

Jan. 11, 1949.

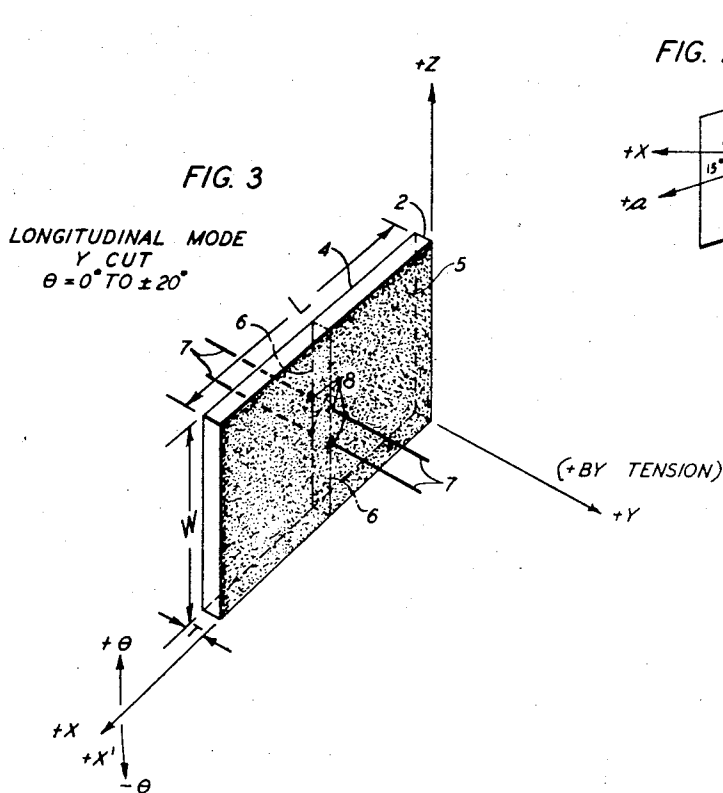
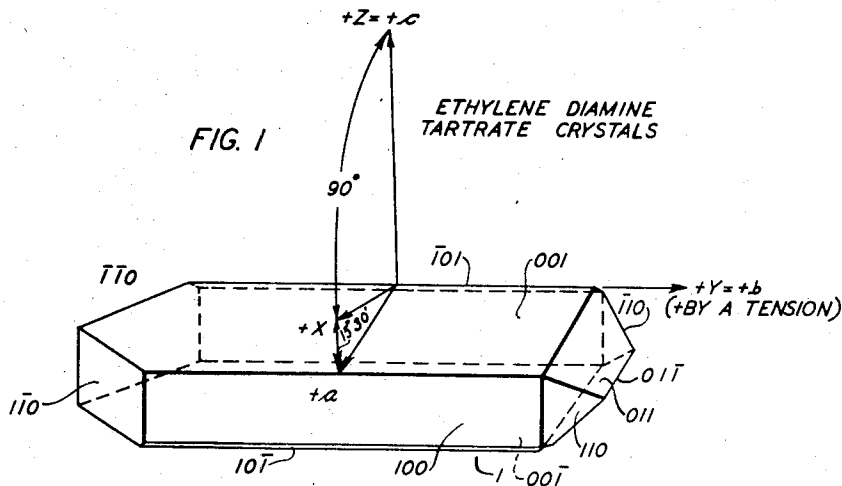
W. P. MASON

2,458,615

PIEZOELECTRIC CRYSTAL APPARATUS

Filed March 28, 1946

2 Sheets-Sheet 1



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

Jan. 11, 1949.

W. P. MASON

2,458,615

PIEZOELECTRIC CRYSTAL APPARATUS

Filed March 28, 1946

2 Sheets-Sheet 2

FIG. 4

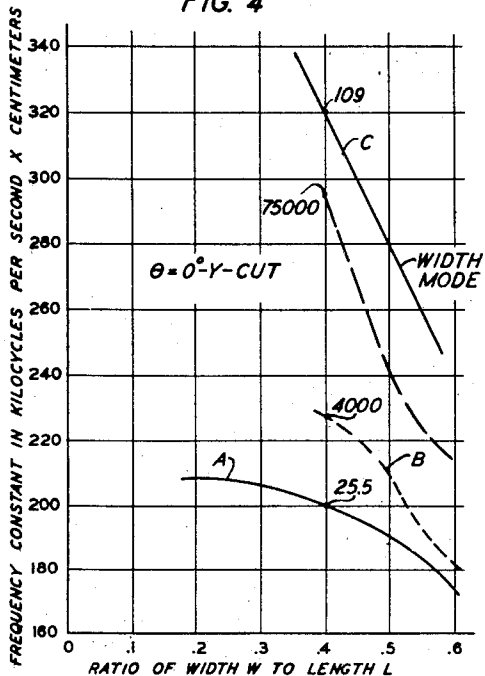


FIG. 6

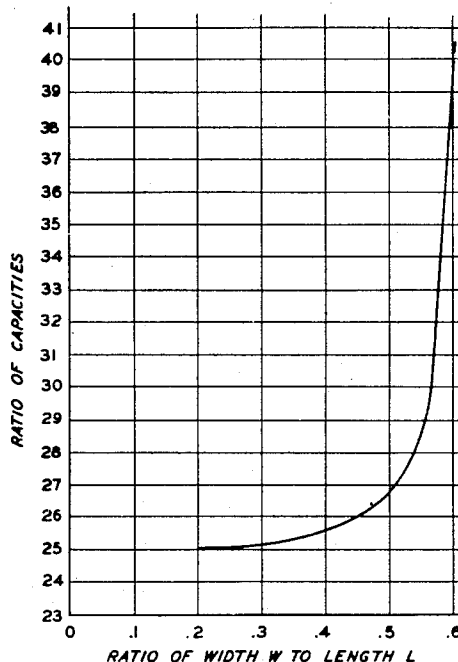


FIG. 5

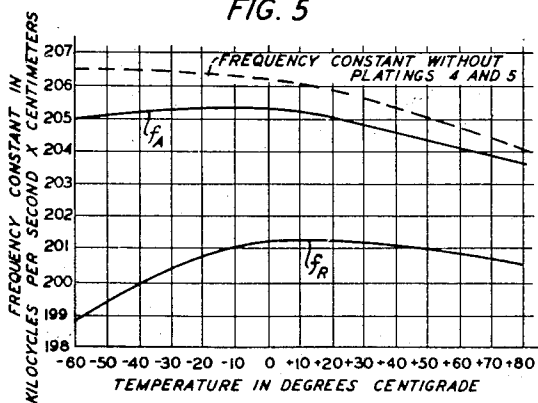


FIG. 8

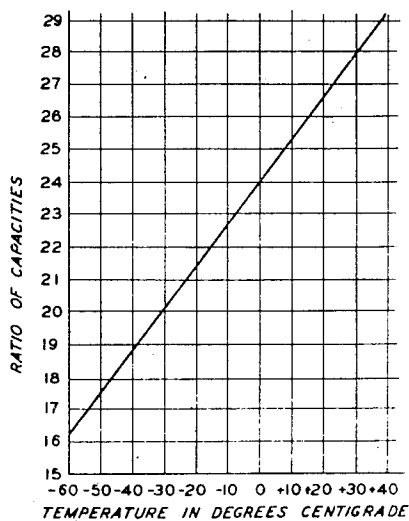
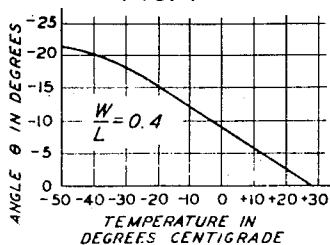


FIG. 7



INVENTOR
W. P. MASON
BY *w. j. o'neill*
ATTORNEY

UNITED STATES PATENT OFFICE

2,458,615

PIEZOELECTRIC CRYSTAL APPARATUS

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

Application March 28, 1946, Serial No. 657,886

20 Claims. (Cl. 171—327)

1

This invention relates to crystal apparatus and particularly to piezoelectric crystal elements comprising ethylene diamine tartrate ($C_6H_{14}N_2O_6$). 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 and modes of motion 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 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.

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, or in the thickness shear or in thickness longitudinal modes of motion controlled mainly by the thickness dimension. Also,

2

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 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 mode of motion.

In the case of ethylene diamine tartrate ($C_6H_{14}N_2O_6$) which has no water of crystallization, there are among other useful cuts, longitudinal-mode zero temperature coefficient Y-cut crystal elements which may be used, for example, as circuit elements in an electric wave filter system; and high frequency thickness-shear-mode zero temperature coefficient Z-cut rotated 15 to 25-degree cut crystal elements as disclosed and claimed in my copending application for Piezoelectric crystal apparatus, Serial No. 659,678, filed April 5, 1946, now United States Patent 2,440,695, dated May 4, 1948, which may be used, for example, as circuit elements for the frequency control of oscillators. 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.

In accordance with this invention, the 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 and operating in the longitudinal mode of motion along the longest or lengthwise dimension thereof, the length dimension being disposed or inclined at an angle θ which may be an angle in the region from 0 to ± 20 degrees with respect to the +X axis; or in the region of $\theta = 0$ degrees where a zero temperature coefficient of frequency is desired at ordinary room temperatures in the region of about $+27^\circ$ centigrade. The temperature at which the zero temperature coefficient occurs for

the longitudinal length mode of motion varies according to the value of the angle of θ selected, and is at about $+27^\circ$ centigrade for a θ angle of about 0 degrees, at about $+20^\circ$ centigrade for a θ angle of about $-2\frac{1}{2}$ degrees, and at values between -40° and $+27^\circ$ centigrade for values of θ angles between 0 and -20 degrees. The coupling of the longitudinal length mode of motion to other modes of motion therein is small, and at the θ angle of about 0 degrees, there is no face shear mode of motion in the crystal element.

The synthetic tartrate crystal elements provided in accordance with this invention have a high electromechanical coupling which is 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 being obtained by methods presently used in connection with 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 Y-cut type ethylene diamine tartrate crystal elements rotated in effect about the Y or b axis to a position corresponding to angles of θ in the region of about 0 degrees, or more broadly from 0 to ± 20 degrees with respect to the $+X$ axis;

Fig. 4 is a graph illustrating the frequency spectrum characteristics of $\theta=0$ -degree Y-cut ethylene diamine tartrate crystal elements, for various dimensional ratios of width to length;

Fig. 5 is a graph illustrating the resonant and anti-resonant frequency constants of a $\theta=0$ -degree Y-cut ethylene diamine tartrate crystal element, as a function of temperature;

Fig. 6 is a graph illustrating the ratio of capacities of $\theta=0$ -degree Y-cut ethylene diamine tartrate crystal elements for various dimensional ratios of width to length;

Fig. 7 is a graph illustrating the relation between the temperature for the zero temperature coefficient of frequency in longitudinal mode Y-cut ethylene diamine tartrate crystal elements, and the angles of θ from about 0 to -22 degrees; and

Fig. 8 is a graph illustrating the ratio of capacities of a $\theta=0$ -degree ethylene diamine tartrate crystal element as a function of temperature.

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 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° centigrade. At a temperature of about 130° 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.

Crystals 1 comprising ethylene diamine tartrate ($C_6H_{14}N_2O_6$) 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 for 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-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 dia-

mine 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 24½ 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 24½ 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 (+) direction 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 dimension L, a breadth or width 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 dimension T being measured between the opposite parallel major or electrode faces of the crystal element 2. The length dimension L and the width 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 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.

As illustrated in Fig. 3, the crystal element 2 has its major faces and major plane section disposed perpendicular or nearly perpendicular with respect to the Y or *b* axis, and has its longest or length dimension L disposed or inclined at an angle θ with respect to the +X axis, where θ may be an angle in the region of 0 degrees, or more broadly from 0 to ± 20 degrees or more with respect to the +X axis, the X axis in the case of ethylene diamine tartrate being spaced about $15\frac{1}{2}$ degrees from the *a* axis. At the angle of θ —about 0 degrees with respect to the X axis as particularly illustrated in Fig. 3, the crystal element 2 has a zero temperature coefficient at about $+27^\circ$ centigrade for its longitudinal mode of motion along the length dimension L, and at that θ angle the mechanical coupling of that longitudinal mode of motion to a face shear mode of motion therein is zero. At angles of θ above and below about 0 degrees, the position 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 about $+270^\circ$ centigrade according to the angle of θ selected, as illustrated in Fig. 7.

It will be noted that the natural top and bottom surfaces 001 and 00 $\bar{1}$, respectively, of the mother crystal 1 of Fig. 1 extend in the plane of the *a* and *b* axes which plane consequently has a normal Z' which makes an angle of about $15\frac{1}{2}$ degrees from the Z or *c* axis as illustrated in Fig. 1. As shown in Fig. 2, when the length dimension L of the crystal element 2 follows the X axis of the mother crystal 1, it will not be parallel to the *a* axis by the angle of about $15\frac{1}{2}$ degrees. The properties of the crystal element 2 vary considerably with such a change in the orientation angle θ .

As particularly illustrated in Fig. 3, the length axis X', the longest dimension L and the longest edges of the major faces of the crystal element 2 lie substantially in the plane of the X and Z axes and are disposed or inclined at an angle in the region of $\theta=0$ degrees with respect to the X axis. The width dimension W of the major faces of the crystal element 2 being perpendicular to the length dimension L thereof will also make the same angle with respect to the Z axis. The thickness dimension T extends along or nearly along the Y or *b* axis. 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 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 $+27^\circ$ centigrade.

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 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.

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 and the metallic coatings 4 and 5 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 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.

Fig. 3 also illustrates Y-cut ethylene diamine tartrate crystal elements 2 cut from a mother crystal 1 such as that illustrated in Fig. 1, and having an orientation similar to that of the $\theta=0$ -degree Y-cut crystal element 2 particularly illustrated in Fig. 3, except for the position of the longest or length dimension L thereof, which may be rotated in effect about the Y axis, and thereby inclined at an angle θ up to 10 or 20 degrees or more with respect to the +X axis, instead of $\theta=0$ degrees. For example, in case where $\theta=-10$ degrees, the crystal element 2 of Fig. 3 has its length dimension L disposed at substantially -10 degrees from the +X axis and gives a resonant frequency which has a zero temperature coefficient at about 0° centigrade; instead of at about $+27^\circ$ centigrade as in the case of the $\theta=0$ degree Y-cut crystal element 2 of Fig. 3. Accordingly, the crystal element 2 of Fig. 3 may be oriented for 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 general direction of the thickness 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 a high electromechanical coupling and a low temperature coefficient of frequency over any ordinary temperature range.

Fig. 4 is a graph illustrating an example of the frequency spectrum of a $\theta=0$ -degree Y-cut ethylene diamine tartrate crystal element 2 of Fig. 3, for various dimensional ratios of the width W with respect to the length L within the range between about 0.15 and 0.60. As shown in Fig. 4, the main mode of motion, which is the fundamental longitudinal mode of vibration along the X-axis length dimension L , is represented by the curve labeled A in Fig. 4, and has a frequency constant which varies from about 175 to 208 kilocycles per second per centimeter of the length dimension L , depending upon the dimensional ratio of width W to length L selected. Thus, as an example a $\theta=0$ -degree Y-cut crystal element 2 having a length dimension L of one centimeter and a dimensional ratio of width W to length L of about 0.4 will have a frequency of about 200 kilocycles per second for its fundamental longitudinal mode of motion along the X-axis length dimension L . A similar $\theta=0$ -degree Y-cut crystal element 2 having a length dimension L of another value will have a corresponding frequency which varies inversely as the value of its length dimension L .

The curve B in Fig. 4 represents a nearby secondary mode of motion which has a slight coupling to the length longitudinal mode of motion represented by the curve A. At a dimensional ratio of width W to length L of around 0.4, for example, the main length longitudinal mode of motion represented by the curve A has a ratio of capacities around 25, while the secondary face mode of motion represented by the curve B has a ratio of capacities of around 4000, as indicated by the numerals placed alongside the curves A and B in Fig. 4. Hence, the effect of the secondary face mode of motion represented by the curve B upon the main length longitudinal mode of motion represented by the curve A is comparatively negligible.

The higher frequency modes of motion shown by the upper set of curves in Fig. 4 are related to the width longitudinal mode of motion, the main fundamental longitudinal mode of motion along the width dimension W being represented by the curve C in Fig. 4. The higher frequency resonances related to the width mode of motion represented by the curve C are, for a $\theta=0$ -degree Y-cut crystal element 2 having a width dimension W equal to less than about one-half of its length dimension L , disposed above twice as high in frequency as the frequency of the main longitudinal mode of motion represented by the curve A, and do not produce any troublesome interference therewith. The numerals placed alongside the curves in Fig. 4 represent the approximate values of the ratio of capacities of the corresponding resonance. No face shear mode of motion exists since the s_{15} shear coupling constant is zero for the angle $\theta=0$ degrees. By cutting the crystal element 2 at θ angles different from $\theta=0$ degrees the position of the zero coefficient temperature may be lowered below $+27^\circ$ centigrade by the negative ($-$) angles of θ , and may be raised above $+27^\circ$ centigrade by the positive ($+$) angles of θ . The ratio of capacities is a function of the dimensional ratio of the width W with respect to the length L and is around 25 for such dimensional ratios in the region below about 0.4.

Fig. 5 is a graph illustrating an example of the variation in the resonant and antiresonant frequency constants with varying temperatures from -60° to $+80^\circ$ centigrade, in a $\theta=0$ -degree Y-cut

ethylene diamine tartrate crystal element 2 of Fig. 3, the crystal element 2 having an X-axis length dimension L and a Z-axis width dimension W of values which give a width W to length L dimensional ratio of about 0.4, and having a thickness dimension T of about 1.0 millimeter more or less. As illustrated in Fig. 5, the variation in the antiresonant frequency is given by the curve labeled f_A , and the variation in the resonant frequency is given by the curve labeled f_R . As shown by the curve f_R in Fig. 5, the resonant frequency f_R has a zero temperature coefficient at about $+27^\circ$ centigrade, and from about 0° to $+40^\circ$ centigrade the total variation in frequency gives a sufficiently low temperature coefficient of frequency to be suitable for use in electric wave crystal filters and in other crystal systems at ordinary temperatures.

The longitudinally clamped dielectric constant of Y-cut type ethylene diamine tartrate crystals over a temperature range from -80° to $+100^\circ$ centigrade is of the order of 8.0 expressed in centimeter-gram-seconds (c. g. s.) units.

Fig. 6 is a graph illustrating an example of the ratio of capacities of a $\theta=0$ -degree Y-cut ethylene diamine tartrate crystal element 2 of Fig. 3, for various dimensional ratios of the width W with respect to the length L within the dimensional ratio range about from 0.2 to 0.60. As shown in Fig. 6, the ratio of capacities of the main mode of motion, which is the fundamental longitudinal or extensional mode of vibration along the X-axis length dimension L , is represented by the curve in Fig. 6, and has a ratio of capacities which varies from about 25 to 40 and upwards depending upon the selected dimensional ratio of the width W with respect to the length L . Thus, as an illustrative example, a $\theta=0$ -degree Y-cut crystal element 2 having a dimensional ratio of width W to length L of about 0.2 will have a ratio of capacities of about 25 for its fundamental longitudinal mode of motion along the X-axis length dimension L . As illustrated by the curve in Fig. 6, at the dimensional ratio of width W to length L of around 0.4, for example, the main length longitudinal mode of motion has a ratio of capacities around 25.5, and around 0.5 the same mode of motion has a ratio of capacities of about 26.5. Hence, the ratio of capacities of the main longitudinal mode of motion is lowest in the region of dimensional ratios from .2 to .4, for example.

Fig. 7 is a graph showing a plot of the θ angle of rotation of the length dimension L measured from the $+X$ axis, against the temperature for the zero temperature coefficient of frequency, for Y-cut length longitudinal mode ethylene diamine tartrate crystal elements 2 of Fig. 3, when rotated in effect about the Y axis, the dimensional ratio of width W to length L being about 0.4 in all cases. As shown by the curve in Fig. 7, a $\theta=0$ -degree Y-cut crystal element 2 of Fig. 3 has its zero temperature-frequency coefficient at a temperature of about $+27^\circ$ centigrade, and a $\theta=-20$ -degree Y-cut crystal element 2 of Fig. 4 has its zero temperature-frequency coefficient at a temperature of about -40° centigrade. Similarly, for other angles of θ between 0 and -20 degrees, the temperature for the zero temperature-frequency coefficient in Y-cut ethylene diamine tartrate crystal elements 2 may be obtained from the curve of Fig. 7. Where the ambient temperature is between 0° and $+30^\circ$ centigrade, the corresponding angle θ may conveniently be a value between 0 and -10 degrees, as shown by the curve in Fig. 7.

Fig. 8 is a graph illustrating the approximate

value of the ratio of capacities of a $\theta=0$ -degree Y-cut length longitudinal mode ethylene diamine tartrate crystal element 2 of Fig. 3, as a function of temperature over a range from -60° to $+40^\circ$ centigrade. At ordinary temperatures from $+20^\circ$ to $+30^\circ$ centigrade, the ratio of capacities is in the region of 26 as shown by the curve in Fig. 8. The term ratio of capacities, as used in this specification, has its usual significance.

It will be noted that among the advantageous cuts illustrated 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. Piezoelectric crystal apparatus comprising means including an ethylene diamine tartrate crystal body for producing a substantially zero temperature coefficient of vibrational frequency within a temperature range substantially between 0 and $+40$ degrees centigrade, said frequency being determined by the lengthwise or longest dimensional axis of said crystal body, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, the angular orientation of said crystal body with respect to the mutually perpendicular X, Y and Z axes thereof being a value corresponding to and related to the value of said substantially zero temperature coefficient of frequency, and electric field-producing means for operating said crystal body at said frequency having said substantially zero temperature coefficient of frequency.

2. A frequency determining device comprising a synthetic piezoelectric ethylene diamine tartrate crystal body having a selected vibrational frequency of low or substantially zero temperature coefficient within a temperature range substantially between 0 and $+40$ degrees centigrade, said frequency being determined by a dimension of said crystal body, said dimension being made of a value corresponding to the value of said frequency, and the angular orientation of said crystal body with respect to the mutually perpendicular X, Y and Z axes thereof being a value corresponding to and related to the value of said substantially zero temperature coefficient of frequency.

3. A frequency determining device comprising a synthetic piezoelectric ethylene diamine tartrate crystal body having a natural vibrational frequency of low or substantially zero temperature coefficient within a temperature range substantially between 0 and $+40$ degrees centigrade, said frequency being determined by a dimension of said crystal body, said dimension being made of a value corresponding to the value of said frequency, and the angular orientation of said crystal body with respect to the mutually perpendicular X, Y and Z axes thereof being a value

corresponding to and related to the value of said substantially zero temperature coefficient of frequency, said dimension being a major face length axis dimension of said crystal body, said major face being disposed substantially parallel to said X axis, and said length axis dimension being disposed at one of the angles within the range of angles substantially from 0 to 10 degrees with respect to said X axis.

4. Piezoelectric crystal apparatus comprising means including an ethylene diamine tartrate crystal body for producing a substantially zero temperature coefficient of vibrational frequency within a temperature range substantially between 0 and $+40$ degrees centigrade, said frequency being determined by the lengthwise or longest dimensional axis of said crystal body, said lengthwise axis dimension being made of a value corresponding to the value of said frequency, the angular orientation of said crystal body with respect to the mutually perpendicular X, Y and Z axes thereof being a value corresponding to and related to the value of said substantially zero temperature coefficient of frequency, and electric field-producing means for operating said crystal body at said frequency having said substantially zero temperature coefficient of frequency, said lengthwise axis dimension being disposed at one of the angles within the range of angles substantially from 0 to 10 degrees with respect to said X axis.

5. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, said major faces being disposed substantially parallel to the X axis, the lengthwise axis dimension and longest edges of said major faces being disposed at one of the angles from substantially 0 to ± 10 degrees with respect to the +X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension of said crystal element.

6. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, said major faces being disposed substantially parallel to the X axis, the lengthwise axis dimension and longest edges of said major faces being disposed at one of the angles from substantially 0 to 5 degrees with respect to the +X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being one of the values less than 0.6.

7. Crystal apparatus comprising an ethylene diamine tartrate crystal element, the major faces of said crystal element being substantially parallel to the X axis, the lengthwise axis dimension of said major faces being disposed at an angle of

13

substantially 0 degrees with respect to the X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise axis dimension

8. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Y axis, the lengthwise axis dimension and longest edges of said major faces being disposed at one of the angles from substantially 0 to ± 20 degrees with respect to the +X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension of said crystal element.

9. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Y axis, the lengthwise axis dimension and longest edges of said major faces being disposed at one of the angles from substantially 0 to ± 20 degrees with respect to the +X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being one of the values less than 0.6.

10. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Y axis, the lengthwise axis dimension and longest edges of said major faces being disposed at one of the angles from substantially 0 to -10 degrees with respect to the +X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being one of the values less than 0.6.

11. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, said major faces being disposed substantially

14

perpendicular to the Y axis, the lengthwise axis dimension and longest edges of said major faces being disposed at one of the angles from substantially 0 to 5 degrees with respect to the +X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension of said crystal element.

12. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Y axis, the lengthwise axis dimension and longest edges of said major faces being disposed at one of the angles from substantially 0 to 5 degrees with respect to the +X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being one of the values from substantially 0.2 to 0.5.

13. Crystal apparatus comprising an ethylene diamine tartrate crystal element, the major faces of said crystal element being substantially perpendicular to the Y axis, the lengthwise axis dimension of said major faces being disposed at an angle of substantially 0 degrees with respect to the X axis, said lengthwise axis dimension being a value corresponding to the value of the operating frequency of said crystal element and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a longitudinal mode of motion along said lengthwise dimension, the ratio of the width axis dimension of said major faces with respect to said lengthwise axis dimension thereof being one of the values substantially from 0.4 to 0.5.

14. Piezoelectric crystal apparatus comprising a Y-cut ethylene diamine tartrate crystal element adapted for longitudinal motion along the length axis dimension of its substantially rectangular major faces, said major faces being substantially perpendicular to the Y axis of the three mutually perpendicular X, Y and Z axes thereof, and said length axis dimension being disposed at an angle of substantially 0 degrees with respect to said X axis, the ratio of the width axis dimension of said major faces with respect to said length axis dimension being a value not greater than substantially 0.6, said length axis dimension being a value corresponding to the value of the frequency for said longitudinal mode of motion and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, said length axis dimension expressed in centimeters being one of the values substantially from

15

175 to 208 divided by the value of said frequency expressed in kilocycles per second, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in said longitudinal mode of motion.

15. Piezoelectric crystal apparatus comprising a Y-cut ethylene diamine tartrate crystal element adapted for longitudinal motion along the length axis dimension of its substantially rectangular major faces, said major faces being substantially perpendicular to the Y axis of the three mutually perpendicular X, Y and Z axes thereof, and said length axis dimension being disposed at an angle of substantially 0 degrees with respect to said X axis, the ratio of the width axis dimension of said major faces with respect to said length axis dimension being a value of substantially 0.4, said length axis dimension being a value corresponding to the value of the frequency for said longitudinal mode of motion and said angle being a value corresponding to a substantially zero temperature coefficient value for said frequency, said length axis dimension expressed in centimeters being one of the values substantially from 199 to 202 divided by the value of said frequency expressed in kilocycles per second, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in said longitudinal mode of motion.

16. Crystal apparatus comprising an ethylene diamine tartrate crystal element of low or substantially zero temperature coefficient of frequency having mutually perpendicular width and length axis dimensions for its major faces, said major faces being substantially perpendicular to the Y axis, and said length axis dimension being disposed at an angle of substantially 0 degrees with respect to the X axis, said width axis dimension being substantially less than said length axis dimension.

17. A Y-cut type ethylene diamine tartrate crystal element of long or substantially zero tem-

16

perature coefficient of frequency having its major faces disposed substantially perpendicular to the Y axis, the lengthwise or longest axis dimension of said major faces being disposed at one of the angles in the range of angles substantially from 0 to ± 20 degrees with respect to the +X axis.

18. A Y-cut type ethylene diamine tartrate crystal element of low or substantially zero temperature coefficient of frequency having its substantially rectangular major faces disposed substantially perpendicular to the Y axis, the lengthwise or longest axis dimension of said major faces being disposed at one of the angles in the range of angles substantially from 0 to 10 degrees with respect to the +X axis.

19. A Y-cut type ethylene diamine tartrate crystal element of low or substantially zero temperature coefficient of frequency having its substantially rectangular major faces disposed substantially perpendicular to the Y axis, the lengthwise or longest axis dimension of said major faces being disposed at one of the angles in the range of angles substantially from 0 to 10 degrees with respect to the +X axis, and the ratio of the width axis dimension of said major faces with respect to said lengthwise or longest axis dimension thereof being a value less than 0.5.

20. A Y-cut type ethylene diamine tartrate crystal element of low or substantially zero temperature coefficient of frequency having its substantially rectangular major faces disposed substantially perpendicular to the Y axis, the lengthwise or longest axis dimension of said major faces being disposed at an angle of substantially 0 degrees with respect to the X axis.

WARREN P. MASON.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,309,467	Mason	Jan. 26, 1943