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March 28, 1967 W. P. MASON 3,311,854
SINGLE CRYSTAL QUARTZ FILTER ELEMENTS, TRANSDUCERS AND DELAY LINES
Filed June 13, 1962 2 Sheets-Sheet 1

FIG. 1
PRIOR ART

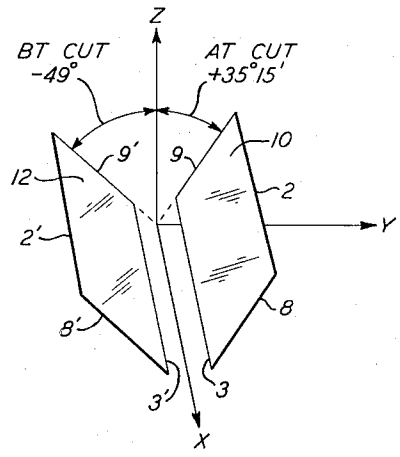



FIG. 2

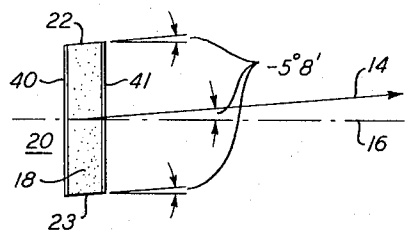



FIG. 3

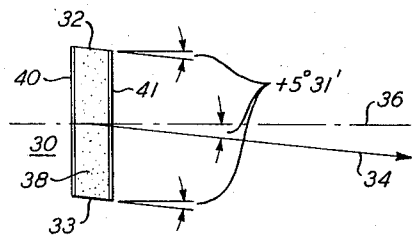
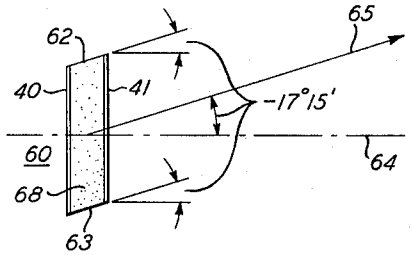



FIG. 4




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SINGLE CRYSTAL QUARTZ FILTER ELEMENTS, TRANSDUCERS AND DELAY LINES

Filed June 13, 1962 2 Sheets-Sheet 2

FIG. 5

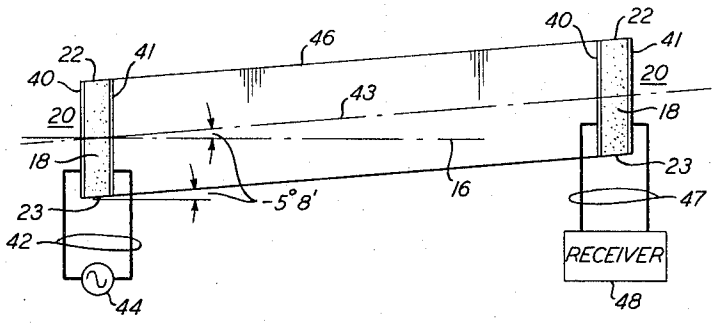



FIG. 6

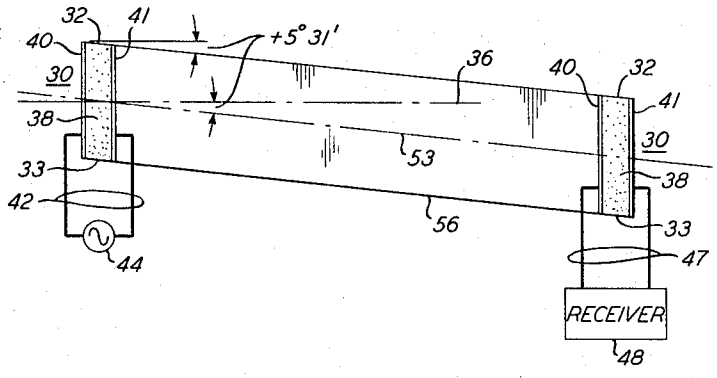
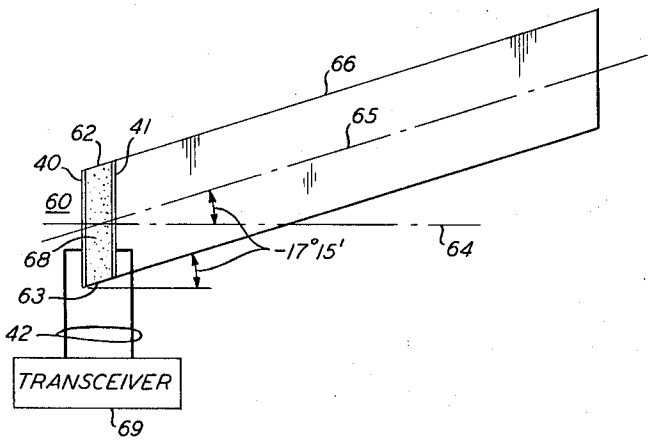



FIG. 7




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3,311,854

# SINGLE CRYSTAL QUARTZ FILTER ELEMENTS, TRANSDUCERS AND DELAY LINES

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12 Claims. (Cl. 333—30)

This invention relates to piezoelectric members and acoustic delay lines cut from single crystals of quartz. More particularly, it relates to members of the above-mentioned types adapted for use as filter elements, acoustic and ultrasonic transducers, acoustic and ultrasonic delay lines and the like.

Piezoelectric members cut from single crystals of quartz have been widely used and numerous and varied orientations with respect to the crystallographic axes known in the art as "cuts" have been devised, each "cut" having particular advantages (and usually some limitations, as well) for specific and varied uses. For example, applicant's books entitled, "Electromechanical Transducers and Wave Filters," and "Piezoelectric Crystals and Their Application to Ultrasonics," and R. A. Heising's book entitled, "Quartz Crystals for Electrical Circuits," may be referred to for detailed descriptions of a large number and variety of quartz members cut from a single crystal at specifically designated different orientations with respect to the crystallographic axes. These are, as mentioned above, known in the art as "cuts." A single letter or a pair of letters are usually assigned as a designation for each "cut." The majority of such designations which are normally used by those skilled in the art, together with detailed descriptions of the specific orientations and characteristics of each "cut" will be found in the above-mentioned books. These books were all published by D. Van Nostrand Company, Inc., of New York, N.Y., and Princeton, N.J. The first mentioned book was published originally in 1942 and a second edition thereof was published in 1948. The second mentioned book was published in 1950 and the third in 1946. A fourth book entitled "Physical Acoustics and the Properties of Solids" written by applicant and published by D. Van Nostrand, Inc., Princeton, N.J., in 1958 is also of interest in connection with the subject matter of the present application.

On account of the anisotropy of quartz, i.e., the change in the elastic moduli with orientation relative to the crystallographic axes, there are only a few directions in the crystal for which a pure longitudinal wave or a pure shear wave can be propagated. In other directions quasi-longitudinal or quasi-shear waves are propagated and the direction of propagation in general deviates from the normal to the major surfaces of the major cuts employed in most practical applications. The orientations that produce pure modes are, of course, optimum for such purposes as delay line members and filter crystals which are to have a minimum number of resonances in addition to their respective principal resonances.

For most practical purposes, however, the X cut is the principal cut employed when longitudinal waves are to be used, while when shear waves are to be used, the AT and BT cuts are employed where a zero temperature coefficient of frequency is necessary or the Y cut is employed where a maximum electromechanical coupling coefficient is necessary. For high frequency use the AT, BT and Y cuts are of principal interest. It can be shown, as will be discussed in more detail below, that the axis or direction of propagation of energy through and the direction of radiation of energy from each of these three latter cuts deviates from the normal to the major surfaces of the cut by an appreciable angle, as will be discussed in more detail hereinbelow.



The deviation of the axis of propagation from the normal to the principal surfaces results in reflections of energy from particular side or edge surfaces of the crystal, as will be discussed in detail hereinbelow, which reflections produce interferences with the main resonance of the crystal. Also, other deleterious effects to be mentioned hereinbelow may be encountered. The interfering modes are particularly objectionable in certain instances since, for example, if the crystals are employed as filter elements intended to operate over wide ranges of frequencies the interfering modes usually result in undesired attenuation at a number of frequencies within a band of frequencies it is desired to transmit freely and/or they cause serious lowering of the attenuation at various frequencies within a frequency region the filter is intended to strongly suppress.

Furthermore, when such crystals are employed as transducers connected to a delay line, and, as in the usual case, the longitudinal axis of the delay line is normal to the transducer face, energy will be multiply reflected from the side or edge walls of the delay line and cause objectionable distortion of pulses or other signals it is desired to transmit through the delay line. The effect is aggravated by the delay line itself especially if, as is frequently the case, the latter is also cut from a single crystal of quartz with its principal or end surfaces parallel to the same crystal plane as are the principal surfaces of the transducer and its longitudinal axis is perpendicular to this plane.

Accordingly, principal objects of the invention are to eliminate difficulties which arise on account of the deviation of the direction of propagation of acoustic or ultrasonic energy by piezoelectrically driven quartz crystal transducers or resonators from the normal (perpendicular) to the principal or major faces of the crystal and/or the principal or end surfaces of an associated delay line.

A further object is to eliminate difficulties arising from side or edge wall reflections of the energy within the filter or transducer crystals themselves and in delay lines when the energy is to be transmitted through delay lines.

Other and further objects, features and/or advantages of the invention will become apparent from a perusal of the following description of specific illustrative structural arrangements embodying principles of the invention taken in conjunction with the accompanying drawing, in which:

FIG. 1 illustrates the orientation of the AT and BT planes in a single crystal of quartz with respect to the crystallographic axes of the single crystal, as taught in the art, the X axis being the electrical axis, the Y axis being the mechanical axis, and the Z axis being the optic axis of the crystal;

FIG. 2 illustrates the beveling of the upper and lower edges of a rectangular AT cut quartz crystal to improve its frequency spectrum;

FIG. 3 illustrates the beveling of the upper and lower edges of a rectangular BT cut quartz crystal to improve its frequency spectrum;

FIG. 4 illustrates the beveling of the upper and lower edges of a rectangular Y cut quartz crystal to improve its frequency spectrum;

FIG. 5 illustrates a combination of beveled edge AT cut quartz crystal transducers and a delay line cut from a single crystal of quartz with the principal or end surfaces of the delay line in the AT plane and the longitudinal axis of the delay line inclined with respect to its principal or end surfaces to avoid reflections from edge or side wall surfaces of the delay line;

FIG. 6 illustrates a combination of beveled edge BT cut quartz crystal transducers and a delay line cut from a single crystal of quartz with the principal or end surfaces of the delay line in the BT plane and the longitudinal axis of the delay line inclined with respect to its prin-

cipal or end surfaces to avoid reflections from edge or side wall surfaces of the line; and

FIG. 7 illustrates a combination of a beveled edge Y cut quartz crystal transducer and a delay line cut from a single crystal of quartz with the principal or end surfaces of the delay line in the Y plane and the longitudinal axis of the delay line inclined with respect to its principal or end surfaces to avoid reflections from edge or side wall surfaces of the line.

Piezoelectric transducers and filter resonating crystals cut from single crystals of quartz with their principal or major surfaces in either the AT or BT planes have been selected for illustrative purposes in the present application as they are indeed representative of "cuts" in which the axis of propagation deviates from the normal to the principal or major faces of the crystal and they are widely used because they have zero temperature coefficients of frequency and good high frequency characteristics in the important frequency range of one to fifteen megacycles or more at their fundamental resonances. The Y cut member has been selected for illustrative purposes since it has the maximum electromechanical coupling coefficient.

As mentioned hereinabove, crystals of the AT, BT and Y cuts have axes of propagation, that is, propagation directions deviating from the normal to their principal or major surfaces. The angle of deviation and its direction for any specific cut can be calculated or it can be determined by physical tests.

For the AT cut crystal the angle of deviation is found to be −5°8′ (the negative sign indicating that the angle is to be measured in a counterclockwise direction with respect to the Z or optic axis). For the BT cut crystal the angle of deviation is +5°31′ (measured in a clockwise direction). For the Y cut crystal the angle of deviation is −17°15′. For all of these cuts the direction of propagation is parallel to the YZ plane of the crystal from which it is cut. Since the front and rear edges of both these cuts are also parallel to the YZ plane, they are likewise parallel to the direction of propagation.

With reference to FIG. 1, the orientation of the plane **10** which is the AT plane of a single quartz crystal and of the plane **12** which is the BT plane of a single quartz crystal, with respect to the crystallographic axes X (electrical), Y (mechanical) and Z (optic) of a single quartz crystal, is shown.

The AT plane of a single quartz crystal, as illustrated in FIG. 1, has its upper and lower edges **2**, **3** parallel to the X axis, its front and rear edges **8**, **9** parallel with the plane of the Y and Z axes and the principal or major surface of the AT plane is at a positive (clockwise) angle of 35 degrees and fifteen minutes with respect to the plane of the X and Z axes.

Similarly, the BT plane of a single quartz crystal, as illustrated in FIG. 1, has its upper and lower edges **2′**, **3′** parallel to the X axis and its front and rear edges **8′**, **9′** parallel with the plane of the Y and Z axes and the principal or major surface of the BT plane is at a negative (counterclockwise) angle of 49 degrees with respect to the plane of the X and Z axes.

The Y cut crystal has its major surfaces normal to the Y axis, i.e., its major surfaces are parallel with the plane of the axes X and Z. Its upper and lower edges are therefore parallel to the X axis and its front and rear edges are parallel to the Z axis.

With reference to FIG. 2, as stated hereinabove, the direction of propagation **14** of an AT cut crystal **20** deviates by a negative (counterclockwise) angle of five degrees eight minutes from the normal or perpendicular **16** to its principal or major surfaces. FIG. 2 is an end view of crystal **20**, the front edge **18** being in the plane of the paper. The general shape of crystal **20** can, for example, be rectangular, the crystal dimensions being determined by the specific frequency characteristics desired in accordance with principles well known to those skilled in the art and as discussed in detail in the above-mentioned books.



In some instances the principal or major surfaces of the crystal may be of oval, triangular or other non-rectangular contour but the axis of propagation and the normal to the major surfaces will obviously be oriented in the same way with respect to the crystallographic axes of the single crystal from which the element is cut as for rectangular elements. For normal uses, as is well known in the art, conductive electrodes **40** and **41** are placed on the principal or major surfaces of the crystal and connected to an electrical source (see FIGS. 6 and 5) of appropriate frequency, whereupon acoustic and/or ultrasonic energy is generated within the crystal by piezoelectric action and is propagated from the principal or major surfaces.

As mentioned above, when the upper edge **22** and lower edge **23** of the AT cut crystal **20** are beveled or cut at the angle (−5°8′) by which the axis or direction of propagation deviates from the normal to the principal or major surfaces, so that these edges are parallel to the axis or direction of propagation, as shown in FIG. 2, reflection of energy from these edges is eliminated and the crystal is not subject to the deficiencies described hereinabove which may limit the range or spectrum of frequencies over which the crystal will operate satisfactorily.

In FIG. 3 the corresponding situration for a BT cut crystal **30** is illustrated. Its axis or direction of propagation **34** is at a positive (clockwise) angle of five degrees thirty-one minutes with respect to the normal **36** to the principal or major surfaces of the crystal. Its upper edge **32** and lower edge **33** are beveled at the same positive angle to be parallel to the direction of propagation as illustrated in FIG. 3. Its major surfaces are substantially covered by conductive electrodes **40** and **41**, respectively.

Finally, in FIG. 4 the situation for a Y cut crystal **60** is illustrated. Its axis or direction of propagation **65** is at a negative angle (counterclockwise) of seventeen degrees fifteen minutes with respect to the normal **64** to the principal or major surfaces of the crystal. Its upper edge **62** and its lower edge **63** are beveled to this same angle so that they are parallel to the direction of propagation **65** as illustrated in FIG. 4. Its major surfaces are substantially covered by conductive electrodes **40** and **41**, respectively.

From the above illustrative examples we may derive the general rule for application to crystals of oval, triangular or other nonrectangular shapes that all side edges should be parallel to the axis or direction of propagation. Side surfaces and edges in turn may be generally characterized as surfaces intersecting and interconnecting the principal or major surfaces. The principal or major surfaces obviously define to a large extent the contour and shape of the element.

The improved AT, BT and Y cut crystals of FIGS. 2, 3 and 4, respectively, equipped with electrodes are suitable for use in crystal filters in manners well known and understood in the art. The AT and BT cuts will have substantially zero temperature coefficients of frequency and will operate satisfactorily over a wide range or spectrum of frequencies. The Y cut members will have maximum electromechanical coupling factors. All three cuts are suitable for use as transducers and can, for example, be connected to improved delay lines of the invention, the delay lines also being cut from single crystals of quartz and equipped with transducers as illustrated in FIGS. 5, 6 and 7, respectively. Like designation numbers occurring in FIGS. 2 through 7, inclusive, indicate corresponding features of two or more of the figures.

In FIG. 5 a crystal **20** of FIG. 2, provided with conductive electrodes **40**, **41** which may, for example, be metallic layers deposited on the principal or major surfaces, is fastened, as with a strongly adhesive cement, to the left and right ends, that is, the "principal" surfaces, of a delay line **46**, as shown. Delay line **46** is cut from a

single crystal of quartz, its principal or end surfaces being parallel to the AT plane of the single crystal from which it is cut and otherwise oriented as are the principal or major surfaces of the crystal **20** of FIG. 2. The longitudinal axis **43** of the delay line is at a negative (counterclockwise) angle of five degrees and eight minutes from the normal **16** to the AT plane of the said single crystal, as shown.

Electrical leads **42** connect the electrodes **40, 41** of the left transducer crystal **20** to energy source **44** which may, for example, generate short pulses of megacycle frequency energy. Corresponding ultrasonic pulses will be generated by the left crystal **20** and since the longitudinal axis of delay line **46** is parallel to the axis or direction of propagation of the transducer crystal the ultrasonic pulses will be transmitted to the right transducer **20** by delay line **46** with substantially no reflection of energy from the edge or side walls of the delay line.

The right transducer **20** will re-convert the ultrasonic pulses to electrical pulses and leads **47** will conduct the electrical pulses to utilization circuit **48** which may, for example, be a unit of a computer system or the like. As is well known in the art, delay lines equipped with transducers as illustrated in FIGS. 5 and 6 are widely used for information storage purposes and various other purposes as well. In many instances, as is well known in the art, a single transducer at one end of the line, as illustrated for example in FIG. 7, may serve both to inject ultrasonic pulses into the line and to receive reflections or echoes of the injected pulses arriving back at the transducer during intervals in which it is not transmitting.

The arrangement of FIG. 6 is obviously similar to that of FIG. 5 except that BT type crystals **30** equipped with electrodes **40, 41** are employed at the two ends of the delay line **56**. The delay line **56** is cut from a single crystal of quartz with its principal or end surfaces parallel to the BT plane of the crystal from which it is cut and oriented as for the major surfaces of crystal **30** of FIG. 3 but with its longitudinal axis at a positive (clockwise) angle of five degrees thirty-one minutes from the normal to the BT plane, as shown.

Finally, the arrangement of FIG. 7 resembles those of FIGS. 5 and 6 except that a single transducer comprising the Y cut transducer **60** of FIG. 4 is employed and a transceiver **69**, which may take any of numerous forms well known in the art, is connected by leads **42** to electrodes **40, 41** of the crystal.

In FIGS. 5, 6 and 7 the cross-sectional area and shape of the delay lines **46, 56** and **66**, respectively, are preferably substantially the same as the area and shape of the principal or major surfaces of the transducers affixed to their respective ends.

The over-all arrangements of FIGS. 5, 6 and 7 will be substantially free from difficulties arising from the reflection of energy from the edge or side walls of the delay line and from the reflection of energy from the upper and lower edges of the transducer crystals. Also, for AT and BT cuts, the over-all arrangement will have a zero temperature coefficient of frequency. The Y cut transducer as previously mentioned has a maximum electromechanical coupling factor. All three arrangements will operate satisfactorily over a wide range or spectrum of frequencies.

It should be noted that although it is obviously preferable and desirable that the upper and lower edges of the transducer crystals of FIGS. 5, 6 and 7 be beveled as illustrated, the inclinations of the longitudinal axes of the delay lines of these figures should be the same as shown, respectively, even if corresponding AT, BT and Y cut crystal transducers without beveled upper and lower edges are used, respectively, since the reflection of energy from the edge or side walls of the delay lines would still be substantially eliminated.

Numerous and varied modifications and rearrangements of the illustrative embodiments described in detail above can be readily devised by those skilled in the art without departing from the spirit and scope of the principles of the invention.



What is claimed is:

**1.** A member cut from a single crystal of quartz with two principal faces parallel to each other and to a specific plane, which plane has a particular orientation with respect to the crystallographic axes of the single crystal from which the member is cut such that if driven by an electrostatic force applied perpendicularly between said principal faces the member will generate acoustic energy directed at a specific acute angle of appreciable magnitude with respect to the normal to the principal faces, all of the side or edge surfaces of the member which extend between the principal faces of the member being parallel to the said direction of propagation.

**2.** The member of claim **1** and a conductive electrode on each principal face of the member.

**3.** The combination of a piezoelectric transducer and an acoustic delay line attached to the transducer, the transducer and the delay line each being cut from a single crystal of quartz, the principal surfaces of the transducer and the principal or end surfaces of the delay line all being parallel to a specific plane of the crystal from which they are cut, the transducer having a direction of propagation of acoustic energy deviating by a specific acute angle of appreciable magnitude from the normal to its principal surfaces, the longitudinal axis of the delay line being directed to deviate from the normal to its principal or end surfaces by the same specific angle so that the direction of propagation of ultrasonic waves in the said combination transducer and delay line is parallel to all of the side or edge surfaces.

**4.** The combination of claim **3** in which the principal faces of both the transducer and the delay line are parallel to the AT plane of the single crystal from which they are cut thereby providing a device exhibiting a minimum of frequency and delay time deviation with temperature variations.

**5.** The combination of claim **3** in which the principal faces of both the transducer and the delay line are parallel to the BT plane of the single crystal from which they are cut thereby providing a device exhibiting a minimum of frequency and delay time deviation with temperature variations.

**6.** The combination of claim **3** in which the principal faces of both the transducer and the delay line are normal to the mechanical or Y axis of the single crystal from which they are cut.

**7.** An AT cut quartz crystal, the pair of edges of the crystal which are parallel to the electrical or X axis of the crystal from which it is cut being beveled planar at an angle of five degrees and eight minutes with respect to the normal to the principal faces of the crystal, the angle being measured in an anticlockwise direction with respect to the optic or Z axis of the crystal from which it is cut.

**8.** A BT cut quartz crystal, the pair of edges of the crystal which are parallel to the electrical or X axis of the crystal from which it is cut being beveled planar at an angle of five degrees and thirty-one minutes with respect to the normal to the principal faces of the crystal, the angle being measured in a clockwise direction with respect to the optic or Z axis of the crystal from which it is cut.

**9.** A Y cut quartz crystal, the pair of edges of the crystal which are parallel to the electrical or X axis of the crystal from which it is cut being beveled planar at an angle of seventeen degrees and fifteen minutes with respect to the normal to the principal faces of the crystal, the angle being measured in a counterclockwise direction with respect to the optic or Z axis of the crystal from which it is cut.

**10.** A delay line cut from a single crystal of quartz with its end surfaces parallel to the AT plane of the crystal, the longitudinal axis of the delay line being at an angle

of five degrees and eight minutes with respect to the normal to the end surfaces of the delay line, the angle being measured in an anticlockwise direction with respect to the optic or Z axis of the crystal from which it is cut.

11. A delay line cut from a single crystal of quartz with its end surfaces parallel to the BT plane of the crystal, the longitudinal axis of the delay line being at an angle of five degree and thitry-one minutes with respect to the normal to the end surfaces of the delay line, the angle being measured in a clockwise direction with respect to the optic or Z axis of the crystal from which it is cut.

12. A delay line cut from a single crystal of quartz with its end surfaces normal to the mechanical or Y axis of the crystal, the longitudinal axis of the delay line being at an angle of seventeen degrees and fifteen minutes with respect to the normal to the end surfaces of the delay line, the angle being measured in a clockwise direction with respect to the optic or Z axis of the crystal from which it is cut.



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