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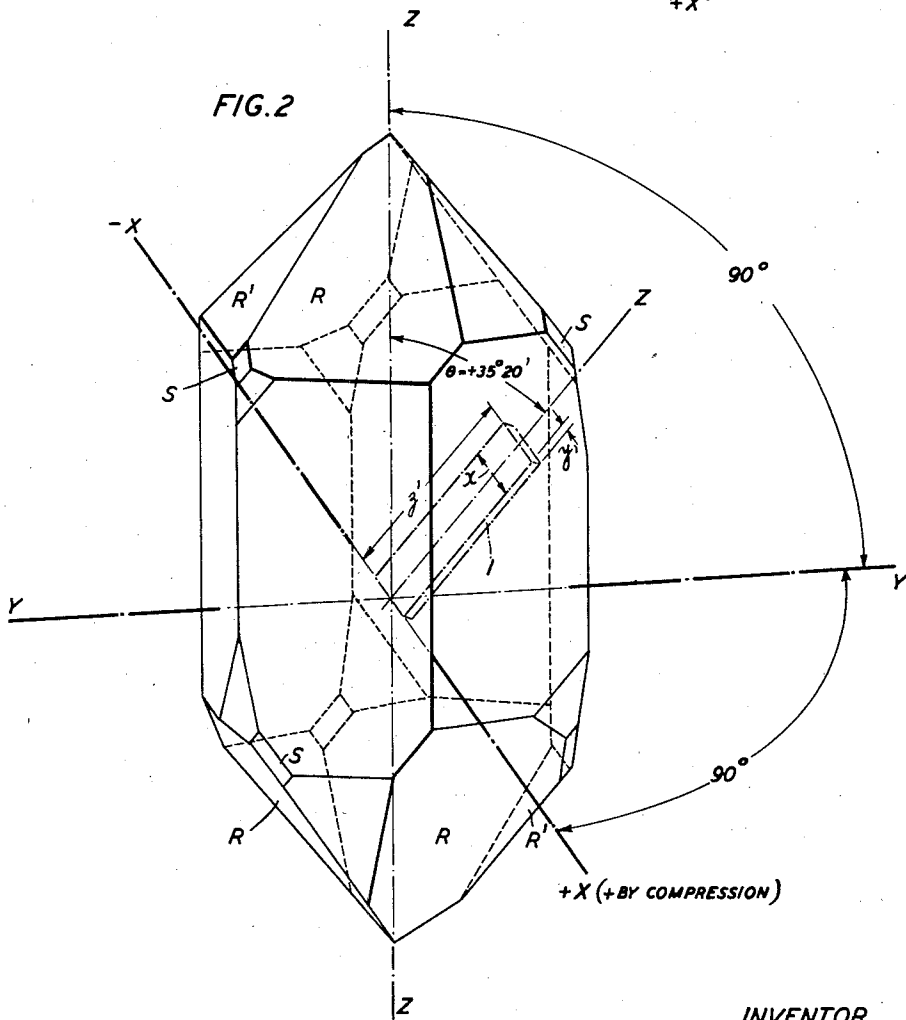
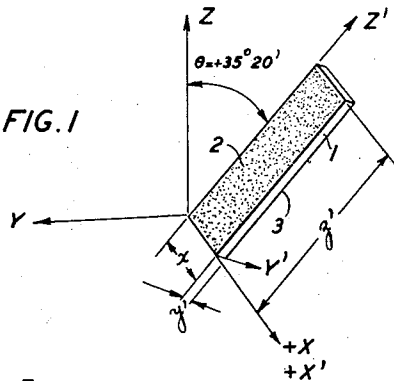
R. A. SYKES

2,306,909

PIEZOELECTRIC CRYSTAL APPARATUS

Filed June 9, 1939

4 Sheets-Sheet 1



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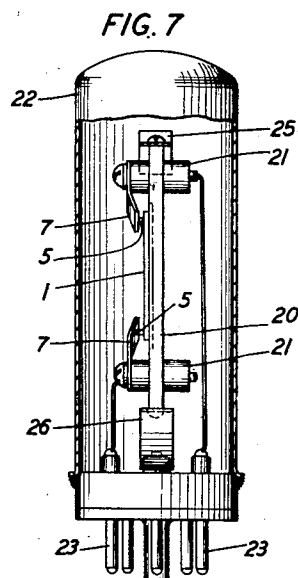
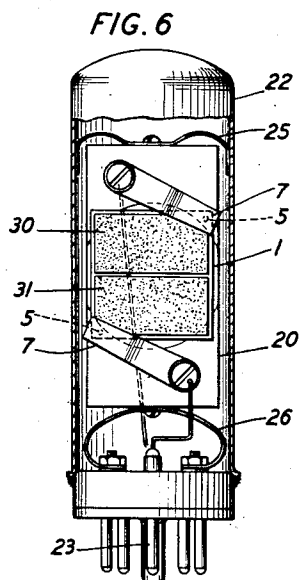
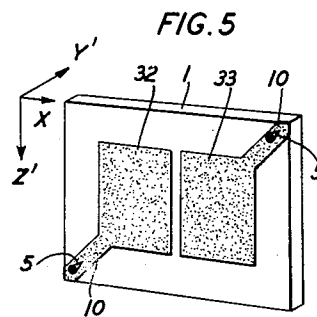
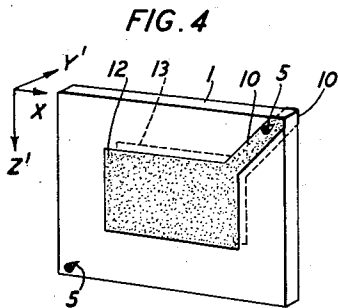
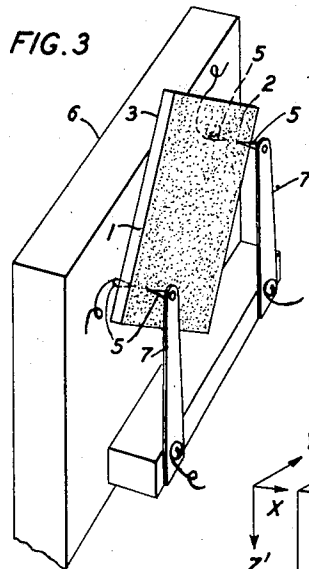
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PIEZOELECTRIC CRYSTAL APPARATUS

Filed June 9, 1939

4 Sheets-Sheet 2



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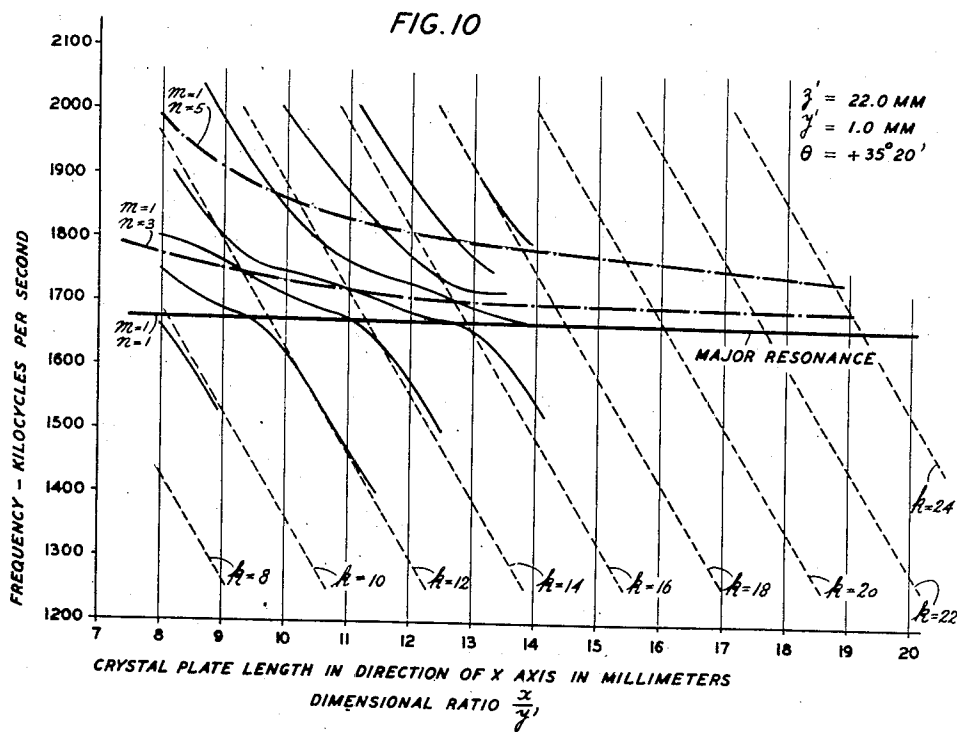
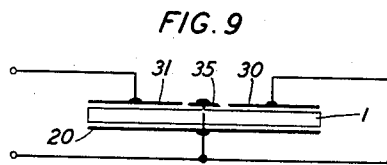
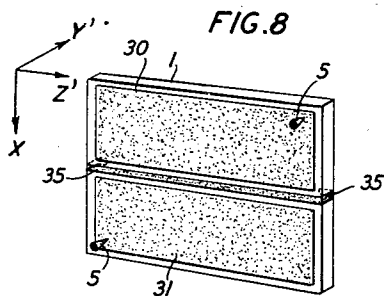
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PIEZOELECTRIC CRYSTAL APPARATUS

Filed June 9, 1939

4 Sheets-Sheet 3



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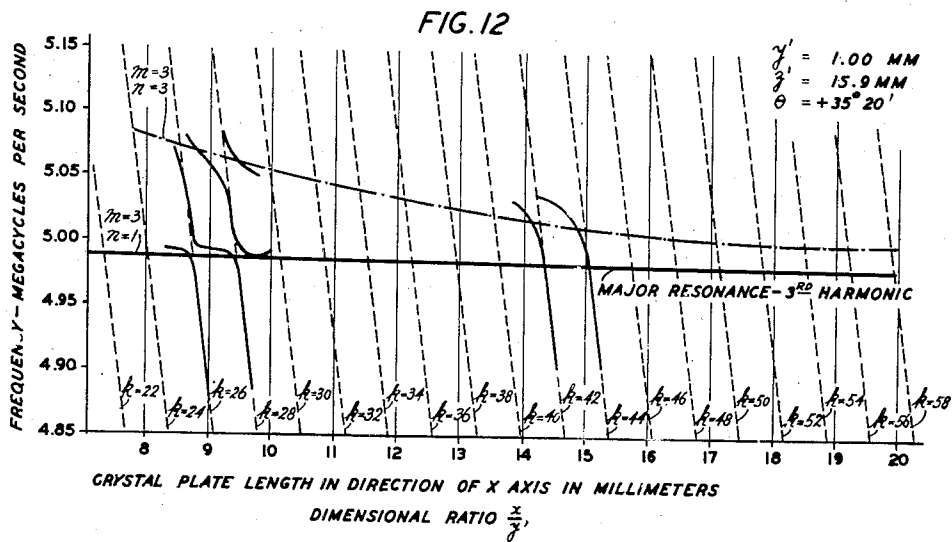
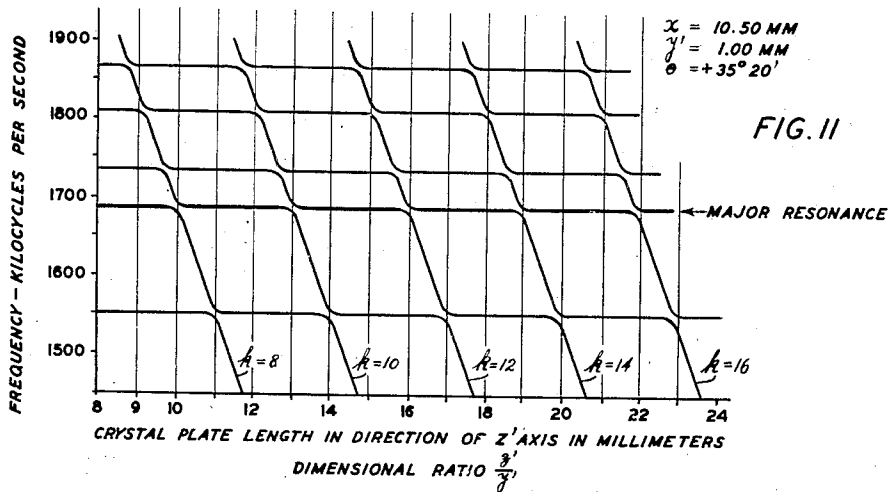
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PIEZOELECTRIC CRYSTAL APPARATUS

Filed June 9, 1939

4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,306,909

PIEZOELECTRIC CRYSTAL APPARATUS

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Application June 9, 1939, Serial No. 278,237

30 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to piezoelectric quartz crystal elements used as circuit elements in electric wave filter systems and in electromechanical vibratory systems generally.

This application is a continuation in part of my copending application for Wave filters, Serial No. 169,123, filed October 15, 1937, now U. S. Patent No. 2,169,301, dated August 15, 1939.

One of the objects of this invention is to reduce or eliminate the effects of undesired extraneous modes of vibration in a piezoelectric crystal element upon the desired principal or major resonance frequency thereof.

For frequencies of the order of several megacycles per second, AT cut and other Y cut quartz crystal plates rotated in effect about an electric axis X are useful. In crystal plates of this type the desired principal resonance corresponds to a shear mode of vibration, fundamental or harmonic, and its frequency is dependent mainly on the thickness or smallest dimension which lies in the direction of the Y' axis of the crystal plate. Thin plates of relatively major face area may, therefore, be used.

The problem of using such quartz crystal plates in electric wave filters, for example, is complicated by the fact that such plates may exhibit a multiplicity of resonances, many of which may occur at frequencies quite close to the principal or desired thickness mode resonance fundamental frequency or a desired harmonic thereof.

In accordance with this invention, the effect of the undesired subsidiary or extraneous resonances upon the desired shear mode major resonance frequency may be diminished or eliminated. I have found by extensive tests and mathematical analysis that the locations of the undesired subsidiary resonances of a Y cut crystal and crystals of related types of cut rotated in effect substantially about an electric axis X are dependent upon and may be systematically controlled by proportioning the length and width dimensions of the crystal plate with respect to its thickness or thinnest dimension. For certain particular types of crystal cut, a series of optimum plate configurations are hereinafter given which correspond to the most advantageous spacings of the subsidiary resonances of the crystal.

For the purpose of illustrating the dependence of the resonance frequencies of a quartz crystal plate upon the plate dimensions, an AT cut quartz crystal plate as shown in the accompanying drawings has been chosen. This type of crystal cut is characterized by having a principal resonant

frequency substantially independent of ordinary temperature changes, and is described in a paper by Messrs. Lack, Willard and Fair entitled "Some improvements in quartz crystal circuit elements," Bell System Technical Journal, vol. XIII, No. 3, pages 453-463, July, 1934, and also in a paper by Mr. G. W. Willard entitled "Elastic vibrations of quartz," Bell Laboratories Record, vol. XIV, No. 8, page 253, April, 1936.

To reduce extraneous resonances in such AT cut or other high frequency shear mode Y cut crystal elements rotated in effect about an electric axis X, they may be clamped or otherwise damped adjacent the four corners thereof if the quartz element is rectangular faced, or around the periphery if circular faced. For the same purpose, such crystal elements may be provided with an electrode or electrodes effectively covering only a part, as the central part, of the total major face area. The crystal electrode coating may be split or divided, for example, centrally and longitudinally along a Z' or X axis of the crystal element, to provide two separate electrodes on the same face of the crystal element and to reduce the capacity thereof. Between such divided electrodes, an electrostatic shield may be provided in the form of a narrow strip of metallic coating formed integral with the major face of the crystal element.

For a clearer understanding of the nature of this invention and the additional features and objects thereof, reference is made to the following description taken in connection with the accompanying drawings, in which like reference characters represent like or similar parts and in which:

Fig. 1 is a perspective view of an AT cut piezoelectric quartz crystal plate showing the orientation thereof with respect to its orthogonal X, Y and Z axes;

Fig. 2 is a perspective view showing the orientation of the AT cut quartz plate of Fig. 1 with respect to the X, Y and Z axes and also with respect to the natural faces of a natural quartz crystal from which it may be cut;

Fig. 3 is a perspective view of a crystal mounting arrangement;

Fig. 4 is a perspective view of a crystal element having partial electrodes;

Fig. 5 is a perspective view of a crystal element having a centrally divided partial electrode;

Figs. 6 and 7 are front and side views of another form of crystal mounting and electrode arrangement;

Fig. 8 is a perspective view of a crystal element

provided with a strip of metallic plating between its centrally divided partial electrodes;

Fig. 9 is a schematic diagram of connections for the crystal unit of Fig. 8;

Fig. 10 is a graph showing the relation between the resonance frequencies and the x/y' dimensional ratios of fundamental mode AT cut quartz plates;

Fig. 11 is a graph showing the relation between the resonance frequencies and the z'/y' dimensional ratios of fundamental mode AT cut quartz plates; and

Fig. 12 is a graph showing the relation between the resonance frequencies and the x/y' dimensional ratios of third harmonic AT cut quartz plates.

This specification follows the conventional terminology as applied to crystalline quartz which employs three orthogonal or mutually perpendicular X, Y and Z axes to designate an electric, a mechanical and the optic axes respectively of piezoelectric quartz 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 any or all of the X, Y and Z axes thereof. Where the orientation is obtained by rotation of the quartz element 1 in effect about an electric axis X, as particularly illustrated in Figs. 1 and 2, the X' axis is parallel or nearly parallel to the X axis and the angle θ designates the angle between the optic axis Z and the Z' axis of the crystal element as measured in the YZ plane perpendicular to said X axis.

Quartz crystals may occur in two forms, namely right-handed and left-handed. A right-handed quartz crystal is one in which the plane of polarization of a plane polarized light ray traveling along the optic axis Z in the crystal is rotated in a right-hand direction, or clockwise as viewed by an observer located at the light source and facing the crystal. This definition of right-handed quartz follows the convention which originated with Herschel. Trans. Cam. Phil. Soc. vol. 1, page 45 (1821); Nature vol. 110, page 807 (1922); Quartz Resonators and Oscillators, P. Vigoureux, page 12 (1931). The natural faces of the natural crystal for such right-handed quartz are illustrated in Fig. 2. Conversely, a quartz crystal is left-handed if it rotates such plane of polarization referred to in the left-handed or counter-clockwise direction, namely in the opposite direction to that given hereinbefore for the right-handed crystal.

If a compressional stress or a squeeze be applied to the ends of an electric axis X of a quartz body 1 and not removed, a charge will be developed which is positive at the positive end (+) of the X axis and negative at the negative end (-) of such electric axis X, for either right-handed or left-handed crystals. The magnitude and sign of the charge may be measured with a vacuum tube electrometer, for example. In specifying the orientation of a right-handed crystal, the sense of the angle θ which the new axis Z' makes with the optic axis Z as the crystal plate is rotated in effect about the X axis is deemed positive (+) when, with the compression positive end (+) of the X axis pointed toward the observer, the rotation is in a clockwise direction as illustrated in Figs. 1 and 2. A counter-clockwise rotation of such a right-handed crystal about the X axis gives rise to a negative orientation angle θ with respect to the Z axis. Conversely, the orientation angle of a left-handed

crystal is positive when, with the compression positive end of the electric axis X pointed toward the observer, the rotation is counter-clockwise and is negative when the rotation is clockwise. The crystal material illustrated in Figs. 1 and 2 is right-handed as the term is used herein.

Referring to the drawings, Figs. 1 and 2 illustrate the orientation of an AT cut piezoelectric crystal quartz plate 1 with respect to the orthogonal X, Y and Z axes and also with respect to the faces of a right-handed natural quartz crystal from which the quartz element 1 may be cut as shown in Fig. 2.

As shown in Figs. 1 and 2, the AT cut crystal plate 1 is a relatively thin quartz plate of substantially rectangular parallelepiped shape having substantially square or rectangular opposite major or electrode faces. The dimensions of the major faces are designated x and z' , and the thickness or thinnest dimension of the quartz plate 1 is designated as y' . The orthogonal dimensions x , y' and z' of the quartz element 1 extend along the orthogonal X, Y' and Z' axes, respectively, of the crystal. The major faces of the quartz plate 1 have one pair of opposite edges parallel or nearly parallel to an X axis and the other pair of opposite edges are parallel to a Z' axis which is inclined at an acute angle θ of about +35 degrees and 20 minutes with respect to the optic axis Z or toward parallelism with the plane of any minor apex face as the minor apex face R' of the natural crystal from which the quartz plate 1 is cut. The minor apex faces R' of the natural crystal occur at an angle of about $\theta = +38$ degrees with respect to the Z axis and accordingly the major faces of the AT cut plate 1 having an orientation angle θ of about +35 degrees and 20 minutes, are within a few degrees of parallelism with the plane of a minor apex face R' of the natural crystal, for either right-handed or left-handed quartz.

It will be understood that the orientation angle $\theta = +35$ degrees and 20 minutes of Figs. 1 and 2 may be varied slightly as between about +33 to +36 degrees to obtain the desired minimum temperature coefficient of frequency depending upon the range of temperatures to be applied thereto and the frequency determining thickness dimension y' that is used. Small angle departures of the major faces of the quartz plate 1 from parallelism with the X axis up to 5 degrees or more do not greatly alter the corresponding angle θ of substantially 35 degrees and 20 minutes required to obtain the substantially zero temperature coefficient of frequency.

Suitable conductive electrodes such as the electrodes 2 and 3 of Figs. 1 and 3 may be placed on or adjacent the opposite major faces of the quartz plate 1 to apply an electric field thereto in the direction of the thickness dimension y' and by means of any suitable circuit such as, for example, a filter circuit, the crystal element 1 may be excited to vibrate in the desired xy' shear mode of motion at a fundamental or odd harmonic vibration response frequency which depends mainly upon and varies inversely as the thickness dimension y' . The same electrodes may be used to excite either the fundamental shear mode vibration frequency or any odd harmonic frequency thereof such as the third, fifth, seventh, ninth, etc., harmonic frequencies. The AT crystal 1 has a frequency constant of substantially 1662 kilocycles per second for one millimeter of thickness dimension y' at the desired fundamental vibrational mode and substantially an integral

multiple of this value, for harmonic frequencies according to the order of the harmonic. For example, the third harmonic frequency thereof is about three times 1662 or substantially 4986 kilocycles per second for one millimeter of thickness dimension y' and varies inversely as the thickness dimension y' . In AT cut crystal elements, all of these major resonance frequencies, fundamental and odd harmonic frequencies, produce a low or substantially zero temperature coefficient of frequency of about 1 to 5 cycles per million per degree centigrade throughout ordinary temperature ranges from 0 to 50° centigrade, for example.

Any of several types of holders may be used for mounting any of the AT cut crystals elements referred to. One form of mounting may consist of an ordinary air-gap type of holder in which the unclamped crystal element 1 may rest upon a lower horizontal metal electrode plate of the same or smaller effective area than the crystal element 1 and a similar upper electrode may be spaced above the crystal with a uniform air-gap of about .001 inch. Suitable retaining means may be placed adjacent the periphery edges of the crystal element to prevent excessive bodily movement edgewise. Other forms of mountings may be those disclosed in U. S. Patent 2,115,145 granted to L. F. Koerner on April 26, 1938, wherein the crystal element is mounted either unclamped, or clamped at the four corners thereof between two electrodes, 50, each of which have four flat clamping surface corner projections.

Fig. 3 illustrates a crystal mounting arrangement similar to that shown in Fig. 2 of U. S. Patent 2,155,035 granted on April 18, 1939, to C. A. Bieling but in Fig. 3 the electroded element is an AT cut crystals element 1 and is rigidly clamped near or adjacent to two of its opposite corners and at opposite points of relatively small area between two pairs of conductive clamping projections 5. Two of the clamping projections 5 may be attached to a supporting block 6. The remaining two of the clamping projections 5 are shown as being secured to the free ends of the cantilever springs 7, which exert sufficient pressure to hold the crystal element 1 against bodily movement out of a predetermined position between the clamping projections 5. Such pressure may be about one pound at the point of contact with the crystal element 1. Electrical connections may be established by means of a circuit including the crystal electrode coatings 2 and 3, the conductive clamping projections 5 and the conductive springs 27.

The crystal electrodes 2 and 3 of Figs. 1 and 3 are there shown as substantially wholly covering the total area of each of the opposite major faces of the AT cut quartz plate 1. Where the crystal electrodes, such as the electrode coatings 12 and 13 of Fig. 4, are partial electrodes and cover the central part only of the total area of each of the opposite major or electrode faces of the AT cut crystal element 1, connectors 10 consisting of metallic plating formed integral with the crystal face or faces may be utilized to establish electrical connections between the integral crystal electrodes 12 and 13 and the corresponding conductive clamping projections 5.

The electrodes 2 and 3 of Figs. 1 and 3, the electrodes 12 and 13 of Fig. 4, and the connectors 10 of Figs. 4 and 5, as well as all other integral plated metallic coatings referred to in this specification, may consist of aluminum or other suitable conductive material deposited on the crystal

faces by evaporation in vacuum or other suitable method. While the metallic material is being so deposited on the crystal surfaces, the crystal element 1 may be simultaneously subjected to high frequency vibration by induced piezoelectric action or otherwise to obtain a stronger bond by reason of the greater penetration of the molten or sublimated metallic material into the interstices of the crystal surface. The crystal element 1 after being coated with the aluminum or other metallic material by evaporation in vacuum sputtering or otherwise, may be annealed at a temperature of about 400° centigrade for about sixty minutes to obtain an increase in the Q or reactance-resistance ratio of the vibratory unit.

As an alternative mounting arrangement, the crystal element 1 may be supported by means of electrically conductive spring wires secured to the electrodes 2 and 3 adhering to the crystal. The spring wires may be secured to the center of the crystal electrodes by soldering, welding or other suitable method. While the soldering or welding material is in molten or fluid state, a strong bond between the parts to be attached together may be obtained by simultaneously subjecting the crystal elements to high frequency vibration by piezoelectric action or otherwise.

Figs. 6 and 7 illustrate another form of crystal mounting suitable for fundamental or harmonic mode AT cut crystals. In this mounting the AT cut crystal element 1 may have one of its major faces coated wholly or partially with divided or non-divided metallic plating formed integral therewith and its opposite electrode face may be free of such plating to permit convenient adjustment of the frequency determining thickness dimension y' of the crystal element 1. The electrode for the unplated face of the crystal element 1 may consist of a plate 20 of nickel plated steel, stainless steel or other suitable metal having a flat surface facing the crystal element 1. As illustrated in Figs. 6 and 7, such inner flat surface may be countersunk centrally and circular in form to a uniform depth of about .001 inch from the flat surface of the metal plate 20 to provide contact with the four corner portions of the unplated major face of the crystal element 1, thereby to provide an air-gap separation from the crystal element 1 at the remaining or central portion thereof. Such pressure contact at the corners of the crystal element 1 provides damping of undesired extraneous resonances in the crystal element 1.

Instead of being countersunk, the electrode plate 20 may have a flat surface facing the crystal element 1. Between the flat surface of such electrode plate and the crystal element 1, a thin mica spacer may be placed to separate the parts a distance of the order of .001 inch. The mica spacer may have a central circular opening to permit its remaining surface to provide damping contact with the four corners only of the crystal element 1.

As illustrated in Figs. 6 and 7, the crystal element 1 may be held and clamped in position against the electrode plate 20 by means of two springs 7 and clamping projections 5 secured to the free ends of the springs 7 and contacting the crystal plating at points of relatively small area adjacent two opposite corners on the same side of the crystal element 1 to hold the crystal element 1 against bodily movement out of a predetermined position. Such clamping at some or all of the four corners of the crystal element 1 provides damping of undesired extraneous

resonances in the crystal element 1. Means including insulating bushings 21 may support the springs 7 from the metal plate 20. The springs 7 may each exert pressure of approximately one to one and one-half pounds at the point of contact on the electroded crystal plate 1. The crystal element 1 so mounted against the metal plate 20 may be assembled in a metal bulb 22 evacuated to about .01 millimeter of mercury absolute, and equipped with pin terminals 23 arranged for mounting in a corresponding socket (not shown). The terminal pins 23 may establish the electrical connections with the crystal element 1 through a circuit or circuits including the electrode plate 20, the springs 7 and the conductive clamping projections 5. Metal springs 25 and 26 may be utilized to mount and space the crystal assembly within the metal bulb 22.

Both major faces of the crystal element 1 may be metal plated, wholly or partially. If silver plating or platinum plating, for example, be used, the resonance frequency of the electroded crystal unit is changed more by the loading from such relatively heavy metals than by that of a light metal such as aluminum. Since removing a small amount of the plating will change the resonance frequency slightly, this method may be used to produce a final adjustment in frequency. If the electrode plate 20 is ground so that the air-gap is less than about .02 millimeter, no plating will be required for the adjacent crystal face. This considerably simplifies the adjustment of the resonance frequency since by employing integrally plated electrode material only on one of the electrode faces of the crystal, the opposite surface being free of electrode plating may be conveniently ground to the correct thickness dimension y' required for the desired fundamental or odd harmonic major resonance frequency which is dependent mainly upon such thickness dimension y' .

As illustrated in Figs. 6 and 7, the crystal element 1 is provided with two plated divided electrodes 30 and 31 formed integral with one of its major faces, the opposite crystal face being entirely free of metal coating and pressed in direct contact with the metal electrode plate 20 by the springs 7. The electrodes 30 and 31 may be separated about 1 or 2 millimeters or more centrally and longitudinally along the z' dimension of the crystal element 1 to reduce the capacity and to provide two separate circuits in a single crystal element 1.

The coupling to undesired flexure modes in the crystal element 1 may be decreased by reducing the area of the electrode plating on one or both of the major faces of the crystal element, as illustrated in Figs. 4 to 8, especially in crystal elements of the higher capacities such as, for example, a fundamental shear mode AT cut crystal at frequencies of the order of 3000 kilocycles per second. As shown in Figs. 6 and 7, the electrodes 30 and 31 partially cover one electrode face of the crystal element 1. Connectors 10 of metal coating formed integral with the crystal face may be utilized to establish electrical connections with the corresponding clamping projections 5 when the partial electrodes such as the crystal electrodes 32 and 33 are located remotely from the edges of the crystal element 1 as illustrated in Fig. 5. The partial electrodes 30 to 33 may ordinarily be from 1 to 3 or more millimeters back from the edges of the crystal face. The amount of plating removed can be determined by the im-

pedance that crystal shall possess. It will be understood that any AT cut crystal element may be provided with such partial electrodes either divided or non-divided and on one or both of the electrode faces of the crystal element 1 to serve to reduce undesired extraneous resonances in the crystal element 1.

The partial plating arrangement of electrodes, and the connectors 10 if any are used, may be obtained from a wholly plated crystal electrode face by burning off the unwanted part electrically or by chemical means. The latter is useful for removing thick aluminum platings. One method consists in outlining the plated areas desired with a crayon pencil and then applying with a fine point pen a 50 per cent solution of sodium hydroxide to the aluminum plating to be removed between the crayon lines and the edge of the crystal. As soon as chemical action stops, the crystal unit may be thoroughly washed in clean water to remove the sodium hydroxide. Carbon tetrachloride or acetone may be used to remove the crayon marks. Alternatively, the centrally located partial electrodes such as the electrodes 30 and 31 may be formed from plating wholly covering the crystal face by electrically burning or otherwise providing a fine division line of about 0.25 millimeter separation between the centrally located plating forming the partial electrodes 30 and 31 and the plating located outwardly therefrom to the edges of the crystal element thus electrically isolating the central plating from the outwardly located plating without necessarily physically removing the latter from the crystal face.

It will be understood that any AT cut crystal element may be used with wholly plated electrode faces as illustrated in Figs. 1 and 3, or with the partially plated electrode faces as illustrated in Figs. 4 to 8, the partial electrodes serving to decrease coupling with the undesired extraneous modes.

As illustrated in Fig. 8, a narrow strip of metal plated integral coating 35 about one millimeter wide may be disposed between and separated from the two high impedance electrodes 30 and 31 and may extend centrally along the Z' axis over and around the edge of the crystal element 1 to the opposite major face thereof to provide a connection with the ground or low potential electrode plate 20 as illustrated schematically in Fig. 9. The strip of plating 35 functions as an electrostatic shield between the two adjacent electrode platings 30 and 31 to prevent electrical coupling between the two electrically separate parts of the crystal element 1 and may be utilized to place the peak of attenuation sufficiently remote from the pass region to maintain high loss in the attenuating region. This arrangement may be applied to crystal filters utilizing narrow or wide bands and singly or doubly resonant crystals.

Figs. 10 to 12 are graphs illustrating the frequency spectrum of AT cut quartz plates in fundamental and third harmonic mode vibrations, Figs. 10 and 11 representing the fundamental mode crystal and Fig. 12 the third harmonic mode crystal. Most of the prominent frequencies can be identified as shear vibration frequencies which are illustrated by the curves m , n and harmonic or overtone flexure vibration frequencies the strongest of which are controlled by the X axis dimension of the crystal element and are illustrated by the diagonal curves such as the curves k of Figs. 10 to 12.

The curves of Fig. 10 illustrate the most prominent resonance frequencies of fundamental mode ($m=1, n=1$) rectangular faced AT cut quartz plates 1 as functions of the length dimension x lying in the direction of the electric axis X, the quartz plates 1 being assumed to have a thickness dimension y' of one millimeter and a fixed length z' of 22.0 millimeters in the Z' axis direction which is perpendicular to the X axis dimension x .

As shown in Fig. 10, for any particular X axis length of the crystal element 1, there are a plurality of resonances at somewhat irregularly separated frequencies. As the x dimension of the quartz plate 1 is varied, the most prominent frequencies follow variations that conform roughly to the pattern formed by two sets of intersecting lines, one set being the curves m, n and the other set being the curves k . These curves represent substantially the frequencies that the quartz crystal 1 would have under appropriate excitation if there were no coupling between the different vibrational modes.

The curves $m1n1, m1n3$, and $m1n5$ of Fig. 10 represent shear mode vibrations, the frequencies of which are given substantially by the formula:

$$f = 1662 \sqrt{\left(\frac{m}{y'}\right)^2 + \left(\frac{n'}{x}\right)^2} \quad (1)$$

where f denotes the frequency in kilocycles per second; x the plate dimension in millimeters in the direction of the X axis; y' the thickness dimension y' in millimeters; $n' = (2n-1)$ and where m and n are integers corresponding to values of m equal to unity and n equal to 1, 3 and 5.

The curve $m1n1$ of Fig. 10 represents the desired fundamental major resonance shear mode vibration frequency of AT cut quartz plates 1. The curves $m1n3$ and $m1n5$ of Fig. 10 represent odd order overtone shear mode extraneous resonances. The curves for the even order overtone shear mode extraneous resonances may be similarly obtained from Equation 1 where m is made equal to unity and n is an even order integer as 2, 4, etc. Such even order overtone shear mode resonances may be present in addition to the odd order overtone shear mode extraneous resonances illustrated by the curves $m1n3$ and $m1n5$ of Fig. 10 when a divided form of electrodes such as the electrodes 30 and 31 of Figs. 5 and 8 are used to drive the crystal element 1.

The curves $k8$ to $k24$ of Fig. 10 represent even order harmonics or overtones of low frequency flexural vibrations along the X axis the frequencies of which depend upon the relative dimensions of the crystal element. The curves $k8$ to $k24$, representing such even order overtone flexure mode extraneous resonances, intersect the curve $m1n1$ representing the desired major fundamental shear mode resonance at points corresponding to certain x/y' dimensional ratios of the crystal element 1 given substantially by the formula:

$$x/y' = .8(k + .22) \quad (2)$$

where k is an even order integer, such as $k8$ to $k24$ illustrated in Fig. 10, or in addition an odd order integer where the electrodes on the same face of the crystal element are divided as illustrated in Figs. 5 and 8. Accordingly, to avoid the most serious interfering modes in any fundamental shear mode AT cut quartz plate 1, the x/y' dimensional ratio of the AT cut quartz plate 1 may be a value other than those given by 75

Equation 2 where k is an even or odd order integer.

The solid lines of Fig. 10 represent typical measured resonance frequencies. These tend to coincide with different portions of the several shear mode curves m, n and the overtone flexure modes curves k referred to but do not intersect with each other. This is because of the mechanical coupling that exists between the shear and flexural modes of vibration referred to. Near the points of intersection of the shear mode curves m, n with the flexure mode curves k the crystal element 1 exhibits pairs of resonances, the separation of which depends upon the degree of coupling between the vibrational modes.

If the x dimension of the AT cut quartz plate 1 in the direction of the X axis were held fixed and its z' dimension perpendicular thereto were varied, the resonance frequency characteristics would follow a set of curves, somewhat similar to those of Fig. 10, but corresponding to the interaction of a different set of shear and overtone flexural vibrations. This is illustrated by the curves of Fig. 11 which illustrate the most prominent resonances of the AT cut crystal 1 as the z' dimension thereof perpendicular to the X axis is varied, the ratio of the x dimension to the thickness dimension y' being held fixed at the value 10.50 and the thickness dimension y' being one millimeter. The horizontal lines of Fig. 11 correspond to the resonances shown in Fig. 10 for the value of x equal to 10.5 therein; and the diagonal lines of Fig. 11 represent harmonics or overtones of low frequency transverse modes propagated in the general direction of the axis Z'. A notable feature of the resonance characteristics shown in Fig. 11 is that the two sets of modes of vibration are very loosely coupled with the result that the resonances determined by the x dimension are displaced only at points very close to the virtual intersections with the diagonal lines.

The dimensional ratios of z'/y' which represent the virtual points of intersection of the diagonal lines of Fig. 11 with the horizontal line representing the desired main resonance are given substantially by the formula

$$z'/y' = 1.425(k - .74) \quad (3)$$

where k is an integer such as 8, 10, 12, 14, etc.

Accordingly, the z'/y' dimensional ratio of any fundamental mode AT cut crystal element may be made a value other than given by Equation 3 to avoid minor extraneous resonances.

In addition to the resonance discussed, AT cut crystals exhibit many other minor resonances due to coupling of additional vibrational modes; but by giving the crystal plates certain optimum dimensional relationships, the most prominent extraneous resonances may be effectively removed from the neighborhood of the desired principal or major resonance by sufficient amounts to prevent affecting the desired major resonance. In the case of AT cut crystals as shown in Figs. 1 and 2, the preferred dimensional ratios for the fundamental shear mode crystal may be obtained from the curves of Figs. 10 and 11 and from Equations 2 and 3. Denoting the thickness dimension of the crystal plate 1 by y' and the major face dimensions by x and z' , the dimensional ratio x/y' may approximate to one or other of the values of substantially 9, 10.5, 12.5, 13.8 etc. as given by the major resonance curve $m1n1$ of Fig. 10 intermediate the points of its intersection with the curves $k8$ to $k24$ thereof or in general

to values other than those given by Equation 2 where k is an odd or even integer from about $k8$ to $k50$; and the dimensional ratio z'/y' may approximate to one or other of the values of substantially 10.8, 12.5, 14, 15.5, 17, 18, 19.5, 21 etc. as given by the horizontal major resonance curve of Fig. 11 intermediate the points of its virtual intersection with the diagonal curves thereof or in general to values other than those given by Equation 3 where k is an integer from about $k8$ to $k50$ for example.

It will be understood that the most serious interfering extraneous resonances may be eliminated in the fundamental shear mode AT cut crystal elements by adjusting the dimensional ratio x/y' alone to make it some value other than that substantially given by Equation 2 where k is any odd or even integer as illustrated in Fig. 10.

From the curves of Fig. 10 the relationship of the most serious extraneous resonances to that of the desired basic or fundamental shear vibration resonance is readily determined. For example, for an x/y' dimensional ratio of 9, the nearest significant resonances are at frequencies about 1.032 and 1.065 times the desired major resonance; for an x/y' ratio of 10.5, the values are about 1.025, 1.061, and 1.102; and for a ratio x/y' of 12.5 the values are about 1.020, 1.040 and 1.075 times the basic or fundamental resonance. The basic resonance frequency is inversely proportional to the thickness dimension y' of the crystal 1 but since it is also dependent to some extent on the X axis plate dimension, AT cut quartz plates having different x/y' proportions will have slightly different thickness dimensions y' for the same fundamental shear mode vibration frequency. While the extraneous resonances appear at frequencies differing only by a small percentage from that of the basic resonance, the actual frequency difference at high frequencies may be quite large. For example, at a frequency of 2,000,000 cycles per second, a difference of one per cent represents a frequency interval of 20,000 cycles per second. The minimum separations indicated by the figures given above represent intervals of about 40,000 cycles per second or more, which permits the formation of adequate frequency bands for most transmission purposes.

For frequencies between about 1,000 and 3,000 kilocycles per second, fundamental shear mode AT cut crystals 1 of selected relative dimensions may be conveniently used. For frequencies above 3 megacycles per second, such fundamental mode crystals may become of an inconveniently small thickness dimension y' and then harmonic such as third harmonic shear mode AT cut crystals of selected relative dimensions may be more conveniently used. Such harmonic AT cut crystals also have a low temperature coefficient of frequency and in accordance with this invention may be made substantially free from interfering secondary resonances. By the use of the third harmonic AT cut crystals of proper dimensional ratios it is possible to extend the range of filters to about 10 megacycles per second or more.

Fig. 12 is a graph illustrating the frequency spectrum of third harmonic AT cut quartz crystal plates. Most of the prominent frequencies can be identified as shear vibration frequencies and overtone flexure vibration frequencies the strongest of which are controlled by the X axis dimension of the crystal plate 1. As illustrated in Fig. 12, the most prominent frequencies follow variations that roughly conform to sets of intersect-

ing lines, one set being the curves m , n and the other set the curves $k22$ to $k58$. These curves, like the corresponding curves of Fig. 10, represent the frequencies if there were no coupling between the different vibrational modes.

The curves $m3n1$ and $m3n3$ represent shear mode vibrations the frequencies of which are substantially given by Equation 1 where m and n are integers corresponding to values of m equal to 3 and n equal to 1 and 3. The curve $m3n1$ of Fig. 12 represents the desired third harmonic major resonance xy' shear mode vibration frequencies of AT cut quartz plates 1. The frequency of this resonance varies slightly with changes in the x/y' dimensional ratio for a given thickness dimension y' as illustrated by the curve $m3n1$ of Fig. 12, which indicates a slightly decreasing frequency with increasing values of the dimensional ratio x/y' .

The curve $m3n3$ of Fig. 12 represents the third order overtone shear mode extraneous resonance. The curves for other odd order and also for the even order overtone shear mode extraneous resonances may be similarly obtained from Equation 1 where m is made equal to 3 and n is an odd or even order integer as 2, 3, 4, etc. Such even order overtone shear mode extraneous resonances may be present in addition to the odd order overtone shear mode extraneous resonance illustrated by the curve $m3n5$ of Fig. 12 when a divided or split form of electrodes such as the electrodes 30 and 31 of Figs. 5 and 8 are used to drive the crystal element 1.

The curves $k22$ to $k58$ of Fig. 12 illustrate another set of interfering frequencies in third harmonic mode AT cut crystal elements which may be termed even order overtone flexure mode vibrations along the X axis dimension of the crystal element 1. The curves $k22$ to $k58$ intersect the curve $m3n1$ representing the desired major shear mode third harmonic resonance at points corresponding to certain x/y' dimensional ratios given substantially by the formula:

$$x/y' = .347 (k - .74) \quad (4)$$

where k is an even order integer such as $k22$ to $k58$ illustrated in Fig. 12 or in addition an odd order integer where the electrodes on the same face of the crystal element 1 are divided or split as illustrated in Figs. 5 and 8. Accordingly to avoid the most serious interfering modes in any third harmonic AT cut quartz plate 1, the x/y' dimensional ratio may be a value other than those given by Equation 4 where k is an even or odd order integer.

The solid line curves of Fig. 12, like those of Fig. 10, represent typical measured resonance frequencies. These tend to coincide with portions of the shear mode curves m , n and the overtone flexure mode curves k of Fig. 12.

As illustrated in Fig. 12, suitable x/y' dimensional ratios may include any of the values of substantially 7.5, 7.9, 8.2, 8.6, 9.0, 9.3, 9.6, 10.0, 10.4, 10.7, 11.0, 11.4, 11.7, 12.0, 12.4, 12.7, 13.1, 13.5, 13.8, 14.1, 14.5, 14.8, 15.2, 15.5, 15.9, 16.2, 16.6, 16.9, 17.3, 17.6, 18.0, 18.3, 18.7, 19.0, 19.4, 19.7, 20.0 or other values other than those given by Equation 4 and the curve $m3n1$ of Fig. 12 at points of intersection with the curves $k22$ to $k58$. The z'/y' dimensional ratios may ordinarily be substantially equal to that of the x/y' dimensional ratio giving a substantially square-faced crystal element, or may avoid the z'/y' dimensional ratios illustrated by curves similar to Fig. 11 and an equation similar to Equation 3.

As an example, a third harmonic AT cut crystal element, of 6700 kilocycles per second may have a thickness dimension y' of about 0.75 millimeter and square face dimensions x and z' of about 9 millimeters following the x/y' ratio of 12 given by the curve $m3n1$ of Fig. 12 intermediate the intersection therewith of the curves $k34$ and $k36$.

In addition to the extraneous overtone shear and flexure modes referred to, there may be present in fundamental and odd harmonic AT cut crystal elements other nearby extraneous small modes which may be avoided by suitable final adjustments in the relative x , y' and z' dimensions of the crystal element. In general, these small extraneous modes have an appreciable temperature coefficient of frequency. As the temperature of the crystal element is changed, they will change from a frequency position below to a position above that of the desired major resonance mode. In the process, the major mode may be shifted slightly in frequency and if the change is in the direction of the major mode, its Q or reactance-resistance ratio may decrease considerably. To avoid this condition, the crystal element 1 may be measured over the operating temperature range to determine the position of these small modes and then edge ground to reduce the z' dimension edge by a slight amount until the undesired small extraneous modes are about equally spaced in frequencies above and below the desired major mode frequency at the mean of the operating temperature.

In some cases, it may be desirable to adjust the ratio of x , y' and z' axes of the crystal so that all extraneous modes having a negative temperature coefficient of frequency are placed on one side below the desired major resonance frequency and those with positive temperature coefficients of frequency are placed on the opposite side above the major resonance frequency at the low operating temperature.

When crystals of the relatively smaller x/y' dimensional ratios—of the order of less than 20 for example—are operated over a relatively wide temperature range, the small extraneous resonances may have sufficient coupling to the desired major shear mode resonance to adversely affect its frequency as well as its reactance-resistance ratio Q . In such a case, if the relatively larger x/y' dimensional ratios of more than 20, for example, be used, the extraneous modes are of a higher order and have less coupling to the major resonance. However, for such larger values of x/y' dimensional ratios, there will be stronger subsidiary shear mode resonances immediately above the principal resonance so that the amount of discrimination allowed above the pass band will then determine the permissible temperature range.

A point of interest is that most of these small extraneous resonances may be raised in frequency, while the major resonance remains fixed, by reducing or shortening the z' dimension of the crystal element 1 by grinding on either edge perpendicular to the Z' axis, the z' dimension being reduced sufficiently to raise the frequencies of the extraneous resonances above the desired major resonance frequency.

Another point of interest is that the major resonance may be adjusted in frequency by shortening or reducing the x dimension of the crystal element by grinding either edge of the crystal element that is perpendicular to the X axis thereof. If, in the last-mentioned operation,

it is found that a minor resonance occurs near the major one, the procedure would be to grind an edge perpendicular to the Z' axis. This will materially raise the frequency of the objectionable resonance without changing the major resonance except when actually passing it. The Q or ratio of reactance to resistance of the major resonance may be considerably lowered when any other resonance is very near it, but will increase to its former desired value as the frequency of the unwanted resonance is raised above the major resonance.

The procedure for adjusting filter crystals to the correct frequency may consist in reducing the thickness dimension y' by grinding the unplated crystal face until the principal mode resonance frequency is slightly above the desired frequency. At the same time, the X axis dimension of the crystal element 1 may be reduced to some value slightly greater than the value that gives a proper x/y' dimensional ratio. After plating one or both of the electrode faces of the crystal element 1 with electrode material of suitable metal, some of the metal may be ground off until the desired frequency is obtained on the upper edge of the frequency band. The X axis dimension may then be reduced until the next lower transmission region increases to the desired value. The final adjustment may be made under varying temperature ranges. This may be accomplished quickly by having two chambers, one maintained hot and the other cold, at the two limits of the temperature requirements which may be -5 to $+65^\circ$ centigrade, for example. If any small extraneous resonances are present near the desired principal mode, they will shift its frequency and cause a variation in loss in the transmitted band when the temperature of the crystal is varied. In general, the extraneous frequencies will have negative temperature coefficients of frequency. These extraneous frequencies may be increased by grinding either edge of the crystal element that is perpendicular to the Z' axis, preferably by not more than .01 millimeter at a time. When the crystal element is so ground free from variations greater than say .5 decibel due to temperature change, its principal mode may then be increased by removing some of the electrode coating until the frequency is in the center of the band at the middle of the operating temperature range.

The major faces of AT cut crystal elements 1 may be made very slightly convex, the center of the crystal element then being the thickest dimension y' . The slightly convex major faces are easier to make than strictly flat surfaces and operate about as well as the strictly flat faces and much better than slightly concave major surfaces in AT cut crystals or similar crystals.

By the use of a small exploring electrode moved on the major face of the crystal element to various positions thereon, precise measurements of the thickness dimension y' at various positions may be obtained by noting the frequencies corresponding to such several positions of the exploring electrode on the face of the crystal element. By this method, the flatness or the convexity of the major faces of the crystal element may be measured with great accuracy and ground to the desired degree of flatness or convexity.

While fundamental and third harmonic AT cut crystal elements have been particularly disclosed herein it will be understood crystals of other harmonic frequencies separated from the nearby

extraneous resonances may be similarly constructed.

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. A piezoelectric quartz element adapted to respond to a predetermined shear-mode frequency, said element having at least one of its greater dimensions relatively so proportioned with respect to its frequency determining dimension that it exhibits a single frequency response when vibrated at a frequency which is a function of its thickness dimension.

2. A piezoelectric quartz element adapted to respond to a predetermined shear-mode frequency, said element having at least one of its greater dimensions relatively so proportioned with respect to its frequency determining dimension that it exhibits a single frequency response when vibrated at a frequency which is a function of its thickness dimension, said frequency being a fundamental frequency, and said thickness dimension being made of a value corresponding to the value of said fundamental frequency.

3. A piezoelectric quartz element adapted to respond to a predetermined shear-mode frequency, said element having at least one of its greater dimensions relatively so proportioned with respect to its frequency determining dimension that it exhibits a single frequency response when vibrated at a frequency which is a function of its thickness dimension, said frequency being an odd order harmonic of the fundamental frequency thereof, and said thickness dimension being made of a value corresponding to the value of said odd order harmonic frequency.

4. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having one of its dimensions substantially parallel to the XY plane and relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said frequency which is a function of said thickness dimension.

5. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having one of its dimensions substantially parallel to the XY plane and relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said frequency which is a function of said thickness dimension, said major surface being substantially rectangular and having an edge substantially parallel to said XY plane.

6. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having one of its dimensions substantially parallel to an X axis and relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said

frequency which is a function of said thickness dimension.

7. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having one of its dimensions substantially parallel to an X axis and relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said frequency which is a function of said thickness dimension, said major surface being substantially rectangular and having an edge substantially parallel to said X axis.

8. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having one of its dimensions substantially parallel to an X axis and relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said frequency which is a function of said thickness dimension, said frequency being an odd order harmonic of the fundamental frequency thereof, and said thickness dimension being made of a value corresponding to the value of said odd order harmonic frequency.

9. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having two mutually perpendicular dimensions each relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said frequency which is a function of said thickness dimension.

10. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having two mutually perpendicular dimensions each relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said frequency which is a function of said thickness dimension, one of said major surface dimensions being substantially along an X' axis in the region of an X axis.

11. A piezoelectric quartz crystal element adapted to respond to a desired shear-mode frequency determined mainly by its thickness dimension, the major surface of said element having two mutually perpendicular dimensions each relatively so proportioned with respect to said frequency-determining thickness dimension that said element exhibits a substantially single frequency response when vibrated at said frequency which is a function of said thickness dimension, one of said major surface dimensions being substantially along an X' axis in the region of an X axis, said major surface being substantially rectangular.

12. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency of substantially zero temperature coefficient and dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, said thickness dimension being made of a value substantially in accordance with the value of said frequency, each of said

major faces having one pair of edges substantially parallel to an X axis and the other pair of edges inclined substantially +35 degrees 20 minutes with respect to the Z axis, the ratio of the dimension of said element in the direction of said X axis with respect to said thickness dimension being made of such a value as to reduce the effect of undesired modes upon said desired frequency, said value being substantially one of the values 7.5, 8.6, 9.3, 10.4, 10.7, 11.0, 11.7, 12.0, 12.4, 12.7, 13.5, 14.1, 15.2, 15.5, 16.6, 17.3, 18.3, 18.7, and 19.7, said desired thickness-mode frequency being one of the frequencies fundamental and third harmonic.

13. A quartz crystal element in accordance with claim 12 wherein the ratio of the dimension of said element in the direction perpendicular to said X axis with respect to said thickness dimension is made of such a value as to reduce the effect of undesired modes upon said desired frequency, said value being substantially one of the values 10.8, 12.5, 14, 15.5, 17.5, 19.5, 21 and 22.

14. A quartz crystal element in accordance with claim 12 wherein said major faces are substantially square.

15. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired main resonance frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, each of said major faces having one pair of edges substantially parallel to an X axis and the other pair of edges inclined substantially +35 degrees 20 minutes with respect to the Z axis, the ratio of the dimension of said element in the direction of said X axis with respect to said thickness dimension being such a value as to reduce the effect of undesired modes upon said desired main resonance frequency, said value being substantially one of the values given by the main resonance curves of Figs. 10 and 12 intermediate the points of intersection with the k curves thereof.

16. A quartz crystal element in accordance with claim 15 wherein said major faces are substantially square.

17. A quartz crystal element in accordance with claim 15 wherein the dimension of said element perpendicular to said X axis is sufficiently reduced until the frequency of an extraneous resonance near to said desired frequency is raised effectively above said desired frequency.

18. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, each of said major faces having one pair of edges substantially parallel to an X axis and the other pair of edges inclined substantially +35 degrees 20 minutes with respect to the Z axis, the ratio of the dimension of said element in the direction of said X axis with respect to said thickness dimension being such a value that the frequency of an undesired mode near to said desired frequency is effectively removed therefrom, said value being substantially one of the values other than those given by the expressions $0.8(k+22)$ and $0.347(k-74)$ where k is an integer.

19. A piezoelectric element in accordance with claim 18 wherein k is an even order integer, and electrodes for said element, at least one of said electrodes effectively covering the central area only of one of said major faces.

20. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired

frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, each of said major faces having one pair of edges substantially parallel to an X axis and the other pair of edges inclined substantially +35 degrees 20 minutes with respect to the Z axis, the ratio of the dimension of said element in the direction of said X axis with respect to said thickness dimension being substantially one of the values given by the main resonance curve of Fig. 10 intermediate the points of intersection with the k curves thereof, electrodes adjacent said major faces, at least one of said electrodes effectively covering the central area only of one of said major faces, and means contacting the corners of said element for damping extraneous frequencies.

21. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, each of said major faces having one pair of edges substantially parallel to an X axis and the other pair of edges inclined substantially +35 degrees 20 minutes with respect to the Z axis, the ratio of the dimension of said element in the direction of said X axis with respect to said thickness dimension being substantially one of the values given by the main resonance curve of Fig. 12 intermediate the points of intersection with the k curves thereof, and conductive coating formed integral with one of said major faces comprising electrode coating effectively covering only a part of the total area of said major face for reducing undesired extraneous frequencies.

22. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, each of said major faces having one pair of edges substantially parallel to an X axis and the other pair of edges inclined substantially +35 degrees 20 minutes with respect to the Z axis, the ratio of the dimension of said element in the direction of said X axis with respect to said thickness dimension being substantially one of the values given by the main resonance curves of Figs. 10 and 12 intermediate the points of intersection with the k curves thereof, conductive coating formed integral with one of said major faces comprising electrode coating effectively covering only a part of the total area of said major face for reducing undesired extraneous frequencies, and means disposed in contact with the corners of said major faces for damping undesired extraneous frequencies.

23. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, said major faces being substantially parallel to an X axis and inclined substantially +35 degrees 20 minutes with respect to the Z axis as measured in a plane perpendicular to said major faces, said thickness dimension being made of a value in accordance with the value of said desired frequency, and the X axis dimension of said element being sufficiently reduced until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, conductive plating formed integral with one of said major faces, said plating including an electrode plating effectively covering the central part only of said

one major face, and means including conductive clamping projections disposed in contact with said plating at points of relatively small area adjacent two opposite corners of said one major face for exerting clamping pressure on said element.

24. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, said major faces being substantially parallel to an X axis and inclined substantially +35 degrees 20 minutes with respect to the Z axis as measured in a plane perpendicular to said major faces, said thickness dimension being made of a value in accordance with the value of said desired frequency, and the X axis dimension of said element being sufficiently reduced until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, and conductive plating formed integral with one of said major faces comprising electrode plating effectively covering the central part only of the total area of said one major face, said electrode plating being electrically divided centrally and longitudinally to form a pair of divided electrodes.

25. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its major faces, said major faces being substantially parallel to an X axis, said thickness dimension being made of a value in accordance with the value of said desired frequency, and the X axis dimension of said element being sufficiently reduced until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, conductive platings formed integral with one of said major faces comprising electrode plating effectively covering the central part only of the total area of said one major face and being electrically divided centrally and longitudinally to form divided electrodes, connector plating extending from one of said divided electrodes to a corner of said one major face, and another connector plating extending from the other of said divided electrodes to an opposite corner of said one major face, and means including conductive clamping projections in individual contact with said connector platings at points of relatively small area adjacent said opposite corners of said one major face for exerting clamping pressure on said element.

26. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its major faces, said major faces being substantially parallel to an X axis, said major faces having at least one dimension thereof proportioned with respect to said thickness dimension until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, conductive platings formed integral with one of said major faces comprising electrode plating divided centrally and longitudinally to form a pair of divided electrodes, and a strip of shielding plating disposed between and separated from said divided electrodes.

27. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its major faces, said major faces being substantially parallel to an

X axis, said major faces having at least one dimension thereof proportioned with respect to said thickness dimension until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, conductive platings formed integral with one of said major faces comprising electrode plating divided centrally and longitudinally to form divided electrodes, and a strip of shielding plating disposed between and separated from said divided electrodes and extending around an edge of said element to the opposite major face thereof.

28. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its major faces, said major faces being substantially parallel to an X axis, said major faces having at least one dimension thereof proportioned with respect to said thickness dimension until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, conductive platings formed integral with one of said major faces comprising electrode plating effectively covering the central part only of the total area of said one major face and being divided centrally and longitudinally to form divided electrodes, and a strip of shielding plating disposed between and separated from said divided electrodes and extending around an edge of said element to the opposite major face of said element for connection with an electrode adjacent said opposite major face.

29. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its major faces, said major faces being substantially parallel to an X axis, said major faces having at least one dimension thereof proportioned with respect to said thickness dimension until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, conductive platings formed integral with one of said major faces comprising electrode plating effectively covering the central part only of the total area of said one major face and being electrically divided centrally and longitudinally to form divided electrodes, and a strip of shielding plating disposed between and separated from said divided electrodes and extending around an edge of said element to the opposite major face of said element for connection with an electrode adjacent said opposite major face, and means including conductive clamping projections in individual contact with said divided electrodes at points of relatively small area adjacent the opposite corners of said one major face for clamping said element against said electrode adjacent said opposite major face.

30. A quartz crystal piezoelectric element adapted to vibrate in a shear mode at a desired frequency dependent mainly upon its thickness dimension perpendicular to its substantially rectangular major faces, each of said major faces having one pair of edges substantially parallel to an X axis and the other pair of edges inclined substantially +35 degrees with respect to the Z axis, said major faces having at least one dimension thereof proportioned with respect to said thickness dimension until the frequency of an extraneous resonance near to said desired frequency is effectively removed from said desired frequency, conductive metallic platings formed

integral with one of said major faces comprising electrode plating effectively covering the central part only of the total area of said one major face and being electrically divided centrally and longitudinally along the Z' axis perpendicular to said X axis to form divided electrodes, a strip of shielding plating disposed between and separated from said divided electrodes and extending around an edge of said element to the opposite major face of said element for connection with an electrode adjacent said opposite major face, connector plating formed integral with said one major face and extending from one of said divided electrodes to a corner of said one major face, another connector plating extending from the other of said divided electrodes to an opposite corner of said one major face, and conductive clamping projections in individual contact with said connector platings at points of relatively small area adjacent said opposite corners of said one major face for clamping said element against said electrode adjacent said opposite major face.

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