March 17, 1931. J. R. HARRISON 1,796,650

METHOD OF EXCITING PIEZO ELECTRIC CRYSTALS AND APPARATUS THEREFOR

Filed March 5, 1927 2 Sheets-Sheet 1

Fig. 1

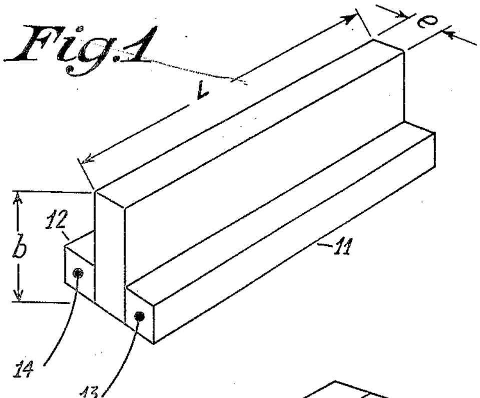


Fig. 2

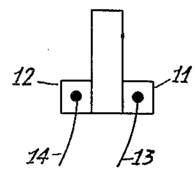


Fig. 3

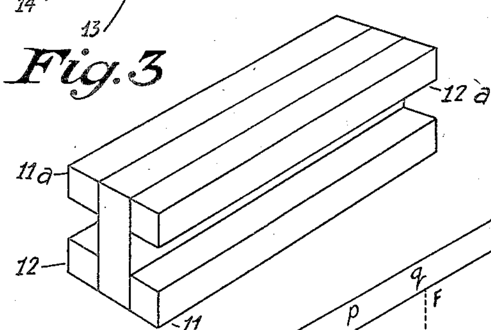


Fig. 4

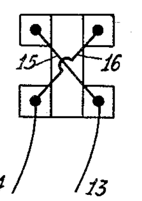


Fig. 5

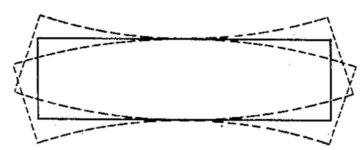


Fig. 6

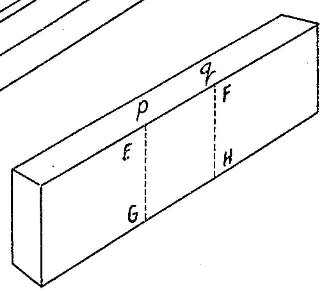


Fig. 7

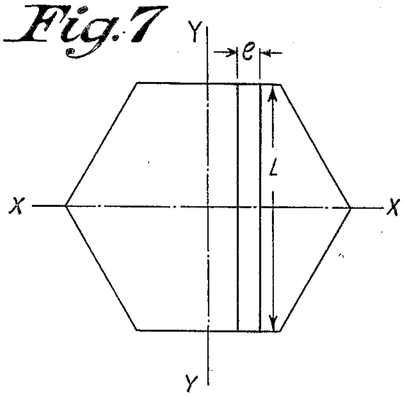
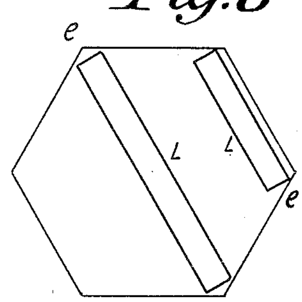


Fig. 8



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METHOD OF EXCITING PIEZO ELECTRIC CRYSTALS AND APPARATUS THEREFOR

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Fig. 9

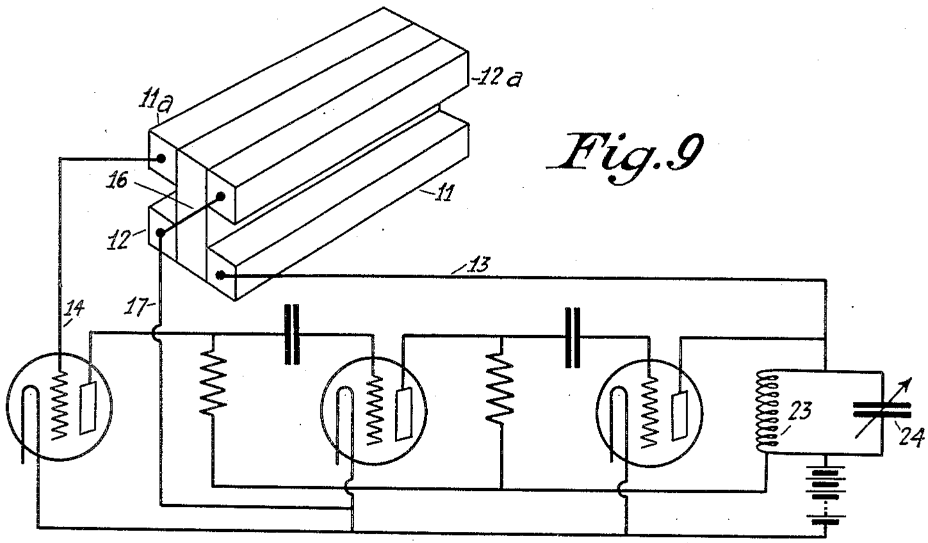


Fig. 10

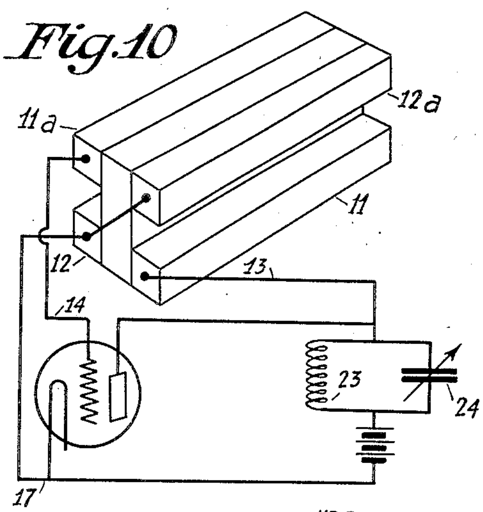


Fig. 11

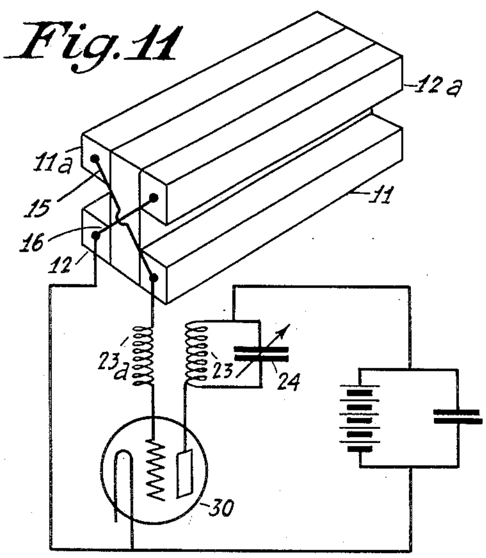


Fig. 12

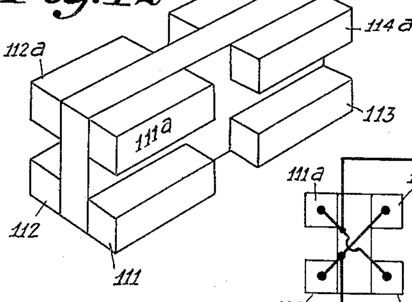
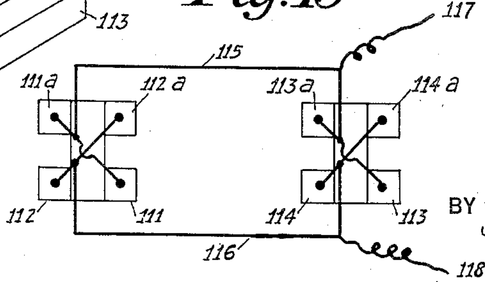


Fig. 13



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Patented Mar. 17, 1931

1,796,650

UNITED STATES PATENT OFFICE

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METHOD OF EXCITING PIEZO-ELECTRIC CRYSTALS AND APPARATUS THEREFOR

Application filed March 5, 1927. Serial No. 173,207.

This invention relates to the piezo-electric art and deals more specifically with an improved method and means for exciting a piezo-electric crystal to vibrate at frequencies other than its fundamental of longitudinal vibration. It is already known that if a plate is cut from a quartz crystal in a certain relation with respect to the optical and electrical axes of the crystal, that such quartz plate will exhibit the well known piezo-electric effect, and that it will have two well-defined modes of vibration. One of such modes of vibration is in accordance with the well known transverse effect in which case the length of the crystal determines the natural period. The other well known mode of vibration is in accordance with the longitudinal effect in which case the thickness of the crystal determines the frequency of vibration. Reference is made to an article by Professor Cady in the "Proceedings of the Institute of Radio Engineers", April, 1922, volume 10, page 85, for a detailed description of the method of preparing the quartz plates from the crystal, as well as a description of the transverse and longitudinal modes of vibration. It is also known that the crystal may be made to vibrate at various overtones for both these modes of vibration.

In accordance with the transverse and longitudinal modes of vibration the electromagnetic wave length corresponding to the frequency of vibration of the crystal is of the order of 110 meters per millimeter of crystal in the direction referred to, that is, either in the direction of the length of the crystal or in the direction of its thickness.

Much difficulty has been experienced in securing a crystal which would vibrate at a wave length of the order of magnitude of 5,000 to 20,000 meters, for the reason that in order to obtain a crystal which would vibrate over this range of frequencies in accordance with either its transverse or its longitudinal effect, the quartz plate must be of such large size that it is extremely difficult to secure. Also the difficulty of properly grinding such a large quartz plate to the exact dimensions required renders its use almost prohibitive. It has been suggested that in place of a large crystal having the dimensions necessary to give the lower frequencies of vibration a crystal of the usual size be employed, which crystal shall be made to actuate a large steel resonator, which in turn shall react upon another crystal, the entire system being properly designed to give the required frequencies. This method has also been found undesirable for the reason that it is extremely difficult to cement the piezo-electric crystals to the steel rod, and also for the reason that there is coupling between the two piezo-electric crystals used.

It is, therefore, an object of this invention to cause a quartz crystal of the dimensions now commonly used to vibrate at lower frequencies than either of the frequencies at which the crystal would normally vibrate in accordance with the well known transverse or longitudinal effects.

It is a further object of this invention to cause a piezo-electric crystal to vibrate flexurally.

It is a further object of this invention to provide a piezo-electric resonator which has a frequency of virbation which is a function of two of the physical dimensions of the crystal.

It is a further object of this invention to provide a method of vibrating a crystal to cause the same to become luminous on one of its edges.

It is a further object of this invention to provide a piezo-electric means to hold the frequency of an oscillation generator constant over a range of frequencies lower than the frequencies heretofore attained in a crystal controlled oscillator.

It is a further object of this invention to provide a method of vibrating a crystal at a subfundamental frequency.

These and other objects of the invention will be apparent to those skilled in the art from the following description taken in connection with the accompanying drawing in which:

Figures 1, 3 and 6 are perspective views of a quartz plate employed in this invention showing the relation of crystal and electrodes.

Figures 2 and 4 are end views of piezo-electric resonators showing the relation of the crystal and plates.

Figure 5 shows the mode of vibration of the crystal.

Figures 7 and 8 show the method of cutting the crystal.

Figures 9 to 11 inclusive are diagrammatic views showing the piezo-electric resonator connected in an oscillation circuit.

Figures 12 and 13 show a modification of the invention.

Refering in detail to the drawing a plate of quartz such as shown in Figure 1 having the length L, breadth *b* and the thickness *e* is cut from a crystal such as shown in Figure 7. As explained in the above referred article by Professor Cady there are three sets of electrical axes *xx* and *yy* for the crystal, each set being displaced 120 degrees from its preceding one and the optical axis extends at right angles to the plane of the paper upon which the Figure 7 is shown. For the purposes of the present invention most satisfactory results have been obtained when the crystal was cut as shown in Figure 7. It has been found also that a crystal cut with its length parallel to one of the faces of the native crystal, that is, with its length at an angle of 30 degrees to the length as shown in Figure 8, will exhibit the new mode of vibration although not as strongly as with a crystal shown in Figure 7. While the present disclosure refers specifically to quartz crystals it is to be understood that this invention is not limited to this particular material but since the flexural vibrations produced by utilizing the well known transverse effect in a particular and herein described manner the invention applies equally well to any of the well known piezo-electric materials which exhibit the transverse piezo-electric effect. Rochelle salt and tourmalin both exhibit this transverse piezo-electric effect as will be found by examining their piezo-electric constants in Graetz, "Handbuch der Elektrizitat und der Magnetismus," vol. 1, p. 360 et seq.

In order to cause a piezo-electric plate such as shown in Figure 1 to vibrate flexurally I apply the metallic plates or electrodes 11 and 12 to opposite sides of the crystal as shown in Figure 1. The plates may be in contact with the crystal or alternatively they may be spaced from the crystal by a very minute distance. The plates 11 and 12 are then connected into the oscillator circuit by means of leads 13 and 14. It has been found most desirable to make the plates 11 and 12 not more than half as wide as the crystal in the direction *b* (Figure 1), and of a length equal to that of the crystal. The plates are mounted with their bottom edges flush with the bottom of the crystal.

Under certain conditions it has been found advantageous to employ four electrodes as shown in Figures 3 and 4. The electrodes 11*a* and 12*a* being mounted adjacent to the upper longitudinal edges of the crystal as shown. The electrodes in this case should preferably be equal to the length of the crystal, but they may be somewhat shorter, and also each plate should preferably cover approximately one-third of the width of the crystal in the direction *b* (Figure 1). The electrodes 11 and 11*a* are joined together electrically by a jumper 15 while the electrodes 12 and 12*a* are electrically connected by a jumper 16. Leads 13 and 14 serve to connect the resonator in an oscillation circuit. With resonators such as shown in Figures 1 to 4 inclusive the following data has been determined experimentally:

A crystal having the dimensions 30 x 10 x 1 millimeters will vibrate in accordance with the transverse effect at a wave length of about 3,300 meters. The same crystal when vibrated in accordance with my invention has a frequency corresponding to about 6,000 meters.

With a crystal having the dimensions 40 x 10 x ½ millimeters a frequency of vibration in accordance with the transverse mode of vibration was found to be 4,400 meters. The same crystal when vibrated in accordance with my invention gave a frequency of 10,100 meters.

A crystal having the dimensions 37.0 x 5.1 x 2.35 millimeters vibrated at a fundamental of 4,000 meters in accordance with the transverse effect, whereas in accordance with my invention this same crystal vibrated at a wave length of 14,600 meters.

These and other experiments show that this new low frequency of vibration is doubtless a flexural vibration in the length-breadth plane (Figure 6). In accordance with the transverse and longitudinal effects described above the frequency of vibration depends essentially upon one dimension of the crystal; whereas in accordance with the present invention the frequency of vibration depends on two dimensions of the crystal, namely, the length and breadth.

The observed response frequency of the crystal agrees approximately with that calculated from the flexural theory when the length of the plate is large compared with the breadth. The formula for the frequency of a flexural vibration in a bar is:

$$1. \quad N=\frac{m^2K}{2L^2}\sqrt{q/p}$$

where N is the frequency, K the radius of gyration, L the length, q Young's modulus, p the density, and m is a constant depending upon the order of vibration. For further details see Barton's textbook on "Sound," page 281 et seq.

Now substituting in the above Equation (1) the constants for quartz, the electro-magnetic wave length corresponding to the calculated frequency becomes:

$$2. \quad \lambda = 518L^2/b$$

where λ is the electro-magnetic wave length in meters, L and b are the length and breadth of the plate respectively, in centimeters.

For a crystal 2.89 centimeters long and 0.44 centimeters wide the calculated sub-fundamental or flexural frequency in accordance with the formula 2 is 9,850 meters. The observed value was found to be 9,900.

Likewise for a crystal 1.97 centimeters long, 0.44 centimeters wide the calculated wave length for the flexural mode of vibration is 4,560 meters; while the observed value for the same crystal is 5,200 meters.

When the ratio of length to breadth of the quartz plate becomes of the order of 4 or less the observed response frequency is not in good agreement with that calculated from the flexural theory as would be expected. In such cases the following empirical formula has been found to give better agreement with the observed results:

$$\lambda = \frac{520L^{1.7}}{b^{0.57}}$$

Also I have found as would be expected from theory (Barton quoted above) that in addition to the fundamental flexural vibration frequency or the subfundamental there are other modes or orders of flexural vibration at which the quartz plate may be made to vibrate. Although these higher modes give rise to higher frequencies which are not exact multiples of the lowest flexural vibration frequency, and are not, therefore, strictly speaking overtones yet they will hereafter be referred to as overtones of the flexural vibration. As in the case of the lowest flexural vibration the overtone vibrations take place in the length-breadth plane of the crystal. For the crystal having the dimensions 2.89 centimeters x 0.44 centimeters, the first overtone was found to be 4,160 meters. The fundamental transverse and subfundamental or flexural were 3,460 meters and 9,900 respectively.

The crystal having the dimensions 1.97 centimeters x 0.44 centimeters has a fundamental frequency in accordance with the transverse effect of 2,070 meters. The sub-fundamental or flexural as given above was found to be 5,200 (observed) and 4,560 calculated. For this crystal the first overtone of the flexural or subfundamental was found to be 2,220 meters.

The first overtone of the flexural or sub-fundamental is found to be prominent only in long bars. In the case of the 1.97 centimeter bar given above the wave length of the first overtone is nearly equal to that of the fundamental transverse. If the bar were made a little shorter those two values would coincide.

In order to cause the crystal to vibrate at the first overtone of the flexural or sub-fundamental the holder shown in Figures 12 and 13 was used. The crystal was placed in the field of eight electrodes connected together as follows:

111 to 111*a*; 112 to 112*a*; 113 to 113*a*; and 114 to 114*a*. The pair 111 and 111*a* was then connected to the pair 113 and 113*a*; by means of the lead 115 while the pair 112 and 112*a* was connected to the pair 114 and 114*a* by means of the lead 116. Leads 117 and 118 were in turn connected to leads 115 and 116 and served as the terminals for the system when it was connected into an alternating current circuit. Each one of the eight electrodes was a little less than one half the length of the electrodes shown in Figures 1 and 3.

With the electrodes connected as shown in Figure 3, when the direction of the field is from left to right in the upper pair of electrodes, the direction of the field will be from right to left in the lower pair of electrodes. This reversed direction of the field between the upper and lower pairs of electrodes indicates that there is a contraction along the upper edge of the crystal when there exists an elongation along the lower edge and vice versa. This follows from the well known effects of the direction of the field upon the crystal as described by Cady, and is further evidence of the fact that the vibrations of the crystal in the length-breadth plane is of a flexural nature as illustrated in Figure 5.

The new low frequency of vibration of the crystal which may be called either a flexural vibration or subfundamental vibration, preferably the former, has associated with it all the phenomena commonly found with the other modes of vibration. For example, the "Crevasse" phenomenon described in Professor Cady's publication in the Journal of the Optical Society, vol. 10, page 475 et seq., especially Figure 2 and also described in Professor Cady's paper in the Proceedings of the Institute of Radio Engineers supra is had with full effect in connection with the vibration of the crystal in accordance with my invention. The reaction of the crystal upon an oscillation generator, whereby the frequency of the latter is held equal to the frequency at which the crystal vibrates obtains also when the crystal is vibrated in accordance with my invention. There is thus provided a means to control an oscillator at frequencies lower than was possible heretofore.

Also, the luminous phenomena discovered by Giebe and Scheibe disclosed in Elektrotechnische Zeitschrift, vol. 13, page 380 et seq., Wireless World, vol. 17, page 896, December 23, 1926, takes place with the following variation when the crystal is vibrated in accordance with my invention.

When the crystal vibrates at the transverse fundamental frequency the Giebe and Scheibe effect consists of a luminous glow in the region EFGH of Figure 6. In accordance with my invention, however, when the crystal is vibrated a luminous glow is observed only on the upper edge of the crystal in the region of *p.q* of Figure 6. This glow is for a certain range of low pressure in the form of beads or striations running on the edge of the crystal in the direction *e* of Figure 1. These beads are found to be from 1 to 1½ millimeters apart and as many as nine have been observed with certain crystals.

The pressure of the residual gas in the crystal chamber is not critical and the luminous glow may be observed over quite a range of low pressures. The luminous effects have been obtained for a range of pressures from 2 to 0.1 millimeters of mercury, and the range could be extended doubtless, by using a more powerful vacuum tube oscillator. The luminous phenomenon is observed when the oscillator is tuned to crystal frequency. The number of luminous beads or striations appearing on the edge of the crystal depends upon the gas pressure in the crystal container. I have found that as the pressure decreases the number of beads present decreases but the luminosity becomes more intense up to a certain point and then the luminosity decreases and finally disappears at a pressure of about 0.1 millimeters of mercury. A piezo-electric resonator embodying my invention may be used with any of the well known types of circuits used in connection with oscillation generators for the purpose of exciting the crystal to vibrate at the subfundamental frequency. However, I have found that most favorable results are obtained when the resonator is connected in the circuits which I am now about to describe.

Referring in detail to Figure 9 I show a three stage resistance coupled amplifier which is provided with a resonant circuit 23—24 connected in the plate circuit of the last tube. The lead 14 connected to the grid of the first tube serves as one terminal for the resonator while the lead 13 connected to the plate of the last tube serves as the other terminal. The plates 12 and 12*a* of the resonator are connected together by the jumper 16. A return circuit from the plates 12 and 12*a* to the filament circuit of the amplifier is made through the lead 17. The operation of this system is as follows:

The tubes of the amplifier are energized in the usual way and the circuit 23—24 is tuned approximately to the desired frequency whereupon, the system goes into oscillation and excites the piezo-electric crystal to vibrate at its subfundamental frequency in accordance with the principles explained above. The frequency of oscillation of this system is held substantially constant due to the reaction of the crystal upon the amplifier system.

In Figure 10 there is shown a modified form of the invention which is substantially the same as that shown in Figure 9 except that one vacuum tube is used in place of three.

Referring to Figure 11 I have shown another modification of the combined oscillation generator and piezo-electric crystal resonator. The vacuum tube 30 having the usual grid, filament and plate is provided with a resonant circuit 23—24 in its plate circuit and a coil 23*a* in the grid circuit. The plate 11 of the resonator is connected to the filament of the vacuum tube while the plate 12 is connected to the grid of the vacuum tube. The plates 11*a* and 12*a* are connected to the plates 11 and 12 respectively, by the jumpers 15 and 16 respectively, in the same way as shown in Figure 4. The coupling between the coils 23 and 23*a* is adjusted until the system goes into oscillation, whereupon the crystal resonator is excited, and vibrates at its subfundamental frequency to give the various effects described above.

While I have disclosed certain specific embodiments of the invention it is to be understood that these are merely used for the purposes of illustration and that many changes will suggest themselves readily to those skilled in the art. Therefore, I do not intend to be limited in the scope of my invention except as defined in the appended claims.

Having thus described my invention, what I claim is:

1. The method of creating a luminous glow in the edge portion of a piezo-electric plate which comprises, mounting said plate in a vacuum, and vibrating said plate flexurally by means of an alternating current field.

2. The method of creating a luminous glow in the edge portion of a piezo-electric plate which comprises, mounting said plate in a vacuum, and causing said plate to vibrate at its flexural mode.

3. The method of causing a piezo-electric body to vibrate at an overtone of its flexural mode which comprises subjecting a first edge portion of said body to an alternating current field in one direction, simultaneously

subjecting to said alternating current field in reverse direction a portion of said body adjacent to said first edge portion, simultaneously subjecting a second edge portion of said body to said field in the same direction as said last mentioned field, and simultaneously subjecting a portion adjacent to said second edge portion of said body to an alternating current field in the same direction as said first mentioned field.

4. A piezo-electric resonator comprising a body of piezo-electric material, a first pair of electrodes connected to said body on opposite sides and along an upper edge thereof, a second pair of electrodes connected to opposite sides of said body and along said upper edge thereof, a third pair of electrodes connected to opposite sides of said body and along a lower edge thereof, a fourth pair of electrodes connected to opposite sides of said body and along said lower edge thereof, and means for connecting said electrodes to an electrical circuit, whereby each electrode is of a polarity opposite to the polarity of the electrode with which it forms said pairs, and also whereby each electrode is of opposite polarity with respect to the electrode which lies adjacent to it on a given side of said body.

5. A piezo-electric resonator comprising a body of piezo-electric material having two side faces, four electrodes connected to each of said side faces, means for connecting each of said four electrodes on one side face to a separate electrode on the other side face, and means for connecting said electrodes to an electric circuit.

6. A piezo-electric resonator comprising a body of piezo-electric material having two side faces and a top and bottom edge, four pairs of electrodes connected to said body, one electrode of each of said pairs being connected to one side of said body along the top edge and the other electrode of each of said pairs being connected to the other side of said body along the bottom edge, and means for connecting said electrodes in an electrical circuit.

7. A piezo-electric resonator comprising a body of piezo-electric material having two side faces and a top and bottom edge, four pairs of electrodes connected to said body, one electrode of each of said pairs being connected to one side of said body along the top edge and the other electrode of each of said pairs being connected to the other side of said body along the bottom edge, means for connecting said electrodes in an electrical circuit, and a means to connect together every two of said electrodes which comprise said pairs.

8. A piezo-electric resonator comprising a piezo-electric body substantially in the shape of a rectangular parallelopiped, four electrodes connected respectively to each of two opposite side faces of said body, and means to connect said electrodes in an electrical circuit, whereby the polarity of each electrode on a given side of said body is opposite to the polarity of its adjacent electrode and the same polarity as that of the electrode diagonally disposed with respect thereto on the same side of said body.

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