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## BENDER TYPE PIEZOELECTRIC TRANSDUCER

Filed June 20, 1955

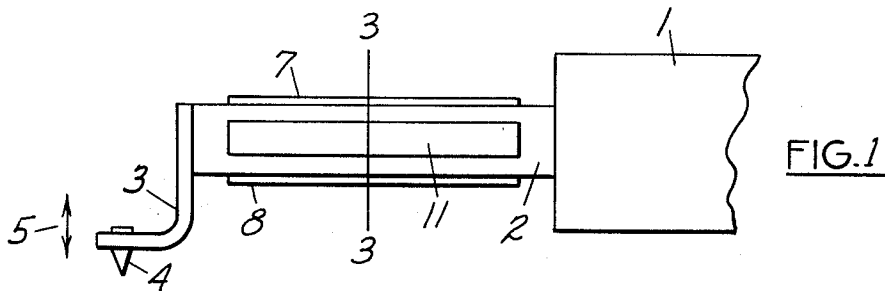


FIG.1

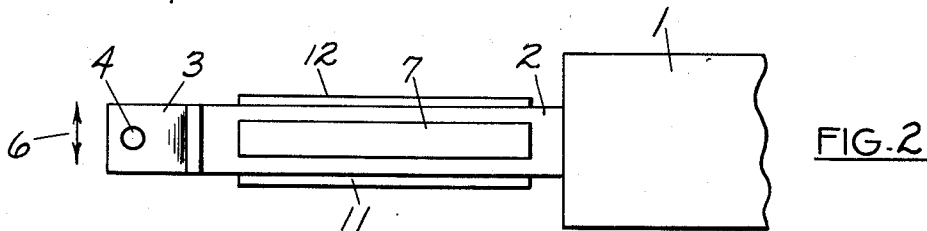


FIG. 2

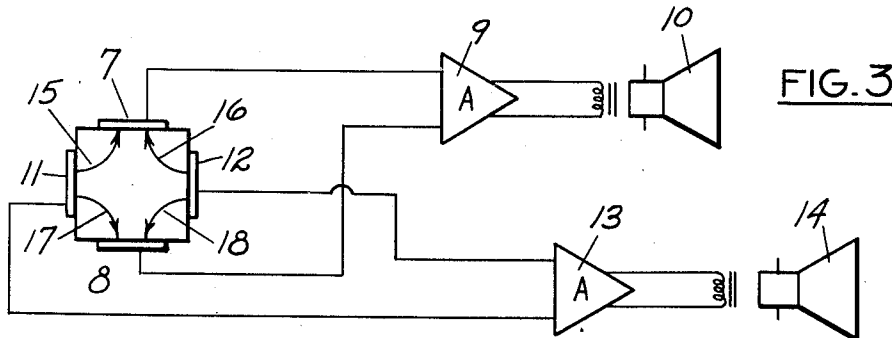


FIG. 3

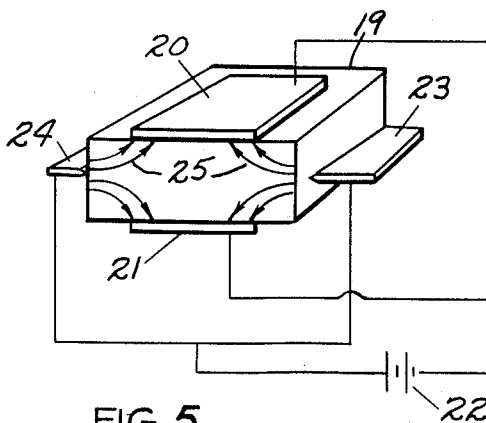


**FIG. 5**

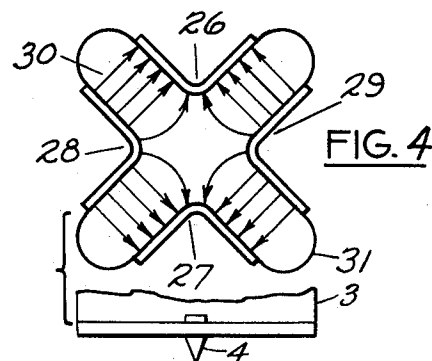


FIG. 4

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## BENDER TYPE PIEZOELECTRIC TRANSDUCER

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This invention is a piezoelectric transducer which produces from a solid body of polarizable ferro-electric ceramic the response heretofore obtained from a bimorph made from two oppositely poled bodies fixed together. By having take-off electrodes at right angles to each other and to the direction of polarization, the transducer can be responded independently to motions at right angles to each other such as lateral and up and down motion. One use is in a binaural record player where a single sound groove having both lateral and up and down formations can reproduce binaural sound effects.

The effects are obtained by polarizing the ceramic body along lines of electrostatic force which do not extend directly between opposite electrodes. For example, in a four electrode body having two pairs of electrodes at right angles to each other, the polarizing would be along lines of force extending between any two adjacent electrodes but not between any pair of electrodes.

In the drawing, Fig. 1 is a side elevation of a tone arm and phonograph pick-up for a binaural record player; Fig. 2 is a top view; Fig. 3 is a circuit diagram of the binaural record player; Fig. 4 is a cross-section of a modified form of transducer element showing a possible orientation and position of the needle relative to the transducer element, and Fig. 5 is a diagram showing the method of polarizing and a still further form of transducer element.

In Figs. 1 and 2 of the drawing, there is diagrammatically shown tone arm 1 fixed at one end to a square piezoelectric ceramic bar 2. The other end of the ceramic bar is fixed to a holder 3 for a phonograph needle 4. When the needle 4 tracks in a sound groove having hill and dale formation, the needle moves in the direction of arrow 5 causing the ceramic bar 2 to bend in a vertical plane relative to the tone arm 1. When the needle 4 tracks in a sound groove having lateral formation, the needle moves in the direction of the arrow 6 and causes the ceramic bar to bend relative to the tone arm 1 in a lateral direction. Since a record groove can contain both hill and dale and lateral formations, the pick-up is adapted to binaural record players where the hill and dale formation in the sound groove is obtained from one of two binaural microphones while the lateral formation in the same sound groove is obtained from the other of two binaural microphones.

In order to obtain the binaural effect, the ceramic bar is provided with upper and lower take-off electrodes 7 and 8 across which appears the output due to the up and down motion of the phonograph needle 4. This output is fed through an amplifier 9 to a speaker 10. The lateral motion of the phonograph needle 4 produces an output which appears across electrodes 11 and 12 on opposite sides of the ceramic bar which output is fed through an amplifier 13 to a speaker 14. The separate speakers 10 and 14, when spaced apart, reproduce the binaural sound resulting from the separate lateral and hill and dale formations in the sound groove of the record.

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In order to obtain the response described above, the ceramic bar must be one of the piezoelectric or ferro-electric ceramics which are polarizable by a unidirectional electrostatic field. One of such ceramics is barium titanate. Other ceramics are known which can be polarized in the same manner as barium titanate. Referring specifically to the upper and lower electrodes 7 and 8 as the needle 4 moves up and down in the direction of the arrow 5, the ceramic bar 2 acts as a cantilever beam having tension stresses along one side and compression stresses along the opposite side. Accordingly, if a piezoelectric response is to be obtained, the polarization of the ceramic adjacent the electrode 7 should be opposite the polarization of the ceramic adjacent the electrode 8. Then tension stress adjacent the electrode 7 will produce the same response as the compression stress adjacent the electrode 8. If the polarization adjacent the electrodes 7 and 8 were in the same direction, then the voltage generated by the tension stress at the electrode 7 would be equal and opposite to the voltage generated by the compression stress adjacent the electrode 8 and the two voltages would cancel out. This would result in no net piezoelectric output. Because of the requirement of opposite polarization, bender type piezoelectric elements have heretofore been made by sandwiching together two oppositely poled bodies.

As diagrammatically shown in Fig. 3 and also in Fig. 5, in the present invention the opposite polarization is obtained in a solid ceramic body by connecting the polarizing voltage between adjacent electrodes. This produces lines of electrostatic flux 15 and 16 extending respectively from the electrodes 11 and 12 to the electrode 7 and symmetrical lines of electrostatic flux 17 and 18 extending respectively from the electrodes 11 and 12 to the electrode 8. It will be noted that the direction of polarization indicated by the arrows on the electrostatic flux lines 15 to 18 inclusive is opposite at the electrodes 7 and 8 and is likewise opposite at the electrodes 11 and 12. Accordingly, in the region of greatest stress, namely, adjacent the electrodes 8, 7, 11 and 12 the polarization is in the proper direction for a response due to bending. Furthermore, it will be noted that because the electrodes 7, 8 and 11, 12 are at right angles to each other, the up and down movement of the needle produces an output only at the electrodes 7 and 8 while the lateral movement of the needle produces an output only at the electrodes 11 and 12. Applicant, accordingly, produces in a solid ceramic body a piezoelectric device having independent response to bending motions at right angles to each other.

The method of polarizing is illustrated in Fig. 5 where there is a ceramic bar 19 of rectangular section having electrodes 20 and 21 on its upper and lower faces. In order to polarize this bar so that it will respond to bending in a direction normal to electrodes 20 and 21, the electrodes 20 and 21 are connected to one side of a source 22 of polarizing voltage while metal electrodes 23 and 24 which may be knife edges at opposite sides of the ceramic bar and midway between the electrodes 20 and 21 are connected to the opposite terminal of the source 22 of polarizing voltage. With this connection there results the electrostatic field indicated generally by the arrows 25 which extend in opposite directions toward the electrodes 20 and 21 and accordingly produce the proper polarization for response due to bending.

With the rectangular shape shown in Fig. 5, the intensity of the electrostatic field is less midway between the electrodes 20 and 21 than it is at the edges. Accordingly, the polarization toward the center of the electrodes 20 and 21 will be less than at the edges and the output will be somewhat less than with uniform intensity of polarization.

In Fig. 4 is shown another shape of ceramic bar which will produce greater output than the square or rectangular shapes illustrated in Figs. 3 and 5. This bar is of cross-shape section with electrodes 26 and 27 on the upper and lower angular faces and electrodes 28 and 29 on the side faces. For polarization, the upper and lower electrodes 26 and 27 are connected to one side of the polarizing voltage and electrodes 28 and 29 are connected to the opposite side of the polarizing voltage. This produces the electrostatic field indicated by the arrows 30 which it will be noted extends at right angles to the electrodes and in opposite directions for any pair of opposite electrodes. Accordingly, when the Fig. 4 ceramic bar is substituted in the tone arm of Figs. 1 and 2, up and down movement causes a response to appear at electrodes 26 and 27, while the lateral movement causes the response to appear at electrodes 28 and 29. Because the polarization is primarily on opposite sides of the arms 31 of the cross-shaped bar, the electrical capacity between the electrodes can be high and the polarization intensity can be uniform. From one aspect, the cross-shaped section of Fig. 4 makes the polarization between any two adjacent electrodes more uniform and cuts down the size of the dead space at the center of the body in which there is a less intense or perhaps even an entire lack of polarization.

The Fig. 4 body may be described as having a center section with a pair of longitudinally extending flanges at the top and another pair of longitudinally extending flanges at the bottom and with the flanges of each pair projecting on opposite sides of the vertical center line of the center section of the body.

In each of the transducers, the area of each of the upper and lower and side faces of the ceramic body is large relative to the cross sectional area of the body transverse to the length of the body.

What is claimed as new is:

1. A bender type piezoelectric transducer comprising an elongated body of polarized ferro-electric ceramic, said body having upper and lower exterior faces and opposite exterior side faces connecting the opposite edges of the upper and lower faces and each of the faces being of area large compared to the cross sectional area of the body transverse to the length of the body, a pair of longitudinally extending take-off electrodes, one on each of the upper and lower faces, said body being polarized by an electrostatic field applied along the length of the body to at least one of said exterior side faces and diverging from between said one exterior side face to the conducting electrodes, and means supporting the body at one end for bending about an axis perpendicular to the length of the body and between the upper and lower electrodes.

2. A bender type piezoelectric transducer comprising an elongated body of polarized ferro-electric ceramic, said body having a center section with a pair of longitudinally extending flanges at the top and another pair of longitudinally extending flanges at the bottom and with the flanges of each pair projecting on opposite sides of the vertical center line of the center section of the body, the body having a pair of upper and lower surfaces including the upper and lower faces of the flanges and a pair of opposite side surfaces between said upper and lower surfaces and including faces of the flanges on the sides of the flanges respectively opposite said upper and lower faces of the flanges, a pair of longitudinally extending take-off electrodes, one on each of the upper and lower faces, and said body being polarized by an electrostatic field applied along the length of the body and diverging from between said opposite side surfaces to the electrodes on the upper and lower surfaces.

3. The transducer of claim 2 in which a longitudinally extending conducting electrode is applied to each of the opposite side surfaces and the body is polarized by an electrostatic field applied from the electrodes on said

side surfaces to the electrodes on the upper and lower surfaces.

4. A bender type piezoelectric transducer comprising an elongated body of polarized ferro-electric ceramic, said body having upper and lower faces and opposite side faces connecting the opposite longitudinal edges of the upper and lower faces, a pair of longitudinally extending electrodes, one on each of the upper and lower faces of said body, and said body being polarized by an electrostatic field applied along the length of the body and diverging from said opposite side faces of said body to the electrodes on the upper and lower faces.

5. The transducer of claim 4 in which a longitudinally extending conducting electrode is applied to each of the opposite side faces of the body and the body is polarized by an electrostatic field applied from the electrodes on said side faces to the electrodes on the upper and lower faces.

6. A binaural pickup having a needle capable of simultaneously following two record formations substantially at right angles to each other and producing corresponding motions substantially at right angles to each other, a bender type piezoelectric transducer comprising an elongated bar of polarized ferroelectric ceramic symmetrical about two neutral axes substantially at right angles to each other, means supporting one end of the bar, means coupling the other end of the bar to the needle in such orientation that the needle motion corresponding to one of the record formations bends the bar about one of said neutral axes and the needle motion corresponding to the other of the record formations bends the bar about the other of said neutral axes, a plurality of longitudinally extending electrodes on the bar grouped in two pairs with the respective pairs centered on axes at right angles to each other, said bar being polarized to produce an output in one pair of electrodes in response to bending of the bar by the needle motion corresponding to one of the record formations, and said bar being polarized to produce an output in the other pair of electrodes corresponding to bending of the bar by the needle motion corresponding to the other of the record formations.

7. A transducer having independent response to bending motions substantially at right angles to each other comprising an elongated bar of polarized ferro-electric material, said bar having a pair of opposite surfaces transverse to one of the motions of response and another pair of opposite surfaces substantially normal to the first pair and transverse to the other motion of response and connecting the longitudinal edges of the first pair of surfaces, and each of the surfaces of each pair being of area large compared to the cross sectional area of the bar transverse to the length of the bar, a pair of electrodes respectively on a surface of the pair normal to said one direction of response for receiving the output from bending in said one direction, another pair of electrodes respectively on a surface of the pair normal to said other direction of response for receiving the output from bending in said other direction, and said bar being polarized by a voltage from one pair of electrodes to the other pair of electrodes.

8. A phonograph pickup comprising an elongated unitary bar of polarized ferro-electric ceramic, means supporting the bar at one end, a needle coupled to the other end of the bar, said bar having a center section with two pairs of longitudinally extending integral flanges projecting from the center section, one pair of flanges being on one side of a longitudinal center line of the body and the other pair being on the other side of said center line, said bar being oriented with the flanges transverse to a component of movement of the needle whereby the bar and its flanges are bent in a direction transverse to the flanges by such movement, and a pair of take-off electrodes respectively on the outer surfaces of each pair of said flanges, said bar being

polarized in one direction at one of said electrodes and in the opposite direction at the other of said electrodes.

9. A phonograph pickup comprising an elongated unitary bar of polarized ferro-electric ceramic, means supporting the bar at one end, a needle coupled to the other end of the bar, said bar having a center section with four substantially symmetrical angularly spaced longitudinally extending integral flanges projecting therefrom, said bar being oriented with the flanges transverse to a component of movement of the needle whereby the bar and its flanges are bent in a direction transverse to the flanges by such movement, and a pair of take-off electrodes respectively on the outer surfaces of said flanges, said bar being polarized in one direction at one of said electrodes and in the opposite direction at the other of said electrodes.

10. A transducer comprising an elongated bar of polarized ferroelectric ceramic, said bar having a center section with four substantially symmetrical angularly spaced longitudinally extending integral flanges projecting therefrom, said bar being symmetrical about each of two neutral axes passing through the bar substantially at right angles to each other and to the longitudinal axis of the bar, four electrodes each arranged between two adjacent flanges, and said bar being polarized in one direction at one electrode and in the opposite direction at the two electrodes adjacent said one electrode.

11. A transducer comprising an elongated bar of polarized ferroelectric ceramic, said bar having a center section with four substantially symmetrical angularly spaced longitudinally extending integral flanges projecting therefrom, said bar being symmetrical about each of two neutral axes passing through the bar substantially at right angles to each other and to the longitudinal axis of the bar, four angularly spaced electrodes comprising two pairs with the electrodes in each pair on opposite sides of said bar, said bar being polarized in one direction at one electrode and in the opposite direction at the two electrodes adjacent said one electrode.

12. A transducer having independent response to bending motions about two neutral axes substantially at right angles to each other comprising an elongated unitary body of ferro-electric ceramic of the type polarizable by an electrostatic field and with both of said axes passing through said body and said body being symmetrical about both of said axes, take-off electrodes on said body disposed on opposite sides of each of said axes, said body being polarized transverse to said electrodes and in opposite directions on opposite sides of each of said axes.

13. A phonograph pickup comprising an elongated unitary bar of polarized ferro-electric ceramic, means supporting the bar at one end, a needle coupled to the other end of the bar, said bar having a center section with two pairs of longitudinally extending integral flanges projecting from the center section, one pair of flanges being on one side of a longitudinal center line of the body and the other pair being on the other side of said center line, and a pair of take-off electrodes respectively on the surfaces between the flanges of each pair of said flanges, said bar being polarized in one direction at one of said electrodes and in the opposite direction at the other of said electrodes.

14. A phonograph pickup comprising an elongated unitary bar of polarized ferro-electric ceramic, means supporting the bar at one end, a needle coupled to the other end of the bar, said bar having a center section with four symmetrical angularly spaced longitudinally extending integral flanges projecting therefrom, and four electrodes, each electrode lying on the adjacent surface of two flanges, and said electrodes being symmetrically disposed with respect to two axes substantially at right angles to each other and passing between pairs of electrodes, and said bar being polarized transverse to elec-

trodes on opposite sides of said axes in the sense to develop voltage by bending about each of said axes.

15. A binaural pickup having a needle capable of simultaneously following record groove formations producing motions substantially at right angles to each other, a bender type piezoelectric transducer comprising an elongated bar of polarized ferro-electric ceramic, said bar having a center section with a pair of longitudinally extending flanges at the top spaced substantially 90 degrees apart and another pair of longitudinally extending flanges at the bottom spaced substantially 90 degrees apart and with the flanges of each pair projecting on opposite sides of the vertical center line of the center section of the bar, the bar having a pair of upper and lower surfaces including the upper and lower faces of the flanges and a pair of opposite side surfaces between said upper and lower surfaces and including faces of the flanges on the sides of the flanges respectively opposite said upper and lower faces of the flanges, said bar being supported at one end and coupled at the other end to the needle with the upper and lower surfaces centered on an axis normal to the record groove, one pair of electrodes respectively on the upper and lower surfaces, another pair of electrodes respectively on the side surfaces, and said bar being polarized by a voltage from said one pair of electrodes to said other pair of electrodes.

16. A transducer comprising an elongated bar of polarized ferroelectric ceramic, said bar being symmetrical about each of two neutral axes passing through the bar substantially at right angles to each other and to the longitudinal axis of the bar, four electrodes symmetrically disposed on the bar, and said bar being polarized in one direction at one electrode and in the opposite direction at the two electrodes adjacent said one electrode.

17. A transducer comprising an elongated bar of polarized ferroelectric ceramic, said bar being symmetrical about each of two neutral axes passing through the bar substantially at right angles to each other and to the longitudinal axis of the bar, a plurality of angularly spaced electrodes on the bar arranged in two pairs with each pair symmetrically disposed about a different one of said neutral axes, said bar being polarized in one direction at one electrode and in the opposite direction at the two electrodes adjacent said one electrode.

18. A phonograph pickup comprising an elongated unitary bar of polarized ferroelectric ceramic, means supporting the bar at one end, a needle coupled to the other end of the bar, said bar having a center section with four substantially symmetrical angularly spaced longitudinally extending integral flanges projecting therefrom, said bar being oriented so that at least two of the flanges are on opposite sides of the axis about which said bar is bent by a component of movement of the needle, and a pair of take off electrodes on at least one of said two flanges, said bar being polarized in one direction at one of said electrodes and in the opposite direction at the other of said electrodes.

19. A phonograph pickup comprising an elongated unitary bar of polarized ferroelectric ceramic, means supporting the bar at one end, a needle coupled to the other end of the bar, said bar having a center section and four electrodes, said electrodes being symmetrically disposed with respect to two axes substantially at right angles to each other and passing between pairs of electrodes, and said bar being polarized transverse to electrodes on opposite sides of said axes in the sense to develop voltage by bending about each of said axes.

20. A piezoelectric transducer for producing an output in response to bending about each of two axes intersecting each other and normal to a longitudinal axis comprising an elongated unitary body of ferroelectric ceramic of the type polarizable by an electrostatic field and of a shape symmetrical about two neutral axes intersecting each other and normal to the longitudinal axis of said body, said body having a pair of exterior faces respec-

tively spaced on one and the opposite side of one of said neutral axes and having a pair of exterior side faces respectively connecting opposite edges of the first pair of faces, at least two longitudinally extending conducting electrodes on said body, one electrode being on one face of the first pair of faces and the other electrode being on the other face of the first pair of faces, and said body being polarized by an electrostatic field applied from at least one of said side faces to the conducting electrodes, said field being of one polarity at said one of the side faces and of the opposite polarity at said conducting electrodes.

21. A transducer as claimed in claim 20 in which the body has flanges symmetrically disposed on opposite sides of the axes of bending and the polarization is transverse to said flanges.

22. A transducer as claimed in claim 20 in which, in addition, a longitudinally extending conducting electrode is applied to at least one of the opposite side faces and the body is polarized by an electrostatic field applied from at least one of the electrodes on said side faces to the other electrodes.

23. A transducer as claimed in claim 22 in which the body has four longitudinally extending flanges and the electrodes are arranged on the surfaces between adjacent flanges.

24. A transducer as claimed in claim 23 in which the flanges are symmetrically disposed to provide a body of cross shaped transverse cross section.

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