Jan. 13, 1948. H. F. FRUTH ET AL 2,434,266

PIEZOELECTRIC CRYSTAL UNIT

Filed July 18, 1945

FIG. 1

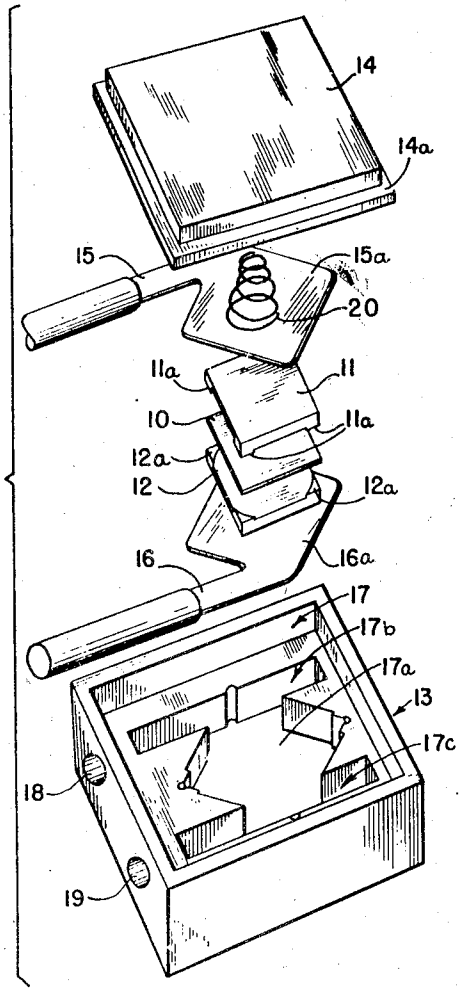


FIG. 4

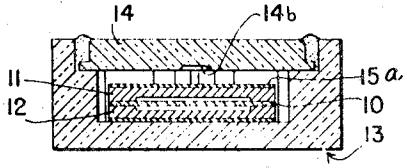


FIG. 3

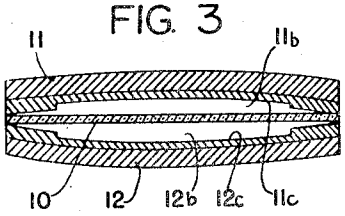
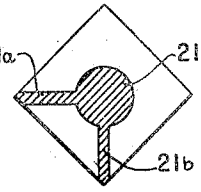


FIG. 5



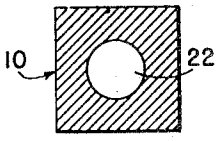


FIG. 6

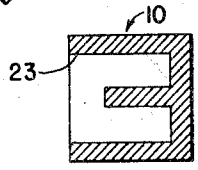


FIG. 7

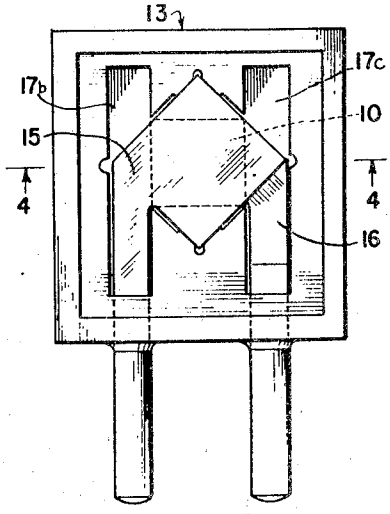


FIG. 2

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UNITED STATES PATENT OFFICE

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PIEZOELECTRIC CRYSTAL UNIT

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10 Claims. (Cl. 171—327)

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The present invention relates to piezoelectric crystal units of the character employed for frequency control purposes in high frequency circuits and more particularly to an improved holder for a piezoelectric crystal.

It is well known that the frequency of oscillation of a piezoelectric crystal changes with variations in the temperature of the crystal, occasioned by ambient temperature changes. It is also well known that the output frequency of a crystal varies with variations in the air gap spacing between the crystal faces and the associated electrodes. Various arrangements have been proposed and employed for producing a temperature controlled variation in the crystal face-crystal electrode air gap spacing in order to minimize variations in the output frequency of the crystal with ambient temperature changes. For the most part such arrangements have been used in crystal units of the so-called floating crystal type, as exemplified by Marrison Patent No. 1,785,036, granted December 16, 1930, wherein the crystal is mechanically divorced from one electrode and hence is free of vibrational restraint through the thickness thereof. This form of crystal unit, while providing for maximum activity of the crystal response, is usually somewhat unstable in operation due to the difficulty involved in maintaining the crystal properly oriented relative to its associated electrodes. On the other hand, when pressure mounting of the crystal is employed to obviate the problem of frequency instability, conventional expedients for compensating the crystal against frequency drift occasioned by ambient temperature changes can no longer be used. Another problem involved in compensating crystals against frequency drift with ambient temperature changes is that of preventing the temperature controlled variations in the crystal face-crystal electrode air gap spacing from impairing the activity of the crystal. Thus it is generally known that the activity of a crystal decreases as the spacing between the crystal and its electrodes increases, which means that under conditions of extreme temperature variations, the activity of the crystal may be seriously impaired. Moreover, in the case of certain crystals the degree of air gap change required to provide full compensation over a desired temperature range may be so small as to render conventional thermostatic strips unsuitable for use in obtaining compensation.

It is an object of the present invention, therefore, to provide an improved holder for pressure

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mounting a piezoelectric crystal and for minimizing variations in the output frequency of the crystal with ambient temperature changes.

It is another object of the invention to provide improved facilities for minimizing variations in the output frequency of a piezoelectric crystal without seriously changing the activity of the crystal.

It is a further object of the invention to provide an improved arrangement for decreasing the magnitude of frequency change which is produced in response to a given increment of electrode movement relative to the crystal face.

According to another object of the invention, an improved piezoelectric crystal holder is provided in which at least one of the electrodes acts to maintain the crystal under pressure and yet is thermally deformable to change the air gap spacing between itself and one face of the crystal and thus prevent ambient temperature changes from appreciably changing the crystal output frequency.

It is a still further object of the invention to provide an improved crystal unit which is characterized by the above-mentioned features, is of simple and compact structure, may be easily and cheaply manufactured in production quantities, and yet is completely reliable in its operation to provide precise frequency control.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which:

Fig. 1 is an explosion view illustrating the components of an improved piezoelectric crystal holder characterized by the features of the present invention;

Fig. 2 is a top view of the holder with the cover removed therefrom;

Fig. 3 is a detail view in section illustrating the mode of obtaining temperature compensation of the crystal output frequency;

Fig. 4 is a sectional view of the holder shown in Fig. 1 taken on line 4—4 of Fig. 2, assuming Fig. 2 shows a complete unit with the cover in place; and

Figs. 5, 6 and 7 illustrate various arrangements of the crystals which may be embodied in the complete crystal unit.

Referring now to the drawings and more particularly to Fig. 1 thereof, the present improved crystal holder is there illustrated in its use to sup-

port under pressure a piezoelectric quartz crystal 10 of rectangular configuration and having a thickness determined by the particular frequency at which the crystal is designed to oscillate. Along its lower face, the crystal 10 is adapted to be supported by a thermally deformable bi-metallic electrode 12 having raised corner parts or feet 12a which bear against the corner portions of the lower crystal face. This electrode, together with the crystal 10, is adapted to be received within the portion 17a of an open cavity 17 formed within an insulating housing member 13 which is preferably comprised of a suitable ceramic material. Along one edge thereof, this housing member is provided with a pair of holes 18 and 19 communicating with elongated recesses 17b and 17c within which conductive terminals 15 and 16 are respectively disposed. At their inner ends these conductors terminate in rectangular plates 15a and 16a between which the crystal and electrode assembly is insertable. Preferably, the conductors 15 and 16 are stamped out of flat conductive stock and have sufficient flexibility to permit insertion of the crystal and electrode assembly therebetween.

Along its upper face the crystal is supported by a second thermally deformable bi-metallic electrode 11. Specifically, this electrode is provided with downwardly depending corner parts or feet 11a which are coextensive with the corner parts 12a of the lower electrode 12 and bear against the corner portions of the upper crystal face. In order to urge the electrodes 11 and 12 toward each other, thereby to clamp the corner portions of the crystal 10 between the corner parts of the electrodes, a helical coil spring 20 is provided which, during the assembly of the holder, is compressed between the upper terminal plate 15a and a ceramic cover 14 which is utilized to close the open side of the housing member 13. The upper end of this spring seats in a depression 14b (see Fig. 4 of the drawings) provided at the underside of the cover in the center thereof. Thus, with the cover 14 sealed in place within the cover receiving portion of the recess 17, the spring 20 reacts between this cover and the electrode 11 to clamp the corner portions of the crystal 10 between the two electrodes.

In accordance with the present invention, conductive layers are respectively provided between a part of the movable portion of each of the electrodes 11 and 12 and the adjacent faces of the crystal to determine the degree of frequency control effected in response to given increments of movement of the electrodes relative to the crystal faces. Specifically, these conductive layers, which partially cover the opposite faces of the crystal and are respectively connected electrically to the electrodes 11 and 12, are conductive films, such, for example, as gold films, bonded to the crystal face surfaces and may be formed by conventional sputtering processes. The patterns of the conductive films may take various forms. Thus, and as shown in Fig. 5 of the drawings, the faces of the crystal may be provided with circular conductive spots 21 of appropriate diameter which are connected with the electrodes 11 and 12 by narrow strips 21a and 21b extending to two of the crystal corners to underlie the corner parts 11a and 12a of the electrodes. Alternatively, and as shown in Fig. 6 of the drawings, the conductive film may cover the entire surface of each crystal face except for a circular spot 22 of appropriate diameter located at the center of each crystal face. A still further arrangement is shown in Fig. 7 wherein the conductive films 23 are of E-shaped configuration. Regardless of the configuration of the conductive films, it will be understood that the film dimensions are properly proportioned to achieve the desired degree of frequency change in response to given increments of movement of the electrodes relative to the crystal faces.

In the assembly of the described components of the holder, the terminal conductors 15 and 16 are first inserted through the openings 18 and 19, respectively, following which the space between the conductors and the side walls of the identified holes is sealed. To this end, the inner surfaces of the holes are preferably metalized by employing a conventional silver and copper plating technique, following which the metalized surfaces are tinned to permit a soldered connection to be formed between the conductors 15 and 16 and the prepared metalized surfaces of the hole walls. With the terminal conductors 15 and 16 thus assembled with the housing member 13, the crystal 10 having the conductive films performed upon the faces thereof is matched with a set of electrodes 11 and 12 in the manner more fully described below, following which the matched crystal and electrode set is inserted between the conductor plates 15a and 16a. The spring 20 is next placed in position over the terminal plate 15a and compressed by positioning the cover 14 within the cover receiving portion of the recess 17. Here also, a sealed connection is provided between the housing member 13 and the cover 14 in order to completely seal the crystal assembly against exposure to moisture, dirt and other foreign matter. To this end the cover 14 is cut back along the top edge thereof as indicated at 14a, and the adjacent surfaces of the cover edge and housing member are metalized and tinned in the manner explained above, thereby to permit a soldered connection to be made at all points around the periphery of the cover between the cover edges and the adjacent metalized surfaces of the housing member.

From the preceding explanation, it will be apparent that the crystal 10 is positively restrained against lateral motion relative to the electrodes 11 and 12 by virtue of the spring developed clamping pressure exerted upon the corner portions thereof by the corner parts 11a and 12a of the two electrodes. Further, the configuration of the cavity portion 17a is such as to preclude any appreciable lateral movement of the crystal and electrode assembly. In this regard it will be noted that only a very small portion of the crystal face area is held under compression between the two electrodes, thus minimizing the decrease in crystal activity resulting from the restraining forces exerted through the thickness of the crystal. With this structure, and as best shown in Fig. 3 of the drawings, an air gap 12b is provided between the unmetalized portion of the upper surface of the lower electrode 12 and the lower face of the crystal. A similar air gap 11b is provided between the unmetalized portion of the lower surface of the upper electrode 11 and the upper face of the crystal. These two air gaps, due to the thermally deformable characteristics of the electrodes 11 and 12 are each variable in accordance with variations in the ambient temperature to which the holder is subjected.

In production, quartz crystals may be so cut that the output frequency of each crystal varies directly with temperature, i. e., as the crystal

temperature decreases the frequency of vibration decreases and vice versa. Another important and well known factor which appreciably affects the output frequency of a crystal unit is the mass, density and elasticity of the air between the crystal and the electrodes associated with the two faces thereof. This factor is, of course, determined by the area and length of the air gaps 11b and 12b between the crystal faces and the two electrodes, and varies with temperature. To a lesser extent, the interelectrode capacitance between the electrodes 11 and 12 affects the output frequency of the crystal, which capacitance is varied in response to expansion and contraction of the crystal through the thickness thereof in response to changing temperature of the crystal. Specifically, and for an air gap of given area, the two last-mentioned variable factors are changed to produce an increase in the output frequency of the crystal unit as the air gap length is increased. Conversely as the air gap length is decreased, a decrease in the crystal unit output frequency is produced.

The activity of a piezoelectric quartz crystal, on the other hand, decreases as the length of one or both of the air gaps is increased. This, of course, means that a change in the crystal activity is produced in response to any change in air gap length which is produced in order to maintain the output frequency of the crystal reasonably constant.

In order to reduce the variations in crystal output frequency which are produced in the above-described manner in response to ambient temperature changes, the bi-metallic thermally deformable electrodes 11 and 12 are assigned the function of varying the length of the air gaps 11b and 12b in the correct sense to compensate for the frequency drift which would otherwise be produced. To this end the high coefficient of expansion side 11c of the electrode 11 is disposed adjacent the upper crystal face and the high coefficient of expansion side of the electrode 12 is disposed adjacent the lower face of the crystal so that as the ambient temperature rises to produce a corresponding rise in the temperature of the crystal 10, the center regions of the electrodes 11 and 12 are cupped toward the adjacent crystal faces effectively to reduce the average lengths of the air gaps 11b and 12b. Conversely, as the temperature decreases, the central regions of the deformable electrodes 11 and 12 are cupped away from the adjacent crystal faces, thereby effectively to increase the average lengths of the air gaps 11b and 12b. Preferably, the electrodes are so designed that they are perfectly flat and unstressed at a normal temperature of approximately 72 degrees Fahrenheit, such that departure from this temperature value in opposite senses produces a corresponding opposite cupping of the electrodes. It will thus be apparent that as the temperature of the crystal is increased from a normal value in response to a corresponding increase in the ambient temperature, the electrodes 11 and 12 are deformed to produce a corresponding decrease in the lengths of the air gaps 11b and 12b which counteracts the frequency change which would otherwise occur. Conversely as the crystal temperature is decreased from a normal value, the electrodes 11 and 12 are deformed to change the lengths of the air gaps 11b and 12b in the correct sense to counteract the crystal output frequency change which would otherwise occur.

As indicated above, the degree of control

effected in response to any given amount of electrode distortion is determined by the proportion of each crystal face which is covered by the conductive films. Thus if the crystal faces were completely covered by the conductive films, the described temperature controlled changes in the lengths of the air gaps 11b and 12b would have negligible effect. In such case the crystal would be driven almost entirely by the conductive films by the driving voltage impressed thereon through the electrodes. In such case also, variations in the lengths of the air gaps would have negligible effect upon the crystal activity. On the other hand, when the conductive films are omitted from the structure, the described temperature controlled changes in the lengths of the air gaps have a relatively large effect in determining the output frequency of the crystal. Thus by providing the conductive films to cover only parts of the crystal faces, the degree of frequency control effected in response to given increments of electrode movement is reduced to an extent determined by the percentage of the total crystal face area which is covered. By appropriate design of the electrodes 11 and 12, in the matter of the choice of metals from which the electrodes are made and the relative thicknesses of the metals, and by appropriate selection of the portions of the crystal faces covered by the conductive films, substantially exact temperature compensation of the crystal unit against frequency drift may be obtained.

The described arrangement is very useful in temperature compensating against frequency drift those crystals which exhibit only a small tendency to change output frequency with temperature. Thus, to compensate such crystals against frequency drift, bi-metallic electrodes having substantial temperature change-deformation characteristics may be used in conjunction with crystal face conductive films of appropriate size. In this way, the necessity for using specially designed bi-metallic electrodes is obviated.

A further advantage of the described structure resides in the reduced tendency to decrease the activity of the crystal as the air gap lengths are increased. Thus, the crystal is in substantial part driven directly by the conductive films and in part through the air gap coupling between the uncovered crystal faces and the electrodes. Since the driving component produced through the action of the conductive films is independent of the air gap lengths, the activity of the crystal is not seriously reduced even though the air gaps 11b and 12b become quite long.

In the production of piezoelectric quartz crystals on a volume basis, crystals ground to the same frequency exhibit different frequency drift-temperature characteristics. Accordingly, in the manufacture of crystal units embodying the present invention on a production basis, it is preferable to classify the crystals, after the conductive films have been formed thereon, according to their frequency drift-temperature characteristics and employ correspondingly classified electrode pairs in matching the crystals and electrodes for assembly with the other components of the holder. Specifically, the crystals of a given group may have individual frequency drift - temperature characteristics conforming with greatest accuracy to any one of several arbitrarily selected empirical characteristics. Accordingly, they may be classified and separated on this empirical basis. For ease in matching the crystals with the thermally deformable electrodes, these electrodes are designed to fall in a corresponding number of classes

which provide substantially exact compensation for crystals having the several empirical frequency drift-temperature characteristics. Thus, in order to match a pair of thermally deformable electrodes with a given crystal, it is only necessary to know the particular frequency drift-temperature class in which the particular crystal belongs, in order to make a proper selection of the electrodes which will most nearly provide exact temperature compensation. By this method of crystal and electrode classification, matching of the crystals and electrodes to produce units having the desired constancy of frequency output under varying temperature conditions may be easily and rapidly accomplished.

Although the present improved holder has been described as employing two thermally deformable bi-metallic electrodes, it will be understood that if desirable or necessary only one of the electrodes 11 and 12 may be formed of bi-metallic thermally deformable material. In such case, the compensating action of the one deformable electrode is, of course, only a fraction of that obtained by using two electrodes of this character.

While there has been described what is at present considered to be the preferred embodiments of the invention, it will be understood that various modifications may be made therein which are within the true spirit and scope of the invention as defined in the appended claims.

We claim:

1. A holder for a piezoelectric crystal comprising a pair of electrodes, a piezoelectric crystal supported between said electrodes, at least a portion of one of said electrodes being movable toward and away from the other electrode to control the output frequency of the crystal, and a conductive layer at the same electrical potential as said one electrode and interposed between a part of the movable portion of said one electrode and the adjacent face of the crystal to determine the degree of frequency control effected in response to a given increment of movement of said movable electrode portion relative to said crystal.

2. A piezoelectric crystal unit comprising a pair of electrodes, a piezoelectric crystal supported between said electrodes, at least a portion of one of said electrodes being movable toward and away from the other electrode to control the output frequency of the crystal, and a conductive film at the same electrical potential as said one electrode and covering a portion of the crystal face which is opposite the movable portion of said one electrode, thereby to determine the degree of frequency control effected in response to a given increment of movement of said movable electrode portion relative to said crystal.

3. A piezoelectric crystal unit comprising a pair of electrodes, a piezoelectric crystal supported between said electrodes, at least a portion of one of said electrodes being movable toward and away from the other electrode to control the output frequency of the crystal, and a conductive film bonded to and covering a portion of the crystal face which is opposite the movable portion of said one electrode and at the same electrical potential as said movable electrode, thereby to determine the degree of frequency control effected in response to a given increment of movement of said movable electrode portion relative to said crystal.

4. A piezoelectric crystal unit comprising a pair of electrodes, a piezoelectric crystal supported between said electrodes, at least the center portion of one of said electrodes being movable toward and away from the other electrode to control the output frequency of the crystal, a conductive film spot bonded to and covering a center portion of the crystal face which is opposite a part of the movable portion of said one electrode, and a conductive strip bonded to said last-named crystal face and connecting said spot to said one electrode, thereby to render said spot effective to determine the degree of frequency control effected in response to a given increment of movement of said movable electrode relative to said crystal.

5. A holder for a piezoelectric crystal comprising a pair of electrodes, a piezoelectric crystal supported between said electrodes, at least one of said electrodes being spaced from said crystal by an air gap and being at least in part movable relative to said crystal in response to ambient temperature variations in the crystal output frequency with said ambient temperature variations, and a conductive layer at the same electrical potential as said one electrode and interposed in said air gap between a part of the movable electrode and the adjacent face of the crystal to determine the degree of frequency control effected in response to a given increment of movement of said movable electrode relative to said crystal.

6. A holder for a piezoelectric crystal comprising an electrode adapted to support one face of a crystal, a crystal associated with said electrode, a thermally deformable electrode adapted to support the other face of said crystal, said thermally deformable electrode being effective to develop a variable air gap between said other crystal face and at least a portion thereof in the correct sense to reduce variations in the output frequency of the crystal with ambient temperature changes, a conductive layer at the same electrical potential as said thermally deformable electrode and disposed in said air gap to cover a portion of said other crystal face and thus determine the degree of control of said crystal output frequency which is effected in response to a given deformation of said thermally deformable electrode, and means urging one of said electrodes toward the other, thereby to clamp said crystal between said electrodes.

7. A piezoelectric crystal unit comprising a crystal, a pair of electrodes supporting said crystal therebetween, one of said electrodes being thermally deformable to develop a variable air gap between the adjacent crystal face and at least a portion thereof in the correct sense to reduce variations in the output frequency of the crystal with ambient temperature changes, a conductive film at the same electrical potential as said one electrode and covering a portion of said crystal face, thereby to determine the degree of control of said crystal output frequency which is effected in response to a given deformation of said one electrode, and means urging one of said electrodes toward the other, thereby to clamp said crystal between said electrodes.

8. A piezoelectric crystal unit comprising a crystal, a pair of electrodes supporting said crystal therebetween, one of said electrodes being thermally deformable to develop a variable air gap between the adjacent crystal face and at least a portion thereof in the correct sense to reduce variations in the output frequency of the crystal with ambient temperature changes, a conductive film bonded to and covering a portion of said crystal face and at same electrical potential as said one electrode, thereby to determine the degree of control of said crystal output fre-

quency which is effected in response to a given deformation of said one electrode, and means urging one of said electrodes toward the other, thereby to clamp said crystal between said electrodes.

9. A piezoelectric crystal unit comprising a crystal, a pair of electrodes supporting said crystal therebetween and at least one of which is comprised of thermally deformable bi-metallic material, said one electrode being variably cupped to develop a variable air gap between the adjacent crystal face and the cupped portion thereof in response to ambient temperature changes, said cupping being in the correct sense to reduce variations in the output frequency of the crystal with ambient temperature changes, a conductive layer at the same electrical potential as said one electrode and disposed in said air gap to cover a portion of said crystal face, thereby to determine the degree of control of said crystal output frequency which is effected in response to a given amount of cupping of said one electrode, and means urging one of said electrodes toward the other, thereby to clamp said crystal between said electrodes.

10. A piezoelectric crystal unit comprising a crystal, a pair of electrodes supporting said crystal therebetween and at least one of which is

comprised of thermally deformable bi-metallic material, said one electrode being variably cupped to develop a variable air gap between the adjacent crystal face and the cupped portion thereof in response to ambient temperature changes, said cupping being in the correct sense to reduce variations in the output frequency of the crystal with ambient temperature changes, a conductive film bonded to and covering a portion of said crystal face and at the same electrical potential as said one electrode, thereby to determine the degree of control of said crystal output frequency which is effected in response to a given amount of cupping of said one electrode, and means urging one of said electrodes toward the other, thereby to clamp said crystal between said electrodes.

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