United States Patent

[11] 3,614,483

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[73] Assignee **Clevite Corporation**

[54] **WIDTH FLEXURAL RESONATOR AND COUPLED MODE FILTER**
26 Claims, 13 Drawing Figs.

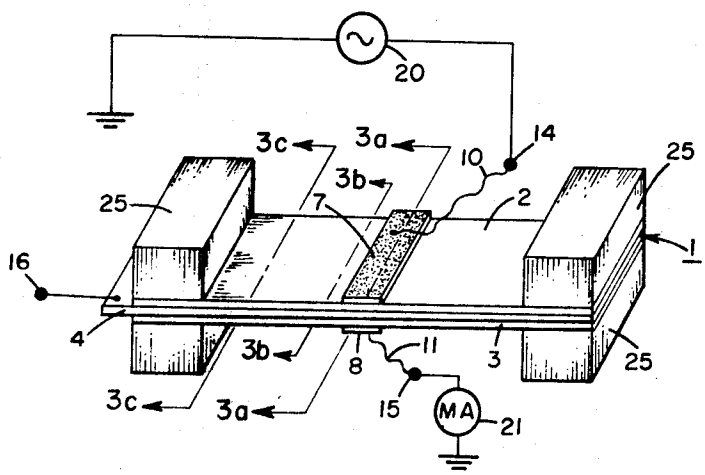
[52] **U.S. Cl.** **310/8.1,** 310/8.2, 310/8.5, 310/9.8, 333/72
[51] **Int. Cl.** **H01v 7/00**
[50] **Field of Search** 310/8, 1, 8.2, 8.3, 8.5, 8.6, 9.5, 9.7, 9.8; 333/72, 30

[56] **References Cited**
UNITED STATES PATENTS

2,484,950	10/1949	Jaffe	310/8
1,860,529	5/1932	Cady	310/8.1
3,325,743	6/1967	Blum	310/8.3 X
1,803,274	4/1931	Sawyer	310/8.5
2,472,753	6/1949	Mason	310/9.5
3,531,742	9/1970	Saito et al.	310/9.8 X

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ABSTRACT: Ceramic and crystal resonators and coupled mode filters are disclosed. They are platelike assemblies and operate in the width flexural mode. The operating frequency is determined primarily by the width and thickness of the assembly.



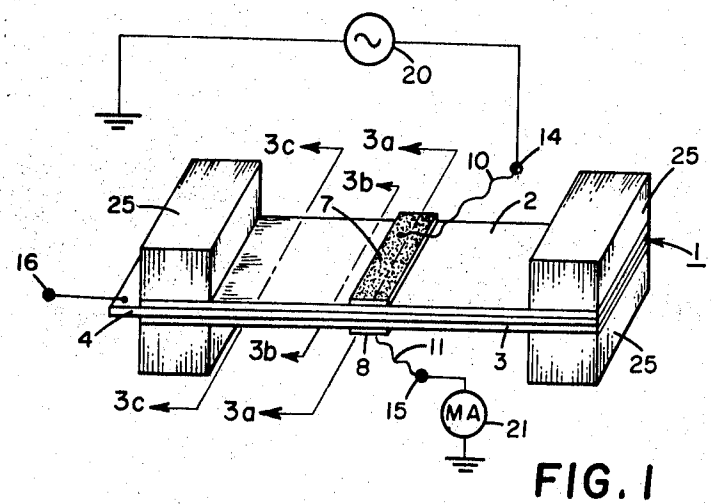


FIG. 1

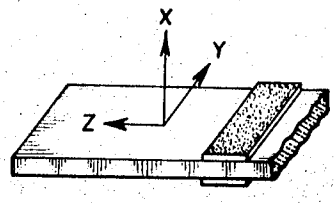


FIG. 1a

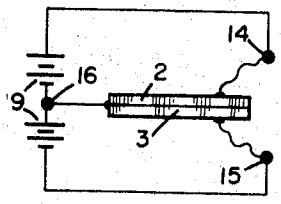


FIG. 2a

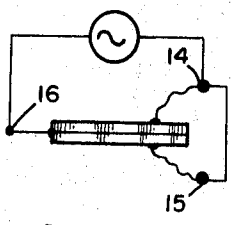


FIG. 2b

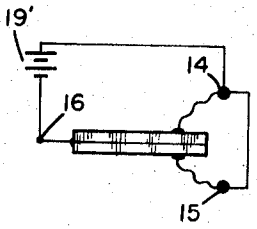


FIG. 2c

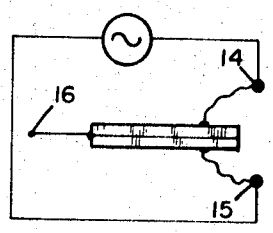


FIG. 2d

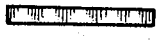


FIG. 3c



FIG. 3b



FIG. 3a

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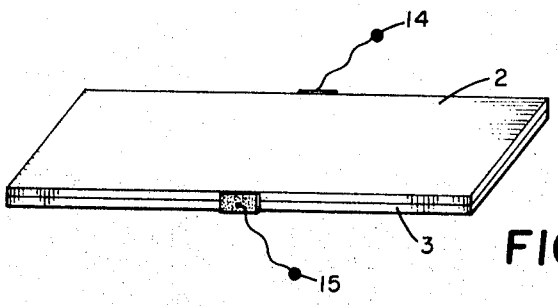


FIG. 4

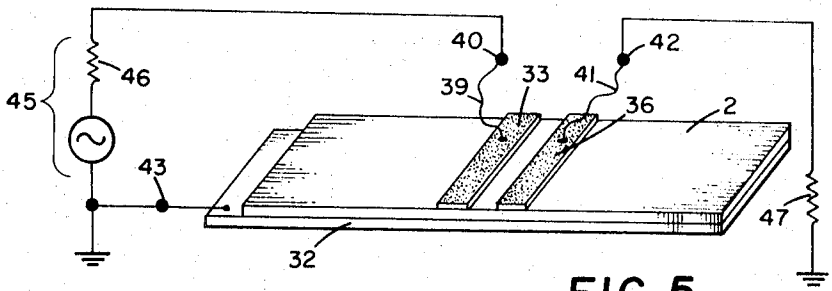


FIG. 5

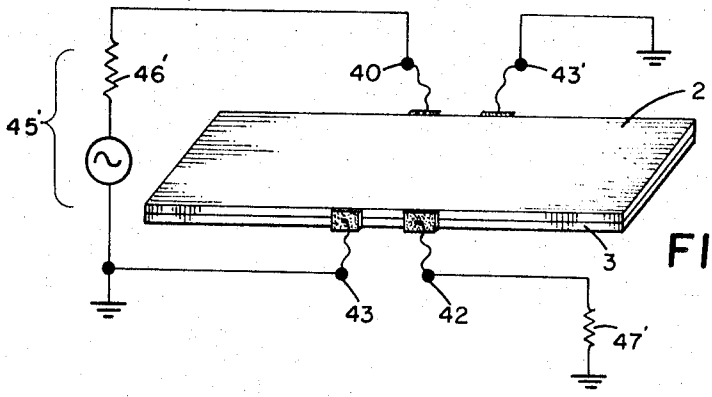


FIG. 6

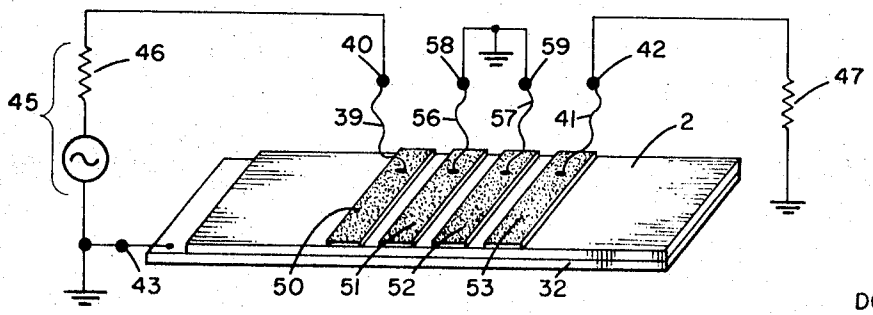


FIG. 7

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WIDTH FLEXURAL RESONATOR AND COUPLED MODE FILTER

This application is related to another application Ser. No. 49,286,filed concurrently herewith by the same inventor and entitled "Width Extensional Resonator and Coupled Mode Filter."

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to resonators and electric wave filters and, more particularly, to a new type of trapped-energy resonator, and to coupled mode band-pass filters employing such resonators.

2. Description of the Prior Art

Coupled mode filters, known in the prior art, have a plurality of similar thickness controlled resonators formed on a single plate of a piezoelectric crystal, typically quartz, or piezoelectric ceramic. Each resonator is established by a pair of small electrodes in registration on opposite faces of the plate. The resonance vibrations of each resonator, which may be thickness extensional or thickness shear, are confined to the area under the electrodes and immediately surrounding the electrodes by the energy-trapping principle. Such trapped resonators have heretofore been known only for thickness modes. Modes with propagation in the plane of the plate, in cases allowed by crystallographic symmetry, are only very weakly excited with the electrode configuration employed in the prior art. The prior art thickness mode resonators are placed sufficiently close together so that there is acoustic coupling to adjacent resonators, thereby producing the band-pass characteristic. For a more detailed treatment of thickness mode coupled mode filters, reference may be had to the following publications:

M. Onoe and H. Jumonji, Analysis of Piezoelectric indicate Resonators Vibrating in Trapped-Energy Modes, Electronics and Comm. Eng. (Japan), Vol. 4809,Sept. 1965, pp. 84–93.

R. A. Sykes, W. L. Smith W. J. Spencer Monolithic Crystal Filters, 1967IEEE International Convention Record, Part II, pp. 78–93.

Prior art monolithic coupled mode filters offer advantages of small size, reliability, and low cost. However, they have been limited by practical consideration to frequencies generally above about 4MHz.

Band-pass filters operating at lower frequencies are widely used. They are constructed of inductors and capacitors or they employ a plurality of individual piezoelectric ceramic resonators interconnected to form a filter. One successful form of such piezoelectric low-frequency resonator is disclosed in U.S. Pat. No. 3,423,700 to D. R. Curran et al. The large number of individual components requiring individual handling lead to cost, size, and reliability problems. Furthermore, prior art piezoelectric resonators are difficult to support for operation under conditions of high shock and vibration. It is highly desirable to have the advantage of monolithic filter design at these lower frequencies, and to have resonator devices which operate at these frequencies which may be supported at peripheral areas without interfering with the desired resonant vibrations.

Accordingly, an object of this invention is to provide a new type of resonator and a new type of monolithic coupled mode filter which are suitable for use at lower frequencies and have the advantages of small size and low cost.

Another object of this invention is to provide a resonator and a monolithic filter which can withstand severe mechanical shock and vibration without damage.

SUMMARY OF THE INVENTION

This invention provides a piezoelectric resonator comprising a first elongated plate, at least a portion of which remote from the ends thereof, is piezoelectric and adapted to vibrate in extension parallel to the width of the plate when subjected to an alternating piezoelectric field. A second elongated plate secured to the first plate in face-to-face relation is adapted to restrain the width extensional vibrations and thereby induces width flexural vibrations. Electrode means are secured to the first plate and adapted to apply an electric field through a piezoelectric region remote from the ends thereof in a direction which would induce such width extensional vibrations in the absence of the restraint imposed by the second plate. The electrode means, the portion of the piezoelectric region adjacent to the electrodes, and the second plate cooperate to establish a width flexural resonator. The assembly may be supported at the ends, which do not vibrate at the operating resonance frequency of the resonator. The supports may be of energy-absorbing material to damp unwanted length related vibrations. Additional electrode means may be provided to form additional width flexural mode resonators; and the spacing between adjacent resonators may be sufficiently small to provide elastic coupling to form a band-pass filter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a resonator constructed according to this invention connected in a test circuit.

FIG. 1*a* shows one suitable orientation of a quartz crystal plate that may be used for the resonator of FIG. 1.

FIG. 2*a*–2*d* shows alternate orientations of poling axes and corresponding electrode connections for ceramic plates which may be used in the assembly of FIG. 1.

FIGS. 3*a*–3*c* illustrates the nature and distribution of the width flexural mode of this invention.

FIG. 4 illustrates a resonator having a different electrode arrangement.

FIG. 5 illustrates a coupled mode filter employing two resonators of the type shown in FIG. 1.

FIG. 6 illustrates a two resonator coupled mode filter having a different electrode arrangement.

FIG. 7 illustrates a coupled mode filter similar to the filter of FIG. 5 but having four resonators.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a resonator assembly 1 constructed according to this invention. It comprises two plates 2, 3 secured together in face-to-face relation with a thin metal contact plate 4 interposed between 2 and 3. Plates 2, 3 may be suitably cut from a piezoelectric crystal or may be formed of suitable ceramic material and polarized in the thickness direction as further described in connection with FIG. 2. Among suitable ceramic materials are solid solutions of lead zirconate and lead titanate, barium titanate, and lead metaniobate. Modified lead zirconate-lead titanate compositions particularly suitable for this use are disclosed in U. S. Pat. Nos. 3,006,857, Kulcsar, and 3,179,594, Kulcsar et al.

Electrode 7 is secured to the exposed face of plate 2 at the center thereof and electrode 8 is secured to plate 3 at the center thereof. Electrodes may be formed by various known electroding techniques such as vacuum deposition of metal.

If plates 2, 3 are formed of material having a low-dielectric constant, contact plate 4 may act as a common counter electrode for the adjacent faces of the two plates. Then plate 4 and electrode 7 constitute electrode means for applying an alternating electric field to a portion of plate 2; and plate 4 and electrode 8 constitute means for applying an alternating electric field to plate 3. If the dielectric constant of the material is high, it is preferable to apply counterelectrodes directly to each plate opposite electrodes 7, 8, or the adjacent faces at the two plates may be coated with electrode material over their entire surfaces. Metal plate 4 then provides electrical connections to such counterelectrodes.

The assembly 1 may be held together by means of an adhesive such as an epoxy resin. To insure good electrical connections between contact plate 4 and counterelectrode means on the adjacent faces of plates 2, 3 the epoxy may be loaded with conducting particles.

Another way to secure the plates together is to coat them with a paint comprising finely divided glass and finely divided silver suspended in a carrying vehicle, press the assembly together, and then heat the assembly to a temperature sufficient to sinter the glass, as more fully described in U.S. Pat. No. 2,771,969. When this is done, separate counterelectrodes may be omitted as the fired silver makes intimate contact with the surfaces of plates 2, 3. It is convenient also to use the same paint to form electrodes 7, 8. When external connection to the counterelectrodes is not required, contact plate 4 may be omitted.

Electrode 7 is connected by thin wire 10 to terminal 14. The wire may be attached to the electrode by conducting cement or by solder, preferably about one-quarter of the way in from either edge of the plate. Electrode 8 is connected to terminal 15 by wire 11. Contact plate 4 is shown connected to terminal 16 but this connection may be omitted in some circumstances, as more fully described in connection with FIG. 2. The terminals are shown in schematic form. In practice, suitable terminals may be supported by and extend through the walls of a protective housing and support for assembly 1 not shown.

If plates 2 and 3 are formed of ceramic material they may be polarized through the use of electrodes 7, 8 and the corresponding counterelectrodes contacted by plate 4. This results in polarizing only the portions of plates 2, 3 between electrodes 7, 8 and closely adjacent thereto and, thus only these portions become piezoelectric. Alternatively, temporary electrodes may be applied to the plates or pressed against them to polarize more or all of the ceramic material. If high-temperature bonding of the assembly is not used the plates may be polarized prior to assembly.

The process of polarizing a ceramic plate is well understood in the art and need not be detailed here. Briefly, it involves applying a suitable high DC voltage to electrodes on the plate for a prescribed period of time. For the assembly of FIG. 1 there are alternate ways of connecting the electrodes for poling and for use and these are shown in FIG. 2.

In FIG. 2*a*, plates 2, 3 are in series during poling. The connection shown from terminal 16 to the midpoint of the polarizing DC supply 19 is not a requirement but it is desirable because it equalizes the voltages across the two plates, even though they have different leakage resistance. An assembly thus polarized is connected in parallel for use as shown in FIG. 2*b*. Thus, in use, one plate is reversed piezoelectrically with respect to the other

FIG. 2*c* shows the alternate poling connection where the plates are in parallel. An assembly thus poled is connected in series for use as shown in FIG. 2*d*. Again, one plate is reversed piezoelectrically with respect to the other.

In FIG. 2*d*, terminal 16 is not used. Thus, if series operation is desired, terminal 16 may be omitted entirely and temporary connection may be made to contact plate 4 during poling.

The choice between parallel and series connection is a matter of electrical impedance, the series connection having four times the impedance of the parallel connection. In FIG. 1, the series connection is shown.

When an alternating signal voltage from generator 20 is applied between terminals 14 and 15, as shown in FIG. 1, the well-known piezoelectric effect results in a tendency of the piezoelectric material to vibrate in synchronism with the signal in the region between electrodes in each plate. For ceramic plates poled as described, the vibration tendency of interest is the tendency to expand and contract alternately in both length and width. However, since one plate is piezoelectrically reversed with respect to the other, each plate acts as a restaining means for the other, thus preventing extensional vibration in the length and width directions, and resulting in flexural vibrations. If the frequency of generator 20 is varied over a sufficiently wide range a plurality of flexural resonances may be excited in sequence and detected as current peaks indicated at meter 21. If the plates are formed of ceramic material and assembly 1 is free at the ends, the lowest frequency resonance is a length flexural resonance. At higher frequencies, length flexural overtones may be excited.

At a frequency well above the fundamental length flexural resonance, a width flexural resonance may be excited and it is this mode which is used in the present invention. Width flexural overtones also may be used. Due to energy trapping, the width flexural vibrations occur only under and relatively close to the electrodes. Thus, electrodes 7, 8, together with the piezoelectric material therebetween, and the restraining influence of each plate on the other, establish a width flexural resonator.

In FIG. 1 plate 3 may be omitted. Then, preferably, contact plate 4 is increased in thickness to the order of the thickness of plate 2. In this arrangement, plate 4 acts as the restraining means for plate 2 and similar width flexural resonances may be developed.

FIG. 3 illustrates, in greatly exaggerated form, the nature and distribution of the trapped energy width flexural vibrations in the fundamental mode.

FIG. 3*a* is a sectional view taken through the resonator along lines 3*a*—3*a* of FIG. 1. The solid lines indicate the peak of flexural deflection in one direction, and the dashed lines indicate the opposite peak of deflection.

FIG. 3*b*, taken along lines 3*b*—3*b* of FIG. 1, just beyond the edge of electrode 7, shows similar flexure, but at much reduced amplitude.

FIG. 3*c*, taken along line 3*c*—3*c* of FIG. 1, remote from the electrodes, indicates no observable deflection.

The length of the plates should be selected so that length flexural mode overtones do not fall close to the desired width flexural mode resonance. Furthermore, the length flexural mode vibrations may be damped by pads or blocks of vibration absorbing material 25 attached to or pressed against assembly 1 at the end areas as shown in FIG. 1. Pads 25 may be made of silicone rubber having high vibration absorbing characteristics such as Sylgard No. 188 made by Dow Corning. The pads may also constitute the supporting means for the assembly within a protective housing not shown. This relieves leads 10, 11 of the burden of supporting the assembly and provides a resonator which can withstand severe mechanical shock and vibration without damage.

Since the width flexural mode is employed in the operation of this resonator, the assembly may be made slightly oversized in width and then final adjustment to frequency may be made by grinding or otherwise removing material from the edge surfaces in the vicinity of the resonator.

This invention is not confined to the use of ceramic plates. Any suitable piezoelectric material may be used, for example, plates of X-cut quartz, as shown in FIG. 1*a*. With electrodes perpendicular to the X-axis, as shown, the only piezoelectric excitation in quartz is extensional, along the Y- and X-axes. The plates are oriented so that the Y-axis is parallel to the width. Thus, the desired width flexural vibrations may be induced. This arrangement minimizes difficulties from length flexural vibrations because piezoelectric excitation along the Z-axis is absent. For parallel connection, two identical plates should be stacked one above the other. For series connection, one plate should be turned over face-for-face to obtain the required piezoelectric reversal.

In all figures the electrodes are shown extending to the edges of the surfaces on which they are mounted. However, for convenience in manufacturing, it may be desirable to make the electrodes slightly smaller so that they do not quite reach those edges. In the embodiments of FIGS. 1, 5, 7 this reduction in the electrode dimensions may be desirable also because it will improve slightly the electromechanical coupling of the resonator.

In applications where higher electrical impedance is desired, the piezoelectric plates may be provided with electrodes on the edge faces as shown in FIG. 4. If plates 2, 3 are cut from crystal material, the orientation must be suitably selected to provide opposed piezoelectric actions in the width mode. If the plates are ceramic, they should be polarized in opposite directions through the width. Length flexural mode resonances may be suppressed by damping pads as in FIG. 1.

One of the plates in FIG. 4 may be made of nonpiezoelectric insulating material. In this case, the electrodes preferably are confined to the piezoelectric plate.

FIG. 5 shows a coupled mode filter employing two resonators similar to the resonator of FIG. 1, but using only one piezoelectric plate. Piezoelectric ceramic or crystal plate 2 is secured to metal plate 32 which electrically may act as common counterelectrode means, or as a contact plate for counterelectrode means which may be deposited on the lower face of plate 2. Mechanically, plate 32 acts as restraining means for piezoelectric plate 2 to translate the width expansion-contraction tendency thereof into flexure.

Electrode 33 on the upper face of plate 2 establishes with the piezoelectric material adjacent to the electrode and restraining means 32 a width flexural mode resonator, which is the input resonator. Similarly, an output resonator is established at electrode 36.

Thin wire 39 connects electrode 33 to input terminal 40 and wire 41 connects electrode 37 to output terminal 42. Common input-output terminal 43 is connected to plate 32. A signal source 45 having resistance 46 selected for suitable termination of the filter is shown connected to the resonator established at electrode 33, through input terminals 40, 43. Terminating resistor 47 is connected to the resonator established at electrode 36 through output terminals 42, 43. The assembly may be supported on damping pads, as is shown in FIG. 1, to suppress length flexural vibrations.

Due to the close proximity of the resonators, elastic coupling exists between resonators. Thus, when the input resonator is excited by generator 45, at or near the selected width resonance frequency, energy is elastically coupled to the output resonator which generates an electric signal across load 47. When the spacing between resonators is sufficiently close, critical coupling, or "overcoupling," provides a band-pass characteristic.

FIG. 6 shows a filter having two resonators of the type shown in FIG. 4 in order to obtain a higher electrical impedance. The assembly may be supported in the same manner shown in FIG. 1.

FIG. 7 shows a filter similar to the filter of FIG. 5, but having four resonators. Plate 2 of crystal or ceramic, is secured to metal plate 32, as in FIG. 5. The four resonators correspond to electrodes 50, 51, 52, 53. The design of coupled mode filters employing more than two coupled resonators usually requires that the intermediate resonators be short-circuited; thus, electrodes 51, 52 are grounded through leads 56, 57 and terminals 58, 59.

Metal restraining plate 32 in FIGS. 5 and 7 may be replaced by a piezoelectric plate, with or without a contact plate such as 4 in FIG. 1. In the latter case, separate counterelectrodes may be employed for each resonator, permitting series operation of the piezoelectric plates at each resonator. With a common counterelectrode, the parallel connection should be used to permit grounding of the counterelectrode. In still another variation, plate 32 may be replaced by a nonconductive, nonpiezoelectric plate, and this also permits use of separate counterelectrodes.

Common and separate counterelectrodes are substantially equivalent. Common electrodes offer convenience in fabrication and installation, while separate electrodes reduce undesirable common impedance coupling between input and output. Slightly different resonator spacing may be required for the same bandwidth in the two cases.

The resonators and filters of this invention differ structurally from prior art trapped-energy resonators and coupled mode filters in that the electrodes of this invention extend to both edges, or nearly to the edges, of the surface to which they are attached.

Functionally, the action of the resonators of this invention differs from the prior art in that the present resonators in their selected mode vibrate in flexure, whereas trapped-energy resonators of the prior art in their selected mode vibrate in the thickness direction.

For best results, the width and thickness of the filter assemblies should be uniform along the length, in the vicinity of the resonators, within a percentage very small compared to the percent bandwidth of the filter. Departures from uniform length of the assembly have little or no effect on performance of the filter. In contrast, for a thickness mode coupled mode filter (prior art) the lateral dimensions need not be carefully controlled, but the thickness must be held to very close limits.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is aimed, therefore, in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A piezoelectric resonator comprising:
   - a first elongated plate, at least a portion of which remote from the ends thereof, is piezoelectric and adapted to vibrate in extension parallel to the width of the plate then subjected to an alternating electric field;
   - a second elongated plate secured to said first plate in face-to-face relation and adapted to restrain said width extensional vibrations and thereby induce width flexural vibrations;
   - electrode means secured to said first plate and adapted to apply an alternating electric field to a piezoelectric region of said first plate remote from the ends thereof in a direction which would induce said width extensional vibrations in the absence of the restraint imposed by said second plate;
   - said electrode means cooperating with the piezoelectric material adjacent thereto and with said second plate to establish a width flexural resonator.

2. A piezoelectric resonator as described in claim 1 further comprising damping means engaging the plates at end regions thereof to suppress length related vibrations.

3. A piezoelectric resonator as described in claim 1 in which the second plate is similar to the first plate and has electrode means secured thereto as on the first plate.

4. A piezoelectric resonator as described in claim 3 in which the electrode means are secured to the major faces of the two plates.

5. A piezoelectric resonator as described in claim 3 in which the electrode means are secured to the long edge faces of the two plates.

6. A piezoelectric resonator as described in claim 4 further comprising a metal plate sandwiched between the said first and second plates.

7. A piezoelectric resonator as described in claim 6 in which said metal plate provides electrical connections to electrode means secured to the adjacent faces of the said first and second plates.

8. A piezoelectric resonator as described in claim 6 in which said metal plate functions as electrode means for the adjacent faces of the said first and second plates.

9. A piezoelectric resonator as described in claim 1 in which the electrode means are secured to the major faces of the first plate and said second plate is a metal plate.

10. A piezoelectric resonator as described in claim 9 in which said metal plate provides electrical connection to electrode means on the adjacent face of the first plate.

11. A piezoelectric resonator as described in claim 9 in which said metal plate functions as electrode means for the adjacent face of the first plate.

12. A piezoelectric resonator as described in claim 1 in which said first plate is comprised of lead zirconate-lead titanate.

13. A piezoelectric resonator as described in claim 1 in which said first plate is an X-cut quartz crystal plate with width parallel to the Y-axis.

14. A piezoelectric band-pass filter comprising:

a first elongated plate having substantially uniform width and thickness, at least a portion of said plate remote from the ends thereof being piezoelectric and adapted to vibrate in extension parallel to the width when subjected to an alternating electric field;

a second elongated plate having uniform width and thickness secured to said first plate in face-to-face relation and adapted to restrain said width extensional vibrations and thereby induce width flexural vibrations;

a plurality of electrode means secured to said first plate, each adapted to apply an alternating electric field through a piezoelectric region of said first plate remote from the ends thereof in a direction which would induce said width extensional vibrations in the absence of the restraint imposed by said second plate;

each of said electrode means cooperating with the piezoelectric material adjacent thereto and with said second plate to establish a width flexural resonator;

the spacing between adjacent resonators being sufficiently small so that elastic coupling exists between adjacent resonators, thereby establishing a band-pass characteristic.

15. A piezoelectric band-pass filter as described in claim **14** further comprising damping means engaging the plates at end regions thereof to suppress length related vibrations.

16. A piezoelectric band-pass filter as described in claim **14** in which the second plate is similar to the first plate and has electrode means secured thereto as in the first plate.

17. A piezoelectric band-pass filter as described in claim **16** in which the electrode means are secured to the major faces of the two plates.

18. A piezoelectric band-pass filter as described in claim **16** in which the electrode means are secured to the long edge faces of the two plates.

19. A piezoelectric band-pass filter as described in claim **17** further comprising a metal plate sandwiched between the said first and second plates.

20. A piezoelectric band-pass filter as described in claim **19** in which said metal plate provides electrical connections to electrode means secured to the adjacent faces of the said first and second plates.

21. A piezoelectric band-pass filter as described in claim **19** in which said metal plate functions as electrode means for the adjacent faces of the said first and second plates.

22. A piezoelectric band-pass filter as described in claim **14** in which the electrode means are secured to the major faces of the first plate and said second plate is a metal plate.

23. A piezoelectric band-pass filter as described in claim **22** in which said metal plate provides electrical connection to electrode means on the adjacent face of the first plate.

24. A piezoelectric band-pass filter as described in claim **22** in which said metal plate functions as electrode means for the adjacent face of the first plate.

25. A piezoelectric band-pass filter as described in claim **14** in which said first plate is comprised of lead zirconate-lead titanate.

26. A piezoelectric band-pass filter as described in claim **14** in which said first plate is an X-cut quartz crystal plate with width parallel to the Y-axis.