

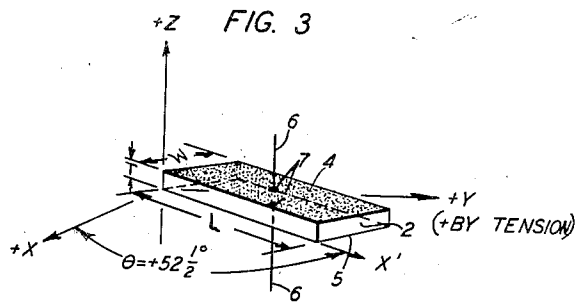
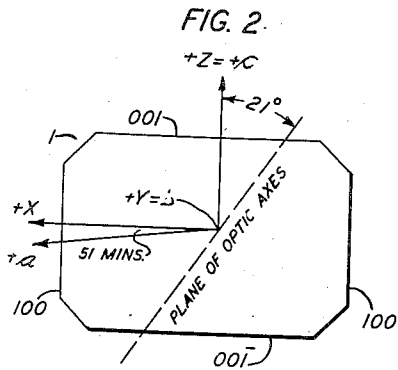
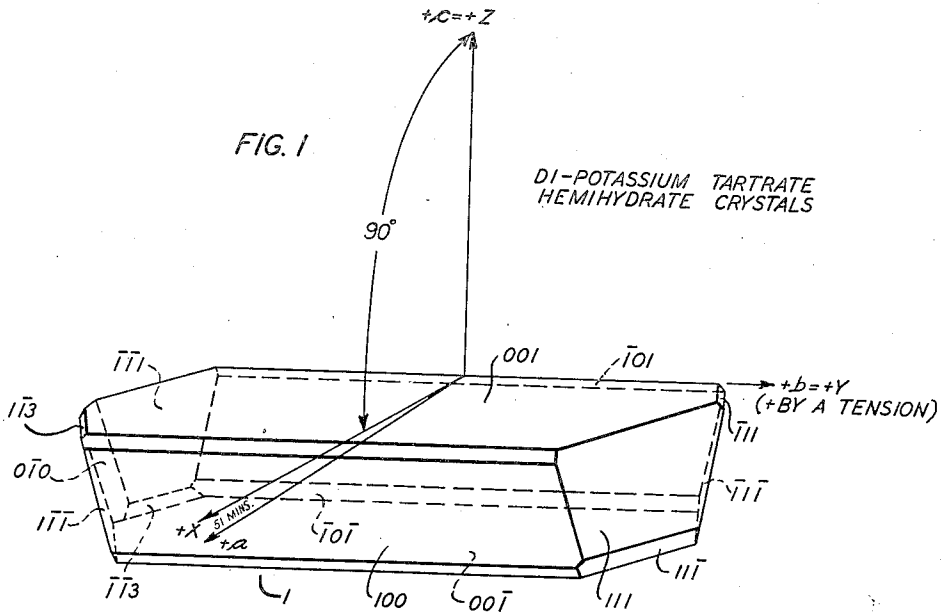
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PIEZOELECTRIC CRYSTAL APPARATUS

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PIEZOELECTRIC CRYSTAL APPARATUS

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This invention relates to crystal apparatus and particularly to piezoelectric crystal elements comprising di-potassium tartrate hemihydrate ($K_2C_4H_4O_6 \cdot \frac{1}{2}(H_2O)$). 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 di-potassium tartrate hemihydrate.

Other objects of this invention are to provide crystal elements comprising di-potassium tartrate hemihydrate that may possess useful characteristics, such as effective piezoelectric constants and minimum coupling of the desired longitudinal mode of motion to undesired modes of motion therein.

A particular object of this invention is to provide a di-potassium tartrate hemihydrate crystal element having a zero or nearly zero coupling between the longitudinal lengthwise mode of motion and the face shear mode of motion therein.

Di-potassium tartrate hemihydrate is a salt of dextrotartaric 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 in this instance is the monoclinic sphenoidal crystal class. By virtue of its chemical structure, di-potassium tartrate hemihydrate will form ionic and hydrogen bonded crystals offering high piezoelectric constants. In addition, the crystalline material affords certain cuts with low coupling to other modes of motion therein, and a fairly high Q or low dielectric loss and mechanical dissipation.

Crystal elements of suitable orientation cut from crystalline di-potassium tartrate hemihydrate may be excited in different modes of motion such as the longitudinal length or the longitudinal width modes of motion, or the face shear mode of motion controlled mainly by the major face dimensions, or the thickness shear mode of motion controlled mainly by the thickness dimension. Also, low frequency flexural

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modes of motion of either the width bending flexure type or the thickness bending flexure duplex type may be obtained. These various modes of motion are similar in the general form of their motion to those of similar or corresponding names that are already known in connection with 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 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 di-potassium tartrate hemihydrate adapted to operate in a face longitudinal mode of motion. Such crystal elements cut from di-potassium tartrate hemihydrate may have advantageous elastic properties whereby the longitudinal mode of motion therein may be free from coupling or interference with the face shear mode of motion therein, or the face shear mode of motion may be free from coupling with other modes of motion therein.

In accordance with this invention, the crystal elements cut from the crystalline di-potassium tartrate hemihydrate may be Z-cut type crystal elements having their major faces perpendicular or nearly perpendicular to the Z or c axis and operating in the longitudinal mode of motion along the longest or length dimension thereof, the length dimension being inclined at an angle θ of about $+52\frac{1}{2}$ degrees with respect to the $+X$ or $+a$ axis. Where the angle θ is an angle in the region from $+30$ to $+45$ degrees, a zero temperature coefficient of frequency may be obtained at ordinary temperatures, as disclosed and claimed in my copending application for Piezoelectric crystal apparatus, Serial No. 646,639 filed February 9, 1946. Where the angle θ is an angle between $+22$ and $+53$ degrees, the piezoelectric coupling is of high value at all such θ angles, and has its maximum value at the θ angle of about 45 degrees. As disclosed in my application referred to above, the temperature at which the zero temperature coefficient of frequency occurs for the longitudinal length mode of motion varies according to the value of the

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angle of θ selected, and is at about $+16\frac{1}{2}$ degrees centigrade for a θ angle of about 45 degrees at about $+30$ degrees centigrade for a θ angle of about $+37\frac{1}{2}$ degrees, and at a value of about -45 degrees centigrade for values of θ angles in the region of $+52\frac{1}{2}$ degrees. The coupling of the longitudinal length mode of motion to the face shear mode of motion in crystal elements having the θ angle of about $+52\frac{1}{2}$ degrees is zero, as disclosed and claimed in the present application.

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, have a high reactance-resistance ratio Q at resonance, and a small or zero coupling of between the longitudinal length mode of motion and the face shear mode of motion therein. These advantageous properties together with the low cost and freedom from supply troubles indicate that these crystal elements may be used 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 be especially useful in filter systems for example. For use in channel filters for example, the electro-mechanical 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 provided 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 for the sharpest peaks nearest the pass band. The tartrate crystal elements in accordance with this invention have high 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 provided in accordance with this invention may also be used for control of frequency modulated oscillators. On account of the large electromechanical coupling, the frequency variation and shift may be made to 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, fea-

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tures 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 di-potassium tartrate hemihydrate may be crystallized, and also illustrating the relation of the surfaces of the mother crystal with respect to the mutually perpendicular X, Y and Z axes, and the crystallographic a , b and c axes;

Fig. 2 is another 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 di-potassium tartrate hemihydrate crystals; and

Fig. 3 is a perspective view illustrating longitudinal-mode Z-cut type di-potassium tartrate hemihydrate crystal elements rotated in effect about the Z or c axis to a position corresponding to an angle of θ —about $+52\frac{1}{2}$ degrees with respect to the $+X$ axis.

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 di-potassium tartrate hemihydrate, is a small angle of about 51 minutes. 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 di-potassium tartrate hemihydrate may crystallize, the natural faces of the di-potassium tartrate hemihydrate 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 $\bar{0}\bar{0}\bar{1}$ plane, and other surfaces and facets 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 are to be cut is relatively easy to grow in shapes and sizes that are suitable for cutting useful crystal plates or elements therefrom. Such mother crystal 1 may be conveniently grown to sizes around 2 inches or more for the X and Y dimensions or of any sufficient size to suit the desired size for the piezoelectric circuit elements 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 a reciprocating rotary gyrator type crystallizer.

Crystals 1 comprising di-potassium tartrate hemihydrate, $(K_2C_4H_4O_6 \cdot \frac{1}{2}(H_2O))$ form in the monoclinic sphenoidal class of crystals which has

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as its element of symmetry the Y or b crystallographic axis, the Y or b axis being an axis of binary symmetry. There are four dielectric constants, eight piezoelectric constants and 13 elastic constants involved in such crystalline material. Di-potassium tartrate hemihydrate crystals 1 have $\frac{1}{2}$ molecule of water of crystallization, as compared to 4 for Rochelle salt crystals. As a result, the water of crystallization is much more tightly bound for crystals of di-potassium tartrate hemihydrate than those of Rochelle salt. When held at about 80 degrees centigrade, there appears to be no observable dehydration of the crystalline di-potassium tartrate hemihydrate; but at about 150 degrees centigrade the vapor pressure of the crystal reaches atmospheric pressure and will cause bubbling that may be observed in an oil bath. If the di-potassium tartrate hemihydrate crystal is placed in a sealed container that is evacuated or filled with dry air, it will give off enough moisture to establish its equilibrium vapor pressure, which may be around 10 per cent relative humidity, and it will be stable from then on. Sudden changes of temperature do not appreciably affect the crystal 1 since the stable relative humidity at room temperature is so low.

Di-potassium tartrate hemihydrate crystals 1 have three cleavage planes which lie along the three planes determined by the three crystallographic axes a, b and c. While such cleavage planes may make the crystals 1 somewhat more difficult to cut and process, nevertheless satisfactory processing may be done, as by using a sanding or abrasive belt cooled by oil or by a solution of water and ethylene glycol, for example.

As illustrated in Fig. 1, monoclinic crystals 1 comprising di-potassium tartrate hemihydrate 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 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 51 minutes above the a axis for di-potassium tartrate hemihydrate, as shown in Fig. 1. The X, Y and Z axes form a mutually perpendicular system of axes, the b or 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 di-potassium tartrate hemihydrate 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 21 degrees with respect to the Y axis, as illustrated in Fig. 2.

Fig. 2 is a diagram illustrating the plane of the

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optic axes for crystals 1 comprising di-potassium tartrate hemihydrate. As shown in Fig. 2, the plane of the optic axes of a di-potassium tartrate hemihydrate 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 21 degrees from the +c or +Z 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 Figs 1 and 2 determines the positive (+) directions of all three of the X, Y and Z axes. Hence the positive directions of all three X, Y and Z axes may be specified with reference to the plane of the optic axes of the crystal 1. A similar optical method of procedure may be used for orienting and specifying the direction of the three mutually perpendicular X, Y and Z axes of other types of monoclinic crystals. Oriented crystal cuts are usually specified in practice by known X-ray orientation procedures.

Fig. 3 is a perspective view illustrating a crystal element 2 comprising di-potassium tartrate hemihydrate 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 shaped 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 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 largest or 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 the surface 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. 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 a pair of coaxial pressure type clamping pins or by conductive supporting spring wires 6 each cemented by a spot of con-

ductive cement 7 to the respective 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 disposed perpendicular or nearly perpendicular to the Z or c axis and has its longest or lengthwise dimension L inclined at an angle θ with respect to the +X axis where θ may be an angle of about $+52\frac{1}{2}$ degrees with respect to the +X or +a axes, the X axis in the case of di-potassium tartrate hemihydrate being very near to the a axis. At the angle of θ about $52\frac{1}{2}$ degrees with respect to the +X axis as particularly illustrated in Fig. 3, the crystal element 2 has a large piezoelectric coupling, has a zero temperature coefficient of frequency at about -45 degrees centigrade for its longitudinal mode of motion along the length dimension L, and at that θ angle of about $52\frac{1}{2}$ degrees the mechanical coupling of that longitudinal mode of motion to the face shear mode of motion therein is zero. At angles of θ above and below about $52\frac{1}{2}$ degrees, the piezoelectric coupling is of effective values, the mechanical coupling of the longitudinal length L mode of motion to the face shear and other modes of motion therein is small, and 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 according to the angle of θ selected.

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 consequently has a normal which makes an angle of about 51 minutes from the Z or c axis, as illustrated in Figs. 1 and 2. For practical purposes and ease in processing, the major faces of the crystal element 2 may follow the natural a axis and b axis surface directions of the mother crystal 1, in which case they will not be quite perpendicular to the Z and c axis by the angle of about 51 minutes. However, the properties of the crystal element 2 do not vary much with such a small change in the orientation angle. Accordingly, the crystal element 2 of Fig. 3 may have its major faces nearly perpendicular to the Z axis and in the plane formed by the crystallographic axes a and b.

As particularly illustrated in Fig. 3, the length or longest dimension L of the major faces of the crystal element 2 lies substantially in the plane of the X and Y axes and is inclined at an angle of about $+52\frac{1}{2}$ 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 make an angle of about $52\frac{1}{2}$ degrees with respect to the Y axis. The thickness dimension T extends along or nearly along the Z or c axis. The electrodes 4 and 5 disposed adjacent the opposite 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 piezoelectric or high electromechanical coupling and a low mechanical coupling to the face shear mode of motion therein.

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 may be made of the order of about 0.5 for longitudinal length mode crystal elements 2. The smaller values of the 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 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 mounted and electrically connected by any suitable means such as by one or more pairs of opposite spring wires 6 which may be cemented to the metallic coatings 4 and 5 in the nodal region 7 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. 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 No. 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 No. 2,292,886, dated August 11, 1942.

The electrode coatings 4 and 5 disposed adjacent the opposite 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 or zero mechanical coupling to the face shear mode of motion therein, as is shown by the frequency spectrum of a $+52\frac{1}{2}$ degree Z cut di-potassium tartrate hemihydrate 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 0.65 for example. The main mode of motion, which is the fundamental longitudinal mode of vibration along the length dimension L, has a frequency constant which varies from about 160 to 180 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 $+52\frac{1}{2}$ degree Z cut crystal element 2 having a length dimension L of one centimeter and a dimensional ratio of width W to length L of about 0.5 will have a frequency of about 175 kilocycles per second for its fundamental longitudinal mode of motion along the length dimension L. A similar $+52\frac{1}{2}$ degree Z cut crystal element 2 having a length dimension L of another value will have a corresponding frequency which varies inversely as the value of the length dimension L. The secondary face shear mode of motion has no coupling to the main length L longitudinal mode of motion at the θ angle of about $+52\frac{1}{2}$ degrees.

At a dimensional ratio of width W to length L of around 0.5, for example, the main length L longitudinal mode of motion has a ratio of capacities around 19.5 to 20, while the secondary face shear mode of motion has a ratio of capacities of around 5,000 to 10,000. The effect of the secondary face shear mode of motion on the main length L longitudinal mode of motion is negligible.

The still higher frequency secondary modes of motion are related to the width W longitudinal mode of motion and are, for a $+52\frac{1}{2}$ degree Z cut crystal element 2 having a width dimension W equal to 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 along the length dimension L , and do not produce any troublesome interference therewith.

The longitudinally clamped dielectric constant of Z cut type di-potassium tartrate hemihydrate crystal elements 2 over a temperature range from -80 to $+100$ degrees centigrade is of the order of 6.0 expressed in centimeter-gram-seconds (c. g. s.) units.

A feature of special interest is that at the θ angle of about $+52\frac{1}{2}$ degrees, the crystal element 2 has a longitudinal length L mode of motion that has no coupling to the face shear mode of motion, and accordingly corresponds, in respect to the feature of freedom from coupling effect, to the -18.5 degree X cut quartz crystal element of W. P. Mason et al. United States Patent 2,173,589, dated September 10, 1939, and to the 42 degree 26' Y cut Rochelle salt crystal element of W. P. Mason United States Patent 2,292,885, dated August 11, 1942, Fig. 2. It will be understood that a coupling between the length L longitudinal mode of motion and the face shear mode of motion produces an extra resonance which is often undesirable for filter purposes. The cause of the coupling between the longitudinal length L mode of motion and the face shear mode of motion is the shear-longitudinal elastic constant. In this case, since the length L longitudinal motion is along the X' axis and the face shear motion is in the XY or $X'Y'$ plane, the shear coupling constant is S'_{16} , and vanishes when the θ angle is in the region of $+52\frac{1}{2}$ degrees, with respect to $+X$ axis as illustrated in Fig. 3.

It will be noted that the $\theta = +52\frac{1}{2}$ degree Z cut crystal element as illustrated in Fig. 3 is an orientation for which the frequency variation is such over ordinary room temperature ranges as to be useful for example in filter systems, and that the low or zero coupling therein with undesired modes of motion together with the high electromechanical coupling, the high Q , the ease of procurement and the low cost of production 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 Z -cut type di-potassium tartrate hemihydrate crystal element having its major plane section disposed substantially perpendicular to the Z axis, the lengthwise axis dimension of said major plane section being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the

$+X$ axis to obtain substantially zero coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major plane section.

2. A Z -cut type di-potassium tartrate hemihydrate crystal element having its substantially rectangular major plane section disposed substantially perpendicular to the Z axis, the lengthwise axis dimension of said major plane section being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the $+X$ axis to obtain substantially zero coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major plane section.

3. A Z -cut type di-potassium tartrate hemihydrate crystal element having its major faces disposed substantially perpendicular to the Z axis, the lengthwise axis dimension of said major faces being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the $+X$ axis to obtain substantially zero coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major faces.

4. A Z -cut type di-potassium tartrate hemihydrate crystal element having its substantially rectangular major faces disposed substantially perpendicular to the Z axis, the lengthwise or longest axis dimension of said major faces being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the $+X$ axis to obtain substantially zero coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major faces.

5. Piezoelectric crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element having major faces, said major faces being disposed substantially perpendicular to the Z axis, the lengthwise axis dimension of said major faces being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the $+X$ axis to obtain substantially zero coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major faces, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion along said lengthwise dimension of said crystal element.

6. Piezoelectric crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Z axis, the lengthwise axis dimension and longest edges of said major faces being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the $+X$ axis, to obtain substantially zero coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major faces, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width dimension of said major faces with respect to said lengthwise dimension thereof being one of the values less than 0.7.

7. Piezoelectric crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Z axis, the lengthwise axis dimension and longest edges of said major faces being inclined at one of the angles from

substantially +50 to +55 degrees with respect to the +X axis to obtain substantially zero coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major faces, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion along said lengthwise dimension of said crystal element.

8. Piezoelectric crystal apparatus comprising a dipotassium tartrate hemihydrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Z axis, the lengthwise axis dimension and longest edges of said major faces being inclined at one of the angles from substantially +50 to +55 degrees with respect to the +X axis to obtain substantially no coupling between the longitudinal motion along said lengthwise dimension and the shear motion in said major faces, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width dimension of said major faces with respect to said lengthwise dimension thereof being one of the values less than 0.7.

9. Piezoelectric crystal apparatus comprising a dipotassium tartrate hemihydrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Z axis, the lengthwise axis dimension and longest edges of said major faces being inclined at one of the angles from substantially +50 to +55 degrees with respect to the +X axis to obtain substantially no coupling between the fundamental longitudinal motion along said lengthwise dimension and the shear motion in said major faces, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said fundamental longitudinal mode of motion along said lengthwise dimension of said crystal element.

10. Piezoelectric crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Z axis, the lengthwise axis dimension and longest edges of said major faces being inclined at one of the angles from substantially +50 to +65 degrees with respect to the +X axis to obtain substantially no coupling between the fundamental longitudinal motion along said lengthwise dimension and the shear motion in said major faces, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said fundamental longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width dimension of said major faces with respect to said lengthwise dimension thereof being one of the values less than 0.7.

11. Piezoelectric crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element having substantially rectangular major faces, said major faces being disposed substantially perpendicular to the Z axis, the lengthwise axis dimension and longest edges of said major faces being inclined at one of the angles from substantially +50 to +55 degrees with respect to the +X axis to obtain substantially no coupling between the longitudinal motion along said lengthwise dimension and the shear motion

in said major faces, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion along said lengthwise dimension of said crystal element, the ratio of the width dimension of said major faces with respect to said lengthwise dimension thereof being substantially 0.5.

12. Crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element, the major faces of said crystal element being substantially perpendicular to the Z axis, the lengthwise axis dimension of said major faces being inclined at an angle of substantially +52½ degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a longitudinal mode of motion along said lengthwise dimension with substantially no coupling to the face shear mode of motion therein.

13. Crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element, the major faces of said crystal element being substantially rectangular-shaped and disposed substantially perpendicular to the Z axis, the lengthwise axis dimension of said major faces being inclined at an angle of substantially +52½ degrees with respect to the +X axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a longitudinal mode of motion along said lengthwise dimension with substantially no coupling to the face shear mode of motion therein.

14. Piezoelectric crystal apparatus comprising a Z-cut di-potassium tartrate hemihydrate 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 Z axis of the three mutually perpendicular X, Y and Z axes thereof, and said length axis dimension being inclined at an angle of substantially +52½ degrees with respect to said +X axis, the ratio of the width dimension of said major faces with respect to said length dimension being a value not greater than substantially 0.6, said length dimension being a value corresponding to the frequency for said longitudinal mode of motion, said length dimension expressed in centimeters being one of the values substantially from 160 to 180 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 longitudinal mode of motion.

15. Piezoelectric crystal apparatus comprising a Z-cut di-potassium tartrate hemihydrate 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 Z axis of the three mutually perpendicular X, Y and Z axes thereof, and said length axis dimension being inclined at an angle of substantially +52½ degrees with respect to said +X axis, the ratio of the width dimension of said major faces with respect to said length dimension being a value not greater than substantially 0.6, said length dimension being a value corresponding to the frequency for said longitudinal mode of motion, said length dimension expressed in centimeters being one of the values substantially from 160 to 180 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 longitudinal

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mode of motion with substantially no coupling to the face shear mode of motion therein.

16. Crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element having mutually perpendicular width and length axis dimensions for its major faces, said major faces being substantially perpendicular to the Z axis, and said length axis dimension being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the +X axis, said width dimension being substantially less than said length dimension.

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17. Crystal apparatus comprising a di-potassium tartrate hemihydrate crystal element having mutually perpendicular width and length axis dimensions for its substantially rectangular major faces, said major faces being substantially perpendicular to the Z axis, and said length axis dimension being inclined at an angle of substantially $+52\frac{1}{2}$ degrees with respect to the +X axis, said width dimension being substantially less than said length dimension.

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