May 9, 1933. A. HUND 1,908,479

PIEZO-ELECTRIC PLATE

Filed May 17, 1926

FIG. 1

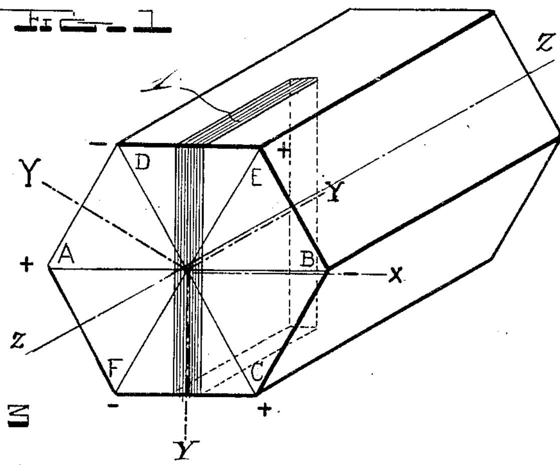


FIG. 3

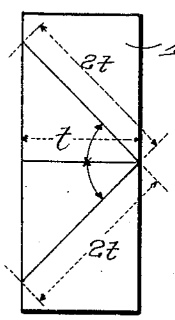


FIG. 2

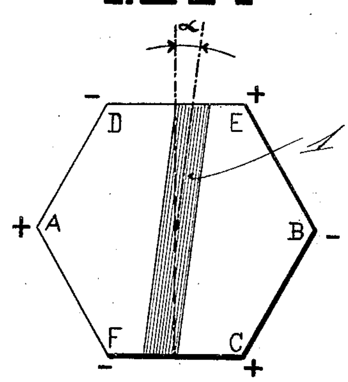


FIG. 4

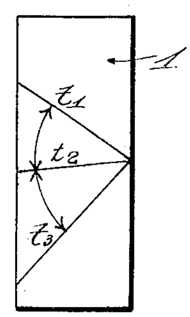
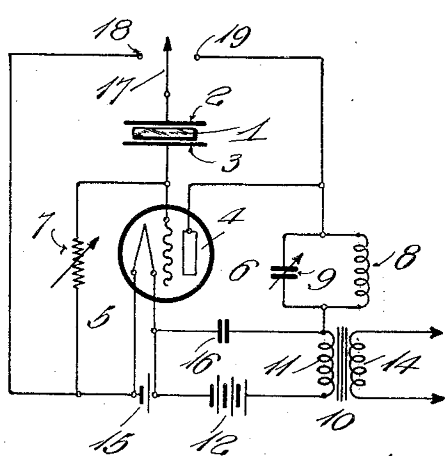


FIG. 5



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Patented May 9, 1933 **1,908,479**

UNITED STATES PATENT OFFICE

AUGUST HUND, OF BETHESDA, MARYLAND, ASSIGNOR, BY MESNE ASSIGNMENTS, TO WIRED RADIO, INC., OF NEW YORK, N. Y., A CORPORATION OF DELAWARE

PIEZO-ELECTRIC PLATE

Application filed May 17, 1926. Serial No. 109,786.

My invention relates broadly to methods of preparing piezoelectric plates and more particularly to a process for cutting and grinding piezoelectric plates for the production of piezoelectric elements capable of sustaining oscillations of audio frequency.

One of the objects of my invention is to provide a method for preparing piezoelectric plates from natural quartz whereby audio frequency oscillations may be sustained in an associated electrical circuit where the plate is relatively thin.

Another object of my invention is to provide a piezoelectric element of relatively small size which is capable of sustaining low frequency electrical oscillations.

A further object of my invention is to provide a piezoelectric element which is so cut and ground from natural quartz that a plurality of differing high frequency oscillations may be produced thereby and integrated in a common circuit for the development of an audible frequency beat note for application in a variety of different ways.

A still further object of my invention is to provide a piezoelectric crystal element having a plurality of differing axes wherein the different high frequency oscillations may be generated for the production of a beat frequency for securing an audible note from a relatively small size plate.

My invention will be more fully understood from the specification hereinafter following by reference to the accompanying drawing wherein:

Fig. 1 is a perspective view of a quartz body in its natural crystalline state showing the cutting of a piezoelectric plate therefrom in a plane parallel to the optical axis in a manner as set forth in more detail in my U. S. Patent No. 1,822,928, issued September 15, 1931; Fig. 2 is an end view representing an end section of the natural quartz body wherein a piezoelectric plate is cut therefrom in a plane disposed at an angle to a plane determined by one of the Y axes and the Z axis in accordance with the principles of my invention herein; Fig. 3 is a theoretical view showing the normal electrical polarization existent in a piezoelectric plate prepared in the manner illustrated in Fig. 1; Fig. 4 is a theoretical view illustrating the electrical polarizations within a piezoelectric plate which has been prepared in accordance with the principles of my invention illustrated in Fig. 2; and Fig. 5 shows the arrangement of a piezoelectric plate prepared in accordance with Figs. 2 and 4 in an electron tube circuit arranged for the generation of several different radio frequencies and the production of a relatively low frequency beat note.

In accordance with the conventional practice in the piezoelectric crystal art the optic electric and crystallographic axes of the quartz crystal from which the piezoelectric element is cut are designated respectively by the letters Z, X and Y as illustrated in Fig. 1 of the drawing.

A piezoelectric plate when properly cut and ground serves to sustain oscillations in an electron tube circuit where the oscillations are of a constant frequency and a value corresponding to a function of the thickness of the piezoelectric plate. Where the piezoelectric plate is cut and ground according to the principles set forth in my aforementioned patent only one thickness vibration is possible. This thickness vibration occurs along the electrical polarization axis indicated in Fig. 3 at t, which is an electrical polarization effect along the X-axis of Fig. 1. There are three X-axes or electrical polarization axes spaced 120° apart because of the threefold symmetry of quartz, and I have indicated the other two of these in Fig. 3 each by the symbol $2t$. The values $2t$ are both equal to each other and their length is twice as great as that of the line t. A compression wave along the axis t is therefore the first harmonic of the frequency corresponding to that produced by a compression wave along either of the axes $2t$. A single frequency with its first harmonic is therefore produced which is directly related to the thickness of the plate.

I have discovered that by cutting the piezoelectric plate as represented in Fig. 2 at an angle to a plane determined by one of the Y axes and the Z axis, that three different effective polarization axes exist through the piezoelectric plate as represented at t_1, t_2 and t_3 in Fig. 4 which generally have no harmonic relations. By reason of the plurality of effective axes through the piezoelectric plate in Fig. 4 there will be several modes of vibration through the piezoelectric plate. By cutting the piezoelectric plate at an angle α to the normal cut it is therefore possible to affect any two of the three effective thicknesses as to make them almost alike and such as to produce an audible beat frequency which results in an audible beat current in circuits associated with the piezoelectric plate. The frequency of the other effective thickness or mode of vibration may be so far removed from the frequencies of the first two effective thicknesses or modes of vibration as not to be pulled into step with the frequencies of these two effective thicknesses. One of the modes of vibration may be prevented from interfering with the other modes of vibration by proper arrangement of the electrical circuits in which the piezoelectric plate is connected. It is also possible to adjust the lengths along the axis t_1, t_2 and t_3 such that t_1 and t_2 produce one beat note and t_2 and t_3 another beat note and t_1 and t_3 a third beat note of different pitch. These different beat notes may be effectively separated and utilized in an associated circuit by the adjustment of the inductance and capacity values as represented in Fig. 5. The method of cutting the piezoelectric plates provides a plate having polarizations along a plurality of axes so that the plate may sustain oscillations at a plurality of different frequencies. The parallel planes of the faces of the crystal lie at an acute angle to a plane determined by one of the Y axes and the Z axis and intercept different lengths along the piezoelectric axes. The lengths of the piezoelectric axes are of such value as to individually produce vibrations of a frequency above the audible range yet so related to each other that the plate is capable of producing vibrations of a frequency within the audible range.

The piezoelectric plate is shown positioned between conductive plates 2 and 3 which serve to connect the piezoelectric plate in circuit with the electron tube 4. Electron tube 4 has an input circuit 5 and an output circuit 6. The input circuit 5 is shunted by means of a variable high resistance leak path 7 as illustrated. The output circuit 6 includes inductance 8 and variable capacity 9 with an audio frequency transformer 10 having its primary 11 disposed in series therewith in the plate circuit, which includes high potential battery 12. The audio frequency transformer 10 has a secondary winding 14 for delivering audio frequency current to any desired work circuit.

The cathode of electron tube 4 is heated from a suitable source 15. Radio frequency by-pass condenser 16 is connected in shunt with the primary winding 11 and a high potential battery 12 or its equivalent for providing a path of oscillation for the high frequency currents and energy for sustaining the oscillations of the piezoelectric crystal 1. A switch 17 is arranged for connecting the crystal effectively across the grid and cathode of electron tube 4 by moving the switch 17 to terminal 18, or the piezoelectric crystal 1 may be connected in shunt with the grid and anode of electron tube 4 by closing switch 17 on contact 19 for sustaining high frequency oscillations in the tube system. The audio frequency oscillations occur simultaneously in the electron tube circuits and are effectively utilized through iron core audio frequency transformer system 10.

In the process of grinding, the angles between $2t$ and t in Fig. 3 will be equal and correspondingly the angles between t_1 and t_2 and t_2 and t_3 in Fig. 4 will be equal. The production of several modes of vibration in the same piezoelectric plate 1 gives rise to a relatively small instrumentality for the generation of audible frequency of a constant characteristic.

As an example of the effectiveness of the piezoelectric audio frequency oscillator, it may be considered that the crystal in Fig. 4 may be ground in such manner that oscillations produced along the thickness t_2 may have a value of 500 kilocycles, while the oscillations generated along thickness t_1 may have a value of 499 kilocycles. The resultant beat frequency would be one kilocycle. The frequency t_3 may be so far removed from these thicknesses that it is without the range of the beat frequency which it is desired to utilize.

The preparation of piezoelectric plates in accordance with my invention herein for the production of low frequency oscillations reduces the size and cost of calibration apparatus to a considerable degree, and while I have illustrated my invention in its preferred embodiments I desire that it be understood that modifications may be made and that no limitations upon the invention are intended other than are imposed by the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. A piezoelectric element comprising a section cut from a natural quartz crystal, said element having a pair of parallel faces disposed parallel to the optical axis and at an angle to a plane defined by the optical axis and a crystallographic axis such that the element is naturally resonant to two fundamental frequencies which have an audible beat frequency relationship to one another.

2. A piezoelectric element having its electrode faces substantially parallel to the optic axis and disposed at an angle to one of the

lateral faces of the mother crystal such that the element is naturally resonant to two fundamental frequencies having an audible beat frequency relationship to one another, each of said frequencies being a function of one of the oblique distances between said electrode faces measured along the X-axes, respectively.

3. A quartz piezo-electric element having its electrode faces substantially parallel to the optic axis and disposed at an angle greater than zero and less than thirty degrees to one of the lateral faces of the mother crystal, said angle being such as to render the element naturally resonant to two different frequencies having an audible beat frequency relationship to one another.

4. A piezoelectric element having two substantially parallel faces disposed at different angles to each of the three electrical axes of the crystal from which said element is cut, whereby the element is made resonant to at least two superaudible frequencies having an audible beat-frequency relationship to one another.

5. A piezoelectric crystal having two substantially parallel faces in which the dimension normal to said parallel faces is disposed at different angles to each of the three electrical axes of said crystal, whereby the element is made resonant to at least two superaudible frequencies having an audible beat-frequency relationship to one another.

6. A piezoelectric vibrator comprising a plate of natural quartz having two flat faces parallel to the optical axis and inclined with respect to one of the Y-axes so as to comprehend three different lengths of X-axes between said faces, the comprehended length of each said X-axis being a function of one of the natural frequencies at which said vibrator is resonant and the ratios between said comprehended lengths of X-axes being such as to produce an audible beat-frequency between two of said natural frequencies.

7. A piezoelectric vibrator comprising a plate of natural quartz having two flat faces parallel to the optical axis and comprehending between said faces three different lengths of piezo-electric axes, said lengths being so related to one another as to render said vibrator naturally resonant to each of two fundamental frequencies between which the difference frequency is within the range of audibility.

In testimony whereof I affix my signature.

AUGUST HUND.