectively. The temperature at which the zero temperature coefficient of frequency value occurs is in the region around -10 degrees centigrade, as illustrated by the curve A in Fig. 15.

It will be understood that the crystal plates 2

of Figs. 3, 9 and 13 may in accordance with this invention be provided with a selected dimensional ratio of the thickness axis T with respect to the length axis L in order to avoid coupling with any undesired thickness mode such as the thickness flexure mode therein, which if it should get too close to the main length mode resonance, may cause troublesome interference therewith. The optimum dimensional ratios of thickness T to length L may be ascertained by trial and experimental measurements, in accordance with methods heretofore employed in connection with the dimensioning of quartz crystal plates.

It will be understood that the frequency of the main length mode of motion substantially along the length axis dimension L varies inversely as the value of the length axis dimension L , and that the frequency and temperature coefficient of frequency will vary with the value of the dimensional ratio of width W to length L that is selected, and that the ratio of capacities is also a function of the dimensional ratio of the width W with respect to the length L , and that at the smaller values of dimensional ratio of width W to length L , as below 0.6 for example, the effects of the more remote secondary width W modes of motion upon the main length L mode of motion are comparatively negligible.

Fig. 16 is a perspective view of the elongated crystal plate 2 of Figs. 3, 9 and 13, 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-length type 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 Figs. 3, 9 and 13, 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. 16. For this purpose the electrodes 4a, 4b, 5a and 5b may be integral metal coatings similar to those shown in Figs. 3, 9 and 13 but arranged as shown in Fig. 16, the electrode arrangement and connections being of the type described in United States Patent No. 2,259,317, granted October 14, 1941 to W. P. Mason, for example. It will be understood that the flexure mode crystal plate 2 of Fig. 16 may comprise any of the ethylene diamine tartrate crystal plates 2 of Figs. 3, 9 and 13 or other suitable longitudinal mode ethylene diamine crystal plate such as a Y-cut plate having its major faces cut perpendicular to the Y axis with its length axis dimension from 0 to 25 degrees with respect to the X axis, as disclosed in the earlier application Serial No. 657,886, filed March 28, 1946, by W. P. Mason, hereinbefore referred to.

While in Fig. 16 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 glued, cemented or otherwise bonded together in major-face-to-major-face relation in order to form a duplex type crystal unit for operation at a still lower frequency in a thickness-length bending type of flexure motion. For this purpose, the crystal poling, electrode arrangement and electrode connections may be of the forms 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 artificial 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 over-all low temperature coefficient of frequency.

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.

While the crystal element 2 of Figs. 3, 9 and 13 is particularly described herein as being operated in the fundamental lengthwise 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 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.

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. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal plate adapted for vibration substantially along its lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal plate having substantially rectangular shaped major electrode faces, the width axis dimension of said major faces being substantially less than said lengthwise axis dimension, the thickness axis dimension between said opposite major faces being substantially less than either of said width axis and lengthwise axis dimensions, the orientation of said crystal plate with respect to the mutually perpendicular X , Y and Z axes being such that said lengthwise axis dimension makes a substantially smaller angle with respect to said X axis than with respect to

either of said Y and Z axes and said major faces make an angle substantially greater than 0 degrees and less than 25 degrees with respect to the plane of said X and Z axes, said orientation of said crystal plate being a value corresponding to said low temperature coefficient value for said frequency.

2. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal plate adapted for vibration substantially along its lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal plate having substantially rectangular shaped major electrode faces, the width axis dimension of said major faces being substantially less than said lengthwise axis dimension, the thickness axis dimension between said opposite major faces being substantially less than either of said width axis and lengthwise axis dimensions, the orientation of said crystal plate with respect to the mutually perpendicular X , Y and Z axes being such that said lengthwise axis dimension makes a substantially smaller angle with respect to said X axis than with respect to either of said Y and Z axes and said major faces make an angle substantially greater than 0 degrees and less than 25 degrees with respect to the plane of said X and Z axes, said orientation of said crystal plate being a value corresponding to said low temperature coefficient value for said frequency, and said lengthwise axis dimension expressed in centimeters being one of the values in the range substantially from 180 to 210 divided by the value of said frequency expressed in kilocycles per second.

3. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal plate adapted for vibrational motion substantially along its elongated lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal plate having opposite substantially rectangular shaped major electrode faces, said major faces being disposed substantially parallel to one axis of the three mutually perpendicular X , Y and Z axes and inclined at one of the angles in the range substantially from 10 to 20 degrees with respect to another axis of said X , Y and Z axes as measured in a plane perpendicular to said one axis of said three X , Y and Z axes, said lengthwise axis dimension being disposed at one of the angles in the range from 0 to 20 degrees with respect to said X axis of said three X , Y and Z axes, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being one of the values in the range from 0.3 to 0.6, said lengthwise axis dimension expressed in centimeters being one of the values in the range substantially from 180 to 210 divided by the value of said frequency expressed in kilocycles per second, and means comprising electrodes disposed adjacent said opposite major faces and applying an electric field to said crystal plate in the direction of the thickness axis dimension between said major faces for operating said crystal plate in said lengthwise mode of motion at said frequency of low temperature coefficient.

4. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension, said crystal body having its major electrode faces disposed substantially parallel to the X axes and inclined at an angle of substan-

tially 10 degrees with respect to the Z axis as measured in a plane perpendicular to said X axis, said lengthwise axis dimension being disposed substantially parallel to said X axis.

5. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension, said crystal body having its major electrode faces disposed substantially parallel to the X axis and inclined at an angle of substantially 20 degrees with respect to the Z axis as measured in a plane perpendicular to said X axis, said lengthwise axis dimension being disposed substantially parallel to said X axis.

6. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension, said crystal body having its major electrode faces disposed substantially parallel to the X axes and inclined at an angle of substantially 20 degrees with respect to the Z axis as measured in a plane perpendicular to said X axis, said lengthwise axis dimension being inclined at an angle of substantially -5 degrees with respect to said +X axis.

7. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal body having its major electrode faces disposed substantially parallel to the X axis and inclined at one of the angles in the range substantially from greater than 5 degrees to less than 25 degrees with respect to the Z axis as measured in a plane perpendicular to said X axis, said lengthwise axis dimension being disposed at one of the angles in the range from 0 to 10 degrees with respect to said +X axis as measured in a plane parallel to said major faces, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being one of the values in the range from 0.2 to 0.6.

8. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension of its major faces at a frequency of low temperature coefficient, said major faces being substantially rectangular shaped, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said lengthwise axis dimension being disposed at a substantially smaller angle with respect to the X axis than with respect to the Y and Z axes of the three mutually perpendicular X, Y and Z axes, said major faces of said crystal body being disposed substantially parallel to said X axis and inclined at an acute angle with respect to said Z axis, said angle being one of the angles within the range from substantially 5 to 25 degrees as measured in a plane parallel to the plane of said Y and Z axes, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being a value less than 0.6.

9. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension of its major faces at a frequency of low temperature coefficient, said major faces being substantially rectangular shaped, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said

lengthwise axis dimension being disposed at a substantially smaller angle with respect to the X axis than with respect to the Y and Z axes of the three mutually perpendicular X, Y and Z axes, said major faces of said crystal body being disposed substantially parallel to said X axis and inclined at an acute angle with respect to said Z axis, said angle being one of the angles within the range from substantially 5 to 25 degrees as measured in a plane parallel to the plane of said Y and Z axes, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being a value less than 0.6, said lengthwise axis dimension expressed in centimeters being one of the values in the range substantially from 180 to 210 divided by the value of said frequency expressed in kilocycles per second.

10. An ethylene diamine tartrate piezoelectric crystal body adapted for vibration substantially along its lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal body having substantially rectangular major electrode faces, said major faces being disposed substantially parallel to the X axis and inclined at one of the angles in the range from substantially 10 to 20 degrees with respect to the Z axis, said angle being measured in the plane of the Y and said Z axis, said lengthwise axis dimension of said major faces being disposed substantially parallel to said X axis, the ratio of the width dimension of said major faces with respect to said lengthwise dimension thereof being a value less than 0.6, and the ratio of said lengthwise axis dimension with respect to the thickness axis dimension between said major faces being of a value less than 30.

11. An ethylene diamine tartrate piezoelectric crystal body adapted for vibration substantially along its lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal body having substantially rectangular major electrode faces, said major faces being disposed substantially parallel to the X axis and inclined at an angle of substantially 10 degrees with respect to the Z axis, said angle being measured in the plane of said Z axis and the Y axis, said lengthwise axis dimension of said major faces being disposed substantially parallel to said X axis, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being a value less than 0.6.

12. An ethylene diamine tartrate piezoelectric crystal body adapted for vibration substantially along its lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal body having substantially rectangular major electrode faces, said major faces being disposed substantially parallel to the X axis and inclined at an angle of substantially 10 degrees with respect to the Z axis, said angle being measured in the plane of said Z axis and the Y axis, said lengthwise axis dimension of said major faces being disposed substantially parallel to said X axis, the ratio of the width dimension of said major faces with respect to said lengthwise dimension thereof being a value less than 0.6, said lengthwise axis dimension expressed in centimeters being one of the values in the range substantially from 197 to 204 divided by the value of

said frequency expressed in kilocycles per second.

13. An ethylene diamine tartrate piezoelectric crystal body adapted for vibration substantially along its lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal body having substantially rectangular major electrode faces, said major faces being disposed substantially parallel to the X axis and inclined at an angle of substantially 20 degrees with respect to the Z axis, said angle being measured in the plane of said Z axis and the Y axis, said lengthwise axis dimension of said major faces being disposed at an angle of substantially -5 degrees with respect to said X axis, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being a value less than 0.6.

14. An ethylene diamine tartrate piezoelectric crystal body adapted for vibration substantially along its lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal body having substantially rectangular major electrode faces, said major faces being disposed substantially parallel to the X axis and inclined at an angle of substantially 20 degrees with respect to the Z axis, said angle being measured in the plane of said Z axis and the Y axis, said lengthwise axis dimension of said major faces being disposed at an angle of substantially -5 degrees with respect to said X axis, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being a value less than 0.6, said lengthwise axis dimension expressed in centimeters being one of the values in the range substantially from 197 to 204 divided by the value of said frequency expressed in kilocycles per second.

15. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension, said crystal body having its major electrode faces disposed substantially parallel to the Z axis and inclined at an angle of substantially 10 degrees with respect to the X axis as

measured in a plane perpendicular to said Z axis, said lengthwise axis dimension being disposed substantially in said plane and inclined at said angle with respect to said X axis.

16. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimensions, said crystal body having its major electrode faces disposed substantially parallel to the Z axis and inclined at an angle of substantially 10 degrees with respect to the X axis as measured in a plane perpendicular to said Z axis, said lengthwise axis dimension being disposed at one of the angles in the range from 0 to 10 degrees with respect to said plane as measured in a plane parallel to said major faces.

17. A rotated Y-cut type ethylene diamine tartrate piezoelectric crystal body adapted for motion substantially along its elongated lengthwise axis dimension at a frequency of low temperature coefficient, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, said crystal body having its major electrode faces disposed substantially parallel to the Z axis and inclined at one of the angles in the range substantially from greater than 5 degrees to less than 25 degrees with respect to the X axis as measured in a plane perpendicular to said Z axis, said lengthwise axis dimension being disposed at one of the angles in the range from 0 to 10 degrees with respect to said plane as measured in a plane parallel to said major faces.

WARREN P. MASON.

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