

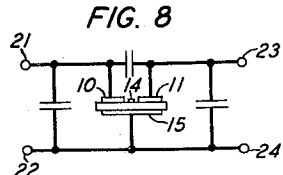
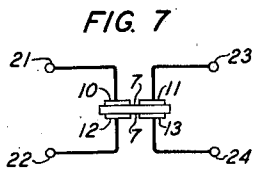
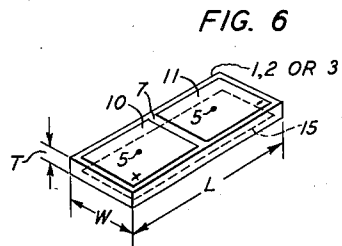
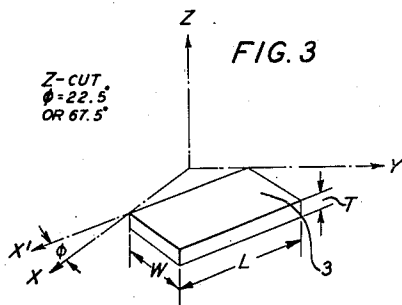
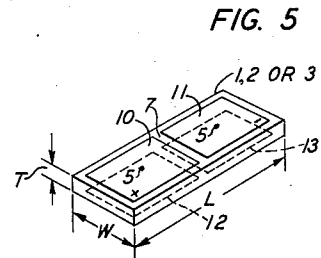
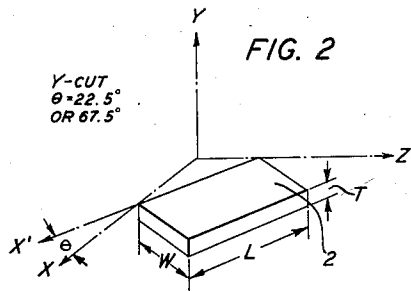
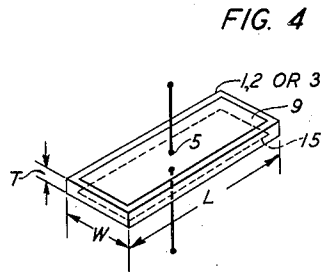
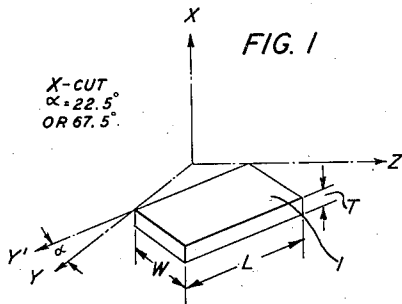
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2,292,388

ROCHELLE SALT PIEZOELECTRIC CRYSTAL APPARATUS

Filed May 23, 1941



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ROCHELLE SALT PIEZOELECTRIC CRYSTAL
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Application May 23, 1941, Serial No. 394,753

20 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to 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 type piezoelectric crystal element having one or more useful low frequency modes of motion that may be utilized alone or simultaneously.

Another object of this invention is to provide a Rochelle salt crystal element having a plurality of simultaneously useful and independently controlled frequencies that may be substantially uncoupled with each other and free from spurious or undesired frequencies.

Another object of this invention is to provide Rochelle salt crystal elements of such orientation and dimensional ratio that the fundamental longitudinal width mode frequency and the double shear mode frequency thereof may be utilized simultaneously without interference from other modes of motion thereof.

Another object of this invention is to reduce the number and the cost of 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 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 such 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 or independent 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, the crystal element being provided with a suitable electrode arrangement and connections for separately driving either or simultaneously driving both of two 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 a X-cut or Y-cut or Z-cut Rochelle salt crystal plate rotated in effect a selected angle in degrees about 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 modes of motion, one particular set of which is described herein as the fundamental width axis dimension longitudinal or extensional mode of motion and the other as the second or double shear mode of motion. Both of these shear and longitudinal modes of motion are in the major plane of the crystal element, and due to the crystal orientation can be driven 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 thereof 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 (Case 1—8).

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 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 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 any substantial 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 drawing, 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 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 which may be utilized with any of the Rochelle salt crystal elements of Figs. 1, 2 or 3 in order to drive the crystal element separately in either or simultaneously in both of two independently controlled 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 the piezoelectric crystal element of Figs. 1, 2 or 3 in the fundamental longitudinal mode of motion along either the length axis or the width axis thereof;

Figs. 5 and 6 are perspective views of electrode arrangements that may be used to drive the crystal element of Fig. 1, 2 or 3 in the second or double shear mode of motion, and the fundamental longitudinal width 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; and

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.

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 drawing, 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 thickness dimension axis X, Y or Z of the piezoelectric body as illustrated in Figs. 1, 2 and 3, respectively, the orientation angles α , θ and ϕ —substantially 22.5 or 67.5 degrees designate in degrees the effective angular position of the length axis dimension L of the crystal plate as measured from one of the other two 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 the X, Y and Z axes respectively.

Referring to the drawing, Figs. 1, 2 and 3 represent perspective views of thin bare X-cut, Y-cut and Z-cut type 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 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 being perpendicular to the other two dimensions L and W. In accordance with the particular frequency selected, the final width dimension W of the Rochelle salt crystal element 1, 2 or 3 of Figs. 1, 2 and 3 may be made of a suitable value according to the desired longitudinal mode resonant frequency. The width dimension W also may be related to the length dimension L in accordance with the value of the desired double shear mode 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 element 1, 2 or 3 of Figs. 1, 2 and 3 may be utilized.

As shown in Fig. 1, the length or longest dimension L of the X-cut type crystal element 1 illustrated in Fig. 1 lies along a Y' axis in 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 and is inclined at an angle of α degrees with respect to said Y axis, the angle α being one of the values in the region of substantially 22.5 degrees or 67.5 degrees. The major surfaces and the major plane of the Rochelle salt crystal element 1 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 lying along the Y' axis and the Z' axis, respectively, both of which lie in the plane of the Y and Z axes mentioned, the Y' axis and the Z' axis being inclined at the angle α with respect to the Y axis and the optic axis Z, respectively. The axis Y' is accordingly the result of a single rotation of the length dimension L about the X axis α degrees. It will be noted that the crystal element 1 of Fig. 1 is in effect an X-cut Rochelle salt crystal plate rotated $\alpha=22.5$ or 67.5 degrees about the X axis.

Fig. 2 is a perspective view of a Y-cut type Rochelle salt piezoelectric crystal element 2 hav-

ing its longest or length dimension L along the X' axis and inclined at an angle of $\theta=22.5$ or 67.5 degrees with respect to the X axis, the major surfaces of the crystal element 2 being parallel or nearly parallel to the plane of the Z axis and the X axis.

Fig. 3 represents a Z-cut type Rochelle salt crystal element 3 having its length or longest dimension L along the X' axis and inclined at an angle ϕ which may be an angle of either 22.5 or 67.5 degrees with respect to the X axis, the major surfaces of the crystal element 3 being parallel or nearly parallel to the plane of the X and Y axes.

The orientations illustrated in Figs. 1, 2 and 3 accordingly represent X-cut, Y-cut and Z-cut type Rochelle salt piezoelectric crystal elements 1, 2 and 3, respectively, which may be adapted for independently controlled longitudinal width W mode vibrations, and also low frequency double shear 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 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 plates 1, 2 or 3 of Figs. 1, 2 and 3 in order to apply electric field excitation to the Rochelle salt plates 1, 2 or 3, which may be vibrated alone or simultaneously in the desired width W fundamental longitudinal mode of motion and/or the double shear mode of motion at independently controlled resonant response frequencies which depend upon different sets of dimensions involving the width dimension W and the length dimension L , the fundamental longitudinal width W mode frequency for the crystal elements illustrated in Figs. 1, 2 and 3 being a value between roughly about 137 and 208.4 kilocycles per second per centimeter of the width dimension W depending upon the orientation selected, and the double shear mode frequencies being values above and below that longitudinal mode frequency value depending upon the dimension ratio selected for the width dimension W with respect to the length dimension L .

The crystal electrodes when formed integral with the major surfaces of the crystal elements of Fig. 1, 2 or 3 may consist of thin coatings of colloidal carbon, silver, gold, platinum, aluminum or other suitable metal or metals deposited upon the 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 $\alpha=22.5$ or 67.5 degrees with respect to the Y axis as illustrated in Fig. 1, or θ or $\phi=22.5$ or 67.5 degrees with respect to the X axis as illustrated in Figs. 2 and 3, the longitudinal mode of motion including the fundamental longitudinal or extensional mode of motion along the width dimension W of the crystal plate may be used simultaneously, for example, with the double shear mode of motion.

To obtain such shear and longitudinal modes of motion simultaneously, it is necessary that the crystal element have a piezoelectric constant which will generate a longitudinal motion along the width dimension W and also another piezoelectric constant that will generate a shear mo-

tion in the major plane formed by the width dimension W and the length dimension L .

In the case of the X-cut type Rochelle salt crystal element 1 illustrated in Fig. 1, the requirement of suitable piezoelectric constants may be met when the length dimension L is inclined at an angle $\alpha=22.5$ degrees with respect to either the Y axis or the Z axis of the YZ plane, the YZ plane 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 Equations 31 and 32 of my paper "A dynamic measurement of the elastic, electric and piezoelectric constants of Rochelle salt" published April 15, 1939 in Physical Review, vol. 55, page 775, for information on the piezoelectric constants d'_{12} and d'_{13} involved in the longitudinal or extensional mode vibrations along the length dimension L and along the width dimension W , respectively of the X-cut type Rochelle salt crystal element 1 illustrated in Fig. 1. The longitudinal mode piezoelectric constants d'_{12} and d'_{13} are of equal value and reach their maximum values when the angle $\alpha=45$ degrees or when the length dimension L of the Rochelle salt crystal element 1 of Fig. 1 is inclined 45 degrees with respect to the Y and Z axes thereof, the major surfaces thereof being parallel to the plane of such Y and Z axes. The angle α may be made substantially 22.5 or 67.5 degrees to provide for either the length or the width longitudinal modes of motion and the face shear mode of motion. While the maximum values of the longitudinal mode piezoelectric constants d'_{12} and d'_{13} and the minimum values for the shear mode piezoelectric constants occur when the angle $\alpha=45$, at the angle of $\alpha=22.5$ or 67.5 degrees good values of piezoelectric constants may at the same time be obtained for the desired longitudinal and shear modes of motion involving the length dimension L and the width dimension W without interference or coupling with each other. Such an X-cut type Rochelle salt crystal element 1 of Fig. 1 has a relatively strong electro-mechanical coupling which varies somewhat with temperature change, and is easily driven by suitable electrodes in the desired longitudinal and shear modes of motion.

As illustrated in Fig. 2, a Y-cut type Rochelle salt piezoelectric crystal element 2 having its length dimension L inclined at an angle of $\theta=22.5$ or 67.5 degrees with respect to 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 22.5 or 67.5 degrees, the double shear mode of motion and the width W longitudinal mode of motion may be excited simultaneously, substantially free from coupling with each other.

A Z-cut type Rochelle salt crystal element 3 as illustrated in Fig. 3 having its major surfaces perpendicular to the Z axis also may be used to generate longitudinal mode width W and double shear mode vibrations of the kind useful for a doubly resonant crystal element. Such a Z-cut type Rochelle salt crystal element 3 may be utilized at ϕ angles other than those of 0 or 90 degrees and particularly at the angles of $\phi=22.5$ or 67.5 degrees.

It will be noted that when the angle α , θ or ϕ in Figs. 1, 2 and 3 is zero, all of the motion in the crystal element 1, 2 or 3 will be shear and none longitudinal, while if the angle α , θ or ϕ is 45 degrees in Figs. 1, 2 and 3, the shear motion will

be zero and the longitudinal motion a maximum. At or near any of the six angles of α , θ , or $\phi = 22.5$ or 67.5 degrees as illustrated by the Rochelle salt crystal elements in Figs. 1, 2 and 3, both modes of motion will be of about equal strength and can be excited simultaneously in the desired width W fundamental longitudinal mode of motion and the double or second shear mode of motion, although at the same time both the length L longitudinal mode of motion and the first shear major face mode of motion will be strongly excited but somewhat lower in frequency.

The principal modes of interest that are particularly considered herein in connection with each of the six Rochelle salt crystal orientations illustrated in Figs. 1, 2 and 3 are the fundamental of the width longitudinal mode of motion along the width axis W, and the double shear mode of motion in the major plane of the crystal elements 1, 2 and 3 illustrated in Figs. 1, 2 and 3. As illustrated in Fig. 2 of the McSkimin and Sykes application Serial No. 369,694 hereinbefore referred to, the longitudinal width W mode of motion operates to alternately extend and shorten the width dimension W of the crystal element about a nodal line which extends across the center line length dimension L of the crystal element. Similarly, as illustrated in Fig. 3 of the McSkimin and Sykes application referred to, the double shear mode of motion operates to alternately extend and shorten the opposite corners and edges of the crystal element about two nodal points 5 located as illustrated in Figs. 5 and 6, on the center line length dimension L of the crystal elements 1, 2 or 3. The broken lines and the arrows shown in Figs. 2 and 3 of the H. J. McSkimin and R. A. Sykes application referred to hereinbefore, represent, in greatly enlarged scale, the general configuration of the edges of a crystal element vibrating in the types of motion involved in the width W longitudinal mode of motion and the double shear mode of motion, respectively.

Since the nodes 5 involved in the double shear mode of motion are located on the nodal line involved in the width longitudinal mode of motion, the crystal elements of Fig. 1, 2 or 3 may be mounted thereat or near the nodal point or points 5 without damping or interfering with the simultaneous operation of either the width W longitudinal mode vibration or the double shear mode vibration. In the second or double shear mode vibration, the two nodal point regions 5 on each of the major surfaces are 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 as shown in Figs. 5 and 6. Accordingly, at these nodal points 5, the crystal element of Fig. 1, 2 or 3 may be mounted by rigidly 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 provided at the four nodal points 5 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 values of the resonance frequencies associated with the width W longitudinal mode of motion and with the double shear mode of motion in the crystal elements having the orientations illustrated in Fig. 1, 2 or 3 may be con-

trolled by value of the width dimension W and the dimensional ratio of the width W with respect to the length L. The fundamental of the width W longitudinal mode frequency thereof has a frequency-dimension constant value within the range from about 130 to 210 kilocycles per second per centimeter of width dimension W independent of the dimensional ratio of the width W with respect to the length L. The double shear mode of motion may have a frequency-dimension constant of the same values, or above and below such values, dependent upon the value of the selected dimensional ratio of the width W with respect to the length L. The frequencies of these two modes of motion, namely, the second or double shear mode of motion, and the fundamental longitudinal width mode of motion approach each other when the ratio of the width dimension W with respect to the length dimension L is made of the proper value in the region from about .5 to .85; and in this region of special interest, the resonances of these two modes of motion are substantially uncoupled or only very loosely coupled when the α , θ or ϕ angle of the Rochelle salt crystal element 1, 2 or 3 has a value of 22.5 or 67.5 degrees, as illustrated in Figs. 1, 2 and 3.

Accordingly, when the dimensional ratio of the width W with respect to the length L is in the proper region and the orientation of the crystal element is that of Fig. 1, 2 or 3, the frequencies of the two independent modes of vibration may be placed close together but 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.

The fundamental frequency in kilocycles per second of the longitudinal width W mode vibration, the frequency in kilocycles per second of the double shear mode vibration, and the dimensional ratio W/L of the width dimension W with respect to the length dimension L, corresponding to equal values, expressed in kilocycles per second, of the fundamental width W longitudinal mode frequency $f(w)$ and the second shear mode frequency $f(ss)$, for the doubly resonant X-cut, Y-cut, and Z-cut type Rochelle salt crystal elements of the six orientations illustrated in Figs. 1 to 3, are as follows:

For the X-cut type Rochelle salt crystal element 1 illustrated in Fig. 1, when $\alpha = 22.5$ degrees and the length dimension L is inclined 22.5 degrees with respect to the Y axis,

$$f(w) = \frac{204.9}{W} \text{ kilocycles per second}$$

$$f(ss) = 129 \sqrt{\frac{1}{W^2} + \frac{4}{L^2}} \text{ kilocycles per second}$$

where W and L are, respectively, the width dimension W and the length dimension L, expressed in centimeters.

When both of such frequencies $f(w)$ and $f(ss)$ are to be equal,

$$\frac{204.9}{W} = 129 \sqrt{\frac{1}{W^2} + \frac{4}{L^2}}$$

and the critical dimensional ratio for such equal

frequencies in the 22.5 degrees α angle X-cut type crystal element 1 of Fig. 1 becomes

$$\frac{W}{L} = \sqrt{\frac{1.52}{4}} = 0.616$$

Similarly, for the other X-cut type crystal element 1, illustrated in Fig. 1, when $\alpha=67.5$ degrees and the length dimension L is inclined 22.5 degrees with respect to the Z axis,

$$f(w) = \frac{208.4}{W} \text{ kilocycles per second}$$

$$f(ss) = 129 \sqrt{\frac{1}{W^2} + \frac{4}{L^2}} \text{ kilocycles per second}$$

and when both of such frequencies $f(w)$ and $f(ss)$ are to be equal, the critical dimensional ratio for the 67.5 degrees α angle X-cut type crystal element 1 of Fig. 1 becomes

$$\frac{W}{L} = \sqrt{\frac{1.62}{4}} = 0.637$$

Similarly, for the Y-cut type crystal element 2 illustrated in Fig. 2, when $\theta=22.5$ degrees and the length dimension L is inclined 22.5 degrees with respect to the X axis,

$$f(w) = \frac{137.25}{W} \text{ kilocycles per second}$$

$$f(ss) = 78.6 \sqrt{\frac{1}{W^2} + \frac{4}{L^2}} \text{ kilocycles per second}$$

and when both of such frequencies $f(w)$ and $f(ss)$ are to be equal, the critical dimensional ratio becomes

$$\frac{W}{L} = \sqrt{\frac{2.06}{4}} = 0.715$$

Similarly, for the other Y-cut type crystal element 2, illustrated in Fig. 2, where $\theta=67.5$ degrees and the length dimension L is inclined 22.5 degrees with respect to the Z axis,

$$f(w) = \frac{151.6}{W} \text{ kilocycles per second}$$

$$f(ss) = 78.6 \sqrt{\frac{1}{W^2} + \frac{4}{L^2}} \text{ kilocycles per second}$$

and when both of such frequencies $f(w)$ and $f(ss)$ are to be equal, the critical dimensional ratio becomes

$$\frac{W}{L} = \sqrt{\frac{2.71}{4}} = 0.822$$

For the Z-cut type crystal element 3 illustrated in Fig. 3, when $\phi=22.5$ degrees, the length dimension L being inclined 22.5 degrees with respect to the X axis,

$$f(w) = \frac{173.2}{W} \text{ kilocycles per second}$$

$$f(ss) = 113.5 \sqrt{\frac{1}{W^2} + \frac{4}{L^2}} \text{ kilocycles per second}$$

and when both of such frequencies are to be equal, the critical dimensional ratio becomes

$$\frac{W}{L} = \sqrt{\frac{1.325}{4}} = 0.576$$

For the other Z-cut type crystal element 3 illustrated in Fig. 3, when $\phi=67.5$ degrees, the length dimension L being inclined 22.5 degrees with respect to the Y axis,

$$f(w) = \frac{200}{W} \text{ kilocycles per second}$$

$$f(ss) = 113.5 \sqrt{\frac{1}{W^2} + \frac{4}{L^2}} \text{ kilocycles per second}$$

and when both of these frequencies are to be equal, the critical dimensional ratio becomes

$$\frac{W}{L} = \sqrt{\frac{2.12}{4}} = 0.728$$

Figs. 4, 5 and 6 illustrate forms of electrode arrangements which may be utilized to drive any of the six crystal elements of Fig. 1, 2 or 3. In Fig. 4, the pair of opposite electrodes 9 and 15 may be used to drive either the fundamental of the width W longitudinal mode of motion or the fundamental of the longitudinal length L mode of motion to obtain separately but not simultaneously either of two independent longitudinal fundamental mode resonance frequencies of a desired value.

In Fig. 4 which is a perspective view of any of the six crystal elements of Figs. 1, 2 and 3 a single pair of opposite electrodes 9 and 15 may be utilized to usefully operate separately but not together in the X-cut, Y-cut and Z-cut type crystal elements 1, 2 or 3 of Figs. 1 to 3 the fundamental of the longitudinal length L mode of motion or the fundamental of the longitudinal width W mode of motion, at a frequency which is dependent upon the crystal orientation and which ranges roughly from 130 to 210 kilocycles per second per centimeter of length dimension L or width dimension W. 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 means of conductive members disposed in contact with each of the electrodes 9 and 15, as illustrated in Fig. 4. It will be understood that Rochelle salt crystal elements having the orientation angles α , θ , and $\phi=22.5$ or 67.5 degrees as illustrated in Figs. 1, 2 and 3 and provided with a single pair of electrodes 9 and 15 of the type illustrated in Fig. 4 may be utilized to obtain a desired fundamental of either the length L or width W longitudinal mode vibrational frequency. Where a harmonic of such longitudinal mode of motion is used, the harmonic frequency may be of any desired order and may be obtained by the use of electrode arrangements known in the art in connection with quartz longitudinal mode crystal elements.

Referring to Fig. 5, the second or double shear face 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 longitudinal width W mode of the motion may be driven at the same time by one of the connected sets of electrode platings, with the result that two useful and independently controlled resonance frequencies of the crystal element may be made to appear simultaneously. As illustrated in Fig. 5, the Rochelle salt crystal elements 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 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 line 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, with the center line of such splits 7 in the platings on the opposite sides of the crystal plate being aligned with respect to each other.

Fig. 7 is a schematic diagram illustrating an example of balanced filter connections which may be used with the electrode 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 Figs. 5 and 7 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 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 Figs. 6 and 8 in the second or double shear 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 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 the 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 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 7 angularly with respect to the length dimension L as described in my application Serial No. 303,757 and the McSkimin and Sykes application Serial No. 369,694, hereinbefore referred to. The angle may be of any desired value over a wide range of angles. This adjustment does not materially affect the impedance of the longitudinal width W 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 the double shear mode resonance, without materially affecting the impedance of the width W longitudinal 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 double 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 longitudinal width W mode resonance.

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 No. 2,198,684 granted April 30, 1940, to R. A. Sykes.

The electroded doubly resonant crystal elements of Figs. 5 and 6 may be mounted in any suitable manner, such as by clamping, or otherwise. Where the clamping form of mounting is used, two pairs of opposite conductive clamping projections may resiliently contact the electroded crystal element at its nodal points 5 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 5 only. Such fine supporting wires secured to the electroded crystal element may extend horizontally from vertically 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. 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. An X-cut type low frequency double shear face mode piezoelectric Rochelle salt type crystal element having its substantially rectangular major surfaces substantially parallel to the plane of a Y axis and a Z axis, the major axis length dimension of said major surfaces being inclined at an angle of substantially 22.5 degrees 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 substantially 0.616 and 0.637.

2. A Y-cut type low frequency double shear face mode piezoelectric Rochelle salt type crystal element having its substantially rectangular major surfaces substantially parallel to the plane of an X axis and a Z axis, the major axis length dimension of said major surfaces being inclined at an angle of substantially 22.5 degrees 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 substantially 0.715 and 0.822.

3. A Z-cut type low frequency double shear face mode piezoelectric Rochelle salt type crystal element having its substantially rectangular major surfaces substantially parallel to the plane of an X axis and a Y axis, the major axis length dimension of said major surfaces being inclined at an angle of substantially 22.5 degrees 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 substantially 0.576 and 0.728.

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 inclined at an angle of substantially 22.5 degrees with respect 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 0.576 and 0.822, 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 different sets of said major surface dimensions, one of said frequencies being dependent upon the fundamental of the longitudinal or extensional mode vibration along said width dimension.

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 inclined at an angle of substantially 22.5 degrees with respect 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 0.576 to 0.822, 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 of the longitudinal or extensional mode vibration along said width dimension, and another of said frequencies being dependent upon the second or double shear mode vibration controlled by said width and length dimensions.

6. An X-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and another being the double shear mode frequency dependent upon the width and length dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of a Y axis and a Z axis and inclined at an angle of substantially 22.5 degrees with respect to one of said Y and Z axes, 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 0.616 to 0.637, said width dimension expressed in centimeters being one of the values substantially from 204.9 to 208.4 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

7. A Y-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and another being the double shear mode frequency dependent upon the width and length dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of an X axis and a Z axis and inclined at an angle of substantially 22.5 degrees with respect to one of said X and Z axes, 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 of substantially 0.715 and 0.822, said width dimension expressed in centimeters being one of the values of substantially 137 and 152 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

8. A Z-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of desired independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and another being the double shear mode frequency dependent upon the width and length dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane

of an X axis and a Y axis and inclined at an angle of substantially 22.5 degrees with respect to one of said X and Y axes, 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 of substantially 0.576 and 0.728, said width dimension expressed in centimeters being one of the values of substantially 173 and 200 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

9. An X-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and the other being the double shear mode frequency dependent upon the length and width dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of a Y axis and a Z axis and inclined at an angle of substantially 22.5 degrees 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 in the region of substantially 0.616, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies, said width dimension expressed in centimeters being substantially 204.9 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

10. An X-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and the other being the double shear mode frequency dependent upon the length and width dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of a Y axis and a Z axis and inclined at an angle of substantially 67.5 degrees with respect to said Y axis, said major surfaces being substantially parallel with respect to the YZ plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values in the region of substantially 0.637, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies, said width dimension expressed in centimeters being substantially 208.4 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

11. A Y-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and the other being the double shear mode frequency dependent upon the length and width dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of an X axis and a Z axis and inclined at an angle of substantially 22.5 degrees 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 in the region of substantially 0.715, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies, said width dimension expressed in centimeters being substantially 137.25 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

12. A Y-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and the other being the double shear mode frequency dependent upon the length and width dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of an X axis and a Z axis and inclined at an angle of substantially 67.5 degrees 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 in the region of substantially 0.822, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies, said width dimension expressed in centimeters being substantially 151.6 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

13. A Z-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and the other being the double shear mode frequency dependent upon the length and width dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of an X axis and a Y axis and inclined at an angle of substantially 22.5 degrees with respect to said X axis, said major surfaces being substantially parallel with respect to the XY plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values in the region of substantially 0.576, said width dimension and said length dimension being a set of corresponding values in accordance with the values of said frequencies, said width dimension expressed in centimeters being substantially 173.2 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

14. A Z-cut type piezoelectric Rochelle salt type crystal element adapted to vibrate simultaneously at a plurality of independently controlled frequencies, one being the fundamental longitudinal mode frequency dependent mainly upon the width dimension, and the other being the double shear mode frequency dependent upon the length and width dimensions of its substantially rectangular major surfaces, said length dimension being substantially in the plane of an X axis and a Y axis and inclined at an angle of substantially 67.5 degrees with respect to said X axis, said major surfaces being substantially parallel with respect to the XY plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values in the region of substantially 0.728, said width dimension and said length di-

mension being a set of corresponding values in accordance with the values of said frequencies, said width dimension expressed in centimeters being substantially 200.0 divided by the value of said longitudinal mode frequency expressed in kilocycles per second.

15. An X-cut type Rochelle salt piezoelectric crystal element adapted to vibrate at a desired 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, the ratio of said width dimension with respect to said length dimension being substantially 0.616 and made of a value 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 length dimension being inclined at an angle of substantially 22.5 degrees with respect to said Y axis, said width dimension expressed in centimeters being equal to substantially 204.9 divided by the value of said desired frequency expressed in kilocycles per second.

16. An X-cut type Rochelle salt piezoelectric crystal element adapted to vibrate at a desired 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, the ratio of said width dimension with respect to said length dimension being substantially 0.637 and made of a value 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 length dimension being inclined at an angle of substantially 67.5 degrees with respect to said Y axis, said width dimension expressed in centimeters being equal to substantially 208.4 divided by the value of said desired frequency expressed in kilocycles per second.

17. A Y-cut type Rochelle salt piezoelectric crystal element adapted to vibrate at a desired 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, the ratio of said width dimension with respect to said length dimension being substantially 0.715 and made of a value 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 length dimension being inclined at an angle of substantially 22.5 degrees with respect to said X axis, said width dimension expressed in centimeters being equal to substantially 137.0 divided by the value of said

desired frequency expressed in kilocycles per second.

18. A Y-cut type Rochelle salt piezoelectric crystal element adapted to vibrate at a desired 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, the ratio of said width dimension with respect to said length dimension being substantially 0.822 and made of a value 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, said length dimension being inclined at an angle of substantially 67.5 degrees with respect to said X axis, said width dimension expressed in centimeters being equal to substantially 152.0 divided by the value of said desired frequency expressed in kilocycles per second.

19. A Z-cut type Rochelle salt piezoelectric crystal element adapted to vibrate at a desired 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, the ratio of said width dimension with respect to said length dimension being substantially 0.576 and made of a value 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 length dimension being inclined at an angle of substantially 22.5 degrees with respect to said X axis, said width dimension expressed in centimeters being equal to substantially 173.0 divided by the value of said desired frequency expressed in kilocycles per second.

20. A Z-cut type Rochelle salt piezoelectric crystal element adapted to vibrate at a desired 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, the ratio of said width dimension with respect to said length dimension being substantially 0.728 and made of a value 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 Y axis thereof, and said length dimension being inclined at an angle of substantially 67.5 degrees with respect to said X axis, said width dimension expressed in centimeters being equal to substantially 200.0 divided by the value of said desired frequency expressed in kilocycles per second.

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