

May 4, 1948.

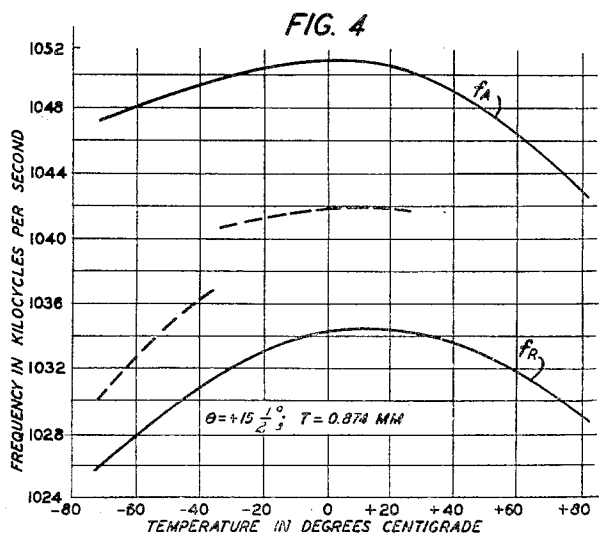
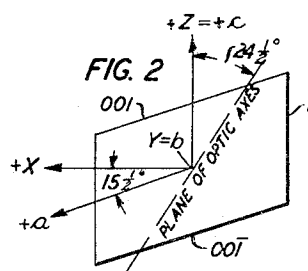
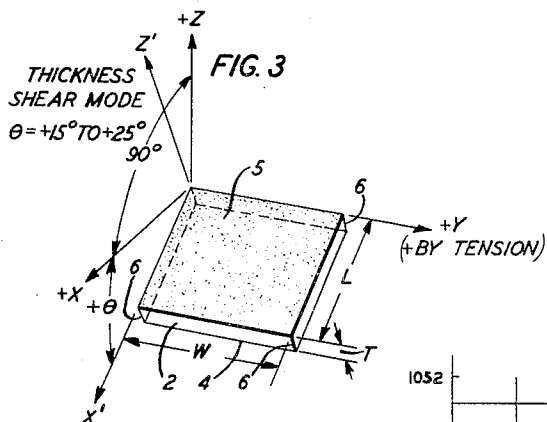
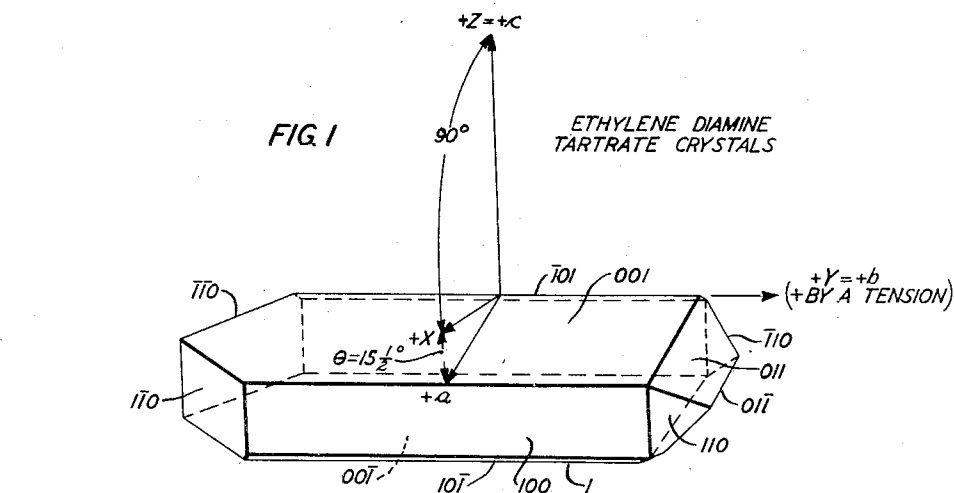
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2,440,695

PIEZOELECTRIC CRYSTAL APPARATUS

Filed April 5, 1946

2 Sheets-Sheet 1



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PIEZOELECTRIC CRYSTAL APPARATUS

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2 Sheets-Sheet 2

FIG. 5

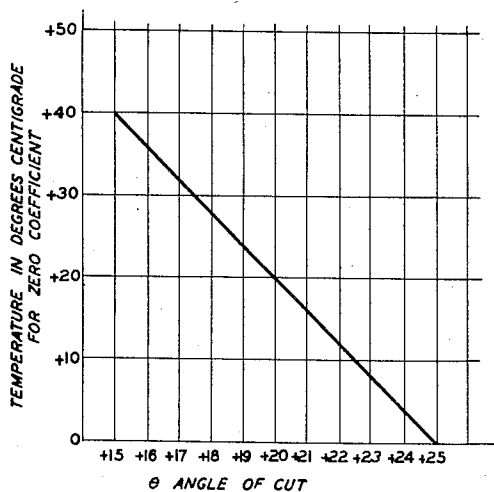
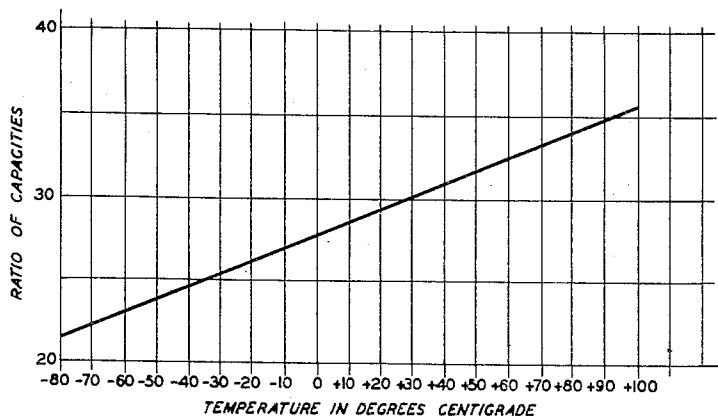


FIG. 6



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PIEZOELECTRIC CRYSTAL APPARATUS

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Application April 5, 1946, Serial No. 659,678

16 Claims. (Cl. 171—327)

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

One of the objects of this invention is to provide advantageous orientations for thickness-shear 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 synthetic 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, and low or zero temperature coefficients 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 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 of motion, or the thickness-shear or thickness-longitudinal modes of motion controlled mainly by the thickness dimension. Also, low frequency

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flexural modes of motion of either the width bending flexure type or the thickness bending duplex flexure 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 other crystalline substances such as quartz, Rochelle salt and ammonium dihydrogen phosphate crystals.

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 tartrate crystals and the tartrate crystals may be suitable cuts taken from crystalline ethylene diamine tartrate adapted to operate in a suitable thickness mode of motion.

In the case of ethylene diamine tartrate



which has no water of crystallization, there are among other useful cuts, high-frequency thickness-shear mode zero-temperature coefficient Z-cut rotated 15 to 25-degree cut crystal elements which may be used, for example, as circuit elements for the frequency control of oscillators. Such zero temperature coefficient 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 thickness-shear mode Z-cut type crystal elements having square or rectangular or circular major faces, the major faces being disposed parallel or nearly parallel to the Y or b axis and the major faces being inclined at an angle θ ranging from 15 to 25 degrees more or less with respect to the X axis where a zero temperature coefficient of frequency is desired at ordinary room temperatures in the region of around $+20^\circ$ centigrade. The temperature at which the zero temperature coefficient of frequency occurs for the thickness-shear mode of motion varies according to the value of the angle of θ selected, and is at about $+40^\circ$ centigrade for a θ angle of about $+15$ degrees, at about 0° centigrade for a θ angle of about $+25$ degrees, and at values between 0° and $+40^\circ$ centigrade for values of θ angles between $+15$ and $+25$ degrees. The coupling of the thickness-shear mode of motion to other modes of motion therein is small at such θ angles of about 15 to 25 degrees.

The synthetic tartrate crystal elements provided in accordance with this invention have a high electromechanical coupling of the order of 20 to 25 per cent, a high reactance-resistance ratio Q at resonance, and a relatively 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 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 also be used in filter systems, for example. When used in filters, the electromechanical coupling in these crystal elements is high. The tartrate crystal elements in accordance with this invention have a low ratio of capacities and accordingly may be used in wide band filters, and 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 axis, and the crystallographic a , b and c axes;

Fig. 2 is an edge view 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 thickness-shear mode Z -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 from 15 to 25 degrees with respect to the X axis;

Fig. 4 is a graph illustrating the resonant and anti-resonant frequency constants of a $\theta=15$ -degree Z -cut type ethylene diamine tartrate crystal element, as a function of temperature;

Fig. 5 is a graph of the temperature for which a zero coefficient exists as plotted against the angle of rotation θ ; and

Fig. 6 is a graph illustrating how the ratio of capacities of a crystal cut at an angle of $\theta=+15^\circ$ varies with 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 $00\bar{1}$ plane, and the bottom surface thereof as a 001 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 2 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 is the $0, 0, 1$ crystallographic plane. 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 a sanding belt cooled by oil or by a solution of water and ethylene glycol, for example.

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

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coincide with the *c* axis and the *Y* axis coincide with the *b* axis, and to have the *X* axis lie in the plane of the *a* and *c* crystallographic axes at an angle with respect to the *a* axis, the *X* axis angle being about 15 degrees 30 minutes above the *a* axis for ethylene diamine tartrate, as shown in Figs. 1 and 2.

The *X*, *Y* and *Z* axes form a mutually perpendicular system of axes, the *Y* axis being a polar axis which is positive (+) by a tension at one of its ends, as shown in Fig. 1. In order to specify which end of the *Y* axis is the positive end, the plane of the optic axes of the crystal 1 may be located. A monoclinic crystal 1 is an optically biaxial crystal and for crystalline ethylene diamine tartrate, the plane that contains these optic axes is found to be parallel to the *b* or *Y* crystallographic axis and inclined at an angle of about 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 (+) 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 crystals 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 a plate of substantially rectangular parallelepiped shape having a 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 major or electrode faces of the crystal element 2. The thickness dimension *T* of the crystal element 2 may be made of a value to suit the desired frequency thereof. The thickness or thin dimension *T* may also 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. The length and width dimensions *L* and *W* may be made of suitable values to avoid nearby spurious modes of motion which, by proper dimensioning of the larger length and width dimensions *L* and *W* relative to the smaller thickness dimension *T*, may be placed in a location that is relatively remote from the desired thickness-shear mode of motion which is dependent mainly upon the value of the thickness dimension *T*.

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

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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 the 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 thickness-shear mode 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 mounted and electrically connected by any suitable means, such as, for example, by pressure type clamping plates or pins, or by conductive supporting spring wires cemented by conductive cement or glued to the crystal element or to the metallic coatings 4 and 5 deposited on the crystal element 2 at or adjacent the periphery or the corners 6 thereof, as already known in connection with quartz, Rochelle salt and other crystals having similar or corresponding thickness-shear modes of motion.

As illustrated in Fig. 3, the crystal element 2 has its major faces disposed parallel or nearly parallel to the *Y* or *b* axis, and inclined at an angle θ with respect to the *X* axis, where θ may be an angle in the region of about +15 to +25 degrees or more broadly from 0 to ± 25 degrees with respect to the +*X* axis, the +*X* axis in the case of ethylene diamine tartrate being spaced about 15½ degrees from and above the *a* axis. At the angle of θ = about +15 degrees with respect to the +*X* axis as illustrated in Fig. 3, the major plane section of the crystal element is in the plane of the *a* and *b* crystallographic axes and the crystal element 2 has a zero temperature coefficient at about +40° centigrade for its thickness-shear mode of motion controlled by the thickness dimension *T*. At the θ angles of +15 to +25 degrees the mechanical coupling of that thickness-shear mode of motion to other modes of motion therein is small. At angles of θ above and below about +15 degrees, the position of the temperature at which the zero temperature coefficient of frequency occurs for the thickness-shear mode of motion is raised or lowered according to the angle of θ selected.

As particularly illustrated in Fig. 3, the axis *X'*, the dimension *L* and one set of the 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 about θ = 15 to 25 degrees with respect to the +*X* axis. The dimension *W* of the major faces of the crystal element 2 is perpendicular to the dimension *L* thereof and is parallel or nearly parallel with respect to the *Y* axis. The thickness dimension *T* extends along the *Z'* 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 thickness-shear mode of motion controlled mainly by thickness dimension *T* of the crystal element 2, with relatively high electromechanical coupling and a low temperature coefficient of frequency over a temperature range in the region above and below about +15° centigrade.

When the crystal element 2 is operated in the fundamental or odd order harmonic thickness-shear mode of motion, which is dependent mainly upon the thickness dimension T thereof, the crystal element 2 may be mounted and electrically connected by any suitable means such as by spring wires cemented to the crystal element 2 and the metallic coatings 4 and 5 thereof in the region of the corners 6 of the crystal element 2. United States Patent No. 2,392,429, issued January 8, 1946, to R. A. Sykes, illustrates an example of a wire mounting system suitable for mounting a thickness-shear mode crystal element.

While the crystal element 2 is particularly described herein as being operated in the fundamental thickness-shear mode of motion along its thickness dimension T, it will be understood that it may be operated in any odd order harmonic thereof in a known manner by means of the pair of opposite electrodes 4 and 5, as in a known manner in connection with thickness-shear mode type quartz crystal elements.

Fig. 3 may be taken to illustrate ethylene diamine tartrate crystal elements 2 having an orientation similar to that of the $\theta=15$ to 25-degree Z-cut type crystal elements 2 particularly illustrated in Fig. 3, except for the position of the dimension L thereof, which may be inclined at any angle θ with respect to the X axis, instead of $\theta=15$ to 25 degrees. 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 thickness-shear mode of motion along the thickness dimension T of the crystal element 2 with a high electromechanical coupling and a low temperature coefficient of frequency over any ordinary temperature range. The ethylene diamine tartrate crystal elements 2 of Fig. 3 may have square, or rectangular major faces with various dimensional ratios of the width W with respect to the length L, the frequency varying inversely as the value of its thickness dimension T.

Fig. 4 is a graph illustrating an example of the variation in the resonant and anti-resonant frequency constants with varying temperatures from -70° to $+80^{\circ}$ centigrade, in a $\theta=+15\frac{1}{2}$ -degree rotated Z-cut ethylene diamine tartrate crystal element 2 of Fig. 3, the crystal element 2 having an X' axis dimension L equal to about 9.225 millimeters and a Y axis dimension W of a value of about 17.373 millimeters, and having a thickness dimension T of about 0.874 millimeter. As illustrated in Fig. 4, the variation in the anti-resonant 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. 4 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.

As shown in Fig. 4, the frequency spectrum of the thickness-shear mode ethylene diamine tartrate crystal element 2 is relatively clear. The ratio of capacities of the crystal element 2 is roughly 30 at a temperature around $+30^{\circ}$ centigrade. The length and width dimensions L and W of the crystal element 2 may be adjusted rela-

tive to the thickness dimension T in order to obtain freedom from secondary modes of motion. The major faces of the crystal element 2 may be rectangular, square or circular in shape. The θ angle of rotation may conveniently be an angle between $+15$ and $+25$ degrees according to the specific use.

The ethylene diamine tartrate crystal element 2 operates in the thickness-shear mode of motion with high piezoelectric coupling and a low temperature coefficient of frequency. The frequency constant is roughly one megacycle per second per millimeter of the thickness dimension T, and accordingly a fundamental thickness mode frequency as high as 3 megacycles per second or more may be conveniently obtained directly from the fundamental thickness mode of motion of the crystal element 2. High order harmonics of the fundamental thickness-shear mode of motion may also be driven by the same electrodes 4 and 5. As a substitute for quartz, good stability may be obtained with a moderate degree of temperature control, when used in controlling the frequency of a high frequency oscillation generator, for example. The crystal element 2 may also be used for a frequency modulated oscillator for allowing a higher starting frequency to obtain a given frequency sweep, than can be obtained with a quartz crystal.

Accordingly, ethylene diamine tartrate has advantageous thickness modes not possessed by cuts from other synthetic crystals thus far developed. It has a thickness-shear mode of motion, with a high electromechanical coupling that may be given a zero temperature coefficient of frequency when made of a suitable orientation and accordingly may be advantageously utilized in controlling high frequency oscillators, and for frequency modulated oscillators, since the large separation between the resonant and anti-resonant frequencies allows the frequency of an oscillator to be varied considerably by means of a suitable reactance tube or by means of an applied direct current voltage, for example.

Fig. 5 is a graph showing a plot of the θ angle of rotation of the X' axis dimension L measured from the +X axis against the temperature for the zero temperature coefficient of frequency, for rotated Z-cut thickness-shear mode ethylene diamine tartrate crystal elements 2 of Fig. 3, when rotated in effect about the Y axis. As shown by the curve in Fig. 5, a $\theta=+15$ -degree rotated Z-cut crystal element 2 of Fig. 3 has its zero temperature-frequency coefficient at a temperature of about $+40^{\circ}$ centigrade, and a $\theta=+25$ -degree rotated Z-cut crystal element 2 of Fig. 3 has its zero temperature-frequency coefficient at a temperature of about 0° centigrade. Similarly, for other angles of θ between 15 and 25 degrees, the temperature for the zero temperature-frequency coefficient in rotated Z-cut ethylene diamine tartrate crystal elements 2 may be obtained from the curve of Fig. 5. Where the ambient temperature is between 0° and $+30^{\circ}$ centigrade, the corresponding angle for θ may conveniently be a value between $+17.5$ and $+25$ degrees, as shown by the curve in Fig. 5.

Fig. 6 is a graph illustrating the approximate value of the ratio of capacities of a $\theta=+15$ -degree rotated Z-cut thickness-shear mode ethylene diamine tartrate crystal element 2 of Fig. 3, as a function of temperature over a range from -80° centigrade to $+100^{\circ}$ centigrade. At ordinary temperatures from $+20^{\circ}$ to $+30^{\circ}$ centigrade, the ratio of capacities is in the region of

30 as shown by the curve in Fig. 6. 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 and oscillator systems. The low temperature coefficient of frequency together with the high electromechanical coupling, the high reactance-resistance ratio 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. A rotated Z-cut type ethylene diamine tartrate crystal element of low temperature coefficient of frequency having its substantially rectangular major faces disposed substantially parallel to the Y axis, said major faces being disposed at one of the angles in the range of angles substantially from +15 to +25 degrees with respect to the +X axis.
2. A rotated Z-cut type ethylene diamine tartrate crystal element of low temperature coefficient of frequency having one set of edges of its substantially rectangular major faces disposed substantially parallel to the Y axis, the other set of edges of said major faces being disposed at one of the angles in the range of angles substantially from +15 to +25 degrees with respect to the +X axis.
3. A rotated Z-cut type ethylene diamine tartrate crystal element of low temperature coefficient of frequency having its major faces disposed substantially parallel to the Y axis, said major faces being disposed at one of the angles in the range of angles substantially from +15 to +25 degrees with respect to the +X axis.
4. A rotated Z-cut type ethylene diamine tartrate crystal element of low temperature coefficient of frequency having its substantially square major faces disposed substantially parallel to the Y axis, said major faces being disposed at one of the angles in the range of angles substantially from +15 to +25 degrees with respect to the +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 Y axis, one set of the edges of said major faces being disposed at one of the angles in the range of angles from substantially +15 to +25 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a shear mode of motion controlled by the thickness dimension of said crystal element between said major faces.
6. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially square major faces, said major faces being disposed substantially parallel to the Y axis, one set of the edges of said major faces being disposed at one of the angles in the range

of angles from substantially +15 to +25 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a shear mode of motion dependent upon the thickness dimension of said crystal element between said major faces.

7. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having its major faces disposed substantially parallel to the Y axis, said major faces being disposed at one of the angles in the range of angles from substantially +15 to +25 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a shear mode of motion dependent upon the thickness dimension of said crystal element between said major faces.

8. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency having substantially rectangular major faces, said major faces having one set of opposite edges disposed substantially parallel to the Y axis, another set of the opposite edges of said major faces being disposed at one of the angles in the range of angles from substantially +15 to +25 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a shear mode of motion at said frequency controlled mainly by the thickness dimension of said crystal element between said major faces.

9. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency having its major faces disposed substantially parallel to the Y axis, said major faces being disposed at one of the angles in the range of angles from substantially +15 to +25 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a shear mode of motion at said frequency controlled mainly by the thickness dimension of said crystal element between said major faces.

10. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency having its major faces disposed substantially parallel to the Y axis, said major faces being disposed at one of the angles in the range of angles from substantially +15 to +25 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a harmonic shear mode of motion at said frequency dependent mainly upon the thickness dimension of said crystal element between said major faces.

11. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency having substantially rectangular major faces, one set of the opposite edges of said major faces being disposed substantially parallel to the Y axis, another set of the opposite edges of said major faces being disposed at one of the angles in the range of angles from substantially +15 to +25 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a harmonic shear mode of motion at said frequency controlled mainly by the thickness dimension of said crystal element between said major faces.

12. Crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency, the major faces of said crystal element being substantially parallel to the Y axis, said major faces being substantially parallel to the α axis which is inclined at an angle of substantially +15 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element at said frequency in a thickness mode of motion.

13. Crystal apparatus comprising an ethylene diamine tartrate crystal element, the major faces of said crystal element being substantially parallel to the Y axis, one pair of the edges of said major faces being disposed substantially parallel to the α axis which is inclined at an angle of substantially +15 degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a thickness mode of motion.

14. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency adapted for motion along the thickness dimension between its substantially rectangular major faces, one set of the opposite edges of said major faces being substantially parallel to the Y axis of the three mutually perpendicular X, Y and Z axes thereof, and another set of the opposite edges of said major faces being disposed at an angle of substantially +15 to +20 degrees with respect to said +X axis, said thickness dimension being a value corresponding to said frequency for said mode of motion, said thickness dimension expressed in millimeters being a value of substan-

tially 1,000 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 in said thickness mode of motion.

15. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency adapted for motion along the thickness dimension between its substantially rectangular major faces, one set of the opposite edges of said major faces being substantially parallel to the Y axis of the three mutually perpendicular X, Y and Z axes thereof, and another set of the opposite edges of said major faces being disposed at one of the angles from substantially +15 to +25 degrees with respect to said +X axis, said thickness dimension being a value corresponding to said frequency for said shear mode of motion, said thickness dimension expressed in millimeters being a value substantially of the order of 1,000 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 in said thickness mode of motion.

16. Crystal apparatus comprising an ethylene diamine tartrate crystal element of low temperature coefficient of frequency having mutually perpendicular width and length dimensions for its major faces, said major faces being substantially parallel to the Y axis, and one of said dimensions being inclined at one of the angles in the range from substantially +15 to +25 degrees with respect to the +X axis.

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