

Aug. 9, 1966

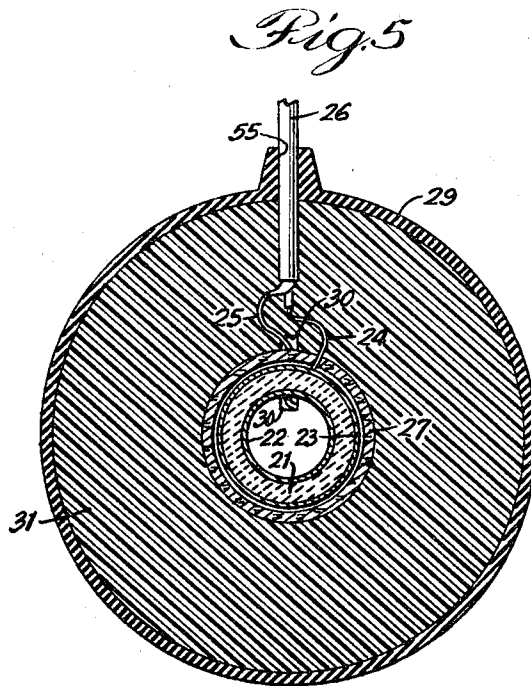
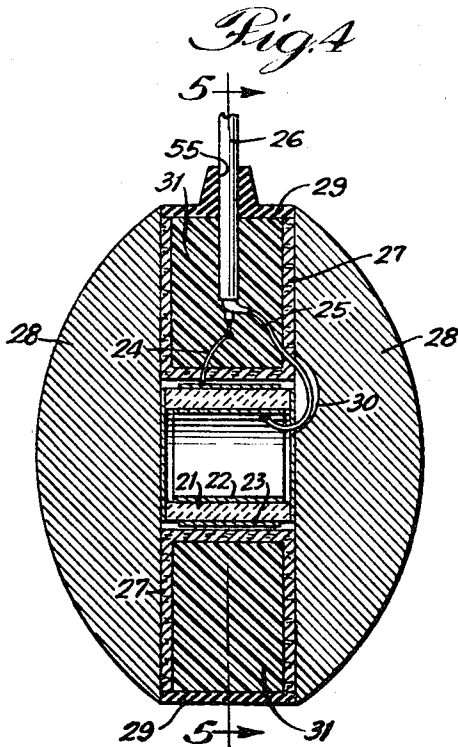
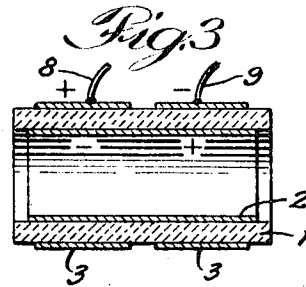
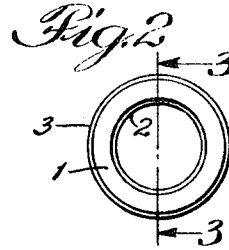
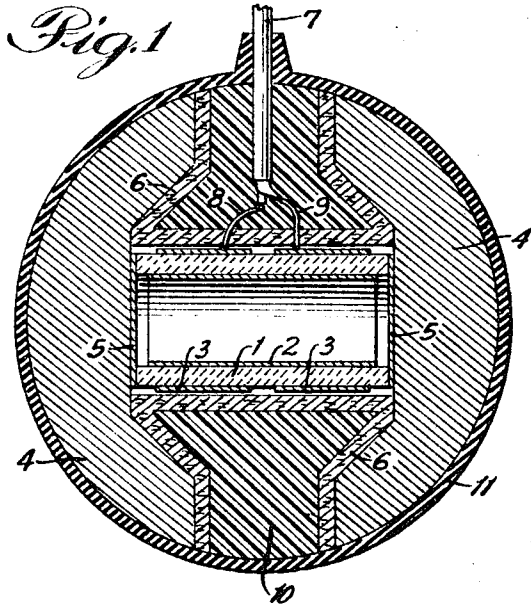
F. MASSA

3,266,011

HYDROPHONE

Filed Dec. 18, 1961

2 Sheets-Sheet 1



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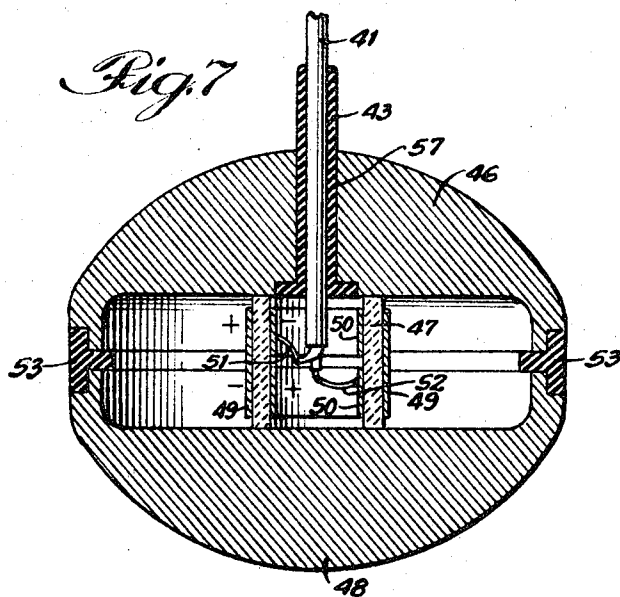
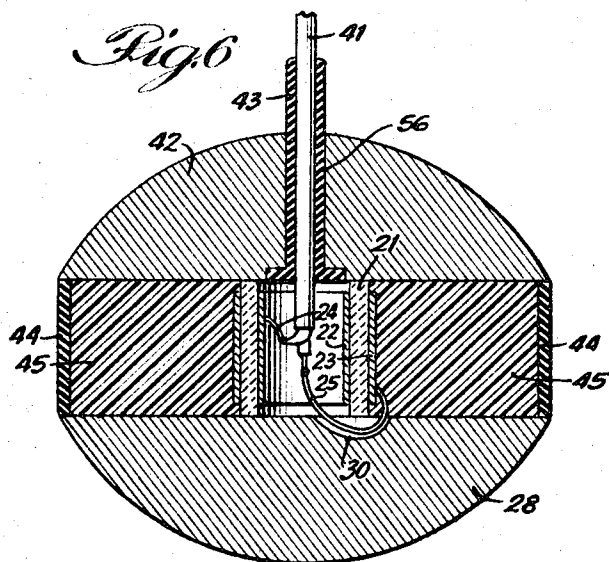
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2 Sheets-Sheet 2



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3,266,011

HYDROPHONE

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Filed Dec. 18, 1961, Ser. No. 160,021
6 Claims. (Cl. 340—8)

This invention relates generally to hydrophones, and more particularly to new and improved low cost hydrophones which find advantageous use in expendable systems, such as in sonobuoy and similar applications.

Those skilled in the art appreciate that it is a common practice in sonobuoy applications to employ a relatively long cable with the hydrophone so that it may operate under water to depths which may be greater than 50 ft. In order to avoid the use of a preamplifier in the submerged hydrophone element, it is necessary to provide a transducer structure in the hydrophone whose impedance is compatible with the impedance of the long cable so that there will be no serious loss in signal level through the attached cable.

One prior art attempt to solve this problem involves the use of a bi-laminar transducer construction in which two thin discs of polarized barium titanate are bonded together. The combined discs then are mounted at their periphery such that external pressure over the surface of the disc assembly causes bending over the disc area to induce additive voltages in the bi-laminar plates which are transmitted along the cable. The primary advantage of this prior art construction is that the electrical impedance of the active element may be kept low in comparison with the impedance of the cable and, therefore, a reasonably low cable coupling loss is realized. Another advantage of this design is that relatively high sensitivity is obtained by virtue of the stress multiplication that is caused in the active element by the bending mode of operation of the thin discs.

Skilled workers familiar with this prior art construction realize, however, that a very serious disadvantage of the bi-laminar transducer construction has been the relative mechanical weakness of the assembly in which the fiber stress in the thin discs under hydrostatic pressure heads of the order of 100 ft. becomes high enough to cause variations in the sensitivity of the hydrophone and, in some cases, actually cause mechanical failure of the assembly. An even more serious fault of this prior art construction lies in the inherent variation in the boundary conditions of the assembly imposed by the peripheral mounting. In actual structures of this type, the inherent variations in the effective stiffness of the peripheral mounting cause a large variation in the resonant frequency of the assembly which, in turn, introduces a large variation in the response characteristic of the hydrophone over the audible frequency range. In addition to the variation in the shape of the response curve, there is a corresponding high degree of variation in sensitivity which occurs with aging during storage of the assemblies and this results in low reliability in the performance characteristic of the hydrophone.

Accordingly, it is a general object of this invention to provide a new and improved hydrophone assembly which overcomes the problems of prior art constructions, as set forth hereinabove.

It is another object of this invention to provide an improved, low cost hydrophone having stable response characteristics and which is capable of operating with long cables.

It is still another object of this invention to increase the sensitivity of a hydrophone over the audible frequency range by the provision of novel mechanical amplification means that results in a stable vibrating system.

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It is a further object of this invention to provide a sensitive hydrophone of improved construction whose response characteristic is flat over most of the audible frequency range.

It is a still further object of this invention to provide a novel hydrophone comprising a relatively small number of low cost parts and having a stable vibrating system whose characteristics are not subject to variation with age.

The novel features which are characteristic of the invention are set forth with particularly in the appended claims. The invention itself, however, 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 taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a vertical cross-sectional view of one illustrative hydrophone construction embodying the invention;

FIGURE 2 is an end view of a tubular piezoelectric element advantageously utilized in the illustrative embodiment of FIGURE 1;

FIGURE 3 is a cross-sectional view taken along the line 3—3 of FIGURE 2;

FIGURE 4 is a vertical cross-sectional view of another illustrative hydrophone construction embodying the invention;

FIGURE 5 is a cross-sectional view taken along the line 5—5 of FIGURE 4;

FIGURE 6 is a vertical cross-sectional view of a further illustrative hydrophone construction embodying the invention; and

FIGURE 7 is a vertical cross-sectional view of still another illustrative hydrophone construction embodying the invention.

Referring now to the drawings, and more particularly to FIGURES 1, 2 and 3 thereof, the reference numeral 1 represents a hollow cylinder of polarized barium titanate or lead zirconate or any other piezoelectric material capable of converting alternating pressures to alternating voltage and vice versa. Those skilled in the art will understand that the piezoelectric material is shown as a cylinder in the drawing only for illustration, and that it would also be possible for the piezoelectric material to be in other forms, such as rectangular plates of piezoelectric crystals, including 45° X-cut Rochelle salt or 45° Z-cut ammonium dihydrogen phosphate, without departing from the principle of the invention.

The piezoelectric cylinder 1 has a conducting electrode surface 2 applied to its inner wall and two separated conducting electrode surfaces 3 applied to the outer wall, as shown. When the piezoelectric cylinder 1 is polarized, the D.C. polarizing potential is applied through the wall thickness in opposite directions from each of the separated electrodes 3 to the single inner electrode 2. The polarity of the D.C. polarizing potential is illustrated by the + and — signs in FIGURE 3. This method of polarization effectively places the two halves of the cylinder in series which doubles the voltage generated by the cylinder when pressure is applied along its axis as compared to the generated voltage that would be produced if a single electrode surface were used on each of the inner and outer walls of the cylinder. A more complete discussion of the technique of multiple polarization through a ceramic element and the advantages that may be realized thereby may be found in U.S. Patent 2,967,957, issued to Frank Massa on January 10, 1961, and these details are not repeated herein since they do not form a part of the present invention.

Advantageously, the piezoelectric cylinder 1 is bonded between two end plates 4 by means of a suitable adhesive, such a cement film 5. The outer surfaces of the plates

4 preferably are spherical in shape so as to minimize turbulence caused by the motion of the structure through the water during its use. However, those skilled in the art will readily appreciate that the end plates 4 need not be limited to a spherical shape and could, for example, be plane discs without affecting the acoustic operation of the invention.

A thin layer of low acoustic impedance material forming a lining 6, such as cork or a molded mixture of cork and rubber, advantageously may be applied to the outer surface of the piezoelectric cylinder 1 and to the inner faces of the end plates 4. The purpose of this lining is to prevent acoustic coupling between the external medium and the covered surfaces. A more complete discussion of the reasons for uncoupling those undesired surfaces which are not to take part in the radiating system may be found in U.S. Patent 2,613,261, issued to Frank Massa on October 7, 1952, and need not be reiterated herein.

Electrical leads 8 and 9 are connected to each of the electrode surfaces 3 and pass through suitable slits or openings in the lining material 6 which surrounds the piezoelectric cylinder 1. The respective conductors of electrical cable 7 are connected to the leads 8 and 9 as shown. After making these electrical connections, the region between the inner faces of the plates 4 and the outer surface of the piezoelectric cylinder 1 is filled or potted with an electrical insulating waterproof compound 10, such as epoxy or the like. As a result of this potting operation, the cable 7 becomes permanently anchored to the hydrophone structure and the hydrophone can now be suspended from the cable 7 without difficulty. An outer waterproof layer 11, which may be applied by dipping, by brushing or by molding, covers the outer surface as illustrated in FIGURE 1 to complete the assembly.

The principle of operation of the novel hydrophone assembly above described will now be given. When the assembly is placed in a sound field, the sound pressure striking the outer surface is transferred by the end plates 4 to the ends of the polarized piezoelectric cylinder 1. The pressure changes applied to the ends of the cylinder 1 generate corresponding electrical voltages, in a well understood manner, which are transmitted along the cable 7 for amplification and use. Conversely, if an electrical voltage is applied to the cable 7, the piezoelectric cylinder 1 will be set into vibration, which in turn cause vibrations of the end plates 4 and a corresponding sound wave will be generated in the medium within which the transducer is immersed.

In accordance with an important feature of the present invention, the hydrophone assembly has an electrical impedance which is low compared to the impedance of the relatively long cable 7 and the electrical signal, therefore, is transmitted without great loss. In addition, a large pressure amplification between the sound wave in the medium and the active surface of the transducer material is achieved as a result of the unique hydrophone construction. A still further feature of this invention is that in the selection of cylindrical element 1 having a relatively thin wall, a relatively high electrical capacitance may be realized for the assembly. The ratio of the area of the end plate 4 to the cross sectional area of the cylindrical shell 1 is proportional to the pressure amplification and, therefore, a measure of the sensitivity increase of the hydrophone. In an illustrative hydrophone structure constructed in accordance with the invention and having an outside diameter in the neighborhood of 2 inches, a flat response over the entire audible frequency range to about 10 kc. with a pressure amplification in the approximate range 10 to 100 times was realized. Further, with the use of either barium titanate or lead zirconate cylinders, an electrical capacitance greater than 1000 mmf. was achieved, which can be coupled to relatively long cables without suffering large coupling losses.

The maximum permissible pressure amplification in the present invention largely is determined by two operational

requirements. One limitation is the frequency range desired for flat response and the second is the maximum depth of underwater operation. The larger the ratio of the area of the end plates 4 to the cross sectional area of the cylindrical shell 1, the lower will be the resonant frequency of the system; therefore, the lowest frequency at which resonance can be permitted determines one limitation of the pressure multiplication factor. The second limitation is determined by the depth of operation. The stress in the cylinder 1 due to water pressure is multiplied by the same factor that multiplies the sensitivity; therefore, for deep water use, the limitation imposed by the maximum desired static pressure on the piezoelectric element will limit the ratio of the areas accordingly.

An alternate design embodying the teachings of the present invention is illustrated in FIGURES 4 and 5. This embodiment employs a polarized piezoelectric cylinder 21 with a single inner electrode 22 and a single outer electrode 23 as the active elements. For this construction, those skilled in the art may prefer lead zirconate titanate to barium titanate because the former has a higher piezoelectric coefficient and, therefore, generates a higher voltage for a given applied pressure. However, either may be used, as desired.

The piezoelectric cylinder 21 is cemented between the two end plates 28, in the same manner as described in connection with the embodiment of FIGURES 1 to 3. An electrical lead 25 is attached to the inner electrode 22 and an electrical lead 24 is attached to the outer electrode 23. In order to permit passage of the lead 25 from the inner surface of the cylinder 21 to the outer region of the cylinder, a small slot 30 may be provided in the inner wall of the plate 28, as shown, which slot forms a channel for holding the lead 25 out of the way of the cemented edge of the piezoelectric cylinder 21 during assembly. The respective conductors of an electrical cable 26 are connected to the leads 24 and 25 as shown. Advantageously, a thin layer of low acoustic impedance material 27 is used as a liner for the outer surface of the cylinder 21 and the plane faces of the end plates 28. The liner 27 serves the same function as the liner 6 serves in FIGURE 1. After completing the mechanical assembly, the region between the inside surfaces of the end plates 28 and the outside surface of the cylinder 21 is filled with epoxy or a similar waterproof compound 31. When the epoxy 31 is poured into place, a suitable form advantageously may be used to confine the material as desired. In FIGURE 4, there is shown the contour of the outer periphery of the epoxy slightly recessed from the outer periphery of the end plates. A central sleeve or band 29, formed of resilient material such as rubber, is positioned around the epoxy fill with a tight fitting clearance hole 55 formed therein to fit over the cable as shown in FIGURE 4. When making the final assembly of the central band 29, a rubber cement may be utilized to hold the band 29 firmly in place.

FIGURE 6 shows still another embodiment of a hydrophone employing the basic principles of the invention. In this embodiment the cylinder assembly structure shown in FIGURE 4 is effectively rotated through 90° with the cable 41 passing through a hole 56 drilled through the center of the end plate 42. Advantageously, a rubber sleeve 43 is cemented over the end of the cable 41, using any suitable type of rubber cement, and the outer surface of the rubber sleeve 43 is, in turn, cemented to the wall of the hole 56 which is drilled through the end plate 42. A polarized piezoelectric cylinder 21, which may be identical to the cylinder 21 employed in the embodiment of FIGURE 4, is similarly provided with an inner electrode 22 and outer electrode 23. The end plate 28 may be identical to the end plate 28 of FIGURE 4 embodiment and it likewise may contain a small recessed slot 30 in the inner wall, as shown in FIGURE 6, which forms a channel to serve as a passageway for the lead 25. The lead 25 is electrically connected to the outer electrode

surface 23 and to one of the conductors of the cable 41, as illustrated. A second lead 24 provides electrical connection from the inner electrode 22 to the other terminal end and conductor of the cable 41.

The piezoelectric cylinder 21 is bonded to the plane surface of the end plates 42 and 28 using an epoxy or other suitable cement. A thin sleeve or band 44 of a semirigid plastic, rubber, or other suitable material, is positioned near the outer peripheries of the end plates 42 and 28 to enclose the epoxy potting. Although not shown in the embodiment of FIGURE 6, those skilled in the art will appreciate that a layer of low acoustic impedance material, such as cork, may be provided to line the outer surface of the cylinder 21 and the plane surfaces of the end plates 28 and 42, in the same manner that the lining material 27 is used in FIGURE 4. Alternately, the layer of low acoustic impedance material may be eliminated and the region bounded by the plane surfaces of the end plates 42 and 28 and the outer surface of the cylinder 21 may be filled with a foam type of plastic filler 45 which has sufficient rigidity to withstand the hydrostatic pressure to which the hydrophone is subjected and which does not serve as a good transmitting medium for the sound wave. The entrapped air bubbles within the aggregate of the foam plastic or epoxy serve as a suitable insulator against the passage of the sound waves through the material.

The outer sleeve 44, which is sealed to the peripheries of the end plates 42 and 28, serves as a retaining wall for pouring the filling compound 45. The necessary criterion for specifying the mechanical properties of the retaining sleeve 44 is that the mechanical stiffness of the sleeve for a force applied parallel to its cylindrical axis must be very much lower than the stiffness of the piezoelectric cylinder 21 for the same force applied parallel to its cylindrical axis. For satisfactory operation of the hydrophone, it has been found that if the material chosen for the sleeve 44 has a modulus of elasticity less than one million p.s.i., the sensitivity of the hydrophone is not appreciably reduced provided the piezoelectric cylinder 21 is formed of barium titanate or lead zirconate or any other similar material.

In FIGURE 7 there is illustrated another embodiment of a similar construction to the embodiment of FIGURE 6. In this embodiment, the cable 41 passes through a hole 57 in the end plate 46 and a rubber sleeve 43 is cemented both to the cable 41 and to the wall of the hole 57 in the end plate 46 in the same way that was described in the embodiment of FIGURE 6. The polarized ceramic cylinder 47 is employed as a piezoelectric voltage generator in the same way that the polarized cylinder 21 was employed in FIGURE 6 embodiment. In FIGURE 7, there is shown a single outer electrode surface 49 and two separate inner electrode surfaces 50 on cylinder 47. The application of the D.C. potential during polarization of the piezoelectric cylinder 47 is made in opposite polarity from each separated inner electrode to the common outer electrode. This dual polarization through the use of divided electrodes accomplishes exactly the same results as was described in connection with the embodiment of FIGURE 1 in which the separated electrodes were placed on the outer surface of the cylinder instead of on the inside surface. The reason for placing the separated electrodes on the inner surface of the piezoelectric cylinder in this embodiment is to make it convenient for connecting the electrical leads 51 and 52 to the terminal ends of the cable 41, as shown, which avoids the necessity for providing a groove in the end plate 48.

In the process of assembling the hydrophone structure of FIGURE 7 embodiment, it is advantageous to assemble the electrical cable and wiring, and then to cement the piezoelectric cylinder 47 to the flat surface of the end plate 46 using an epoxy type cement or any other suitable bonding material. Then a sealing rubber ring

53, having a T-shaped cross section, as illustrated is placed into the recess provided at the periphery of end plate 46. Finally, an epoxy cement is applied to the end surface of the piezoelectric cylinder 47 that is to become attached to the plane face of end plate 48 and rubber-to-metal cement is also applied over the peripheral machined surfaces of the end plate 48. The end plate 48 is pressed into position to firmly bond the piezoelectric cylinder 47 to the flat surface of the plate 48 and also to firmly lock the sealing rubber ring 53 in place. When the cements have set, the structure is ready for use without any necessity for filling the empty annular cavity that remains between the plane surfaces of the plates 46 and 48. It is, of course, obvious to those skilled in the art that, if desired, the ceramic cylinder 21 of the FIGURE 6 embodiment may be utilized with the assembly of the FIGURE 7 embodiment, and an undercut slot provided in plate 48 similar to the slot 30 in plate 28. It is a feature of this invention that the structure of FIGURE 7 and the technique of assembling the few parts that are involved produce a very rugged hydrophone having exceptionally uniform performance characteristics at a very low manufacturing cost.

An additional operating advantage of the hydrophone construction embodiments illustrated in FIGURE 6 and FIGURE 7 is that the directional response in a horizontal plane, which will be at right angles to the axis of the suspended cable, will be omnidirectional, because of the acoustic symmetry of the structure in the horizontal plane. The construction illustrated in FIGURE 1 and FIGURE 4 will show some variation in the directional pattern in the horizontal plane at the high frequency region when the overall dimensions of the hydrophone structure become greater than approximately $\frac{1}{4}$ wavelength of sound in the medium.

The operation of the hydrophones shown in the FIGURES 4, 6 and 7 embodiments is identical in principle to the operation of the hydrophone in the FIGURE 1 embodiment. All of these structures employ pressure amplification and all employ a thin walled piezoelectric element for obtaining an electrical capacitance sufficiently large to permit use of a long cable without incurring a large loss in the transmission of the generated electrical signal. All of the hydrophone embodiments disclosed herein produce a flat response characteristic from a few cps. to several kilocycles. It is possible to set the resonant frequency of the vibrating systems of any of the embodiments illustrated at a value higher than 5 or 10 kc., which means that flat response to 5 kc. or 10 kc. is easily possible. Those skilled in the art will understand that because the piezoelectric material is used in its normal compressional mode of vibration, the performance characteristics of the improved hydrophone are inherently very uniform among large quantities of mass produced structures, and that these uniform characteristics remain very stable over long periods of time.

While there has been shown and described a specific embodiment of the present invention, it will, of course, be understood that various modifications and alternative constructions may be made without departing from the true spirit and scope of the invention. Therefore, it is intended by the appended claims to cover all such modifications and alternative constructions as fall within their true spirit and scope.

What is claimed as the invention is:

1. In an electroacoustic symmetrical transducer for operating underwater, the combination of a transducer element having a pair of opposite end faces in parallel planes and capable of generating an alternating voltage upon application of an alternating pressure to said end faces, electrode means associated with said transducer element for delivering said alternating voltage, a pair of similar rigid end plates on a common axis having spaced facing generally flat surface portions in parallel planes transverse to said common axis and having con-

vex outer surfaces symmetrical about said common axis, the ratio of the projected area of each end plate to the area of each end face of said transducer element being in the approximate range of 10 to 100, means bonding said end faces of said transducer element to said facing generally flat surface portions of said end plates with said transducer element being symmetrically disposed on said common axis for defining a peripheral space between said end plates and around said external surface of said transducer element, cable means connected electrically to said electrode means and arranged to support said transducer at a peripheral point such that said end plates are maintained in symmetrical relation on said common axis, and low acoustic impedance means at least partially filling said peripheral space and arranged to provide support to said cable and end plates to maintain both end plates in symmetrical relation with said common axis such that the compliance of the transducer is substantially determined by the compliance of said transducer element.

2. In an electroacoustic transducer as defined in claim 1, said cable means extending out through said low acoustic impedance means midway between said end plates.

3. In an electroacoustic transducer as defined in claim 1, one of said end plates having a central opening there-through a said common axis, and said cable means extending out through said central opening in said one of said end plates thereby to obtain an omnidirectional response in a horizontal plane at right angles to the axis of said supporting cable means.

4. In an electroacoustic transducer as defined in claim 1, said low acoustic impedance means comprising relatively thin liner elements of low acoustic material attached to the solid wall surfaces of said end plates which define said peripheral space and additional rigid material between said liner elements.

5. In an electroacoustic transducer as defined in claim 1, said low acoustic impedance means comprising a foam type plastic filler having sufficient rigidity to withstand high hydrostatic pressures.

6. In an electroacoustic transducer as defined in claim 1, said low acoustic impedance means comprising a sealing ring having a T-shaped cross-section to provide a portion extending into said peripheral space for providing said material support of said end plates.

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