United States Patent [19]

Massa

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[45] **Dec. 23, 1975**

[54] **DIRECTIONAL ULTRASONIC TRANSDUCER WITH REDUCED SECONDARY LOBES**

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[73] Assignees: **Fred M. Dellorfano, Jr.; Donald P. Massa,** both of Cohasset, Mass.

[22] Filed: **Aug. 26, 1974**

[21] Appl. No.: **500,391**

[52] **U.S. Cl.** ..... **310/8.2;** 310/8.3; 310/8.7; 310/8.9; 310/9.4; 340/8 MM; 340/10

[51] **Int. Cl.²** **H01L 41/04**

[58] **Field of Search** ..... 310/8.2, 8.3, 8.7, 8.9, 310/9.1, 9.4; 340/10, 8 MM

[56] **References Cited**

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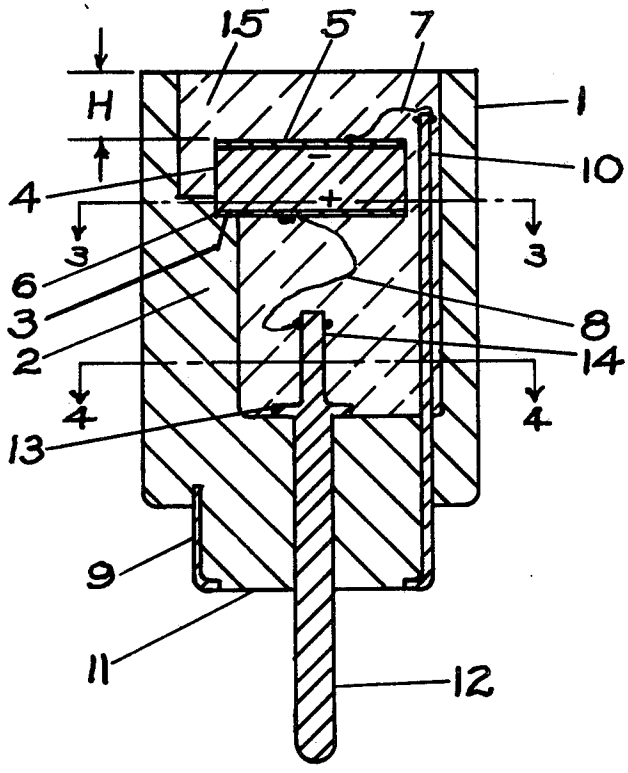
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Primary Examiner—Mark O. Budd

[57] **ABSTRACT**

The invention describes a novel design of an acoustic transformer which serves as an impedance matching device between the transducer material and the atmosphere. The transformer serves also to effectively increase the limited maximum permissible amplitude of vibration of the transducer material whereby the maximum acoustic power radiated into the atmosphere is substantially increased. The novel acoustic transformer design also results in a significant reduction in the magnitude of the secondary lobes in the directional pattern thereby additionally improving the performance characteristics of the transducer.

5 Claims, 7 Drawing Figures



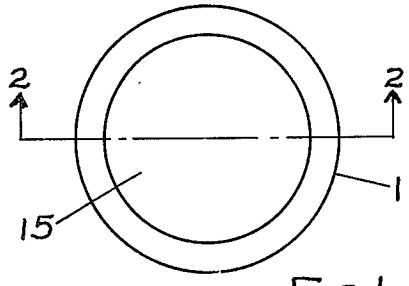


FIG 1

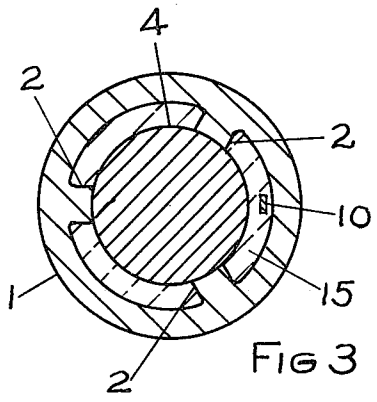


FIG 3

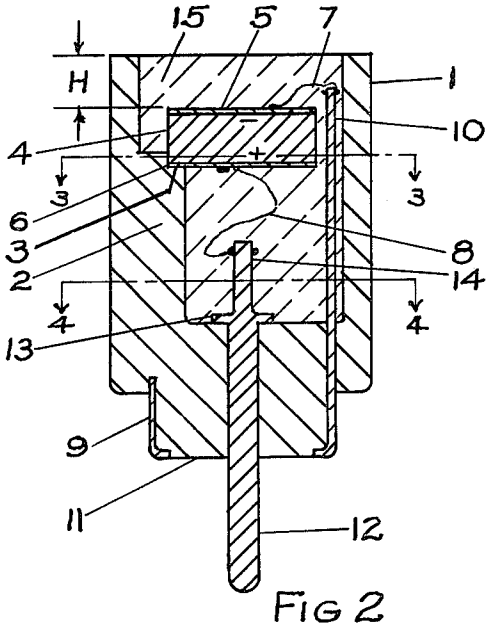


FIG 2

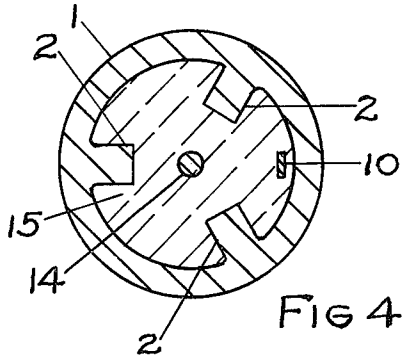


FIG 4

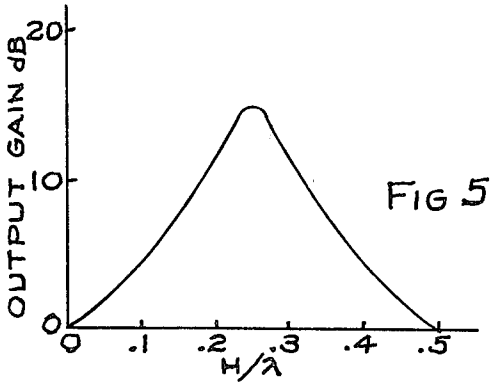


FIG 5

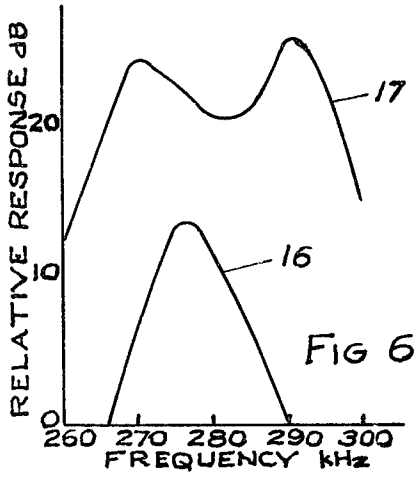


FIG 6

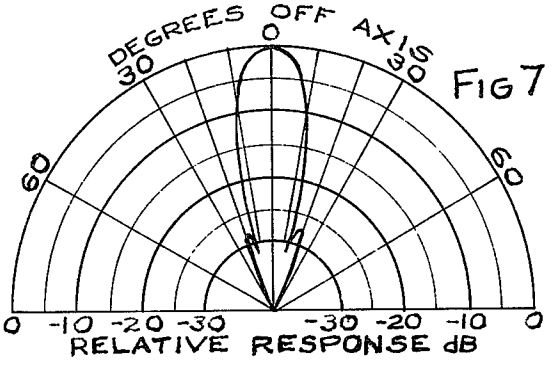


FIG 7

DIRECTIONAL ULTRASONIC TRANSDUCER WITH REDUCED SECONDARY LOBES

This invention is concerned with electroacoustic transducers and, more specifically, with electroacoustic transducers for transmitting or receiving sound in a gaseous medium. Although not limited to the ultrasonic frequency region, this invention is particularly useful for improving the performance characteristics of electroacoustic transducers to be used in the ultrasonic frequency region.

Many types of transducer materials such as, for example, magnetostrictive rods, piezoelectric crystals, and polarized ceramic elements, have been widely used in the design of ultrasonic sound generators. As is well known to anyone skilled in the art, a design requirement for achieving reasonably high transducer efficiency at ultrasonic frequencies is to operate the transducer element at or near resonance. If the transducer material employed in the design is a polarized ceramic plate, for example, the operating frequency region of the transducer can correspond to the frequency region in the vicinity of the thickness resonance of the ceramic plate or, if the ceramic plate is in the form of a circular disc, the planar resonant frequency mode of vibration of the disc could be used for establishing the frequency region of operation.

The use of the transducer materials above mentioned have all proved very successful in connection with the design of underwater transducers because the relatively high acoustic impedance of the transducer material is reasonably well matched to the relatively high acoustic impedance of the water into which the sound is radiated. However, when such a transducer is to be used for generating sound in a gaseous medium, such as air, the low acoustic impedance of the air is mismatched considerably from the relatively high acoustic impedance of the transducer material and as a consequence the transducer output and bandwidth are significantly reduced. To overcome these limitations this invention provides a novel design of an acoustic transformer which, in addition to serving as an impedance matching device between the transducer material and the air, also serves to effectively increase the limited maximum permissible amplitude of vibration of the transducer material whereby the maximum acoustic power radiated into the atmosphere is substantially increased. The novel acoustic transformer design disclosed in this invention also results in a significant reduction in the amplitude of the secondary lobes in the directional radiation pattern of the transducer and also in a virtual elimination of the tertiary and higher order lobes thereby additionally improving the performance characteristics of the transducer.

The primary object of this invention is to improve the radiation efficiency and bandwidth of an ultrasonic transducer which is to operate in a gaseous medium by providing an acoustic transformer between the vibrating surface of the transducer element and the atmosphere into which the sound is to be radiated.

Another object of this invention is to improve the acoustic impedance match between the vibrating surface of a transducer element and the atmosphere into which the vibrations are to be transmitted.

An additional object of this invention is to provide an acoustic transmission line between the vibrating surface of a transducer element and the atmosphere into which the vibrations are to be transmitted.

A still further object of this invention is to greatly improve the performance characteristics and power handling capacity of an ultrasonic transducer designed for transmitting acoustic energy into the atmosphere at ultrasonic frequencies.

Another object of this invention is to greatly reduce the secondary lobes in the directional pattern of an ultrasonic transducer which includes an acoustic transmission line as a coupling element between the vibrating surface of the transducer element and the atmosphere.

An additional object of this invention is to increase the acoustic power output of an ultrasonic transducer operating in a gaseous medium beyond the acoustic power output which can be realized from the limited amplitude of vibration of the surface of the transducer material when the vibrating surface is directly exposed to the atmosphere.

In keeping with an aspect of this invention a polarized ceramic disc is operated at either its planar resonant frequency mode or at its thickness resonant frequency mode and its efficiency, bandwidth, and directional pattern are greatly improved by providing an acoustic transmission line between the vibrating ceramic plate and the atmosphere. The transmission line comprises a material whose specific acoustic impedance is less than the specific acoustic impedance of the ceramic and greater than the specific acoustic impedance of air. The dimensions and configuration of the material are uniquely chosen to achieve the various objects of the invention and the improved performance characteristics listed above.

The novel features which are characteristic of the invention are set forth with particularity in the appended claims. However, the invention itself, 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 description when taken in conjunction with the accompanying drawings in which:

FIG. **1** is a plan view of a transducer employing the teachings of this invention.

FIG. **2** is a vertical section taken along the line **2—2** of FIG. **1.**

FIG. **3** is a cross-sectional view taken along the line **3—3** of FIG. **2** except that the view is taken for the complete transducer.

FIG. **4** is a section taken along the line **4—4** of FIG. **2** except that the section is taken for the complete transducer.

FIG. **5** is a plot showing the relative increase in sensitivity achieved by the transducer illustrated in FIG. **2** as a function of H/λ where H is the height of the potting material illustrated in FIG. **2** and λ is the wavelength of sound in the potting material at the frequency of operation.

FIG. **6** is a plot showing the measured improvement in the transmitting response characteristic of an electroacoustic transducer employing the teachings of this invention.

FIG. **7** shows the measured directional pattern of a transducer employing the teachings of this invention and indicates the virtual elimination of secondary lobes.

Referring more particularly to the figures in which one preferred form of the invention is illustrated, **1** is a

housing structure which, for convenience, is illustrated as being of molded plastic. The plastic housing **1** is represented as a hollow cylinder with three internal rib portions **2.** Each of the rib portions is provided with an undercut section **3** to form a locating nest for accurately positioning the ceramic disc **4** as illustrated in FIGS. **2** and **3.** The ceramic disc **4** may be any one of the well known polarized ceramic materials such as, for example, lead-zirconate-titanate or barium titanate. The flat faces of the disc **4** are provided with metallic electrodes **5** and **6** as is well known in the art. An electrical conductor **7** is soldered to electrode surface **5** and electrical conductor **8** is soldered to electrode surface **6** as illustrated in FIG. **2.** A metallic cylindrical collar **9,** which includes an extended **8***c* tab member **10,** is fitted over the rear projection portion **11** of the plastic housing **1** as illustrated in FIG. **2.** The tab portion **10** passes through a rectangular slot in the rear portion **11** of the housing and becomes a terminal post in the vicinity of the ceramic element **4** as illustrated in FIG. **2.** The free end of electrical conductor **7** is soldered to the free end of the tab member **10** as illustrated. A cylindrical terminal pin **12** having a shoulder portion **13** and an extension tip portion **14** is pressed through a central hole in the base portion **11** of the housing **1** as illustrated in FIG. **2.** The free end of electrical conductor **8** is soldered to the tip portion **14** of the terminal pin **12** as illustrated.

In the embodiment illustrated the external electrical terminal connections for the ceramic disc appear in the form of a coaxial connector having a center pin portion **12** and a cylindrical collar portion **9** as illustrated in FIG. **2.** To complete the transducer assembly a sound conducting material **15,** preferably in the form of a potting compound, is used to fill the open end of the housing to provide a height H of material which is bonded to the electrode surface **5** of the ceramic as illustrated in FIG. **2.** The height of the acoustic coupling material H is chosen, as will be disclosed, to provide optimum improvement in the performance characteristics of the transducer at the desired frequency.

For the construction illustrated in FIG. **2,** the potting material **15,** in addition to serving its primary function as an acoustic transmission line of length H between the surface **5** of the ceramic disc and the atmosphere, is also used to provide additional mechanical damping to the ceramic by permitting it to make direct contact with the peripheral edge surface of the disc and also with the bottom surface **6.** For applications where the transducer is not required to have maximum damping it is possible to isolate the edge and bottom surfaces of the ceramic disc from the potting compound by applying a layer of low acoustic impedance material to either or both of these surfaces prior to potting. A suitable isolating material is a thin layer of commercially available foam rubber or foam plastic tape which may be easily attached to the edge and bottom surfaces of the ceramic disc prior to inserting the disc into position in the housing. The layer of foam tape which may be applied to the ceramic surfaces as an alternate construction is not illustrated in the drawings because the description in the text is sufficiently clear and it is not necessary to complicate the drawings which the illustration of the optional design including the added foam layer.

In order to achieve increased radiation efficiency and bandwidth for the transducer, I have found it advantageous to choose a potting material **15** whose specific acoustic impedance is greater than the specific acoustic impedance of air and less than the specific acoustic impedance of the ceramic material. The specific acoustic impedance is defined as the product of density times the velocity of sound in the material. I have also found that the maximum improvement in sensitivity occurs when the height of the acoustic coupling material H is made equal to 0.25λ, where λ is the wavelength of sound in the material **15** at the frequency of operation. The increase in sensitivity of a particular transducer incorporating the teachings of this invention as a function of the dimension H is shown in FIG. **5.** The data indicates that maximum efficiency occurs at $H/\lambda = 0.25$. It also shows that significant improvement is realized if H/λ lies between 0.1 and 0.4. I have also found that if the potting material **15** contains a silicon base that the variation in the specific acoustic impedance of the potting compound with temperature can be minimized and the transducer will remain more uniform in its operational characteristics over a wide range of environmental temperature changes.

FIG. **6** shows the measured transmitting response characteristic of an ultrasonic transducer employing a ceramic disc of polarized lead-zirconate-titanate. Curve **16** shows the measured response characteristic of the transducer when the vibrating surface of the ceramic disc is exposed directly to the atmosphere without any coupling material **15** present. Curve **17** shows the improved sensitivity and bandwidth which results when the acoustic coupling material **15** is added to the ceramic to serve as an acoustic transmission line as illustrated in FIG. **2** and H is made equal to 0.25λ at the operating frequency of the transducer.

If the transducer employs a ceramic disc **4** which is made of one of the common types of polarized lead-zirconate-titanate materials and if the transducer is operated at or near the planar resonant frequency mode of vibration of the disc, the beam angle of the directional radiation pattern of the transducer will be approximately 10° to 12° wide at the −3 dB points. The measured directional pattern of such a transducer designated for operating in the vicinity of 280 kHz is shown in FIG. **7.** If barium titanate were chosen as the ceramic material, the planar resonance frequency would be approximately 50 percent higher for the same size disc and the beam angle would accordingly be somewhat smaller. In any case, by using any of the generally available ceramic materials for the disc the beam angle of the transducer will generally be between approximately 8° to 12° at the operating frequency corresponding to the planar resonant frequency of the disc.

I have also found that by using a height of potting compound H ranging between 0.1λ and 0.4λ that the magnitude of the secondary lobes that appear in the directional pattern of the transducer are greatly reduced in comparison to the magnitude of the secondary lobes which are normally present in the directional radiation pattern of a circular vibrating piston. FIG. **7** shows the measured directional pattern of a transducer incorporating the teachings of this invention and employing a lead-zirconate-titanate ceramic disc operating at the planar resonant frequency mode. As can be seen in FIG. **7** the secondary lobes are reduced in magnitude by more than 25 dB below the sensitivity on the main axis as compared to a secondary lobe reduction of approximately 17 dB which is typical for a circular piston. It is also noted in FIG. **7** that any additional higher order lobes beyond the secondary lobes are

virtually eliminated in the directional pattern of the inventive transducer. The improvement in secondary lobe reduction results from the internal refraction of the sound generated by the vibrating ceramic disc as it passes through the acoustic transmission line **15.** The refraction, in turn, is caused by the relatively high velocity of sound in the potting material **15** as compared to the velocity of sound in air.

The invention has disclosed a novel design of an ultrasonic transducer for generating sound in air. The teachings of this invention have resulted in greatly improved performance characteristics of the transducer. Although specific examples have been described to illustrate the basic teachings of this invention, it will be obvious to anyone skilled in the art that variations may be made in some of the specific details which have been disclosed without departing materially from the novel teachings of this invention. Therefore, I desire that my invention shall not be limited except insofar as is made necessary by the prior art and that the appended claims be construed to cover all equivalent structures.

I claim:

1. In combination in a directional electroacoustic transducer, a housing structure having an opening, a polarized ceramic disc characterized in that its periphery is smaller than the periphery of said opening, and further characterized in that it operates at a frequency near its planar resonant vibrational mode, said ceramic disc includes a vibratile surface, means for locating said ceramic disc within said opening in said housing structure with said vibratile surface placed opposite said opening, means for reducing the amplitude of the secondary lobes in the directional pattern of said transducer, said means including a sound conducting material located within said opening and making intimate contact with said vibratile surface.

2. The invention in claim **1** characterized in that the thickness of said sound conducting material lies in the range 1/10 to 4/10 wavelength of the sound generated in said sound conducting material at the planar resonant vibrational mode of said ceramic disc.

3. The invention in claim **2** further characterized in that said sound conducting material also makes intimate contact with the peripheral edge surface of said ceramic disc.

4. The invention of claim **2** further characterized in that said sound condueting material is an elastomer.

5. The invention in claim **4** further characterized in that said elastomer contains silicone.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,928,777 Dated December 23, 1975

Inventor(s) Frank Massa

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Item (73) should read;

Fred M. Dellorfano, Jr. and Donald P. Massa,
Trustees of the Stoneleigh Trust u/d/t
December 4, 1973, Cohasset, Massachusetts

Signed and Sealed this

Twenty-first Day of September 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

UNITED STATES PATENT OFFICE
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[SEAL]

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RUTH C. MASON
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C. MARSHALL DANN
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