Dec. 8, 1942. P. D. GERBER 2,304,760

PIEZO-ELECTRIC CRYSTAL ELEMENT

Filed Jan. 31, 1940 2 Sheets-Sheet 1

Fig. 2.

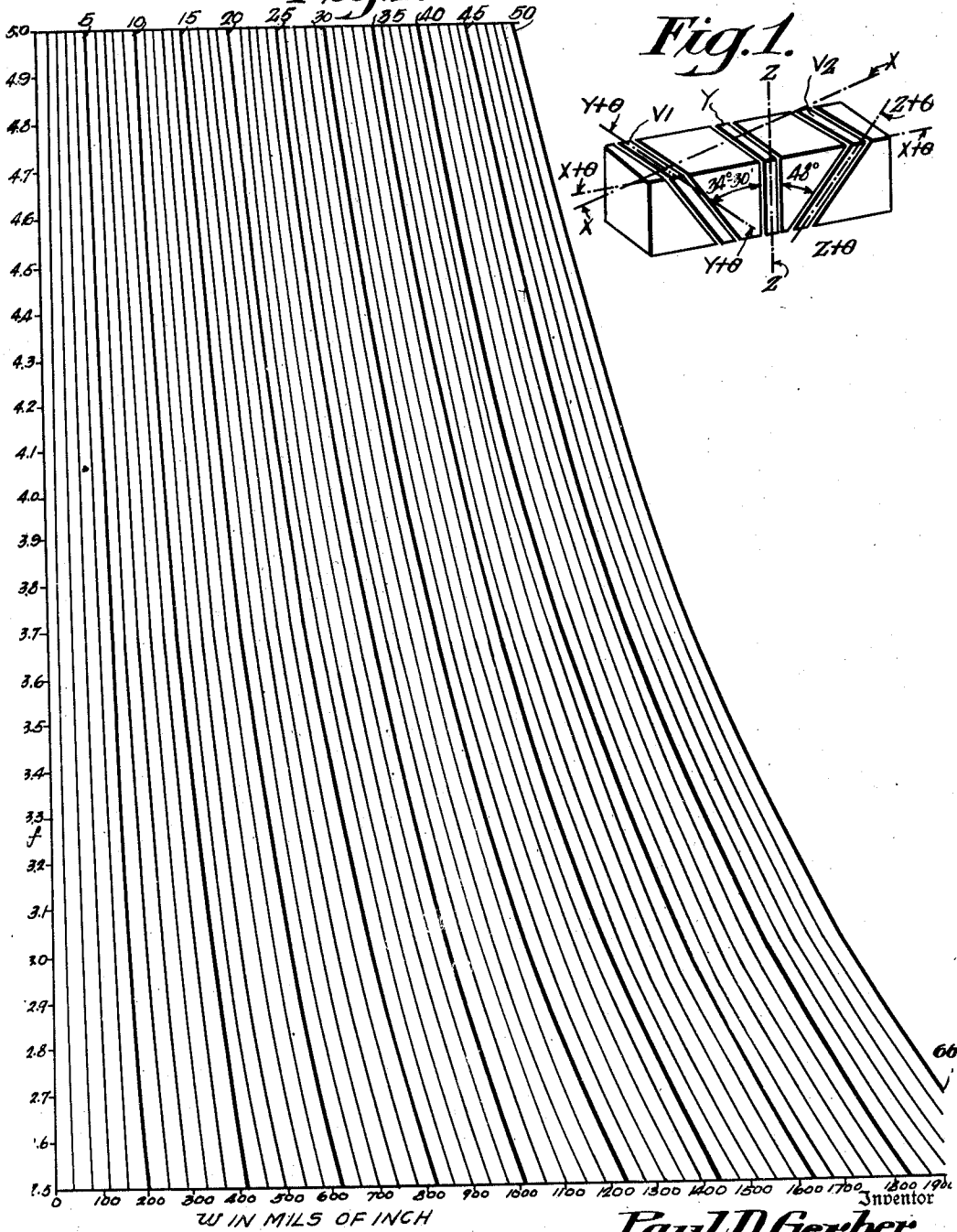


Fig. 1.

Inventor

Paul D. Gerber

By

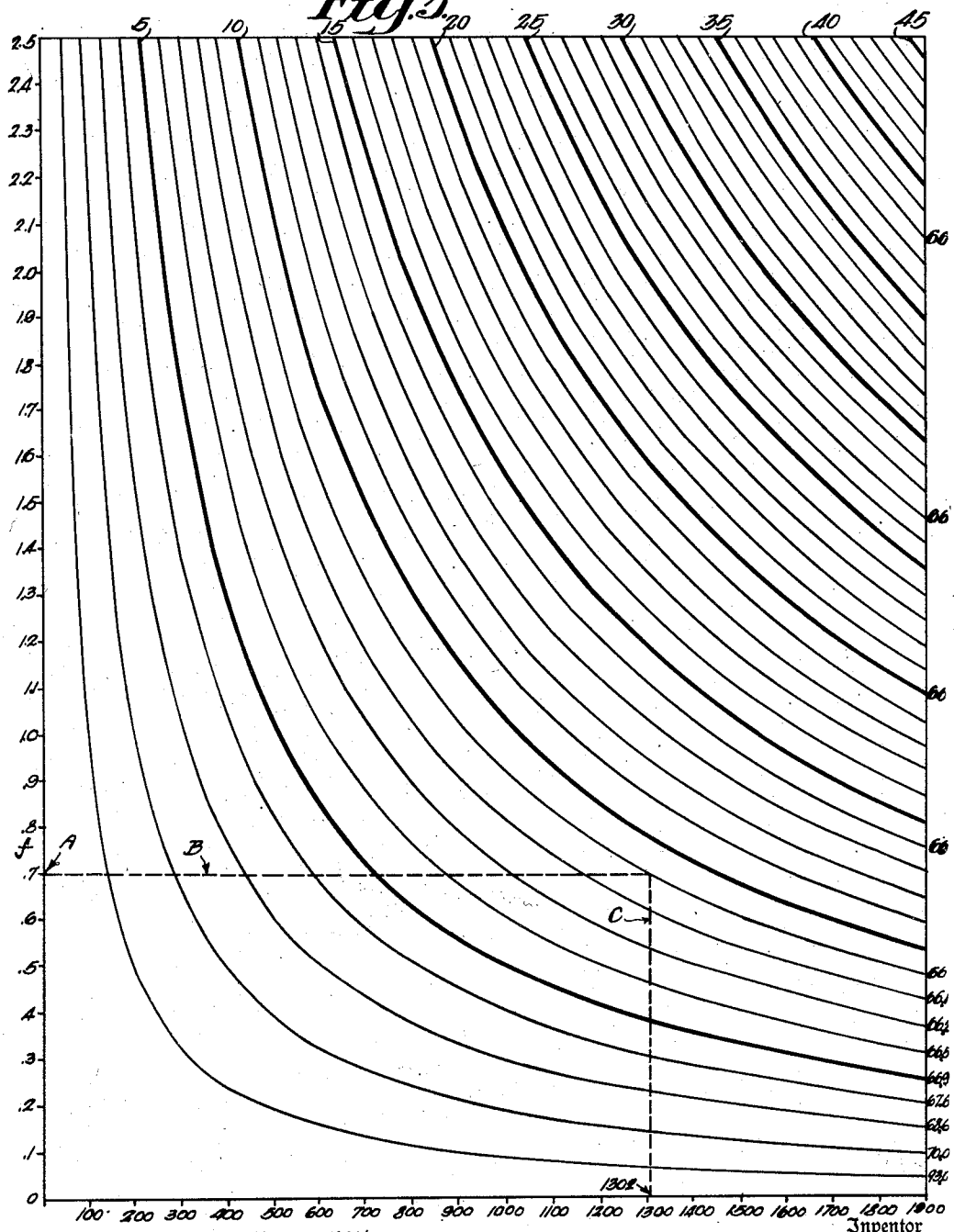
Attorney

Dec. 8, 1942. P. D. GERBER 2,304,760

PIEZO-ELECTRIC CRYSTAL ELEMENT

Filed Jan. 31, 1940 2 Sheets-Sheet 2

Fig. 3.



Inventor

Paul D. Gerber

By

Attorney

Patented Dec. 8, 1942

2,304,760

UNITED STATES PATENT OFFICE

2,304,760

PIEZOELECTRIC CRYSTAL ELEMENT

Paul D. Gerber, Woodlynne, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 31, 1940, Serial No. 316,612

4 Claims. (Cl. 171—327)

This invention relates to the art of cutting quartz piezo-electric elements of the type that exhibits a "shear type" of thickness vibration. Thus, it will be understood that the invention herein described is applicable to all thickness-mode quartz blanks or elements wherein the electrode or major faces are tilted with respect to the optic (Z) axis of the mother crystal (see British Patent 457,342 of 1936), as well as to so-called Y-cut crystals (see Tillyer 1,907,613) and to X+θ crystals (see Bokovoy 2,176,653), but is not applicable to X-cut crystals (see Taylor and Crossly 1,724,232). (As is now appreciated by those skilled in the art, X-cut crystals exhibit a "longitudinal" type of thickness vibration.)

The ordinary electrical constants (e. g., resistance, capacitance and inductance) have their equivalents in quartz. These equivalent constants or characteristics are known to those skilled in the art and, in any event, can be readily ascertained in the case of a given element. Thus, a technician confronted with two piezo-electric elements having the same thickness-mode frequency but of different length-breadth dimensions can readily ascertain which of the two is the better adapted, electrically, for use in a circuit having known circuit constants. The trouble with this procedure is that his calculations may dictate the use of a crystal element whose piezo-electric properties are unsuited for the particular task in hand. By way of example, the crystal selected by this procedure may exhibit a relatively weak piezo-electric effect or its operation may be characterized by the presence of disturbing "spurious" frequencies. The same objections obviously obtain when one calculates in advance the dimensions required to endow a crystal blank with the electrical (as distinguished from piezo-electrical) characteristics necessary to match it to a particular circuit.

Considered from another aspect: It would be of considerable advantage to the manufacturer of thickness-mode crystals if he could adopt certain length-breadth dimensions as a standard not only for his crystals but also for the holders or mountings therefor, and could adhere to such standard dimensions substantially irrespective of the frequencies of the various crystal elements which he is called upon to produce. But such standardization has heretofore been thought impossible of practical achievement since, as previously indicated, of two crystal elements having the same length and breadth dimensions but of different thickness-mode frequencies, the one may exhibit excellent piezo-electric properties while the other, judged by present day standards, may be such a poor performer that it is of little or no commercial value.

Accordingly, the principal object of the present invention is to provide a "shear type" thickness-mode crystal which shall exhibit (*a*) the optimum piezo-electric effect, (*b*) a unitary freedom for its thickness-mode of vibration, and (*c*) one which is nevertheless of a size approximating that suggested, for example, by the electrical constants of the circuit or by the size of the holder or other apparatus in which or with which it is to be used.

Other objects and advantages, together with certain preferred methods of procedure for carrying the invention into effect, are brought out in the specification and in the accompanying drawings, wherein

Figure 1 is a quartz bar from which three blanks of different known orientations have been cut, and

Figures 2 and 3 comprise a family of curves which, when fitted together by placing Fig. 3 under and in register with Fig. 2, form a chart which will be referred to in explaining the practice of the invention.

The present invention teaches that if a shear type thickness-mode quartz piezo-electric crystal element is so dimensioned that its width bears any one of certain given dimensional ratios with respect to its thickness, then, and then only, will the finished element exhibit (*a*) its optimum or maximum useful piezo-electric effect and (*b*) substantial freedom from undesired or "spurious" thickness-mode frequencies.

In carrying the invention into effect, it is necessary to know the "standard" frequency constant (K), for thin plates, of the particular crystal blank to which the invention is to be applied. Unfortunately, the published tables of frequency constants now available are not always in agreement. This may be so because the tables are based in part upon mathematical calculations which, more often than not, are figured for blanks of a single size, whereas the fact of the matter is that blanks of different sizes exhibit slightly different constants. Accordingly, where there is any doubt as to the value of K, the technician desiring to practice the invention should, as a matter of routine, ascertain the thickness-mode frequency constant for blanks of the desired orientation as by cutting a thin blank (of the said desired orientation) whose width dimension is at least approximately fourteen times its thickness, and having a length of, say, 1 inch,

and compute its constant (K) in agreement with the well-known formula

$$K = f \text{ times } t \qquad (1)$$

where f is the fundamental thickness-mode frequency of the blank expressed in megacycles, and t is the thickness of the blank measured in mils (thousandths) of an inch. The constant (K) thus obtained is the "standard" constant to which reference is made in the following examples.

Referring now to Fig. 1. The "standard" frequency constants (K) for the thin quartz blanks V1, Y and V2 are

V1, K equals 66
Y, K equals 78
V2, K equals 99

Each of these blanks is of a known orientation. The center blank Y is a Y-cut blank (see Tillyer 1,907,613) and the blanks V1 and V2 are so-called "V-cut" blanks, which, as described in the aforesaid British Patent 457,342 exhibit a very low temperature coefficient of frequency.

The blank V1 has its major or "electrode" faces rotated substantially 34°30' about a $Y+\theta$ axis which is normal to a reference axis $X+\theta$ which lies substantially 25° removed from an X-axis in the X—Y plane. The direction of rotation is toward parallelism with the plane of a minor (n) apex face (not shown) of the mother crystal. The orientation of the blank V1 may, accordingly, be expressed as follows:

$$25° \; X+\theta, \; 34°30' \; Z+\theta^n$$

The blank V2 has its major or "electrode" faces rotated substantially 48° about a reference axis $Y+\theta$ which is normal to a reference axis $X+\theta$ which lies substantially 25° removed from an X-axis in the X—Y plane. The direction of rotation is toward parallelism with the plane of a major (m) apex face (not shown) of the mother crystal. The orientation of the blank V2 may, accordingly, be expressed as follows:

$$25° \; X+\theta, \; 48° \; Z+\theta^m$$

Using the same symbols, the orientation of the Y-cut (or "Tillyer-cut" or 30°-angle cut) blank "Y" of Fig. 1 may be described as follows:

$$30° \; X+\theta, \; 0° \; Z+\theta$$

That dimension of the blanks V1 and V2 which lies along the reference axis $Y+\theta$ is hereinafter referred to as the "width dimension." The length dimension of each of these blanks V1 and V2 thus lies along a $Z+\theta$ axis and the thickness dimension is in the general direction of the $X+\theta$ axis.

The width dimension of the Y-cut blank lies along an X-axis and the length dimension lies along the Z-axis.

EXAMPLE No. 1

The problem: To determine how the quartz blank V1 of Fig. 1 should be "finished" to provide a piezo-electric resonator or oscillator (of any desired frequency) which shall exhibit all three (*a*, *b*, and *c*) of the characteristics described in the fourth paragraph of this specification.

As previously set forth, the "standard" frequency constant (K) for blanks of the orientation of the blank V1 is 66. All of the other information necessary to the solution of the foregoing problem is contained in Figs. 2 and 3 which, when joined (by placing Fig. 3 beneath Fig. 2) comprise a single chart.

This chart shows a family of curves which are separately numbered 1 to 50 inclusive. Each curve is individual to a crystal element whose width is some multiple (usually not an integral multiple) of its thickness dimension. The chart is calibrated along its abscissa (in Fig. 3) in terms of mils of an inch of the width dimension of a crystal element whose length dimension will be understood to be 1 inch, or thereabouts. The left ordinate of the chart is calibrated for frequency in terms of megacycles and fractions of a megacycle. The right ordinate of the chart has been marked to indicate the constants peculiar to crystals of the described V1 orientation. (As will hereinafter more fully appear, when this chart is employed in the design of crystal elements of other orientations, the calibration of the bottom scale and the values of K may be changed to suit crystal elements of that particular orientation.)

A technician, in using the chart of Figs. 2 and 3 and desiring to make a finished piezo-electric element or oscillator of a particular frequency from the quartz blank V1 of Fig. 1, may first select the desired frequency on the left-hand ordinate of the chart. By way of example, let us assume that a frequency of, say, .7 of a megacycle (i. e., 700 kcs.) is selected, as indicated at A in Fig. 3. Now, if a line B is projected at a right angle across this chart and a perpendicular line C is moved across the chart to each point where the line B intersects these curves, one may read at the bottom of the chart a number of different width dimensions, any one of which will ensure a finished 7 kc. element possessing the desired characteristics. More specifically, this chart shows that a 700 kc. V1 type crystal will exhibit the foregoing desirable characteristics provided that its width is of any of the following dimensions, as expressed in mils of an inch: 135; 275; 424; 572; 712; 863; 1010; 1155; 1302; 1458; 1606; 1704 and 1910.

If the crystal is finished to a width other than above indicated, its amplitude of vibration and its freedom from spurious frequencies will be more or less directly proportional to the degree of departure from these dimensions. Thus, the weakest response and the most disturbing spurious frequencies will ordinarily be present in a crystal whose width dimension falls midway between any two successive dimensions in the above summary of dimensions.

An even greater choice of suitable width dimensions can be obtained simply by extending the abscissa and curves of the chart. Such extension has been omitted in the interests of brevity since it is very seldom that one desires to make a crystal element of a width more than substantially two inches. Obviously, one practicing the invention may select that width of crystal most nearly suited for the particular circuit or holder in which the element is to be used.

The thickness dimension required to endow the blank with the particular frequency desired remains to be calculated. It has been determined in reducing the invention to practice that the value of K is fixed in the case of all crystals wherein the width is more than approximately fourteen (say, 13.88) times the thickness dimension but varies in the case of crystals wherein the width dimension is less than substantially fourteen times the thickness dimension. The variation in the case of the described V1 type of crystal element is indicated by the values of K marked along the right-hand ordinate of Fig. 3.

Thus, to determine the exact thickness dimension for any V1 type element, the value of K for the particular width dimension desired may be selected from the said right-hand scale. By way of example, if a blank whose width dimension is, say, 1302 mils of an inch is selected for finishing, its frequency constant K is equal to 66 (indicated adjacent curve 9), whereas one whose width is, say, 424 mils of an inch has a frequency constant (indicated adjacent curve No. 3) of $K=68.6$. Substituting these values of K in the well-known formula

$$t=\frac{K}{f} \qquad (2)$$

it will be seen that the exact thickness of a 700 kc. V1 type crystal whose width is 1302 mils should be approximately 94.3 mils of an inch, whereas the thickness dimension of a similar blank 424 mils wide should be approximately 98 mils of an inch.

EXAMPLE NO. 2

Referring still to the chart of Figs. 2 and 3, it can be shown that the ratio of width to thickness of any crystal whose dimensions are dictated by a particular curve of this chart are as follows:

Table #3

Curve	$\frac{W}{t}$	Curve	$\frac{W}{t}$
1	1	26	40.30
2	2.74	27	41.85
3	4.35	28	43.40
4	5.91	29	44.95
5	7.49	30	46.50
6	9.08	31	48.05
7	10.68	32	49.60
8	12.28	33	51.15
9	13.88	34	52.70
10	15.47	35	54.25
11	17.05	36	55.80
12	18.60	37	57.35
13	20.15	38	58.90
14	21.70	39	60.45
15	23.25	40	62.00
16	24.80	41	63.55
17	26.35	42	64.10
18	27.90	43	66.65
19	29.45	44	68.20
20	31.00	45	69.75
21	32.55	46	71.30
22	34.10	47	72.85
23	35.65	48	74.40
24	37.20	49	75.95
25	38.75	50	77.50

In applying the invention to a crystal blank of an orientation other than a V1 blank (Example 1) it is first necessary to ascertain the "standard" frequency constant (K) which obtains for the particular orientation of the blank which has been selected for finishing. As previously set forth, the "standard" frequency constant is that constant which obtains in all blanks (of the same orientation) whose width is 13.88 or more times its thickness dimension.

The "standard" frequency constant for crystal blanks of the orientation of blank V2 of Fig. 1 is $K=99$.

For crystals having a width less than 13.88 times the thickness dimension the frequency constant (hereinafter occasionally designated K') varies in the same ratio as it does in the case of the standard frequency constant given in the chart of Figs. 2 and 3. The following table of "correction factors" (S) for the standard frequency constant has been derived from the said chart.

Table #4

Curve	Correction factor (S)
1	1.41
2	1.06
3	1.038
4	1.023
5	1.014
6	1.008
7	1.004
8	1.002
9–50	1.000

Let us now assume that it is desired to make a 1 megacycle oscillator from the blank V2 of Fig. 1. Let us also assume (for one of the reasons heretofore given) that it is desired that the finished plate be about one inch square, i. e., as near to these dimensions as it is possible to make an oscillator which exhibits (*a*) the optimum piezo-electric effect, and (*b*) a unitary freedom for its thickness-mode of vibration.

As above mentioned the "standard" frequency constant for the blank V2 is $K=99$. We know that the length dimension is not critical and may be exactly 1 inch, if desired. It is also apparent that in order to obtain an oscillating crystal whose width is approximately one inch, a width-to-thickness ratio of

$$\frac{1000}{(K)99}$$

or 10.1 should be employed. Reference to the foregoing Table #3, however, shows that this exact width-to-thickness ratio does not appear on this table, that is to say, if the width dimension of a V2, 1 megacycle blank were to be made 10.1 times its thickness dimension, the finished element would not exhibit the characteristics (*a* and *b*) desired. It is accordingly necessary to select from the said Table #3 that width-to-thickness ratio which most nearly approximates 10.1, i. e. 10.68. It will be observed from an inspection of the said Table #3 that this ratio of 10.68 is peculiar to curve 7 of the chart of Figs. 2 and 3.

Having identified the number of the "mode" or curve of the finished blank (i. e., curve No. 7) it now remains to determine the substantially exact thickness and width dimensions required to achieve the desired 1 megacycle oscillator. The thickness dimension is determined by the formula

$$t=\frac{K \text{ times } S}{f} \qquad (5)$$

where f=the desired frequency of 1 megacycle, K=the "standard" frequency constant (99) and S=a correction factor which, for the seventh "mode" or curve, is shown (in Table #4) to be 1.004. Therefore:

$$t=\frac{99\times 1.004}{1} \qquad (6)$$

or, solved, thickness=approximately 99.4 mils of an inch.

Finally, to ascertain the width dimension, it is necessary to multiply the thickness dimension 99.4 by the width-to-thickness ratio peculiar to the "mode" or curve No. 7. As shown in Table 3, this ratio is 10.68, hence the width dimension of the finished element should be 99.4 times 10.68 or approximately 1062 mils of an inch.

EXAMPLE NO. 3

Let us assume that it is desired to finish the Y-cut blank of Fig. 1 to provide an oscillator

having a single thickness-mode response of, say 1500 kc. Assume, further, it is desired that the finished element be as near to .5" width, by 1" length, as is possible for an element possessing the desired characteristics (*a* and *b*) to be.

We know that the standard frequency constant of a Y-cut blank is 78. Therefore, the thickness of a blank constructed in agreement with Formula No. 2

$$\left(t=\frac{K}{f}\right)$$

would be 52 mils of an inch. Following the procedure outline in Example No. 2, we find the approximate

$$\frac{w}{t}$$

ratio in this case to be approximately 9.62. Referring to Table 3, we find that the ratio which is closest to 9.62 on this table is the one given in connection with curve or "mode" 6, i. e., 9.08.

Having identified the number of the "mode" or curve (i. e. curve No. 6) of the finished blank, it now remains to determine the substantially exact thickness and width dimensions required to achieve the desired 1500 kc. response. As in Example 2, the thickness dimension is determined by Formula No. 5, i. e., $t=K$ times S, divided by $f=1.5$ (megacycles), $K=78$, and S is the correction factor which, for the 6th "mode" or curve is shown in Table No. 4 to be 1.008. Therefore:

$$t=\frac{78\times 1.008}{1.5} \qquad (7)$$

or, solved, thickness dimension=approximately 52.4 mils of an inch.

Finally, in order to ascertain the width dimension, it is necessary to multiply the thickness dimension of 52.4 mils of an inch by the width-to-thickness ratio peculiar to the mode or curve No. 6. As shown in Table No. 3, this ratio is 9.08; hence, the width dimension of the Y-cut blank of Fig. 1 when finished to a frequency of 1.5 megacycles should be approximately 476 mils of an inch.

The invention is obviously not limited to any particular manner of cutting, grinding, lapping or finishing the quartz blank or elements.

It is well known in the art that in order to obtain a desired frequency characteristic in a piezo-electric quartz element with a nice degree of precision, frequent tests should be made between successive stages of the finishing operation. Such tests may indicate minor departures from the tables, charts and graphs of this specification. Accordingly, the invention 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. A piezo-electric quartz element adapted to respond to a predetermined thickness shear-mode frequency and having a width to thickness ratio selected from Table No. 3 of the accompanying specification, the thickness dimension of said element measured in mils of an inch being substantially that dictated by the formula

$$t=\frac{K \text{ times } S}{f}$$

where f is the said thickness shear-mode frequency of said element, K is the "standard" frequency constant for a quartz blank of the same orientation, and S is a factor peculiar to the said width-to-thickness ratio, the value of said factor being substantially that indicated in Table No. 4 of the accompanying specification.

2. The invention as set forth in claim 1 and wherein K is equal to substantially 66.

3. The invention as set forth in claim 1 and wherein K is equal to substantially 78.

4. The invention as set forth in claim 1 and wherein K is equal to substantially 99.

PAUL D. GERBER.