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[15] **3,671,784**

[45] **June 20, 1972**

[54] PIEZO-ELECTRIC TRANSDUCERS HAVING VARIABLE SENSITIVITY BETWEEN THE BOUNDARIES OF THE PIEZO-ELECTRIC CRYSTAL

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[73] Assignee: **U.S. Philips Corporation**

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[30] **Foreign Application Priority Data**

July 29, 1969 Great Britain 38,052/69

[52] **U.S. Cl.** ....**310/9.5,** 29/25.35, 333/30 R
[51] **Int. Cl.** **H01v 7/02,** H04r 17/00
[58] **Field of Search**....................310/8, 8.9, 9.5; 333/30 R, 333/72; 29/25.35

[56] **References Cited**

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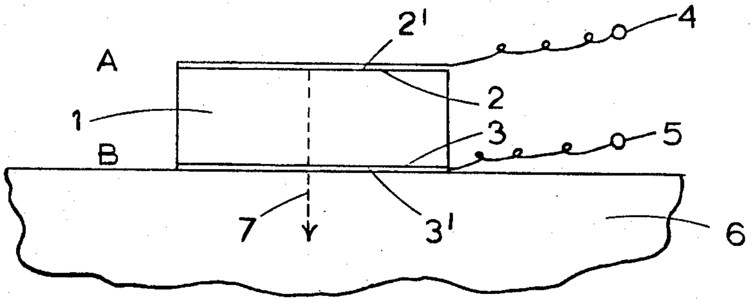
Primary Examiner—J. D. Miller
Assistant Examiner—Mark O. Budd
Attorney—Frank R. Trifari

[57] ABSTRACT

An acoustical transducer having an improved electrical impedance at the lower end of the useful acoustical passband comprises a body of material in which a stress is produced by the application of a magnetic or electrical field. The body of material has a first boundary substantially free of acoustical boundary, a second boundary acoustically matched to an acoustic wave transmission media and means for producing an electrical field stress in the material which will propagate from the first boundary to the second boundary with the stress decreasing in a substantially continuous manner along the propagation direction.

7 Claims, 9 Drawing Figures



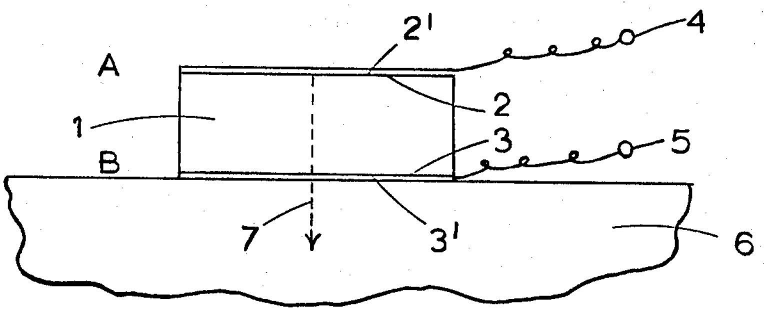


FIG. 1.

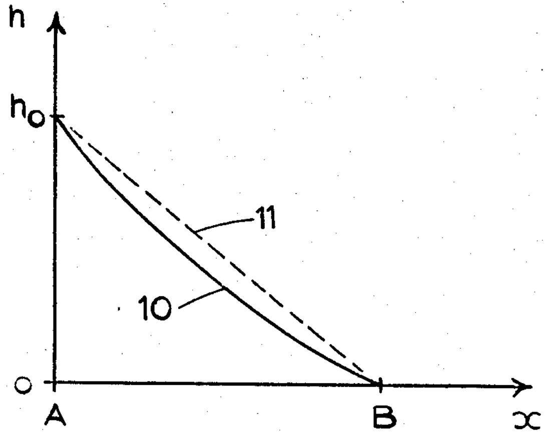


FIG. 2.

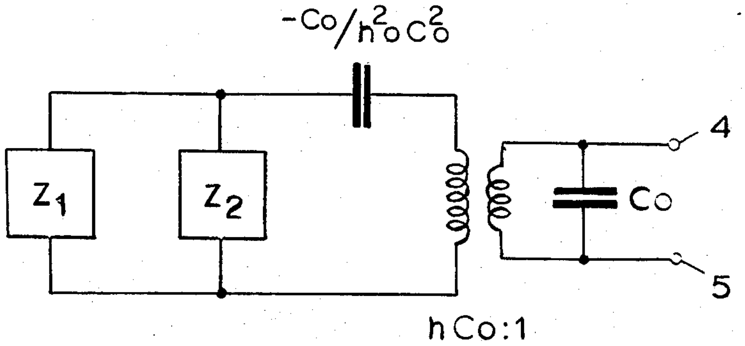


FIG. 3.

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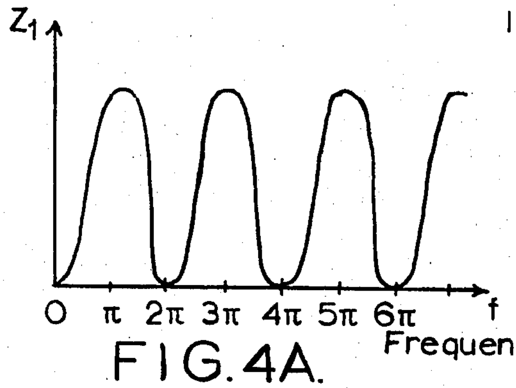

FIG.4A.

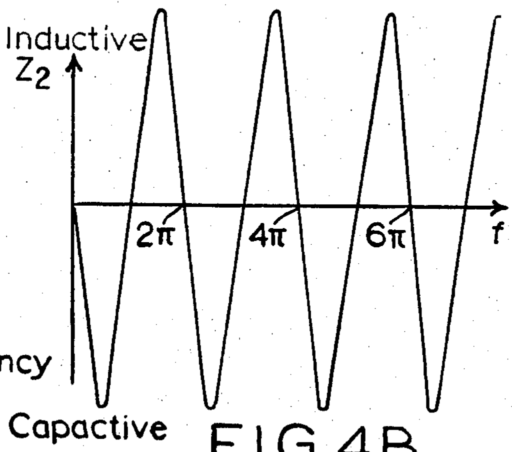

FIG.4B.

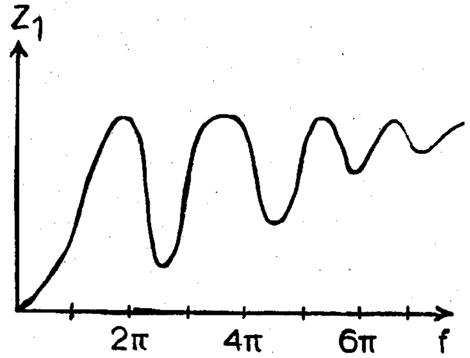

FIG.5A.

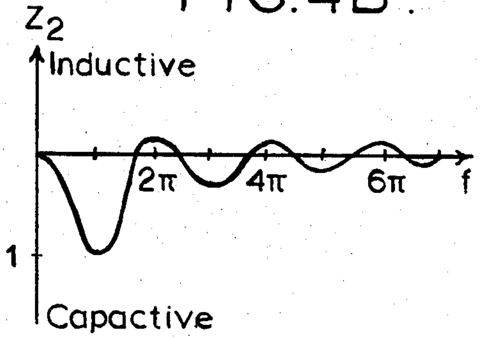

FIG.5B.

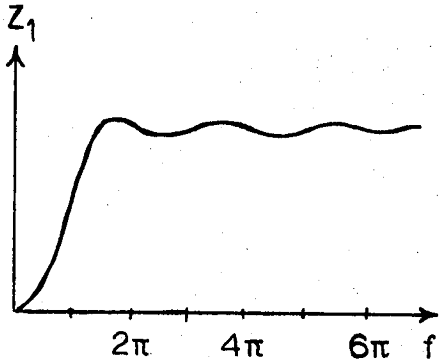

FIG.6A.

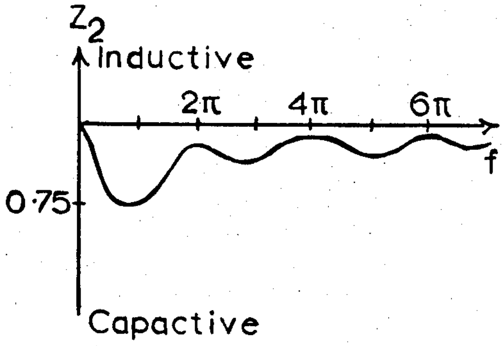

FIG.6B.

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PIEZO-ELECTRIC TRANSDUCERS HAVING VARIABLE SENSITIVITY BETWEEN THE BOUNDARIES OF THE PIEZO-ELECTRIC CRYSTAL

This invention relates to electro-acoustical transducers comprising piezo-electric material provided with electrodes, and to magneto-acoustical transducers comprising piezo-magnetic material and electro-magnetic means for producing a magnetic field therein.

The most common sources of ultrasonic waves normally comprise a plate of piezo-electric material sandwiched between two electrodes. The piezo-electric constant and instantaneous electric field strength E or flux D are usually assumed uniform throughout the material, falling to zero at each electrode. Thus, the piezo-electric stress produced by the application of a potential difference between the electrodes is also substantially uniform throughout the material. This form of transducer displays a resonant behavior which restricts the useful acoustic bandwidth and also causes the reactive and resistive components of the electrical impedance to vary rapidly with frequency, and the reactive component to change sign, within the acoustic pass band. This gives rise to difficulties in the electrical matching of the transducer.

U.S. Pat. No. 3,343,105 discloses a transducer in which the piezo-electric constant of the material decreases gradually in the direction of propagation of the resulting mechanical stress-wave through the material.

It is an object of the invention to provided an acoustic transducer which exhibits an improved electrical impedance at the lower frequency end of the usefull acoustic pass band.

According to the invention there is provided an acoustic transducer comprising a body of material in which a stress is produced by the application of a magnetic or electric field to said material, said body having first and second facing boundary surfaces, said first boundary surface being substantially free of acoustic loading, said second boundary surface being adapted to be a substantially acoustically matched to an acoustic wave transmission medium, a pair of supply terminals electrically connected to field producing means for producing a said field in said material, said material and said field producing means being such that an electrical potential applied between said terminals will result in the creation of a field produced stress in said material resulting in a mechanical stress which can propagate in a propagation direction through the material from said first boundary surface to said second boundary surface, both the magnitude and the rate of change of the magnitude of said field produced stress being arranged to decrease in a substantially continuous manner along said propagation direction from said first boundary surface to said second boundary surface such that the reactive element of the acoustic component of the impedance present across said supply terminal does not change in sign within the acoustic passband of the transducer. In one preferred embodiment of the invention the magnitude of the field produced stress varies in said direction of propagation as a function of the distance X from said first boundary surface in correspondence with the amplitude term

$$\left(d-x-\frac{d}{2\pi}\sin\frac{\pi x}{d}\right)$$

where d is the distance between said first and second boundary surfaces.

The transducer can be an electro-acoustic transducer comprising a body of piezo-electric material having electrodes for producing an electric field in the material, said electrodes being connected to said supply terminals.

In this embodiment, said field produced stress corresponds to the piezo-electric stress which means herein either the product eE or hD where D is the electric flux, E is the electric field, and e and h are standard piezo-electric constants.

If the piezo-electric coupling constant of the material is constant with a change in position along said direction, the required variation in the piezo-electric stress can be obtained by arranging that the applied potential gives rise to an electric field or flux through the material which varies in the required manner. On the other hand if the electric field or flux is arranged to be constant throughout the material along said direction the required variation in the piezo-electric stress can be obtained by arranging that the piezo-electric coupling constant of the material varies in the required manner through the material along said direction. Furthermore, both the electric field or flux and the piezo-electric coupling constant can be varied provided that the resultant piezo-electric stress varies in the required manner.

Alternatively, the transducer can be a magneto-acoustic transducer comprising a body of piezo-magnetic material and electro-magnetic means connected to said supply terminals and arranged to produce a magnetic field in said material. In this case, the field produced stress corresponds to the piezo-magnetic stress which can be caused to vary in the required manner by arranging that said electro-magnetic means gives rise to a magnetic field or flux through the material which varies in the required manner, or that the piezo-magnetic coupling constant is varied, or that both the field and the coupling constant are together varied to bring about the required effect.

It will be readily apparent that an acoustical wave travelling from said acoustic transmission medium, via said second boundary surface, into said body in a direction opposite to said propagation direction, will give rise to a corresponding electrical signal output from said supply terminals. The transducer is therefore equally adapted to function as a transmitter or as a receiver.

In order that the invention may be clearly understood and readily carried into effect, embodiments thereof will now be described, by way of example, with reference to the accompanying drawings of which:

FIG. **1** is a diagram illustrating an electro-acoustical transducer employing the invention,

FIG. **2** is a graph depicting the piezo-electric constant along the propagation axis of the transducer shown in FIG. **1**,

FIG. **3** is an equivalent electrical circuit for the transducer shown in FIG. **1**, and

FIGS. **4A**, **4B**, **5A** and **5B**, and **6A** and **6B** are graphs depicting the variations in the resistive and reactive components of the acoustic impedance for a transducer having a form similar to that shown in FIG. **1**, for different profiles of piezo-electric constant.

Referring first to FIG. **1**, this is a sectional diagram illustrating the form of an electro-acoustic transducer embodying the invention. A body of piezo-electric material **1**, for example cadmium sulphide, is provided with conducting electrode layers **2'**, **3'**, connected to two supply terminals **4**, **5**, and attached respectively to first and second facing boundary surfaces 2 and 3 of the body **1**. The other side of the electrode layer **3'** is in acoustical contact with an acoustic propagation medium **6**. The acoustic propagation impedance of the medium **6** must either substantially match the acoustic propagation impedance of the material **1**, or a suitable impedance matching means must be interposed therebetween. The outer surface of the electrode layer **2'** on the first boundary surface **2** of the body **1**, must be arranged to be substantially free from acoustic loading, for example by exposing it to a gas, such as air, or to a vacuum environment. The acoustic propagation medium **6** can be an ultrasonic delay line, or it can be an impedance matching window leading to a body of water. The electrodes **2'** and **3'** can be made of a vapor-deposited metal such as gold.

The material **1** is formed, for example by vapor deposition, so that its piezo-electric coupling constant h falls from a maximum value at or near the first boundary surface **2**, along the direction of propagation for an acoustical stress disturbance generated by the transducer indicated by the arrow **7**, in accordance with the function:

$$h=h_o\left(d-x-\frac{d}{2\pi}\sin\frac{\pi x}{d}\right)$$

Where h_o is the maximum value of the piezo-electric coupling constant h at the first boundary surface **2**, d is the distance between the first and second boundary surfaces **2** and **3**, and x is the distance from the first boundary surface **2** along the direction **7** at which the value of h is given.

The profile of the variation in the piezo-electric constant is depicted in the graph of FIG. **2**, by the continuous curve **10**. A linear change in the piezo-electric constant with the distance x is shown by the dashed line **11**, and it will be apparent that while the rate of change in piezo-electric constant of the line **11** is constant, the corresponding rate of change represented by the curve **10** decreases in a substantially continuous manner in the direction **7**.

A transducer of the form shown in FIG. **1** will have an equivalent electrical circuit as shown in FIG. **3**. Across the supply terminals **4** and **5** there appears a capacitance Co which represents the static capacitance formed mainly by the capacitance between the electrodes **2'**, **3'** shown in FIG. **1**. This capacitance is substantially constant with frequency, and can readily be tuned out electrically by means of an inductance if desired. Also, across the supply terminals **4** and **5** there appears the acoustic resistive and reactive impedances Z1, Z2 respectively in series with a capacitive reactance $\mathrm{Co}/h^2 0\mathrm{C}0^2$, transformed in the ratio of hCo:1 via the piezo-electric coupling effect. The series reactance $-h^2$Co is normally small and of negligible effect. However the terms Z1 and Z2 are important, and as they can vary with frequency, this can make for difficulties in matching the transducer to an electrical circuit.

FIGS. **4A** and **4B** are graphs depicting the variation Z1, Z2 with frequency, for an electro-acoustical transducer of the form shown in FIG. **1**, in which the magnitude of the piezo-electric constant h and the electric field is uniform, in other words the piezo-electric stress is uniform, throughout the body **1**. It will be apparent that both the resistive and the reactive components of the acoustic impedance undergo periodic large variations in magnitude. The peaks in the value of z1 represent frequency bands over which acoustical power is dissipated by the transducer, and could form the usefull passband of the device. However it will be apparent from FIG. **4B**, that the reactance Z2 changes in sign from being a capacitance to being an inductance in the middle of each passband. This makes the transducer especially difficult to match electrically within a passband.

FIGS. **5A** and **5B** are graphs depicting the variation of Z1 and Z2 with frequency for an electro-acoustical transducer of the form shown in FIG. **1**, in which the piezo-electric constant h, and hence the piezo-electric stress, varies linearly as shown by the dashed line **11** in FIG. **2**. It will be apparent that while the variations in Z1 and Z2 are less extreme in this case, their range is still inconveniently large at lower frequencies, and the reactance 2 still suffers numerous changes in sign, making the device difficult to match electrically, at the lower frequencies.

FIGS. **6A** and **6B** are graphs depicting the variation of Z1 and Z2 with frequency for an electro-acoustical transducer employing the invention and as shown in FIG. **1**. It will be apparent that the resistive acoustical impedance Z1, now has an optimum form in which a reasonable response at low frequencies is combined with only a slight amplitude ripple in the acoustical passband, which itself extends smoothly upward in frequency. Corresponding to this, the reactive acoustical impedance Z2 remains capacitive, at least at the lower frequencies, and until the variation in reactance becomes negligible, thus simplifying electrical matching.

While an embodiment employing one optimum variation in the piezo-electric stress in the direction **7** has been described, other variations can be employed to control the impedance-frequency response, while preventing the reactive component from changing sign at the lower frequencies, at least where the magnitude of the reactive component is significant. The form of other optimum variations will be apparent to those skilled in the art of filter theory and aerial theory. Such variations must exhibit a substantially continuous decrease in the rate of change of the piezo-electric stress from the first boundary surface **2** to the second boundary surface **3** at which the piezo-electric stress should be substantially zero. The invention can equally well be applied to magneto-acoustic transducers and can be employed for receiving transducers as well as for transmitting transducers.

What we claim is:

1. An acoustic transducer comprising a body having opposing boundary faces, said body comprising a material having a variation in piezo-electric coupling constant between said boundary faces, and means for eliminating an acoustic resonance within the passband of the transducer; said means comprising means for producing an electric field in said material, said electric field resulting in a piezo-electric stress amplitude variation in said material substantially in accordance with

$$\left(d-x\frac{d}{2\pi}\sin\frac{\pi x}{d}\right)$$

where d is the distance between said boundary faces and x is the distance from one of said boundary faces to a point within said material.

2. An acoustic transducer as claimed in claim **1** wherein said piezo-electric coupling constant has an amplitude variation substantially in accordance with

$$\left(d-x-\frac{d}{2\pi}\sin\frac{\pi x}{d}\right)$$

where d is the distance between said boundary faces and x is the distance from one of said boundary faces to a point within said material.

3. An acoustic transducer as claimed in claim **2** wherein said means for producing an electric field produces a substantially uniform electric field within said material.

4. An acoustic transducer comprising a body having opposing boundary faces, said body comprising a material having a variation in piezo-magnetic coupling constant between said boundary faces, and means for eliminating an acoustic resonance within the passband of the transducer; said means comprising means for producing a magnetic field in said material.

5. An acoustic transducer as claimed in claim **4** wherein said means for producing a magnetic field results in a piezo-magnetic stress amplitude variation in said material substantially in accordance with

$$\left(d-x\frac{d}{2\pi}\sin\frac{\pi x}{d}\right)$$

where d is the distance between said boundary faces and x is the distance from one of said boundary faces to a point within said material.

6. An acoustic transducer as claimed in claim **5** wherein said piezo-magnetic coupling constant has an amplitude variation substantially in accordance with

$$\left(d-x-\frac{d}{2\pi}\sin\frac{\pi x}{d}\right)$$

where d is the distance between said boundary faces and x is the distance from one of said boundary faces to a point within said material.

7. An acoustic transducer as claimed in claim **6** wherein said means for producing a magnetic field produces a substantially uniform magnetic field within said material.

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