

April 10, 1945.

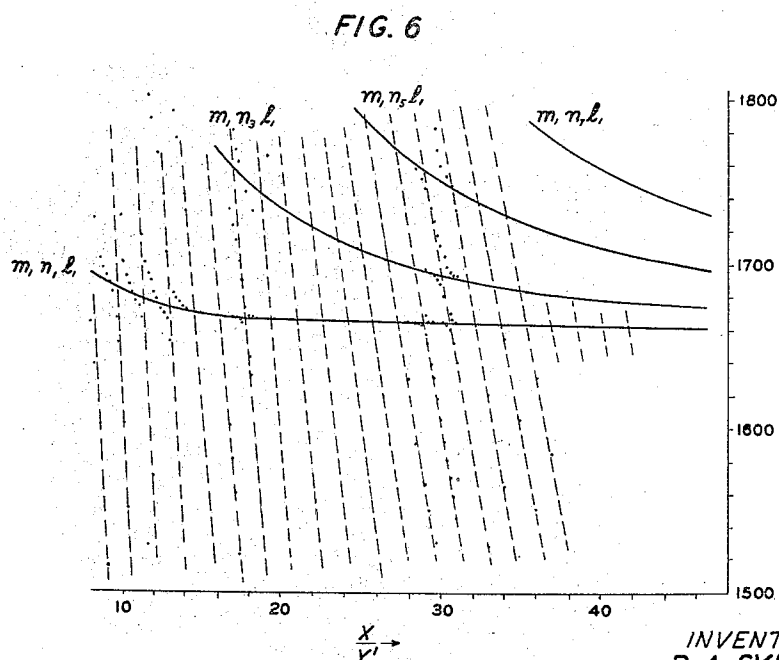
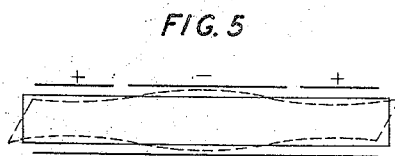
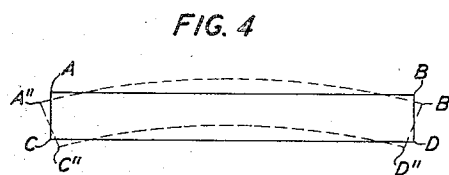
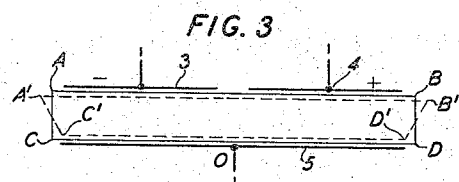
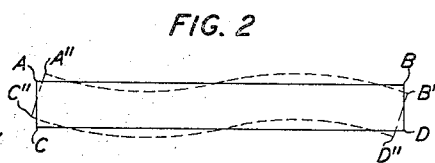
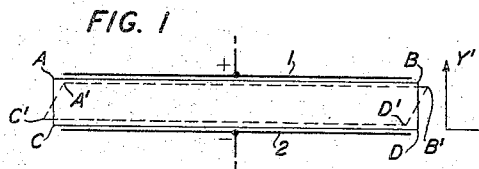
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2,373,431

ELECTRIC WAVE FILTER

Filed March 30, 1943

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

FIG. 7

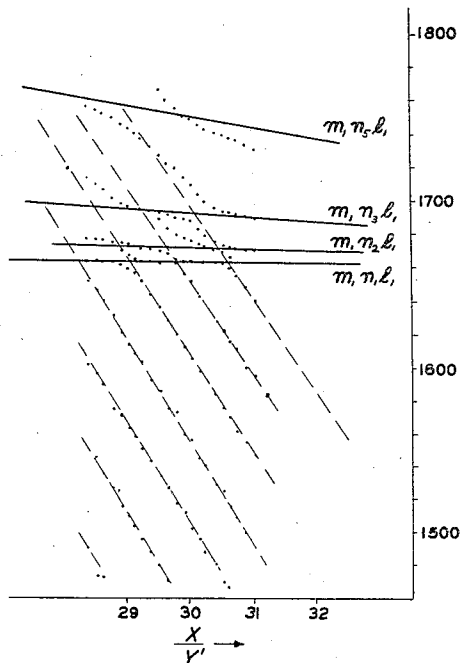


FIG. 8

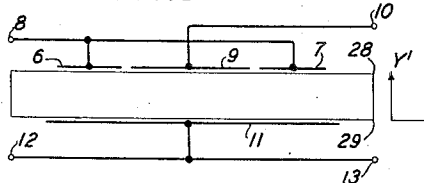


FIG. 10

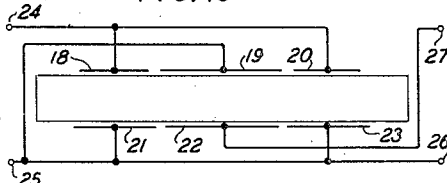


FIG. 9

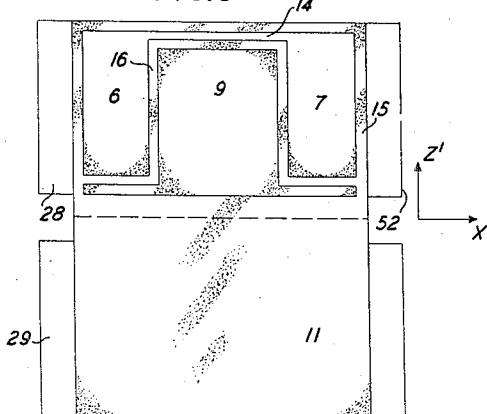
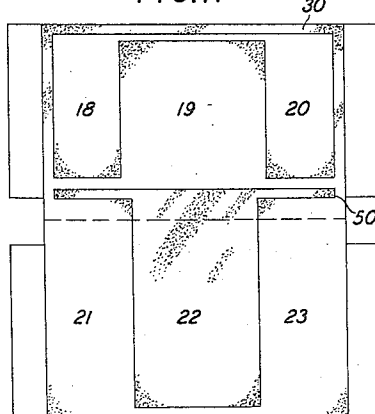


FIG. 11



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3 Sheets-Sheet 3

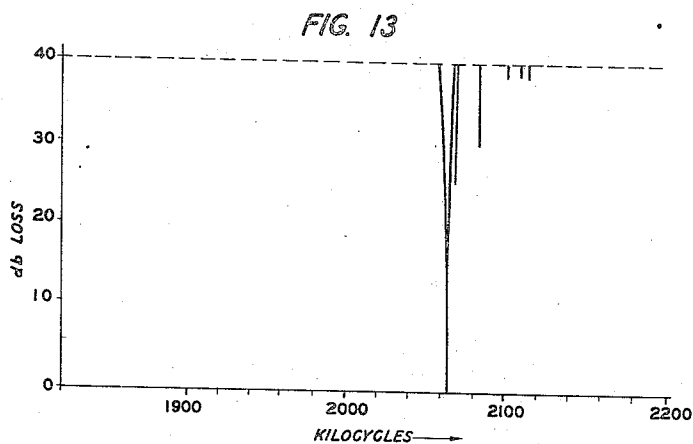
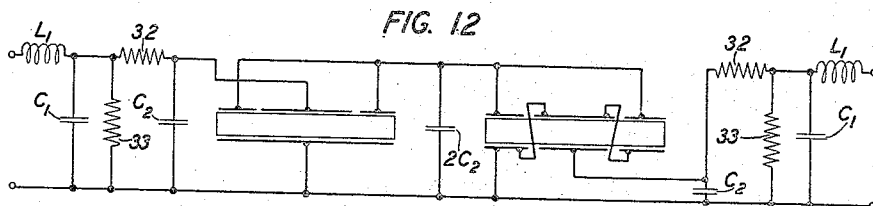


FIG. 14

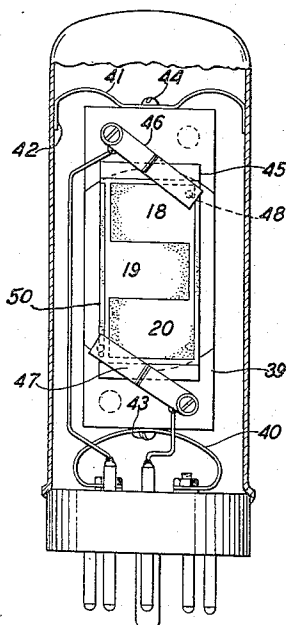
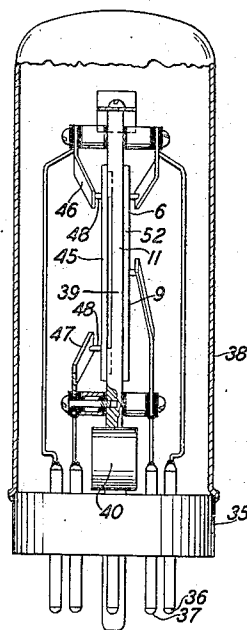


FIG. 15



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2,373,431

ELECTRIC WAVE FILTER

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Application March 30, 1943, Serial No. 481,089

5 Claims. (Cl. 178-44)

This invention relates to electric wave filters and more particularly to narrow band-pass piezoelectric filters.

An object of the invention is to simplify and cheapen filters of the type required to select a single frequency electric current or a narrow band of currents at frequencies of the order of 2000 kilocycles.

Another object is to improve the attenuation characteristics of a piezoelectric narrow band-pass filter operated at a midband frequency of the order of 2000 kilocycles.

An additional object of the invention is to reduce the effects of undesired modes of vibration which tend to be induced in AT type crystals driven in shear modes of vibration.

An additional object is to obtain narrow band-pass filter characteristics with two divided coating AT cut quartz crystals similar to those obtained with singly resonant crystals.

Another object is to operate an AT type crystal in a fundamental shear mode of vibration while inhibiting deleterious flexural mode oscillations.

A still further object of the invention is to obtain narrow band filter characteristics with AT cut crystals similar to those obtained with singly resonant crystals.

In accordance with the invention, one pair of terminals of an AT cut quartz crystal filter is connected between a ground electrode on one side of the crystal plate and two outer electrodes positioned at different points along the X axis on the opposite side of the crystal plate while one terminal of the other pair of terminals is connected to an electrode intermediate the two outer electrodes and the other terminal is connected to the ground electrode. In a modified form each crystal face is provided with three electrodes arranged at different positions along the X axis, the outer electrodes on one face and the intermediate electrode on the other being connected to the common ground terminals of each pair of terminals while the remaining terminals are connected respectively one to the remaining outer pair of electrodes and the other to the remaining intermediate electrode. Since the filter section with the single ground electrode presents a peak of attenuation beyond the lower cut-off frequency of the band and the filter section with the split ground electrode presents an attenuation peak beyond the upper cut-off frequency, the two filter sections may be advantageously connected in tandem to constitute a band-pass filter having satisfactory attenuation at each side of the band. The two sections may, moreover, be mounted in the same container on a single supporting structure.

The AT cut quartz crystal plate is described in a paper by Lack, Willard and Fair entitled "Some improvements in quartz crystal circuit elements," Bell System Technical Journal, vol. XIII, No. 3,

pages 453-463, July 1934. It is also described and claimed in U. S. Patent 2,218,200 issued October 15, 1940, to Lack, Willard and Fair.

The most prominent resonances in AT cut crystals are of two types, shear and flexure. The fundamental high frequency shear resonance results in a deformation which possesses some characteristics in common with that of certain flexure vibrations. It is possible, however, to excite still higher frequency shear vibrations by a disposition of electrodes that induces distortions which are not so conducive to initiation of flexural vibrations. In general, even multiple harmonics of flexure will be driven by and strongly coupled to shear modes of vibration having a frequency which is an odd order overtone of the fundamental shear frequency. Likewise odd harmonics of flexure will be driven by and strongly coupled to shear modes having a frequency which is an even order overtone of the fundamental shear frequency.

A series of measurements of partially plated AT quartz crystals has shown that a completely plated crystal exhibits considerably greater coupling between the fundamental frequency mode resonance and the flexure resonances than does a crystal whose plating extends only to within 10 per cent of the edges parallel to the Z' axis. If, moreover, a grounded shield plating be applied to the end portions of the crystal plate to reduce the electric field thereacross and the piezoelectric excitation the displacement or deformation of the crystal in that region is likewise reduced and with it the tendency to excite parasitic flexural vibrations.

Other features and objects of the invention will be apparent from a consideration of the following detailed specification taken in connection with the accompanying drawings in which

Fig. 1 illustrates the displacements which occur in an AT cut quartz crystal operating in XY' shear vibration;

Fig. 2, the corresponding displacement of an AT quartz crystal operating in the first even order overtone flexural mode vibration;

Fig. 3, the displacements which occur in an AT quartz crystal operating in an even order XY' shear mode vibration.

Fig. 4, the corresponding displacement in the fundamental flexural mode;

Fig. 5, the displacements of an AT cut quartz plate operating in an odd multiple XY' shear vibration;

Fig. 6 indicates the measured resonances of a completely plated AT crystal plotted with respect to the ratio of X to Y';

Fig. 7 indicates the measured resonances of an AT crystal with divided plating as in Fig. 3 plotted with respect to the ratio of X to Y';

Fig. 8 illustrates schematically a piezoelectric

filter section of narrow pass-band type in accordance with this invention;

Fig. 9 shows the plating of the two principal faces of the crystal element of Fig. 8;

Fig. 10 illustrates schematically a narrow band-pass piezoelectric filter section having characteristics complimentary to those of Fig. 8;

Fig. 11 shows the electrode plating of the crystal of Fig. 10;

Fig. 12 illustrates schematically a narrow band-pass filter comprising tandem sections similar to those of Figs. 8 and 10;

Fig. 13 portrays the frequency selective or attenuation characteristic of the filter of Fig. 12, and

Figs. 14 and 15 are respectively face and side views of one structural embodiment of the piezoelectric elements of the filter of Fig. 12 with parts of the container broken away.

Referring to Fig. 1 there is shown, in solid lines an edge view of an AT cut quartz crystal element, the length of which extends parallel to the X axis and the thickness to the Y' axis with an upper electrode coating 1 and a lower electrode coating 2. The displacement under conditions of XY' shear resonance is shown exaggerated by the broken lines. With the polarity of charge indicated, the upper corners A and B are displaced to the right as indicated at A' and B'; the lower corners C and D to the left as indicated at C' and D'. During the succeeding half cycle when the charge on the electrodes is reversed in polarity the displacement will reverse, points A and B moving to the left of their normal zero positions and points C and D to the right.

Fig. 2 shows in similar fashion the first even order mode flexure vibration in the XY' plane. In this case, as in that of Fig. 1, the upper corners A and B are displaced to the right at A'' and B'', and the lower corners C and D are displaced to the left as at C'' and D''. This indicates something of the nature of the common displacement or coupling that exists between the two modes of vibration, namely, the fundamental shear resonance and the even order harmonic frequency flexural resonance.

Fig. 3 illustrates an AT cut quartz crystal element with two upper electrodes 3 and 4 displaced from each other in the length or X direction and one lower electrode 5. This piezoelectric crystal is designed to be excited in the first even order multiple frequency shear mode of vibration in the XY' plane. As indicated, the upper corners A and B are displaced respectively to the left at A' and to the right at B', the corresponding lower corners C and D being displaced respectively to the right at C' and the left at D'. Midway between A' and B' the crystal is under tension, midway between corners C' and D' it is under compression. Comparing Fig. 3 with Fig. 4 which shows an AT cut crystal in the fundamental flexural vibration in the XY' plane, it will be noted that superficially the even order multiple shear of Fig. 3 gives rise to displacements rather similar to those of the fundamental flexure mode of oscillation of Fig. 4.

The shear vibration and the flexural vibration frequencies of the structures which have been shown are functions of both their X and Y' dimensions. If, however, the X dimension be made very large relative to the Y' dimension the XY' shear resonant frequency is dependent primarily upon the Y' dimension. It will be evident, therefore, that if the X dimension is great enough half that dimension or X/2 will still be large enough

relative to the Y' dimension so that Y will primarily determine the oscillation frequency. It follows from this that if X be made very large relative to Y' so that the resonance is determined primarily by Y' the fundamental mode of vibration will not differ greatly in frequency from that of the harmonic mode. This principle holds as the mode of vibration is broken up into still a greater number of resonant systems so long as the X dimension of the individual resonant systems remains large relative to that of Y'.

In addition to the modes of vibration which have already been described it is possible to obtain still other shear modes by dividing the plating along the Z' dimension so as to cause a reversal of stress to occur at various points along the Z axis. In order to identify any particular mode of vibration the number of sectional shears along the Y' X and Z' axes may be noted respectively by the letters m, n and l with appropriate subscripts. Accordingly, the fundamental shear mode vibration of the XY' type discussed in connection with Fig. 1 may be denoted as the *minil* XY' shear mode. The mode of Fig. 3 in which the number of sectional shears along the X axis is 2, may be designated as the *minil* XY' shear mode.

Fig. 5 shows the displacement which occurs in the case of an AT cut quartz crystal having three plates on its upper surface with the two outer plates polarized in a manner opposite to the central plate. If such a crystal be excited by an alternating electromotive force of the proper frequency it will execute shear vibrations in the XY' plane at a resonance frequency of the third order which, although determined primarily by the Y' dimension, is a somewhat higher frequency for the same dimension of crystal than the modes of oscillation produced by the systems of Figs. 1 and 3. In general, any order of frequency of resonance for the shear mode of vibration may be had depending upon the number of reversals of motion along the X axis. Even order harmonics of the flexure will be driven by and tend to be strongly coupled to the shear modes having an odd value for n such as *n1zn1*.

Fig. 6 shows the measured frequencies of resonance for a completely plated AT cut crystal 1 mm. thick, the graphs being plotted with frequencies as ordinates and with ratio of X to Y' as abscissae. These results are for an approximately square crystal. The dotted lines represent even order flexure modes along the X dimension. Broken lines indicate the predicted positions of flexural resonance for various ratios of X to Y'. Graphs in solid lines show *minil*; *m1n1l1*, and *minil* modes of XY' shear vibration. It will be apparent that as the ratio X/Y, increases the absolute frequencies of these different shear modes of vibration approach each other, the higher mode remaining, however, at high frequency. For example, at

$$\frac{X}{Y'} = 30$$

the relative frequencies are *minil* shear mode, 1684 kilocycles, *minil* shear mode, 1692 kilocycles, and *minil* shear mode, 1749 kilocycles.

In frequency regions where the graphs for shear mode oscillations and flexural mode oscillations intersect the effect of coupling of the two is indicated by the "hops" which occur in the flexural mode graphs. With a decrease in the magnitude of X/Y', the coupling to the flexure modes is considerably increased due to a closer

similarity in motion. This is evident from the graph of the *minli* shear mode in which it will be seen that the dotted line graphs are quite distinct for smaller magnitudes of X/Y' , e. g., at 10.12 and 14 but become less distinct with increasing value of X/Y' , so that for magnitudes of X/Y' , equal to 32 and 34 the two graphs representing flexural and shear modes respectively tend to coincide over a considerable distance. It may also be observed that with an increase in the order of n the coupling to the flexure modes is considerably increased due to a closer similarity in motion.

A series of measurements of partially plated crystals has shown a considerably decreased coupling between the *minli* shear and the troublesome flexure modes than with the crystal whose coating extends over the entire area of the crystal plate. For a completely plated crystal there is a strong tendency for operation in the *minli* shear mode to set up "even order harmonic" flexural vibrations in the X axis direction. If the coating extends along the X axis only to within one-tenth of the X dimension from the end of the crystal plate a substantial reduction of this coupling is achieved. A still further reduction in coupling between the *minli* shear and the even flexural harmonics along the X axis will result if only the central third of the crystal plate is coated. While this restricted coating will result in about as good a piezoelectric coupling to the *minli* shear mode as to the *minli* mode, these two shear mode oscillation frequencies are sufficiently separated for the purpose of this invention to enable discrimination between them to be had.

Fig. 7 shows the measured resonances of the crystal plating arrangement of Fig. 3 with the crystal driven between one top plate and ground as, for example, between plate 3 and 5 and the resulting electromotive force measured between the other top plate and ground as between plates 4 and 5. With such a device used as a filter we may expect to measure resonances corresponding to both even and odd flexures along the X axis for the reason that the two top plates 3 and 4 may assume the same as well as opposite polarities. It will be apparent from Figs. 6 and 7 that the coupling is high between even mode shears and odd mode flexures and between the odd mode shears and even mode flexures but that it is quite low between like order shears and flexures.

Referring to Fig. 8 there is shown an AT quartz crystal adapted for operation in an odd shear mode, the coating being split so that there is no tendency for generating shears corresponding to even values for n . With no even value for n there will be no odd flexure harmonics along X . The top coatings 6 and 7 electrically connected together to a terminal 8 of the filter section are spaced in the direction of the X axis from a central coating 9 which is electrically connected to a terminal 10 of the filter section. On the opposite face of the crystal plate is a coating 11 electrically connected to the filter terminals 12 and 13. Fig. 9 shows the structural arrangement of the electrodes in more detail. The coatings 6, 7 and 9 may be formed by first plating the entire crystal and then removing the plating along the solid lines. This permits coatings 6 and 7 to be connected by the narrow integral strip 14. It also permits the lower coating 11 to be integrally connected with a marginal surrounding strip 15 on the upper face of the crystal which is, therefore, also placed at ground

potential thus removing piezoelectric stress from the marginal portion of the crystal to reduce the coupling between the odd shear mode vibration and even mode flexural vibration. Moreover, the ground potential plate 11 is also integrally connected to a separating shielding conducting strip 16 positioned between the top coatings 6 and 7 on the one hand and the top coating 9 on the other to reduce any capacitance coupling between these electrodes. As indicated in Fig. 9 the end tenth of the surface measured along the X axis may be left uncoated at each end of the crystal.

In Figs. 9 and 11 of the drawings both the upper and lower surfaces 28 and 29 of the same crystal are shown, one above the other with the plating which covers both surfaces and the intervening edge. Although the entire surface of the crystal may be plated and then divided along the solid lines as has previously been stated, in the Figs. 9 and 11, the plating is shown extending only part way toward the ends of the top and bottom surfaces of the crystal.

Fig. 10 shows diagrammatically an AT cut quartz plate filter section differing from that of Fig. 8 in that it is provided with three upper electrodes 18, 19, 20 and three corresponding lower electrodes 21, 22, 23. Electrodes 18 and 20 are electrically connected together to a terminal 24 of the filter section. Electrode 19 on the upper surface of the crystal plate is electrically connected to the outer electrodes 21 and 23 on the lower face of the plate and to the filter section terminals 25 and 26. The remaining lower central electrode 22 is connected to the filter section terminal 27. As indicated in Fig. 11 the ground terminals 25 and 26 and their directly connected coatings 19, 21 and 23 are connected directly to the integral coating strip 30 adjacent the margin of the upper surface of the crystal plate. In this instance, as in the structure of Figs. 8 and 9, the outer periphery of the crystal plate is free from the piezoelectric stress thus reducing the coupling which would otherwise exist for unwanted even mode flexural vibrations.

Fig. 12 discloses a schematic arrangement of the tandem connection of the filter sections of Figs. 8 and 10 respectively, with associated circuits for properly terminating and connecting these sections by which spurious or unwanted pass bands of each filter section are effectively suppressed by the other section. Capacitance C_2 denotes the input and output stray capacity of each element. The half section low-pass filter L_1C_1 at each terminal provides an impedance transformation over a narrow band of frequencies thus enabling the structure which is inherently of high impedance to be effectively connected in a low impedance transmission system. The principle of operation of this impedance transformer is disclosed and claimed in U. S. patent to W. P. Mason 2,199,921, May 7, 1940. The loss pads comprising series resistors 32 and shunt resistors 33 may be designed in accordance with the principles of U. S. patent to Mason 1,969,571, August 7, 1934, to stabilize the complete filter for variation in the elements due to temperature changes. With such a filter, the mechanical elements of which vibrate in an odd order shear mode, the only couplings which give rise to troublesome flexural oscillations are of the even order flexures. The tendency to excite even order flexure mode vibrations is substantially reduced by the expedient of partial plating by which the end positions of the piezoelectric plates are left uncoated as in Figs.

9 and 11. Consequently, such a filter may operate with an attenuation characteristic which is relatively high beyond each cut-off frequency.

The small shielding coating strips 15, 16 may produce a small force tending to excite even order shears. For that reason it is expedient to keep them as narrow as is feasible.

The transmission characteristic measured on an actual filter designed as indicated in Fig. 12 is disclosed in Fig. 13. This graph discloses a pass band at approximately 2064 kilocycles with an attenuation of at least 25 decibels in the frequency region adjacent the cut-off frequencies of the band.

Figs. 14 and 15 show the mounting of the electromechanical structure of the filter of Fig. 12. A base 35 of dielectric material is provided with the usual lead in plug connectors 36, 37 etc. and an evacuated metal shell 38 is sealed to the base. Within the shell 38 a metal plate 39 is mounted upon a spring 40 which cushions the plate 39 from shocks. At its upper end the plate 39 is given lateral support by the bowed spring 41, the down turned ends 42 of which fit closely within the shell 38. To prevent displacement the spring 40 is anchored at its ends to the base 35 and the two springs are connected to plate 39 by screws 43 and 44. At the front of the plate 39 and in contact therewith is a piezoelectric element 45 which may correspond in all respects to the disclosure of Figs. 10 and 11. Element 45 may be held in position in contact with plate 39 by means of phosphor bronze spring clamping members 46 and 47 each provided with anvil contacts 48. The anvil 48 of member 47 provides both mechanical and electrical contact at a point on the coating 18 and that of member 46 on the strip 50 integrally connected with plate 22. The back of element 45 with its coatings 21, 22 and 23 would, in the absence of special provision to avoid it, lie directly in contact with the grounded metal plate 39. That is the proper connection for coatings 21 and 23 but not for coating 22 which must be insulated from ground. To provide connection for coating 22 a circular countersunk recess is made in the front of plate 39 having a uniform depth of say .001 inch from the normal flat surface of the metal plate. The recess is large enough in diameter to cause the plate 39 to lie entirely out of contact with coating 22 but to permit plate 39 to engage the coatings 21 and 23 over a considerable area. Unitary strip 50 constitutes a direct electrical path from coating 22 to anvil 48 of spring 47. In similar fashion piezoelectric element 52 positioned against the back of grounded metal plate 39 may be held in fixed position and electrically connected in circuit. However, since the grounded coating 11 of element 52 is the only coating on that side of the element 52 it is unnecessary to provide the countersunk area of the back of metallic plate 39.

What is claimed is:

1. A piezoelectric filter comprising an AT cut quartz plate having two substantially parallel faces, three conducting coatings on one face physically separated from each other in the direction of the X axis, a coating on the opposite face, a pair of filter terminals connected respectively one to the outer coatings of the first face and the other to the coating on the opposite face, and a second pair of filter terminals connected respectively one to the intermediate coating on

the first face and the other to the coating on the opposite face.

2. An unbalanced piezoelectric filter comprising an AT cut quartz plate having two substantially parallel faces, one face having two outer coatings separated from each other in the X axis direction by an intermediate coating and the opposite face having a ground or low potential coating passing around a margin of the plate to the first face to extend around the entire edge portion of the first face outside the three coatings thereof, and to extend between the inner coatings and the two outer coatings whereby the three coatings on the same face are effectively shielded from each other and the outer marginal portion of the plate is substantially free from electric stress thus reducing the tendency which shear vibrations may have to induce flexural vibrations.

3. An AT cut quartz plate having two principal substantially parallel opposite faces, three electrodes separated from each other in the X direction on each of the two principal faces, a first pair of terminals of which one is connected to the outermost electrodes of one surface and the other is connected to the central electrode on that same surface and the outermost electrodes on the other surface, and a second pair of terminals of which one is connected to the central electrode on the second face and the other is connected to the second terminal of the first pair.

4. A band-pass filter comprising two tandem sections, the first consisting of a single quartz resonator vibrating in a shear mode and having three electrodes on one face spaced from each other in the direction of the X axis and a single electrode on the opposite face, one pair of terminals having a conductor connected to the two outer electrodes on the first face and a second conductor connected to the single electrode, a second pair of terminals having a conductor connected to the inner electrode on the first face and a second conductor connected to the single electrode, the second section consisting of a single quartz resonator vibrating in a shear mode and having on each of its two principal faces three electrodes spaced from each other in the direction of the X axis, an electrical connection from the single electrode of the first section resonator to the outer electrodes on one face and the inner electrode on the other face of the second section, a second electrical connection from the outer electrodes on the first resonator to the outer electrodes on said other face of the second section resonator and a pair of terminal connections for the second section one of which leads to the single electrode of the first resonator and the other to the remaining central electrode of the second resonator.

5. An electric wave filter comprising two piezoelectric plates each having divided electrical coatings whereby the plates may be excited in harmonic modes of vibration, a flat metallic member to form a common ground connection for said plates, means for holding said piezoelectric plates each in contact with one side of said metallic member, one side of said metallic member having a recessed portion whereby ungrounded electrode surfaces of the contiguous piezoelectric plate may be maintained out of contact with the grounded member.

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