

March 26, 1940.

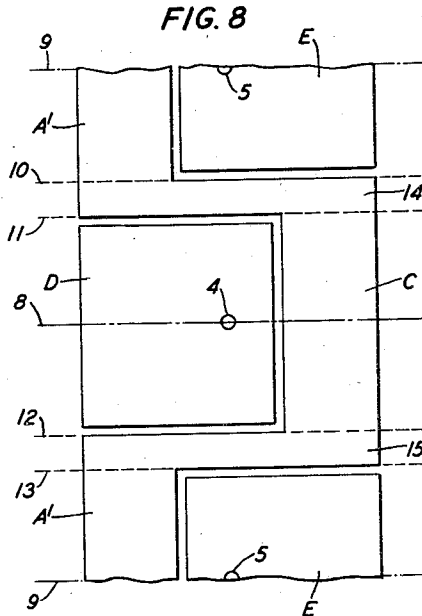
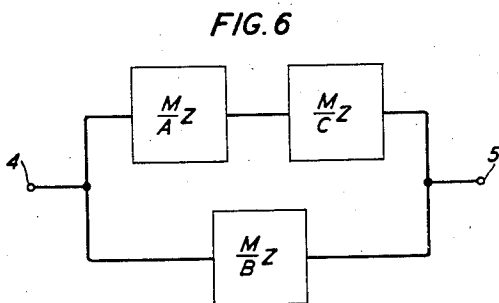
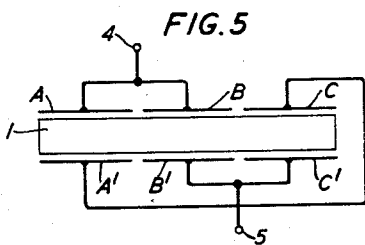
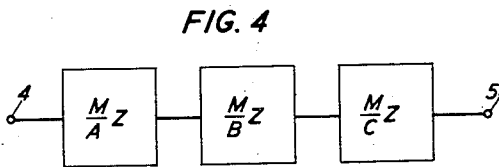
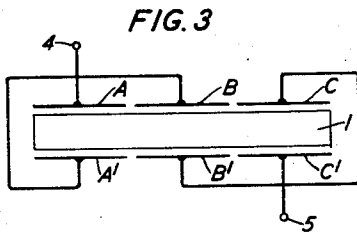
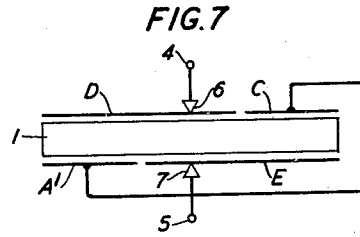
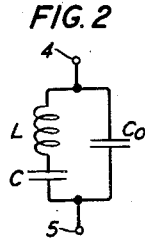
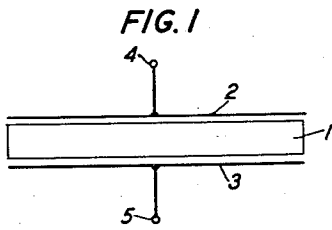
J. F. BARRY ET AL

2,194,539

PIEZOELECTRIC CRYSTAL IMPEDANCE ELEMENT

Filed Sept. 3, 1938

2 Sheets-Sheet 1



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PIEZOELECTRIC CRYSTAL IMPEDANCE ELEMENT

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FIG. 9

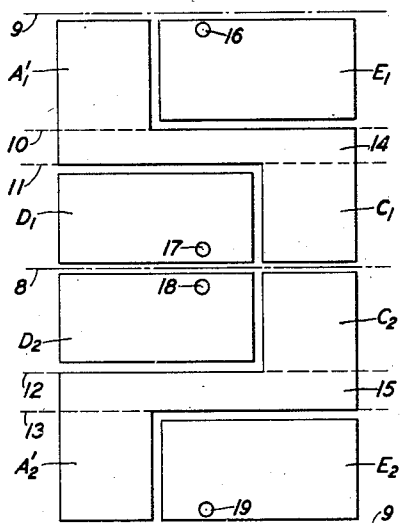


FIG. 10

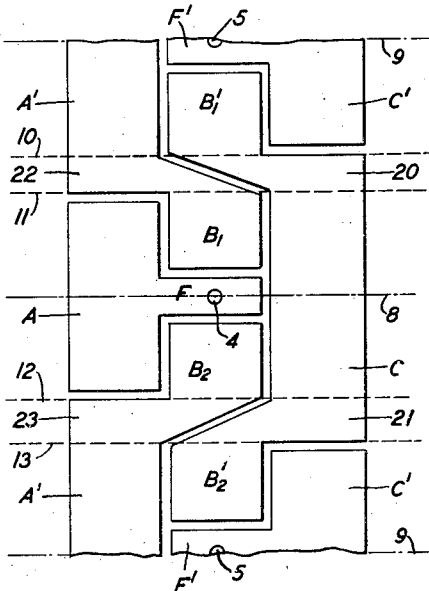


FIG. 11

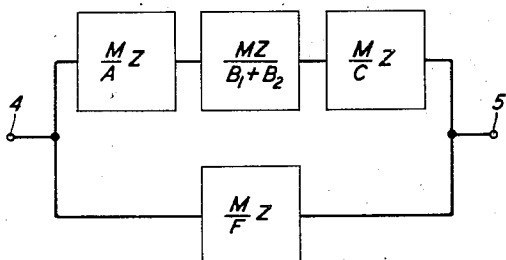


FIG. 12

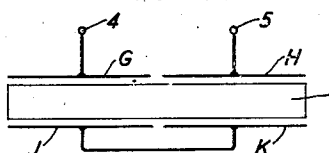


FIG. 13

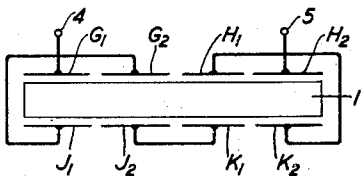
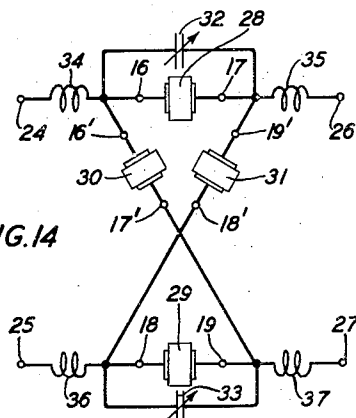


FIG. 14



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2,194,539

PIEZOELECTRIC CRYSTAL IMPEDANCE
ELEMENT

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Application September 3, 1938, Serial No. 228,355

12 Claims. (Cl. 171—327)

This invention relates to piezoelectric crystals and more particularly to crystals adapted for use as impedance elements in electrical circuits.

The principal object of the invention is to increase the impedance of a piezoelectric crystal element by any desired factor. Other objects are to reduce the required thickness and the cost of high impedance crystals.

If a piezoelectric crystal is provided with a pair of electrodes and an alternating electromotive force is impressed upon the electrodes the crystal will constitute an electrical impedance the magnitude of which at any given frequency is dependent upon the electrostatic capacitance between the electrodes and the piezoelectric and elastic constants of the crystal. In general, this impedance is directly proportional to the thickness of the crystal. In order to provide very high impedances it is found that excessively thick crystals are required. These thick crystals are comparatively expensive, due to the extra material required, and are difficult to mount satisfactorily.

In accordance with the present invention the impedance of a given crystal element is increased by any desired factor by dividing or subdividing the electrodes and interconnecting these divisions in such a way that different portions of the crystal are connected in series or in series-parallel combinations. In this way a comparatively thin crystal may be made to provide a high impedance, and the crystal may be easily mounted without resort to special arrangements. Furthermore, the magnitude of the impedance may be readily adjusted simply by changing the relative proportions of the electrodes. The invention is applicable to crystal elements of any piezoelectric material adapted to vibrate either in the flexural mode or in the longitudinal mode at the fundamental frequency or a harmonic frequency. The electrodes may be further divided so that a single crystal element will provide two impedances. By way of example a wave filter circuit is shown which employs the crystal as an impedance element.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, of which:

Fig. 1 shows a piezoelectric crystal element with its associated electrodes;

Fig. 2 represents the equivalent electrical circuit for the crystal element of Fig. 1;

Fig. 3 shows how the electrodes of Fig. 1 may be divided and portions of the crystal interconnected in series to increase the impedance;

Fig. 4 shows diagrammatically the connection of the different portions of the crystal of Fig. 3;

Fig. 5 shows a series-parallel connection for the electrodes of Fig. 3;

Fig. 6 shows diagrammatically the connection of the various portions of the crystal of Fig. 5;

Fig. 7 shows a preferred electrode arrangement when the connections are as shown in Fig. 5;

Fig. 8 shows the development of one mode of carrying out the connections of Fig. 7;

Fig. 9 shows the electrodes of Fig. 8 divided along the center line in order to provide two impedances;

Fig. 10 shows a layout for electrodes so arranged that electrical connection may be made through supports placed at a nodal point;

Fig. 11 shows diagrammatically the circuit for a crystal having the electrodes shown in Fig. 10;

Fig. 12 shows a crystal having two electrodes on each side adapted to vibrate at a harmonic frequency;

Fig. 13 shows how the electrodes of the harmonic crystal of Fig. 12 may be subdivided to increase the impedance; and

Fig. 14 shows a lattice-type wave filter which uses a high impedance crystal having divided electrodes in accordance with the invention.

Fig. 1 is an elevation of a piezoelectric crystal element 1, with its associated electrodes 2 and 3 provided with electrical terminals 4 and 5. The crystal element may be cut from any piezoelectric material such, for example, as quartz, and is preferably in the form of a rectangular plate having any desired orientation with respect to the principal axes of the mother crystal. The electrodes are associated with the two major faces and are preferably metallic coatings applied directly to the surface of the crystal.

When an alternating electromotive force is applied to the terminals 4 and 5 the crystal element will offer an impedance which may be represented by the equivalent electrical circuit of Fig. 2 comprising a capacitance C_0 shunted by a resonant arm consisting of an inductance L in series with a second capacitance C . The capacitance C_0 represents the electrostatic capacitance between the two electrodes 2, 3, and the values of L and C depend upon the piezoelectric and elastic constants of the crystal.

In accordance with the invention, the impedance of the crystal element is increased to any desired extent by dividing the electrodes and electrically interconnecting the divisions. For example, as shown in Fig. 3, the electrode 2 may be divided into three parts designated by their areas A, B and C. The other electrode 3 is divided into corresponding portions A', B' and C'. The lines of division may be either longitudinal or transverse with respect to the face of the crystal. Fig. 3, therefore, may be taken as representing

either an end or a side view of the crystal element 1. It will be found that the impedance of each portion of the crystal is equal to the impedance of the original element multiplied by the ratio of the area of the undivided electrode to the area of the particular portion of the divided electrode. Thus, if the impedance of the original element is Z and the area of the undivided electrode 2 is M the impedances of the three portions of the crystal of Fig. 3 with divided electrodes will be, respectively,

$$\frac{M}{A}Z, \frac{M}{B}Z \text{ and } \frac{M}{C}Z$$

In Fig. 3 the three portions of the crystal are connected in series and therefore the total impedance is the sum of the impedances of the various portions, as indicated diagrammatically in Fig. 4. The total impedance Z_1 is therefore

$$Z_1 = \left(\frac{M}{A} + \frac{M}{B} + \frac{M}{C} \right) Z \quad (1)$$

If the areas A , B and C are equal, each will be approximately equal to $\frac{1}{3}M$ and the total impedance will be

$$Z_1 = \left(\frac{M}{\frac{1}{3}M} + \frac{M}{\frac{1}{3}M} + \frac{M}{\frac{1}{3}M} \right) Z = 9Z \quad (2)$$

In general, if the original electrode is divided into N equal parts and all of the portions of the crystal are connected in series the total impedance will be approximately equal to N^2 . The electrode may, of course, be divided into any number of parts such as 2, 3, 4, N to give resulting impedances which are 4, 9, 16 and N^2 times the original impedance.

When the various portions of the crystal are connected in series the minimum resultant impedance is obtained when all of the electrodes are equal in area. The impedance may be further increased by making the area of one or more pairs of electrodes smaller. For example, in Fig. 3 if the area of the electrode B is made equal to $M/9$ and the areas A and C are made equal, the resulting impedance will be

$$Z_1 = \left(\frac{M}{\frac{4}{9}M} + \frac{M}{\frac{1}{9}M} + \frac{M}{\frac{4}{9}M} \right) Z = 13.5Z \quad (3)$$

On the other hand, the minimum resultant impedance may be decreased by connecting the portions of the crystal in a series-parallel arrangement, as shown in Fig. 5 where the central portion is connected in parallel with a branch consisting of the two outer portions in series. The circuit is shown diagrammatically in Fig. 6. The impedance Z_2 of this arrangement is given approximately by the expression

$$Z_2 = \frac{\frac{M}{B} \left(\frac{M}{A} + \frac{M}{C} \right) Z}{\frac{M}{A} + \frac{M}{B} + \frac{M}{C}} \quad (4)$$

If all of the areas are equal the impedance is approximately

$$Z_2 = \frac{\frac{1}{3}M \left(\frac{1}{3}M + \frac{1}{3}M \right) Z}{\frac{1}{3}M + \frac{1}{3}M + \frac{1}{3}M} = 2Z \quad (5)$$

Other values of Z_2 ranging between Z and $9Z$ may be provided by making the areas unequal. If

the areas of the two end electrodes A and C are kept equal Formula 4 simplifies to

$$Z_2 = \frac{4Z}{1 + 3 \frac{B}{M}} \quad (6)$$

In this case if the area of B is one-ninth the total area M , for example, the impedance is approximately

$$Z_2 = \frac{4Z}{1 + \frac{3}{9}} = 3Z \quad (7)$$

The exact formula for the case where the two outer electrodes are equal is

$$Z_2 = \frac{2Z}{1 + \sin \frac{\pi B}{2M}} \quad (8)$$

However, the approximate Formula 6 can safely be used in making calculations provided the ratio of B to M is small compared to unity. If this ratio is less than one-fifth, the error introduced in the calculated impedance Z_2 by the use of the approximate formula will be less than 6 per cent.

In the arrangement shown in Fig. 5 it will be noticed that the two electrodes A and B are connected together electrically, and likewise the electrodes B' and C' are connected. These electrodes may, therefore, be replaced, respectively, by single electrodes such as D and E as shown in Fig. 7. If the crystal 1 is vibrating in the longitudinal mode there will be a node of motion near the center, and the crystal is preferably supported at this point. The two supports 6 and 7, located at this nodal region, are provided for this purpose. If the supports are of conducting material the terminals may be connected thereto, as shown. Alternatively the leads to the terminals 4 and 5 may be connected directly to the electrodes D and E by means of soft solder, for example.

Fig. 8 shows the development of one mode of interconnecting the electrodes C and A' of Fig. 7. The dot-and-dash lines 8 and 9 indicate, respectively, the center line of the upper face of the crystal plate 1 and the center line of the lower face. The dotted lines 10, 11 represent one pair of edges of the crystal and the lines 12, 13 represent the opposite pair of edges. The electrodes C and A' are electrically connected by means of the strips of plating 14 and 15 which extend along the sides of the crystal.

In order to make one crystal element provide two impedances each of the electrodes may be subdivided along the center line into two equal parts as shown in Fig. 9. The electrode D is thus split into the halves D_1 and D_2 , and the electrodes A' , C and E are divided, respectively, into the parts A'_1 , A'_2 , C_1 , C_2 and E_1 , E_2 . The terminals 4, 5 are replaced by the two sets of terminals 16, 17 and 18, 19. Such a crystal may be used, for example, in a wave filter of the type shown in Fig. 14 and described hereinafter.

In the series arrangement of Fig. 3 it is seen that the terminals 4 and 5 are associated with the diagonally opposite electrodes A and C' . It is not possible, therefore, to support the crystal at a nodal point near the center and make contact through the supports with the proper electrodes. This difficulty is overcome by applying the electrodes as shown in the development of Fig. 10. On one side, the electrode B has been split along the center line into two parts B_1 , B_2 and the extension F from the electrode A inserted

between the two. Likewise, on the other side, the extension F' of the electrode C' has been inserted between the two parts B₁, B₂ of the electrode B'. The crystal may now be supported at its center and contacts made through the supports to the extensions F and F'. The electrode C is connected to the electrodes B₁ and B₂ by the side strips 20 and 21, respectively. In like manner, the electrode A' is connected to the electrodes B₁ and B₂ by the strips 22 and 23. In this case also all of the electrodes may be further subdivided along the center lines 8 and 9, in the same manner as shown in Fig. 9, to provide two impedances.

In Fig. 10 the portion of the crystal between the two overlapping electrodes F and F' is connected in parallel with an arm consisting of the other three portions of the crystal in series, as shown in Fig. 11. The values of the four component impedances are indicated in the figure and the total impedance Z₃ between terminals 4 and 5 is given approximately by the formula

$$Z_3 = \frac{\frac{M}{F} \left(\frac{M}{A} + \frac{M}{B_1+B_2} + \frac{M}{C} \right) Z}{\frac{M}{A} + \frac{M}{B_1+B_2} + \frac{M}{C} + \frac{M}{F}} \quad (9)$$

The side platings 14 and 15 in Figs. 8 and 9, and 20, 21, 22 and 23 in Fig. 10 cause a slight deviation in the measured impedance as compared with the computed value. The magnitude of this deviation depends, among other factors, upon the thickness of the crystal plate, but ordinarily does not amount to more than 6 or 7 per cent. In order to obtain more accurate impedances a suggested procedure is to make a trial division of the electrodes according to the appropriate formula. If the measured impedance is too far from the desired value the crystal is replated and the proper correction applied for a second division. When sufficient care is exercised it has been found that the desired impedance can be obtained by this method within 2 per cent or less.

The invention is also applicable to crystals which are adapted to vibrate at a harmonic frequency. For example, Fig. 12 shows a crystal element 1 with electrodes on each side divided transversely to form the equal electrodes G, H, J and K. If the electrodes J and K on the same side are connected together and an alternating electromotive force is applied at terminals 4 and 5, the crystal will vibrate at the first harmonic, which is approximately twice the fundamental frequency. Now if each electrode is further divided into the equal portions G₁, G₂, H₁, H₂, J₁, J₂ and K₁, K₂ and these are interconnected as shown in Fig. 13, the original impedance of the crystal will be increased by a factor of four. The two adjacent electrodes J₂ and K₁ may, of course, be replaced by a single electrode. Obviously other ratios of impedance may be obtained by changing the relative sizes of the electrodes, as explained above in connection with other figures. Also, each electrode may be divided into more than two parts, and these may be connected in series or in series-parallel combinations to obtain any desired impedance ratio. Furthermore, the electrodes of crystals having 3, 4 or (Q+1) pairs of electrodes and adapted to vibrate at the second, third or Qth harmonic may be subdivided in a similar manner to obtain the desired impedance.

In choosing the permissible combinations of connections for the divided electrodes it must be borne in mind that in every case the direction

of the electrostatic field through the crystal must be the same after the electrodes are divided as before division. For example, in Fig. 1 the direction of the field at any given instant is the same throughout the entire crystal, and therefore in Figs. 3, 5 and 7 the connections are so made that the field is unidirectional. In Fig. 12, however, the field in the left half of the crystal is in the opposite direction to the field in the right half, and in Fig. 13 the same relative directions are preserved in the two halves of the crystal.

Fig. 14 shows how the high impedance crystal element of the invention may be used in a wave filter. The filter is of the symmetrical lattice type and comprises two equal line impedance branches and two equal diagonal impedance branches connected between a pair of input terminals 24, 25 and a pair of output terminals 26, 27. Included in the line branches are the two equal piezoelectric crystal impedances 28, 29, and in the diagonal branches the two equal crystal impedances 30, 31. As mentioned above, the two impedances 28 and 29 may be furnished by a single crystal with the electrode layout shown in Fig. 9. The connections to the terminals 16, 17, 18 and 19 are made as shown. The other two equal impedances 30 and 31 may be supplied by individual crystal elements or by a second single crystal having electrodes as shown in Fig. 9. The terminals 16', 17', 18' and 19' correspond, respectively, to the terminals 16, 17, 18 and 19 and the connections are made as shown. The filter circuit is completed by the addition of two equal variable capacitances 32, 33 in the line branches and four equal series inductances 34, 35, 36 and 37 at the ends. If the crystal elements in the line branches and in the diagonal branches have different resonance frequencies and the other component reactance elements are properly chosen the filter may be designed to pass a band lying between two pre-assigned frequencies while attenuating other frequencies.

What is claimed is:

1. An impedance element comprising a piezoelectric crystal having two oppositely disposed electrode surfaces, a plurality of electrodes associated with one of said surfaces, a plurality of other electrodes associated with the other of said surfaces, two of said electrodes on opposite sides having overlapping portions, each of said two electrodes also being opposed to another electrode on the opposite side, means for making electrical connections to said two overlapping electrodes, and means for interconnecting the remaining electrodes.

2. An impedance element in accordance with claim 1 in which said overlapping portions of said two electrodes are located at a nodal zone of said crystal.

3. An impedance element in accordance with claim 1 in which means are provided for supporting said crystal at said overlapping portions of said two electrodes.

4. An impedance element in accordance with claim 1 in which said overlapping portions are located at a nodal zone of said crystal and means are provided for supporting said crystal at said nodal zone.

5. An impedance element in accordance with claim 1 in which said overlapping portions are located at the center of said crystal, supports of conducting material are provided for supporting said crystal at its center, and said supports serve

to make electrical contact with said overlapping portions.

6. A piezoelectric device in accordance with claim 1 in which each of said electrodes is divided along a center line of said crystal and the divisions of said electrodes are interconnected to provide two piezoelectric impedances.

7. An impedance element comprising a piezoelectric crystal having two oppositely disposed electrode surfaces, two electrodes associated with one of said surfaces, two other electrodes associated with the other of said surfaces, two of said electrodes on opposite sides having overlapping portions, each of said two electrodes also being opposed to the other electrode on the opposite side, means for making electrical connections to said two overlapping electrodes, and an electrical connection between the remaining electrodes.

8. A piezoelectric device in accordance with claim 7 in which each of said electrodes is divided along a center line of said crystal and the divisions of said electrodes are interconnected to provide two piezoelectric impedances.

9. An impedance element comprising a piezoelectric crystal having two oppositely disposed electrode surfaces, three electrodes associated with one of said surfaces, three other electrodes associated with the other of said surfaces, two of said electrodes on opposite sides having overlapping portions, each of said two electrodes also being opposed to another electrode on the op-

posite side, means for making electrical connections to said two overlapping electrodes, and means for interconnecting the remaining electrodes so that the portions of said crystal associated with said remaining electrodes are connected in series.

10. An impedance element comprising a piezoelectric crystal, a plurality of pairs of oppositely disposed electrodes associated, respectively, with a plurality of different portions of said crystal, and means for connecting one of said portions in parallel with a combination comprising a plurality of the remaining portions in series.

11. An impedance element comprising a piezoelectric crystal, three pairs of oppositely disposed electrodes associated, respectively, with three different portions of said crystal, and means for connecting one of said portions in parallel with a combination comprising the remaining portions in series.

12. A piezoelectric device comprising a piezoelectric crystal and associated electrodes so interconnected that in adjacent parts of said crystal the electrostatic field is of opposite direction whereby said crystal is adapted to vibrate at a harmonic frequency, a plurality of pairs of oppositely disposed electrodes associated with one of said parts, and means for connecting in series the portions of the crystal associated with said plurality of pairs of electrodes.

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