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C. F. BALDWIN ET AL

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PIEZOELECTRIC ELEMENT

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Fig. 3.

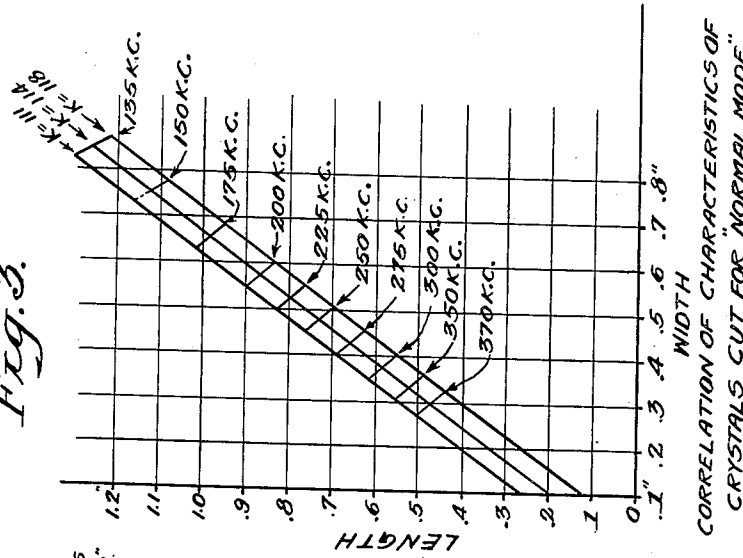
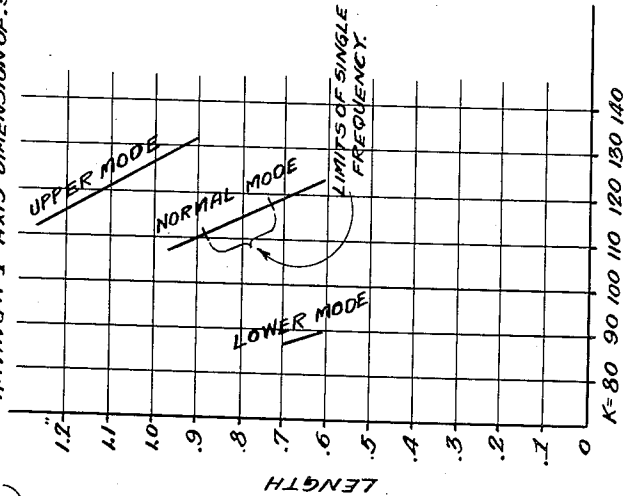


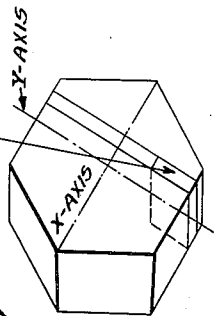
Fig. 2.

TYPICAL CHARACTERISTICS OF PLATES HAVING A Y-AXIS-DIMENSION OF .562"



SLAB FROM WHICH PIEZO-ELECTRIC ELEMENT, HAVING BUT TWO FUNDAMENTAL FREQUENCIES, IS CUT.

Fig. 1.



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PIEZOELECTRIC ELEMENT

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Application June 29, 1935, Serial No. 29,000

13 Claims. (Cl. 171—327)

This invention relates to the piezo-electric art and to the cutting of piezo-electric crystal elements suitable for use in oscillatory circuits. It is an improvement upon the invention disclosed in copending application to Samuel A. Bokovoy, Serial No. 728,377, filed May 31, 1934.

It is known to those skilled in the art that when a quartz-crystal is X-cut, that is to say when it is cut in the form of a rectangular plate so oriented with respect to the mother crystal that its thickness dimension is along an electric (X) axis and its length or width along either the optic (Z) axis, or a mechanical (Y) axis, several modes of vibration and consequently several normal frequency responses are possible of attainment. One of these modes of vibration, namely the thickness or X-mode, is always present.

Where more than one Y-axis mode frequency or oscillatory characteristic is present difficulties sometimes arise because the several modes are not very far apart. It is then possible to tune the tank circuit to any one of these frequencies. In certain instances two of these lower or Y-modes of vibration may be within 50 kilocycles or so of each other. Instances have arisen where, due to a slight misadjustment of the tuning circuit two of the Y-mode frequencies of the crystal would appear simultaneously.

Samuel A. Bokovoy in the above-identified copending application sets forth his discovery that this undesired operating characteristic may be obviated by cutting the piezo-electric element in a novel manner so that of several Y-mode frequencies at first present only one will remain in the finished element. A crystal so cut will, of course, also respond to an X-mode frequency which is always present. In a given crystal the frequency characteristic of this mode of vibration is usually much higher than any of the several Y-modes originally present and seems to bear no definite relation thereto; that is to say, it is usually not a whole number multiple of any of the frequencies characteristic of the lower or Y-axis modes of vibration.

A principal object of the present invention is to provide a piezo-electric crystal element that will oscillate at only two fundamental frequencies, each of the frequencies bearing a predetermined useful relation to the other.

Another object of the invention is to provide a piezo-electric crystal element free to oscillate at only two fundamental frequencies, one of the frequencies being a multiple of the other, the lower frequency being a function of the Y-axis dimension of the element and the higher frequency being a function of its X-axis dimension.

Another object of the invention is to provide a piezo-electric crystal element capable of doing the work of two, especially where the frequencies desired are relatively far apart, as for example 200 k. c. and 2000 k. c., 100 k. c. and 900 k. c., etc.

Another object of the invention is to provide a simple, accurate and efficient mode of procedure for the design and for the cutting of crystals having the described oscillatory characteristics.

Other objects and advantages of the invention will be apparent from the following description taken in connection with the accompanying drawing wherein:

Figure 1 shows a section of a mother crystal of some piezo-electric material, preferably of quartz, having its ends cut off in planes perpendicular to the optic (Z) axis thereof, with a section X-cut into a rectangular plate so oriented with respect to the mother crystal that its thickness dimension is along an electric (X) axis, its width parallel to a mechanical (Y) axis and its length along the optic (Z) axis;

Fig. 2 is a graphic chart showing the relation between the length of a crystal along the optic (Z) axis and the Y-mode frequency constant thereof, and illustrating how crystals of like width but of different lengths may be caused to oscillate to produce any one or more of three Y-mode frequencies; and

Fig. 3 is another graphic chart indicating illustratively certain of the necessary relations between length, width, Y-mode frequency constant and normal Y-mode frequency of quartz crystals.

Both Figs. 2 and 3 are borrowed from the above-mentioned application of Samuel A. Bokovoy, Serial No. 728,377.

Given a crystal cut in accordance with application Serial No. 728,377, that is to say, one having a single Y-mode frequency response and an X-mode response of random or unrelated frequency, we have found that the objects of the present invention may be simply attained by

choosing a suitable thickness for the crystal in accordance with the formula—

$$t = \frac{K_x}{f_x} \quad (1)$$

where the thickness t is expressed in mils or thousandths of an inch; the desired multiple or X-mode frequency f_x in megacycles and the value of K_x is approximately 113.

While it is entirely practical to first achieve the higher, X, or thickness-mode frequency in accordance with the above formula and then correlate the length-width dimensions of the crystal to that of the thickness dimension in order to achieve a desired single, preferably lower, Y-mode frequency, we prefer first to achieve the single Y-mode frequency in accordance with the Bokovoy disclosure and then grind or lap the crystal to the thickness dimension dictated by our present formula.

In following this preferred practice a suitable width for the crystal is first chosen in accordance with the Y-mode frequency desired and in accordance with the earlier Bokovoy formula—

$$W = \frac{K_y}{f_y} \quad (2)$$

The Y-mode frequency f_y is here expressed in megacycles, the width W in mils, or thousandths of an inch, and the value of K_y is a function of the length, as will be observed by reference to Fig. 2.

It is the practice to start with a blank, the width, length and thickness of which are smoothed up to slightly greater dimensions than those to which it will be finished. The X-mode frequency and the Y-axis mode frequencies then obtained should be about 1% to 2% lower than the respective desired frequencies. The length will be approximately 50% greater than the width, assuming that the crystal is to be finished for the so-called "normal" Y-axis or width mode freedom of oscillation. At this point it is best to begin reducing the length and to check the Y-mode frequency at intervals between the grinding operations. Since the width will remain unchanged the values of K_y and f_y will be increased proportionately. By continuing to reduce the length without further reducing the width not only will the Y-mode frequency be brought up to the desired value, but the upper Y-mode frequency will disappear. A single Y-mode frequency having been achieved, the thickness of the plate is then reduced as by lapping or grinding in accordance with Formula (1).

To give a concrete example of how a crystal plate may be cut for normal Y-mode frequency at 200 kilocycles and for an X-mode frequency of 2000 kilocycles, it is preferable to start with a blank having a width of approximately .565", a length of say .85", and a thickness of say .058". Such a crystal will have two low or Y-mode frequencies at around 196 kilocycles and 237 kilocycles, and a high or X-mode frequency of say 1948 kilocycles. The values of K_y will be in the neighborhood of 111 and 132, respectively. Now, if the length is gradually reduced these Y-mode frequencies and constants will increase since K_y equals f_y times the y dimension in thousandths of an inch.

On reducing the length a point will be reached where the upper Y-mode frequency becomes so weak as to be scarcely noticeable. This occurs when the constant for the upper Y-mode frequency reaches a value of approximately 133.

The constant for the lower Y-mode frequency will then be about 112.

With somewhat further reduction of the length, say to .845", the desired single Y-mode frequency rating 200 kilocycles will be obtained. The dimensions of the crystal blank at this point in its manufacture are now: Length, approximately .845", width approximately .565", and thickness .058". As above indicated, it will have a single Y-mode frequency response of 200 kilocycles and an X-mode frequency response of approximately 1948 kilocycles. To obtain the exact desired X-mode frequency response, in this instance 2000 kilocycles, a major face or faces of the crystal is lapped, that is to say, its thickness dimension is reduced, until the desired response is obtained. This point will ordinarily be reached when the blank has been reduced to a thickness of say, .0565 of an inch.

It will be understood that the specific cases of normal Y-mode frequencies shown in Fig. 3 in their relation to length and width are by no means indicative of any limits of Y-mode frequency possible of attainment. This graph could be extended to include crystals of greater dimensions and crystals having a single Y-mode frequency response at other than the so-called "normal" Y-mode. The X-mode, Y-mode frequency relationship, characteristic of the present invention, is, of course, not limited by the Y-mode frequency selected.

It may be desired to cut a crystal having an X-mode frequency and a correlated Y-mode frequency which is other than the normal Y-mode frequency described. The Y-mode characteristics of such a crystal are in no wise indicated in Fig. 2, which covers only a certain range of correlation of length to K_y wherein the lower Y-mode frequency, if it is present, accompanies the normal Y-mode. The lower Y-mode frequency can be obtained exclusively, however, by making the dimension along the Z-axis the width dimension and choosing a value for the dimension along a Y-axis such that this Y dimension or length becomes the principal factor in determining the frequency. This relation can best be explained by the formula—

$$L_y = \frac{K_y}{f_y} \quad (3)$$

where—

$$\frac{K_y}{f_y}$$

has the same significance as given in Formula (2) and L_y is the length in mils along a Y-axis. Without attempting to explain the natural laws governing the limit of values to be assigned to the frequency K_y and to the ratios of length to width for obtaining a single Y-mode frequency response, to the exclusion of other Y-mode responses, it may be well to give below the characteristics of certain specific specimens of piezoelectric plates which have been carefully measured and tested, and let the facts speak for themselves. Others skilled in the art will, no doubt, be able to extend the range of characteristic correlations for producing oscillator elements having single Y-mode frequency responses. The range of possibilities in this respect has by no means been exhaustively explored, although Bokovoy has found that there are available even more than the three Y-modes of vibration represented in Fig. 2, as will be seen in the following tabulation wherein the specimens catalogued are in every case naturally resonant to but one fre-

quency other than the X-mode or thickness frequency.

ing operation. 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.

We claim as our invention:

1. An X-cut piezo-electric quartz crystal element, cut from a mother crystal, said element being free to oscillate at only two fundamental frequencies, characterized in that its dimension along an electric axis (X) is approximately 565 ten-thousandths of an inch, its dimension parallel to a mechanical (Y) axis is approximately 565 one-thousandths of an inch and its dimension parallel to the optic (Z) axis is approximately 845 one-thousandths of an inch, said element having a response frequency of 200 and also of 2000 kilocycles per second.

2. A piezo-electric crystal element having its electrode faces lying in planes substantially parallel to a Y-axis and to the Z-axis, the length and width of each face being so proportioned that said element will oscillate at only one of several Y-modes normally possible when a random relation exists between length and width, and having its thickness so related to its length and width that it will also oscillate at an X-mode frequency which is a multiple of said one Y-mode frequency.

3. A piezo-electric crystal element having its major electrode faces lying in planes substantially parallel to a Y-axis and to the Z-axis, and having its length, width and thickness so proportioned to one another that it will oscillate at only one fundamental Y-mode frequency and at a fundamental X-mode frequency which is a multiple of said Y-mode frequency.

4. A piezo-electric quartz crystal element free to oscillate at only one Y-mode frequency and at an X-mode frequency which is a multiple of said Y-mode frequency, said Y-mode frequency in megacycles being equivalent to between—

$$\frac{103}{W}$$

and

$$\frac{124}{W'}$$

where W equals the dimension of the element along a Y-axis, reckoned in thousandths of an inch and said X-mode frequency being equivalent to—

$$\frac{113}{T}$$

where T equals the dimension of the element along an X-axis reckoned in thousandths of an inch.

5. An X-cut piezo-electric quartz crystal element having a Y-mode frequency constant of between 103 and 124 and an X-mode frequency constant of approximately 113.

6. An X-cut piezo-electric quartz crystal element having a Y-mode frequency constant of between 103 and 110 and an X-mode frequency constant of approximately 113, said element having a dimension along its Z-axis such that it will sustain Y-mode oscillations at only one frequency, and having a dimension along an X-axis such that it will sustain X-mode oscillations at a frequency which is a multiple of said one Y-mode frequency.

7. An X-cut piezo-electric quartz crystal element having a Y-mode frequency constant of between 111 and 118 and an X-mode constant of approximately 113, said element having a length such that it will sustain Y-mode oscillations at one frequency only, and having a thickness such

Mode	Dimensions (mils) along the axes			Ratio Z/Y	Constant K_y	Kilocycles f
	X	Y	Z			
1. Low	169	2120	1044	0.492	108.0	50
Do	135	1145	740	.646	103.1	90
Do	123	1030	678	.658	103.0	100
2. Normal	147	760	1110	1.46	114.0	150
Do	124	650	1000	1.54	113.7	175
Do	186	562	871	1.55	111.3	198
Do	119	572	851	1.49	114.4	200
Do	186	562	842	1.50	114.6	204
Do	186	562	820	1.46	115.8	206
Do	186	562	794	1.41	116.9	208
Do	186	562	764	1.36	118.0	210
3. High	148	536	1166	2.18	119.0	222
Do	88	523	1113	2.13	120.8	231
Do	50	415	823	1.98	116.2	280
4. Higher	149	570	1563	2.74	123.7	217
Do	124	514	1481	2.88	121.3	236
Do	136	420	1212	2.89	122.2	291
Do	88	390	1113	2.85	120.9	310
Do	50	341	823	2.41	119.4	350
5. Still higher	88	370	1113	3.08	122.8	332
Do	133	312	1039	3.33	120.1	385
Do	50	294	823	2.80	121.7	414

In order that a piezo-electric plate may be depended upon to vibrate at a single Y-axis mode frequency and at any of the Y-modes above the normal Y-mode, the limits of values to be assigned to the constant K_y and to the ratio Z/Y have not been generally determined, but in the following instances it has been found that the Y frequencies stated are single Y frequencies only within the limits given.

Y-mode	Kilocycles f_y	Limits of K_y	Limits of Z/Y
3. High	231	118.0-123.4	2.48-1.89
Do	280	114.9-118.1	2.08-1.94
4. Higher	310	118.2-123.8	2.93-2.79
Do	350	117.6-120.1	2.58-2.10

From the foregoing description, tables, graphs and formulae it is apparent that a crystal may be so cut as to have practically any desired Y-mode frequency response characteristic, further, that—in accordance with the present invention and regardless of exactly how this single Y-mode frequency is obtained—the crystal may be so cut that it will respond to a second predetermined and useful frequency. The second frequency will, of course, depend upon the use to which the crystal is to be put, in some cases it may be desirable to have the higher of the two response frequencies an exact multiple of the lower, as for instance 100-900 k. c., 200-2000 k. c. etc., other usage may dictate an apparently unrelated pair of frequencies. An ample choice of frequencies and frequency relations is provided; it may be said generally that a crystal may be cut in accordance with the present invention so that it will have an X-mode frequency response between, say, 400 and 10,000 kilocycles and a Y-mode frequency response between approximately 50 kilocycles and, say 400 kilocycles.

One important use to which crystals of our present invention may be put is that of providing voltages at accurate frequencies for frequency calibration purposes, such as aligning the dial scale of receivers, calibrating test oscillators, etc.

It is well known in the art that in order to obtain the frequency characteristics of a piezo-electric plate with the precision that is required, frequent tests of frequency characteristics should be made between successive stages of the grind-

that it will sustain X-mode oscillations at a frequency which is a multiple of said Y-mode frequency.

8. An X-cut piezo-electric quartz crystal element having a Y-mode frequency constant of between 116 and 124 and an X-mode constant of approximately 113, said element having a length such that it will sustain Y-mode oscillations at one frequency only, and having a thickness such that it will sustain X-mode oscillations at a frequency which is a multiple of said Y-mode frequency.

9. An X-cut piezo-electric quartz crystal element having a Y-mode frequency constant of approximately 113 and an X-mode constant of approximately 113, said element having a length such that it will sustain Y-mode oscillations at one frequency only, and having a thickness such that it will sustain X-mode oscillations at a frequency which is a multiple of said Y-mode frequency.

10. Method of cutting a crystal element so as to exhibit a single Y-mode frequency response and an X-mode frequency response which is a multiple of said first mentioned frequency, said method comprising cutting a slab with its electrode faces perpendicular to an X-axis and parallel to the optic axis reducing the dimension along the Y-axis to such value that it will oscillate at a predetermined Y-mode frequency lower than the Y-mode frequency desired, reducing the dimension along the optic-axis until the one desired Y-mode frequency response is obtained, and then reducing the dimension along the X-axis until the desired X-mode frequency response is obtained.

11. Method of cutting a crystal piezo-electric element having a single Y-mode frequency response and an X-mode frequency response which is a multiple of said first mentioned frequency, said method comprising forming a blank the thickness of which is measured along an X-axis and perpendicular to the Z-axis, reducing the width of said blank along a Y-axis to a desired value, reducing the length, measured along the Z-axis until the desired Y-mode frequency ap-

pears and other Y-mode frequencies disappear, and then reducing the thickness of said blank until the desired X-mode frequency response is obtained.

12. Method of making a quartz crystal piezo-electric element having a single width-length frequency response and another frequency response which is a function of thickness and is a multiple of said first mentioned frequency response, which method comprises cutting a slab to such dimensions as will produce approximate but somewhat lower frequencies than those desired while holding the dimension along a Y-axis to a value in mils between—

$$\frac{103}{f_y}$$

and

$$\frac{124}{f_y}$$

and the dimension along an X-axis to a value in mils which is greater than—

$$\frac{113}{f_x}$$

where f_y and f_x are respectively the desired width-length mode-frequency response and the desired thickness mode frequency response, then reducing the dimension along the Z-axis until the desired width-length frequency response is obtained and other modes of frequency response related to length and width disappear, and finally reducing the dimension along said X-axis until the desired thickness-mode frequency response is obtained.

13. A piezo-electric crystal element having its major electrode faces lying in planes substantially parallel to a Y-axis and to the Z-axis, and having its length, width and thickness so proportioned to one another that it will oscillate at only one fundamental Y-mode frequency and at a fundamental X-mode frequency which bears a predetermined useful relation to said Y-mode frequency.

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