

Dec. 1, 1942.

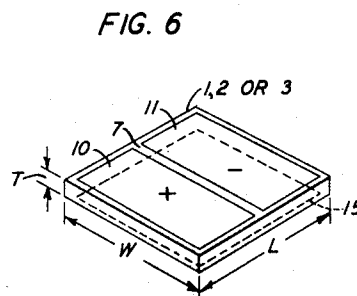
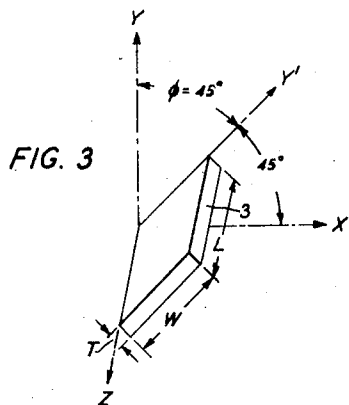
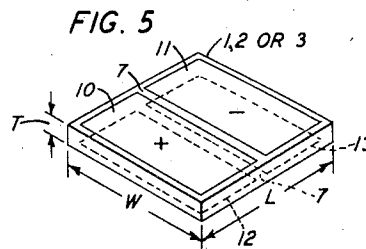
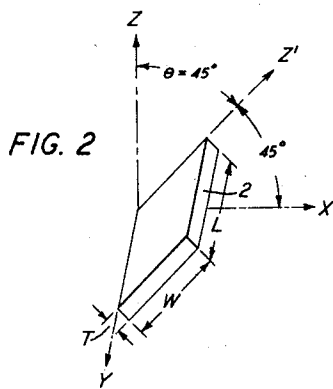
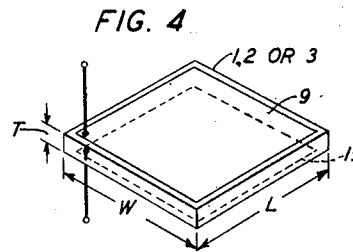
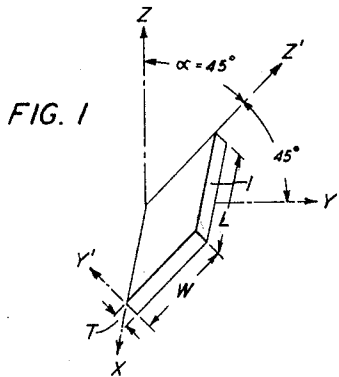
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2,303,375

ROCHELLE SALT PIEZOELECTRIC CRYSTAL APPARATUS

Filed June 10, 1941

3 Sheets-Sheet 1



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ROCHELLE SALT PIEZOELECTRIC CRYSTAL APPARATUS

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FIG. 7

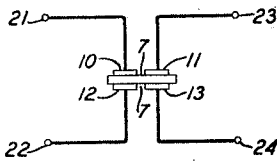


FIG. 8

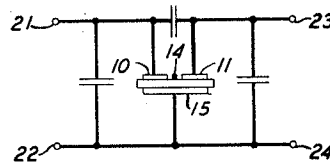
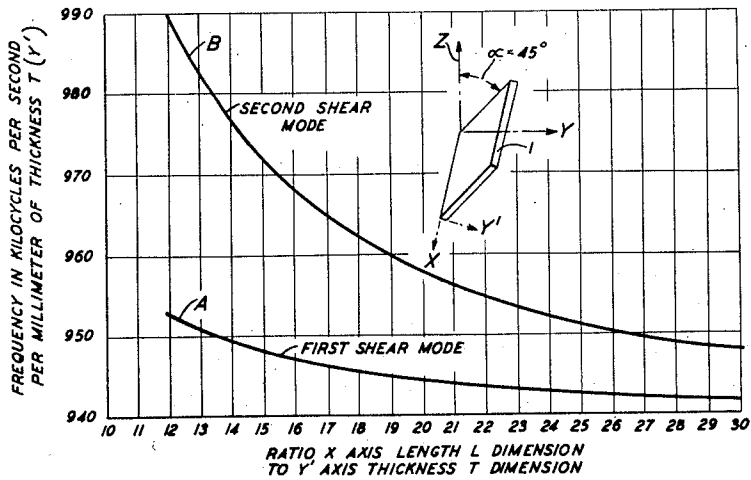


FIG. 9



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FIG. 10

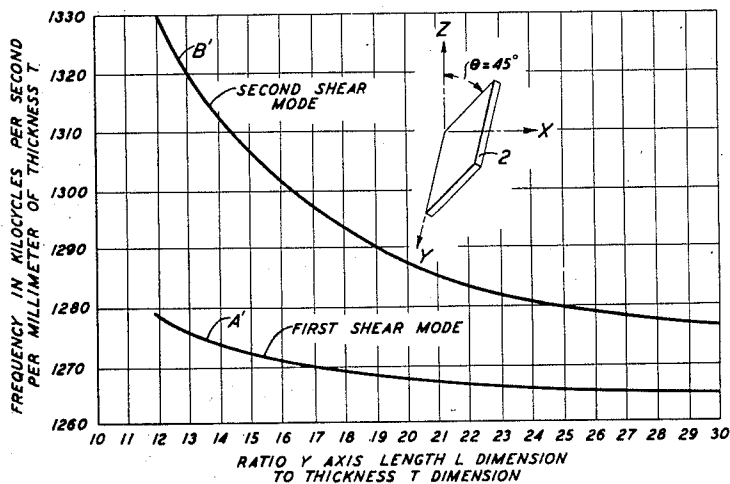
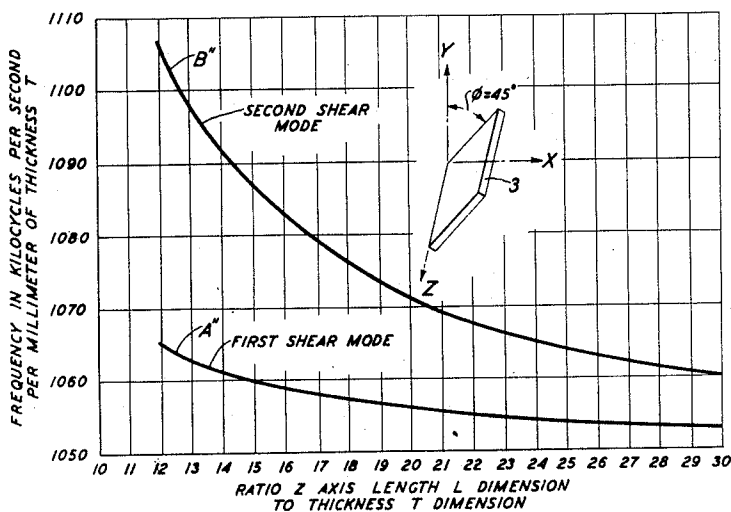


FIG. 11



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UNITED STATES PATENT OFFICE

2,303,375

ROCHELLE SALT PIEZOELECTRIC CRYSTAL APPARATUS

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Application June 10, 1941, Serial No. 397,377

14 Claims. (Cl. 171-327)

This invention relates to piezoelectric crystal apparatus and particularly to high frequency piezoelectric Rochelle salt or sodium potassium tartrate crystal elements suitable for use as circuit elements in electric wave filter systems and oscillator systems, for example.

One of the objects of this invention is to provide a Rochelle salt piezoelectric crystal element having one or more useful high frequency or thickness modes of motion that may be utilized alone or simultaneously without interference with other modes of motion therein.

Another object of this invention is to provide a Rochelle salt crystal element having a plurality of simultaneously useful and independently controlled thickness mode frequencies.

Another object of this invention is to provide Rochelle salt crystal elements utilizing either the first shear thickness mode of motion thereof or the second shear thickness mode of motion thereof.

Another object of this invention is to reduce the number and the cost of crystals used in high frequency electric wave filter systems and other wave transmission networks, and to take advantage of the high piezoelectric activity and low cost of Rochelle salt.

Rochelle salt piezoelectric crystal elements generally may be excited in many different modes of motion such as extensional or longitudinal modes of motion, flexural modes of motion, and shear modes of motion, for example. When crystals are to be applied to filter systems, for example, it is generally desirable to have all of the undesired or extraneous modes of motion therein uncoupled with and considerably higher, or lower in frequency than the desired main mode or modes of motion of the crystal element since otherwise the extraneous resonance frequencies therein may introduce undesirable frequencies or pass bands in the filter characteristics. Accordingly, it is often desirable in filter systems and elsewhere that the desired main mode or modes of motion of a crystal element be substantially independent of other modes of motion and independently controlled in order that such desired mode or modes of motion may be given any desired frequency values to obtain prescribed frequency characteristics.

In accordance with this invention, wave filters and other systems may comprise as a component element thereof, a single piezoelectric crystal element of Rochelle salt which may be adapted to vibrate simultaneously in a plurality of high frequency or thickness modes of motion in order to

provide either separately or simultaneously useful effective resonances which may be independently controlled and placed at predetermined frequencies of nearly the same value or of different values, for use in an electric wave filter, or elsewhere.

The crystal element may be a Rochelle salt type crystal plate of suitable orientation with respect to the X, Y and Z axes thereof, and of suitable dimensional proportions, and provided with a suitable electrode arrangement and connections for separately driving either or simultaneously driving both of two thickness modes of motion therein, and independently controlling the relative strengths of such resonances.

In particular embodiments, the orientation of the Rochelle salt crystal element may be such that one of the major surface dimensions thereof, such as the length dimension, lies along one of the X, Y and Z axes thereof, and the other dimension, such as the width dimension of the major surfaces, is rotated in effect a selected angle in degrees to a position intermediate or midway between the other two of the X, Y and Z axes. The major surfaces may be of rectangular or square shape. The frequency-determining thickness dimension between the major surfaces of the crystal element and the length dimension thereof may be made of selected and related values, as a dimensional ratio of the length dimension with respect to the thickness dimension in the region from 10 to 50, in order to obtain therefrom, separately or simultaneously, either or both of two useful independently controlled resonant frequencies resulting from two independently controlled thickness modes of motion, one particular set of which is described herein as the fundamental or first shear thickness mode of motion and the other as the second shear thickness mode of motion. Both the first and second shear mode frequencies are controlled mainly by the thickness dimension of the crystal element and vary inversely as the value of the thickness dimension of the crystal element.

The Rochelle salt crystal elements described herein may have the same or similar orientations as those described in my United States Patent 2,178,146, dated October 31, 1939, but herein they are adapted for a plurality of thickness mode vibrations of the shear type including the first shear and also the second shear modes of motion.

Such Rochelle salt crystal elements when provided with suitable electrodes may be connected into a filter circuit in such a way that one of the resonances of each crystal element is effective

in the line branch and another of such resonances is effective in the diagonal branch of the lattice portion of the equivalent network thereof, in order to obtain filter circuits using a single crystal which are electrically equivalent to circuits requiring two crystals, thereby reducing the number and cost of crystals therein. Such Rochelle salt crystal elements may be utilized for example in either balanced or unbalanced filter structures such as those disclosed for example in W. P. Mason United States Patent 2,271,870 granted February 3, 1942, on my application Serial No. 303,757, filed November 10, 1930, and in the R. J. McSkimin and R. A. Sykes United States Patent 2,277,709 granted March 31, 1942, on application Serial No. 359,394, filed December 12, 1940.

By using two of such doubly resonant Rochelle salt crystal elements with or without temperature control, filter systems may be inexpensively constructed of frequencies as high as several million cycles per second. With the higher values of frequency, there is more absolute shift in the pass band due to temperature change and temperature control often may be needed at the higher values of frequency for electric wave filters using Rochelle salt crystal elements as the vibrating elements thereof, in order to obtain characteristics nearly as good as those obtained when using quartz crystal elements. Also, due to the relatively high temperature-frequency coefficient of Rochelle salt crystals, it is often desirable to have temperature control to about 1 or 2 degrees centigrade to hold the pass bands to their required frequency. By the use of both wet and dry Rochelle salt material placed in the same enclosing crystal container, the vibratory Rochelle salt crystals may be preserved indefinitely, or for a long period of time without change in the characteristics thereof.

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:

Figs. 1, 2 and 3 are perspective views of three forms of piezoelectric Rochelle salt crystal elements in accordance with this invention, and respectively illustrate particularly the orientation thereof with respect to the X, Y and Z axes of the Rochelle salt crystal material from which the crystal elements may be cut:

Figs. 4 to 8 are views illustrating types of electrodes and connections which may be utilized with any of the Rochelle salt crystal elements of Fig. 1, 2 or 3 to drive the crystal element separately in either, or simultaneously in both, of two independent shear thickness modes of motion, in order to obtain the desired resonance frequency or frequencies;

Fig. 4 is a perspective view of an electrode arrangement that may be used to drive any of the piezoelectric crystal elements of Fig. 1, 2 or 3 in the fundamental or first shear thickness mode of motion;

Figs. 5 and 6 are perspective views of electrode arrangements that may be used to drive any of the crystal elements of Fig. 1, 2 or 3 in the second shear thickness mode of motion and the fundamental or first shear thickness mode of motion, separately or simultaneously;

Fig. 7 is a schematic diagram illustrating an example of balanced filter connections that may

be used with the crystal element electrodes of Fig. 5;

Fig. 8 is a schematic diagram illustrating an example of unbalanced filter connections that may be used with the electrodes of the crystal element of Fig. 6;

Fig. 9 is a graph illustrating the thickness mode frequency-dimension constants of the fundamental or first shear mode of motion and of the second shear mode of motion in the Rochelle salt crystal element illustrated in Fig. 1 having a dimensional ratio of its X axis length L with respect to its thickness T in the region from 12 to 30.

Figs. 10 and 11 are graphs illustrating the thickness-mode frequency-dimension constants of the first and second shear mode vibrations of the Rochelle salt crystal elements illustrated in Figs. 2 and 3 respectively, for ratios of the length L with respect to the thickness T in the region from about 12 to 30.

This specification follows the conventional terminology as applied to crystalline Rochelle salt, which employs three orthogonal or mutually perpendicular *a*, *b* and *c* axes or X, Y and Z axes, respectively, as shown in the drawings, to designate an electric axis, a mechanical axis and the optic axis, respectively, of piezoelectric Rochelle salt or sodium potassium tartrate crystal material, and which employs three orthogonal axes X', Y' and Z' to designate the directions of axes of a piezoelectric body angularly oriented with respect to such X, Y and Z axes thereof. Where the orientation is obtained in effect by a single rotation of the Rochelle salt crystal element, the rotation being in effect substantially about the length dimension axis X, Y or Z of the piezoelectric body as illustrated in Figs. 1, 2 and 3, respectively, the orientation angles, respectively $\alpha=$ substantially 45 degrees, $\theta=45$ degrees, and $\phi=45$ degrees designate in degrees the effective angular position of the width axis dimension W of the crystal plate as measured from one of the other two of the X, Y and Z axes. The relation of the X, Y and Z axes to the outer faces of a grown Rochelle salt crystal body are illustrated in W. P. Mason United States Patent 2,178,146, dated October 31, 1939. Rochelle salt belongs to the rhombic hemihedral class of crystals and has three orthogonal or mutually perpendicular axes generally designated as the *a*, *b*, and *c* axes or the X, Y and Z axes, respectively.

Referring to the drawings, Figs. 1, 2 and 3 represent perspective views of thin bare piezoelectric Rochelle salt crystal elements 1, 2 and 3 cut from crystalline Rochelle salt free from defects and made into a plate of substantially rectangular parallelepiped shape with its major surfaces having a length dimension L, and a width dimension W which is perpendicular to and may be equal to or longer or shorter than the length dimension L. The frequency-determining thickness or thin dimension T between the major surfaces is perpendicular to the other two dimensions L and W. In accordance with the particular orientation and mode or modes of motion selected, the final width dimension W or length dimension L of the Rochelle salt crystal element 1, 2 or 3 of Figs. 1, 2 and 3 may be made of a suitable value with respect to the thickness dimension T according to the desired resonant frequency. The width dimension W also may be equal to or otherwise related to the length dimension L to remove spurious frequencies from the region of the desired resonant frequency. The thickness dimension T may be of the order

of 1 millimeter more or less and made of any suitable value to obtain the desired thickness mode frequency or frequencies for the crystal element 1, 2 or 3 of Figs. 1, 2 and 3.

As shown in Fig. 1, the length dimension L of the Rochelle salt crystal element 1 illustrated in Fig. 1 lies substantially along or parallel to the X axis, the X axis being perpendicular to the plane of the mechanical axis Y and the optic axis Z of the Rochelle salt crystal material from which the element 1 is cut. The width dimension W which is perpendicular to the length dimension L, is inclined at an angle α degrees with respect to said Z axis, the angle α being one of the values in the region of substantially 45 degrees (45°). The major surfaces and the major plane of the Rochelle salt crystal element 1 are disposed parallel or nearly parallel with respect to the X axis, the length dimension L and the width dimension W lying along the X axis and the Z' axis, respectively, the Z' axis being inclined at the angle α with respect to the optic axis Z. The axis Z' is accordingly the result of a single rotation of the width dimension W about the X axis α degrees. It will be noted that the crystal element 1 of Fig. 1 is in effect a Y-cut Rochelle salt crystal plate rotated α degrees about the X axis.

Fig. 2 is a perspective view of a Rochelle salt piezoelectric crystal element 2 having its length dimension L along or parallel to the Y axis and its width dimension W inclined at an angle θ substantially 45 degrees with respect to the Z axis, the major surfaces of the crystal element 2 being parallel or nearly parallel to the Y axis.

Fig. 3 represents a Rochelle salt crystal element 3 having its length dimension L along or parallel to the Z axis and its width dimension W inclined at an angle ϕ which may be any angle in the region of 45 degrees intermediate the X and Y axes, the major surfaces of the crystal element 3 being parallel or nearly parallel to the Z axis.

The orientations illustrated in Figs. 1, 2 and 3 represent Rochelle salt piezoelectric crystal elements 1, 2 and 3, respectively, which may be adapted for a plurality of independently controlled thickness mode vibrations of the shear motion type, which may be utilized either alone or simultaneously, according to the arrangement of the electrodes and connections that are used therewith, and the dimension-frequency constants that are selected therefor.

Suitable conductive electrodes, such as the crystal electrodes of Fig. 4, 5 or 6, for example, may be placed on or adjacent to or formed integral with the opposite major surfaces of the crystal plate 1, 2 or 3 of Fig. 1, 2 or 3 in order to apply electric field excitation to the Rochelle salt plate 1, 2 or 3 which may be vibrated alone or simultaneously in the desired thickness T fundamental or first shear mode of motion and/or the thickness T second shear mode of motion at independently controlled resonant response frequencies which depend upon dimensions involving the thickness dimension T and also the width dimension W or the length dimension L, the fundamental shear thickness mode frequencies for the three cuts of Figs. 1, 2 and 3 being values roughly ranging from about 940 to 1272 kilocycles per second per millimeter of the thickness dimension T and varying inversely as the value of the thickness dimension T.

The crystal electrodes when formed integral with the major surfaces of any of the crystal elements of Fig. 1, 2 or 3 may consist of thin coatings of conductive material such as colloidal carbon, silver, gold, platinum, aluminum or other suitable metal or metals deposited alone or in combination upon the crystal surfaces by painting, spraying, or evaporation in vacuum for example, or by other suitable process.

When the Rochelle salt crystal plate of Fig. 1, 2 or 3 has an orientation angle of α substantially 45 degrees with respect to the Z axis as illustrated in Fig. 1, or θ substantially 45 degrees with respect to the Z axis as illustrated in Fig. 2, or ϕ substantially 45 degrees with respect to the Y axis, as illustrated in Fig. 3, the thickness T shear mode vibrations comprising the first shear mode of motion and the second shear mode of motion in the crystal plate may be used simultaneously.

To obtain the two thickness shear type modes of motion simultaneously, it is necessary that the crystal element have a piezoelectric constant which will generate a first shear motion along the thickness dimension T and also a piezoelectric constant that will generate a second shear motion along the thickness dimension T.

In the case of the Rochelle salt crystal element 1 illustrated in Fig. 1, the requirement of suitable piezoelectric constants may be met when the width dimension W or the length dimension L is inclined at any suitable angle α in the region of 45 degrees between the Y and Z axes of the YZ plane, the X axis being parallel or nearly parallel to the major plane and the major surfaces of the Rochelle salt crystal element 1 of Fig. 1. Reference is made to my paper "A dynamic measurement of the elastic, electric and piezoelectric constants of Rochelle salt" published April 15, 1939, in Physical Review, volume 55, page 775, for information on the piezoelectric constants involved in shear mode vibrations along the thickness dimension T of Rochelle salt crystal elements. The shear mode piezoelectric constants reach their maximum values when the angle $\alpha=45$ degrees or when the plane formed by the width dimension W and the length dimension L of the Rochelle salt crystal element 1 of Fig. 1 is inclined at an angle of 45 degrees with respect to the Y and Z axes thereof, the major plane and major surfaces thereof being perpendicular or nearly perpendicular to the plane of such Y and Z axes.

While the maximum values of the thickness shear mode piezoelectric constants occur when the angle $\alpha=45$, the angles of α in the region of 45 degrees are near enough thereto to obtain good values of piezoelectric constants for the first and second shear thickness modes of motion. Such Rochelle salt crystal elements 1 of Fig. 1 have an electromechanical coupling which varies with temperature change, and are easily driven by suitable electrodes in the two desired thickness modes of motion, one being the first shear mode of motion and the other the second shear mode of motion.

As illustrated in Fig. 2, a Rochelle salt piezoelectric crystal element 2 having its length dimension L along the Y axis and its width dimension W inclined at an angle of θ substantially 45 degrees with respect to the Z axis and the X axis also may be used as a doubly resonant crystal element. Such an element has an electromechanical coupling that does not vary much

with temperature, and with the θ angle equal to substantially 45 degrees, both the thickness T first shear mode of motion and the thickness T second shear mode may be operated alone or together simultaneously.

A Rochelle salt crystal element 3 as illustrated in Fig. 3 having its major surfaces parallel or nearly parallel to the Z axis also may be used to generate thickness mode first and second shear vibrations of the kind useful for a doubly resonant crystal element when the angle of ϕ is in the region of $\phi=45$ degrees, the angle ϕ being measured between the width dimension W of the crystal element 3 and the nearest Z axis thereof as illustrated in Fig. 3.

The principal modes of interest that are particularly considered herein in connection with the crystal orientations illustrated in Fig. 1, 2 or 3 are the first and second shear modes controlled mainly by the thickness dimension T and partly by one of the major surface dimensions of the crystal elements 1, 2 and 3 illustrated in Figs. 1, 2 and 3.

The values of the thickness mode resonance frequencies associated with the first shear mode of motion and with the second shear mode of motion in the crystal elements having the orientations illustrated in Fig. 1, 2, or 3 may be controlled by the value of the thickness dimension T and the dimensional ratio of the length L or width W with respect to thickness T which ratio may be in the region from 10 to 50. The fundamental or first shear mode frequency is dependent upon the crystal orientation and for those of Figs. 1, 2 and 3 has a frequency-dimension constant within the range from 945 to 1272 kilocycles per second per millimeter of the thickness dimension T which is dependent upon but nearly independent of the dimensional ratio of the length L or width W dimensions with respect to the thickness dimension T for the higher ratios as roughly above 20. The second shear mode frequency thereof has a frequency-dimension constant of a slightly higher value dependent upon the value of the selected dimensional ratio of length L or width W with respect to the thickness T . The frequencies of these two thickness modes of motion, namely the second shear mode of motion and the fundamental or first shear mode of motion approach each other when the ratio of the length dimension L or the width dimension W with respect to the thickness dimension T is in a certain region and in this region the resonances of these two modes are substantially uncoupled or only very loosely coupled.

Accordingly, when the dimensional ratio of the length L and the width W with respect to the thickness T is in the proper region, and the crystal orientation is that of Fig. 1, 2 or 3, the frequencies of these two independent modes of vibration may be placed close together but sufficiently uncoupled or separated to provide simultaneously two independently controlled frequencies from the same Rochelle salt crystal element, which may be usefully employed in a filter system for example, to give conveniently two useful frequencies within a range from about 500 to 5000 or more kilocycles per second, for example, with a separation between the two frequencies of any one filter from 3 to 20 or 30 kilocycles per second depending on the band width desired.

The fundamental or first shear thickness mode frequency expressed in kilocycles per second, of the Rochelle salt crystal plate 1 of Fig. 1 hav-

ing substantially square major surfaces is given by the experimentally determined relation:

$$f = \frac{945.2}{T} \sqrt{1 + \frac{2.8T^2}{L^2}} = \frac{945.2}{T} \left[1 + \frac{1.9T^2}{L^2} \right] \quad (1)$$

where L is the value of the X axis length dimension and T is the value of the thickness dimension of the crystal element 1 of Fig. 1 expressed in millimeters.

The second shear thickness mode frequency expressed in kilocycles per second, for the same crystal plate 1 of Fig. 1 having substantially square major surfaces is given by the experimentally determined relation:

$$f = \frac{945.2}{T} \sqrt{1 + \frac{4(3.8)T^2}{L^2}} = \frac{945.2}{T} \left[1 + \frac{7.6T^2}{L^2} \right] \quad (2)$$

where L is the X axis length dimension L and T is the thickness dimension of the crystal plate 1 of Fig. 1 expressed in millimeters.

As indicated by the foregoing Equations 1 and 2, by making the thickness T and length L dimensions of the proper values, the XY' second shear thickness mode frequency of the crystal element 1 of Fig. 1 can be spaced any number of selected cycles higher in frequency than that of the XY' first shear thickness mode frequency, and when used in a filter system, one resonance frequency may appear in one arm, and the other resonance frequency in the other arm, so that a band-pass filter with two attenuation peaks can be made from one crystal. Similarly, the first shear and the second shear thickness mode frequencies of the crystal elements 2 and 3 of Figs. 2 and 3 respectively may be utilized.

The graph of Fig. 9 illustrates the measured resonance frequencies associated with the fundamental or first shear thickness mode of motion (curve A) and also those associated with the second shear thickness mode of motion (curve B), in a Rochelle salt crystal element 1 having square or nearly square major surfaces and an orientation angle of substantially 45 degrees as illustrated in Fig. 1. In Fig. 9, the first or fundamental shear thickness mode frequency is represented by the generally horizontal slightly downwardly sloping curve A and has a frequency-dimension constant of about 940 to 950 kilocycles per second per millimeter of thickness dimension T which is dependent but little upon the dimensional ratio of the X axis length L with respect to the Y' axis thickness T . The second overtone shear thickness mode frequency is represented by the downwardly sloping inclined curve B and has a frequency-dimension constant from about 945 to 990 kilocycles per second per millimeter of thickness dimension T dependent upon the value of the selected dimensional ratio of the X axis length dimension L with respect to the thickness dimension T within the dimensional ratio range from about 12 to 30, the frequency constant values gradually decreasing with increasing values for the dimensional ratio. As shown by the curves A and B of Fig. 9, the frequency of the second shear mode of motion and that of the fundamental or first shear mode of motion approach each other more closely when the ratio of the length dimension L with respect to the thickness dimension T is in the region above 12.

While the curves A and B of Fig. 9 apply particularly to a Rochelle salt crystal element 1 having the orientation as illustrated in Fig. 1, the corresponding curves for the first and second shear mode frequencies of the Rochelle salt crys-

tal element 2 of Fig. 2 and also for the Rochelle salt crystal element 3 of Fig. 3 are, as illustrated by the curves of Figs. 10 and 11, similar in form to the downwardly sloping first and second shear mode curves A and B of Fig. 9 for the crystal element 1 of Fig. 1 but are somewhat higher in frequency than the first and second shear mode frequencies of the crystal element 1 of Figs. 1 and 9 for a given dimensional ratio of the length L or the width W with respect to the thickness T.

The thickness mode frequency-dimension constants for the second shear thickness mode of motion in the Rochelle salt crystal element 2 of Fig. 2 are roughly from 1277 to 1330 kilocycles per second per millimeter of the thickness dimension T within a range of dimensional ratios of the length L and width W with respect to the thickness T from about 12 to 30, the frequency constant values gradually decreasing with increasing values for the dimensional ratio as illustrated by the downwardly sloping curve B' of Fig. 10; and the frequency-dimension constants for the second shear thickness mode of motion in the Rochelle salt crystal element 3 of Fig. 3 are, as illustrated by the downwardly sloping curve B'' of Fig. 11, roughly from 1060 to 1107 kilocycles per second per millimeter of the thickness dimension T within a range of dimensional ratios of the length L and width W with respect to the thickness T from about 12 to 30, the corresponding curves for such second shear mode frequencies of the crystal element 2 of Fig. 2 and for the crystal element 3 of Fig. 3 being similar in form as hereinbefore stated to the downwardly sloping second shear mode curve B of Fig. 9 but somewhat higher in frequency for a given dimensional ratio, the frequency constant values gradually decreasing with increasing values for the dimensional ratio in accordance with the form of the downwardly sloping curve B of Fig. 9.

The thickness mode frequency-dimension constants for the fundamental or first shear mode of motion are somewhat lower than those given above for the second shear mode of motion; and as illustrated by the curves A, A' and A'' of Figs. 9, 10 and 11 for the Rochelle salt crystal elements 1, 2 and 3 of Figs. 1, 2 and 3 are respectively, expressed in kilocycles per second, about from 942.5 to 948, from 1265 to 1272 and from 1052 to 1060, respectively, for dimensional ratios of the length L and width W with respect to the thickness T in the range about from 12 to 30, the frequency constant values gradually decreasing with increasing values for the dimensional ratio in accordance with the form of the slightly downwardly sloping curve B of Fig. 9.

Accordingly, it will be understood that the curves for the first and second shear mode frequencies given in Fig. 9 for the crystal element 1 of Fig. 1 also apply to the crystal elements 2 and 3 of Figs. 2 and 3 using the same length to thickness dimensional ratio values of Fig. 9 but changing the ordinate values thereof to correspond with the limiting ranges of the frequency constant values hereinbefore given for such frequencies. Figs. 4, 5 and 6 illustrate forms of electrode arrangements which may be utilized to drive any of the crystal elements of Fig. 1, 2 or 3. In Fig. 4, the single pair of electrodes 9 and 15 may be used to drive either the thickness T shear fundamental mode of motion or any odd harmonic such as third, fifth, etc., harmonic thereof to obtain separately but not simultaneously any of

such shear thickness mode resonance frequencies of a desired value.

In Fig. 4 which is a perspective view of the Rochelle salt crystal element of Fig. 1, 2 or 3, the pair of opposite electrodes 9 and 15 may be utilized to usefully operate separately in the crystal element 1, 2 or 3 of Figs. 1 to 3, the fundamental or any odd order harmonic thickness shear mode of motion, the fundamental frequency being roughly one of the values from about 942 to 1272 kilocycles per second per millimeter of thickness dimension T, dependent upon the orientation selected. The electrodes 9 and 15 may partially or wholly cover the major surfaces of the crystal element 1, 2 or 3 and may be connected in circuit by a conductive member disposed in contact with each of the electrodes 9 and 15 at or near the corners thereof. It will be understood that Rochelle salt crystal elements having the orientations illustrated in Figs. 1, 2 and 3 and provided with electrodes of the type illustrated in Fig. 4 may be utilized to obtain a desired fundamental or odd order harmonic shear mode vibrational frequency that is dependent substantially upon the thickness dimension T. Where a harmonic of such fundamental shear mode of motion is used, the harmonic frequency may be of any desired odd order and may be obtained by the use of electrode arrangement shown in Fig. 4.

As shown in Fig. 5, the second shear thickness mode of motion may be driven by means of two pairs of divided electrodes 10, 11, 12 and 13 placed on both of the major surfaces of the crystal element of Fig. 1, 2 or 3; and with suitable connections, the fundamental or first shear mode of motion may be driven at the same time by one of the connected sets of electrode platings, with the result that the two useful and independently controlled thickness mode resonance frequencies of the crystal element 1, 2 or 3 may be made to appear simultaneously. As illustrated in Fig. 5, the Rochelle salt crystal element 1, 2 or 3 of Fig. 1, 2 or 3 may be provided with four equal area electrodes 10, 11, 12 and 13, two of the electrodes 10 and 11 being placed on one major surface of the crystal element with a centrally located narrow transverse split or gap 7 therebetween, and the other two electrodes 12 and 13, being oppositely disposed and placed on the opposite major surface of the crystal element and separated with a similar narrow and oppositely disposed split or dividing line 7 therebetween, the dividing lines 7 extending generally in the direction of the width W axis of the crystal element, according to the value of the angle selected between the direction of the dividing line 7 and the direction of the length dimension L. The gap or separation 7 between the electrode coatings or platings on each of the major surfaces of the crystal element may be of the order of about 0.3 millimeter, the center line of such splits in the platings on the opposite sides of the crystal plate 1 being aligned with respect to each other.

When the electrode plates have the same sign across the whole surface of the major surface, the fundamental thickness shear vibration of the crystal element is excited; and when the electrode plates have opposite signs on the same major surface of the crystal element, the second thickness shear mode vibration, corresponding to the fundamental shear mode for a crystal plate half as long as the length L of the original crystal element, is excited, the second shear

mode being a few kilocycles per second higher in frequency than that of the fundamental shear mode, when the proper dimensional ratio of the length L and the width W with respect to thickness T is used.

Fig. 7 is a schematic diagram illustrating an example of balanced filter connections which may be used with the electroded crystal arrangement of Fig. 5 in order to obtain a filter system comprising a single Rochelle salt crystal element having two independently controlled and simultaneously effective resonances which may be placed at desired frequencies, one of which may appear in the line branch of the equivalent lattice and the other in the diagonal branch thereof, as described more fully in connection with Figs. 2 and 3 of the Mason application, Serial No. 303,757 referred to hereinbefore.

The balanced circuit of Fig. 5 may be converted into an unbalanced filter structure by interconnecting the two electrodes 12 and 13 on one of the major surfaces of the crystal element. In this case, the two electrodes 12 and 13 of Figs. 5 and 7 may be replaced by a single electrode 15 as shown in Fig. 6, and the electroded crystal element of Fig. 6 may be connected as shown schematically in Fig. 8 and as described more fully in connection with Figs. 6 and 7 of the Mason application Serial No. 303,757 hereinbefore referred to.

As illustrated in Fig. 8 to reduce the magnitude of the shunting capacitance appearing in the line branch of the lattice portion, a narrow grounding strip 14 of metallic or conductive coating or plating may be placed on one major surface of the crystal element between the electrodes 10 and 11. The strip 14 may extend around one edge of the crystal element to the opposite major surface thereof where it may be electrically connected to the large electrode 15. The ground strip 14 may be approximately 1 millimeter in width and may be placed between and separated from the two electrodes 10 and 11 on the same major surface of the crystal element 1, in order to provide shielding and to reduce stray capacities to a minimum. The strip of plating 14 may extend from one major surface continuously over and around one edge only or both edges of the crystal plate 1 to the opposite major face thereof where it may make contact with the integral electrode 15 on that surface.

It will be noted that in order to drive the electroded crystal element of Fig. 6 in the second shear thickness mode of motion, one-half of the crystal plate 1 is made of opposite polarity to that of the other half, as indicated by the + and - signs in Fig. 6, and that this may be accomplished by utilizing a crystal element having divided metallic coatings 10 and 11, placed on one of its major surfaces and connected in the form of a T network, for example, as illustrated in Fig. 8. Inductance coils may be added in the usual manner in series or in parallel with the network of Fig. 8 to produce broad band low or high impedance filters for example. In order that the crystal impedance may appear in both arms of the lattice structure of Fig. 8, one mode is driven when the terminals 21 and 23 are both of same polarity, and the other mode is driven when these terminals 21 and 23 are of opposite polarity. Since both modes are substantially uncoupled or independent, they may produce simultaneously two independently controlled resonances of predetermined frequencies of desired values.

In order to control the relative impedance levels of the two desired crystal resonances, the crystal electrodes associated with one half of the major surface or surfaces of crystal element 1, 2 or 3 of Figs. 5 and 6 may be extended to cover a portion of the other half thereof. This may be done, for example, by adjustment of the position of the electrode dividing line angle with respect to the length dimension L . The angle may be any desired value over a wide range of angles. This adjustment does not materially affect the impedance of the first shear mode resonance, but with decreasing values for the 90-degree angle shown in Figs. 5 and 6, will increase the impedance level and cut down the drive on second shear mode resonance, without materially affecting the impedance of the first shear mode resonance. Thus, by changing the angle of inclination of the split or division line 7 between the electrodes 10 and 11 with respect to the length dimension L of the crystal element, illustrated by the 90-degree angle in Figs. 5 and 6, the internal capacity associated with the second shear mode resonance, which is nearly a maximum value when the angle equals 90 degrees as shown in Figs. 5 and 6, may be varied and adjusted to a desired value without changing the internal capacity associated with the first shear mode resonance.

It will be understood that the circuit illustrated in Figs. 7 and 8 represent particular circuits. These and other forms of filter circuits, in which a doubly resonant crystal element may be utilized, are described in W. P. Mason application Serial No. 303,757, hereinbefore referred to. If desired, mutual inductance may be used between the end coils of the crystal filter to obtain improved attenuation characteristics as described in United States Patent No. 2,198,684, granted April 30, 1940, to R. A. Sykes.

The electrode doubly resonant crystal elements of Figs. 4, 5 and 6 may be mounted in any suitable manner, such as by clamping or otherwise. Where the clamping form of mounting is used, one or more pairs such as four pairs of opposite conductive clamping projections may resiliently contact the electroded crystal element at or near its four corners only in order to support and to establish individual electrical connections therewith.

Alternatively, instead of being mounted by clamping, the electroded crystal plate may be mounted and electrically connected by cementing or otherwise firmly attaching fine conductive supporting wires directly to a thickened part of the electrodes of the crystal element at or near its four corners only. Such fine supporting wires secured to the electroded crystal element may extend horizontally from the vertical disposed major surfaces of the crystal element, and at their other ends be attached by solder, for example, to vertical conductive wires or rods carried by the press or other part of an evacuated or sealed glass or metal tube. The supporting wires and rods may have one or more bends therein to resiliently absorb mechanical vibrations. Also, bumpers or stops of soft resilient material such as mica may be spaced closely adjacent the edges, ends or other parts of the electroded crystal element in order to limit the bodily displacement thereof when the device is subjected to mechanical shock. Fig. 8, for example, of A. W. Ziegler United States Patent 2,275,122, granted March 3, 1942, on application Serial No. 338,871, filed June 5, 1940, illustrates a suitable mounting of this

type for the crystal element, the horizontal supporting wires being spaced along the vertical rods to suit the corner spacing of the electroded crystal element. It will be understood that any holder which will give stability, substantial freedom from spurious frequencies and a relatively high Q or reactance-resistance ratio for the crystal element may be utilized for mounting the crystal element.

Although this invention had 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, but only by the scope of the appended claims and the state of the prior art.

What is claimed is:

1. A high frequency second shear thickness mode piezoelectric Rochelle salt type crystal element having its substantially square major surfaces substantially parallel to an X axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis and the Y axis, the dimensional ratio of said X axis dimension of said major surfaces with respect to the thickness dimension between said major surfaces being one of the values between substantially 12 and 30, said thickness dimension expressed in millimeters being one of the values between substantially 948 and 990 divided by the value of said frequency expressed in kilocycles per second.

2. A high frequency second shear thickness mode piezoelectric Rochelle salt type crystal element having its substantially square major surfaces substantially parallel to a Y axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis and the X axis, the dimensional ratio of said Y axis dimension of said major surfaces with respect to the thickness dimension between said major surfaces being one of the values between substantially 12 and 30, said thickness dimension expressed in millimeters being one of the values substantially from 1277 to 1330 divided by the value of said frequency expressed in kilocycles per second.

3. A high frequency second shear thickness mode piezoelectric Rochelle salt type crystal element having its substantially square major surfaces substantially parallel to a Z axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Y axis and the X axis, the dimensional ratio of said Z axis dimension of said major surfaces with respect to the thickness dimension between said major surfaces being one of the values between substantially 12 and 30, said thickness dimension expressed in millimeters being one of the values substantially from 1060 to 1107 divided by the value of said frequency expressed in kilocycles per second.

4. A piezoelectric Rochelle salt type crystal element having its substantially rectangular major surfaces substantially parallel to one of the three mutually perpendicular X, Y and Z axes thereof, said major surfaces being inclined at an angle intermediate the other two of said three X, Y and Z axes, the dimensional ratio of the dimension of said major surfaces along said one of said X, Y and Z axes with respect to the thickness dimension between said major surfaces being one of the values between substantially 12 and 30, and means including a plurality of sets of functionally independent electrodes adjacent

said major surfaces for operating said element simultaneously at a plurality of independently controlled frequencies dependent upon said dimensions, one of said frequencies being dependent upon the second shear thickness mode vibration.

5. A piezoelectric Rochelle salt type crystal element having its substantially rectangular major surfaces substantially parallel to one of the three mutually perpendicular X, Y and Z axes thereof, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the other two of said three X, Y and Z axes, the dimensional ratio of the dimension of said major surfaces along said one of said X, Y and Z axes with respect to the thickness dimension between said major surfaces being one of the values substantially in the region of from 10 to 50, and means including a plurality of sets of functionally independent electrodes adjacent said major surfaces for operating said element simultaneously at a plurality of independently controlled frequencies dependent upon said dimensions, one of said frequencies being dependent upon the fundamental or first shear mode vibration along said thickness dimension, and another of said frequencies being dependent upon the second shear mode vibration along said thickness dimension.

6. A piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at desired independently controlled first and second shear thickness mode frequencies dependent mainly upon the length dimension of and the thickness dimension between its substantially rectangular major surfaces, said length dimension being substantially parallel to an X axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis, the ratio of said length dimension of said major surfaces with respect to said thickness dimension being one of the values within the region from substantially 12 to 30, said thickness dimension expressed in millimeters being one of the values from about 948 to 990 divided by the value of said second shear mode frequency expressed in kilocycles per second.

7. A piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at desired independently controlled first and second shear thickness mode frequencies dependent mainly upon the length dimension of and the thickness dimension between its substantially rectangular major surfaces, said length dimension being substantially parallel to a Y axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis, the ratio of said Y axis length dimension of said major surfaces with respect to said thickness dimension being one of the values within the region substantially from 12 to 30, said thickness dimension expressed in millimeters being one of the values substantially from 1277 to 1330 divided by the value of said second shear mode frequency expressed in kilocycles per second.

8. A piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at desired independently controlled first and second shear thickness mode frequencies dependent mainly upon the length dimension of and the thickness dimension between its substantially rectangular major surfaces, said length dimension being substantially parallel to a Z axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the

Y axis, the ratio of said Z axis length dimension of said major surfaces with respect to said thickness dimension being one of the values within the region substantially from 12 to 30, said thickness dimension expressed in millimeters being one of the values substantially from 1060 to 1107 divided by the value of said second shear mode frequency expressed in kilocycles per second.

9. A piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at independently controlled first and second shear thickness mode frequencies dependent mainly upon its length and thickness dimensions, said length dimension of the major surfaces being substantially parallel to an X axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis, said major surfaces being substantially square, the ratio of said X axis length dimension of said major surfaces with respect to said thickness dimension being one of the values within the range from substantially 12 to 30, said thickness dimension and said X axis length dimension being a set of corresponding values in accordance with the values of said first shear and second shear frequencies.

10. A piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at desired independently controlled first and second shear thickness mode frequencies dependent mainly upon its length and thickness dimensions, said length dimension of the major surfaces being substantially parallel to a Y axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis, said major surfaces being substantially square, the ratio of said Y axis length dimension of said major surfaces with respect to said thickness dimension being one of the values within the range from substantially 12 to 30, said thickness dimension and said Y axis length dimension being a set of corresponding values in accordance with the values of said first shear and second shear frequencies.

11. A piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at desired independently controlled first and second shear thickness mode frequencies dependent mainly upon its length and thickness dimensions, said length dimension of the major surfaces being substantially parallel to a Z axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Y axis, said major surfaces being substantially square, the ratio of said Z axis length dimension of said major surfaces with respect to said thickness dimension being one of the values within the range from substantially 12 to 30, said thickness dimension and said Z axis length dimension being a set of corresponding values in accordance with the values of said first shear and second shear frequencies.

12. A Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear thickness mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a

length dimension and a thickness or thin dimension therebetween, said thickness dimension and said length dimension being made of values in accordance with the value of said desired second shear frequency, said major surfaces and said length dimension being substantially parallel to an X axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis, said thickness dimension expressed in millimeters being one of the values substantially from 948 to 990 divided by said desired frequency expressed in kilocycles per second, and the ratio of said X axis length dimension with respect to said thickness dimension being one of the values substantially from 30 to 12, said thickness dimension and said dimensional ratio being corresponding values in accordance with the value of said frequency, as given by the curve B of Fig. 9.

13. A Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear thickness mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a length dimension and a thickness or thin dimension therebetween, said thickness dimension and said length dimension being made of values in accordance with the value of said desired second shear frequency, said major surfaces and said length dimension being substantially parallel to a Y axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Z axis, said thickness dimension expressed in millimeters being one of the values substantially from 1277 to 1330 divided by said desired frequency expressed in kilocycles per second, and the ratio of said Y axis length dimension with respect to said thickness dimension being one of the values substantially from 12 to 30, said thickness dimension and said dimensional ratio being corresponding values in accordance with the value of said frequency.

14. A Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear thickness mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a length dimension and a thickness or thin dimension therebetween, said thickness dimension and said length dimension being made of values in accordance with the value of said desired second shear frequency, said major surfaces and said length dimension being substantially parallel to a Z axis, said major surfaces being inclined at an angle of substantially 45 degrees with respect to the Y axis, said thickness dimension expressed in millimeters being one of the values substantially from 1060 to 1107 divided by said desired frequency expressed in kilocycles per second, and the ratio of said Z axis length dimension with respect to said thickness dimension being one of the values substantially from 12 to 30, said thickness dimension and said dimensional ratio being corresponding values in accordance with the value of said frequency.

WARREN P. MASON.