

Feb. 29, 1944.

S. C. HIGHT

2,343,059

PIEZOELECTRIC CRYSTAL APPARATUS

Filed Sept. 18, 1940

2 Sheets-Sheet 1

FIG. 1

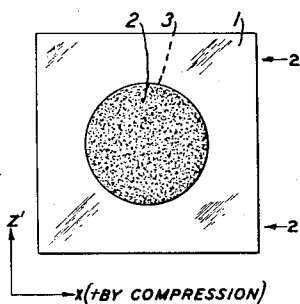


FIG. 2

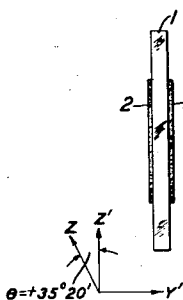


FIG. 3



FIG. 4

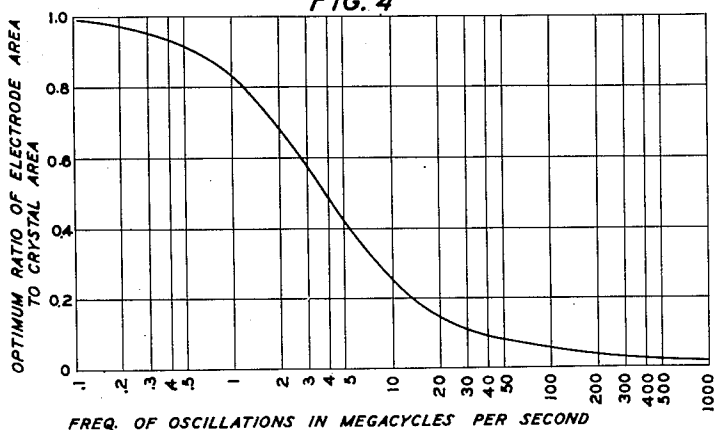


FIG. 6

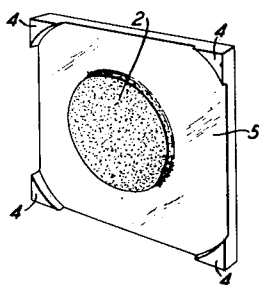
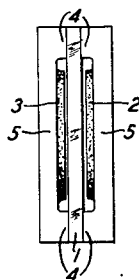


FIG. 5



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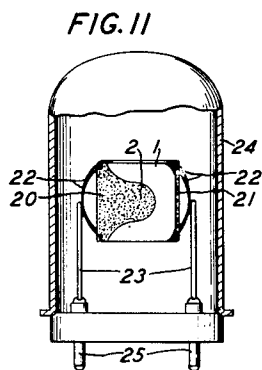
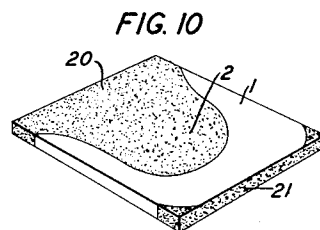
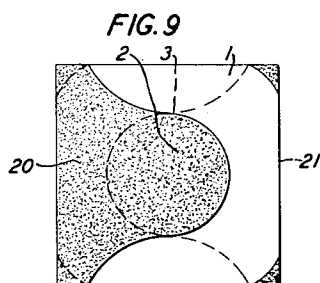
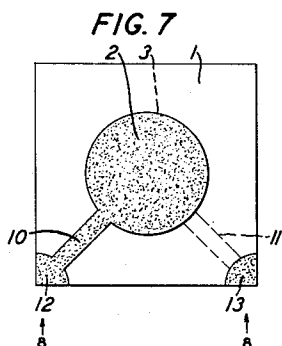
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,343,059

PIEZOELECTRIC CRYSTAL APPARATUS

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Application September 18, 1940, Serial No. 357,251

30 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to the electrodes and coatings for high frequency, thickness-mode piezoelectric crystal elements such as quartz crystal elements suitable for use as circuit elements in such systems as oscillation generator systems and electric wave filter systems, for example.

One of the objects of this invention is to increase the oscillating activity of piezoelectric crystal elements.

Another object of this invention is to increase the frequency stability of piezoelectric crystal elements.

Another object of this invention is to reduce spurious frequencies in piezoelectric crystal elements.

Another object of this invention is to provide improved mountings for thickness-mode piezoelectric crystal elements.

The oscillating activity of high frequency thickness-mode, shear or longitudinally vibrating quartz, tourmaline or other piezoelectric crystal elements, such as thickness-mode shear vibrating AT-cut quartz crystal plates may be improved by utilizing partial or reduced area field producing electrodes that are properly located on or adjacent the opposite major surfaces thereof. In addition to improving the oscillating activity, such reduced-area electrodes may reduce the number and the magnitude of spurious or undesired frequencies, and also increase the range of frequency adjustability of crystal elements, as well as permit rigid corner clamping or mounting thereof with little effect upon the oscillation activity. When such reduced-area or partial electrodes are utilized, the crystal plate, being an elastic body, oscillates effectively only in that part thereof which is subjected to the reduced-area electric field produced by the reduced-area electrodes, the remaining portions of the crystal element that are not traversed by the electric field being relatively motionless.

The proper or optimum size of electrodes to be used on the quartz or other crystal element depends upon the frequency of operation and the major face dimensions of the crystal element. Greater and more uniform oscillating activity may be obtained by using such reduced area electrodes on crystal elements that have been properly thickness shaped. In thickness-mode quartz crystals of the Y-cut type rotated in effect about the X axis which vibrate in the shear mode, such thickness shaping involves making the thickness about one-tenth of one per cent greater at the center of the major faces than at

the edges to provide an active spot at such center. While such thickness shaping and the use of reduced-area electrodes may act separately to improve the operating characteristics of the crystal element, together they act, each assisting the other, to provide crystals of highly improved characteristics.

In addition, the crystal element may be provided with conductive metallic coatings formed integrally with one or more of the corner or marginal portions of its opposite major surfaces and extending around the edge thereof in order to provide inactive corner or marginal portions of no motion where the crystal element may be electrically connected and mounted by clamping means, or by soldered supporting wires, or otherwise, without interfering with the desired vibratory motion in other parts of the crystal element. The soldered or clamping connections may be directly made to the integral metallic coatings at the corners or margins of the crystal element, the metallic coatings being built up in thickness at the points of soldering or clamping, if desired.

In oscillatory crystals of the high frequency type employing thickness modes of vibration and operating continuously at relatively large amplitude, it has been difficult heretofore to utilize electrode coatings of the adherent or integral type. In accordance with this invention, such crystals having electrodes of the integral form may be conveniently made use of.

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:

Figs. 1 and 2 are respectively major surface and edge views of a high frequency shear thickness-mode piezoelectric quartz crystal AT-cut plate provided with centrally located partial or reduced-area electrodes;

Fig. 3 is a central cross-sectional view of the quartz crystal plate of Figs. 1 and 2 showing, in exaggerated form, the crystal plate made thicker at the center of its major surfaces than at the peripheral edges thereof;

Fig. 4 is a graph showing the optimum ratios of area of the field producing electrodes with respect to the area of the major surface of crystal plates for obtaining maximum oscillating activity in thickness-mode crystal plates of various frequencies.

Figs. 5 and 6 are views illustrating an air-gap

type of electrode and mounting arrangement for crystal plates, Fig. 5 being an edge view of the crystal element of Figs. 1 to 3 clamped at its four corners between two metal clamping plate members; and Fig. 6 being a perspective view of one of the electrode-clamping plate members of Fig. 5;

Figs. 7 and 8 are respectively a major surface view and an edge view of the quartz crystal element of Figs. 1 to 3 provided with integral metallic electrode and other coatings in accordance with this invention;

Figs. 9 and 10 are respectively a major surface view and a perspective view of the quartz crystal element of Figs. 1 to 3 provided with another form of integral metallic coatings; and

Fig. 11 is a perspective view of the electroded and metallized crystal element of Figs. 9 and 10 provided with conductive support wires and mounted in an evacuated tube.

Referring to the drawings, Figs. 1 and 2 are respectively major surface and edge views of a relatively thin piezoelectric quartz element or plate 1 provided with oppositely disposed partial or reduced-area electrodes 2 and 3 which may be of circular shape and disposed adjacent to or formed integrally with the central portion only of the major surfaces of quartz crystal plate 1 in order to provide reduced-area electric field for operating the crystal element 1 in thickness-mode vibrations at a fundamental or any harmonic frequency determined mainly by the thickness of the crystal plate 1 between the major surfaces thereof at an active central point or area within the influence of the electric field provided by the partial electrodes 2 and 3.

The crystal element 1 may be, for example, a thickness-shear mode AT-cut quartz crystal plate having its substantially square major plane and electrode surfaces disposed parallel or nearly parallel to an electric or X axis of the quartz crystal material and inclined with respect to the optic axis Z at an angle of substantially 35 degrees measured in a positive (+) direction or towards parallelism with the plane of a minor apex face of the natural crystal from which the plate 1 may be cut. Such AT-cut quartz crystal plates are described in Lack et al., U. S. Patent 2,218,200, granted October 15, 1940, on application Serial No. 728,640, filed June 2, 1934, and in a paper published by Lack et al. in The Bell System Technical Journal, July 1934, pages 453-463. As an example, such an AT-cut crystal element may be a square or circular faced quartz crystal plate 1 vibrating at its third mechanical harmonic mode at 10 megacycles per second, corresponding to a thickness dimension Y' of about .503 millimeter, with major face dimensions of the order of about 25 millimeters, for example, along the X and Z' axes, the Z' axis being inclined substantially $\theta = +35^\circ 20'$ with respect to the Z axis or towards parallelism with the plane of a minor apex face of the natural crystal from which the plate 1 is cut.

It will be understood that the crystal element 1 may have square, rectangular, circular or other shaped major surfaces and may be operated in the fundamental or any harmonic of the thickness-shear mode vibration, and that the same electrodes 2 and 3 may be utilized to operate the crystal plate 1 at its fundamental mode frequency or any odd harmonic thereof, such as the third, fifth, seventh, ninth, etc., harmonic or overtone. Such quartz crystal plates have been successfully operated up to the twenty-seventh mechanical harmonic or overtone at a frequency of the order of 150 megacycles per second.

While the present invention is described particularly in connection with AT-cut quartz crystal elements referred to which employ thickness-mode vibrations of the shear type, it will be understood that the crystal plate 1 may be any other high frequency thickness-mode crystal such as shear mode Y-cut quartz crystals or Y-cut quartz crystals rotated in effect about their major surface X axis, or longitudinal mode X-cut quartz crystals, or longitudinal mode tourmaline crystals, for example.

Fig. 3 is a central cross-sectional view of the crystal plate 1 of Fig. 2. As illustrated in Fig. 3 in exaggerated form, the crystal plate 1 when of the shear-mode type may be made very slightly thicker at the center of the major surfaces than at the peripheral or marginal edges thereof. Such convex thickness shaping of the shear-mode AT-cut crystal plate 1 may be done by making either or both of the major surfaces thereof very slightly and uniformly convex so that the central portion thickness is very slightly greater than that at or near the edges of the major surfaces. The major surface or surfaces of the crystal plate 1 may conveniently be made slightly convex by imparting a turning or rolling motion to the crystal plate 1 and simultaneously exerting pressure on its marginal peripheral edges against an abrading lap, which may be either a flat or slightly concave lap. When the crystal plate 1 is spun or rotated relative to a flat abrasive lap, no motion occurs at the center of rotation located at the center of the major face of the crystal plate, and maximum motion and grinding effect occurs at the outer or peripheral margins thereof resulting in a very slightly but definitely lenticular or convex shape for the major surface of the crystal element 1, the surface curvature being uniform with a comparatively flat portion at the center and a gradual uniform taper therefrom toward the periphery edges.

The oscillating activity of fundamental and harmonic thickness-shear mode crystals 1 is improved by such positive thickness shaping wherein one or both major surfaces thereof are made slightly convex, resulting in a plate slightly thicker at the center of the major surfaces than at the periphery edges, the thickness deviation being within about 5 microns, for example. The type of electrodes 2 and 3 used therewith may be of any size or shape, with or without air-gap, and yet obtain at least some improvement in oscillating activity by reason of such thickness shaping alone. By thickness deviation is meant the difference in the thickness at the center of the major surfaces and that at the periphery edges of the crystal plate 1. A positive thickness deviation is one in which the thickness at the center of the major surfaces is greater than that at the periphery edges. For best oscillating activity, the major surfaces of the AT-cut quartz crystal plate 1 may be nearly flat but actually of slightly positive or convex curvature, the central thickness being a few microns thicker than the thickness at the periphery edges and the radius of curvature of the major surfaces being of the order of 50 to 100 meters. By such thickness shaping, the oscillating characteristics of high frequency fundamental or harmonic thickness-mode quartz crystal plates 1 which may be Y-cut crystals, or Y-cut crystals rotated in effect about the X axis, such as AT-cut quartz plates, may be improved. The manner in which this improvement is brought about, and its relation to further improvements

which result from the use of reduced-area electrodes are described below.

Crystal plates of uniform thickness to within .001 millimeter are usually referred to as having flat major surfaces, but actually contain hills and valleys when examined and measured with great precision. If the crystal plate is an X-cut quartz crystal, the thickness-mode vibrations are of the longitudinal type and the crystal plate tends to oscillate only in the thinnest regions containing a portion of plane parallel major surfaces giving the high frequency longitudinal thickness-mode vibrations that occur in such g-cut plates. But in the case of the high frequency shear thickness-mode vibrations that occur in Y-cut or AT-cut quartz plates 1, it is the thickest regions having plane parallel opposite surfaces that tend to oscillate best and such regions represent active spots of the crystal element 1 where oscillation is most vigorous. Most of the effects of thickness shaping occur within a small range in the vicinity of flatness of the major surfaces of the crystal plate 1. The thickness deviation and shape of the plate surfaces in the region of flatness is difficult to measure and evaluate by purely mechanical means, but the frequency of the low frequency shear major face mode thereof may be conveniently employed to evaluate the total thickness deviation or shape, the difference between the initial frequency of the plate and its frequency after thickness treatment being designated the "Index of total thickness deviation." This index may furnish an integrated summation of the totality of positive and negative thickness deviations occurring over the entire major surface of the crystal element 1.

High frequency thickness-mode quartz crystal plates 1, such as those of a frequency above about 3 megacycles per second, for example, unless thickness shaped, may exhibit an uneven distribution of motion or activity over the major surfaces thereof, the major surfaces being divided into relatively active and inactive areas. A small area electrode placed on or near an active area of the crystal often excites oscillation as well as, or better than, a full coverage electrode, while a small area electrode placed on an inactive area of the crystal surface often cannot be made to excite oscillations. Lycopodium powder sprinkled lightly over the surface of the oscillating crystal element does not remain on the active spots but migrates to the surrounding surface and shows a continuous agitation while in the active areas. A sharp pointed probing rod touching an active spot may stop the oscillation entirely but the rod may touch the crystal surface just outside an active area with little influence upon the voltage or frequency of oscillation. Such active spots are increasingly apparent as the higher frequencies are approached, and occur in fundamental and harmonic thickness-mode operation of the crystal element. The distribution of active spots or areas over the major surface of the crystal plate may be located by experiment. In general, these active spots are found in the central area of the major surfaces and although they may approach to the periphery, edges or corners of the crystal plate 1, they usually do not extend quite to them.

In general, the different active spots oscillate at slightly different frequencies and with substantially full surface coverage electrodes, any active spot may oscillate depending upon the circuit adjustment and conditions external to the crystal element. The occurrence of some of the unde-

sired spurious frequencies in crystals that have full coverage electrodes may perhaps be attributed to this uneven distribution of activity and to variable frequencies occurring over the surfaces of the crystal element.

The presence of active spots or regions, particularly in the relatively higher frequency crystal plates 1, makes it desirable to restrict the applied electric field from the electrodes 2 and 3 to the active portions only of such high frequency crystal elements 1. To additionally excite the inactive areas thereof results in loading the crystal, particularly in crystal elements of the relatively higher frequencies, such loading being both electrical and mechanical. The electrical loading results from the condenser action of the quartz dielectric, and that of the electrodes adjacent the inactive portions thereof which being in parallel relation with the active portion condenser effect, increases the ratio of external to internal capacities of the equivalent circuit, decreases the electromechanical coupling, and produces at least some dielectric loss. The mechanical loading referred to results from the piezoelectric drive of the sluggish or inactive areas of the crystal element in forced vibration with the reduced amplitude and wide phase relations associated with off-resonance operation and with consequent viscous loss due to its motion.

The convex thickness shaping of the shear-mode crystal plate 1 and the concave thickness shaping, if it is a longitudinal thickness-mode plate, produces a substantially central location for a single area fitting the requirements of substantially only one active area remote from the weakening edge effects, and results in fewer spurious frequencies, and increased oscillating activity. A single pair of opposite partial electrodes 2 and 3 may be centrally located on or adjacent the opposite major surfaces of the crystal plate 1 to apply the electric field only to the central active portion of the crystal plate 1, the active portion being so centrally located by reason of the convex thickness shaping of the shear-mode crystal plate 1 hereinbefore described. By placing the electrodes 2 and 3 only on the centrally located active spot or region, which may be made of relatively large area by proper thickness shaping, an increase in oscillating activity of the crystal plate 1 results. The partial electrodes 2 and 3, applying the electric field only to the central active portion of the crystal plate 1, do not electrically drive the more sluggish or relatively inactive peripheral areas thereof, the latter remaining practically motionless except for such motion as may be imparted thereto by mechanical coupling to the active central portion between the electrodes 2 and 3. It has been found that the mechanical coupling of the inactive or sluggish portion to the active central portion of the crystal plate 1 decreases rapidly with increase of its distance from the central active portion and the quartz crystal plate 1 being an elastic material, oscillates vigorously only in the electric field portion produced by the partial electrodes 2 and 3 covering substantially the so-called active spot only of the crystal plate 1, the remaining portions of the plate 1 being relatively motionless. The improvement in the oscillating characteristics of high frequency thickness-mode piezoelectric crystal plates 1 brought about by the use of the small electrodes 2 and 3 which apply the electric field only to a limited portion of the electrode face area of the plate 1 may be explained on the

basis of the active spots which appear on such high frequency crystal elements.

An index of activity P of the crystal element 1 is given by the relation

$$P = \frac{Q}{2r}$$

where Q and r have their usual significance, Q being the ratio of reactance to resistance of the equivalent circuit of the crystal, and r the ratio of shunt to series capacities C/C_0 of the equivalent circuit of the electroded crystal element. The further above unity that P becomes, the easier it is to make the plate 1 oscillate, and hence P may be considered as an index of oscillating activity of a crystal plate 1.

Accordingly, the reduced-area centrally located electrodes 2 and 3 function to increase the activity of the crystal element 1 by removing the field from the outer marginal peripheral portion thereof and confining the excitation to a substantially single frequency-determining thickness dimension of the crystal plate, thereby reducing the number of spurious frequencies.

If desired, the non-electroded surfaces of the crystal element 1 projecting beyond the small central electrodes 2 and 3 may be coated or painted with a non-conductive viscous material to damp out lateral waves and thereby reduce the number of such spurious frequencies.

The reduced-area centrally located electrodes 2 and 3 produce some measure of increased oscillating activity of the crystal element 1 independently of the convex thickness shaping of the shear-mode crystal element 1, and regardless of the type of reduced-area electrodes 2 and 3 that may be used therewith. A part of this gain in oscillating activity comes from the reduction in the electrode capacitance as a result of using small area rather than full coverage electrodes. Such reduction in electrode capacity permits a larger value of condenser external capacitance to be connected across the electroded crystal element 1 by means of which, adjustments in the frequency of oscillation may be made, thus increasing the frequency adjustment range to about three times that of crystal elements employing full coverage electrodes. Such a frequency adjusting condenser (not shown) may be connected in parallel circuit relation with the electrodes 2 and 3 of the crystal element 1 to manually adjust the frequency of oscillation thereof within small limits since the use of the reduced-area electrodes 2 and 3, by reduction of the capacity across the crystal element 1, allows the use of a relatively larger capacity in such a condenser and more flexibility of adjustment in the frequency for a given capacity change.

It will be understood that when the reduced-area electrodes 2 and 3 are used with the symmetrically convex thickness-shaped crystal plate 1, the frequency is definitely determined by the central area thickness dimension.

The optimum area for the electrodes 2 and 3 is dependent upon the frequency of the crystal plate 1, and upon the size of the major surfaces of the crystal plate 1. The optimum electrode size becomes smaller as the crystal major surface area is reduced, the ratio of the electrode area with respect to the major surface area, however, remaining substantially constant for any given frequency, fundamental or harmonic. Since the optimum area for the electrodes 2 and 3 depends upon the value of the frequency, fun-

damental or harmonic, of the crystal plate 1, the optimum area of the electrodes 2 and 3 may be conveniently expressed in terms of a percentage of the major surface area of the crystal element 1 for any given frequency.

Fig. 4 is a graph illustrating the optimum relative area of the electrodes 2 and 3 with respect to the major surface area of the crystal plate 1 to produce the maximum oscillating activity at different thickness-mode frequencies, whether fundamental or harmonic, in square and circular quartz crystal plates 1 of the AT-cut orientation hereinbefore referred to. As shown in Fig. 4, the optimum ratio of the area of the electrodes 2 and 3 decreases as the frequency, fundamental or harmonic, of the crystal plate 1 increases. For example, in a 1 megacycle per second quartz crystal plate 1, the optimum ratio of area of the electrodes 2 and 3 with respect to the total major surface area of the crystal plate 1 is roughly .8; in a 3 megacycle per second quartz crystal plate 1, the optimum ratio of such areas may be roughly between .5 and .6; and in a 10 megacycle per second quartz crystal plate 1, wherein the frequency conveniently may be an odd harmonic frequency of the fundamental thickness-mode frequency, the optimum ratio of such areas may be roughly between .2 and .3, as shown by the curve of Fig. 4. It will be understood that such optimum ratios of areas as given by the curve of Fig. 4 are approximate and not highly critical values, and that such values obtain whether the electrodes 2 and 3 of Figs. 1 and 2 are circular or of other shape, and that these values are also roughly suitable for use with other thickness-mode crystals of orientations other than that of the AT-cut crystal element referred to. Since the active area of the crystal plate 1 is roughly circular, the partial electrodes 2 and 3 may be correspondingly circular in shape, or they may be made square or of other shape, if desired, in order to obtain the desired partial electric field transversing the thickness dimension of the crystal element 1 at the central portion of the major surfaces thereof.

Thickness-mode AT-cut quartz crystal plates 1 made slightly thicker at the center than at the edges and provided with centrally located circular partial electrodes 2 and 3 have been successfully operated at harmonic frequencies of the order of 150 megacycles per second, such high frequencies being odd mechanical harmonics of the fundamental thickness-mode frequency of the quartz crystal element 1. The same electrodes may be used to excite either the fundamental thickness-mode frequency or any odd harmonic overtone thereof, the optimum area of the electrodes 2 and 3 being determined by the value of the frequency irrespective of the order of the harmonic used to produce that frequency. For ultra-high frequencies, very small electrodes 2 and 3 are preferred, as shown by the curve of Fig. 4. For example, when the frequency of the crystal element 1 is 150 megacycles per second, the area of the electrodes 2 and 3 may be of the order of one-tenth the area of the major surface of the crystal plate 1, as shown by the curve of Fig. 4.

It will be understood that the electrodes 2 and 3 applying the electric field to the central portion only of the crystal element 1 may be of any suitable shape and form, such as metal plates disposed in light contact with the quartz element 1 or spaced therefrom a distance of about one-thousandth of an inch, for example, or the electrodes 2 and 3 may consist of thin metallic coat-

ings of silver, aluminum, gold, platinum, or other conductive material or materials deposited on the bare quartz by any suitable process, such as by evaporation in vacuum, sputtering, electroplating or otherwise.

The centrally located circular electrodes 2 and 3, if constructed of conductive plates disposed in light contact with the central areas of the major surfaces of the crystal element 1, may be held in position by any suitable means that restrains bodily motion of the electrodes 2 and 3 without pressing them heavily against the crystal element 1. The corners or edges of the crystal element 1 may be rigidly spring clamped, molded directly into fusible supports, or otherwise mounted.

It will be understood any form of electrodes may be utilized that applies the restricted area electric field to the thickness direction dimension of the crystal element 1. The advantages of the restricted electric field may be obtained by using only one small electrode, the other electrode 2 or 3 being of larger or of full size, if desired.

Figs. 5 and 6 illustrate an air-gap type of electrode arrangement which rigidly clamps the crystal element 1 at its four corners only between four flat surfaced projections 4, and which provides small air-gaps of about .001 inch between each of the circular central electrodes 2 and 3 and the major surfaces of the crystal element 1. The crystal element 1 may be resiliently held between the projections 4 of the electrode plates 5 by spring pressure applied thereto in any suitable manner. While the electrode arrangement of Figs. 5 and 6 produces some measure of undesired electric field in the crystal areas outside of the circular central area provided by the effective circular electrodes 2 and 3, it nevertheless provides at least some improvement in the oscillating activity, frequency stability and frequency adjustability of the crystal element 1 and permits the use of relatively high frequency crystal elements 1.

Alternatively, as illustrated in Figs. 7 to 11, the field producing electrodes 2 and 3 and connections therewith may consist of metallic coatings formed integrally with the crystal element 1, resulting in such advantages as increased oscillating activity, freedom from arcing at the surface of the crystal, simplified mounting, increased power capacity, reduction in weight of the crystal holder unit, and elimination of variable mechanical effects on the operation of the unit.

Figs. 7 and 8 are respectively a major surface view and an edge view of the piezoelectric quartz crystal plate 1 of Figs. 1 to 3 provided with reduced-area circular electrodes 2 and 3 consisting of metallic or other conductive coatings formed integrally with the central portion only of the major surfaces of the crystal element 1 as illustrated in Figs. 1 and 2. In Figs. 7 and 8, the crystal plate 1 is also provided with two conductive tabs 10 and 11 consisting of metallic coatings formed integrally with the opposite major surfaces of the crystal plate 1, and extending from the integral electrodes 2 and 3 respectively to two of the corners of the crystal plate 1 where the external electrical connections and mounting contacts may be made. In this arrangement, the edges and corners of the piezoelectric crystal element 1 are relatively motionless and isolated from the central vibratile portion between the electrodes 2 and 3, and the crystal element 1 may be mounted at the inactive corner portions without wearing away the conductive

metallic coatings 10 and 11 at the points of mounting.

Complete isolation of the corner clamping or mounting points from the active vibratile central region of the crystal element 1 may be attained by the use of conductive coatings 12 and 13 on or formed integrally with and extending around and short-circuiting the corners of the quartz crystal element 1, the effective field producing reduced-area electrodes 2 and 3 being disposed in the central area only of the major surfaces of the crystal element 1, and the narrow strips 10 and 11 of the coating extending from the central electrode coatings 2 and 3 toward and around the edges of any two corners 12 and 13 to the opposite major surface of the crystal element 1 at the corner portions 12 and 13 thereof. This arrangement results in a definitely zero field intensity at the short-circuited corners 12 and 13, a minimum of electric field from the narrow conductive strips 10 and 11 and a concentration of electric field from the electrodes 2 and 3 in the central region only. A very high activity of oscillation is attained by this arrangement. The corners, being completely null, may be rigidly clamped or otherwise supported with no adverse influence on the operation of the crystal element 1. Previous attempts to utilize thickness-mode thinly coated crystals as oscillators have usually resulted in quickly wearing out the thin coatings at the points of support due to the motion of the crystal at the points of contact. Such wear is entirely eliminated from the coatings of the form and position shown in Figs. 7 and 8 by eliminating all motion at the points of contact, and the crystal element 1 may be rigidly held at the corners 12 and 13 by resilient spring clamps, by molding directly into fusible metal supports, or by supporting wires soldered thereto at the corners, for example.

Figs. 9 and 10 are respectively a major face view and a perspective view of the quartz crystal plate 1 provided with the reduced-area field-producing circular central electrodes 2 and 3 and integral connecting coatings 20 and 21 extending from the respective electrodes 2 and 3 to and around the corners and opposite edges of the crystal plate 1. Due to the shape of the overlapping conductive coatings 20 and 21, the overlapping parts thereof produce in effect the reduced-area circular electrodes 2 and 3 which function as hereinbefore described in connection with Figs. 1, 2 and 7 and 8. The conductive integral coatings 20 and 21 may extend up to the edges and corners of the crystal plate 1 and also around such corners and edges onto the respective opposite major surface of the crystal plate 1 to render such corners and edges short-circuited and completely motionless, in the manner described in connection with Figs. 7 and 8. It will be noted that while the central field-producing electrodes 2 and 3 function in the same manner in the arrangements shown in Figs. 7 to 10, the metallic connection coatings 20 and 21 of Figs. 9 and 10 being of larger surface area than the corresponding connection tabs 10 and 11 of Figs. 7 and 8 reduce the current density in the crystal surface metal, increase the contacting areas allowing clamping, supporting and contacting at all four corners thereby reducing the current density at the points of support or contact.

Fig. 11 is a view of the electroded crystal element 1 of Figs. 9 and 10 mounted on conductive supporting spring wires 22 which may be heavily

soldered to the coatings 21 and 22 at eight points adjacent the four corners of the crystal plate 1. The solder may extend around each corner of the crystal plate 1 to reinforce the support. The resilient wires 22 may be supported from conductive support rods 23 carried by the press of an evacuated tube 24 and connected with external pin terminals 25 to provide individual electrical connections with the crystal coatings 20 and 21.

It will be understood that the metallized crystal plate 1 of Fig. 11 instead of being supported by the bent conductive spring wires 22 and 23 which establish the electrical connections therewith may be supported in loosely packed glass or cotton fibers, for example, placed within a suitable container; or if desired, the metallized crystal element of Fig. 10 may be supported by conductive spring members clamping the corners thereof.

Where the electrodes and other metallic coatings are formed integrally with the crystal element 1, as illustrated in Figs. 7 to 11 for example, the thickness of the crystal element 1 may be first adjusted for approximate frequency in the uncoated state, or with only one of its major surfaces coated, and final small adjustments to the desired frequency may be made by abrading the uncoated area of the crystal element 1, or by removing or adding metallic coating material by electroplating or otherwise, the frequency of the thickness-mode crystal element 1 being thereby adjusted by control of the thickness of the metallic plating on its surfaces, the metal being added or removed by electroplating or any other suitable methods. For example, the frequency of the crystal element 1 may be lowered by electroplating additional metal onto the metal of one or both of the major surfaces of the crystal element 1. Conversely, the frequency may be raised by reversing the direction of current in the electroplating bath and thereby removing some metal from the coatings. The frequency change of the metallized crystal element 1 is substantially linear with the quantity of electricity passed and may be calculated from formulae and controlled to a nicety.

The thickness of the uncoated crystal plate 1 may be made of a value corresponding to a frequency slightly higher than the desired final frequency. Then the metallic coatings may be applied using a suitably shaped mask or shield over the portion of the crystal 1 where no metallic deposit is desired. The metallic coating material may consist of silver applied by the Brashear process, or copper, gold, silver, platinum, aluminum or other suitable metal, or metals applied by evaporation in vacuum, sputtering, chemical deposition or any other suitable process. If no mask has been employed during the metallic coating process, the undesired portions of the coatings may be etched off afterward or otherwise removed or segregated electrically and mechanically.

Where the metallic coatings are applied by evaporation in vacuum, the crystal element 1 may be oscillated while it is in the evaporation chamber, the process being cut off or stopped when the frequency of the metallized crystal plate 1 reaches the desired value. Alternatively, an initial coating of the metallic material may be applied to the crystal plate 1 by evaporation in vacuum, the adjustment in frequency thereof being performed afterward by adding or by removing metallic coating by the same

or other methods. Aluminum applied to the quartz by evaporation in vacuum adheres very well to the quartz and is well adapted to the corner clamping form of connection and support for the electroded crystal plate 1. Other metallic coatings such as gold, silver, or platinum offer ease of frequency adjustment by electroplating methods and permit a good soldered connection to be made thereto. In lieu of the evaporation in vacuum method, the initial coating may be applied to the quartz crystal plate 1 by chemical deposition of silver or other metallic material, the thickness of the coating being controlled by temperature, time of immersion in the chemical bath, and successive applications of the metal.

Regardless of the method of application of the integral coatings to the crystal plate 1, if the thickness of the coatings is too great thereby resulting in a frequency below the desired final value, the excess coating may be removed and the frequency brought to the desired value by such methods as abrading the metallic coating with a soft lap such as leather, rubber eraser, or felt, or by etching or dissolving the excess metal in a suitable reagent, or by electro-deplating to remove the excess metal.

Where the electroplating method is used to metallize and adjust the frequency of the crystal element 1, the initial coating applied by evaporation or otherwise to the bare quartz surface as a conductive base may be any metal such as platinum, gold, silver, or copper, for example, that will readily take an additional coating of electroplate thereon of a metal of the same or different kind. Gold or copper, for example, are easily applied by electroplating in simple solutions and their rates of deposition are linear with quantity of electricity over a wide range of current densities. Also the thickness-mode frequency change per coulomb (amperes times seconds) is linear except when influenced by spurious frequency modes or hops in frequency. As the plating thickness is increased, the frequency changes at intervals go through hops or discontinuities in frequency similar to those encountered in the usual method of grinding a crystal element to frequency. Such hops may be removed by slightly grinding on one or more of the edges of the crystal plate or by adding or removing metal by plating or deplating and so ultimately obtain the desired thickness-mode frequency free from undesired spurious frequencies. The thickness-mode frequencies of fundamental and third harmonic quartz crystal plates 1 may be lowered as much as about 10 per cent by electroplating. The amount of frequency change that a certain amount of plating will produce depends upon the mass and thickness of the metal deposited, the thickness and orientation of the crystal element 1 and the type of vibration involved. In the electroplating bath, the mass of metal deposited is directly proportional to the quantity of electricity passed and may be predetermined. As excessive currents tend to deposit a rough coating, it is preferable to use a moderate current density.

Where gold or other non-corrosive metal is utilized as the outer plating, the drift in frequency over periods of time that may result from metal corrosion is eliminated. By mounting the electroded crystal element 1 in an evacuated chamber, as illustrated in Fig. 11 for example, the effects of corrosion on any metal may

be eliminated. The thickness and mass of the metallic coating is relatively very small being less than 1 per cent of the quartz thickness and usually less than .1 per cent thereof.

If copper coatings are utilized, the electroplating solution for copper plating at room temperature may consist of 25 grams cupric sulphate (CuSO_4) and 100 cubic centimeters of distilled water, with added basic cupric carbonate or not over .05 gram sodium hydroxide, the solution to be boiled and afterwards filtered. The electroplating solution for gold plating at temperatures of 50° or 60° centigrade may consist of 10 grams sodium gold cyanide, 10 grams sodium cyanide and 1000 cubic centimeters distilled water.

As disclosed and claimed in my copending application for Piezoelectric crystal elements, Serial No. 406,798, filed August 14, 1941, newly cut crystal elements such as the crystal element 1 gradually change their frequency slightly or age by drift in frequency over a period of time of several days, but may be artificially aged by boiling the bare quartz crystal element 1 in acid, such as strong sulphuric acid or chromic acid, to reduce the period of time that would otherwise be required for the crystal element to acquire frequency stability, and to prevent a possible frequency drift outside of the allowable frequency limits after installation. The frequency of oscillation of the untreated quartz crystal elements ordinarily slightly increases for about a week or so before the crystal reaches frequency stability in operation but the frequency may be increased about the same magnitude by initially boiling it in the uncoated state for a short time in strong chromic or sulphuric acid, thus in effect artificially aging the crystal in a short time. Starting with the unplated crystal 1 immersed in the cold acid, the acid may be gradually brought to a boiling condition and then allowed to cool before removing the crystal plate. Since the acid boils at a temperature of about 300° centigrade, the crystal plate is put through a thermal cycle which tends to reduce strains in the quartz. Also, the boiling liquid having zero surface tension probably works under and breaks loose minute fragments on the quartz surfaces. Whatever may be the explanation of the action of boiling of the quartz plates in acid, there is very little frequency drift or change in frequency during the operation of the quartz plates after being subjected to such treatment. For example, the operating frequency change in an unboiled 10 megacycle per second thickness-mode AT-cut crystal 1 over a period of ten days has been found to be of the order of 300 to 400 cycles per second, whereas the operating frequency change for such a crystal after being boiled in strong sulphuric or chromic acid, for example, has been reduced to about 10 per cent of the values mentioned, or about 30 cycles per second over the same operating period. The change in frequency occurs mostly during the first boiling in the acid and if boiled again in the acid bath, little further change in frequency is obtained.

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 thickness-mode piezoelectric crystal element having substantially rectangular opposite

major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to another corner of said crystal element, conductive supporting spring wires mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners.

2. A thickness-mode piezoelectric crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to another corner of said crystal element, conductive supporting spring wires mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners, the thickness of said crystal coatings being made of a value corresponding to the value of the thickness-mode frequency desired for said coated crystal element.

3. A thickness-mode piezoelectric crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to another corner of said crystal element, conductive supporting spring wires mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners, said coatings comprising gold applied to said crystal element.

4. A thickness-mode piezoelectric crystal element having substantially rectangular opposite major faces, the thickness of said crystal element between said opposite major faces being made of a value corresponding to the value of said thickness-mode frequency thereof, a pair of conductive coatings formed integral with said opposite major faces, said conductive coatings being disposed opposite each other at the central portions only of said major faces and forming electric field-producing electrodes spaced entirely inwardly of all of the peripheral edges of said major faces, one of said coatings on one of said major faces extending to one corner of said crystal element and the other of said coatings on the other of said major faces extending to another corner of said crystal element, conductive supporting spring wires mounting said crystal element at said corners and establishing individual electrical connections with said coatings at said corners, and conductive adhesive means securing said supporting wires to said corners and establishing individual electrical connections with said conductive coatings at said corners, said coatings comprising an electroplated metal.

5. A thickness-mode piezoelectric quartz crystal element having substantially rectangular opposite major faces, the thickness of said element between said opposite major faces being made of a value corresponding to the value of the thickness-mode frequency of said crystal element, a pair of substantially equal size and oppositely disposed field-producing conductive coatings formed integral with the central portions of said opposite major faces and spaced entirely inwardly of all of the peripheral edges of said major faces, and a pair of relatively narrow connective conductive coatings formed integral with said opposite major faces and extending from said field-producing conductive coatings to two different corners of said crystal element.

6. A thickness-mode piezoelectric quartz crystal element having substantially rectangular opposite major faces, the thickness of said element between said opposite major faces being made of a value corresponding to the value of the thickness-mode frequency of said crystal element, a pair of substantially equal size and oppositely disposed field-producing conductive coatings formed integral with the central portions of said opposite major faces and spaced entirely inwardly of all of the peripheral edges of said major faces, and a pair of relatively narrow connective conductive coatings formed integral with said opposite major faces and extending from said field-producing conductive coatings to two different corners of said crystal element, the thickness of said crystal coatings being made of a value corresponding to the value of the thickness-mode frequency desired for said coated crystal element, said coatings comprising gold applied to said bare quartz crystal element.

7. In combination, a thickness-mode piezoelectric crystal element having its thickness made of a value corresponding to the value of its thickness-mode frequency, and a pair of conductive coatings each partially covering an electrode surface of said crystal element, the uncovered area of each of said crystal electrode surfaces being opposite a covered area of the other of said crystal electrode surfaces, and the covered areas of each of said crystal electrode surfaces being disposed opposite each other only at the central portions of said crystal electrode surfaces said oppo-

sitely disposed covered areas forming opposite field producing electrodes having an effective field area covering less than 80 per cent of the area of one of said crystal electrode surfaces, said field area being spaced entirely away from all of the peripheral or marginal edges of said crystal electrode surfaces.

8. In combination, a thickness-mode piezoelectric crystal element having its thickness made of a value corresponding to the value of its thickness-mode frequency, and a pair of conductive coatings each partially covering an electrode surface of said crystal element, the uncovered area of each of said crystal electrode surfaces being opposite a covered area of the other of said crystal electrode surfaces, and the covered areas of each of said crystal electrode surfaces being disposed opposite each other only at the central portions of said crystal electrode surfaces said oppositely disposed covered areas forming opposite field producing electrodes spaced entirely away from all of the peripheral or marginal edges of said crystal electrode surfaces, said oppositely disposed covered areas forming opposite field producing electrodes of substantially circular shape having an effective field area less than 80 per cent of the area of one of said crystal electrode surfaces.

9. In combination, a piezoelectric crystal element having its thickness made of a value corresponding to the value of its thickness-mode frequency, and a pair of conductive coatings each partially covering an opposite major surface of said crystal element, each of said coatings substantially wholly covering a marginal edge portion of one of said major surfaces and tapering in width from said marginal edge portion thereof towards the central portion of each of said major surfaces, said pair of coatings being disposed opposite each other only at said central portions and forming opposite field producing electrodes having an effective field area covering less than 80 per cent of the area of one of said major surfaces, said field area being spaced entirely inwardly of all of the marginal edges of said major surfaces.

10. In combination, a thickness-mode piezoelectric crystal element having its thickness made of a value corresponding to the value of its thickness-mode frequency, said crystal element having substantially rectangular shaped opposite major surfaces, and a pair of independent continuous conductive coatings, each covering partially both of said major surfaces, one of said coatings covering both of said major surfaces adjacent two of the four corners of said crystal element and extending to the central portion of one of said major surfaces, and the other of said coatings covering both of said major surfaces adjacent the other two of said four corners and extending to the central portion of the other of said major surfaces, said central portion coatings forming opposite field producing electrodes that are spaced entirely inwardly of the marginal edges of said major surfaces.

11. In combination, a thickness-mode piezoelectric crystal element having substantially rectangular shaped opposite major surfaces, and a pair of independent continuous conductive coatings, each covering partially both of said major surfaces, one of said coatings covering both of said major surfaces adjacent two of the four corners of said crystal element and extending to the central portion of one of said major surfaces, and the other of said coatings covering both of

said major surfaces adjacent the other two of said four corners and extending to the central portion of the other of said major surfaces, said central portion coatings forming opposite field producing electrodes that are spaced entirely inwardly of the marginal edges of said major surfaces, and conductive members secured to said coatings adjacent said four corners.

12. A thickness-mode piezoelectric quartz crystal element having its maximum thickness between the central portions of its opposite substantially rectangular major surfaces, oppositely disposed field-producing electrodes formed integral with said maximum-thickness central portions of said major surfaces, said field-producing electrodes being spaced entirely inwardly of all of the peripheral or marginal edges of said major surfaces, conductive coatings formed integral with said major surfaces and independently extending from each of said opposite field-producing electrodes to different corners of said major surfaces, and conductive supports contacting said coatings adjacent said corners and establishing individual electrical connections with said opposite electrodes.

13. A piezoelectric crystal element having its frequency-determining thickness dimension between its opposite major faces made of a value corresponding to the value of its thickness-mode frequency, two electrodes having areas oppositely disposed on said opposite major faces of said crystal element, said electrode areas being substantially equal in size and being less in size than the dimensions and areas of said major faces, each of said electrode areas covering less than 70 per cent of the area of one of said major faces, the ratio of each of said electrode areas with respect to the area of one of said major faces being a value substantially in accordance with the value of said frequency, whereby improved oscillating efficiency is obtained.

14. A piezoelectric crystal element having a thickness dimension between its opposite major surfaces of a value corresponding to the desired frequency thereof, and means including electrodes disposed in operative relation with respect to said opposite major surfaces of said crystal element for applying an effective electric field of selected area mainly to the central portion only of said crystal element, the ratio of said area of said electric field with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency.

15. A piezoelectric crystal element having a thickness dimension between its opposite major surfaces of a value corresponding to the desired frequency thereof, and means including electrodes disposed in operative relation with respect to said opposite major surfaces of said crystal element for applying an effective electric field of selected area mainly to the central portion only of said crystal element, the ratio of said area of said electric field with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, at least one of said electrodes being formed integrally with one of said major surfaces of said crystal element.

16. A piezoelectric crystal element having a thickness dimension between its opposite major surfaces of a value corresponding to the desired frequency thereof, and means including electrodes disposed in operative relation with respect

to said opposite major surfaces of said crystal element for applying an effective electric field of selected area mainly to the central portion only of said crystal element, the ratio of said area of said electric field with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, at least one of said electrodes being circular and formed integrally with one of said major surfaces of said crystal element.

17. A piezoelectric quartz crystal element having a thickness dimension between its opposite major surfaces of a value corresponding to the desired frequency thereof, and means including electrodes disposed in operative relation with respect to said opposite major surfaces of said crystal element for applying an effective electric field of selected area mainly to the central portion only of said crystal element, the ratio of said area of said electric field with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, at least one of said electrodes being formed integrally with one of said major surfaces of said crystal element, said crystal element being slightly thicker at the central portion of said major surfaces than at the peripheral margins thereof.

18. A piezoelectric quartz crystal element having its major surfaces substantially parallel to an X axis, said crystal element being adapted to vibrate at a frequency dependent upon a thickness thereof between said major surfaces at the central portions of said major surfaces, said thickness being a value corresponding to the value of said frequency, opposite electrodes adjacent said central portions of said major surfaces, the ratio of area of at least one of said electrodes with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency.

19. A piezoelectric quartz crystal element having its major surfaces substantially parallel to an X axis, said crystal element being adapted to vibrate at a frequency dependent upon a thickness thereof between said major surfaces at the central portions of said major surfaces, said thickness being a value corresponding to the value of said frequency, opposite electrodes adjacent said central portions of said major surfaces, the ratio of area of at least one of said electrodes with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, at least one of said electrodes being formed integrally with one of said major surfaces of said crystal element.

20. A piezoelectric quartz crystal element having its major surfaces substantially parallel to an X axis, said crystal element being adapted to vibrate at a frequency dependent upon a thickness thereof between said major surfaces at the central portions of said major surfaces, said thickness being a value corresponding to the value of said frequency, opposite electrodes adjacent said central portions of said major surfaces, the ratio of area of at least one of said electrodes with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corre-

sponding to the value of said frequency, said electrodes being circular and equal in size.

21. A piezoelectric quartz crystal element having its major surfaces substantially parallel to an X axis, said crystal element being adapted to vibrate at a frequency dependent upon a thickness thereof between said major surfaces at the central portions of said major surfaces, said thickness being a value corresponding to the value of said frequency, opposite electrodes adjacent said central portions of said major surfaces, the ratio of area of at least one of said electrodes with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, at least one of said electrodes being circular and formed integrally with at least one of said major surfaces of said crystal element.

22. A piezoelectric quartz crystal element having its major surfaces substantially parallel to an X axis, said crystal element being adapted to vibrate at a frequency dependent upon a thickness thereof between said major surfaces at the central portions of said major surfaces, opposite and equal size electrodes adjacent said central portions of said major surfaces, the ratio of area of each one of said electrodes with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, said thickness being slightly greater at said central portions of said major surfaces than at the periphery marginal portions thereof and said thickness being a value corresponding to the value of said frequency.

23. An AT-cut piezoelectric quartz crystal element having substantially rectangular major surfaces, each of said major surfaces having one pair of opposite edges substantially parallel to an X axis and the other pair of its opposite edges inclined substantially $+35^{\circ} 20'$ with respect to the Z axis, the thickness of said element between the central portions of said major surfaces being of a value corresponding to a desired frequency, electrodes formed integrally with said major surfaces and having an effective electric field producing area in said central portions only of said major surfaces, the ratio of said effective electric field area with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency.

24. An AT-cut piezoelectric quartz crystal element having substantially rectangular major surfaces, each of said major surfaces having one pair of opposite edges substantially parallel to an X axis and the other pair of its opposite edges inclined substantially $+35^{\circ} 20'$ with respect to the Z axis, the thickness of said element between the central portions of said major surfaces being of a value corresponding to a desired frequency, electrodes on and formed integrally with at least one of said major surfaces and having an effective electric field producing area in said central portions only of said major surfaces, the ratio of said effective electric field area with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, conductive coatings formed integrally with at least one of said major surfaces of said crystal element and extending independently from at least one of said opposite electrodes

substantially to the peripheral edges of said major surfaces.

25. An AT-cut piezoelectric quartz crystal element having substantially rectangular major surfaces, each of said major surfaces having one pair of opposite edges substantially parallel to an X axis and the other pair of opposite edges inclined substantially $+35^{\circ} 20'$ with respect to the Z axis, the thickness of said element between the central portions of said major surfaces being of a value corresponding to a desired frequency, electrodes formed integrally with said major surfaces and having an effective electric field producing area in said central portions only of said major surfaces, the ratio of said effective electric field area with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, conductive coatings formed integrally with said major surfaces of said crystal element and extending independently from each of said opposite electrodes substantially to the peripheral edges of said major surfaces, and each of said conductive coatings extending around said edges and onto the respective opposite major surfaces of said crystal element.

26. An AT-cut piezoelectric quartz crystal element having substantially rectangular major surfaces, each of said major surfaces having one pair of opposite edges substantially parallel to an X axis and the other pair of its opposite edges inclined substantially $+35^{\circ} 20'$ with respect to the Z axis, the thickness of said element between the central portions of said major surfaces being of a value corresponding to a desired frequency, electrodes formed integrally with said major surfaces and having an effective electric field producing area in said central portions only of said major surfaces, the ratio of said effective electric field area with respect to the area of one of said major surfaces being a value given substantially by the curve of Fig. 4 at a point thereon corresponding to the value of said frequency, conductive coatings formed integrally with said crystal element and extending independently from each of said opposite electrodes substantially to the peripheral edges of said major surfaces, each of said conductive coatings extending around said edges and onto the respective opposite major surfaces of said crystal element, and conductive means adjacent said edges for mounting said element and establishing individual connections with said conductive coatings.

27. A piezoelectric quartz crystal element adapted to vibrate at a frequency dependent mainly upon its thickness in the central region of its opposite major surfaces, said thickness being a value corresponding to the value of said frequency, conductive coatings formed integrally with parts of said major surfaces and with parts of the peripheral edge surfaces between said opposite major surfaces of said crystal element, said coatings on said major surfaces being oppositely disposed in said central region only of said major surfaces, and other portions of said coatings extending independently from each of said opposite central portions to and around said peripheral edge surfaces and onto the opposite part of said opposite major surfaces of said crystal element.

28. A piezoelectric quartz crystal element adapted to vibrate at a frequency dependent mainly upon its thickness in the central region of its opposite major surfaces, said thickness be-

ing a value corresponding to the value of said frequency, conductive coatings formed integrally with parts of said major surfaces and with parts of the peripheral edge surfaces between said opposite major surfaces of said crystal element, said coatings on said major surfaces being oppositely disposed in said central region only of said major surfaces, and other portions of said integrally formed coatings extending independently from each of said opposite central portions to and around said peripheral edge surfaces and onto the opposite part of said opposite major surfaces of said crystal element, and conductive means adjacent said edge surfaces for mounting said element and establishing individual connections with said conductive coatings.

29. A thickness-mode piezoelectric quartz crystal element having rectangular shaped major surfaces, the thickness of said crystal element between the central portions of said major surfaces being a value corresponding to the value of said thickness-mode frequency, field-producing electrodes adjacent said central portions of said major surfaces, opposite metallic coatings formed

integrally with said major surfaces of said element adjacent a corner portion thereof, and short-circuiting means conductively interconnecting said opposite coatings for reducing piezoelectric excitation and vibratory motion in said corner portion.

30. A thickness-mode piezoelectric quartz crystal element having rectangular shaped major surfaces, the thickness of said crystal element being a value corresponding to the value of said thickness-mode frequency, opposite metallic coatings formed integrally with said major surfaces of said element adjacent a corner portion thereof, and short-circuiting means conductively interconnecting said opposite coatings for reducing piezoelectric excitation and vibratory motion in said corner portion, said short-circuiting means being formed integrally with the edge surface of said crystal element adjacent said corner portion, one of said opposite coatings being connected to an electrode that is at the central portion of one of said major surfaces.

STUART C. HIGHT.

DISCLAIMER

2,343,059.—*Stuart C. Hight*, South Orange, N. J. PIEZO-ELECTRIC CRYSTAL APPARATUS. Patent dated February 29, 1944. Disclaimer filed January 30, 1945, by the assignee, *Bell Telephone Laboratories, Incorporated*.

Hereby enters this disclaimer to claims 5, 7, and 8 of said patent.

[*Official Gazette March 6, 1945.*]

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