May 20, 1941. T. J. POPE 2,242,755

ACOUSTIC DEVICE

Filed Feb. 11, 1939 2 Sheets-Sheet 1

FIG. 1

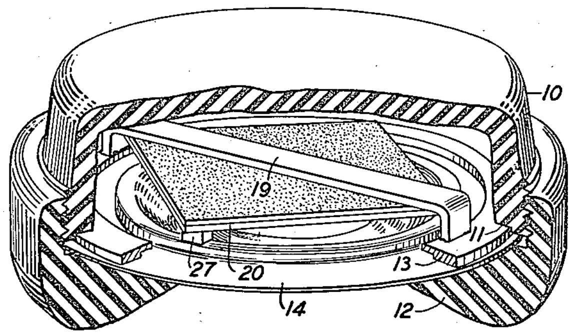



FIG. 2

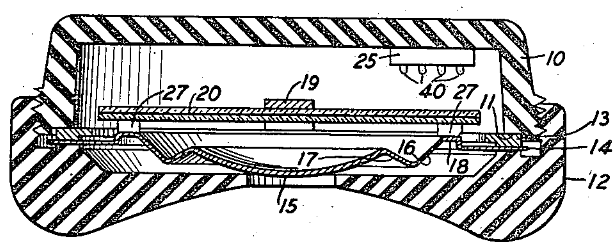



FIG. 4

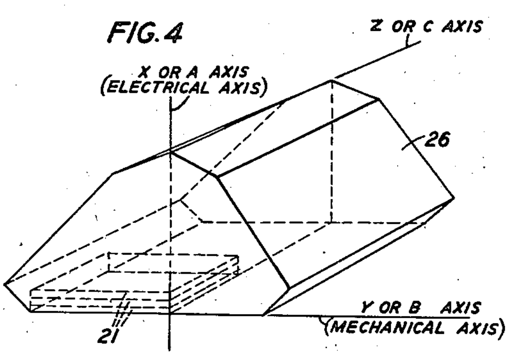
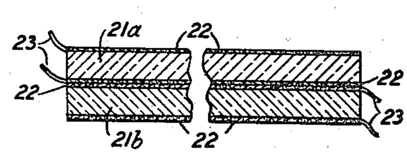



FIG. 3

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May 20, 1941. T. J. POPE 2,242,755

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Filed Feb. 11, 1939 2 Sheets-Sheet 2

FIG. 5

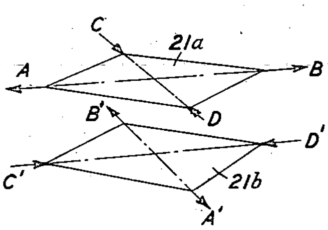



FIG. 8

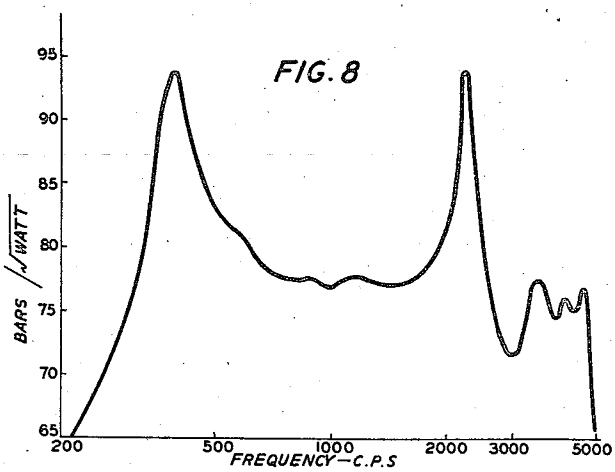



FIG. 6

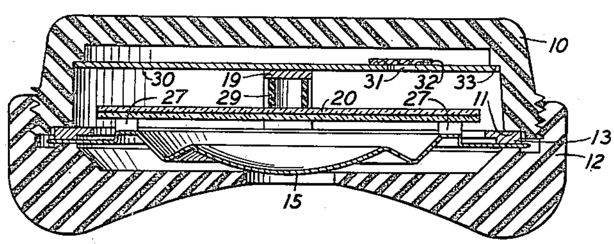
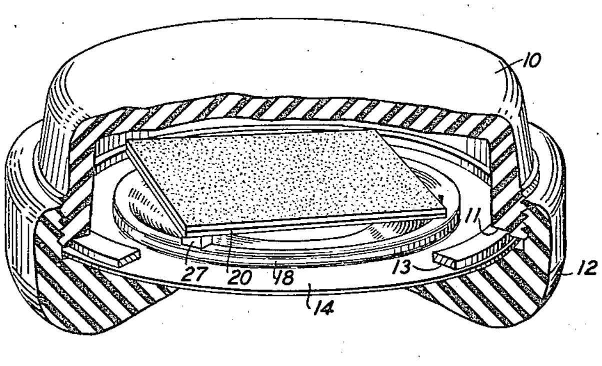



FIG. 7

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# UNITED STATES PATENT OFFICE

2,242,755

## ACOUSTIC DEVICE

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Application February 11, 1939, Serial No. 255,817

8 Claims. (Cl. 179—110)

This invention relates to acoustic devices and more particularly to telephone receivers having a diaphragm actuated by a piezoelectric element.

One object of this invention is to improve the efficiency and response characteristic of electroacoustic devices.

Another object of this invention is to simplify the structure and to reduce the weight of telephone receivers.

Still another object of this invention is to enable the use of relatively thin, large area piezoelectric crystals in electroacoustic devices whereby a small electrical impedance is obtained.

A further object of this invention is to decrease the load or impedance upon the driving point or points of a piezoelectric element in an electroacoustic device.

A still further object of this invention is to obtain a relatively simple mode of movement or vibration of a piezoelectric actuating element in telephone receivers.

In one illustrative embodiment of this invention, a telephone receiver comprises a diaphragm having a radiating portion adapted to reciprocate bodily, analogous to a piston, and a piezoelectric element for actuating the diaphragm, which element may be partially restrained or substantially unrestrained except by virtue of its connection to the diaphragm.

In accordance with one feature of this invention, the piezoelectric element comprises a pair of relatively thin rectangular crystal slabs secured together in face-to-face relation. The two crystal slabs have their axes so oriented that diagonally opposite corners of the piezoelectric element tend to move in the same direction in response to electrostatic forces produced in the crystal slabs.

In accordance with another feature of this invention, one pair of diagonally opposite corners of the composite piezoelectric element is connected to the diaphragm, for example, to diametrically opposite points of the bodily vibratile portion thereof.

In accordance with a further feature of this invention, the piezoelectric element is supported entirely or mainly by the diaphragm and all four corners thereof have freedom of movement.

The invention and the foregoing and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings wherein:

Fig. 1 is a perspective view of a piezoelectric acoustic device illustrative of one embodiment of this invention, a portion of the casing being broken away to show the internal structure;

Fig. 2 is a diametral sectional view of the device shown in Fig. 1;

Fig. 3 is a detail view in section of a composite piezoelectric element constructed in accordance with this invention;

Fig. 4 is a view in perspective illustrating one manner of obtaining crystal slabs incorporated in the device shown in Figs. 1 and 2, and illustrating also the sides of the slabs with reference to the principal axes of the mother crystal;

Fig. 5 is a diagrammatic view illustrating the axes of stress and expansion and contraction in the slabs constituting the composite piezoelectric element;

Fig. 6 is a diametral sectional view of another piezoelectric device illustrative of this invention;

Fig. 7 is a perspective view of still another illustrative embodiment of this invention, a portion of the casing being broken away to show the internal structure; and

Fig. 8 is a graph showing a typical response characteristic of a device of the construction illustrated in Fig. 7.

Referring now to the drawings, the piezoelectric device shown in Fig. 1 comprises a cup-shaped casing 10, for example, of molded insulating material, having at one end an annular internal shoulder 11 and a centrally apertured cap or ear-piece 12 threaded to the casing 10. Seated on the annular shoulder 11 is an annular support or spacer 13, which may be of metal. Seated in turn upon the spacer or support 13 and clamped thereagainst by the cap or ear-piece 12 is a diaphragm, which may be made in a single piece and preferably is of a light-weight metal such as duralumin.

As shown clearly in Fig. 2, the diaphragm comprises a flat flexible peripheral or marginal portion 14, a part of which is held between the cap or ear-piece 12 and the support or spacer 13, and a bodily vibratile portion in line with the opening in the cap or ear-piece 12. The vibratile portion includes a central dished or concavo-convex portion 15, an outer frusto-conical portion 16 and an intermediate frusto-conical portion 17. The outer frusto-conical portion 16 is integrally joined to the peripheral or marginal flange 14 by an annular portion 18, L-shaped in section. It will be understood, of course, that other forms of diaphragms may be used.

A U-shaped bracket or bridge member 19 is affixed at its ends, as by welding, to diametrically opposite areas of the support or spacer 13 and supports a composite, rectangular or square piezoelectric element designated generally as 20. As shown clearly in Figs. 2 and 3, the piezoelectric element 20 comprises a pair of crystal plates or slabs 21a and 21b, for example, 1.0 inch square and 1/64th inch thick, each crystal having upon the opposite faces thereof a coating 22 of electrically conductive material. For example, the coatings 22 may be of metal, e. g. gold evaporated upon the crystals in vacuum, or metal foil cemented to the crystal slabs, or they may be of graphite produced by applying to the slabs a colloidal graphite suspension, known commercially as Aquadag, and drying the applied suspension whereby an adherent film of graphite is obtained. The two slabs are secured together in superposed face-to-face relation, as by cement between the two inner conductive coatings 22. Each coating 22 has extending therefrom a suitable leading-in conductor 23 which may be connected to terminals 40 in an insulating block 25 affixed to or integral with the casing 10. The conductors 23 may be of metal foil suitably cemented to the crystal slabs and in intimate contact with the coatings 22.

The crystal slabs 21 may be cut from a mother crystal 26, for example of Rochelle salt, having its characteristic axes as shown in Fig. 4. As will be apparent from this figure, the faces of the crystal slabs are parallel to the Y or B and Z or C axes and normal to the X or A axis.

As is known in the art, piezoelectric crystals possess the property of expanding and contracting when subjected to electrostatic stresses and, conversely, of producing potential differences in accordance with mechanical stressing of the crystals. The crystals 21a and 21b are associated so that the axes of maximum expansion and contraction are along the diagonals of the crystal slabs, as shown by the arrows in Fig. 5, and so that each of these axes of one crystal slab is at an angle, e. g., at right angles, to the corresponding axis of the other crystal. That is to say, the crystals are so orientated that in response to an electrostatic stress produced therein, when the crystal slab 21a expands along the diagonal AB and simultaneously contracts along the diagonal CD, the crystal slab 21b will contract along the diagonal C'D' and expand along the axis A'B'.

This relationship may be obtained, for example, by applying the potentials between the outer conductive layers, connected together, and the inner conductive layers, connected together, and having the crystal slabs associated so that the Y or B and Z or C axes of one are parallel to the corresponding axis of the other. Alternatively, this relationship may be obtained by orientating the two slabs so that the Y and Z axes of one are at right angles respectively to those of the other and electrically connecting the corresponding electrodes; that is, upper and lower, on the two slabs. In this case, the upper surface of the crystal 21b must be insulated from the lower surface of the crystal 21a.

As will be apparent from Fig. 5, when the polarity of the applied potential is such as to cause expansion and contraction of the crystal slabs in the directions indicated by the arrows, the composite crystal will bend so that the corners AC' and BD' thereof move downwardly and the corners CB' and DA' move upwardly. When the polarity of the potential is reversed, the directions of expansion and contraction will be reversed so that the corners AC' and BD' of the composite crystal will move upwardly and the corners CB' and DA' will move downwardly. Hence, the composite crystal will transform potential variations, such as those corresponding to speech and music frequencies, into mechanical vibrations at the corners of the crystal. Conversely, of course, vibration of the corners of the crystal may be transformed into variable potentials.

As shown in Figs. 1 and 2, the composite crystal 20 is securely affixed, as by a suitable adhesive, along one diagonal to the bridge member or bracket 19. The corners at the ends of the other diagonal are connected to diametrically opposite points on the annular portion 18 of the diaphragm, as by balsa wood blocks 27 cemented to the crystal and the diaphragm.

It will be noted that because of the application of driving forces to two points on the diaphragm, the diaphragm impedance and the air volume stiffness into which the diaphragm works are substantially halved so that relatively thin crystals may be used. The crystals, being of large area, therefore, have a relatively small electrical impedance. The decreased load on each driving point of the crystal assures a simple mode of vibration throughout a wide band of frequencies.

Finally, it is apparent that acoustic devices constructed in accordance with this invention are quite simple structurally, easily fabricated and of light-weight.

In the embodiment of this invention, illustrated in Fig. 6, the diaphragm and crystal are the same as in Figs. 1 and 2, two diagonally opposite corners of the composite crystal 20 being connected to the diaphragm by the members 27. The crystal 20 is supported mainly by the diaphragm and only the center portion thereof is connected to the bracket or bridge member 19 by a resilient damping member 29, such as a soft rubber tube, cemented to the crystal 20 and the bridge member 19. The member 29 prevents displacement of the crystal and restrains vibration thereof as a whole. Two diagonally opposite corners of the crystal, therefore, are free and unrestrained. If desired, however, these two corners may be connected to the diaphragm by lever systems, not shown, so that they impart to the diaphragm forces in the same direction, at any instant, as the other two corners.

If desired, the response characteristic of the device may be controlled by coupling an acoustic impedance to the vibratory element. For example, as shown in Fig. 6, a plate or disc 30 having an aperture 31, or a plurality of apertures therein, the aperture or apertures being covered with an acoustic resistance material 32, such as silk, may be provided behind the crystal 20. The plate or disc 30 may be seated on an internal shoulder 33 in the casing and held thereagainst by the bracket member or bridge 19. The parameters of the disc and plate, the apertures therein and the chambers formed thereby may be made such that the acoustic impedances defined thereby alter the response characteristic of the device in any desired manner. For example, the parameters may be such that the acoustic impedances introduced into the electroacoustic system of the device suppress peaks in the response characteristics or increase the response at particular frequencies.

In the acoustic device shown in Fig. 7, which is of the inertia type, the crystal, diaphragm and casing are the same as in the embodiment shown in Figs. 1 and 2, two diagonally opposite corners of the crystal 20 being connected to diametrically opposite points on the annular portion 18 of the diaphragm by the blocks 27. However, as will be seen, the composite crystal 20 is supported solely by the diaphragm. Two diagonally opposite corners of the crystal 20 may be free as shown, or, if desired, they may be connected to the diaphragm through lever systems as described heretofore in connection with Fig. 6 so that at any instant, forces of the same direction are applied to four equally spaced points of the diaphragm.

A typical response characteristic for a receiver of the construction shown in Fig. 7 is illustrated in Fig. 8 from which it will be apparent that a high average response is obtained throughout the range of frequencies between about 400 and 2,500 cycles per second. The peaks occurring at the extremities of this frequency band may be substantially suppressed and the frequency range extended by the use of an acoustic impedance system as shown in Fig. 6 and described heretofore. Alternatively, these peaks may be compensated for by appropriate design of the electrical system connected to the piezoelectric device.

It will be understood, of course, that an acoustic impedance system may be utilized also in the construction shown in Figs. 1 and 2 and that the output of a system including devices of the construction shown in Figs. 1 and 2 and Fig. 6 may be controlled by design of the electrical system connected to the piezoelectric device.

It will be understood also that although several specific embodiments of this invention have been shown and described, various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. A piezoelectric device comprising a vibratory member, a piezoelectric element including a pair of piezoelectric crystals secured together in face-to-face relation and having their axes orientated so that diagonally opposite points of said element move in the same direction in response to electrostatic forces produced therein, two diagonally opposite points of said element being connected to said vibratory member, and means fixing said element against deflection along a line passing through two other diagonally opposite corners.

2. An acoustic device comprising a diaphragm, a composite piezoelectric element including a pair of crystal plates secured together in face-to-face relation, said plates being orientated so that each of the Y and Z axes of one is parallel to the corresponding axis of the other, means connecting two points on an axis of contraction and expansion of said element to said diaphragm, and rigid means affixed to said element along the other axis of expansion and contraction thereof.

3. A piezoelectric device comprising a composite piezoelectric element including two substantially square crystal plates secured together in face-to-face relation, each of the axes of expansion and contraction of one plate being at right angles to the corresponding axis of the other, a vibratory member connected to one pair of diagonally opposite corners of said piezoelectric element, and a rigid member fixing said element against deflection along a line passing through the other pair of diagonally opposite corners thereof.

4. An acoustic device comprising a diaphragm having a rigid central portion, a substantially square composite piezoelectric element coaxial with said diaphragm, said element including a pair of substantially square Rochelle salt slabs secured together in face-to-face relation with their electrical axes coincident and having diagonal axes of expansion and contraction, each of the axes of expansion and contraction of one being at right angles to the corresponding axis of the other, means connecting two diagonally opposite corners of said element to diametrically opposite points at the margin of said rigid central portion, and means constraining the central portion of said element against movement.

5. A piezoelectric device comprising a rectangular composite element including a pair of piezoelectric plates secured together in face-to-face relation and having their characteristic axes orientated so that diagonally opposite corners of said element move in the same directions in response to electrical potentials impressed upon said element, means rigidly fixing said element along a line connecting one pair of diagonally opposite corners of said element, a vibratory member having a bodily vibratile portion overlying said element, and means extending normal to one surface of said element and connecting spaced points of said portion to the other pair of diagonally opposite corners of said element.

6. An acoustic device comprising a composite piezoelectric element including a pair of crystal plates secured together in face-to-face relation and orientated so that the corresponding axes of expansion and contraction of said plates are at right angles to each other, rigid means extending along one of the axes of expansion and contraction of one of said plates and affixed to said one plate along said one axis thereof, and vibratory means connected to spaced points on the axis of said element normal to said one axis of expansion and contraction.

7. An acoustic device comprising a support, a diaphragm having a portion seated on said support and a central vibratile portion, a bridge member carried by said support, a piezoelectric plate supported by said bridge member and fixed thereto along one of its axes of expansion and contraction, and means connecting spaced points of said plate to said vibratile portion.

8. An acoustic device comprising a support, a diaphragm having a central vibratile portion, an outer supporting portion seated on said support and an intermediate portion, a bridge member affixed to said support, a piezoelectric element including a pair of crystal slabs secured together in face-to-face relation with the Y and Z axes of one each parallel to the corresponding axis of the other, whereby the axes of deflection of said element are at right angles to each other, said bridge member being secured to said element along one axis of deflection thereof, and means connecting spaced points on the other axis of deflection of said element to diametrically opposite points of said intermediate portion.

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