

Sept. 2, 1941.

C. F. BALDWIN ET AL

2,254,866

PIEZOELECTRIC CRYSTAL ELEMENT

Filed March 28, 1936

3 Sheets-Sheet 1

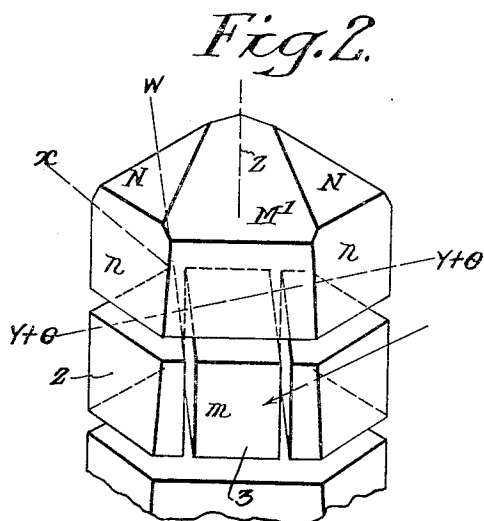
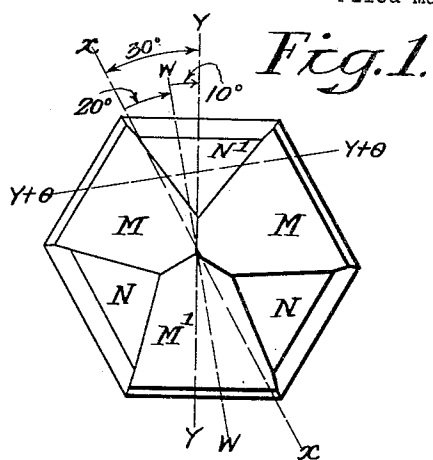


Fig. 3.

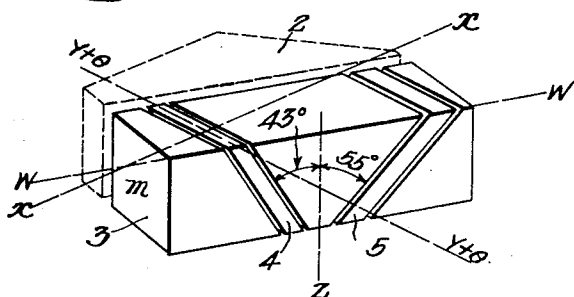


Fig. 4.

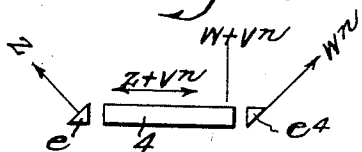


Fig. 5.

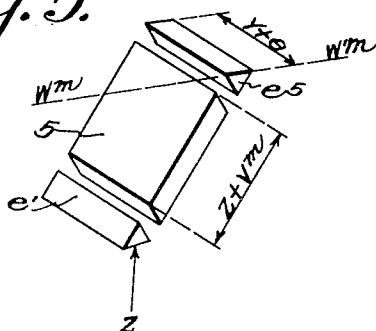
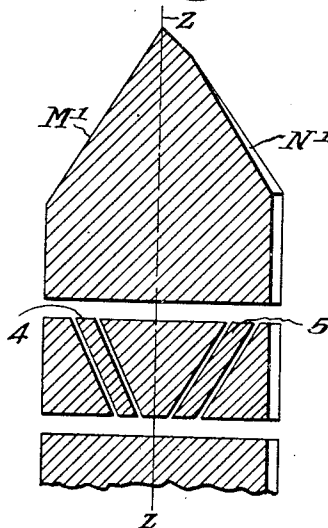


Fig. 6.



Inventors
 Samuel R. Bokoroy
 Charles F. Baldwin
 by *[Signature]*
 Attorney.

Sept. 2, 1941.

C. F. BALDWIN ET AL

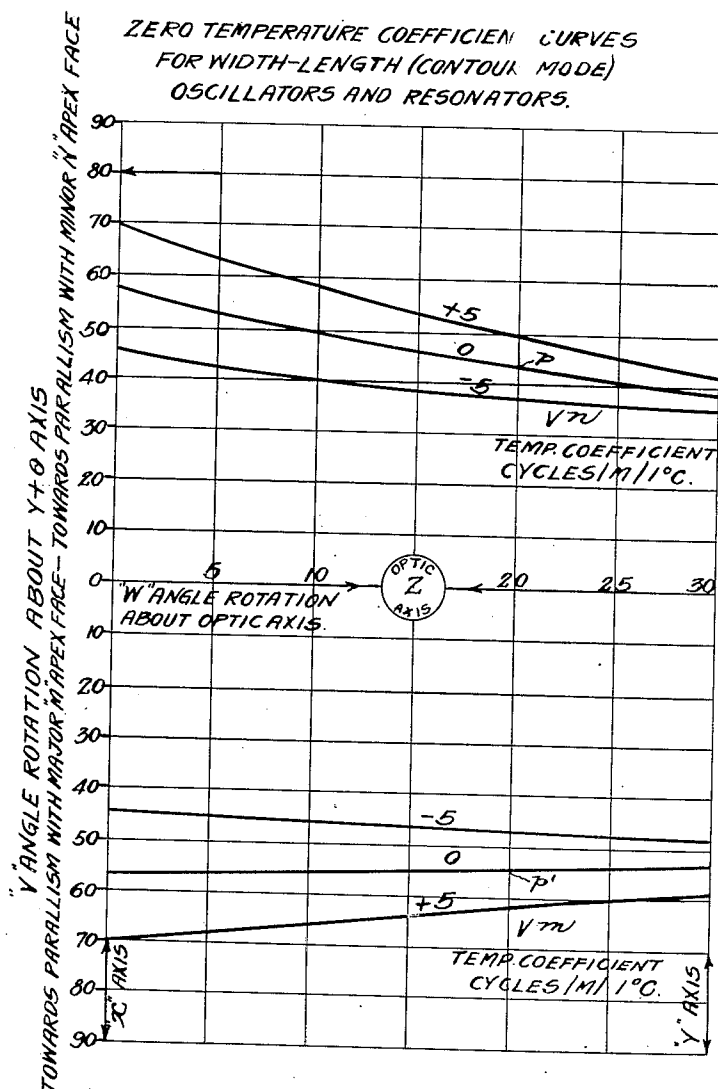
2,254,866

PIEZOELECTRIC CRYSTAL ELEMENT

Filed March 28, 1936

3 Sheets-Sheet 2

Fig. 7.



Inventors
Samuel R. Bokovoy
Charles F. Baldwin
by *J. J. J.*
Attorney.

Sept. 2, 1941.

C. F. BALDWIN ET AL

2,254,866

PIEZOELECTRIC CRYSTAL ELEMENT

Filed March 28, 1936

3 Sheets-Sheet 3

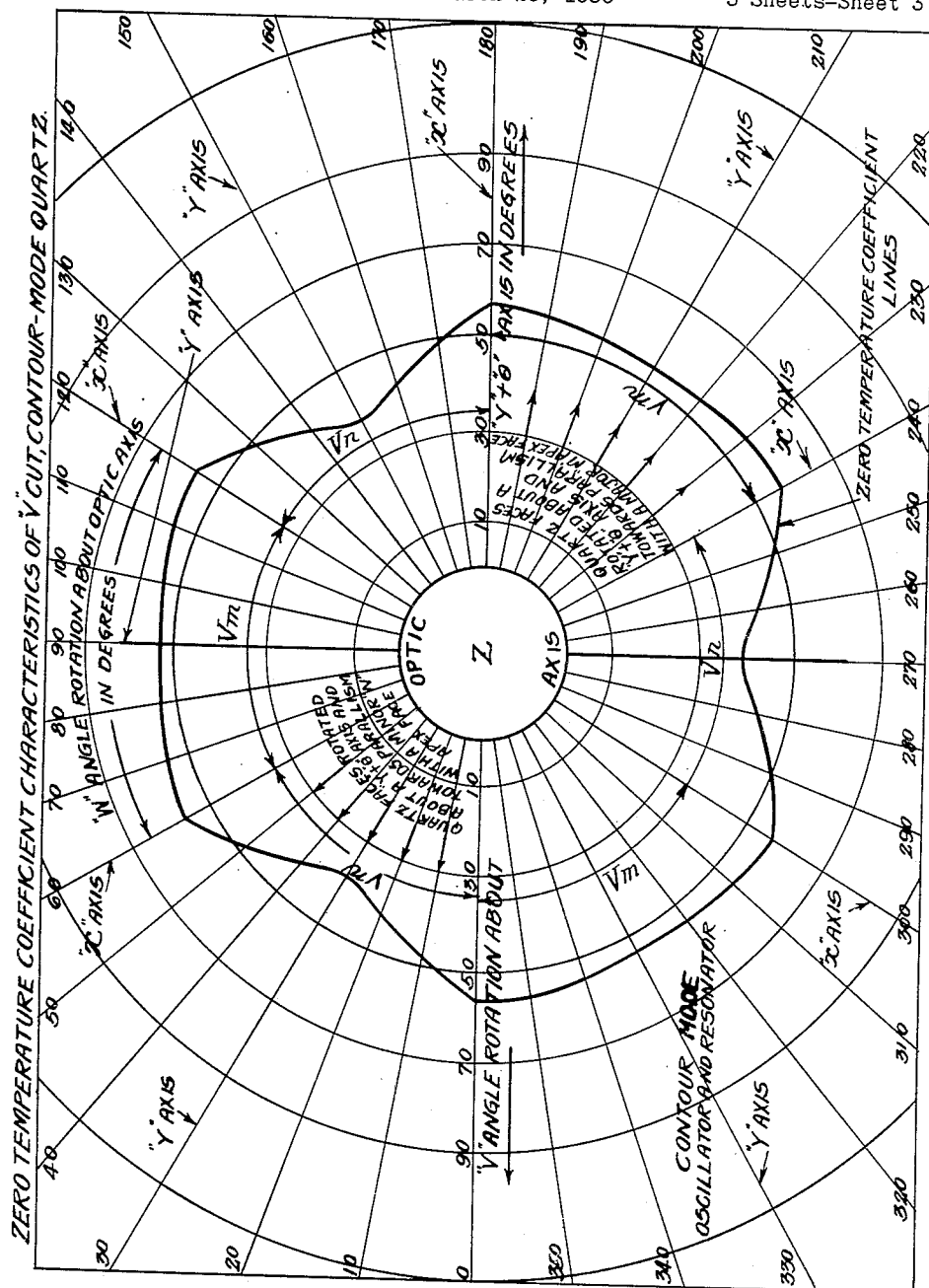


Fig. 8.

Inventors
 Samuel A. Bokoroy
 Charles F. Baldwin
 by *J. H. Hoff*
 Attorney.

UNITED STATES PATENT OFFICE

2,254,866

PIEZOELECTRIC CRYSTAL ELEMENT

Charles F. Baldwin, Schenectady, N. Y., and Samuel A. Bokovoy, Audubon, N. J., assignors to Radio Corporation of America, a corporation of Delaware

Application March 28, 1936, Serial No. 71,388

13 Claims. (Cl. 171—327)

This case is a continuation in part of application Serial No. 733,362 entitled "Piezo-electric crystal elements" to Samuel A. Bokovoy and Charles F. Baldwin, filed July 2, 1934, and assigned to the same assignee as the instant case.

This invention relates to the piezo-electric art, particularly to the cutting of quartz crystals and has special reference to the manufacture of piezo-electric elements of the type possessing a useful natural mode of vibration which is a function of length, or of width. Such crystal elements are known in the art as "contour-mode" or as "length-mode" or "width-mode" oscillators and resonators. Usually the fundamental frequency to which such crystal elements are cut is lower than that characteristic of so called "thickness-mode" crystals.

The principal object of the present invention is to provide a quartz piezo-electric element which shall exhibit a zero or other desired low temperature coefficient of frequency when vibrated at a frequency which is a function of its length or breadth.

Another object of the invention is to provide a simple, accurate and efficient procedure for the cutting of contour-mode crystals and to eliminate as far as possible any uncertainties with regard to the temperature coefficient of frequency and other operating characteristics of the finished elements.

Another object of the invention is to provide a system of orientation for use in the cutting of low temperature coefficient of frequency piezo-electric elements which is applicable, without change, to quartz having a crystalline structure of either "left-hand" or "right-hand" type.

Other objects and advantages will be apparent and the invention itself will be best understood by reference to the following specification and to the accompanying drawings, wherein:

Fig. 1 is plan view of a natural or "mother" quartz crystal, the optic (Z) axis of which is perpendicular to the plane of projection; the relative location of the apex, the major and minor apex surfaces, an electric (X) axis, a mechanical (Y) axis, a reference W axis and a reference $Y+\theta$ axis are also marked as an aid to a clear understanding of the system of orientation followed in producing contour-mode quartz elements in accordance with the invention.

Fig. 2 shows in outline and in perspective a piece of natural quartz having a section cut and divided to provide a rough bar having top and bottom surfaces lying in planes which are normal to the Z-axis and its long edges parallel to

a W-axis which is 20° removed from an X-axis.

Fig. 3 is an elevational view looking in the direction of the arrow of Fig. 2 showing the position of two blanks cut from the bar of Fig. 2, one of these blanks is tilted towards parallelism with the plane of a major apex surface of the mother crystal and the other towards parallelism with the plane of a minor apex surface of the mother crystal.

Fig. 4 shows the left-hand blank of Fig. 3 removed and trimmed, the plane of projection being perpendicular to the plane of the paper.

Fig. 5 shows the right-hand blank of Fig. 3 removed and trimmed.

Fig. 6 is a cross-sectional view taken on the line W—W of Fig. 1 showing the rotation of the blanks about a $Y+\theta$ reference axis of a mother-crystal and with respect to the major and minor apex surfaces thereof.

Fig. 7 is a chart showing the correlation between certain angles W^n-V^n , and W^m-V^m , required to achieve a contour-mode oscillator having a zero or other low temperature coefficient of frequency.

Fig. 8 is a chart indicative of the characteristics of contour-mode quartz plates rotated throughout the entire 360° scale about the Z-axis.

The present invention involves a system of orientation in which (a) the major and minor apex surfaces of the mother crystal are employed as reference planes and (b) certain W-axis and (c) certain $Y+\theta$ axes are employed as reference axes. It is, therefore, necessary to identify these planes and axes.

As to (a), referring to Figs. 1 and 2 of the drawings and having in mind that all unbroken quartz crystals are uniformly shaped hexagonal bi-pyramids, it will be seen that certain of the terminal surfaces of the quartz extend to the apex of the pyramid. These surfaces are designated M and are the major apex surfaces. The terminal surfaces which do not touch the apex are designated N and are the minor apex surfaces of the mother crystal. Occasionally a mother crystal will be found in which more than three of the cap or apex faces extend to the tip of the pyramid, other crystals may have their pyramid ends broken off. No confusion, however, need exist as to the virtual location of the major and minor apex faces of a broken or otherwise abnormal crystal providing that the side faces "m" and "n," or one of them, is intact, for it will be apparent from an inspection of Fig. 2 that those side edges of the mother crystal which

approach each other in the direction of its ends terminate in a major apex face, while those which diverge in this direction terminate in a minor apex face. This is so in the case of both "left-hand" and "right-hand" quartz.

As to (b), Fig. 1 is marked to show an electric, X-axis and an adjacent mechanical or crystallographic, Y-axis. The optic or Z-axis, marked in Fig. 2, is perpendicular to the plane of projection in Fig. 1. The W-axes lie in the X-Y plane, i. e. in a plane normal to the Z-axis. All axes which intersecting a reference X-axis form W-angles of from 0° to 30° therewith are reference W-axes within the purview of the invention. In accordance with this definition a 0° W-axis coincides with an X-axis and a 30° W-axis coincides with a Y-axis 30° removed (in either direction) from said X-axis. In Fig. 1, there is a W-axis marked which forms a W-angle of 20° with that X-axis which is designated X-X.

As to (c), there is $Y+\theta$ axis for each W-axis, each $Y+\theta$ axis is normal to its own W-axis and normal to the Z-axis. It is about a $Y+\theta$ axis that the element is rotated or tilted to achieve a desired temperature coefficient of frequency.

In order to produce a quartz piezo-electric element or "plate" having a predetermined low-temperature coefficient, a suitable angle of orientation (angle W) with respect to an X-axis, and a coordinated angle representing the inclination of the electrode (i. e. "top" and "bottom") faces must be chosen. This latter angle will be referred to generally as the "V-angle" and more specifically as the " V^m angle" or the " V^n angle" as determined by the direction of rotation, i. e. whether toward parallelism with the plane of a major apex surface (m) or a minor apex surface (n) of the mother crystal.

Referring now to Fig. 7 which shows the correlation between the temperature coefficient and the angles W and V. In this chart an X-axis and an adjacent Y-axis are indicated by the vertical, correspondingly designated, lines and the space or region therebetween is calibrated in degrees from the X-axis, the calibrations being along the horizontal line which intersects the centrally marked optic axis, Z. In agreement with the previously given definition a line extending at right angles at any point along this 0°-30° line will coincide with a W-axis.

It will be noted that there are two scales marked along the line representing the X-axis. That scale which reads in an "upward" direction from 0° represents a rotation of the electrode faces of the element about its $Y+\theta$ axis in a direction away from parallelism with the Z-axis and towards parallelism with the plane of a minor apex surface of the mother crystal, the calibrations V^n being in degrees from parallelism (0°) with the Z-axis. That scale which reads in a "downward" direction from 0° represents a rotation of the electrode faces of the element about its $Y+\theta$ axis in a direction away from parallelism with the Z-axis and towards parallelism with the plane of a major apex surface of the mother-crystal; the calibrations V^m like those of V^n being in degrees from parallelism with the optic (Z) axis.

Now, having in mind that there is a $Y+\theta$ axis for and normal to each W-axis, then, from an examination of this Fig. 7 it will be seen that for each W-axis which forms a 0° to 30° angle (W) there is a definite angle of rotation (V^n or V^m) required to achieve a desired temperature coefficient of frequency. For example, assuming

that a piezo-electric element is required which shall exhibit a substantially zero temperature coefficient of frequency, assuming further that such element is to be so cut that its electrode faces are tilted in a direction away from parallelism with the Z-axis and towards parallelism with the plane of a minor apex surface of the mother-crystal. Now, selecting a W angle on the upper scale, say 20°, (read along the horizontal line which intersects the Z-axis), then, the correlated V^n angle of rotation of the electrode surfaces about the $Y+\theta$ axis is substantially 43°, this latter reading being obtained by observing at what point on the upper left hand scale a line will fall projected at right angles to a 20° W-axis from a point (p) at which the said W axis crosses the zero temperature-coefficient line.

An element exhibiting a zero temperature coefficient of frequency may likewise be achieved by tilting the electrode surfaces about a $Y+\theta$ axis towards parallelism with the plane of a major apex surface. Thus, assuming as in the above example that a 20° W-axis is selected, then, reading the lower left-hand scale at the point (p') where a 20° W-axis crosses the zero temperature coefficient line it will be seen that the correlated V^m angle of rotation is substantially 55°.

The curves of Fig. 7 show clearly that the invention is not limited in its scope to the cutting of piezo-electric plates having an exactly zero temperature coefficient of frequency. For certain uses the characteristic to be sought is a definite positive or negative temperature coefficient. Such crystal elements have great utility in oscillator circuits which inherently have certain temperature coefficients of frequency irrespective of the crystal frequency control therefor. Thus it becomes advantageous at times to use a crystal control element having a temperature coefficient of frequency which is of opposite sign to, and substantially compensates for, the natural temperature coefficient of frequency of the oscillator network per se.

To determine the V^n or the V^m angle of rotation required to achieve a piezo-electric element having a particular coefficient of frequency the left-hand scale of Fig. 7 should be read at the point where the selected W-axis crosses the line specific to the temperature coefficient desired. But three temperature coefficient curves are marked in each of the charts of Fig. 7. There is a zero temperature coefficient curve (the center curves, each marked (" ± 0 ") for each direction of tilt. The curves on opposite sides of the "zero line" of the upper chart embrace the V^n and V^m angles, required to achieve an element exhibiting a temperature coefficient of frequency of +5 cycles and -5 cycles, respectively, per million, per degree centigrade. The curves on the opposite sides of the "zero line" of the lower chart embrace the W^m and V^m angles required to achieve an element exhibiting a temperature coefficient of frequency of -5 cycles and +5 cycles, respectively, per million, per degree centigrade. It is obvious that other curves representative of other temperature coefficients of frequency may be derived from the ones illustrated.

As a matter of manufacturing convenience it is often desirable to select "standard" W-angles from the substantially infinite number available within the 0°-30° range. Recommended "standard" W-angles and their correlated V-angles required to achieve a "contour-mode" piezo-electric quartz element of a desired low temperature

coefficient of frequency (as derived from the chart of Fig. 7.) are:

direction of tilt and with the temperature coefficient. Furthermore, it is possible to produce

Electrode faces tilted towards a minor (n) apex surface

	W ⁿ	0°	5°	10°	15°	20°	25°	30°
0 T. C.	V ⁿ	Degrees 57	Degrees 53	Degrees 49	Degrees 46	Degrees 43	Degrees 40	Degrees 38.6
+5 T. C.	V ⁿ	70	63	58	53	49	45	42
-5 T. C.	V ⁿ	45	42	40	38	37	36	35

Electrode faces tilted towards a major (m) apex surface

	W ^m	0°	10°	20°	30°
0 T. C.	V ^m	Degrees 57	Degrees 56	Degrees 55	Degrees 54
+5 T. C.	V ^m	70	66	62	59
-5 T. C.	V ^m	45	46	48	49

Any X-axis may be selected as the reference axis from which the W-axis is measured. This is brought out in the chart of Fig. 8 which shows the correlation required between the W and V angles for zero temperature coefficient "contour-mode" quartz plates, throughout the entire 360° scale about the Z-axis.

Referring in detail to Fig. 8, there are three X-axes and three Y-axes passing through the Z-axis and dividing the 360° scale into twelve 30° segments. Each X-axis coincides with a 0° W-axis, each Y axis coincides with a 30° W-axis, all of these X and Y axes and all of the substantially infinite number of axes lying in the same (X—Y) plane are W-axes and any one may be selected as a reference axis in carrying the invention into effect. There is a zero temperature coefficient line which passes through each (W) axis in the X—Y plane. This line has dissimilar opposite shaped segments, which are marked for purposes of illustration, by the curved arrows Vⁿ and V^m. Wherever a W-axis touches one of these segments V^m or Vⁿ of the zero temperature coefficient line, there, is the second or V-angle of rotation required to be known in the cutting of contour-mode quartz crystal elements possessing a zero temperature coefficient of frequency. The scale for reading V-angles is marked in degrees in two directions along that X-axis which divides the main 360° scale horizontally. The exponents "m" and "n" are indicative of the direction of tilt with respect to the plane of a major (m) and minor (n) apex surface of the mother crystal. The readings obtained from this scale will be found to correspond to those of the chart of Fig. 7.

The dimensions of the finished elements necessary to produce a desired frequency may be determined according to the usual methods. One preferred method, however, is that taught in U. S. Patent 2,064,288 to Samuel A. Bokovoy. In that patent it was shown how a dimension (other than thickness) perpendicular to the optic axis may be chosen according to known frequency constants, and the other of the two greater dimensions may gradually be reduced until the desired frequency is obtained.

It is not deemed essential to a complete disclosure of the present invention that specific constants be given with respect to the relation between dimensions and frequency characteristics. These constants vary extensively not only with the W-angle and with V-angle but also with the

satisfactory crystal elements having a considerable range of length-to-breadth ratios. Square faced crystals have proven very satisfactory as well as those of more or less oblong proportions. The thickness dimension is of almost negligible moment in determining the length-and-breadth mode frequency characteristic.

As illustrative of a preferred manner of cutting contour-mode quartz piezo-electric elements having a zero or some other low temperature coefficient of frequency reference is had to Figs. 1 to 6 inclusive.

Referring first to Fig. 2, a section 2, say one inch thick, is first sliced from the body of the mother crystal, the thickness dimension of this section is parallel with, and the length-breadth dimension of this section is normal to the Z-axis. A bar 3, say one inch wide, is then cut from this section 2, preferably at substantially the exact W-angle selected as a reference axis. In the illustrated embodiment the long dimensions of the bar 3 coincide with a W-axis which is 20° removed from that X-axis (and hence 10° removed from that Y-axis) marked in both Figs. 1 and 2.

Referring to Figs. 3 and 4, the blanks 4 and 5 from which the finished elements are formed are then sliced from bar 2 at either a V^m angle or Vⁿ angle dictated by the temperature coefficient desired. The electrode faces of blank 4, as shown have been rotated substantially 43° (the Vⁿ angle) about its Y+θ axis in a direction away from parallelism with the Z-axis toward parallelism with the plane of that minor apex surface of the mother crystal which is designated N₁ in Figs. 1 and 4. (In Fig. 2, N₁ is opposite the major apex surface designated M₁.) This 43° Vⁿ angle is shown in Figs. 7 and 8, to be the precise angle required to achieve a substantially zero temperature coefficient of frequency—when the selected W-axis forms a W-angle with an X-axis of 20°.

The electrode faces of blank 5 of Figs. 3 and 4 have been rotated substantially 55° (the V^m angle) about its Y+θ axis in a direction away from parallelism with the Z-axis towards parallelism with the plane of that major apex surface of the mother crystal which is designated M₁ in Figs. 1, 2 and 4. This blank 5, like blank 4, will exhibit a substantially zero temperature coefficient of frequency when vibrated at a frequency which is a function of one of its greater dimensions.

The proper length-width dimensions required to achieve a desired contour-mode frequency having been determined, it remains only to grind and lap these blanks to size, and to trim the edges (e, e¹ Fig. 4, e', e⁵ Fig. 5) so that planes of the electrode faces Z+V are normal to the W+V thickness dimension. It is preferable to bevel the edges and round the corners of the otherwise finished elements of Figs. 4 and 5 in order to remove minute irregularities in the cutting and to prevent chipping in case the crystals should be excited at very great amplitudes of oscillations.

As in prior art contour-mode oscillators and resonators the thickness-dimension has little or no effect upon oscillation performance.

Although certain specific ways and means for accomplishing the objects of the invention have been set forth it is to be understood that they have been given for the purpose of explaining the inventive concept and should not be construed as limitations to the scope of the invention. Neither is it to be understood that any statements herein made in regard to the value or relationships between angles or orientation and "temperature coefficients of frequency" are other than close approximations.

The invention, therefore, is not to be limited except insofar as is necessitated by the prior art and by the spirit of the appended claims.

What is claimed is:

1. The invention as set forth in claim 2 wherein in the angle formed by the intersection of said electric (X) axis and said W-axis is at least 1° and not more than 29° .

2. A quartz piezo-electric element cut from a mother crystal having a major apex surface, a minor apex surface, an optic (Z) axis, an electric (X) axis, a mechanical (Y) axis, a W-axis and a $Y+\theta$ axis, said W-axis lying in the X-Y plane and said $Y+\theta$ axis being normal to said W-axis, said element having its electrode faces so tilted about said $Y+\theta$ axis in a direction away from said optic (Z) axis and away from the plane of one of said apex surfaces, toward parallelism with the plane of the other of said apex faces, that it possesses a temperature coefficient of frequency within substantially ± 5 cycles per million per degree centigrade when vibrated at a fundamental contour-mode frequency, the direction and the angle of tilt of said element about the $Y+\theta$ axis necessary to achieve said temperature coefficient of frequency being such a function of the angle formed by the intersection of the W-axis and the electric (X) axis as indicated by the curves of Fig. 7.

3. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 70° to substantially 35° about a $Y+\theta$ axis in a direction away from parallelism with the Z-axis and towards parallelism with the plane of a minor apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° , whereby said element exhibits a temperature coefficient of frequency within substantially ± 5 cycles per million per degree centigrade when vibrated at a fundamental contour-mode frequency.

4. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 70° to substantially 42° about a $Y+\theta$ axis in a direction away from parallelism with the Z-axis and towards parallelism with the plane of a minor apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° , whereby said element exhibits a temperature coefficient of frequency of substantially $+5$ cycles per million

per degree centigrade when vibrated at a fundamental contour-mode frequency.

5. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 45° to substantially 35° about a $Y+\theta$ axis in a direction away from parallelism with the Z-axis and towards parallelism with the plane of a minor apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° , whereby said element exhibits a temperature coefficient of frequency of substantially -5 cycles per million per degree centigrade when vibrated at a fundamental contour-mode frequency.

6. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 57° to substantially 38.6° about a $Y+\theta$ axis in a direction away from parallelism with the Z-axis and towards parallelism with the plane of a minor apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° , whereby said element exhibits a substantially zero temperature coefficient of frequency when vibrated at a fundamental contour-mode frequency.

7. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 70° to substantially 45° about a $Y+\theta$ axis in a direction away from parallelism with the Z-axis and toward parallelism with the plane of a major apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° whereby said element exhibits a temperature coefficient of frequency within substantially ± 5 cycles per million per degree centigrade when vibrated at a fundamental contour-mode frequency.

8. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 70° to substantially 59° about a $Y+\theta$ axis in a direction away from parallelism with the Z-axis and toward parallelism with the plane of a major apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° whereby said element exhibits a temperature coefficient of frequency of substantially $+5$ cycles per million per degree centigrade when vibrated at a fundamental contour-mode frequency.

9. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 45° to substantially 49° about a $Y+\theta$ axis in a direction away from parallelism with

the Z-axis and toward parallelism with the plane of a major apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° whereby said element exhibits a temperature coefficient of frequency of -5 cycles per million per degree centigrade when vibrated at a fundamental contour-mode frequency.

10. A quartz piezo-electric element cut from a mother crystal having major and minor apex surfaces, said element having its electrode faces parallel to a plane which is rotated from substantially 57° to substantially 54° about a $Y+\theta$ axis in a direction away from parallelism with the Z-axis and toward parallelism with the plane of a major apex surface, said $Y+\theta$ axis being normal to a W-axis which lies in a plane containing an X-axis and a Y-axis the angle formed by the intersection of said W-axis and said X-axis being between the limits of substantially 0° and not more than 30° whereby said element exhibits a substantially zero temperature coefficient of frequency when vibrated at a fundamental contour-mode frequency.

11. The invention as set forth in claim 2

wherein the angle formed by the intersection of said electric (X) axis and said W-axis is less than 1° .

12. A quartz piezo-electric element having its electrode faces substantially parallel to an electric (X) axis and inclined substantially 38 degrees with respect to the optic (Z) axis in the positive direction or toward parallelism with a minor apex face of the mother crystal from which said element is cut, whereby said element exhibits a substantially zero temperature coefficient of frequency when vibrated at a fundamental frequency which is a function of one of its greater dimensions.

13. A quartz piezo-electric element having its electrode faces substantially parallel to an electric (X) axis and inclined substantially 53 degrees with respect to the optic (Z) axis in the negative direction or toward parallelism with a major apex face of the mother crystal from which said element is cut, whereby said element exhibits a substantially zero temperature coefficient of frequency when vibrated at a fundamental frequency which is a function of one of its greater dimensions.

CHARLES F. BALDWIN.
SAMUEL A. BOKOVOY.