

Jan. 26, 1943.

W. P. MASON

2,309,467

ROCHELLE SALT PIEZOELECTRIC CRYSTAL APPARATUS

Filed July 25, 1941

2 Sheets-Sheet 1

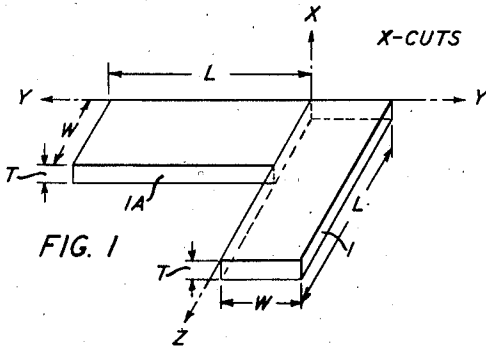


FIG. 1

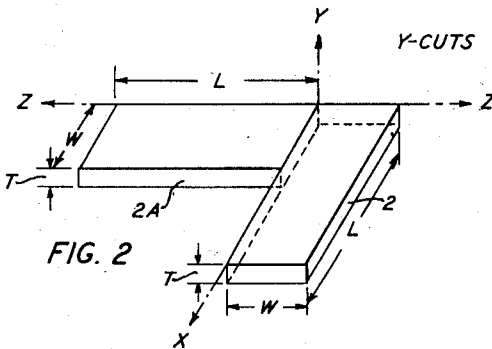


FIG. 2

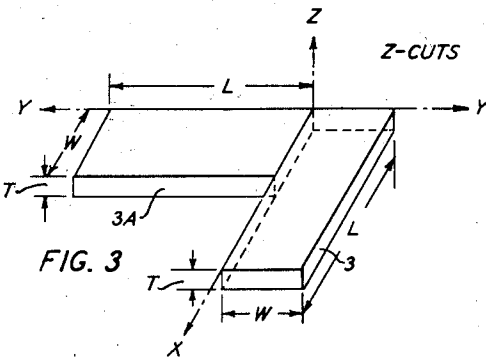


FIG. 3

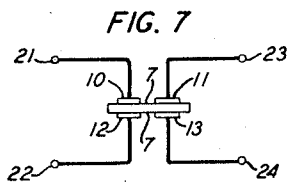


FIG. 7

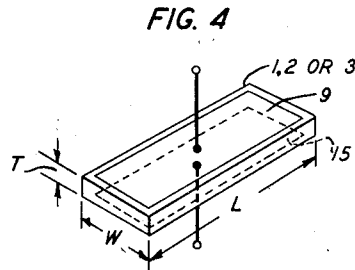


FIG. 4

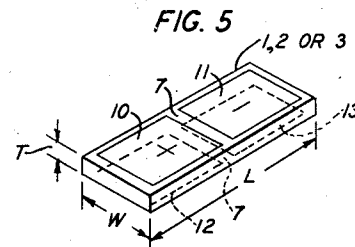


FIG. 5

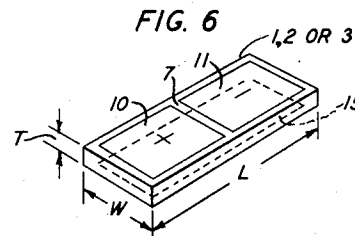


FIG. 6

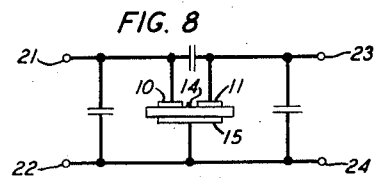


FIG. 8

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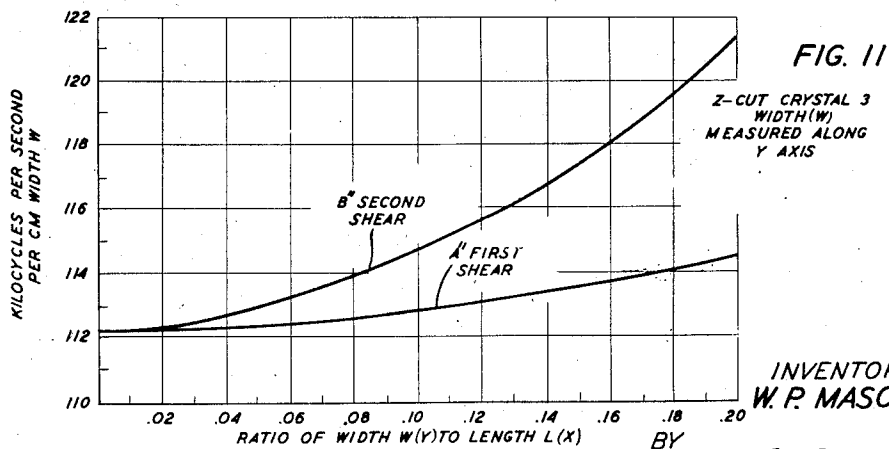
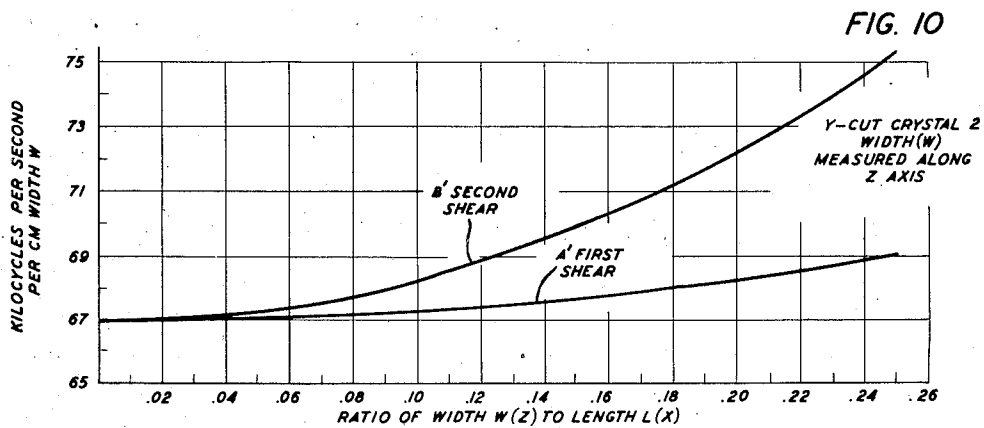
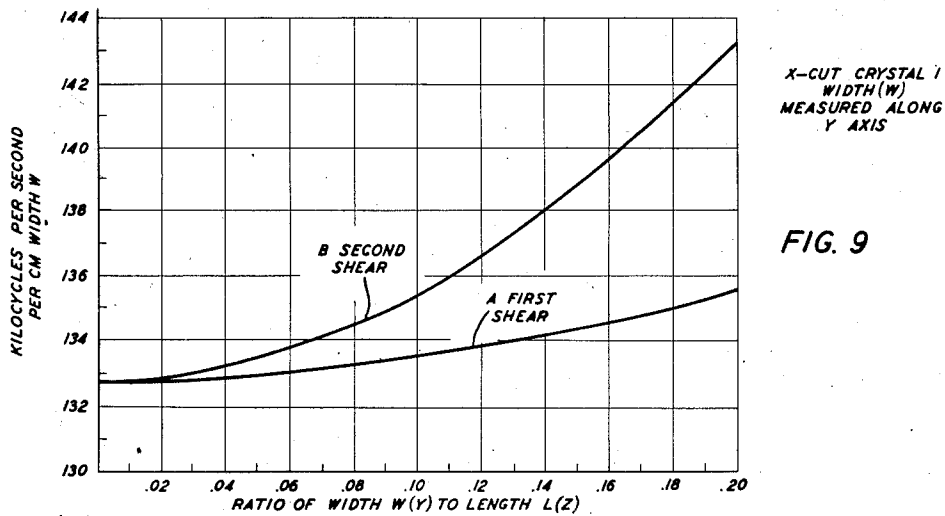
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,309,467

ROCHELLE SALT PIEZOELECTRIC CRYSTAL
APPARATUS

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Application July 25, 1941, Serial No. 403,971

20 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to piezoelectric Rochelle salt or sodium potassium tartrate type 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 type piezoelectric crystal element having one or more useful low frequency face shear type modes of motion that may be utilized either alone or simultaneously, without interference from 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 face shear mode frequencies that may be substantially uncoupled with each other and relatively free from the effects of spurious or undesired frequencies.

Another object of this invention is to provide Rochelle salt crystal elements of such an orientation and dimensional ratio that the fundamental or first shear face mode of motion thereof and the second shear face mode of motion thereof may be utilized separately or simultaneously.

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

Rochelle salt piezoelectric crystal elements generally may be excited in many different modes of motion such as, for example, extensional or longitudinal modes of motion, flexural modes of motion, and shear modes of motion. When crystal elements 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 characteristic. 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 uncoupled to other modes of motion and independently controlled in order that such 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 piezoelectric crystal element of Rochelle salt which may be adapted to vibrate simultaneously in a plurality of substantially uncoupled modes of motion in order to provide either separately or simultaneously a plurality of useful effective resonances which may be independently controlled and placed at predetermined frequencies of nearly the same or of different values for use in an electric wave filter or elsewhere.

The crystal element may be a Rochelle salt 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 uncoupled or independent modes of motion therein and independently controlling the relative strengths of such resonances.

In particular embodiments, the orientation of the crystal element may be that of an X-cut or a Y-cut or a Z-cut type Rochelle salt crystal plate having its major surfaces perpendicular to its X-axis or Y-axis or Z-axis thickness dimension, respectively. The width dimension of its major surfaces and the length dimension thereof may be of selected values in order to obtain therefrom, separately or simultaneously, either or both of two useful independently controlled resonant frequencies resulting from two independently controlled face shear modes of motion, one particular set of which is described herein as the fundamental or first shear face mode of motion and the other as the second shear face mode of motion. Both the first and second shear face modes of motion referred to are in the major plane of the crystal element, and due to the crystal orientation and dimensional ratio selected may be used alone or simultaneously.

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 the 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 U. S. Patent 2,271,870, granted February 3, 1942, on my application Serial No. 303,757, filed November 10, 1939, (Case 58) and in the H. J. McSkimin and R. A. Sykes U. S. Patent 2,277,709, granted March 31, 1942, on application Serial No. 369,694, 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 down to as low as 16 kilocycles per second. With the relatively lower values of frequency, there is less absolute shift in the pass band due to temperature change and therefore temperature control often is not needed at the lower values of frequency and electric wave filters may be made using Rochelle salt crystal elements as the vibrating elements thereof, with characteristics nearly as good as those obtained when using quartz crystal elements. However, due to the relatively high temperature frequency coefficient of Rochelle salt, it is often desirable to have temperature control to about 1° or 2° C. 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 container, the Rochelle salt vibratory crystal 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 respectively perspective views of X-cut, Y-cut and Z-cut type piezoelectric Rochelle salt type crystal elements in accordance with this invention, and 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 therewith which may be utilized with any of the six Rochelle salt crystal elements of Figs. 1, 2 and 3 to drive the crystal element separately in either or simultaneously in both of two independently controlled face shear modes of motion, in order to obtain the desired first or second shear mode resonance frequency or frequencies;

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

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

Fig. 7 is a schematic diagram illustrating an example of balanced filter connections that may be used in connection with the crystal electrodes of Fig. 5;

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

Figs. 9, 10 and 11 are graphs showing the relation between the width to length dimensional

ratio and the first and second shear mode frequencies of particular X-cut, Y-cut and Z-cut Rochelle salt crystal elements 1, 2 and 3 illustrated in Figs. 1, 2 and 3, respectively.

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 an 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 thin or thickness dimension axis X, Y or Z of the piezoelectric body as illustrated in Figs. 1, 2 and 3, respectively, the effective angular position of the length axis dimension L of the crystal plate is parallel or nearly parallel to one of the three 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 U. S. 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 X, Y and Z axes, respectively.

Referring to the drawings, Figs. 1, 2 and 3 represent perspective views of six thin bare piezoelectric Rochelle salt type crystal elements 1, 2 and 3 and 1A, 2A and 3A 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 or longest dimension L and a width dimension W which is perpendicular to the length dimension L. The thickness or thin dimension T between the major surfaces is perpendicular to the other two dimensions L and W. In accordance with the particular mode or modes of motion selected, the final width dimension W of the Rochelle salt crystal elements of Figs. 1, 2 and 3 may be made of suitable value according to the desired resonant frequency. The width dimension W also may be related to the length dimension L in accordance with the value of the desired resonant frequency. The thickness dimension T may be of the order of 1 millimeter or any other suitable value, for example, to suit the impedance of the circuit in which the crystal elements of Figs. 1, 2 and 3 may be utilized.

As shown in Fig. 1, the length dimensions L of the X-cut type Rochelle salt crystal elements 1 and 1A illustrated in Fig. 1 lie along the Z axis and the Y axis, respectively, in the plane of the mechanical axis Y and the optic axis Z of the Rochelle salt crystal material from which the elements 1 and 1A are cut. The major surfaces and the major plane of the Rochelle salt crystal elements 1 and 1A of Fig. 1 are disposed parallel or nearly parallel with respect to the plane of the Y and Z axes. The length dimension L and the width dimension W may lie along the Y axis or the Z axis, or may be placed near thereto in the plane of the Y and Z axes mentioned and lying along a Y' axis and a Z' axis which may be inclined at an angle up to several degrees with respect to the Y axis and the optic axis Z. It will be noted that the crystal elements 1 and 1A of

Fig. 1 are X-cut Rochelle salt crystal plates rotated 90 degrees apart about the X axis thickness dimension T.

Fig. 2 is a perspective view of Y-cut type Rochelle salt piezoelectric crystal elements 2 and 2A having their longest or length dimensions L along the X axis and the Z axis, respectively, or inclined at an angle up to several degrees with respect to the X and Z axes, the major surfaces of the crystal elements 2 and 2A being parallel or nearly parallel to the plane of the Z axis and the X axis.

Fig. 3 is a perspective view representing Z-cut type Rochelle salt crystal elements 3 and 3A having their length or longest dimensions L along the X axis and the Y axis, respectively, or inclined at an angle thereto which may be an angle up to several degrees, intermediate the X and Y axes, the major surfaces of the crystal elements 3 and 3A being parallel or nearly parallel to the plane of the X and Y axes.

The six orientations illustrated in Figs. 1, 2 and 3 accordingly represent X-cut, Y-cut and Z-cut type Rochelle salt piezoelectric crystal elements which may be adapted for independently controlled first shear and second shear low frequency or face mode vibrations, 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 Figs. 4, 5 or 6, for example, may be placed on or adjacent to or formed integral with the opposite major surfaces of any of the crystal plates of Figs. 1, 2 and 3 in order to apply electric field excitation to the Rochelle salt plate 1, 1A, 2, 2A, 3 or 3A which may be vibrated alone or simultaneously in a desired fundamental or first shear mode of motion and/or the second shear mode of motion at independently controlled resonant response frequencies which depend upon the major surface dimensions involving the width dimension W and the length dimension L, the fundamental and second shear mode frequencies being values roughly within the range from about 65 to 145 kilocycles per second per centimeter of the width dimension W, for dimensional ratios of the width dimension W with respect to the length dimension L within the range from 0 to about 0.25.

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

When the Rochelle salt crystal plate has an orientation such that the length dimension L is substantially parallel with respect to the Z axis or the Y axis as illustrated in Fig. 1, or substantially parallel with respect to the X axis or the Z axis as illustrated in Fig. 2, or substantially parallel with respect to the X axis or the Y axis as illustrated in Fig. 3, the fundamental or first shear face mode of motion and the face second shear mode of motion of the crystal plate may be used simultaneously.

To obtain the first and second shear modes of motion simultaneously, both of which involve the length dimension L and the width dimension W,

it is necessary that the crystal element have a piezoelectric constant which will generate a first shear motion and also a second shear motion.

In the case of the X-cut type Rochelle salt crystal elements 1 and 1A illustrated in Fig. 1, the requirement of suitable piezoelectric constants may be met when the length dimension L is parallel or nearly parallel to the Y or Z axis in the YZ plane, the YZ plane being parallel or nearly parallel to the major plane and the major surfaces of the Rochelle salt crystal elements 1 and 1A 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 of Rochelle salt crystal elements. The face shear mode piezoelectric constants reach their maximum values when the length dimension L of the X-cut type Rochelle salt crystal elements 1 and 1A of Fig. 1 is parallel with respect to the Y axis or the Z axis thereof, the major surfaces thereof being parallel to the plane of such Y and Z axes.

While the maximum values for the face shear mode piezoelectric constants in X-cut type crystal elements occur when length dimension L is parallel to one of the Y and Z axes, orientations that are near thereto also may be used to obtain sufficiently good values of piezoelectric constants for obtaining the desired first and second shear modes of motion that are controlled by the length dimension L and the width dimension W. Such X-cut type Rochelle salt crystal elements 1 and 1A of Fig. 1 also have a strong electromechanical coupling which varies somewhat with temperature change; and are easily driven by suitable electrodes in the two desired shear modes of motion, both being controlled by the length dimension L and the width dimension W.

As illustrated in Fig. 2, Y-cut type Rochelle salt piezoelectric crystal elements 2 and 2A having their length dimensions L along the X axis and the Z axis, respectively, also may be used as doubly resonant crystal elements. Such elements have an electromechanical coupling that does not vary much with temperature; and the first shear mode of motion and the second shear mode of motion thereof are substantially free from interference with each other and with any other modes of motion therein.

Similarly, Z-cut type Rochelle salt crystal elements 3 and 3A, as illustrated in Fig. 3, having their major surfaces perpendicular to the Z axis also may be used to generate first and second shear face mode vibrations of the kind useful for a doubly resonant crystal element. In such Z-cut type crystal elements 3 and 3A, either of the two orientation angles illustrated in Fig. 3 may be used for obtaining the two modes of shear motion referred to since the piezoelectric constants controlling these modes are of maximum value when the length or longest dimension L of the crystal element 3 or 3A is parallel to the X axis or the Y axis thereof, as illustrated in Fig. 3.

It will be noted that when the length dimension L of the crystal element is parallel to the X, Y or Z axis as illustrated in Figs. 1, 2 and 3, all of the motion in the crystal element will be shear and none longitudinal, while if the length dimension L is midway between the X and Y, Y and Z or Z and X axes, the shear motion will be zero and the longitudinal motion a maximum.

At or near any of the six orientations illustrated by the Rochelle salt crystal elements in Figs. 1, 2 and 3, both the first and second shear modes of motion will be of about equal strength and can be excited simultaneously.

The principal modes of interest that are particularly considered herein in connection with the X-cut, Y-cut and Z-cut type crystal orientations illustrated in Figs. 1, 2 and 3 are the first shear face mode of motion, and also the second shear face mode of motion, both of which are controlled by the width dimension W and the length dimension L of any of the crystal elements illustrated in Figs. 1, 2 and 3. The first shear face mode vibration operates to alternately extend and contract the opposite corners of the crystal element about a nodal region which for the fundamental or first shear mode vibration is at or near the center of the major surfaces of the crystal element. Similarly, the second shear face mode of motion operates to alternately extend and contract the opposite corners and the edges of the crystal element about nodal regions which for the second shear mode vibration are located on the center line length dimension L of the crystal element. The broken lines and arrows shown in Fig. 3 of the H. J. McSkimin and R. A. Sykes application hereinbefore referred to represent, in greatly enlarged scale, the general configuration of the edges of a crystal element operating in the type of motion involved in the second shear face mode of motion. The first shear face mode of motion is of a similar nature.

Since the nodes involved in the second shear face mode of motion are located near the nodal region involved in the first shear face mode of motion, the crystal elements of Figs. 1, 2 and 3 may be mounted near the nodal point or points without damping or interfering much with the simultaneous operation of either the first shear face mode vibration or the second shear face mode vibration. In the case of the second shear face mode vibration, the two nodal point regions on each of the major surfaces would be located on the center line length dimension L of the crystal element at points spaced about 0.25 of the length dimension L from each end thereof. Accordingly, at such nodal points the crystal element of Fig. 1, 2 or 3 may be mounted by rigidly and resiliently clamping it there between two pairs of oppositely disposed clamping projections of small contact area which may be there placed or inserted in very small indentations or depressions cut or provided at the four nodal points of the crystal element. Such small depressions may be cut in the major surfaces of the crystal element at the nodal points thereof and may have a depth of about 0.05 millimeter and a diameter of about 0.4 millimeter as measured on the major surfaces of the crystal element.

The relative values of the resonance frequencies associated with the first shear face mode vibration and with the second shear face mode vibration in a crystal element having an orientation as illustrated in Figs. 1, 2 or 3, may be controlled by the dimensional ratio of width W with respect to length L . The fundamental or first shear face mode frequency may have a frequency-dimension constant of a value within the range from about 65 to 140 kilocycles per second per centimeter of the width dimension W dependent upon the orientation and the dimensional ratio of the width W with respect to the length L , as illustrated by the

curves A, A' and A'' in Figs. 9, 10 and 11. The second shear face mode vibration has a frequency-dimension constant of a somewhat higher value in kilocycles per second per centimeter of the width dimension W dependent upon the value of the selected dimensional ratio of the width W with respect to the length L , as illustrated by the curves B, B' and B'' in Figs. 9, 10 and 11. The frequencies of these two modes of motion, namely the frequency of the second shear face mode of motion, and the frequency of the first shear face mode of motion approach each other when the ratio of the width dimension W with respect to the length dimension L is in the region from about 0.05 to 0.25; and in this region of special interest, the resonances of these two shear modes of motion are substantially uncoupled or only very loosely coupled.

Accordingly, when the dimensional ratio of the width W with respect to the length L is a value within the region below 0.25 and the orientation is that illustrated in Figs. 1, 2 and 3, the frequencies of these two independent shear modes of vibration may be placed close together but remain sufficiently uncoupled 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 frequencies of the order of 100 to 200 kilocycles per second, for example, within a range of frequencies from 50 or less to 500 or more kilocycles per second, dependent upon the size of the crystal element.

The frequency, expressed in kilocycles per second, for the first shear mode vibration and for the second shear mode vibration is given approximately by the following relations where W is the value of the width dimension W of the crystal element 1, 1A, 2, 2A, 3 or 3A of Figs. 1, 2 and 3, expressed in centimeters, and where L is the length dimension L of the crystal plate expressed in centimeters.

For the X-cut type Rochelle salt crystal element 1 illustrated in Figs. 1 and 9 where the width dimension W is substantially parallel to the Y axis, the first shear and the second shear face mode frequencies f_1 and f_2 respectively are equal to nearly:

$$f_1 = \frac{13.28 \times 10^5}{W} \sqrt{1 + \frac{W^2}{L^2}}$$

$$f_2 = \frac{13.28 \times 10^5}{W} \sqrt{1 + \frac{4W^2}{L^2}}$$

For the other X-cut type Rochelle salt crystal element 1A illustrated in Fig. 1, where the width dimension W and the length dimension L are substantially parallel to the Z axis and the Y axis, respectively, the first shear and the second shear face mode frequencies f_1 and f_2 , respectively, are also equal to nearly:

$$f_1 = \frac{13.28 \times 10^5}{W} \sqrt{1 + \frac{W^2}{L^2}}$$

$$f_2 = \frac{13.28 \times 10^5}{W} \sqrt{1 + \frac{4W^2}{L^2}}$$

For the Y-cut type Rochelle salt crystal element 2 illustrated in Figs. 2 and 10, where the width dimension W and the length dimension L are substantially parallel to the Z axis and the X axis, respectively, the first shear and the

second shear face mode frequencies f_1 and f_2 , respectively, are equal to nearly:

$$f_1 = \frac{6.705 \times 10^5}{W} \sqrt{1 + \frac{W^2}{L^2}}$$

$$f_2 = \frac{6.705 \times 10^5}{W} \sqrt{1 + \frac{4W^2}{L^2}}$$

For the other Y-cut type Rochelle salt crystal element 2A illustrated in Fig. 2, where the width dimension W and the length dimension L are substantially parallel to the X axis and the Z axis, respectively, the first shear and the second shear face mode frequencies f_1 and f_2 , respectively, are also equal to nearly:

$$f_1 = \frac{6.705 \times 10^5}{W} \sqrt{1 + \frac{W^2}{L^2}}$$

$$f_2 = \frac{6.705 \times 10^5}{W} \sqrt{1 + \frac{4W^2}{L^2}}$$

For the Z-cut type Rochelle salt crystal element 3 illustrated in Figs. 3 and 11, where the width dimension W and the length dimension L are substantially parallel to the Y axis and the X axis, respectively, the first shear and the second shear face mode frequencies f_1 and f_2 , respectively, are equal to nearly:

$$f_1 = \frac{11.24 \times 10^5}{W} \sqrt{1 + \frac{W^2}{L^2}}$$

$$f_2 = \frac{11.24 \times 10^5}{W} \sqrt{1 + \frac{4W^2}{L^2}}$$

For the other Z-cut type Rochelle salt crystal element 3A illustrated in Fig. 3, where the width dimension W and the length dimension L are substantially parallel to the Y axis and the X axis, respectively, the first shear and the second shear face mode frequencies f_1 and f_2 thereof are respectively equal to nearly:

$$f_1 = \frac{11.24 \times 10^5}{W} \sqrt{1 + \frac{W^2}{L^2}}$$

$$f_2 = \frac{11.24 \times 10^5}{W} \sqrt{1 + \frac{4W^2}{L^2}}$$

As indicated by the foregoing equations, by making the width W to length L dimensional ratio of the proper value, the second shear face mode frequency of any of the six crystal elements of Figs. 1, 2 and 3 can be spaced any given number of selected cycles higher than the value of the first shear face mode frequency, and when used in a filter system, one resonance may appear in one arm, and the other resonance in the other arm, so that a band-pass filter with two attenuation peaks can be made from one crystal.

The graphs of Figs. 9, 10 and 11 illustrate the resonance frequencies associated with the fundamental or first shear face mode of motion (curves A, A', A'') and also associated with the second shear face mode of motion (curves B, B', B'') in the Rochelle salt crystal elements 1, 2 and 3 having their width dimensions W parallel to the Y, Z and Y axes, respectively, as illustrated in Figs. 1, 2 and 3. The first or fundamental shear face mode frequency of the X-cut type crystal element 1 of Fig. 1 is represented by the more horizontal line curve A of Fig. 9 and has a frequency-dimension constant ranging from about 133 to 136 kilocycles per second per centimeter of the width dimension W dependent upon the dimensional ratio of the Y axis width W with respect to the Z axis length L . The second shear face mode

frequency of the same X-cut type crystal element 1 of Fig. 1 is represented by the more inclined curve B of Fig. 9 and has a frequency-dimension constant ranging from about 133 to 144 kilocycles per second per centimeter of the width dimension W dependent upon the value of the selected dimensional ratio of the Y-axis width W with respect to the Z-axis length L , within the dimensional ratio range from 0 to about 0.20. 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 when the ratio of the width dimension W with respect to the length dimension L is in the region below 0.20.

Similarly, the first shear face mode frequency for the Y-cut type Rochelle salt crystal element 2 of Fig. 2 is represented by the curve A' of Fig. 10 and has a frequency-dimension constant from about 67 to 69 kilocycles per second per centimeter of the width dimension W dependent upon the dimensional ratio of the Z axis width W with respect to the X axis length L within the range from 0 to about 0.25 as illustrated by the curve A' of Fig. 10. The second shear face mode frequency of the same Y-cut type crystal element 2 of Fig. 2 is represented by the curve B' of Fig. 10 and has a frequency-dimension constant ranging from about 67 to 76 kilocycles per second per centimeter of the width dimension W dependent upon the value of the dimensional ratio of the Z axis width W with respect to the X axis length L within the dimensional ratio range from 0 to 0.25 covered by the curve B' of Fig. 10. As shown by the curves A' and B' of Fig. 10, the frequencies of the first and second shear face modes of motion approach each other below the dimensional ratio value of 0.25.

Similarly, the first shear face mode frequency for the Z-cut type Rochelle salt crystal element 3 of Fig. 3 is represented by the curve A'' of Fig. 11 and has a frequency-dimension value from about 112 to 115 kilocycles per second per centimeter of the width dimension W dependent upon the dimensional ratio of the Y axis width dimension W with respect to the X axis length dimension L within the range covered by the curve A'' of Fig. 11. The second shear face mode frequency of the same Z-cut type crystal element 3 of Fig. 3 is represented by the curve B'' of Fig. 11 and has a frequency-dimension value ranging from about 112 to 122 kilocycles per second per centimeter of the width dimension W dependent upon the value of the dimensional ratio of the Y-axis width W with respect to the X-axis length L within the dimensional ratio range from 0 to 0.20 covered by the curve B'' of Fig. 11. As shown by the curves A'' and B'' of Fig. 11, the frequencies of the first and second shear face modes of motion approach each other below the dimensional ratio value of 0.20.

For dimensional ratios of values higher than those given by the curves of Figs. 9, 10 and 11, the frequency-dimension values corresponding thereto may be obtained from the foregoing equations. In the case of the second shear face mode crystals, for example, having dimensional ratios of width W with respect to length L within the range from about 0 to 0.5, for example, the corresponding frequency-dimension values as expressed in kilocycles per second per centimeter of the width dimension W will be within the range from about 132.8 to 188 for the X-cut type crystal elements 1 and 1A of Fig. 1; from about 67 to 95 for the Y-cut type crystal elements 2 and 2A of Fig. 2;

and from about 112.4 to 159 for the Z-cut type crystal elements 3 and 3A of Fig. 3.

While the curves of Figs. 9, 10 and 11 are designated as applying particularly to the crystal elements 1, 2 and 3, respectively, of Figs. 1 to 3, the corresponding curves for the crystal elements 1A, 2A and 3A of Figs. 1 to 3 are the same as those for the crystal elements 1, 2 and 3, respectively.

Figs. 4, 5 and 6 illustrate forms of electrode arrangements which may be utilized to drive any of the crystal elements of Figs. 1, 2 and 3. As illustrated in Fig. 4, a single pair of electrodes 9 and 15 may be used to drive the crystal element in either the first or fundamental shear mode vibration or certain odd multiples thereof to obtain separately, but not simultaneously, any of such resonance frequencies of a desired value.

More particularly, Fig. 4 is a perspective view of any crystal element of Figs. 1, 2 and 3 provided with a single pair of opposite electrodes 9 and 15 which may be utilized to usefully operate separately, but not together, in the crystal element, the fundamental or first shear mode of motion at a frequency value ranging from about 60 to 150 kilocycles per second per centimeter of the length dimension L or the width dimension W dependent upon the orientation and dimensional ratio selected. For this purpose the electrodes 9 and 15 may partially or wholly cover the square or other rectangular shaped major surfaces of the crystal element and may be supported and connected in circuit by means of suitable conductive members disposed in contact with each of the electrodes 9 and 15. It will be understood that Rochelle salt crystal elements of the type illustrated in Figs. 1, 2 and 3, and provided with a pair of electrodes of the type illustrated in Fig. 4 may be utilized to obtain a desired fundamental or first shear face mode vibrational frequency or an odd multiple harmonic of such fundamental frequency.

As shown in Fig. 5, the so-called second shear face mode of motion illustrated by the curves B, B' and B'' of Figs. 9 to 11, may be driven by means of two pairs of electrodes 10, 11, 12 and 13 placed on both of the major surfaces of any of the crystal elements of Figs. 1, 2 and 3; and also with suitable connections, the fundamental or first shear face mode of motion illustrated by the curves A, A' and A'' of Figs. 9 to 11, may be driven at the same time by one set of the connected sets of electrode platings 10 to 13, with the result that the two useful and independently controlled resonance frequencies of the crystal element may be made to appear simultaneously. More particularly, as illustrated in Fig. 5, the Rochelle salt crystal element of Figs. 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, gap or dividing line 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 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, with the center line of such splits 7 in the platings 10 to 13 on the opposite sides of the crystal plate 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 face 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 shear face mode vibration is excited, the second face 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 width W with respect to the length L 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 1 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. 5 or 6 in the second shear face mode of motion, one half of the crystal plate is made of opposite polarity to that of the other half, as indicated by the + and - signs in Figs. 5 and 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 im-

pedance 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 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 the crystal element of Figs. 5 and 6 may be extended to cover a portion of the other half thereof. As illustrated and described in the hereinbefore-mentioned patents, namely, the McSkimin and Sykes Patent No. 2,277,709 and the Mason Patent No. 2,271,870, this may be done, for example, by adjusting of the angular position of the electrode dividing line 7 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 face mode resonance, but with decreasing values for the 90-degree angle shown in Figs. 5 and 6 will increase the impedance level of and cut down the drive on second shear face mode resonance, without materially affecting the impedance of the first shear face 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 a 90-degree angle in Figs. 5 and 6, the internal capacity associated with the second shear face mode of motion, 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 first shear face mode of motion.

It will be understood that the circuits 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 the 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 U. S. Patent 2,198,684, granted April 30, 1940, to R. A. Sykes on application Serial No. 230,775, filed September 20, 1938.

The electroded doubly resonant crystal elements of Figs. 4, 5 and 6 may be mounted in any suitable manner, such as by nodal clamping, or otherwise. Where the clamping form of mounting is used, opposite conductive clamping projections may resiliently contact the electroded crystal element at or near its nodal points 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 nodal points only. Such fine supporting wires may be secured to the electroded crystal element by conductive cement and may extend horizontally from the vertically disposed major surfaces of the crystal element and at their other ends be attached by solder, for example, to ver-

tical 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 bands 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 U. S. 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 nodal point of the electroded crystal elements. 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 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, but only by the scope of the appended claims and the state of the prior art.

What is claimed is:

1. An X-cut type low frequency or face mode piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of predetermined shear mode frequencies dependent upon the dimensions of its substantially rectangular major surfaces, said major surfaces being substantially parallel to the plane of the Y axis and the Z axis, the major axis length dimension of said major surfaces being substantially parallel with respect to one of said Y and Z axes, the dimensional ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values between substantially 0 and 0.25, said dimensional ratio being made of a value in accordance with the values of said frequencies.

2. A Y-cut type low frequency or face mode piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of predetermined shear mode frequencies dependent upon the dimensions of its substantially rectangular major surfaces, said major surfaces being substantially parallel to the plane of the X axis and the Z axis, the major axis length dimension of said major surfaces being substantially parallel with respect to one of said X and Z axes, the dimensional ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values between substantially 0 and 0.25, said dimensional ratio being made of a value in accordance with the values of said frequencies.

3. A Z-cut type low frequency or face mode piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of predetermined shear mode frequencies dependent upon the dimensions of its substantially rectangular major surfaces, said major surfaces being substantially parallel to the plane of the X axis and the Y axis, the major axis length dimension of said major surfaces being substantially parallel with respect to one of said X and Y axes, the dimensional ratio of the width dimension of said major surfaces with respect to

said length dimension thereof being one of the values between substantially 0 and 0.25, said dimensional ratio being made of a value in accordance with the values of said frequencies.

4. A piezoelectric Rochelle salt type crystal element having its substantially rectangular major surfaces substantially parallel to the plane of two of the three mutually perpendicular X, Y and Z axes thereof, the major axis length dimension of said major surfaces being in said plane and substantially parallel to one of said two of said three X, Y and Z axes, the dimensional ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values between substantially 0 and 0.25, 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 major surface dimensions, one of said frequencies being dependent upon the fundamental or first shear mode vibration in the plane of said width and length dimensions.

5. A piezoelectric Rochelle salt type crystal element having its substantially rectangular major surfaces substantially parallel to the plane of two of the three mutually perpendicular X, Y and Z axes thereof, the major axis length dimension of said major surfaces being in said plane and substantially parallel to one of said two of said three X, Y and Z axes, the dimensional ratio of the width dimension of said major surfaces with respect to said length dimension thereof being one of the values substantially in the region from 0 to 0.25, 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 major surface dimensions, one of said frequencies being dependent upon the fundamental or first shear mode vibration in the plane of said length and width dimensions, and another of said frequencies being dependent upon the second shear mode vibration in the plane of said length and width dimensions.

6. An X-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled shear mode frequencies which are dependent upon the width and length dimensions of its substantially rectangular major surfaces, said width dimension being substantially in the plane of a Y axis and a Z axis and substantially parallel with respect to said Y axis, said major surfaces being substantially parallel with respect to said YZ plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the region substantially from 0 to 0.25, said width dimension expressed in centimeters and said dimensional ratio being a set of values in accordance with the values of said plurality of frequencies, as given by the curves A and B of Fig. 9.

7. A Y-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled shear mode frequencies which are dependent upon the width and length dimensions of its substantially rectangular major surfaces, said width dimension being substantially in the plane of the X axis and the Z axis and substantially parallel with respect to said

Z axis, said major surfaces being substantially parallel with respect to said XZ plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the region substantially from 0 to 0.25, said width dimension expressed in centimeters and said dimensional ratio being a set of values substantially in accordance with the values of said frequencies expressed in kilocycles per second as given by the curves A' and B' of Fig. 10.

8. A Z-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled shear mode frequencies which are dependent upon the width and length dimensions of its substantially rectangular major surfaces, said width dimension being substantially in the plane of an X axis and the Y axis and substantially parallel with respect to said Y axis, said major surfaces being substantially parallel with respect to said XY plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the region substantially from 0 to 0.25, said width dimension expressed in centimeters and said dimensional ratio being a set of values substantially in accordance with the values of said frequencies expressed in kilocycles per second, as given by the curves A'' and B'' of Fig. 11.

9. An X-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of independently controlled shear mode frequencies dependent mainly upon the length and width dimensions of its substantially rectangular major surfaces, said width dimension being substantially in the plane of a Y axis and a Z axis and substantially parallel with respect to said Z axis, said major surfaces being substantially parallel with respect to said YZ plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0 to 0.25, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies.

10. A Y-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled shear mode frequencies dependent mainly upon the length and width dimension of its substantially rectangular major surfaces, said width dimension being substantially in the plane of an X axis and a Z axis and substantially parallel with respect to said X axis, said major surfaces being substantially parallel with respect to said XZ plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0 to 0.25, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies.

11. A Z-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled shear mode frequencies dependent mainly upon the length and width dimensions of its substantially rectangular major surfaces, said width dimension being substantially in the plane of an X axis and a Y axis and substantially parallel with respect to said X axis, said

major surfaces being substantially parallel with respect to said XY plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0 to 0.25, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies.

12. An X-cut type piezoelectric Rochelle salt type crystal element and means including two functionally independent pairs of opposite electrodes cooperating with said element for vibrating said element simultaneously at two independently controlled desired shear mode frequencies dependent mainly upon the length and width dimensions of the rectangular major surfaces of said element, said length dimension being substantially in the plane of a Y axis and a Z axis and disposed substantially parallel with respect to one of said Y and Z axes, said major surfaces being substantially parallel with respect to said YZ plane.

13. A Y-cut type piezoelectric Rochelle salt type crystal element and means including two functionally independent pairs of opposite electrodes cooperating with said element for vibrating said element simultaneously at two independently controlled desired shear mode frequencies dependent mainly upon the length and width dimensions of the rectangular major surfaces of said element, said length dimension being substantially in the plane of an X axis and a Z axis and disposed substantially parallel with respect to one of said X and Z axes, said major surfaces being substantially parallel with respect to said XZ plane.

14. A Z-cut type piezoelectric Rochelle salt type crystal element and means including two functionally independent pairs of opposite electrodes cooperating with said element for vibrating said element simultaneously at two independently controlled desired shear mode frequencies dependent mainly upon the length and width dimensions of the rectangular major surfaces of said element, said length dimension being substantially in the plane of an X axis and a Y axis and disposed substantially parallel with respect to one of said X and Y axes, said major surfaces being substantially parallel with respect to said XY plane.

15. An X-cut type Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a length or longer dimension and a width or shorter dimension, said length and width dimensions being made of values in accordance with the value of said desired frequency, said major surfaces and said length and width dimensions being substantially parallel to the plane of a Y axis and a Z axis thereof, and said width dimension being substantially parallel with respect to said Y axis, the ratio of said width dimension with respect to said length dimension being one of the values from 0 to 0.5, and said width dimension expressed in centimeters being one of the values substantially from 132.8 to 188 divided by said desired frequency expressed in kilocycles per second.

16. An X-cut type Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a

length or longer dimension and a width or shorter dimension, said length and width dimensions being made of values in accordance with the value of said desired frequency, said major surfaces and said length and width dimensions being substantially parallel to the plane of a Y axis and a Z axis thereof, and said width dimension being substantially parallel with respect to said Z axis, the ratio of said width dimension with respect to said length dimension being one of the values from 0 to 0.5, and said width dimension expressed in centimeters being one of the values substantially from 132.8 to 188 divided by said desired frequency expressed in kilocycles per second.

17. A Y-cut type Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a length or longer dimension and a width or shorter dimension, said length and width dimensions being made of values in accordance with the value of said desired frequency, said major surfaces and said length and width dimensions being substantially parallel to the plane of an X axis and a Z axis thereof, and said width dimension being substantially parallel with respect to said Z axis, the ratio of said width dimension with respect to said length dimension being one of the values from 0 to 0.5, and said width dimension expressed in centimeters being one of the values substantially from 67 to 95 divided by said desired frequency expressed in kilocycles per second.

18. A Y-cut type Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a length or longer dimension and a width or shorter dimension, said length and width dimensions being made of values in accordance with the value of said desired frequency, said major surfaces and said length and width dimensions being substantially parallel to the plane of an X axis and a Z axis thereof, and said width dimension being substantially parallel with respect to said X axis, the ratio of said width dimension with respect to said length dimension being one of the values from 0 to 0.5, and said width dimension expressed in centimeters being one of the values substantially from 67 to 95 divided by said desired frequency expressed in kilocycles per second.

19. A Z-cut type Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear mode frequency, said crystal element having substantially rectangular shaped major surfaces, said major surfaces having a length or longer dimension and a width or shorter dimension, said length and width dimensions being made of values in accordance with the value of said desired frequency, said major surfaces and said length and width dimensions being substantially parallel to the plane of an X axis and a Y axis thereof, and said width dimension being substantially parallel with respect to said Y axis, the ratio of said width dimension with respect to said length dimension being one of the values from 0 to 0.5, and said width dimension expressed in centimeters being one of the values substantially from 112.4 to 159 divided by said desired frequency expressed in kilocycles per second.

20. A Z-cut type Rochelle salt type piezoelectric crystal element adapted to vibrate at a desired second shear mode frequency, said crystal element having substantially rectangular shaped

major surfaces, said major surfaces having a length or longer dimension and a width or shorter dimension, said length and width dimensions being made of values in accordance with the value of said desired frequency, said major surfaces and said length and width dimensions being substantially parallel to the plane of an X axis and a Y axis thereof, and said width dimension being

substantially parallel with respect to said X axis, the ratio of said width dimension with respect to said length dimension being one of the values from 0 to 0.5, and said width dimension expressed in centimeters being one of the values substantially from 112.4 to 159 divided by said desired frequency expressed in kilocycles per second.

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