United States Patent

Massa

[15] **3,638,052**

[45] **Jan. 25, 1972**

[54] ELECTROACOUSTIC TRANSDUCERS OF THE BILAMINAR FLEXURAL VIBRATING TYPE

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[73] Assignee: **Dynamics Corporation of America, Massa Division,** Hingham, Mass.

[22] Filed: **Feb. 12, 1970**

[21] Appl. No.: **10,748**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 859,677, Sept. 22, 1969, Pat. No. 3,578,995.

[52] **U.S. Cl.** ....**310/8.2,** 179/110 A, 310/8.3, 310/8.5, 310/8.9, 310/9.4

[51] **Int. Cl.** **H04r 17/00**

[58] **Field of Search** ....310/8.2, 8.3, 8.5, 8.6, 8.9, 310/9.1, 9.4, 9.6, 8.7; 340/10; 179/110 R, 110 A; 181/31, 32

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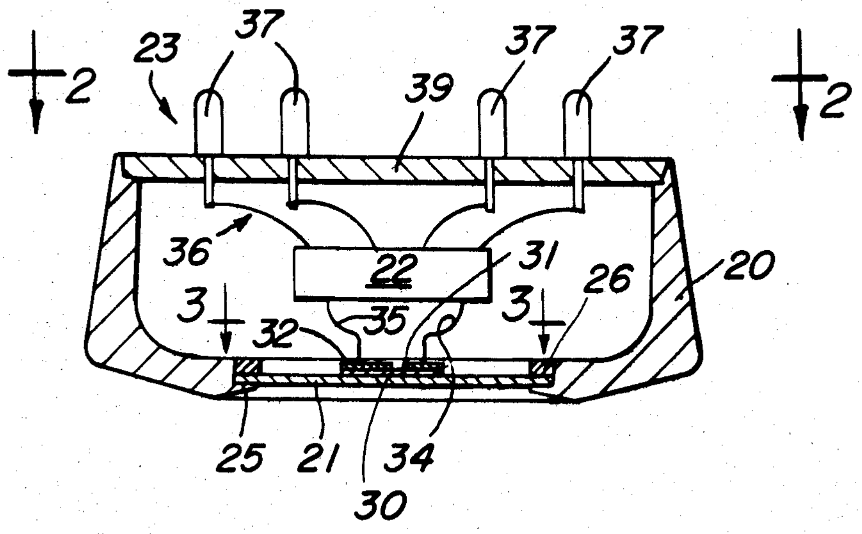
Primary Examiner—J. D. Miller
Assistant Examiner—Mark O. Budd
Attorney—Louis Bernat

[57] **ABSTRACT**

A transducer includes a piezoelectric driven, vibratile diaphragm which acts as the closure for a circular opening in a rigid housing which encloses electronic components. The flexure mode of the diaphragm is controlled to give a sound pattern which is more uniform over a large area. The housing and diaphragm assembly is combined with a set of electrical terminals which serve as a plug for inserting the transducer assembly into a mating socket. The resulting structure provides an economical transducer design with improved sound radiation characteristics and controlled uniformity in large production quantities.

7 Claims, 10 Drawing Figures



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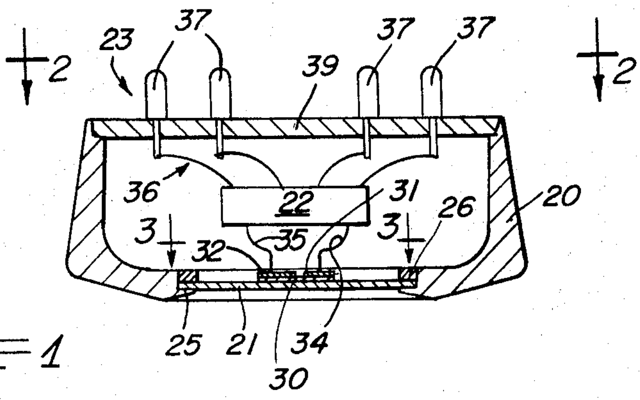


FIG-1

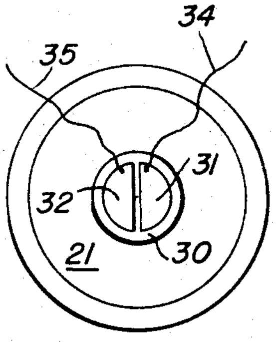
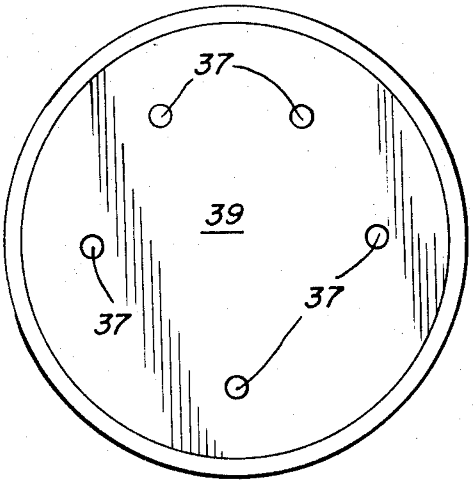


FIG-3

FIG-2



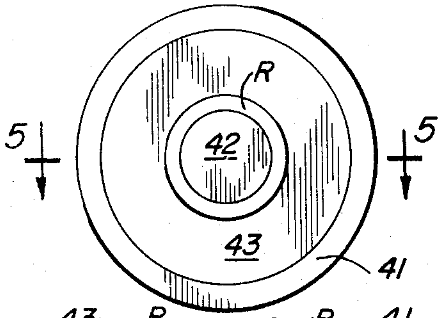


FIG-4

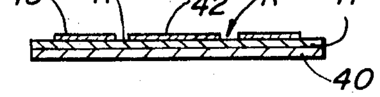


FIG-5

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FIG. 6

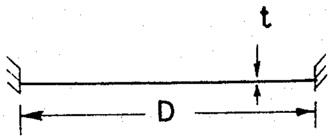


FIG. 7

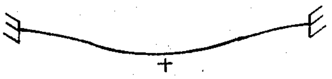


FIG. 8

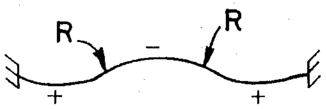


FIG. 9

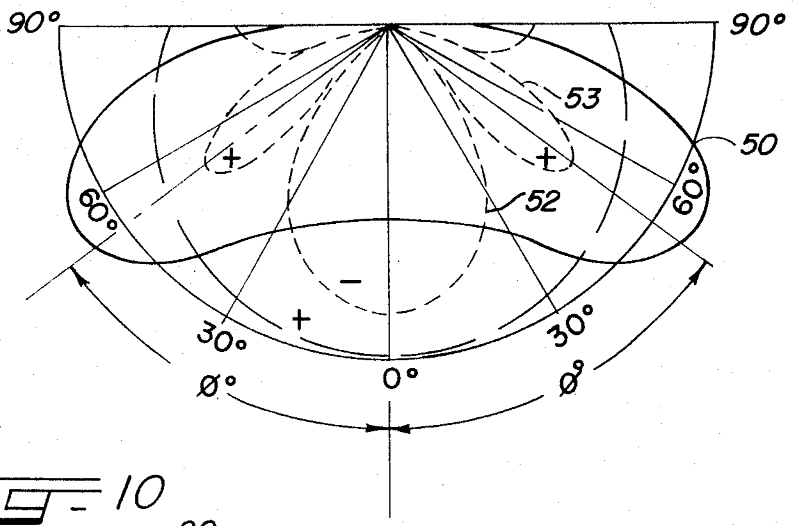
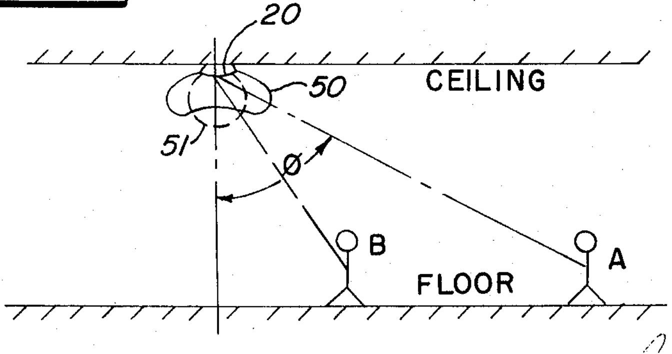


FIG. 10



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ELECTROACOUSTIC TRANSDUCERS OF THE BILAMINAR FLEXURAL VIBRATING TYPE

This is a continuation-in-part of my copending application Ser. No. 859,677, filed Sept. 22, 1969, entitled "ELECTROACOUSTIC TRANSDUCER," now U.S. Pat. No. 3,578,995, and assigned to the assignee of this invention.

This invention relates to electroacoustic transducers and more particularly to electroacoustic transducers adapted for radiating uniformly distributed fields of sound over specified areas.

While the invention may find use in many different environments, it has special value as a transducer for use in electroacoustic burglar alarm systems. Among other things, this means that the sound field must be predictably uniform throughout a specified area. These transducers must be relatively low cost devices, which have a high degree of reliability, and do not attract an undue amount of attention.

Accordingly, an object of this invention is to improve the performance characteristics of an electroacoustic transducer designed for operating in air.

Another object of this invention is to provide a vibratile diaphragm which produces a specified radiation pattern at a specific operating frequency.

A further object of this invention is to provide a simple diaphragm assembly which also acts as the closure of an open end of a rigid housing structure.

Yet another object of this invention is to provide a vibratile diaphragm which operates in a desired overtone resonance mode when it is driven at a specified frequency.

A still further object of this invention is to provide a piezoelectric ceramic disc with an increased sensitivity.

In keeping with one aspect of the invention, these and other objects are accomplished by providing a vibratile disc driven by a piezoelectric transducer. The disc is made to vibrate in a complex mode of vibrations. The modes are selected to provide a sound field with an energy distribution which is more uniformly controlled over a specified area than was hitherto available out of comparable devices.

These and other objects, features, and advantages of the invention will become more apparent from a study of the following description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a cross-sectional view of a transducer assembly incorporating one embodiment of this invention;

FIG. 2 is a plan view of the bottom of the transducer taken along the line 2—2 of FIG. 1;

FIG. 3 is a plan view of a bilaminar diaphragm assembly taken along line 3—3 of FIG. 1;

FIG. 4 is a plan view of a second embodiment of a bilaminar diaphragm assembly which may be substituted for the diaphragm assembly of FIG. 3;

FIG. 5 is a cross-sectional view of the diaphragm taken along the line 5—5 of FIG. 4;

FIG. 6 is a schematic representation of an edge mounted diaphragm in its rest position as shown in FIG. 2;

FIG. 7 schematically represents the peak amplitude when it is driven at its fundamental resonance frequency;

FIG. 8 schematically illustrates the peak amplitude displacement of the diaphragm, when it is driven at its first overtone, nodal circle, resonance frequency;

FIG. 9 graphically illustrates the directional radiation pattern obtained from a diaphragm operating in its overtone resonance mode as illustrated in FIG. 8; and

FIG. 10 illustrates the improved uniformity of a sound field extending across a floor area in the vicinity of a ceiling mounted transducer having the improved radiation pattern illustrated in FIG. 9.

The transducer is enclosed in a generally circular, somewhat tubular housing 20 (FIG. 1) structure having a rigid wall portion terminated at its opposite ends in circular openings. Housing 20 may be fabricated from molded plastic or a die casting of zinc or aluminum, for example. The major elements in the housing 20 are a thin metal diaphragm or disc 21, an electronic circuit 22, and a plug terminal 23. The electronic circuit 22 may take any known form adapted to work with piezoelectric transducers.

The circular opening through the lower part of the housing contains a shouldered rim section 25. This section is dimensioned to enable a rigid attachment to be made between the housing and the periphery of the circular diaphragm disc 21. This attachment may be made by epoxy, or any other suitable cement, bonding the periphery of the diaphragm disc to the rim portion 25. A ring-shaped member 26 may be cemented with epoxy, for example, to the outer edge of the diaphragm disc 26 to provide additional rigid support to the area. The periphery of the diaphragm is thus made relatively stiff, as compared with the stiffness of the rim section 25.

FIG. 3 shows one embodiment of a bilaminar diaphragm assembly. More particularly, a piezoelectric disc 30 is cemented to the center of the diaphragm 21 with a suitable rigid cement, such as epoxy. Any one of many well-known polarized ceramics may be used at this point. The piezoelectric disc 30 covers less than one-half the diaphragm area, in the construction of FIGS. 1 and 3. The unattached surface of the ceramic disc 30 is provided with two divided electrodes 31 and 32. The cemented side of the ceramic disc 30 is provided with a single electrode extending over the entire surface. The disc 30 is then polarized, as described in U.S. Pat. No. 2,967,957. Electrical conductors 34 and 35 are connected to the electrode surfaces 31 and 32, as by soldering, for example. The leads 34 and 35 are then connected to the electronic components schematically illustrated by the box 22. The wires 36 are connected between electronics 22 and the terminal pins 37 which make up the plug 23. This plug provides for establishing external connections to the transducer assembly.

The pin terminals are fastened to an electrical insulating baseplate 39, such as plastic. Finally, the outer periphery of the baseplate 39 is cemented to seal one open end of the housing 20. The arrangement of these pin terminals may be seen in FIG. 2, where a certain nonsymmetry enables a polarization of the plug-in unit. This precludes plugging the pin terminals 37 into the wrong socket terminals, not shown.

FIGS. 4 and 5 show a second embodiment of a bilaminar diaphragm assembly. In this instance, a circular plate diaphragm 40 is rigidly bonded to a polarized ceramic disc 41, again by using epoxy or other suitable cement. In this embodiment, the ceramic disc covers practically the entire area of the diaphragm. Two separated concentric electrode surfaces 42 and 43 are provided on the exposed surface of the ceramic disc. The separation between the electrodes 42, 43 is placed in the region of the nodal diameter for the first overtone resonance mode of the mounted bilaminar disc.

FIGS. 6–10 are helpful for an understanding of the design criteria for the bilaminar diaphragm assemblies, illustrated in FIG. 3 or FIG. 4. FIG. 6 shows a disc or circular plate, of diameter D and thickness t, clamped at its periphery. The diameter of the diaphragm is determined by the desired frequency of operation and the desired resonance mode for producing the improved directional pattern illustrated in FIG. 9. The fundamental resonant frequency of the plate is proportional to

$$\frac{t}{D^2}\sqrt{\frac{E}{\rho}}$$

where:

E = Young's modulus, and ρ = density of the material.

D = Diaphragm diameter, and t = diameter thickness.

To achieve the best acoustic coupling between the vibrating diaphragm and the air, it is desirable to make the thickness t as small as possible for a given diameter D. This means that the ratio e/ρ should be a maximum. Also, it is necessary to keep the total mass at a minimum. Therefore, ρ should also be a minimum. Of all the common metals, aluminum best satisfies these requirements; therefore, it is the preferred metal for the diaphragm material.

In order to achieve satisfactory operating characteristics and to be able to control the uniformity of transducers during large quantity production, I have found it necessary to make the thickness of the diaphragm less than one-twentieth of its perimeter. I also found it preferable to make the thickness of the ceramic disc less than the thickness of the aluminum diaphragm. Otherwise, the thicker ceramic would tend to restrict an efficiently established normal overtone mode of vibration.

Various modes of vibration for a clamped disc are shown by the two FIGS. **7** and **8**. More particularly, FIG. **7** illustrates the deflection of a clamped disc operating at its fundamental resonance mode. The curve is uniform along a diameter of a clamped circular plate diaphragm. The displacement is in the same phase over the entire diaphragm surface. FIG. **8** illustrated the deflection of a clamped disc when operating at its first overtone nodal circle resonance frequency. There is a reverse bend in the curve which results along the diameter of the diaphragm. This overtone frequency occurs at approximately 3.9 times the fundamental resonance frequency. For this mode of operation, the displacement of the center portion of the diaphragm has a phase which is opposite to the phase of the displacement of the outer portion of the diaphragm.

In FIG. **9**, the solid curve **50** shows the type of directional radiation pattern, which is obtained from a clamped disc when the diaphragm is operating in the overtone mode illustrated in FIG. **8**. This curve assumes that the diaphragm lies in the plane defined by the line 90°–90°. It is desirable to use this higher resonance mode of vibration, at the operating frequency of the transducer, since an improved directional radiation pattern is obtained from this operational mode.

The curve **50** is derived from the sum of the radiation pattern **51** which is generated by the center portion of diaphragm and the pattern **52** which is generated by the outer annular portion of the diaphragm. The area of reduced sensitivity lies along the line 0° which is perpendicular to the diaphragm. The angle $\theta°$ indicates the axis of maximum sensitivity which generally corresponds to the major axis of the secondary lobes **53**. Plus (+) and minus (−) signs indicate the relative phases of the sound pressure transmitted into the various zones defined by the primary and secondary lobes of the component directional patterns **51** and **52**. The pattern **51** is typical of a pattern produced from a small circular diaphragm having a diameter which is less than the wavelength of sound at the frequency of operation. The pattern **52** is typical of a pattern produced from a vibrating annular shaped diaphragm having a diameter which is greater than the wavelength of sound at the frequency of operation.

Two conclusions can be drawn from the information given by the patterns of FIG. **9**. First, there is a reduction in sensitivity along the zero degree axis which is normal to the diaphragm. This reduction depends on the relative magnitudes of the individual sound pressure levels generated along the 0° axis by the center and outer portions of the diaphragm assembly when operating at the overtone mode illustrated in FIG. **8**. Second, the magnitude of the maximum sensitivity angle, $\theta°$ corresponds approximately to the angle at which the secondary lobe **53** occurs in the pattern **52**. The position of this lobe may be controlled by a selection of the ratio of the diaphragm diameter D as compared to the wavelength λ of sound at the frequency of operation.

If the ratio D/λ is as small as 1½ the location of the region of maximum response is such that the angle $\theta°$ is approximately equal to 90°. On the other hand, if the ratio D/λ is larger than 4, the location of the region of maximum response is located where $\theta°$ is less than 30°. An undesirable ragged directional response curve results in the region where $\theta°$ is greater than 45°. Therefore, to produce a satisfactory directional pattern with a smoothly increased sensitivity in the region extending 30° beyond the normal axis of the diaphragm, the preferred diameter of the diaphragm is within the approximate range 1½ to 4 times the wavelength of sound at the operating frequency.

When the ceramic construction of FIG. **3** is operated in the overtone mode of FIG. **8**, the diameter of the ceramic disc **30** must be less than ½ the diameter of the metal diaphragm **21**. If the ceramic disc is larger, the entire ceramic will not be stressed in the same phase during each displacement cycle of the diaphragm.

one-half the ceramic construction of FIG. **4** is used, the diameter of the center electrode **42** must be less than ½ the diameter of the diaphragm **40**. Preferably, the separation between the electrode surfaces **42** and **43** should be in the reverse curve region R of the nodal diameter for the overtone mode of operation illustrated in FIG. **8**. An advantage of the electrode arrangement shown in FIG. **4** is that the ratio of the signal across each electrode section **42** and **43** can be adjusted by a voltage-dividing network to permit a more accurate control of the shape of the directional pattern **50** (FIG. **9**) in the region near the 0° axis.

FIG. **10** illustrates an advantage of the improved directional pattern. There is a better sound level distribution over an area in the vicinity of the transducer **20**, as compared with earlier designs. More particularly, a transducer housing **20** is mounted on a ceiling. The improved directional pattern **50** indicates a higher intensity level along the maximum sensitivity axis $\theta°$ to a distant position A, as compared to an intermediate position B. The higher intensity along the axis to position A compensates for the greater distance between the transducer **20** and the position A. This improves the uniformity of the sound intensity level over the entire area as compared with the uncompensated conventional directional pattern shown in FIG. **10**, by the dotted line **51**. This conventional pattern fails to achieve the desirable objective of equalizing the sound intensity level over the area.

While several specific embodiments have been shown and described, it should be understood that various modifications may be made without departing from the true spirit and scope of the invention. Therefore, the appended claims are intended to cover all equivalent constructions which fall within the true spirit and scope of the invention.

I claim:

1. An electroacoustic transducer for operating in the air, said transducer comprising a housing structure including a rigid peripheral wall section surrounding an opening having a circular rim section, means for sealing said opening comprising a circular diaphragm for operating in the flexural mode rigidly clamped at its periphery to said circular rim section, said clamped diaphragm having a diameter between 1½ and 4 times the wavelength of sound at the operating frequency and being characterized in that the length of its periphery is more than 20 times greater than its thickness, said thickness being substantially uniform and unvarying throughout the entire area defined by said clamped periphery, transducer means including a piezoelectric disc having a diameter which is less than one-half the diameter of the diaphragm rigidly bonded to one side of said clamped diaphragm, means for driving said diaphragm at the resonant flexural mode frequency, and means comprising electrical conductors attached to said piezoelectric disc for imparting driving signals thereto for causing said flexing with an amplitude sufficient to transmit sonic energy through the air.

2. The invention in claim **1** further characterized in that said diaphragm is aluminum.

3. The invention in claim **2** further characterized in that said piezoelectric disc is a polarized ceramic.

4. The invention of claim **1** further characterized in that said piezoelectric disc has a thickness which is less than the thickness of said diaphragm.

5. An electroacoustic transducer comprising a housing structure including a rigid peripheral wall section surrounding an opening having a circular rim section, means for sealing said opening comprising a circular aluminum diaphragm rigidly clamped at its periphery to said circular rim section, the periphery of said diaphragm being more than 20 times greater than its thickness, said diaphragm having a diameter exceeding 1½ times the wavelength of sound at the operating frequency, transducer means including a polarized ceramic piezoelectric disc rigidly bonded to one side of said diaphragm for vibrating said diaphragm, said disc being less than one-half the diameter of said diaphragm, and two separate spaced-apart electrodes mounted on the unbonded side of said disc for imparting driving signals thereto for causing said disc and diaphragm to operate in a flexural mode.

6. An electroacoustic transducer comprising a housing structure including a rigid peripheral wall section surrounding an opening having a circular rim section, means for sealing said opening comprising a circular diaphragm rigidly clamped at its periphery to said circular rim section, the periphery of said diaphragm being more than 20 times greater than its thickness, said diaphragm having a diameter exceeding 1½ times the wavelength of sound at the operating frequency, transducer means including a polarized ceramic piezoelectric disc rigidly bonded to one side of said diaphragm for vibrating said diaphragm, said disc being less than one-half the diameter of said diaphragm, and two separate spaced apart electrodes mounted on the unbonded side of said disc for imparting driving signals thereto for causing said disc and diaphragm to operate in a flexural mode.

7. An electroacoustic transducer comprising a housing structure including a rigid peripheral wall section surrounding an opening having a circular rim section, means for sealing said opening comprising a circular diaphragm rigidly clamped at its periphery to said circular rim section, the periphery of said diaphragm being more than 20 times greater than its thickness, said diaphragm having a diameter exceeding 1½ times the wavelength of sound at the operating frequency, transducer means including a polarized ceramic piezoelectric disc rigidly bonded to one side of said diaphragm for vibrating said diaphragm, said disc being less than one-half the diameter of said diaphragm, and electrical connection making means comprising at least one electrode mounted on the unbonded side of said disc for imparting driving signals thereto for causing said disc and diaphragm to operate in a flexural mode.

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