

Dec. 3, 1940.

R. A. SYKES

2,223,537

PIEZOELECTRIC CRYSTAL APPARATUS

Filed July 15, 1938

2 Sheets-Sheet 1

FIG. 1

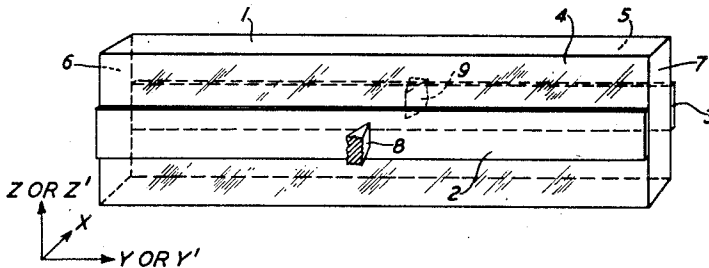


FIG. 2

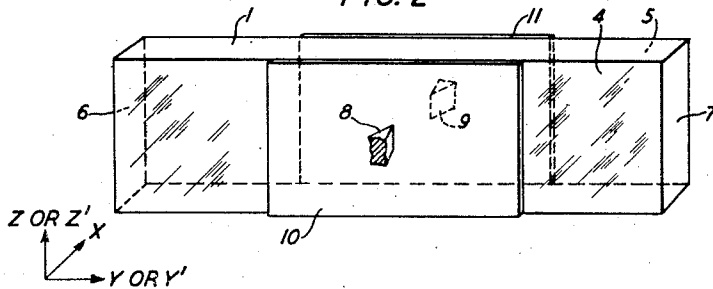


FIG. 3

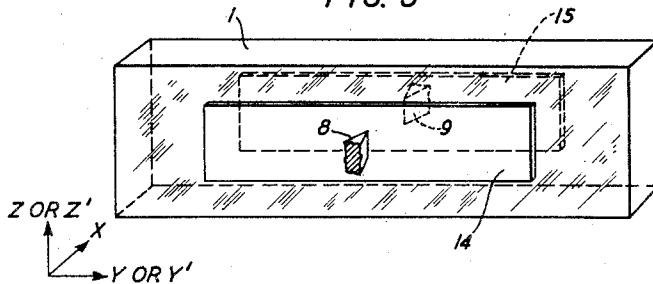
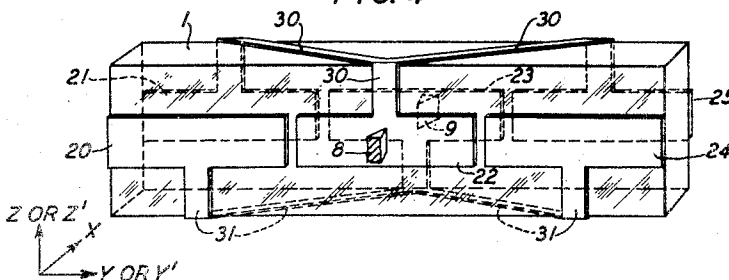


FIG. 4



INVENTOR
R. A. SYKES
BY
W. J. O'Neill
ATTORNEY

Dec. 3, 1940.

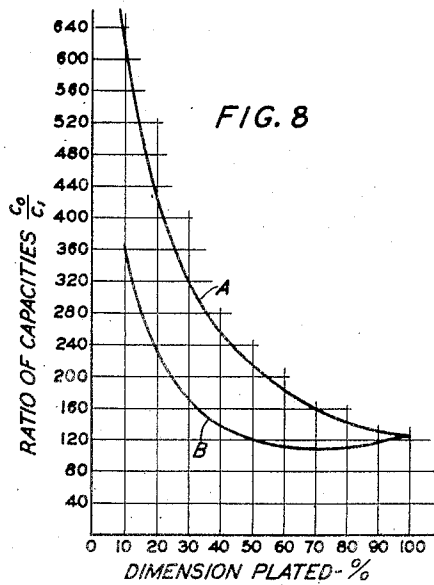
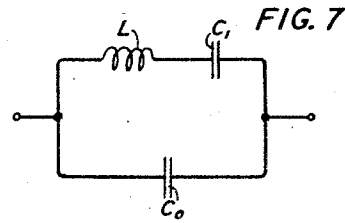
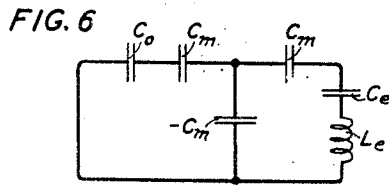
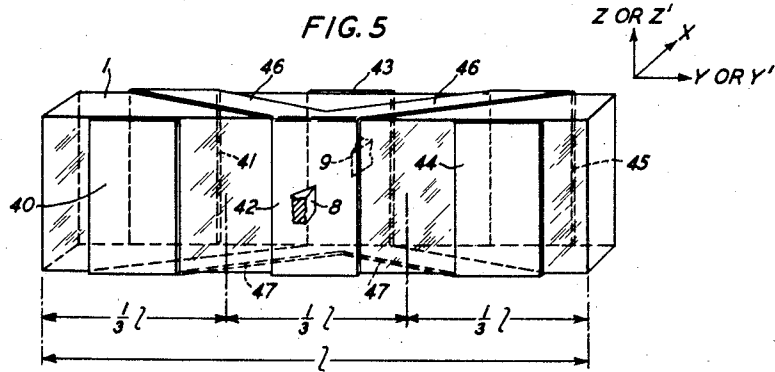
R. A. SYKES

2,223,537

PIEZOELECTRIC CRYSTAL APPARATUS

Filed July 15, 1938

2 Sheets-Sheet 2



INVENTOR
R. A. SYKES
BY W. J. O'Neill
ATTORNEY

UNITED STATES PATENT OFFICE

2,223,537

PIEZOELECTRIC CRYSTAL APPARATUS

Roger A. Sykes, Fanwood, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 15, 1938, Serial No. 219,325

18 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystal apparatus and particularly to quartz crystal elements having electrodes covering selected parts only of the crystal electrode surfaces and adapted for use as reactance elements in electric wave filter systems or as frequency determining elements in oscillation generator systems, for example.

This application is a continuation in part of my copending application, Serial No. 64,692, filed February 19, 1936, now U. S. Patent No. 2,124,596 dated July 26, 1938.

One of the objects of this invention is to reduce or otherwise adjust to a desired value the effect of the internal or series capacity of an electrode piezoelectric crystal element.

Another object of this invention is to provide filter crystals of higher impedance.

Another object of this invention is to increase the electromechanical driving efficiency of piezoelectric quartz crystal elements which may be utilized as reactance elements in filter systems or as frequency determining elements in oscillation generator systems, for example.

Another object of this invention is to increase the band width of electric wave filters employing piezoelectric elements as reactance elements thereof.

Another object of this invention is to increase the breakdown voltage of a piezoelectric crystal element.

In accordance with this invention, electrodes covering certain selected parts of the electrode surfaces of longitudinally vibrating quartz crystal elements such as X-cut crystals or X-cut crystals in effect rotated about the X axis —18 degrees or +5 degrees, for example, may be utilized for such purposes as to lower the internal or series capacity of the crystal without requiring the use of capacities external thereto, to provide filter crystals of higher impedance with reasonably sized crystals, to increase the breakdown voltage of the crystal element, to increase the electromechanical driving efficiency and the electro-mechanical coupling coefficient of the plated crystal element, and to increase the band width of crystal filters of the type employing crystals and condensers.

In a piezoelectric device, it is often desirable to obtain the maximum displacement of the crystal-line material for a given input of electrical power. This occurs when the coupling coefficient between the electrical and mechanical systems of the crystal is a maximum. In accordance with

one feature of this invention, the driving efficiency as determined by the coupling coefficient between the electrical and mechanical systems of the crystal may be increased or rendered a maximum by means of electrodes partially covering certain parts of the electrode surfaces of the crystal.

In the case of a longitudinally vibrating quartz crystal element such as an X cut quartz element particularly described herein by way of illustrative example, the maximum electromechanical driving efficiency and the maximum or optimum coupling between the electrical and mechanical systems occurs when the opposite electrodes cover substantially 70 per cent of the area of each of the crystal electrode surfaces which in this instance are perpendicular to the electric axis X thereof, the electrodes being opposite, extending substantially from edge to edge or near to the edges of the crystal in a direction axially transverse or perpendicular to the direction of vibrations and the frequency determining dimension and being centrally disposed with respect to the ends of the frequency determining dimension.

Such a longitudinally vibrated quartz element plated with electrodes covering substantially 70 per cent of the frequency determining dimension may be utilized also as a reactance element in an electric wave filter to increase the band width thereof.

Where a crystal is about 70 per cent metal plated centrally on both major surfaces thereof substantially in the direction parallel to the optic axis and perpendicular to the direction of vibration thereof and intermediate the small ends of the crystal, the crystal may be driven more efficiently than when its two major surfaces are wholly plated. Also, where such central and oppositely disposed pair of partial platings disposed perpendicular to the direction of vibrations, cover only about half of the major surfaces of the crystal, the crystal may be driven nearly as efficiently as if the whole area of the two major surfaces were plated.

In accordance with another feature of this invention, the major surfaces of the crystal may be partially electrode to obtain very low or any desired values of series or internal capacity C_1 with crystals of physically normal size, of high Q (ratio of reactance to resistance) and of values of capacity to suit the particular design of electric wave filter, without necessarily requiring the use of a separate series connected air condenser. In this case, the electrodes may be disposed either

axially perpendicular or axially parallel to the frequency determining dimension, or in a combination of these two arrangements wherein the electrodes are arranged entirely away from the edges and may cover ordinarily from 40 to 70 per cent of the crystal electrode faces according to the capacity or impedance that it may be desired to obtain to suit the particular application.

To guard against voltage breakdown over the edges between the two plated surfaces of a crystal, particularly at frequencies off resonance where, in general, the voltages are higher, the partial platings may be disposed only on the central area of each electrode surface of the crystal element back from the marginal edges of the crystal to thereby increase the path length distance over the crystal surfaces between the two plated electrodes on opposite electrode surfaces of the crystal.

For a clearer understanding of the nature of this invention and the additional 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 an enlarged perspective view of a piezoelectric quartz crystal plate having an electrode arrangement in accordance with this invention;

Fig. 2 is a perspective view of another crystal electrode arrangement in accordance with this invention;

Fig. 3 is a perspective view of another crystal electrode arrangement representing a combination in part of both the electrode arrangements illustrated in Figs. 1 and 2;

Fig. 4 is a perspective view of the electrode arrangement of Fig. 1 modified and adapted to obtain the third harmonic frequency of the longitudinal mode of motion;

Fig. 5 is a perspective view of the electrode arrangement of Fig. 2 modified and adapted to obtain the third harmonic frequency of the longitudinal mode of motion;

Figs. 6 and 7 are diagrams showing the electro-mechanical representation of the electroded crystals illustrated in Figs. 1 to 5; and

Fig. 8 is a graph showing the relation between the ratio of capacities C_0/C_1 and the percentage of partial plating for the crystal electrode arrangements of Figs. 1 and 2 particularly.

Referring to the drawings, Fig. 1 illustrates an elongated quartz crystal piezoelectric bar, plate or element 1 of rectangular parallelepiped shape having two oppositely-disposed, equal-dimensioned, rectangular-shaped electrodes 2 and 3 formed integral with the opposite major or electrode surfaces 4 and 5 of the piezoelectric quartz element 1, the electrodes 2 and 3 being adapted to apply an electric field to the crystal 1 to drive the crystal 1 in a fundamental longitudinal mode of motion along its length or longest axis dimension Y or Y' at a frequency determined substantially by such length dimension as measured axially between the small ends 6 and 7 of the crystal element 1.

In Fig. 1 as well as in Figs. 2 to 5, the major surfaces 4 and 5 and the major plane of the quartz plate 1 are disposed substantially perpendicular to an electric axis X and accordingly lie in planes which are substantially parallel to the plane formed by the optic axis Z and a mechanical axis Y of the quartz crystal material. The longitudinal or major axis of the quartz element 1

may lie along such Y axis or may be inclined thereto in a Y' direction at an acute angle of substantially -18.5 degrees, for example, or substantially $+5$ degrees, for example, as measured from such Y axis in the plane formed by the Z axis and such Y axis.

When the longitudinal axis Y' of an X-cut quartz plate 1 rotated about its X axis is inclined at an angle of substantially -18.5 degrees with respect to the nearest Y axis of the quartz crystal element 1 as disclosed in French Patent 785,235, issued May 13, 1935, corresponding to U. S. Patent No. 2,173,589, granted September 19, 1939, on application Serial No. 702,334, filed December 14, 1933, by W. P. Mason and R. A. Sykes and as described in a publication, Electrical wave filters employing quartz crystals as elements, by W. P. Mason, Bell System Technical Journal, vol. XIII, July 1934, pages 405 to 452, the desired longitudinal vibrations along the Y' axis at the fundamental or any harmonic frequency thereof are substantially uncoupled with undesired shear vibrations in the crystal element 1.

When the longitudinal axis Y' of an X-cut quartz plate 1 rotated about its X axis is inclined with respect to the Y or mechanical axis at an angle of substantially $+5$ degrees, as described by Matsumara and Kanzaki in a publication, On the temperature coefficient of frequency of Y waves in X-cut quartz plates, Reports of Radio Researches and Works in Japan, March 1932, and as disclosed for harmonic vibrations in U. S. Patent No. 2,185,599, granted January 2, 1940 on application Serial No. 65,022, filed February 21, 1936 by W. P. Mason, the desired longitudinal vibration along the Y' axis of the quartz bar 1 may have a very small or substantially zero temperature coefficient of frequency at the fundamental or any harmonic frequency thereof.

The electrodes 2 and 3 of Fig. 1 as well as the electrodes of the remaining Figs. 2 to 5 may be thin, equal area, oppositely disposed aluminum films or coatings deposited in intimate contact with a selected part of the opposite surfaces 4 and 5 of the crystal element 1, by evaporation in vacuum, for example. Alternatively, the integral electrodes 2 and 3 may be formed of any suitable conductive material such as, for example, thin coatings of platinum, gold, silver, copper, chromium on platinum or other combinations thereof, deposited on parts of the surfaces 4 and 5 of the quartz element 1 in any suitable manner such as, for example, by the well-known processes of evaporation in a vacuum, sputtering at low pressures, or spraying, or otherwise. The plated crystal 1 may be annealed to reduce strains therein and increase the Q thereof.

When connected in circuit relation with a suitable electrical system, the electrodes 2 and 3 may be utilized to apply an electric field to the quartz element 1 in a direction along the X axis thereof which is perpendicular to the major surfaces 4 and 5 thereby to cause the quartz bar 1 to vibrate in a fundamental longitudinal mode of motion along the longest axis thereof at a frequency which is determined by its longest axis or length dimension as measured axially between the small ends 6 and 7 of the crystal element 1.

The crystal element 1 having the integral electrodes 2 and 3 of Fig. 1 or other electrode arrangements as illustrated in Figs. 2 to 5 may be mounted in any suitable manner, such as, for example, by rigidly clamping the element 1 between opposite conductive clamping projections 8 and 9 at one or more points along the nodal

line which may be substantially midway between the small ends 6 and 7 of the quartz element 1, as disclosed, for example, in U. S. Patent 2,032,865, granted March 3, 1936, to C. A. Biel-ing.

The rectangular electrodes 2 and 3 of Fig. 1 are oppositely disposed, extend substantially from one end 6 to the opposite end 7 of the quartz plate 1, are located centrally along the major surfaces 4 and 5 in the direction of vibrations along the Y or Y' axis, and cover a selected part only of the total area of such surfaces 4 and 5 and of the width of the crystal 1 along the optic axis Z, and may function for such purposes as to reduce the internal capacity C_1 of a given partially electroded crystal 1 or to increase the impedance thereof in accordance with the percentage of the area of the crystal surfaces 4 and 5 that are covered by the electrodes 2 and 3.

Fig. 2 illustrates the longitudinally vibrating quartz plate 1 of Fig. 1 provided with a modified electrode arrangement. In Fig. 2, the oppositely disposed, rectangular-shaped electrodes 10 and 11 extend substantially from side edge to side edge or near to such edges, are located centrally along the major surfaces 4 and 5 and axially perpendicular to the desired or principal direction of vibration which is along the frequency determining length dimension Y or Y', and cover a selected part only of the total area of such surfaces 4 and 5 and of said length dimension. The partially plated crystal 1 of Fig. 2 is adapted to function for such purposes as to reduce the internal capacity C_1 of a given crystal 1, or to increase the impedance thereof, or to increase the electromechanical driving efficiency thereof, according to the percentage area and with dimension Z or Z' of the crystal surfaces 4 and 5 covered by the integral electrodes 10 and 11.

The coupled circuit representation of a piezoelectric quartz crystal is discussed in a publication by W. P. Mason, Proceedings of the Institute of Radio Engineers, vol. 23, pages 1252 to 1263, October 1935, and for the crystal 1 of Figs. 1 to 5 is as illustrated in Fig. 6 wherein the electrostatic capacitance C_0 is coupled by a T network of capacities to the electrical circuit equivalent of the mechanical system of the crystal 1, the coupling coefficient k thereof being defined as

$$k = \sqrt{\frac{C_0 C_e}{C_m^2}} \quad (1)$$

where C_0 is the mechanical compliance of the crystal, C_m is the mutual compliance, and C_0 is the electrostatic capacitance of the electroded crystal unit. Such a coupled circuit representation may be reduced to the conventional circuit shown in Fig. 7 and also shown in Fig. 2A of a publication, Electrical wave filters employing quartz crystals as elements, by W. P. Mason, Bell System Technical Journal, vol. 13, pages 405 to 452, July 1934, where C_0 is, as before stated, the electrostatic capacity of the crystal, and C_1 is the internal or series capacity of the crystal.

In terms of the coupling coefficient k , the ratio of capacities C_0/C_1 is equal to

$$r = \frac{C_0}{C_1} = \frac{1}{k^2} - 1 \quad (2)$$

showing that a variation in the coupling coefficient k will vary the internal capacity C_1 of the electroded crystal element.

The value of the internal capacitance C_1 is a function of both the coupling coefficient k and

the static shunt capacitance C_0 and is given by the expression:

$$C_1 = \frac{k^2}{1 - k^2} C_0 \quad (3)$$

Fig. 8 illustrates the effect on the ratio of capacities C_0/C_1 of plating a part only of the total area of the electrode surfaces 4 and 5 of the crystal 1, one of the purposes of which may be to reduce the effect of the internal capacity C_1 in a given crystal. The experimental results of partial platings each extending centrally along the entire Y axis length dimension of the major faces 4 and 5 of the fundamental mode X-cut quartz plate 1 and each covering only a selected part or percentage of the optic or Z axis width dimension thereof, as illustrated by the electrodes 2 and 3 of Fig. 1, are given by the curve A of Fig. 8; and the experimental results of partial platings each extending centrally along the entire Z axis width dimension of the major faces 4 and 5 of the quartz plate 1 and each covering only a selected part or percentage of the Y axis length dimension thereof, as illustrated by the electrodes 10 and 11 of Fig. 2, are given by curve B of Fig. 8. The results, as shown by curve A of Fig. 8, indicate that a decrease in the internal capacity C_1 may be more readily obtained with a plating, such as the electrode plating 2 and 3 of Fig. 1, covering only part of the optic axis Z of the crystal 1 since with this form of plating of Fig. 1, the ratio of capacities C_0/C_1 increases more and the internal capacity C_1 decreases more with any decrease in per cent of the plated area below 100 per cent, as illustrated by curve A of Fig. 8. The results as shown by the curve B of Fig. 8 indicate that a decrease in internal capacity C_1 may be obtained also with a plating such as the electrode plating 10 and 11 of Fig. 2 covering less than about 50 per cent of the Y axis or length dimension of the crystal 1, since, with decreasing values below 50 per cent of the Y axis dimension plate, the ratio of capacities C_0/C_1 increases and the internal capacity C_1 decreases as illustrated by the rising part of the curve B of Fig. 8.

Curve B of Fig. 8 also indicates from the values of ratios of capacities C_0/C_1 given therein that a partial plating covering the Z axis width dimension and covering only a selected part or percentage of the Y axis length dimension of the quartz plate 1 as illustrated by the electrode plating 10 and 11 of Fig. 2 may be utilized to drive the crystal plate 1 nearly as efficiently with only about half or 50 per cent of the area covered by the electrodes 10 and 11 as when the whole area of the electrode surfaces 4 and 5 are covered with electrode plating; and further that the maximum electromechanical driving efficiency and maximum or optimum electromechanical coupling between the electrodes 10 and 11 and the crystal 1 may be obtained when the electrodes 10 and 11 cover from about 60 to 80 per cent or an optimum value of substantially 70 per cent of the Y axis dimension and 70 per cent of the area of the electrode surfaces 4 and 5 of the crystal 1.

The experimental results given in Fig. 8 which were taken in using, as an illustrative example, a rectangular parallelepiped quartz plate 1 having a thickness dimension of 2.00 millimeters along an electric axis X, a width dimension of 16.50 millimeters along the optic axis Z and a length dimension of 45.03 millimeters along a mechanical or third axis Y, the crystal being vibrated in

the longitudinal mode along the length dimension Y at a fundamental frequency of 60,000 cycles per second determined by the length dimension Y.

- Similar results may be obtained with crystals of other dimensions, frequencies and orientations when vibrated in the same mode at the fundamental frequency or harmonics thereof.

- Accordingly, in the case where the crystal 1 has its electrodes centrally located along and axially parallel to the principal direction of vibration Y or Y' as illustrated in Figs. 1 and 4, the coupling coefficient k decreases as the electrode area decreases and at the same time the static capacitance decreases, resulting in a material reduction in the value of the internal capacity C_1 as indicated by Equation 3 where C_1 is shown to be a function of both the static shunt capacity C_0 and the coupling coefficient k and as illustrated by curve A of Fig. 8 where the ratio C_0/C_1 is shown to materially increase as the area of the electrodes 2 and 3 of Fig. 1 is reduced.

- In the case of the crystal 1 having electrodes 10 and 11 centrally located and partially covering the frequency determining length dimension along the principal direction of vibration Y or Y', as illustrated in Figs. 2 and 5, the coupling coefficient k which has a certain fixed value for a crystal whose major surfaces are substantially completely electroded, rises above that fixed value to a maximum or optimum value when the plated area is about 70 per cent of that of each crystal electrode surface and then decreases as more electrode plating is removed as illustrated by curve B of Fig. 8 where the ratio of capacities C_0/C_1 is shown to decrease to a minimum value of about 110 at roughly 70 per cent plating area and then to increase as the area of the electrodes 10 and 11 of Fig. 2 is further reduced.

- Accordingly, the arrangement of the electrodes shown in Figs. 2 and 5 may be utilized to increase the electromechanical driving efficiency and to obtain the maximum displacement of the crystal-line medium for a given input of electrical power into the quartz element 1, which may be employed as a reactance element in a filter system or as a frequency determining element in an oscillation generator system, for example. The maximum efficiency occurs when the coupling coefficient k between the electrical and mechanical systems is a maximum and, in the arrangement shown in Figs. 2 and 5 when the electrodes are individually centrally located with respect to the frequency determining length dimension along the principal direction of vibration and cover about 70 per cent of each of the electrode or major faces of the crystal 1.

- Also, the arrangement of the electrodes shown in Figs. 2 and 5, for example, may be utilized to increase the band width of electric wave filters employing quartz crystals as reactance elements thereof. The frequency band width of filters such as the band-pass filters of the types shown, for example, in Figs. 7, 12 and 13 of the W. P. Mason publication referred to in Bell System Technical Journal, vol. No. 13, pages 405 to 452, July 1934, or in the U. S. Patent 1,974,081 to W. P. Mason, September 18, 1934, is limited by the ratio of capacities r and may be shown to be:

$$\frac{f_2 - f_1}{f_1} = \frac{1}{r}$$

as expressed in terms of the ratio of capacities $r = C_0/C_1$; and

$$\frac{f_2 - f_1}{f_1} = \frac{k^2}{1 - k^2}$$

as expressed in terms of the electromechanical coupling coefficient k . The ratio of capacities $C_0/C_1 = r$ reaches a minimum value of about 110 as shown by curve B of Fig. 8 and the electromechanical coupling coefficient reaches a maximum when the electrode plating is centrally located with respect to the frequency determining length dimension Y' along the principal direction of vibration and covering about 70 per cent of the area of each of the electrode faces 4 and 5 of the crystal 1 as illustrated in Figs. 2 and 5. This is therefore the condition for maximum band width in crystal filters. The band width of electric wave filters employing crystals and condensers as elements thereof may be increased up to as much as about 13 per cent, by utilizing quartz crystals plated with electrodes covering parts of the electrode surfaces as illustrated in Figs. 2 and 5, instead of covering substantially the whole area of the crystal electrode surfaces.

Fig. 3 illustrates the quartz plate 1 provided with opposite rectangular-shaped electrodes 14 and 15 centrally located on the electrode faces 4 and 5 entirely inwardly of the edges thereof and covering so much of the area of each electrode face 4 and 5 as may be desired to obtain a desired internal capacity C_1 , impedance, or electromechanical coupling for the device, or a desired increase in band width for a filter system with which it may be associated as a reactance element. The electrode arrangement shown in Fig. 3 represents a combination of those shown in Figs. 1 and 2 since in Fig. 3 the electrode platings 14 and 15 are reduced in both a direction parallel to the direction of vibrations as shown in Fig. 2 and in a direction transverse or perpendicular thereto as shown in Fig. 1, and being such a combination of these two methods, its characteristics will be in the nature of a composite thereof and will roughly follow a composite of curves A and B of Fig. 8 with respect to its ratio of capacities C_0/C_1 in relation to the percentage of area of the electrode surfaces covered by the electrodes 14 and 15. The arrangement of Fig. 3 accordingly is useful to obtain a reduced internal capacity C_1 and an increased impedance for the crystal element 1 and at the same time a large electromechanical driving efficiency as measured by the electromechanical coupling coefficient k thereof.

It will be noted that a considerable decrease in internal capacity C_1 of a plated X-cut quartz crystal 1 vibrating longitudinally may be effected by reducing the amount of the area of the major surfaces of the crystal covered by the electrodes. This area covered by the electrodes may be centrally located and axially disposed parallel to the principal direction of vibration along the length of the crystal in the Y or Y' direction as illustrated in Fig. 1. If the area covered by the electrodes be centrally located and axially perpendicular to the principal direction of vibration as illustrated in Fig. 2, the electromechanical coupling coefficient and consequently the driving efficiency will be a maximum when the area covered by the electrodes is roughly 70 per cent of that of the total area of the electrode surfaces. Reduction of the electrode plating in both directions as illustrated in Fig. 3 will also reduce the internal capacity with the electromechanical coupling coefficient not decreasing materially until less than 50 per cent of the area is covered by the electrodes. This is a very desirable feature since the internal capacity C_1 may be lowered without impairment of the driving efficiency as

determined by the electromechanical coupling coefficient k .

Fig. 4 illustrates the electrode arrangement of Fig. 1 so modified as to drive the quartz plate 1 at the third harmonic frequency of its longitudinal mode of motion along the Y or Y' axis direction instead of at the fundamental frequency vibration as illustrated in Fig. 1. In the case of the third harmonic vibration of Fig. 4 the crystal 1 is in effect divided into three equal sections as illustrated in Fig. 5 which determine the third harmonic frequency. In Fig. 4, each of the three sections is provided with a pair of equal and opposite electrodes bearing the same relation to the area of each sectional electrode surface as the electrodes 2 and 3 of Fig. 1 bear to the entire crystal electrode surfaces 4 and 5. As illustrated in Fig. 4, the three pairs of electrodes may consist of the opposite electrodes 20 and 21, the opposite electrodes 24 and 25, all six of which are of equal rectangular dimensions and area. The electrodes 21, 22 and 25 are connected together by means of metallic connector plating 30 which may be formed integral with the surfaces of the crystal 1 as illustrated in Fig. 4. Similarly, the electrodes 20, 23 and 24 are connected together by means of the metallic connector plating 31 which may be formed integral with the surfaces of the crystal element 1. External electrical connections may be made by oppositely disposed conductive clamping projections disposed in contact with the middle pair of electrodes 22 and 23 to clamp the element 1 along the nodal line midway between the small ends of the crystal 1 in the manner illustrated by the clamping projections 8 and 9.

It will be noted that the individual pairs of electrodes of Fig. 4 follow the same proportions with respect to their corresponding sections, each of one third of the total electrode surface area as do the electrodes 2 and 3 of Fig. 1 with respect to the whole electrode surfaces 4 and 5 of the crystal 1.

Fig. 5 illustrates the electrode arrangement of Fig. 2 modified to provide three pairs of equal and opposite electrodes 40 to 45 and connectors 46 and 47 therefor, the arrangement being adapted to drive the crystal 1 at its third harmonic or third overtone longitudinal mode of motion along the frequency determining length axis dimension Y or Y' in the same manner as is shown in Fig. 4. The electrodes 41, 42 and 45 are interconnected by the connectors 46 which may be formed integral with the crystal 1. Similarly, the electrodes 40, 43 and 44 are connected together by means of the conductive plating 47 which may be formed integral with the crystal 1.

Oppositely disposed conductive clamping projections 8 and 9 disposed in contact with the middle pair of opposite electrodes 42 and 43 may be utilized to establish electrical connections and to rigidly and nodally clamp the element along a nodal line midway between the small ends 6 and 7 of the crystal 1.

It will be understood that the crystal 1 may be driven at its third harmonic frequency with electrodes of the type illustrated in Fig. 3 interconnected as is illustrated in Figs. 4 and 5.

While the third harmonic longitudinal mode of motion is particularly illustrated in Figs. 4 and 5, it will be understood that the partial platings of the invention disclosed herein may be adapted to any order of harmonic frequency vibrations of the fundamental longitudinal mode of motion of

Figs. 1, 2 and 3, such as, for example, the second, fifth or any higher odd or even harmonic frequency vibration, by providing a suitable number of pairs of oppositely disposed electrodes corresponding in number of pairs to the order of the desired harmonic and connecting all positive electrodes together and all negative electrodes together in the manner illustrated in Figs. 4 and 5 for the third harmonic vibration.

The fundamental vibration and any of the odd harmonics thereof are of special interest since then a nodal line occurs substantially midway between the small ends 6 and 7 of the crystal 1 and the crystal 1 may therefore be rigidly clamped and electrically connected therealong such nodal line by means of oppositely disposed conductive clamping projections such as those designated 8 and 9 as illustrated in Figs. 1 to 5. It will be understood that in such arrangements for harmonic longitudinal vibrations, the individual pairs of oppositely disposed electrodes may each cover partial areas of the same relative proportions of their respective sectional space as the electrodes of Figs. 1, 2 and 3 bear to the total area of the electrode surfaces 4 and 5.

Also, it will be understood that the electrodes of Figs. 1 to 3 may be longitudinally split or divided centrally along the Y or Y' axis, as disclosed in U. S. Patent No. 2,124,596 granted July 26, 1938, on application Serial No. 64,692 heretofore referred to, and also that the electrodes of Figs. 4 and 5 may be divided as disclosed in application Serial No. 65,022, filed February 21, 1936, by W. P. Mason, now U. S. Patent 2,185,599, granted January 2, 1940, to provide two separate circuits of equal impedance and frequency in a single crystal 1 vibrating at the fundamental frequency or at an overtone thereof.

It will be noted that, in accordance with this invention, the internal capacity C_1 of an electroded quartz crystal may be lowered without requiring the use of external capacities in the form of a separate series connected condenser, for example, and that the partially plated crystal 1 of this invention as illustrated in the several figures hereof and particularly as illustrated in Figs. 1 and 4 makes it possible to obtain very low values of the series or internal capacity C_1 with quartz crystals physically of normal size. While it is possible that the same low values of internal capacity C_1 may be obtained by the use of a crystal 1 having its electrode surfaces 4 and 5 substantially totally plated as in the prior art and a fixed condenser connected in series relation therewith, such a condenser would be required to have an extremely high Q or ratio of reactance to resistance, as of the order of 20,000 or more, to obtain for the combined condenser-crystal arrangement, the same high value of Q that is readily obtainable with the partially plated crystal 1 of Figs. 1 to 5 used alone. This method of lowering the series or internal capacity C_1 of a quartz crystal 1 by partial electroding has been successfully used with good results in electric wave filter systems to obtain values of capacity to fit the particular design where the addition of a separate series connected air condenser would have been inconvenient and troublesome.

Since the internal capacity C_1 of the crystal 1 partially plated with the electrodes of Figs. 1 to 5, for example, may be reduced or made to be of any desired value below a certain maximum determined by the fully plated crystal, the construction of crystal filters of higher im-

pedance with reasonably sized crystals or with crystals of substantially the same size as are used in low impedance filters is made possible.

As an example, in high-pass filters or in low-pass filters of the type as shown, for example, in Fig. 16D of the W. P. Mason publication in the Bell System Technical Journal, July 1934, pages 405 to 452, or in Fig. 9 of U. S. Patent 1,974,081, granted September 18, 1934, to W. P. Mason, the partially plated crystal of this invention may be of use where the design calls for quartz crystals of both high and low impedances in the same filter section. In this type of filter two crystals are used. In a particular case for a cut-off frequency placed at 350 kilocycles per second, the internal capacities C_1 of the two crystals may be calculated to be .0162 micro-microfarad and .0842 micro-microfarad, respectively. If, in this particular case, two completely plated major surface quartz crystals were used here of the same length and width, one of them would be about five times as thick along the X axis dimension as the other in order to obtain the proper relative impedances, whereas both of them may be of the same size where one of them has its electrodes centrally located, axially disposed parallel to the principal direction of vibration and covering about 40 per cent of the total area of each major surface of the crystal, as illustrated in Fig. 1. It will be understood that the percentage area plated may be adjusted to obtain the proper value of relatively high impedance to suit the particular design. When it is desired to obtain a crystal of relatively high impedance with a reasonably low ratio of capacities C_0/C_1 , the electrode plating may be centrally arranged as illustrated in Fig. 3 to cover only a part of the length and width dimensions of each of the electrode surfaces 4 and 5 of the crystal element.

As another example, in a particular high-pass filter of the bridge T type employing two crystals as reactance elements, similar to that of Fig. 1 of U. S. Patent 1,967,250, July 24, 1934, to W. P. Mason, the series arm quartz crystal longitudinally vibrating plate thereof of 108,009 cycles per second having an X axis thickness dimension of 3.20 millimeters, a width dimension of 12.971 millimeters and a frequency determining length dimension of 23.584 millimeters inclined at an angle of -18 degrees with respect to the nearest Y axis as described in the Mason paper, Bell System Technical Journal, July 1934, and in French Patent 785,235, referred to, was provided with electrodes of rectangular-shaped aluminum platings centrally located entirely inwardly of the edges as illustrated in Fig. 3 and covering 54.7 per cent of the area of each of its major surfaces to increase the impedance level thereof by a factor of 3. It will be understood that the percentage area of the electrode surfaces covered by the electrodes may be adjusted in each case to obtain the desired impedance level of the crystal according to the requirements of the particular filter under consideration.

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 longitudinally vibrated piezoelectric

quartz crystal plate of substantially rectangular parallelepiped shape having its opposite major electrode faces substantially perpendicular to an X axis and having oppositely disposed metal-plated electrodes formed integral and in intimate contact with parts less than the whole of the areas of said major electrode faces, said electrodes being substantially centrally located on said electrode faces inwardly of the width dimension edges thereof which are substantially perpendicular to the direction of said principal longitudinal vibrations, and covering substantially 70 per cent of the total area of each of said electrode faces to obtain substantially the maximum electromechanical coupling coefficient for said plated crystal plate.

2. A longitudinally vibrated piezoelectric quartz crystal plate of substantially rectangular parallelepiped shape having its opposite major electrode faces substantially perpendicular to an X axis and having oppositely disposed metal-plated electrodes formed integral and in intimate contact with parts less than the whole of the areas of said major electrode faces, said electrodes being substantially centrally located on said electrode faces entirely inwardly of the peripheral edges thereof and covering predetermined areas of said faces substantially between 40 and 70 per cent of the total areas thereof.

3. The method of adjusting to a desired value the series or internal capacity of a quartz crystal having opposite electrodes adjacent its opposite electrode faces which consists in adjusting the area of said electrodes to a value between substantially 40 and 70 per cent of the total area of said faces, and arranging the location of said electrodes centrally with respect to the total area of and covering only a part of the width and length dimensions of said crystal electrode faces until said desired value is obtained.

4. A longitudinally vibrated quartz piezoelectric element having its electrode surfaces disposed substantially perpendicular to an X axis, and opposite centrally disposed electrodes substantially wholly covering the longitudinal frequency determining dimension of said electrode surfaces and only partially covering the width dimension of said electrode surfaces in accordance with one of the percentages less than 80 per cent as given by the curve A of Fig. 8 to obtain a predetermined value of ratio of capacities as given substantially by said curve A.

5. A longitudinally vibrated quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, and opposite electrodes covering substantially 70 per cent of the surface substantially at the center on each of said electrode faces, leaving uncovered substantially 15 per cent of each of said electrode faces at the opposite ends thereof.

6. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, said element being adapted for longitudinal vibrations in the direction of its frequency determining dimension, and opposite electrodes on said opposite electrode faces, said electrodes extending substantially from one edge to an opposite edge of said element, disposed substantially centrally with respect to said frequency determining dimension, covering substantially 70 per cent of said frequency determining dimension and substantially 70 per cent of the surface on each of said electrode faces, leaving uncovered substantially 15 per cent of said frequency de-

termining dimension along the opposite ends thereof, to obtain substantially the maximum electromechanical coupling for said electrodes and said quartz element.

7. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, said element being adapted for longitudinal vibrations in the direction of its frequency determining dimension, and opposite electrodes on said opposite electrode faces, said electrodes extending substantially from one edge to an opposite edge of said element, and covering substantially 70 per cent of the surface on each of said electrode faces leaving uncovered substantially 30 per cent of the surface on each of said electrode faces.

8. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, said element being adapted for longitudinal vibrations in the direction of its frequency determining dimension, and opposite electrodes on said opposite electrode faces, said electrodes extending substantially from one edge to an opposite edge of said element, and covering a predetermined area between 40 and 80 per cent of the surface on each of said electrode faces on the central part only of said frequency determining dimension leaving uncovered the remaining parts of said frequency determining dimension on opposite sides of said central part.

9. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, said element being adapted for longitudinal vibrations in the direction of its frequency determining dimension, and opposite electrodes on said opposite electrode faces, said electrodes extending substantially from one edge to an opposite edge of said element, and covering the central part only and a predetermined part less than 80 per cent of said frequency determining dimension in accordance with a predetermined percentage thereof as given by the curve B of Fig. 8 leaving uncovered a substantial portion of the remaining parts of said frequency determining dimension on opposite sides of said central parts to obtain a predetermined ratio of electrostatic capacitance C_0 to internal or series capacity C_1 .

10. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, means including a plurality of pairs of opposite electrodes on said electrode faces for vibrating said element in longitudinal vibrations in the direction of its frequency determining dimension at an harmonic or overtone frequency which is a function of said frequency determining dimension, said electrodes extending substantially from one edge to an opposite edge of said element, being substantially equally spaced at intervals along said frequency determining dimensions, and covering substantially 70 per cent of the surface on each of said electrode faces and substantially 70 per cent of said frequency determining dimension leaving uncovered substantially 30 per cent of said frequency determining dimension at intervals along the length thereof.

11. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, means including a plurality of pairs of opposite electrodes on said electrode faces for vibrating said element in longitudinal vibrations in the direction of its frequency determining dimension at an harmonic or overtone frequency which is a function of said frequency determining dimension, said electrodes extending substan-

tially from one edge to an opposite edge of said element and covering substantially 70 per cent of the surface on each of said electrode faces leaving uncovered substantially 30 per cent of the surface on each of said electrode faces.

12. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, means including a plurality of pairs of opposite electrodes on said electrode faces for vibrating said element in longitudinal vibrations in the direction of its frequency determining dimension at an harmonic or overtone frequency which is a function of said frequency determining dimension, said electrodes extending substantially from one edge to an opposite edge of said element, covering a predetermined area substantially between 60 and 80 per cent of the total surface on each of said electrode faces, and being substantially equally spaced at intervals along said frequency determining dimension said intervals constituting a substantial portion of the entire length of said frequency determining dimension to obtain a reduced series or internal capacity with improved electromechanical coupling for said electrode element.

13. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, said element being adapted for longitudinal vibrations in the direction of its frequency determining dimension, and opposite electrodes on said electrode faces, said electrodes extending substantially from one end to the opposite end of said frequency determining dimension along the central part only of said electrode faces and covering between 40 and 80 per cent of the surface on each of said electrode faces leaving uncovered the remaining parts of said electrode faces on opposite sides of said central parts.

14. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, said element being adapted for longitudinal vibrations in the direction of its frequency determining dimension, and opposite electrodes on said electrode faces, said electrodes extending substantially from one end to the opposite end of said frequency determining dimension along the central part only of said electrode faces and covering the central part only of said electrode faces leaving uncovered a substantial portion of the remaining parts of said electrode faces on opposite sides of said central parts.

15. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, means including a plurality of pairs of opposite electrodes on said electrode faces for vibrating said element in longitudinal vibrations in the direction of its frequency determining dimension at an harmonic or overtone frequency which is a function of said frequency determining dimension, said electrodes extending along the central part only of said electrode faces in the direction of said frequency determining dimension and covering between 40 and 80 per cent of the surface on each of said electrode faces leaving substantially uncovered the remaining parts of the width dimension of said electrode faces on opposite sides of said central parts.

16. A longitudinally vibrated quartz crystal element coated with opposite equal electrodes covering a predetermined area between 40 and 80 per cent of the central part only of the total area on each of its opposite electrode surfaces leaving uncovered the remaining parts of the width and longitudinal dimensions of said surfaces on opposite sides of said central parts to obtain a

predetermined impedance characteristic for said electroded element.

- 5 17. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, said element being adapted for longitudinal vibrations in the direction of its frequency determining dimension, and opposite electrodes on said electrode faces, said electrodes covering a selected value between 40 and 80 per cent of the area of the surface on each of said electrode faces and being substantially centrally thereof and entirely inwardly of the peripheral edges of said electrode faces.
- 10

18. A quartz piezoelectric element having opposite electrode faces substantially perpendicular to an X axis, means including a plurality of pairs of opposite electrodes on said electrode faces for vibrating said element in longitudinal vibrations in the direction of its frequency determining dimension at an harmonic or overtone frequency which is a function of said frequency determining dimension, said electrodes being entirely inwardly of the edges of said electrode faces and covering between 40 and 80 per cent of the area of the surface on each of said electrode faces.

5 10

ROGER A. SYKES.