PIEZOELECTRIC CRYSTAL APPARATUS

Filed Jan. 11, 1940 2 Sheets-Sheet 1

Fig. 1.

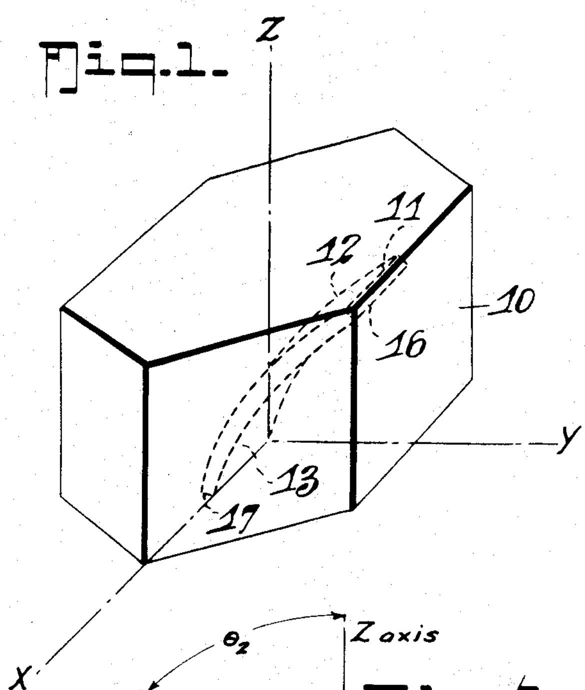


Fig. 2.

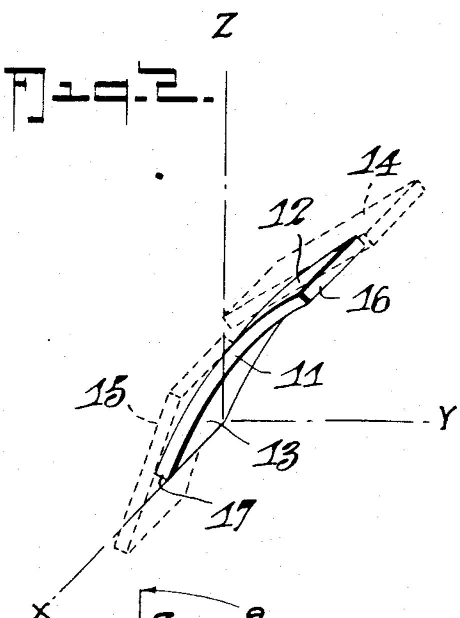


Fig. 4.

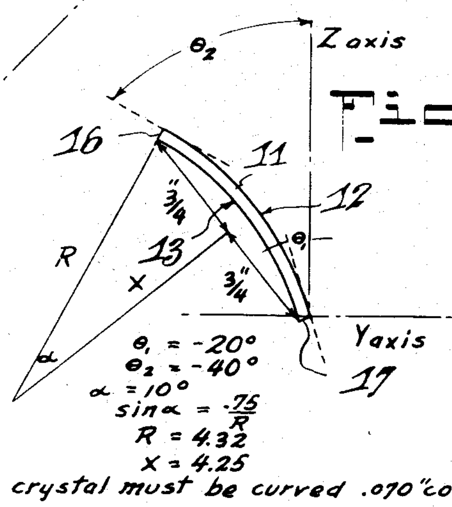


Fig. 3.

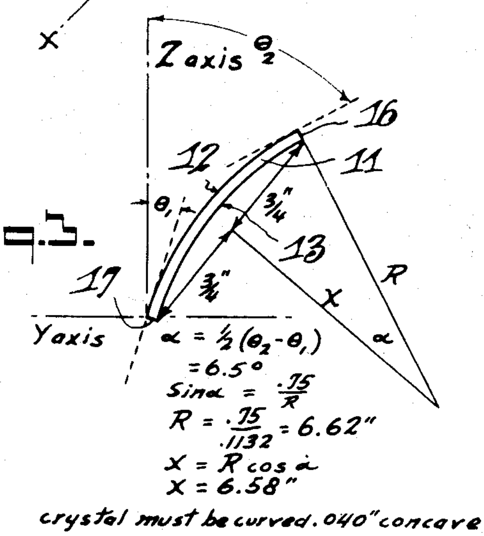


Fig. 6.

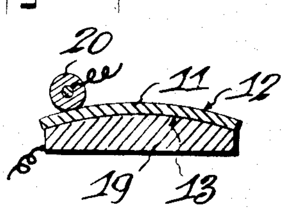
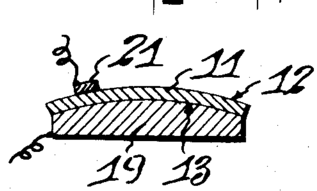


Fig. 7.



Inventor

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Dec. 10, 1940. J. M. WOLFSKILL 2,224,700

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Jan. 11, 1940 2 Sheets-Sheet 2

Fig. 9.

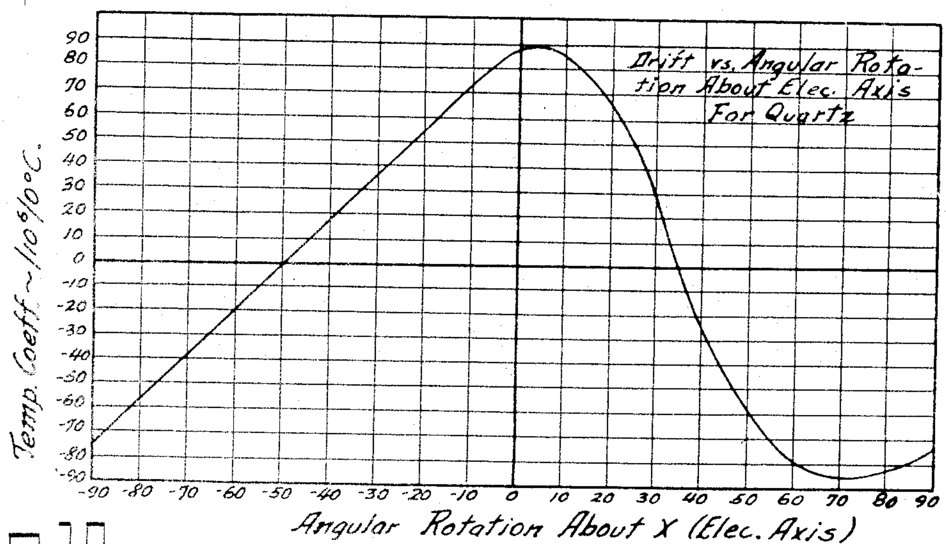


Fig. 10.

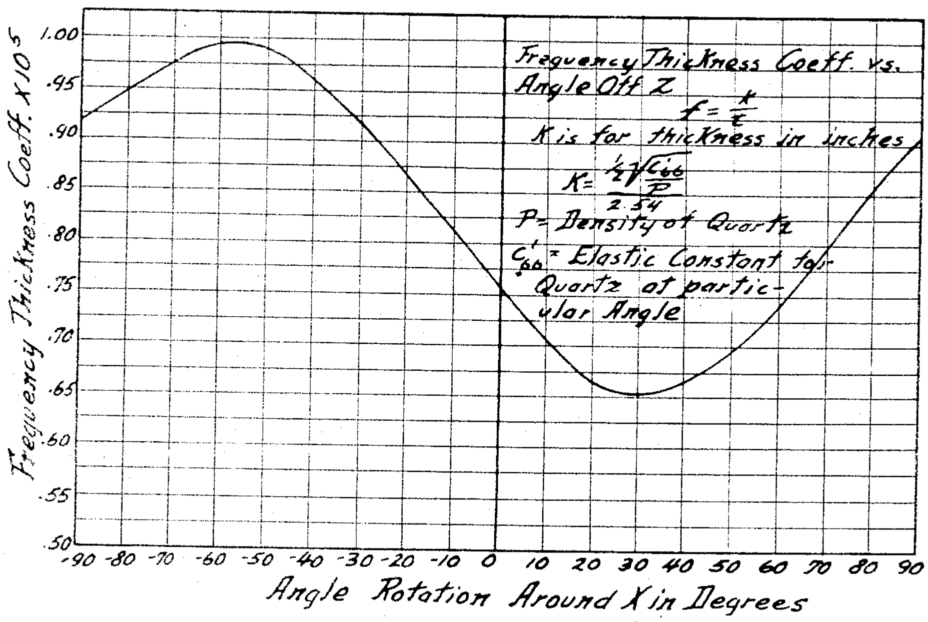


Fig. 5.

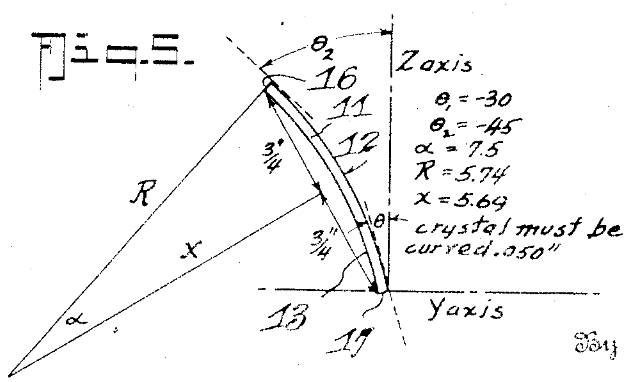
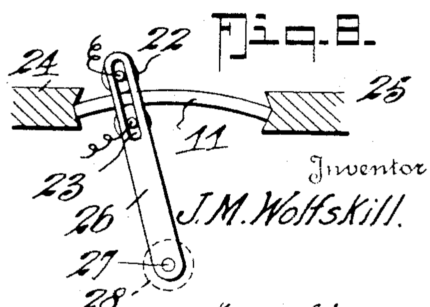


Fig. 8.



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UNITED STATES PATENT OFFICE

2,224,700

PIEZOELECTRIC CRYSTAL APPARATUS

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Application January 11, 1940, Serial No. 313,462

14 Claims. (Cl. 171—327)

This invention relates to a variable frequency piezoelectric crystal element and more particularly to a method of so cutting the crystal element from the crystal as to produce a variable frequency characteristic.

One of the main objects of this invention is to obtain a wide continuous frequency variation with a crystal which is of substantially constant thickness.

Another object of the invention is to provide a piezoelectric element with which a wide frequency variation may be obtained. By wide frequency variation is meant up to 100 kilocycles or several hundred kilocycles.

A further object is to provide a piezoelectric crystal with which a wide continuous frequency variation may be obtained.

Another object is to provide a wide range variable frequency quartz element whose thickness is constant but whose frequency thickness coefficient varies along the length of the crystal.

The need for a wide range variable frequency quartz crystal is becoming more and more important in communication art, and this is particularly true in the amateur field where it is desirable to change frequency rapidly from one portion of the band to another to avoid interference from other stations. Various methods have been devised for varying the controlling frequency, these include electron coupled and other self-excited oscillators as well as narrow range variable frequency crystal controlled oscillators.

The variation obtainable with a single quartz crystal by present methods known to the art, however, is relatively small, and it has generally been conceded that the variation obtainable by an air-gap type of holder is insufficient for certain services. A method of continuously varying the frequency of a quartz crystal over a relatively narrow frequency range is described in my Patent No. 2,079,540. This invention covers a wedge type adjustable air-gap which is associated with a quartz crystal, and the variation of the gap controls the frequency variation of the crystal.

Other methods of obtaining step frequency variation include those of using a number of individual crystals connected with a tap switch for rapid switching from one crystal to another. Such arrangements, however, do not have the advantages of a self-excited oscillator because often it is desirable to use a frequency or frequencies somewhere between the frequencies of the step crystals. The advantages of quartz crystal controlled oscillators over the self-excited type are well known to the art, and there was therefore a need for a method of obtaining a much wider continuous frequency variation without sacrificing any of the advantages of crystal control.

This invention relates to a method of cutting and grinding a quartz crystal as to enable a wide continuous frequency range to be obtained in a single crystal. In general, the method consists of making the crystal in the form of a section of a cylinder such that by moving from one end of the section to the other, the angle of the elemental sections to the optic axis varies continuously. The axis of the cylinder from which the section is cut is made substantially parallel to the electric axis, and the angle to the optic axis of the elemental sections can vary anywhere from 0 to plus or minus 90 degrees, depending on the desired frequency variation.

From some of the curves described in detail further in the specification, it is seen that as the angle at which the crystal is cut to the optic axis is varied, the thickness coefficient varies according to the curve, and since the frequency for any given thickness of crystal is dependent on this thickness coefficient from the simple relation

$$F=\frac{K}{T}$$

the frequency also varies. It is then possible to obtain any desired frequency variation along such a section of a cylinder by properly choosing the limits of angle of the tangent to the quartz section. From the limits of angle and the length of the crystal section, the required radius of the cylindrical section may be computed. In the use of a crystal of this type, one electrode naturally will have to assume the same curvature as the section of crystal, and another movable electrode (which can be in the form of a flat narrow electrode or a roller) which is of necessity small in dimension serves to excite the elemental crystals. The crystal will be of a constant thickness along its length, and the frequency variation between the elements is obtained entirely by virtue of the varying thickness coefficient.

Further details of this invention are set forth in the following specification, the claims and the drawings in which briefly, Fig. 1 illustrates the manner in which the crystal element is cut from the mother crystal; Fig. 2 shows a crystal element forming a section of a cylinder and two imaginary flat crystal elements are positioned tangent thereto for purposes of explanation of this invention; Figs. 3, 4 and 5 illustrate examples of crystal elements cut in accordance with this invention; Figs. 6, 7 and 8 show forms of electrodes and holders that may be employed with the crystal elements described herein; Fig. 9 is a curve showing the relation between the temperature coefficient and the angle of rotation of a crystal element about an electric axis; and Fig. 10 is a curve illustrating the relation between the frequency thickness coefficient and the angular rotation about an electric axis.

Referring to Fig. 1 of the drawings in detail reference numeral 10 designates the mother quartz crystal having the optic or Z axis, an electric or X axis and a mechanical or Y axis designated therein as illustrated. The crystal element 11 having the principal faces 12 and 13 of curved or bowed configuration so as to form sections or surfaces of a cylinder, is shown in dotted outline in the crystal 10. In Fig. 2 a similar view of the crystal element 11 is shown with two substantially flat crystal elements 14 and 15 drawn in dotted outline tangent to the ends of crystal section 11. These two imaginary plane crystals 14 and 15 represent the limits of the angular variation of the elemental crystals which make up the bowed crystal 11. In choosing the section of the frequency thickness curve shown in Fig. 10, over which it is best to obtain angular variation, it is naturally desirable to keep the temperature coefficient as low as possible and the activity of the crystal as high as possible. An angle of plus 30 degrees was selected for the end 16 and the crystal element was cut with its principal faces substantially parallel to the X axis and with the elemental section of said faces at the end 16 at an angle of substantially 30 degrees with respect to the optic or Z axis; this angle, however, is decreased as far as it is necessary to obtain the desired frequency variation. It is of course obvious that these angles and positions are not the only ones that are desirable and that these are set forth here only to explain features of this invention which may be applied to other angles and different types of crystal cuts. From the curve Fig. 10, it is seen that the imaginary plane crystal 14 cut at plus 30 degrees has a frequency thickness coefficient of 0.655×10^5. Consequently for a frequency of, for example, 3500 kilocycles, the crystal will have to be 0.0187″ thick. Assuming that a variation of 100 kilocycles is to be obtained, the thickness coefficient of the other imaginary crystal 15 at the other end 17 of the section 11 will have to be equal to $(K=FT)=0.0187\times3600$ kilocycles or 0.673×10^5. From the curve, Figure 10, it is seen that for a thickness coefficient of 0.673, the angle of the imaginary crystal 15 tangent to the section 11 will have to be approximately plus 17 degrees. In moving along the section, then, the angle of the elemental crystals to the optic axis will vary from plus 17 to plus 30 degrees or a total change of 13 degrees. In order to have a reasonable sized crystal and also a relatively large size movable electrode, the crystal is made one and one-half inches long by three-fourths inch wide, however, of course, these dimensions are simply arbitrary and do not influence the performance of the crystal.

Referring to Figure 3, it is seen that for a crystal element 11 approximately one and one-half inches long, the radius R of curvature required to obtain the angular variation of plus 17 degrees for angle θ_1 to plus 30 degrees for angle θ_2 of the tangents at ends 17 and 16 respectively, is 6.62″. The radius R is obtained by calculating the value of the angle α and from this the values for the sine and cosine are obtained as shown on the drawings. This radius of curvature is used in grinding the inner surface 18 of the section. The outer radius of the crystal is this radius plus the crystal thickness, this difference however is generally so small that the same radius may be used for grinding both surfaces.

In Fig. 4 another example is given of a crystal cut in accordance with this invention to further demonstrate the manner in which the dimensions and the proper curvature of the crystal are computed to obtain some definite specified frequency variation. Referring to Fig. 10 showing the frequency thickness coefficient versus angular rotation curve, it is seen that the curve is practically a straight line from plus 10 degrees to minus 40 degrees. This means that the frequency variation along a crystal 11 curved so that the tangents to the ends 16 and 17 of the crystal make angles of plus 10 degrees for θ_1 and minus 40 degrees for θ_2 with the optic axis, is linear with angular rotation.

Theoretically, this would be the best range in which to work all crystals of this type. Unfortunately, however, the temperature coefficient of the crystal between the angles plus 10 degrees and minus 10 degrees is relatively high as seen from Fig. 9, and as a result it is desirable to eliminate this portion of the curve. The crystal can be cut at angles between minus 20 degrees and minus 45 degrees and still maintain a fairly low temperature coefficient over the range. A crystal of this type may be conveniently used in the low drive circuit described and claimed in my copending application Serial No. 313,461, filed January 11, 1940.

If it is desired to obtain a crystal which works on the straight portion of the frequency thickness curve and thus obtain a very large frequency variation, of for example 400 kilocycles, this can be done by starting at an angle of minus 20 degrees. At this angle the frequency thickness coefficient is 0.865×10^5 and consequently for a 3500 kilocycle crystal, the thickness is 0.0247″. The upper frequency limit, assuming the 400 kilocycle frequency variation is 3900 kilocycles and for a crystal 0.0247″ thick, the coefficient K must be $(K=FT)$ equal to $0.0247\times3900\times10^3$. On the frequency thickness coefficient curve, Fig. 10 this corresponds to an angle of minus 40 degrees. For computing the radius of curvature required for a crystal one and one-half inches long, reference is made to Figure 4 and in this case the calculations are similar to those in the case of Fig. 3. The total angular variation of the crystal shown in Fig. 4 is 20 degrees which means that the angle $\alpha=\frac{1}{2}(\theta_2-\theta_1)=10°$. From this it is found that R is equal 4.32″ and X=4.25, or in other words, the crystal is actually ground concave on one side by .070″ and convex on the other side by substantially the same amount.

For a still lower drift over the frequency range, the crystal may be cut between minus 30 degrees and minus 45 degrees as illustrated in Fig. 5. The drift at the minus 30 degree end 17 is about plus 36 cycles/10^6/° centigrade, and decreases to about plus 8 cycles/10^6/° centigrade at the 45 degree angle end 16 as seen by referring to the curve shown in Fig. 9. By choosing the two angular limits first for the crystal element the frequency range over which the frequency may be varied is automatically limited. The thickness required for a 3500 kilocycle crystal cut at minus 30 degrees is 0.0262". Using this same thickness and the frequency thickness coefficient of the minus 45 degree angle, the other extreme end of the frequency range of this crystal will be 3720 kilocycles. From the calculations given in Fig. 5, it is found that the radius R required on a crystal of this type is 5.74".

In the manufacture of such a crystal as described in this invention, certain manufacturing difficulties are encountered. When it is noticed that even in the crystal which gave a frequency variation of 400 kilocycles, the amount of curvature or concaving was only on the order of 0.070 inch, the obvious method of manufacture is to first slice a parallel blank at the angle half way between the two extreme tangent angles θ_1 and θ_2. By then using a grinding surface which takes the form of a cylinder, having the same radius of curvature as desired on the crystal, the inner surface 18 of the crystal is ground concave. The opposite side of the crystal may be ground in the same manner by using the inside of the cylinder as a grinding surface or grinding it on a concave section of a cylinder. In doing this grinding, the crystal must be moved in such a manner that the end edges move parallel to the axis of the cylinder. It must also be ground in such a way that the thickness of the crystal, as measured along the radius R, remains constant.

Due to the odd shape of the crystal of this invention, it can be seen that a special holder is required to utilize all the advantages of the crystal. The holder may be made in various forms, several of which are shown in Figs. 6, 7 and 8. Fig. 6 shows the crystal 11 mounted on a curved bottom electrode 19, curved convex to the same radius as the crystal and with a movable electrode 20 in the form of a cylinder which is made to move along the length of the crystal so as to excite a small elemental area as it moves along the length. Fig. 7 shows the same arrangement, but instead of a roller electrode, a flat movable narrow electrode 21 is used to excite the crystal. A small air gap may be left between the electrode 21 and the crystal surface to eliminate abrasion. Fig. 8 shows another method of exciting the crystal and this makes use of two movable cylinders 22 and 23 which are made to move along the length of the crystal by the slotted bar 26 of insulation material which is attached to the pivot rod 27 actuated by the knob 28. The ends of the crystal rest in the notched members 24 and 25. Any one of these three fundamental types of holders may be used and the mechanical arrangement for moving the electrodes may be varied to suit the size and external design of the complete unit.

It is of course obvious that I do not desire to limit this invention to the exact details shown and described except insofar as they are defined by the claims.

What I claim is:

1. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different elemental segments thereof have different frequency thickness coefficients.

2. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof ground so that different elemental segments of the said crystal element have different frequency thickness coefficients.

3. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different elemental segments thereof have different frequency thickness coefficients, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between plus or minus 90 degrees with respect to the optic axis.

4. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different elemental segments thereof have different frequency thickness coefficients, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between plus 17 degrees and plus 30 degrees with respect to the optic axis.

5. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different elemental segments thereof have different frequency thickness coefficients, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between minus 30 degrees and minus 45 degrees with respect to the optic axis.

6. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different elemental segments thereof have different frequency thickness coefficients, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between plus 10 degrees and minus 40 degrees with respect to the optic axis.

7. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different segments of said crystal element have different frequency thickness coefficients, a pair of electrodes for said crystal element, at least one of said electrodes being movable over the surface of the corresponding principal face to select different sections of said crystal element for generating electrical oscillations the frequency of which may be continuously varied as said electrode is moved over the different crystal sections.

8. A piezoelectric crystal element adapted to

respond to and generate electrical oscillations the frequency of which may be varied continuously over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof cut to form sections of a cylinder whereby said crystal element consists of a multiplicity of segments of substantially uniform thickness all having different frequency thickness coefficients so that said crystal element is responsive to and adapted to generate electrical oscillations the frequency of which may be continuously varied as different ones of said crystal segments are selected.

9. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be varied continuously over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof cut to form sections of a cylinder whereby said crystal element consists of a multiplicity of segments of substantially uniform thickness all having different frequency thickness coefficients so that said crystal element is responsive to and adapted to generate electrical oscillations the frequency of which may be continuously varied as different ones of said crystal segments are selected, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between plus or minus 90 degrees with respect to the optic axis.

10. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be varied continuously over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof cut to form sections of a cylinder whereby said crystal element consists of a multiplicity of segments of substantially uniform thickness all having different frequency thickness coefficients so that said crystal element is responsive to and adapted to generate electrical oscillations the frequency of which may be continuously varied as different ones of said crystal segments are selected, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between plus 17 degrees and plus 30 degrees with respect to the optic axis.

11. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be varied continuously over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof cut to form sections of a cylinder whereby said crystal element consists of a multiplicity of segments of substantially uniform thickness all having different frequency thickness coefficients so that said crystal element is responsive to and adapted to generate electrical oscillations the frequency of which may be continuously varied as different ones of said crystal segments are selected, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between minus 30 degrees and minus 45 degrees with respect to the optic axis.

12. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be varied continuously over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof cut to form sections of a cylinder whereby said crystal element consists of a multiplicity of segments of substantially uniform thickness all having different frequency thickness coefficients so that said crystal element is responsive to and adapted to generate electrical oscillations the frequency of which may be continuously varied as different ones of said crystal segments are selected, said principal faces being cut substantially parallel to an electric axis of the mother crystal and at angles between plus 10 degrees and minus 40 degrees with respect to the optic axis.

13. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different segments of said crystal element have different frequency thickness coefficients, a pair of electrodes for said crystal element, one of said electrodes being in the shape of an elongated roller and being movable over the surface of the corresponding principal face to select different sections of said crystal element for generating electrical oscillations the frequency of which may be continuously varied as said electrode is moved over the different crystal sections.

14. A piezoelectric crystal element adapted to respond to and generate electrical oscillations the frequency of which may be continuously varied over a wide frequency range, comprising: a piezoelectric crystal element of substantially uniform thickness having the principal faces thereof of bowed configuration ground so that different segments of said crystal element have different frequency thickness coefficients, a pair of electrodes for said crystal element, said electrodes being roller shaped and means for moving each of said roller shaped electrodes over the surface of the corresponding principal face to select different sections of said crystal element for generating electrical oscillations the frequency of which may be continuously varied as said electrode is moved over the different crystal sections.

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