United States Patent

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[54] **MONOLITHIC CRYSTAL FILTERS**
9 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **333/72,**
310/8.2, 310/9.5, 310/9.8
[51] **Int. Cl.** **H03h 9/00**
[50] **Field of Search** 333/72;
310/8, 8.1, 9, 9.5, 9.8, 8.2, 8.3

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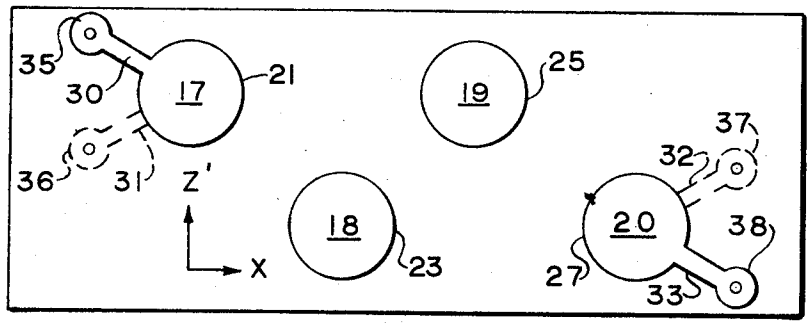
ABSTRACT: The monolithic crystal filters disclosed herein depart from previously known constructions in that adjacent resonators on a quartz plate are disposed on lines which are intermediate the X and Z' axes of the plate. In particular constructions the lines between successive resonator pairs lie in different quadrants relative to the X and Z' axes so that physically nonlinear arrays are formed.



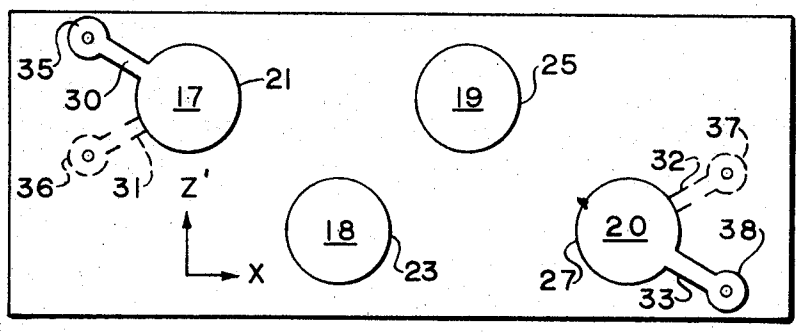


FIG. 1

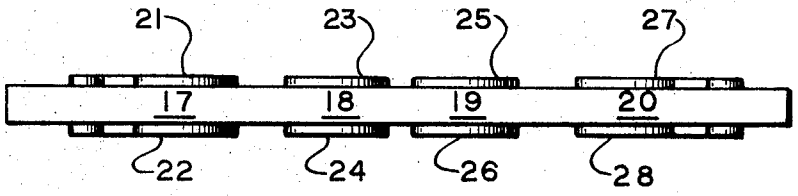


FIG. 2

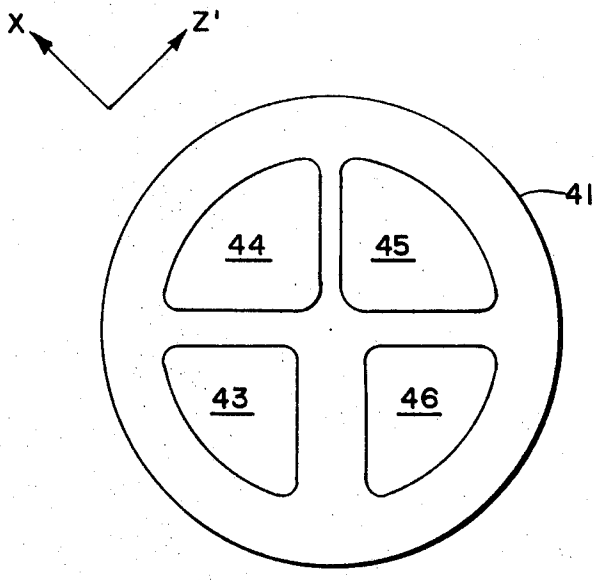


FIG. 3

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MONOLITHIC CRYSTAL FILTERS

BACKGROUND OF THE INVENTION

This invention relates generally to piezoelectric crystal filters and, more specifically, to an improved monolithic crystal filter.

It is known that piezoelectric crystals may be employed as resonators in electric wave filters to select or reject a specific narrow band of frequencies from a broad band containing desired and undesired frequencies. Commonly used filter designs, such as the Butterworth (maximally flat passband) and Chebyshev (equiripple passband), employ a plurality of resonators which are sequentially coupled to one another to provide a passband of desired width and shape. The several crystal resonators in such a filter may be constructed as discrete elements and electrically coupled, e.g. through inductors, transformers and capacitors, but more recently such filters have been constructed as portions of a monolithic structure in which a single crystal plate not only comprises the several resonators but also provides acoustic coupling between the several resonators of the filter.

Heretofore, the several resonators have been disposed in a physically linear array across the quartz plate along a line which is parallel to one of the major axes of the crystal plate. The coupling between adjacent resonators in the series has then been adjusted by varying the separation between the resonators or by varying plateback if only minor adjustment was needed. Adjustment by varying separation, however, is typically relatively expensive and time consuming in that a new mask for depositing the resonator electrodes must be fabricated for each stage of the empirical adjustment procedure.

Among the several objects of the present invention may be noted the provision of a monolithic filter whose construction facilitates adjustment of the several coupling coefficients between a plurality of resonators; the provision of such a filter which may be constructed in extremely compact form; the provision of such a filter which may be reproducibly manufactured to exact tolerances; and the provision of such a filter which is relatively simple and inexpensive.

Other objects and features will be in part apparent and in part pointed out hereinafter.

SUMMARY OF THE INVENTION

Briefly, in a monolithic filter according to the present invention, an AT-cut quartz plate is provided with at least two pairs of electrodes, the electrodes in each pair being in alignment on opposite sides of the plate so that each pair forms a resonator having a resonance frequency which is a function of the thickness of the plate and with the pairs being disposed on a line which is intermediate the X and Z′ axes of the plate, the pairs being acoustically coupled through said plate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of a monolithic crystal filter of the present invention;

FIG. 2 is a side view of the filter of FIG. 1; and

FIG. 3 is a plan view of another embodiment of a filter according to the present invention.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1 and 2, the monolithic crystal filter illustrated there comprises an AT-cut quartz plate 11 having major surfaces 13 and 15. Formed on plate 11 are four resonators 17, 18, 19 and 20 each of which comprises a pair of opposed metallic electrodes 21 & 22, 23 & 24, 25 & 26 and 27 & 28. The resonators 17 and 20 comprise the input and output resonators, respectively, and the opposed electrodes of these resonators are provided with leads 30—33 extending to respective terminals 35—38 for facilitating connection external circuitry. The remaining resonators are so-called internal resonators. The electrodes of the internal resonators are preferably connected top to bottom (by means not shown) to eliminate the effects of static capacities between them. The filter is thus a multipole filter having both externally connected resonators and internal resonators. As is understood by those skilled in the art, the electrodes, leads and terminals may be formed by depositing a suitable metal on the surface of the plate through a correspondingly shaped mask.

As is also understood by those skilled in the art, and AT-cut quartz crystal plate, such as that indicated at 11 in FIGS. 1 and 2, will resonate in the thickness-shear mode. The frequency of resonance of a given resonator is determined not only by the thickness of the quartz plate but also by the mass loading provided by the electrodes defining the resonator. Since the effective resonant frequency of the unloaded crystal plate in the areas outside of the electrodes differs from the resonant frequency of the resonators themselves, which are affected by electrode mass loading, a so-called energy trapping phenomenon is produced in which the amplitude of oscillation is greatest and is substantially uniform beneath the electrodes and decays exponentially as a function of distance outside of the electroded area. It can thus be seen that the degree of coupling between a pair of resonators on the same plate is a function of the separation between the resonators. The rate of exponential decay, however, is not the same along the two different major axes of the quartz crystal and thus the coupling between resonators depends not only upon spacing but also upon the orientation of the electrodes on the quartz plate with respect to the major crystal axes. Further, since the difference in effective resonance frequency between the electroded and nonelectroded areas depends upon the mass loading produced by the electrodes, it will also be seen that the degree of coupling is also a function of the thickness of the electrode material. This thickness is typically referred to in the art as plateback.

In the monolithic crystal filter illustrated in FIGS. 1 and 2, adjacent pairs of electrodes are disposed on lines which are intermediate the X and Z′ axes of the quartz plate 11, as indicated on the drawing. Further, the resonators 18 and 19 lie on a line which is at right angles to the line between resonators 17 and 18 while the resonators 19 and 20 are disposed on a line which is parallel to the line between the resonators 17 and 18. Thus, the lines between adjacent pairs lie in different quadrants between the X and Z′ axes of the crystal plate, the overall arrangement being essentially a Z-shape.

The following general expression has been empirically derived which yields the coupling coefficient K_ϕ between two rectangular or circular electroded resonators arranged at an arbitrary coupling angle θ with respect to the Z′ axis:

$$\ln K = 0.50 \ln (16.8[1+0.53 \sin 2\theta]) - 2.00 \ln (L_e/t + 2.09[1 + 16.6 \cos 2\theta]^{1/2}) - 2.28(1+.60 \cos^2\theta)^{1/2}\Delta^{1/2} d_e/t$$

where t=blank thickness, Δ= ratio of change of frequency caused by plateback to overall resonance frequency, and d=electrode spacing. For circular resonators,

$$L_e = D + d, \text{ and } d_e = d0.12\,D$$

where D is the resonator diameter.

For rectangular resonators,

$$L_e = D + d \text{ and } d_e = d$$

where D is the dimension of the resonator in the direction of coupling.

Agreement is good between calculated and measured coupling coefficients.

An advantage of the type of arrangement illustrated in FIGS. 1 and 2 is that a wide variety of monolithic crystal filters can be produced from a single four-resonator mask by varying the orientation of the mask relative to the crystal axes. This technique is particularly useful in constructing four-pole filters of the popular Butterworth or Chebyshev type. In those

filter designs, the coupling coefficient between the first and second resonators is equal to that between the third and fourth resonators while the coupling coefficient between the second and third resonators is significantly different from the other two coupling coefficients, the difference and absolute values of these coupling coefficients being a function of the bandwidth and shape characteristics desired. As may be seen, the configuration illustrated in FIGS. **1** and **2** readily lends itself to such filter designs when the separations between the adjacent resonators are equal.

In designing monolithic crystal filters for critical applications the following procedure has been found to be useful. Initial design parameters are established using the formula given above. As noted, the use of this formula gives an excellent first approximation of the desired results. The angular orientation of the mask which forms the resonator electrodes is then experimentally adjusted until the exact ratio of coupling coefficients desired is obtained. While varying the angular orientation of the mask can be used to arbitrarily vary the ratio of the coupling coefficients, this procedure may also alter the absolute values from the desired level. However, the desired absolute level can then be obtained by varying the plateback, i.e. the thickness or mass loading provided by the resonator electrodes, until the desired absolute value is obtained. As is understood, varying the plateback will also affect the center frequency of the passband. After the desired ratio of coupling coefficients and their absolute values have been obtained by experimentally varying the mask angle and the plateback parameters as described, the desired center frequency of the passband is then obtained by varying the thickness of the crystal plate. Thus, a filter having particular desired characteristics may be provided without requiring more than one mask. In fact a variety of different filters may be constructed using the same mask, the type of filter being varied by changing the orientation of the resonators with respect to the major axes.

While other electrode shapes such as rectangular may be used, circular electrodes are often desirable where space limitations permit since corner effects, due to the angular disposition of the coupling directions with respect to the major crystal axes, are avoided.

The monolithic crystal filter configuration illustrated in FIG. **3** is particularly useful where extremely small size is desired. In this arrangement a circular AT-cut quartz plate **41** is employed upon the major surfaces of which are deposited pie-or-sector-shaped electrodes which form four resonators **43-46**. The resonators **43** and **46** form the input and output resonators respectively and a relatively large separation is provided between these resonators to minimize unwanted coupling. Connections to outside circuitry may be made by suitable leads (not shown).

In that the filter configuration is symmetrical from side to side and the directions of coupling are generally in an inverted U-shape with the direction of coupling between the third and fourth resonators **45** and **46** being parallel to that between the first and second resonators **43** and **44**, it can be seen that the coupling coefficients between resonators **45** and **46** is equal to that between resonators **43** and **44**. Further, since the direction of coupling between resonators **44** and **45** is at right angles to that between resonators **45** and **46** and since the direction of coupling between any adjacent pair of resonator lies at an arbitrary angle with respect to the major crystal axes as indicated, it can be seen that the coupling coefficients between resonators **44** and **45** will typically be substantially different from the other two coupling coefficients.

Thus, as with the previous embodiments, the value of the coupling coefficient between the second and third resonators can be adjusted in relation to the equal coupling coefficients between the other adjacent pairs of resonators by varying the angular orientation of the electrode forming mask with respect to the major axes of the crystal plate **41** thereby to adjust the passband characteristics of the filter. As the four-pole Butterworth and Chebyshev filter designs typically call for a coupling coefficient between the second and third resonators which is substantially lower than that between the other adjacent pairs, the direction of coupling between resonators **44** and **45** will typically be at an angle providing low coupling. Thus, with the large separation between resonators **43** and **46**, negligible unwanting coupling is present. Using the configuration of FIG. **3**, a four-pole filter for use at 21 megahertz can be constructed in a size which will fit within a standard TO 5 semiconductor package.

In view of the foregoing, it may be seen that several objects of the present invention are achieved and other advantageous results have been attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it should be understood that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. A multipole monolithic filter comprising a crystal plate and four pairs of electrodes, the electrodes in each pair being in alignment on opposite sides of said plate so that each pair forms a resonator having a resonance frequency which is a function of the thickness of said plate and with the directions of acoustic coupling between adjacent pairs being at substantially right angles.

2. A filter as set forth in claim **1** wherein the lines between adjacent resonators form a Z-shape.

3. A filter as set forth in claim **1** wherein the lines between adjacent resonators form a U-shape.

4. A multipole monolithic filter comprising a circular AT-cut quartz plate and four pairs of generally sector-shaped electrodes, the electrodes in each pair being in alignment on opposite sides of said plate so that each pair forms a resonator having a resonance frequency which is a function of the thickness of said plate and the mass of the respective electrodes, the spacing between the first and fourth of said resonators being substantially greater than that between other resonator pairs thereby to reduce the acoustic coupling therebetween whereby said first and fourth resonators are acoustically coupled substantially only through said second and third resonators.

5. A filter as set forth in claim **4** wherein the directions of acoustic coupling between successive resonators are along lines which are intermediate and substantially different from the X and Z′ axes of said plate.

6. A filter as set forth in claim **5** wherein said electrodes are substantially right angle sectors and the separation between the first and second resonators is equal to that between the third and fourth electrodes whereby the respective coupling coefficients are substantially equal.

7. A multipole monolithic filter comprising an AT-cut quartz plate of essentially uniform thickness which, together with a plurality of pairs of electrodes, comprises a plurality of resonators each of which is acoustically coupled to at least one of the other resonators through said quartz plate, each resonator being formed by one pair of electrodes with the electrodes in each pair being in alignment on opposite sides of said plate, the resonant frequency of each resonator being a function of the thickness of the plate and the mass of the respective electrodes, the direction of coupling between acoustically coupled resonators being intermediate and substantially different from the X and Z′ axes of said plate.

8. A multipole monolithic filter comprising an AT-cut quartz plate of essentially uniform thickness which, together with at least three pairs of electrodes, comprises an input resonator, an intermediate resonator which is acoustically coupled to said input resonator through said quartz plate and an output resonator which is acoustically coupled to said intermediate resonator through said quartz plate, each resonator being formed by one pair of electrodes with the electrodes in each pair being in alignment on opposite sides of said plate, the resonant frequency of each resonator being a function of the thickness of the plate and the mass of the respective elec-

trodes, the direction of coupling between acoustically coupled resonators being intermediate and substantially different from the X and Z′ axes of said plate.

9. A filter as set forth in claim 8 wherein the direction of acoustic coupling between said input resonator and said intermediate resonator lies in a different quadrant, relative to said X and Z′ axes, than the direction of coupling between said intermediate resonator and said output resonator.

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(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,582,836 Dated June 1, 1971

Inventor(s) Robert L. Kent

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, last line, after "connection" insert --to--;

Column 2, line 4, "capacities" should be --capacitance--;

Column 2, line 10, "and" should be --an--;

Column 2, at the beginning of line 53, "ln K =" should be --lnKθ =--;

Column 2, line 60, "L_e = D+d, and d_e = d0.12D" should be --L_e =2D+d, and d_e =d+.12D--;

Column 2, line 65, "L_e = D+d and d_e = d" should be --L_e =2D+d and d_e = d--.

Signed and sealed this 14th day of December 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Patents