

Oct. 14, 1941.

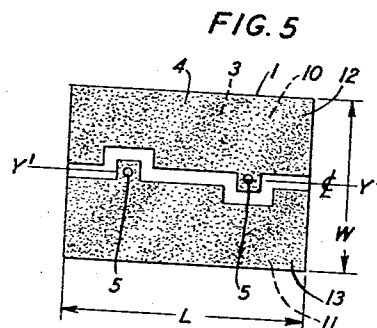
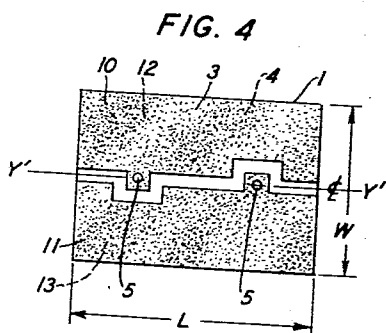
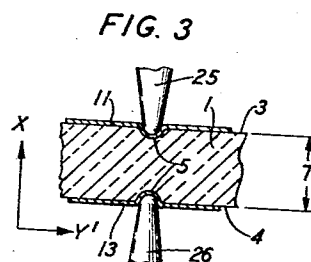
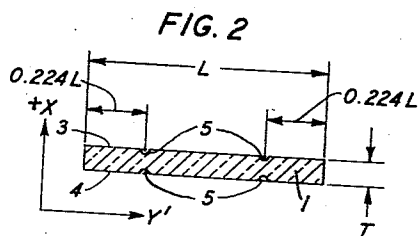
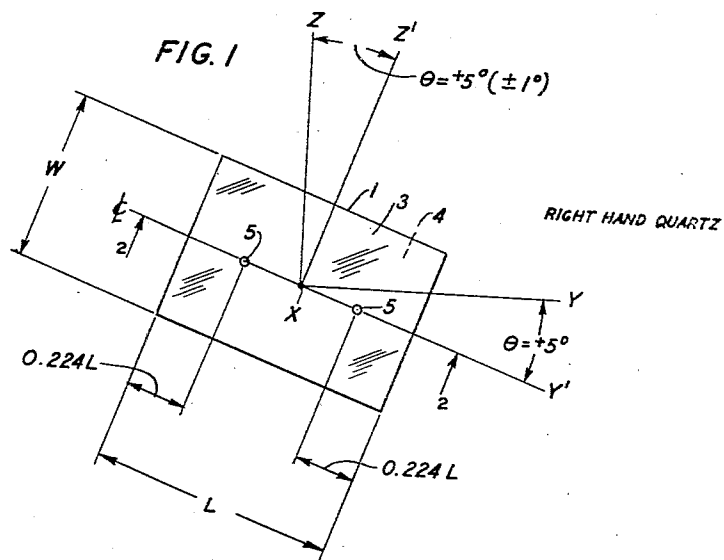
W. P. MASON

2,259,317

PIEZOELECTRIC CRYSTAL APPARATUS

Filed July 11, 1940

2 Sheets-Sheet 1



INVENTOR
W. P. MASON
BY
W. J. O'Neill
ATTORNEY

Oct. 14, 1941.

W. P. MASON

2,259,317

PIEZOELECTRIC CRYSTAL APPARATUS

Filed July 11, 1940

2 Sheets-Sheet 2

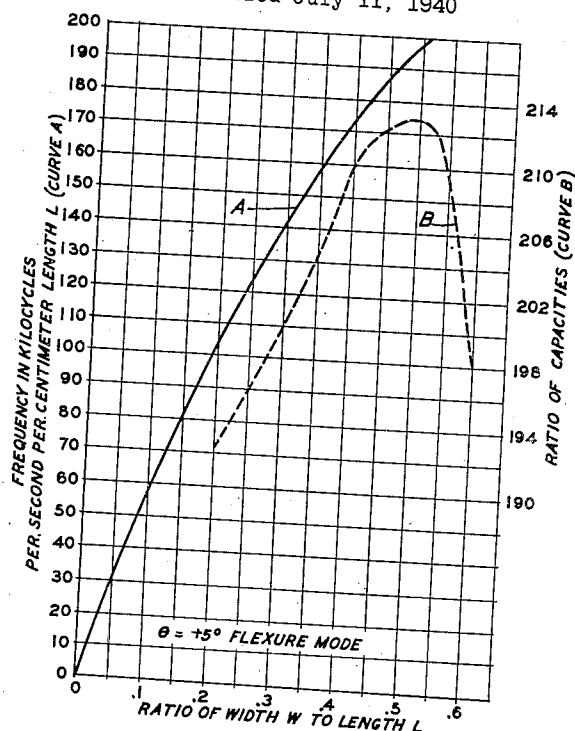


FIG. 6

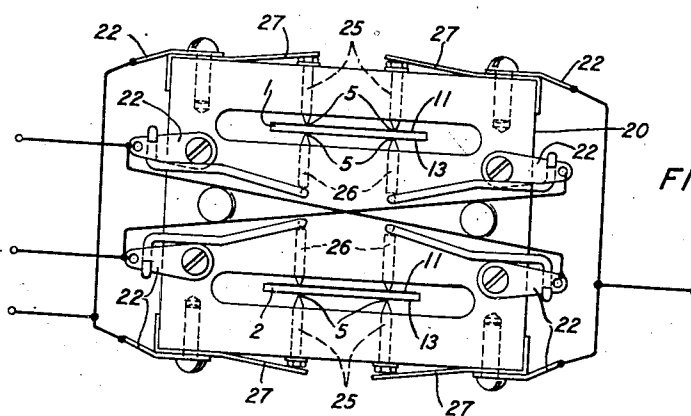
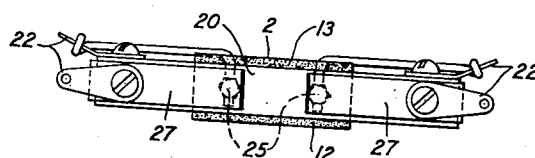


FIG. 7

FIG. 8



INVENTOR
W. P. MASON
BY

W. J. O'Neill
ATTORNEY

UNITED STATES PATENT OFFICE

2,259,317

PIEZOELECTRIC CRYSTAL APPARATUS

Warren P. Mason, West Orange, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application July 11, 1940, Serial No. 344,892

6 Claims. (Cl. 171-327)

This invention relates to piezoelectric crystal apparatus and particularly to vibratory piezoelectric quartz crystal elements suitable for use as circuit elements in such systems as electric wave filter systems and oscillation generator systems for example.

One of the objects of this invention is to provide piezoelectric crystals having a low temperature coefficient of frequency.

Another object of this invention is to provide relatively low frequency piezoelectric crystals having a nearly constant vibrational frequency throughout a range of ordinary temperatures.

Another object of this invention is to provide piezoelectric crystals substantially free from undesired interfering vibrational modes or other undesired frequencies near to the desired frequency.

Another object of this invention is to provide piezoelectric crystal elements that may be of relatively small and economical sizes at relatively low frequencies.

In such systems as electric wave filter systems or oscillation generator systems for example, it is often desirable to utilize vibrating crystals which have a low temperature coefficient of frequency over a range of temperatures and which are so constructed that any undesired prominent secondary resonances therein may be remote or at convenient ratios from the desired main mode of vibration where they will cause no harm. It is also desirable that such crystal elements, when utilized at the relatively lower frequencies such as, for example, below about 100 kilocycles per second, be of relatively small and convenient size in order to avoid the expense that is usually involved in crystal elements of the relatively larger sizes.

Since the crystal elements provided in accordance with this invention may have a relatively small size at low frequencies, they may be constructed economically down to below 50 kilocycles per second, and, accordingly, are advantageous for use in low frequency oscillators, filters and other low frequency systems where a low frequency of low temperature coefficient is desired.

In accordance with this invention, relatively thin piezoelectric quartz crystal plates of suitable orientation with respect to the X, Y and Z axes of the quartz material and of suitable dimensional ratio, may be subjected to a thickness direction electric field and vibrated at a resonance frequency dependent mainly upon the longest or major axis length dimension and the width di-

mension of the crystal plate in a mode of vibration which may be called a flexural mode. The orientation angle may be substantially $+5$ degrees, and the dimensional ratios of the crystal plate may be any of several to produce for the first flexural mode of motion, a low temperature coefficient of frequency of about 5 to 16 parts per million per degree centigrade depending on the ratio of the width to length mentioned, at temperatures within a range between about 0 and $+80^{\circ}$ C. over a wide ratio of the width to length dimension of its major faces, the frequency of the flexural mode vibration being dependent upon such dimensional ratio and the length or longest dimension of the crystal element. In particular embodiments, the ratio of the width dimension with respect to length dimension of the major surfaces may conveniently range from about 0.1 to 0.6 and the orientation may be that of an X-cut crystal element rotated in effect about $+5.0$ degrees about its X axis thickness dimension.

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

Fig. 1 is a major face view showing the orientation and the nodal points of a flexure mode piezoelectric quartz crystal element in accordance with this invention;

Fig. 2 is a cross-sectional view taken on the line 2-2 of Fig. 1;

Fig. 3 is an enlarged view of a nodal region of the view in Fig. 2;

Figs. 4 and 5 are views of electrodes that may be used for the opposite major surfaces of the crystal element of Fig. 1, Fig. 4 being a view looking toward one of the major surfaces of the crystal element and Fig. 5 being a view looking in the opposite direction toward the opposite major surface of the crystal element;

Fig. 6 is a graph illustrating the dimensional ratios and the dimension-frequency characteristics of flexure mode crystal elements in accordance with this invention;

Figs. 7 and 8 are front and side views of a crystal holder which may be used for mounting electroded crystal elements made in accordance with this invention.

This specification follows the conventional terminology as applied to crystalline quartz which employs three orthogonal or mutually per-

pendicular X, Y and Z axes, as shown in the drawing, to designate an electric, a mechanical and the optic axes, respectively, of piezoelectric quartz crystal material, and which employs three orthogonal axes X', Y' and Z' to designate the directions of axes of a piezoelectric body angularly oriented with respect to such X, Y and Z axes thereof. Where the orientation is obtained by a single rotation of the quartz crystal element 1, in effect substantially about an electric axis X, as illustrated in Fig. 1, the orientation angle θ designates in degrees the effective angular position of the crystal plate 1 as measured from the optic axis Z and from the orthogonal mechanical axis Y.

Quartz crystals may occur in two forms, namely, right-handed and left-handed. A right-handed quartz crystal is one in which the plane of polarization of a plane polarized light ray traveling along the optic axis Z in the crystal is rotated in a right-hand direction, or clockwise as viewed by an observer located at the light source and facing the crystal. This definition of right-handed quartz follows the convention which originated with Herschel. Trans. Cam. Phil. Soc., vol 1, page 43 (1821); Nature, vol. 110, page 807 (1922); Quartz Resonators and Oscillators, P. Vigoureux, page 12 (1931). Conversely, a quartz crystal is designated as left-handed if it rotates such plane of polarization referred to, in the left-handed or counter-clockwise direction, namely, in the direction opposite to that given hereinbefore for the right-handed crystal.

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

Referring to the drawings, Fig. 1 is a major face view of a thin piezoelectric quartz crystal element 1 cut from crystal quartz free from twinning, veils or other inclusions and made into a plate of substantially rectangular parallelepiped shape having a length or longest dimension L, 75

a width dimension W which is perpendicular to the length dimension L, and a thickness or thin dimension T which is perpendicular to the other two dimensions L and W.

The final major axis length dimension L of the quartz crystal element 1 is determined by and is made of a value according to the desired resonant frequency. The width dimension W also is related to the frequency and to the length dimension L in accordance with the values of dimensional ratios as given herein in Fig. 6. The thickness dimension T may be of the order of one millimeter or other suitable value to suit the impedance of the circuit in which the crystal element 1 may be utilized.

The length dimension L of the crystal element 1 lies along a Y' axis in the plane of a mechanical axis Y and the optic axis Z of the quartz crystal material from which the element 1 is cut, and is inclined at a positive (+) angle of θ degrees with respect to said Y axis, the angle θ being one of the values between about +4 and +6 degrees or substantially +5 degrees. The major surfaces 3 and 4 and the major plane of the crystal element 1 are disposed substantially in the plane of the Y and Z axes mentioned. The angle between the width dimension W, which lies along the Z' axis in the plane of the Y and Z axes mentioned, and the Z axis is the angle θ with respect to the optic axis Z. The axis Z' and the axis Y' are accordingly the result of a single rotation of the width dimension W and the length dimension L respectively, about the X axis + θ degrees. It will be noted that the crystal element 1 is in effect an X-cut crystal rotated θ =substantially +5 degrees about the X axis. At this angle of θ =+5 degrees, calculations and tests show that the first flexural mode vibrational frequency has its lowest temperature coefficient for X-cut quartz crystals rotated about the X axis thickness dimension T.

While the crystal plate 1 is shown in Fig. 1 as having its opposite major faces 3 and 4 disposed perpendicular to the X axis, it will be understood that they may be positioned nearly perpendicular or within a few degrees of such perpendicular relationship with respect to the X axis.

As illustrated in Fig. 1, the low temperature coefficient flexure mode crystal element 1 has two nodal point regions 5 on each of its major surfaces 3 and 4. This nodal points are located on the center line length dimension L or Y' axis of the crystal element 1 at points spaced about 0.224 of the length dimension L from each end thereof, as shown in Figs. 1 to 5. At these nodal points 5, the crystal element 1 may be mounted as by rigidly clamping it between two pairs of oppositely disposed clamping projections of small contact area which may be inserted in small semi-spherical indentations or depressions 5 provided at the four nodal points on the opposite major surfaces 3 and 4 of the crystal element 1. The small circular depressions 5 cut in the major surfaces 3 and 4 of the crystal element 1 at the nodal points thereof may have a depth of about 0.05 millimeter and a diameter of about 0.4 millimeter as measured on the surfaces 3 and 4.

Fig. 2 is a cross-sectional view of the crystal element 1 taken on the line 2-2 of Fig. 1 and shows the small depressions 5 cut in the major surfaces 3 and 4 of the crystal element 1 at the nodal points thereof.

Fig. 3 is an enlarged view of the nodal region of the crystal section shown in Fig. 2 and, in addition, illustrates portions of the integral elec-

trode coatings therefor and the conductive projections that may be utilized for mounting and establishing electrical connections with the crystal element 1.

As illustrated in Figs. 4 and 5, suitable conductive electrodes, such as the four crystal electrodes 10, 11, 12 and 13, for example, may be placed on or adjacent to or formed integral with the opposite major surfaces 3 and 4 of the crystal plate 1 to apply electric field excitation to the quartz plate 1 in the direction of the X axis thickness dimension T, and by means of suitable electrode interconnections and any suitable circuit, such as for example, a filter or an oscillator circuit, the quartz plate 1 may be vibrated in the desired first flexural mode of motion at a response frequency which depends mainly upon and varies inversely as the major axis length dimension L, and which also depends upon the dimensional ratio of the width W with respect to the length L, the frequency being a value within a range roughly from about 5 to 200 kilocycles per second per centimeter of the length dimension L, the value depending upon the value of the angle θ of the crystal element 1, and the dimensional ratio of width W to length L thereof as illustrated in Fig. 6.

The crystal electrodes 10 to 13 when formed integral with the major surfaces 3 and 4 of the crystal element 1 may consist of thin coatings of silver, aluminum or other suitable metallic or conductive material deposited upon the bare quartz by evaporation in vacuum or by other suitable process. The crystal electrodes 10 and 11 located on one major surface 3 of the crystal element 1 and the crystal electrodes 12 and 13 located on the opposite major surface 4 thereof are longitudinally centrally separated or split along the center line of the length dimension L thereby forming four separate electrodes 10, 11, 12 and 13 in order to operate the crystal elements 1 in the flexural mode of motion. Figs. 4 and 5 illustrate such splits or separations in the crystal electrodes, the electrodes 10 to 13 being provided with ears extending over the nodal points 5 of the crystal element 1 in order to make contact with the points of the conductive clamping projections disposed at such nodal points. The gap or separation between the electrode platings 10 and 11 and also 12 and 13 on the major surfaces 3 and 4 respectively of the crystal element 1 may be about 0.365 millimeter, the center line of such splits in the platings on opposite sides of the crystal plates being aligned with respect to each other. To drive the crystal element 1 in the desired first flexure mode, one pair of opposite electrodes, such as the crystal electrodes 10 and 12, apply a field in one direction through the crystal element 1 in order to lengthen one long edge L thereof while the other pair of opposite electrodes 11 and 13 simultaneously apply a field in the opposite direction in order to simultaneously shorten the opposite long edge L thereof, thus bending the crystal element 1 about the stationary nodal points 5 in the desired first flexural mode of motion. Examples of crystal electrode arrangements that may be utilized for operating the crystal element 1 in flexure mode vibrations are illustrated in W. A. Marrison U. S. Patent 1,823,329 dated September 15, 1931, Figs. 5 to 8, and C. A. Bieling U. S. Patent 2,155,035, April 18, 1939, Fig. 7.

Fig. 6 is a graph showing the characteristics of quartz crystal elements 1 having a θ angle of substantially ± 5 degrees and having various values

of ratio of the width dimension W with respect to the length dimension L, as given by the curve A of Fig. 6. The curve labeled A in Fig. 6 shows the relation between the desired first flexural mode resonant frequency thereof, expressed in kilocycles per second per centimeter of the length dimension L for given ratios of the width dimension W with respect to the length dimension L. For example when the dimensional ratio is about 0.50, the flexural mode frequency of a crystal element 1 having a length dimension L of 1 centimeter and having a θ angle of substantially ± 5 degrees, is about 200 kilocycles per second. Since the frequency is inversely proportional to the length dimension L, a crystal element of the same orientation and dimensional ratio but having a length dimension L of 4 centimeters will have a flexural mode frequency of one-fourth this value or about 50 kilocycles per second. Similarly, the frequency, the corresponding length dimension L and dimensional ratio may be obtained for any other size of crystal element 1 from the curve A of Fig. 6.

As an example, a substantially ± 5 degree θ angle crystal element 1 having a thickness dimension T of 1.662 millimeters, a length dimension L of 29.91 millimeters, and a width dimension W of 11.96 millimeters has a dimensional ratio of width W with respect to length L of about 0.4 and, as shown by curve A of Fig. 6, has a low temperature coefficient first flexural mode frequency of about 174 kilocycles per second per centimeter of length dimension L or about 58 kilocycles per second for the given length dimension of 29.91 millimeters.

As another example, a substantially ± 5 degree θ angle crystal element 1 having a thickness dimension T of 0.800 millimeter, a length dimension L of 65.0 millimeters and a width dimension W of 9.35 millimeters has a dimensional ratio of width W with respect to length L of about 0.145 and, as shown by curve A of Fig. 6, has a low temperature coefficient first flexural mode frequency of about 80 kilocycles per second per centimeter of length dimension L or about 12 kilocycles per second for the given length dimension of 65.0 millimeters.

Such crystals accordingly may provide a low frequency vibration with a low temperature coefficient and may be advantageously utilized as circuit elements in such systems as carrier wave standards, frequency modulation systems, and wave filter systems for example.

The curve B of Fig. 6 gives the corresponding values of ratio of capacities for such flexural mode θ =substantially ± 5 degrees crystal elements 1. The ratio of capacities referred to is the ratio of the internal or series capacity C_1 with respect to the shunt capacity C_0 as explained in a paper entitled Electrical Wave Filters Employing Quartz Crystals as Elements, Bell System Technical Journal, July, 1934, pages 409, 410, 411, published by the applicant.

The crystal elements described herein may be mounted in any suitable manner, such as for example, by rigidly clamping the electroded crystal plate 1 between one or more pairs of opposite conductive clamping projections which may contact the electroded crystal plate 1 at opposite points of very small area at the nodal points 5 of the crystal element 1. Figs. 7 and 8 illustrate a suitable holder of this type for mounting two such crystals in a filter system.

Figs. 7 and 8 are front and side views of a filtered crystal holder unit which consists of two

electroded quartz crystal plates 1 and 2 mounted by clamping means in an Isolantite or other insulating mounting block 20 which may be assembled inside an evacuated container (not shown). As shown in Figs. 4 and 5, each of the quartz crystal plates 1 and 2 of Figs. 7 and 8 are provided with four electrodes 10, 11, 12 and 13 which are formed integral with the opposite major surfaces 3 and 4 of the crystal element by depositing thereon thin films of metal, such as thin films of silver or aluminum deposited by evaporation in vacuum, or by any other suitable process.

In the filter system shown in Figs. 7 and 8, the electroded crystal elements 1 and 2 are alike but for having slightly different resonant frequencies. For example, to select the frequency of 12 kilocycles per second, the crystal elements 1 and 2 may have resonant frequencies of about 12.010 and 11.993 kilocycles per second respectively; or to select the frequency of 56 kilocycles per second, the crystal elements 1 and 2 may have resonant frequencies of about 56.035 and 55.975 kilocycles per second respectively.

Each of the electroded crystal elements 1 and 2 of Figs. 7 and 8 is clamped at its nodal points 5 between four conductive contact clamping pins 25 and 26 which may be of gold-plated brass each having clamping points individually in contact with the four electrodes 10, 11, 12 and 13 of each of the crystal elements 1 and 2. The clamping contact pins 26 which are disposed on one side of each of the crystal elements 1 and 2 are fixed in the Isolantite mounting block 20 while the oppositely disposed clamping contact pins 25 located on the opposite side of the crystal elements 1 and 2 are slidable in suitable brass bushings placed in openings in the mounting block 20. Each of clamping members 25 is resiliently pressed against the electroded crystal element by means of separate springs 27 which are secured to outer surfaces of the mounting block 20. The pressure exerted by the springs 27 on the contacts 25 may be about 1 to 3 pounds or sufficient to hold the clamped crystal elements 1 and 2 against bodily movement out of a predetermined position when placed between the clamping points 25 and 26.

The pairs of clamping points 25 and 26 are oppositely disposed with respect to each other and are axially disposed perpendicular to the major surfaces 3 and 4 of the crystal elements 1 and 2 and since they make contact only at the nodal points 5 of the crystal elements 1 and 2, there is a minimum of damping of the flexural vibratory motion of the crystal elements 1 and 2. The nodal points 5 are located as illustrated in Figs. 1 to 5. The crystal plates 1 and 2 are preferably clamped only at the nodal points 5 in order to obtain the minimum effective resistance at resonance. Each of the crystal plates 1 and 2 is adjusted to its desired series resonance frequency by reducing the length dimension L thereof. The mounted crystal plates 1 and 2 will be found to age over a period of as much as seven days after so adjusting it. During this aging period, the resonance frequency rises and the effective resistance decreases. Suitable allowance for this aging may be made so that the crystal elements 1 and 2 will meet the requirements after they have become stable.

Fig. 7 shows the filter electrical connections between the four crystal electrodes 10, 11, 12 and 13 of each crystal 1 and 2 and the eight terminals 22 which extend from the base 20. As

shown in Fig. 7, the crystal electrode 11 is connected with one of the terminals 22, the crystal electrode 13 is connected with another of the terminals 12. Similarly, the remaining crystal electrodes are each separately connected with the remaining terminals 22. The interconnections between the terminals 22 may be made by flexible insulated wires extending over the surfaces of the mounting block 20 and connected with the proper terminals of the clamping points 25 and 26. The pairs of clamping projections 25 and 26 serve not only to clamp the crystal elements but also to establish the individual electrical connections with the individual electrodes thereof.

Other forms of mountings that may be utilized for clamping the crystal element 1 or 2 are illustrated in C. A. Bieling Patent 2,155,035 dated April 18, 1939, and R. A. Sykes Patent 2,124,596 dated July 26, 1938, the clamping projections thereof being spaced and shaped to suit the nodal points 5 of the flexure mode crystal element 1.

Alternatively, instead of being mounted by clamping, as illustrated in Figs. 7 and 8, the electroded crystal plate 1 may be mounted and electrically connected by soldering, cementing or otherwise attaching four fine conductive supporting wires directly to the bare quartz or to a thickened part of the electroded crystal element 1 at its nodal points 5. The fine supporting wires referred to may be conveniently soldered to four small spots or stripes of baked silver paste or other metallic paste which has been previously applied at the nodal points 5 on the length dimension center line either directly on the bare quartz or on top of the field producing crystal electrodes 10 to 13 which may consist of pure silver applied by the known evaporation in vacuum process. Such fine supporting wires may extend perpendicularly from major surfaces 3 and 4 of the crystal element 1 and be attached by solder for example to form spring conductive wires carried by the press or other part of an evacuated glass tube. If desired, the spring wires may have one or more bends therein to better absorb mechanical vibrations originating outside the device. Also, bumpers or stops of soft resilient material may be spaced adjacent the edges or other parts of the crystal element 1 to limit the bodily displacement thereof when the device is subjected to mechanical shock. It will be understood that any holder which will give stability and a relatively high Q or reactance-resistance ratio for the crystal element 1 may be utilized for mounting the crystal element 1 or 2.

Although this invention has been described and illustrated in relation to specific arrangements, it is to be understood that it is capable of application in other organizations and is therefore not to be limited to the particular embodiments disclosed, but only by the scope of the appended claims and the state of the prior art.

What is claimed is:

1. A piezoelectric quartz crystal element adapted to vibrate at a flexure mode frequency of low temperature coefficient dependent mainly upon the length and width dimensions of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined at an angle of substantially ± 5 degrees with respect to said Y axis, said major surfaces being substantially parallel to said YZ plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within

the range from substantially 0.05 to 0.6, said length dimension expressed in centimeters being a value within the range from substantially 50 to 220 divided by said frequency expressed in kilocycles per second, said length dimension, said frequency, and said dimensional ratio being related values as given by curve A of Fig. 6.

2. A quartz piezoelectric crystal element of low temperature coefficient adapted to vibrate at a flexure mode frequency dependent mainly upon the length and width dimensions of its major surfaces, said major surfaces being substantially parallel to the plane of a Y axis and the Z axis, said length dimension being inclined substantially +5 degrees with respect to said Y axis, the ratio of said width dimension of said major surfaces with respect to said length dimension being substantially one of the values between 0.15 and 0.4, said dimensional ratio and said length dimension in terms of said frequency being related values as given substantially by curve A of Fig. 6.

3. A piezoelectric quartz crystal element having its major surfaces substantially parallel to the plane of a Y axis and the Z axis, the length dimension of said major surfaces being inclined substantially +5 degrees with respect to said Y axis, the value of the ratio of the width dimension of said major surfaces with respect to said length dimension thereof, and the value of said length dimension expressed in terms of the frequency of said element being related values in accordance with those values given by one of the points on the curve A of Fig. 6, and means including electrodes operatively disposed with respect to said major surfaces for vibrating said element in flexure mode vibrations at said frequency of low temperature coefficient.

4. A piezoelectric quartz crystal element having its major surfaces substantially parallel to the plane of a Y axis and the Z axis, the length dimension of said major surfaces being inclined +5 degrees with respect to said Y axis, the value of the ratio of the width dimension of said major surfaces with respect to said length dimension thereof, and the value of said length dimension

expressed in terms of the frequency of said element being related values in accordance with those values given by one of the points on the curve A of Fig. 6, two pairs of opposite electrodes formed integral with said major surfaces, conductive means for supporting said electroded crystal element only at the nodes thereof, said nodes being along the center line of said length dimension at points located from the ends thereof of a distance substantially 0.224 of said length dimension.

5. A piezoelectric quartz crystal element adapted to vibrate at a flexure mode of low temperature coefficient dependent mainly upon the length and width dimensions of its major surfaces, said length dimension being substantially in the plane of a Y axis and the Z axis and inclined at an angle of substantially +5 degrees with respect to said Y axis, said major surfaces being substantially parallel to said YZ plane, the ratio of said width dimension of said major surfaces with respect to said length dimension thereof being one of the values within the range from substantially 0.05 to 0.6, said length dimension expressed in centimeters being a value within the range from substantially 50 to 220 divided by said frequency expressed in kilocycles per second, said length dimension, said frequency, and said dimensional ratio being related values as given by curve A of Fig. 6, two pairs of opposite electrodes formed integral with said major surfaces, and mounting means for supporting said electroded crystal element only at a nodal region thereof.

6. A piezoelectric quartz crystal element having substantially rectangular major surfaces disposed substantially parallel to a Y axis and the Z axis, the length or longest dimension of said major surfaces being inclined substantially +5 degrees with respect to said Y axis, said length dimension and the ratio of the width dimension of said major surfaces with respect to said length dimension being related to the frequency of said element in accordance with one of the values as given by curve A of Fig. 6.

WARREN P. MASON.