

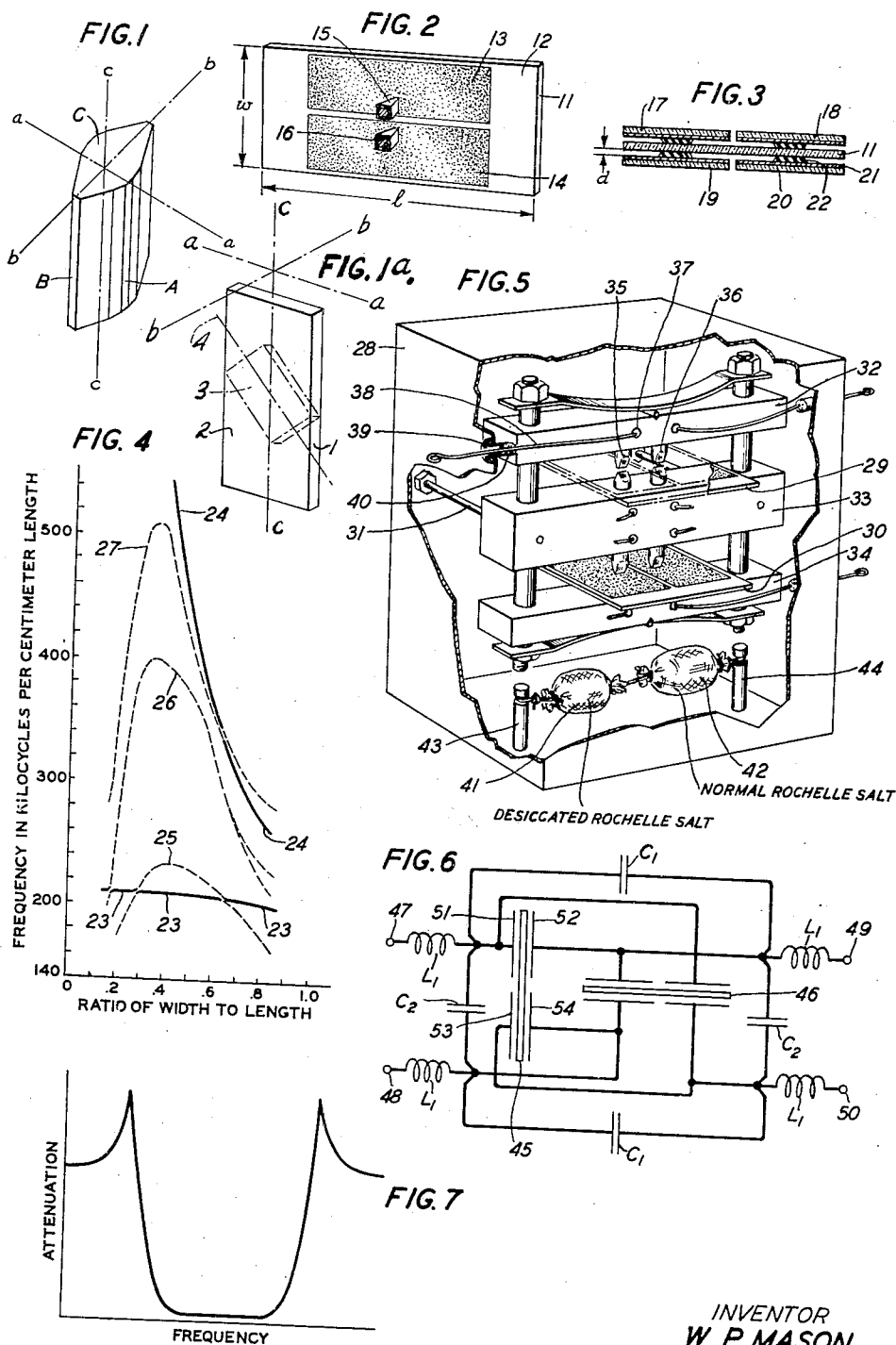
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WAVE FILTER

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## WAVE FILTER

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This invention relates to wave filters and more particularly to the use of Rochelle salt crystals as piezoelectric impedance elements in such filters.

5 An object of the invention is to extend the frequency range in which piezoelectric crystals may be used as reactance elements in wave filters.

10 Other objects are to increase the width of transmission band obtainable and to reduce the cost of such filters.

A further object is to decrease the variation in attenuation with temperature changes in filters of this type.

15 Heretofore, quartz crystals have been used as piezoelectric impedance elements in wave filters having transmission bands located down to about 50 kilocycles. However, due to the comparatively small electromechanical coupling exhibited by quartz, wide bands centered at frequencies below 20 50 kilocycles are obtainable only at the sacrifice of attenuation in the regions of suppression.

In accordance with the present invention, Rochelle salt crystals are adapted for use in wave 25 filters having transmission bands centered in the frequency range from 20 to 60 kilocycles. In the preferred embodiment, the impedance elements are rectangular plates so cut from a Rochelle salt crystal that the two principal faces of the plate are perpendicular to one of the principal axes of the crystal, with a length dimension which makes angles of 45 degrees with the other two axes, and having a width to length ratio lying between 0.35 and 0.55. In order to make the 30 attenuation of the filter more stable with changes in temperature, the electrodes are spaced apart from the crystal plate, or, if integral electrodes are used, the plating is applied only to the central portions of the major faces of the crystal, the 40 portions near the ends being left unplated. Also, in order to preserve the crystals they are placed in a container in which the relative humidity is controlled by exposing therein a quantity of desiccated and a quantity of normal Rochelle salt.

45 Due to the large electromechanical coupling obtainable in Rochelle salt crystals, filters having comparatively wide bands and high discrimination outside the bands may be provided. When the construction outlined above is employed, the 50 filters are sufficiently stable with temperature changes, and the crystals remain in operating condition for an indefinite time.

55 The nature of the invention will be more fully understood from the following detailed descrip-

tion and by reference to the accompanying drawing, of which:

Fig. 1 is a perspective view of a homogeneous Rochelle salt crystal showing the principal axes;

Fig. 1a shows the orientation of the piezo- 5 electric element with respect to the axes of the crystal;

Fig. 2 is a perspective view of a piezoelectric Rochelle salt crystal element with its associated electrodes suitable for use in the wave filter of 10 the invention;

Fig. 3 is an end view of a Rochelle salt crystal element with associated electrodes spaced from the crystal;

Fig. 4 is a set of curves showing the frequency 15 constant and frequency spectrum for a Rochelle salt crystal element such as shown in Fig. 2 or 3;

Fig. 5 shows two Rochelle salt crystal elements mounted within a sealed container with means for maintaining a constant relative humidity 20 therein;

Fig. 6 is a schematic circuit of a lattice type wave filter using Rochelle salt crystals as component impedance elements; and

Fig. 7 shows diagrammatically a typical atten- 25 uation characteristic obtainable with the wave filter of Fig. 6.

Fig. 1 shows in perspective a typical homogeneous Rochelle salt crystal suitable for supplying the piezoelectric impedance elements used in 30 the wave filter of the invention. The crystal has three mutually perpendicular faces A, B, C, and three principal axes *a*, *b*, *c* which are perpendicular, respectively, to the A, B and C faces. The impedance element consists of a parallele- 35 piped or rectangular plate so cut from the Rochelle salt crystal that a principal face of the plate is perpendicular to one of the principal axes of the crystal. Fig. 1a shows, by way of example, such a plate 1 having a face 2 which 40 is perpendicular to the crystal axis *b*. In the preferred form the plate is so oriented that its major axis, that is, a length dimension, makes an angle of approximately 45 degrees with the other two principal axes of the crystal. In Fig. 1a the 45 segment 3 shown in dotted outline has this orientation, the major axis 4 making an angle of approximately 45 degrees with the *a* and *c* axes of the crystal. This type of cut provides an element having a longitudinal vibration quite 50 free from extraneous resonances, and one having a large electromechanical coupling factor.

Each impedance element has electrodes associated with its two principal faces by means of which an alternating electromotive force may be 55

applied. If integral electrodes are employed it is found desirable to apply them only to the central portion, covering approximately 70 per cent of each principal face, while about 15 per cent at each end is left unplated, in order to stabilize the anti-resonant frequency as a function of temperature. Fig. 2 is a perspective view of such a partially plated crystal element 11 having a principal face 12 of length  $l$  and width  $w$  to which has been applied two symmetrically placed electrodes 13 and 14. The electrodes may be made of gold or other suitable metal, preferably applied by a sputtering process. It is to be understood that two other similar electrodes are placed on the other principal face, that is, the one opposite to face 12. A divided plating is used on each face so that a single crystal element may be made to provide portions of two different impedance branches in a wave filter, as explained more fully hereinafter in connection with Fig. 6.

When vibrating in the longitudinal mode the element 11 has a transverse nodal line at the center along which the crystal is preferably supported. As shown in Fig. 2 the supporting means may comprise a pair of clamps 15, 16 on one side and a second pair of similar clamps, not shown, oppositely disposed on the other side between which the crystal plate is held. The clamps may be made of conducting material, or of other material faced with conducting material, and the electrical connections may be made to the clamps or directly to the electrodes.

Another method found to be very effective in stabilizing all of the properties of the crystal element, and especially the anti-resonant frequency, as a function of temperature is to separate the electrodes a short distance from the crystal, leaving a small air gap therebetween. A separation of the order of 0.001 inch has been found to give good results. One way of providing the desired spacing is to make the surfaces of the crystal slightly rough and to allow the electrodes to rest directly thereon. Or, alternatively, spacers of insulating material may be inserted between the electrodes and the crystal. The latter method is illustrated in Fig. 3 which shows an end view of a crystal element 11 with electrodes 17, 18 associated with one principal face and electrodes 19, 20 associated with the opposite face. The area of the electrodes may correspond substantially with the area of the two principal faces of the crystal. The electrodes may, for example, be plates of glass or other material which will retain its form, on the inner side of which is deposited a coating of conducting material, as shown at 21. The conducting material is platinum, aluminum, or some other suitable metal, applied preferably by a sputtering process. Each plate is spaced from the crystal a distance  $d$  by means of a spacer which may, for example, be a deposit of non-conducting cement, shown at 22, located at the nodal line. The crystal and its associated electrodes may be supported by means of suitable clamps, not shown, which contact the outer faces of the electrodes.

In order to provide a crystal element which is sufficiently free from extraneous resonances and one which is comparatively stable with temperature changes it has been found desirable to hold the ratio  $r$  of the width  $w$  to the length  $l$  of each principal face, as indicated in Fig. 2, within certain limits. One reason for this may be deduced from a study of the curves presented in Fig. 4, which relate to a Rochelle salt crystal element

having a principal face cut perpendicular to the  $a$  axis, with a length dimension making an angle of 45 degrees with the  $b$  and  $c$  axes. The resonance frequencies for the various modes of vibration, in kilocycles per second per centimeter of length  $l$ , are shown plotted against the ratio  $r$ . The solid line curve 23 represents the principal mode of vibration, the extensional mode in the direction of the length  $l$ , and curve 24 represents the extensional mode in the direction of the width  $w$ . The dotted line curves 25, 26 and 27 represent extraneous shear vibrations, of which the only one of consequence is 25, due to its proximity to curve 23. It will be noted that curves 23 and 25 have their widest separation near the point where  $r$  is 0.4 and therefore this is the optimum ratio in this respect. However, for values of  $r$  ranging approximately from 0.35 to 0.55 it has been found that there is a sufficient separation between the two curves to insure satisfactory operation of the crystal element in wave filters. The range of  $r$  lying between 0.20 and 0.25 can also be utilized, but the elements have an impedance which is too high for some purposes. The ranges of  $r$  lying just below 0.2, just below 0.3 and between 0.6 and 0.7 where other curves cross curve 23, should particularly be avoided. The region in which  $r$  is greater than 0.7 should also be avoided because of the proximity here of the shear curves.

Rochelle salt crystal elements having a principal face cut perpendicular to the  $b$  axis, as shown in Fig. 1a, also have the type of frequency spectrum shown in Fig. 4, and therefore when this type of element is used the ratio  $r$  should be held within the same limits as those mentioned above.

It has also been found that approximately the same range of  $r$ , namely from 0.35 to 0.55, insures the greatest stability of frequency with changes in temperature, and therefore this is a second reason for employing crystal elements which have principal faces having these relative proportions.

In order to protect the crystal it is placed in a reasonably air-tight container such as 28 shown in perspective, partly cut away, in Fig. 5. There is shown within the container two crystal elements 29 and 30 having integral electrodes of the type shown in Fig. 2. The crystals are mounted in a holder which is supported from one side of the container by means of two metal rods such as 31. The holder comprises three members 32, 33 and 34 made of insulating material in which are embedded four pairs of clamps such as 35 and 36 each held in place by a metal pin such as 37. The crystal plates 29 and 30 are mounted between the four pairs of clamps as shown, and electrical connections to the electrodes are made by means of connectors such as 38 one end of which is soldered to the pin 37. Each connector passes through a hole in the container and is insulated therefrom by means of an insulating seal comprising a flanged metallic cylinder 39 partially filled with a glass bead 40 through which passes the connector. The flange of the cylinder 39 is soldered to the side of the container so as to provide a joint which will not admit air or moisture.

In order to preserve the crystal it is desirable that the relative humidity of the surrounding atmosphere be controlled within certain limits even though changes in temperature occur. This is accomplished by exposing within the container a small quantity of desiccated and a small quantity of normal Rochelle salt. Preferably these

salts are granulated, and may be separately placed in two cloth cartridges such as 41 and 42 supported by means of string between the two uprights 43 and 44, as shown in Fig. 5. It has been found that one cubic inch of each of the salts is sufficient to control the humidity of two cubic feet of air within the sealed container, when the temperature range encountered is not too great. If the temperature changes are not too rapid or too great a comparatively constant humidity will be maintained. When the temperature is lowered and the relative humidity inside the container tends to increase, the excess moisture is absorbed by the desiccated salt, thus maintaining the equilibrium. On the other hand, if the temperature rises the relative humidity will tend to decrease, but the normal salt gives up moisture, again maintaining the equilibrium.

Fig. 6 is a schematic circuit diagram showing how two Rochelle salt crystal elements 45 and 46 of the type illustrated in Fig. 2 or 3 each having two pairs of electrodes may be utilized to provide a portion of each of the four impedance branches of a lattice-type wave filter having a pair of input terminals 47, 48 and a pair of output terminals 49, 50. The pair of electrodes 51, 52 associated with element 45 are connected directly between terminals 47 and 49 to form part of a series impedance branch, and the other pair of electrodes 53, 54 are connected between terminals 50 and 48 to form part of the other series branch. The two pairs of electrodes associated with element 46 are connected, respectively, between the input terminals and the output terminals to form the diagonal impedance branches. The filter is completed by the addition of the two series capacitances  $C_1$ , the two shunt capacitances  $C_2$  and the four series inductances  $L_1$ , as shown. The component reactance elements may be proportioned so that the filter will have a band-pass transmission characteristic, with one or more attenuation peaks on each side of the band, of the type shown in Fig. 7. It is sometimes found that the attenuation in the regions of suppression may be increased by providing an inductive coupling between each inductance at one end of the filter and the corresponding inductance at the other end.

What is claimed is:

1. A wave filter comprising a plurality of impedance branches arranged between a pair of input terminals and a pair of output terminals, one of said impedance branches comprising as a reactance element a Rochelle salt crystal, in the form of a plate having a width to length ratio falling between 0.35 and 0.45, said ratio being so chosen as to provide the widest separation between the resonance frequency of said crystal when vibrating in the extensional mode in the direction of its length and the resonance frequency of the nearest extraneous shear vibration.

2. A wave filter comprising a plurality of impedance branches arranged between a pair of input terminals and a pair of output terminals and so proportioned with respect to each other and to two preassigned frequencies that said filter will transmit the band lying between said frequencies, one of said branches comprising as an impedance element a plate cut from a Rochelle salt crystal, said plate having a face perpendicular to the  $b$  axis of said crystal, the major axis of said plate making an angle of approximately 45 degrees with each of the other principal axes of said

crystal, and said plate having a length so chosen that said plate exhibits a longitudinal resonance at a frequency within the operating range of said filter.

3. A wave filter comprising as an impedance element a crystalline plate of Rochelle salt having integral electrodes which cover the central portions of its two principal faces leaving the end portions of said faces uncovered, a sealed container enclosing said plate, and means within said container for maintaining therein a constant relative humidity over a temperature range.

4. A wave filter comprising as an impedance element a plate cut from a Rochelle salt crystal, said plate having a width to length ratio so chosen that the utilized frequency of vibration predominates over all extraneous frequencies of vibration, a sealed container surrounding said element, and a quantity of normal Rochelle salt and a quantity of desiccated Rochelle salt exposed within said container whereby the relative humidity within said container is maintained within specified limits while the temperature varies over the operating range.

5. In a wave filter, an impedance element comprising a crystalline plate of Rochelle salt and associated electrodes, a principal face of said plate having a width to length ratio of approximately 0.4, whereby the nearest extraneous resonance is located in the frequency spectrum a maximum distance from the vibration frequency of said plate in its principal mode of vibration.

6. In a wave filter, an impedance element comprising a crystalline plate of Rochelle salt, an electrode supported adjacent a face of said plate, said electrode being separated from said plate by a short distance to provide an air gap therebetween in order to stabilize the vibration frequency of said element as a function of temperature, a sealed container enclosing said plate and means within said container for stabilizing the relative humidity with changes in temperature.

7. A piezoelectric impedance element comprising a plate cut from a Rochelle salt crystal and two electrodes, one of said electrodes being associated with each major face of said plate, said electrodes being separated from said plate by spacers which contact said plate only over small areas at the nodal line, and said electrodes being spaced approximately 0.001 inch from said plate in order to minimize changes in the vibration frequency of said element with changes in temperature.

8. A piezoelectric impedance element comprising a plate cut from a Rochelle salt crystal and electrodes associated therewith, said element having a principal face of length  $l$  and width  $w$ , the ratio of  $w$  to  $l$  lying between 0.35 and 0.45 and being so chosen as to provide the widest separation between the resonance frequency of said element when vibrating in the extensional mode in the direction of its length and the frequency of the nearest extraneous shear vibration.

9. A piezoelectric impedance element consisting of a plate cut from a Rochelle salt crystal, each of the two principal faces of said element having a symmetrically placed integral electrode covering approximately 70 per cent of the surface at the center, leaving approximately 15 per cent at each end unplated in order to minimize changes in the vibration frequency of said element with changes in temperature.

10. A piezoelectric element comprising a crystalline plate of Rochelle salt, an electrode supported adjacent a face of said plate with a sepa-

ration of approximately 0.001 inch between said plate and said electrode, a sealed container enclosing said plate, and means within said container for maintaining therein a constant relative humidity over a temperature range.

11. A piezoelectric impedance element comprising a plate cut from a Rochelle salt crystal and an electrode associated with a face of said plate, said electrode being made of glass and having its inner surface coated with conducting material.

12. A resonator comprising an element cut from a piezoelectric crystal and an electrode supported adjacent a face of said crystal element, said electrode consisting of a glass plate the inner surface of which is coated with conducting material.

13. A piezoelectric impedance element comprising a crystalline plate of Rochelle salt and electrodes associated therewith, said plate having a width to length ratio lying between 0.20 and 0.25, and said electrodes covering approximately 70 per cent of the surface at the center of the two principal faces of said plate, leaving approximately 15 per cent at each end uncovered in order to minimize changes in the vibration frequency of said element with temperature variations.

14. In a piezoelectric device, a crystalline plate of Rochelle salt having a width to length ratio lying between 0.35 and 0.45, said ratio being so chosen as to provide the widest separation between the resonance frequency of said plate when vibrating in the extensional mode in the direction of its length and the frequency of the nearest shear vibration.

15. In a piezoelectric device, a crystalline plate of Rochelle salt having a width to length ratio of approximately 0.4, and electrodes associated with the two principal faces of said plate, said electrodes covering approximately 70 per cent of the surface at the center, leaving approximately 15 per cent at each end uncovered whereby the vibration frequency of said plate is stabilized with respect to temperature changes.

16. A resonator comprising an element cut from a piezoelectric crystal and an electrode associated with a face of said element, said electrode consisting of a glass plate the inner surface of which is coated with conducting material, and said electrode being separated from said crystal element by a deposit of non-conducting cement.

17. A piezoelectric element comprising a plate cut from a Rochelle salt crystal, said plate having a face perpendicular to the *b* axis of said crystal, the major axis of said plate making an angle of approximately 45 degrees with each of the other principal axes of said crystal, and said face having a ratio of width to length so chosen as to provide the widest separation between the resonance frequency of said element when vibrating in the extensional mode in the direction of its length and the resonance frequency of the nearest shear vibration.

18. A piezoelectric device comprising a crystalline plate of Rochelle salt having integral elec-

trodes which cover the central portions of its two principal faces leaving the end portions of said faces uncovered, a sealed container enclosing said plate, and means within said container for stabilizing the relative humidity with changes in temperature.

19. An impedance element comprising a piezoelectric crystal of Rochelle salt and a pair of conductive coatings on two opposite faces of said crystal, said coatings covering approximately 70 per cent of the surface of said faces at the center, leaving approximately 15 per cent at each end uncoated in order to stabilize the vibration frequency of said element with temperature variations.

20. An impedance element comprising a piezoelectric crystal of Rochelle salt and a pair of conductive coatings on two opposite faces of said crystal, said coatings covering only the central portions of said faces, leaving at least 15 per cent of the surface at each end uncoated in order to stabilize the vibration frequency of said element with temperature variations.

21. A piezoelectric element in accordance with claim 17 which includes means for supporting said plate in the region of the nodal line.

22. A wave filter in accordance with claim 2 in which said impedance branches are arranged to form a lattice network.

23. A wave filter in accordance with claim 2 in which said face has a ratio of width to length so chosen as to provide the widest separation between the resonance frequency of said element when vibrating in the extensional mode in the direction of its length and the resonance frequency of the nearest shear vibration.

24. A wave filter comprising two pairs of equal impedance branches connected between two input terminals and two output terminals to form a symmetrical lattice network, and a plate cut from a Rochelle salt crystal, said plate having two pairs of oppositely disposed electrodes by means of which it is connected to each of one pair of equal branches, said plate having a principal face perpendicular to the *b* axis of the crystal, the major axis of said plate making an angle of approximately 45 degrees with the *a* and *c* axes, and said plate having a length so chosen that said plate exhibits a longitudinal resonance at a frequency within the operating range of said filter.

25. A wave filter comprising two pairs of equal impedance branches arranged to form a symmetrical lattice, a crystalline plate of Rochelle salt symmetrically coupled electro-mechanically to both branches of one equal pair and a second similar plate similarly coupled to the other pair of equal branches, said plate having different resonance frequencies and each of said plates being cut from a Rochelle salt crystal perpendicular to the *b* axis and with its longest dimension at an angle of approximately 45 degrees to the *a* and *c* axes.

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