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[54] ELECTROACOUSTIC TRANSDUCER WITH
CONTROLLED BEAM PATTERN

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[58] Field of Search 310/8, 8.2, 8.3, 8.5, 8.6,
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C

[56]

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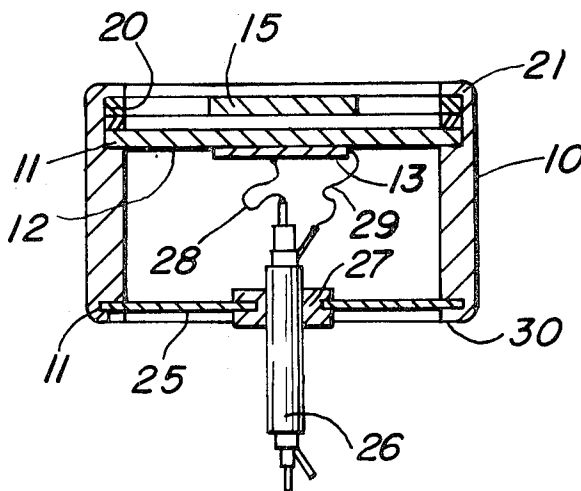
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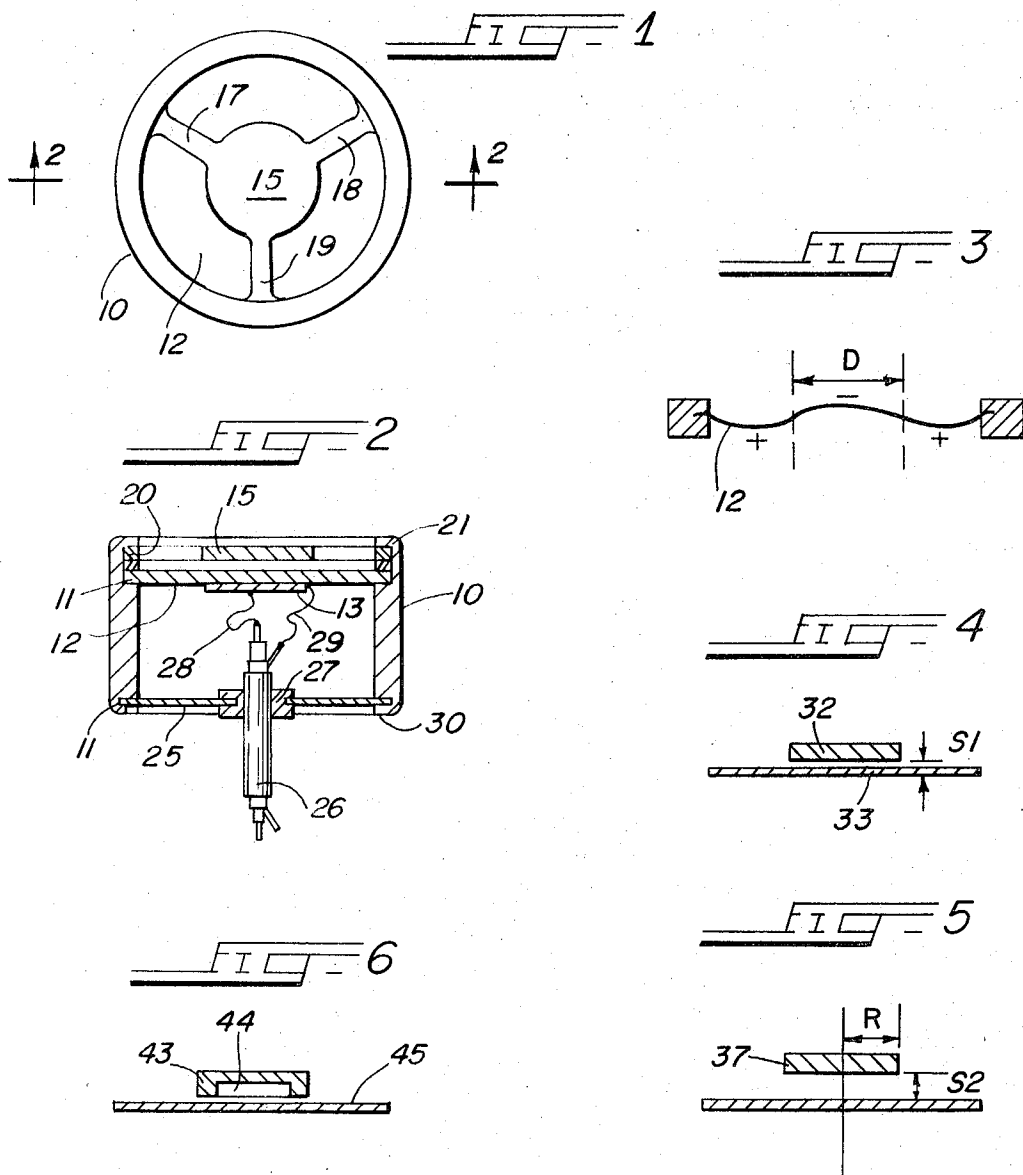
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ABSTRACT

A piezoelectric ceramic disc flexurally drives a thin vibratile diaphragm in its first overtone resonance mode. The center portion of the diaphragm has a displacement which is out of phase with respect to the displacement of the peripheral area of the diaphragm. A sound mask either precludes or selectively controls radiation from the center portion of the diaphragm.

2 Claims, 6 Drawing Figures





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ELECTROACOUSTIC TRANSDUCER WITH CONTROLLED BEAM PATTERN

This is a continuation-in-part of my co-pending application Ser. No. 10,748, filed Feb. 12, 1970, entitled "ELECTROACOUSTIC TRANSDUCERS OF THE BILAMINAAR FLEXURAL VIBRATING TYPE" now U.S. Pat. No. 3,638,052, and co-pending application Ser. No. 17,430, filed Mar. 9, 1970, now abandoned entitled "IMPROVEMENTS IN ELECTROACOUSTIC TRANSDUCERS," both of these applications being assigned to the assignee of this invention.

This invention relates to electroacoustic transducers, and more particularly to transducers especially adapted for radiating sound in a controlled beam pattern.

One way to manufacture an electroacoustic transducer assembly is to place a transducer element at the open end of a rigid housing structure for transmitting sonic energy. The element may also act as a housing closure. Here, the transducer element includes a vibratile diaphragm driven by a piezoelectric disc, in a complex flexural mode of vibration.

More specifically, it is convenient to operate the vibrating diaphragm at its first overtone circular resonance mode, which occurs at approximately 3.9 times the fundamental resonance frequency. For this overtone mode of operation, the center and outer peripheral portions of the diaphragm have displacements in opposite phase. That is, the center moves up while the periphery moves down, and vice versa, with flexure occurring about an annular node. This selected complex mode of vibration may be used to obtain a relatively broad directional pattern. It is possible to use this vibration mode to transmit relatively high intensity levels of sound in regions which are removed from the normal axis of the diaphragm. This form of transmission secures a more uniform sound distribution over a relatively large area in front of the vibrating diaphragm.

A square, freely suspended bilaminar transducer element may be driven at its fundamental flexural resonant mode. The four corners of this element vibrate in phase with each other. However, the phase of the corner displacements is opposite to the phase of the center displacement. For this type of a transducer element, a sound opaque mask may be mounted in close proximity to the center portion of the vibrating plate. Thus, the center of the flexural plate is not able to radiate the out of phase vibrations into the medium receiving the sonic energy.

Accordingly, an object of this invention is to provide new and improved electroacoustic transducers with better performance characteristics.

Another object of this invention is to provide vibratile diaphragms which produce concentrated beams of sound radiation at a specific operating frequency.

A further object of this invention is to provide inexpensive diaphragm assemblies which may also act as closures for the open ends of rigid housing structures.

Yet another object of this invention is to provide vibratile diaphragms which operate in desired overtone resonance modes, when driven at a specified frequency.

In keeping with one aspect of the invention, these and other objects are accomplished by providing a vibratile diaphragm driven by a piezoelectric transducer element, which is preferably a ceramic material. The

diaphragm vibrates in a specific overtone mode, selected to provide a beam-like pattern in a sound field. The energy distribution of this sound field is more concentrated in a beam extending outwardly from the transducer, along an axis normal to the surface of the vibratile diaphragm, than it would be concentrated if the same diaphragm were operating at its fundamental resonance mode.

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 plan view of the top or diaphragm side of a transducer incorporating one embodiment of this invention;

FIG. 2 is a cross-sectional view of the transducer taken along the line 2—2 of FIG. 1;

FIG. 3 schematically illustrates the peak amplitude displacement of the diaphragm when it is driven at its first overtone, nodal circle, resonant frequency;

FIG. 4 is a schematic representation of an edge-mounted diaphragm with a masking plate closely positioned near the center portion of the diaphragm;

FIG. 5 is another schematic representation, which is similar to the representation illustrated in FIG. 4; however, the masking plate is moved to a preferred distance away from the diaphragm surface; and

FIG. 6 is yet another schematic representation wherein the masking plate is undercut so that only the peripheral edge of the plate is in close proximity to the diaphragm surface.

In FIGS. 1 and 2, a section of cylindrical tubing 10 serves as a housing for the transducer assembly. A step-like annular recess 11 is machined into each end of the inner wall of the cylindrical tubing to provide a shoulder for supporting portions of the transducer assembly, and particularly a bilaminar vibratile assembly 12, 13.

A circular diaphragm 12 has a piezoelectric disc 13 attached to its center by means of a suitable rigid cement, such as epoxy. The relationship between the thicknesses and diameters of the ceramic disc 13, and the clamped diaphragm 12, are selected so that the first overtone concentric resonance mode of the bilaminar assembly, occurs at the desired frequency of operation, as illustrated in FIG. 3. Preferably, the optimum diameter for the piezoelectric disc 13 lies in a range extending from about one-fourth to one-half the diameter of the diaphragm 12. An alternate possibility is to use a ceramic disc 13 which covers the entire surface of the diaphragm 12. Before the diaphragm 12 is inserted into the open end of the housing structure 10, a waterproof cement may be applied to the periphery of the diaphragm. This waterproof seal is formed between the edge of the diaphragm and the shoulder 11 of the housing surface.

To complete the assembly of the transducer, a sound masking plate structure 15 is positioned over the central part of the disc. This mask comprises a central circular disc portion held by three radial spoke-like members 17-19. A spacing washer 20 is located over the spokes, as illustrated in FIG. 2. Then, the outer edge of the housing wall is crimped over at 21. This crimp locks the outer periphery of the masking plate structure 15 to thereby complete the assembly and provide a closure for the transducer housing 10. The opposite and open end of the housing, is closed with a waterproof seal by

a plate member 25 having an opening therein for giving passage to a cable 26. The cable 26 is sealed to the center opening in plate 25 by means of a rubber seal 27. The conductors in cable 26 are electrically connected to the ceramic disc by means of wires 28 and 29. Finally, the lower peripheral edge of housing 10 is crimped at 30 to completely seal the transducer assembly.

FIGS. 4, 5, and 6 diagrammatically illustrate various arrangements for constructing and spacing the sound masking plate 15 in relation to the diaphragm 12. The term "sound baffle" is used herein as generically descriptive of the structure shown in FIGS. 4-6. The sound masking disc 5, of FIG. 2, is schematically represented by the disc 32 in FIG. 4. The vibratile diaphragm 12, of FIG. 2, is schematically represented by the diaphragm 33 in FIG. 4. The schematic arrangement of FIG. 4 places the sound masking disc 32 is very closely spaced proximity S1 to the diaphragm 33. Therefore, sound radiating from the center portion of the diaphragm is prevented from being transmitted to the driven medium.

When the spacing S1 between the diaphragm 33 and sound masking plate 32 is sufficiently small, there is a thin air film having a viscosity which causes an absorption of the sound radiated from the center portion of the diaphragm. Preferably, space S1 is less than one-tenth the diameter of the masking plate. Hence, only the peripheral region of the vibratile diaphragm is able to radiate sound outwardly into the medium. The diameter of the masking plate 32 should be made approximately equal to the nodal diameter D of the diaphragm 12 (FIG. 3). This nodal diameter D is somewhat less than one-half the diameter of the diaphragm. The exact nodal diameter D may be determined experimentally by observing a dust pattern on the vibrating diaphragm when it is driven at its desired overtone frequency.

FIG. 5 illustrates another embodiment of the invention for enabling the sound radiation from the center portion of the diaphragm to combine with and enhance the sound radiation from the peripheral portion of the diaphragm. This enhancement is achieved by adjusting the spacing S2 so that the annular area represented by spacing S2 multiplied by the periphery of the sound masking disc 37, is approximately equal to the area of the masking disc 37. A further requirement to be satisfied in order to achieve the enhancement is that the average phase of the sound coming from the center region of the diaphragm is delayed by approximately one-half wavelength. This delay condition is achieved if the radius R of the masking plate 37 lies in the region extending from approximately one-fourth wavelength to one-half wavelength of the frequency of operation. If the radius R is less than one-fourth wavelength, the phase of the sound radiated from the center portion of the diaphragm destructively interferes with the sound radiated from the outer portion of the diaphragm. This interference causes a reduction in total radiation. If the radius R is larger than one-half wavelength, destructive interference also takes place for the sound energy generated by the center portion of the diaphragm. Therefore, this energy does not reach the region lying beyond the periphery of the sound masking disc 37.

Yet another embodiment of the invention prevents radiation from the center portion of the diaphragm (FIG. 6). Here, the sound masking plate 43 has an undercut area forming a cavity 44. The peripheral edge

surrounding the undercut area is then placed in close proximity to the diaphragm 45. By this design, there is an air chamber with a volume 44, terminated at a thin annular slit. As a result, there is a close spacing between the plate 43 and the diaphragm 45. This provides a low pass acoustic filter that prevents the transmission of the sound energy generated by the center portion of the diaphragm, provided that the cut-off frequency of the filter is made to lie below the frequency of the transducer operation.

The low frequency cut-off of the acoustic filter is easily controlled by a proper selection of the spacing between the masking plate periphery and the surface of the diaphragm 45. The principles required to make this selection are well known in the art of acoustic engineering. A wide range of operating frequencies and dimensions of structure may be chosen to satisfy any specific application requirement of a particular transducer design.

It may be possible or desirable under certain conditions to eliminate the sound masking plate 15 from the assembly in FIG. 2 and to operate the transducer at its first overtone resonance mode as illustrated in FIG. 3, without appreciable deterioration in the performance, provided that the diaphragm diameter does not exceed certain limits. If the clamped diameter of the diaphragm 12 leaves a free and unsupported diameter which does not exceed 3 wavelengths of sound in the transmitting medium less than 1 or 2 decibels of loss in sensitivity occurs because of the out of phase radiation at the center portion of the diaphragm. The beam pattern is not significantly deteriorated. Thus, the omission of the masking plate produces a satisfactory transducer at a minimum cost and with a negligible loss in performance.

Thus, it should now be apparent that the invention provides a way of controlling the beam pattern of an electroacoustic transducer. By way of example, spacing S1 (FIG. 4) provides one alternative for absorbing sonic energy and spacing S2 (FIG. 5) provides another alternative for enhancing sonic energy. In between these two alternatives, there are an infinite number of other alternatives. The other embodiments disclose still other alternatives. Thus, the term "selective" is used in the appended claims to mean the "state of being wherein one of the alternatives is selected" by the nature of the structure.

While several specific embodiments have been shown and described, it will 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 their true spirit and scope.

I claim:

1. An electroacoustic transducer comprising a tubular housing open on at least one end, vibratile diaphragm means having a center portion and an outer peripheral portion, means for sealing the periphery of said vibratile diaphragm to close the open end of said tubular housing and form a clamped vibratile disc, transducer means comprising a piezoelectric disc rigidly bonded to one side of said diaphragm, electrical conductor means attached to said piezoelectric disc for imparting electrical signals thereto, the center and peripheral portions vibrating in different modes which give rise to alternative sonic effects depending upon the de-

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gree of interaction between said modes of vibration, and sound baffle means for controlling the radiation of sound from the center portion of said diaphragm as compared with the radiation of sound from the outer peripheral portion of said diaphragm, said vibratile diaphragm operating at its overtone resonant frequency mode of operation, wherein said means for controlling the sound radiating from the center portion comprises a rigid sound masking disc positioned over the center portion of said vibratile diaphragm and spaced away from the radiation surface thereof, the diameter of said sound masking disc being less than one-half the diameter of the free and unsupported portion of said vibratile disc, and the spacing between said sound masking disc and said vibratile diaphragm being a linear distance approximately equal to a number derived by dividing the area of said masking disc by the periphery of said disc.

2. An electroacoustic transducer comprising a tubular housing open on at least one end, vibratile diaphragm means having a center portion and an outer peripheral portion, means for sealing the periphery of said vibratile diaphragm to close the open end of said tubular housing and form a clamped vibratile disc, transducer means comprising a piezoelectric disc rigidly

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bonded to one side of said diaphragm, electrical conductor means attached to said piezoelectric disc for imparting electrical signals thereto, the center and peripheral portions vibrating in different modes which give rise to alternative sonic effects depending upon the degree of interaction between said modes of vibration, and sound baffle means for controlling the radiation of sound from the center portion of said diaphragm as compared with the radiation of sound from the outer peripheral portion of said diaphragm, said vibratile diaphragm operating at its overtone resonant frequency mode of operation, wherein said means for controlling the sound radiating from the center portion comprises a rigid sound masking disc positioned over the center portion of said vibratile diaphragm and spaced away from the radiating surface thereof, the diameter of said sound masking disc being less than one-half the diameter of the free and unsupported portion of said vibratile disc, said masking disc having a recess forming a cavity at its center portion on the side of the mask which faces said diaphragm, characterized in that there is a close spacing between the peripheral surface of said undercut disc and the opposing surface of said vibratile diaphragm.

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