

Jan. 24, 1956

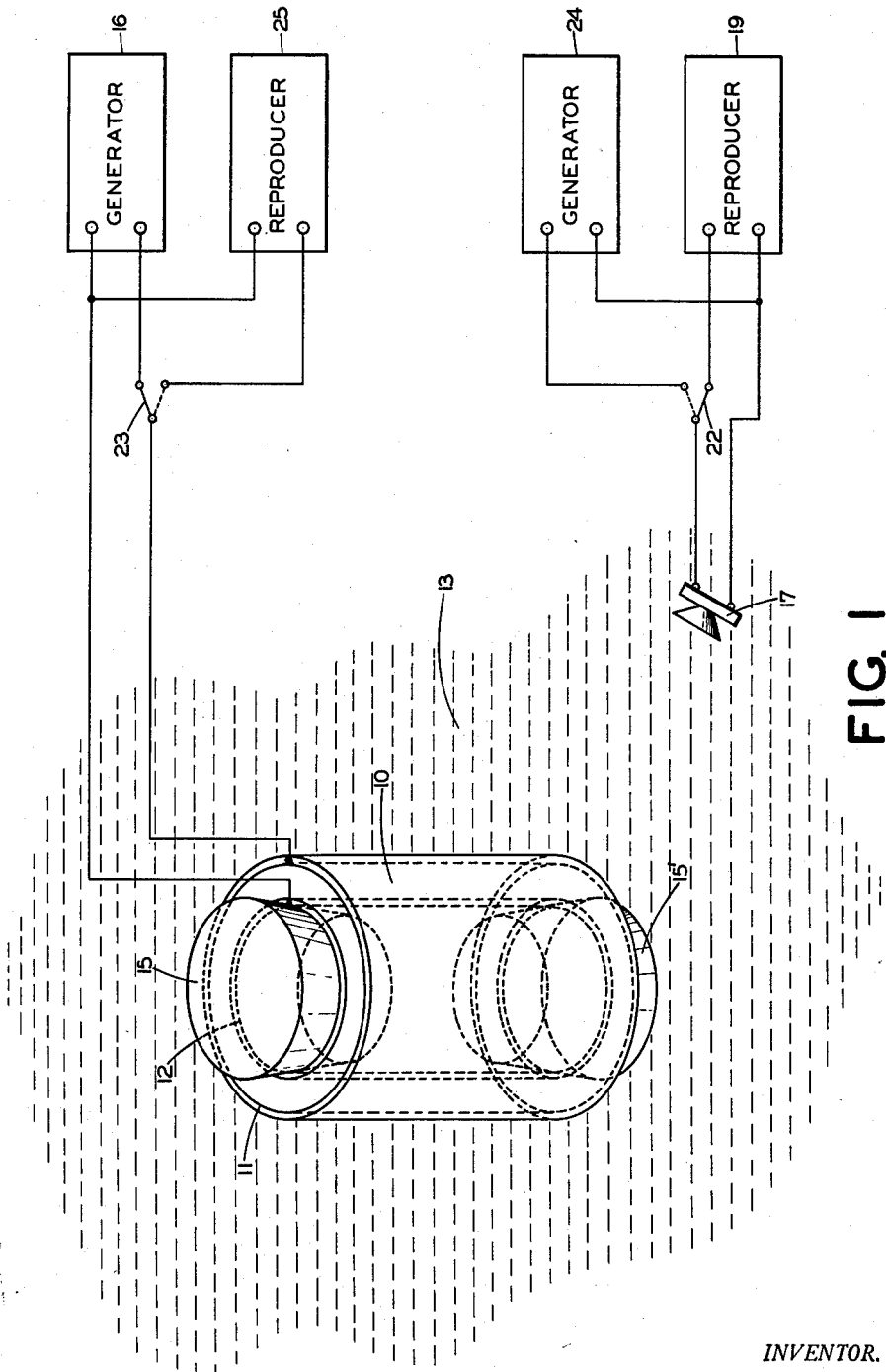
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2,732,536

CYLINDRICAL ELECTROMECHANICAL TRANSDUCER

Filed May 5, 1950

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

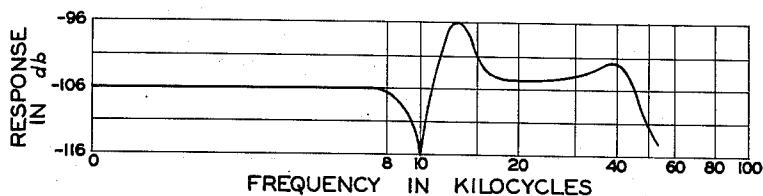


FIG. 2

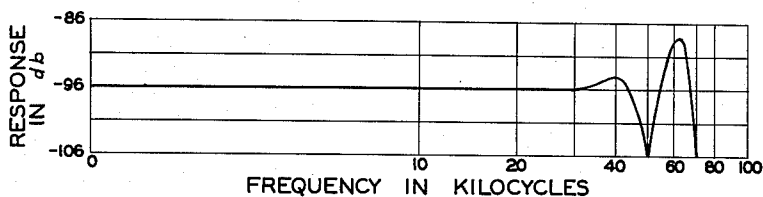


FIG. 4

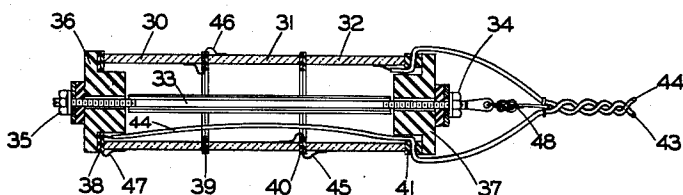


FIG. 3

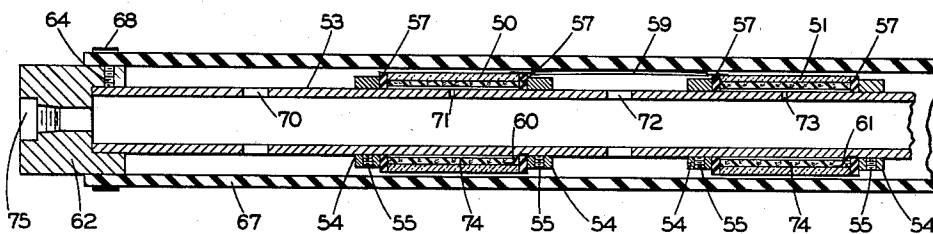


FIG. 5

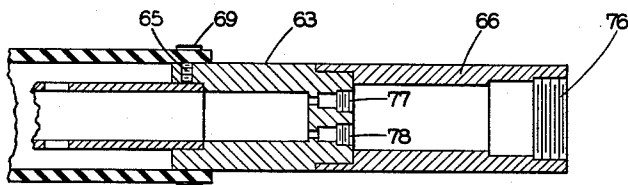


FIG. 6

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CYLINDRICAL ELECTROMECHANICAL TRANSDUCER

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Application May 5, 1950, Serial No. 160,365

14 Claims. (Cl. 340—8)

This invention relates to a transducer for operation in a medium such as water and for transducing therein between electrical and mechanical types of energy. Specifically, the transducer is useful for translating electrical energy into mechanical energy or for translating mechanical energy into electrical energy.

Transducers of the type mentioned above are widely used for translating electrical energy into mechanical energy or vice versa. Specifically, piezoelectric materials and magnetostrictive materials have been used for this purpose. More recently barium titanate, when treated in a particular manner, has been found to have transducing properties which are quite beneficial in certain applications.

Also, it has been known for some time that a cylinder has desirable transducing characteristics for certain applications. It is difficult, however, to provide a cylindrical transducer with the piezoelectric crystals of the prior art for the reasons that, due to their characteristics of growth, it is impossible to provide a cylindrical transducer which moves radially at all points. Such a device can be approximated by the use of single crystals if a large mosaic of crystals is used but this provides a very expensive structure. The use of magnetostrictive materials for the same purpose also has certain inherent disadvantages. On the other hand, it is known that polycrystalline barium titanate which has been vitrified and treated in a manner to provide transducing properties can be made to have a radial action at all points on the surface when in a cylindrical form. The use of a transducer in a liquid such as water, for example, can provide a characteristic which is symmetrical at all points around the surface of the cylinder and in a plane normal to the axis of the cylinder. It, therefore, becomes very desirable in many applications to utilize a tube of electromechanically sensitive dielectric material of the nature of barium titanate to provide a transducing action in a liquid, either for changing electrical energy to mechanical energy, or acoustical energy in the liquid, or for changing such acoustical energy in the liquid into an electrical form.

In the copending application Serial Number 154,037, filed April 5, 1950, in the name of Robert A. Langevin and assigned to the same assignee as the present invention, there is described a transducer of the general type here under consideration which provides certain advantages by the use of a hollow cylindrical transducer element which has a ratio of wall thickness to diameter chosen in a specific manner. Applicant has discovered that, for certain applications of a device of the general type here under consideration, decided advantages can be obtained when the length of the cylinder is proportioned with reference to the diameter or circumference of the cylinder in a particular manner.

It is an object of the invention to provide an improved transducer for use in changing electrical energy to mechanical energy, or vice-versa.

It is still another object of the invention to provide a transducer in the form of a hollow cylinder and which has a substantially improved transducing characteristic over a very wide range of frequencies.

It is a specific object of the invention to provide a

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hollow cylindrical transducer for operation within a liquid with the outside surface of the cylinder acoustically exposed to the liquid and with the inside surface of the cylinder substantially acoustically shielded from the liquid and in which the dimensions of the cylinder are proportioned to provide a relatively uniform response over a very wide range of frequencies.

In accordance with the invention a transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy comprises a hollow cylinder having a length not substantially greater than half its circumference and of electromechanically sensitive material. This transducer also comprises means, including electrodes on the cylinder and provisions for causing one surface of the cylinder to be acoustically exposed to the above-mentioned medium and the other surface of the cylinder to be acoustically shielded from the medium when the cylinder is immersed in the medium, for applying one of the above-mentioned types of energy to the cylinder and for deriving the other above-mentioned types of energy from the cylinder.

For a better understanding of the invention together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

Fig. 1 of the drawings illustrates a transducer in accordance with the invention which can be utilized either for translating electrical energy to mechanical energy, or for translating mechanical energy to electrical energy; Fig. 2 represents a frequency-response characteristic of a transducer used as a microphone and of the general type under consideration and proportioned in accordance with the teaching of the prior art; Fig. 3 shows the frequency-response characteristic of a device proportioned in accordance with the teachings of the present invention; Fig. 4 illustrates an underwater sound microphone which is constructed in accordance with the teaching of the invention; and Figs. 5 and 6 illustrate still another embodiment of an underwater microphone constructed in accordance with the teaching of the invention.

Fig. 1 of the drawings illustrates a preferred embodiment of the invention. Here a transducer 10 is illustrated in the form of a hollow cylinder of electromechanically sensitive dielectric material which may be barium titanate. This cylinder has an electrode 11 on the outside surface and an electrode 12 on the inside surface thereof and, when in operation, is adapted to be immersed in a liquid such as water 13. The arrangement includes means for causing the outer surface of the cylinder to be acoustically exposed to the water 13 and for causing the inner surface of the cylinder to be acoustically shielded from the water when the cylinder is immersed in the water. Specifically, plugs 15 and 15' are provided for the cylinder and these plugs may be comprised of cork, rubber, or any other suitable material. An electrical generator 16 is shown for applying electrical energy to the electrodes 11 and 12. Also, a microphone 17 is included in the liquid 13 in order to generate electrical currents corresponding to the mechanical energy introduced into the liquid by the operation of the cylinder 10 as a transducer for converting the electrical energy of generator 16 to mechanical energy, or specifically to sound energy, in the water 13. This sound energy, of course, may be very much above any audible frequency. A reproducer 19 is illustrated for reproducing or utilizing the energy from the transducer or microphone 17. The reproducer 19 could, for example, be a cathode-ray tube or a loud speaker or any other reproducing device depending upon the purpose for which the apparatus is to be used.

In considering the operation of the device of Fig. 1 as so far described, it will be seen that electrical energy

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generated by the generator 16 is applied to the electrodes 11 and 12 thereby causing, under the conditions to be described in more detail hereinafter, a mechanical action in the cylinder 10 which, in turn, causes sound waves to be propagated into the water 13. These sound waves are picked up by the microphone 17 and reproduced on the reproducer 19 in any desired manner. As described therefore, the arrangement of Fig. 1 is one for changing an electrical input to transducer 10 into a mechanical output which comprises the sound energy propagated into the water 13.

Alternatively, the arrangement of Fig. 1 can be used in the reverse manner. In order to illustrate this use of the arrangement, switches 22 and 23 are shown. When these switches are in their dotted position, the transducer 17 is connected to a generator 24 and the electrodes 11 and 12 are connected to a reproducer 25. Under these conditions, the generator 24 is effective to excite the device 17 and produce sound energy in the liquid 13. This sound energy impinging on the cylinder 10 is transformed by the cylinder 10 into electrical energy and means, including electrodes 11 and 12, are provided for deriving and utilizing this electrical energy. Specifically, the electrical energy is reproduced by reproducer 25 which again may be an oscillograph or any other device which can be actuated by the electrical energy.

In order to explain in detail applicant's novel method of proportioning the transducer 10, it is deemed desirable to assume that the device is operated with the switches 22 and 23 in the dotted position. One such cylinder comprised of commercially available barium titanate, that is substantially pure barium titanate except for commercial impurities, and prepared in the manner indicated in detail in the above-mentioned Langevin application, provided a frequency response characteristic as illustrated in Fig. 2. This ceramic element was 6" long had an outside diameter of 1½" and a wall thickness of ¼". When connected as described, devices of the general type here under consideration are suitable for use as underwater listening devices, for example, for detection of submarines. Fig. 2 shows the frequency response characteristic of the device under consideration. It will be seen that the response characteristic is substantially flat in the lower portion of the range but that there is a decided dip at about 10 kilocycles and a resonant response at about 13 kilocycles. There is an additional resonant response at about 40 kilocycles. Inasmuch as for many applications, specifically for use in applications for detecting submarines, it is essential that such apparatus have a response which is flat over a very wide frequency range, the characteristic of Fig. 2 is totally inadequate for the purpose. It is desirable for applications in most underwater listening devices of the type here under consideration that the apparatus have a response which is substantially flat to at least 30 kilocycles, and a flat response to 40 or even 60 kilocycles is frequently required. Applicant has provided a response of this type by the apparatus illustrated in Fig. 3.

In Fig. 3 there are provided three titanate tubes 30, 31, and 32 of the type here under consideration. Each tube is electroded on its inside and outside surface. These tubes correspond to tube 10 of Fig. 1. These hollow cylinders are proportioned to have a length which is not substantially greater than half the mean circumference for a purpose which will be explained in more detail later. The cylinders 30, 31, and 32 are held in an axial aligned position by means of metal rod 33 through the cylinders. The rod 33 clamps the cylinders by means of nuts 34, 35 and pieces 36 and 37 which, for example, may be of a phenolic condensate such as "Bakelite." Rubber washers 38, 39, 40 and 41 are provided at the ends of the tubes in order to prevent the tubes from being rigidly clamped and to allow the slight end motion in each case which is necessary for the present purposes. The tubes 30, 31 and 32 are electrically connected in series by means of leads 43 and 44 and by means of a

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connection 45 between the outside electrode of cylinder 32 and the inside electrode of cylinder 31 and connector 46 between the outside electrode of cylinder 31 and the inside electrode of cylinder 30. The lead 43 is connected to the inside electrode of cylinder 32 and the lead 44 is connected to the outside electrode of cylinder 30 by means of a connector 47. Alternatively, if desired, the tubes 30, 31, and 32 may be connected in parallel.

A string or cord 48 is provided between an eye in one end of the rod 33 and the leads 43 and 44 in order to prevent tension from being applied to the points at which the leads 43 and 44 are connected when the device is carried or handled by means of the leads 43 or 44.

The three-cylinder device just described may be connected directly in place of the single-cylinder device in the circuit of Fig. 1. The device of Fig. 3 was found to have the characteristic as illustrated in Fig. 4 when operated in water under the same conditions described above with reference to Fig. 1. Here it will be seen that the response is relatively flat to approximately 40 kilocycles and that a decided improvement in the response has been effected.

While applicant does not wish to be limited to any particular theory of operation of the device, it is thought that the reason for the difference in the response characteristic for the Fig. 1 device and for the Fig. 3 device is as follows. The single tube illustrated in Fig. 1 and under the conditions described has two principal resonant characteristics. One of these corresponds to a length mode of resonance and the other corresponds to a circumferential mode of resonance. The frequency of the length mode of resonance varies inversely with the length of the tube involved and the circumferential mode of resonance varies inversely as half the circumference. Therefore, it appears that the length resonance of the Fig. 1 device is represented by the hump in the characteristic of Fig. 2 at about 13 kilocycles, and that the circumferential resonance is represented by the hump at about 40 kilocycles. The length resonance is preceded by a strong dip at about 10 kilocycles, probably for the reason that the titanate material under consideration tends to expand both in length and in circumference due to electrical excitation and tends to contract in circumference while expanding mechanically due to its mechanical action, resulting in a phase relationship between the electromechanical activity and the pure mechanical activity which produces the dip at 10 kilocycles. In any event, the device of Fig. 3 appears to have its length resonance at about 60 kilocycles, so that it is above the circumferential resonance which lies at about 40 kilocycles. Under these conditions, the response characteristic of Fig. 4 is provided resulting in a very great improvement in the operation of the device.

Actually, the proportioning of the ceramic cylinders is not critical so long as the length of each individual tube is not substantially greater than half the outside circumference of the tube. In the device illustrated in Fig. 3, the length of each tube is substantially equal to two thirds of half the circumference. It has been found that very good results can be provided if the length is exactly equal to or just slightly more than half the circumference of the tube. Such a proportioning provides a tube which has only a slight hump in the vicinity of the lower mode and a somewhat stronger response at the higher resonance mode with no dip whatever between the two resonant responses. Such a device has been provided utilizing the teachings described herein which has a strong response to about 45 kilocycles, which is substantially flat to about 35 kilocycles, and which has no strong dips present in the response characteristic.

The device just described may be utilized as a listening device for underwater sounds and, alternatively, when the switches are in the full-line position illustrated in Fig. 1, the device may be utilized as a generator of underwater sounds. In either case the response characteristic is sub-

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stantially uniform around the axis of the tubes for each plane normal to the axis. The response is strongest for the direction perpendicular to the axis of the cylinder. The directional lobe of the device just described becomes sharper as the length of the tube becomes longer. Thus a very long structure can be provided by the use of additional ceramic tubes which is very directional normal to the axis, that is, the principles of the invention can be utilized by dividing the length of the electro-mechanically responsive element into sections as taught in connection with Fig. 3.

Actually, in a long-line device of the type under consideration, it is not necessary to provide a substantially continuous tube of electromechanically responsive material as illustrated in Fig. 3. Specifically, in the long-line device, the individual tubes can have a substantial spacing therebetween as illustrated in Figs. 5 and 6. The device of Figs. 5 and 6 comprises tubes of electromechanically sensitive material 50, 51, etc., having a substantial spacing between the ends of the tubes. The device illustrated may be of any length and one end is illustrated in Fig. 5 and the other end is illustrated in Fig. 6. In the device under consideration, the electromechanically sensitive elements are clamped on a metallic tube 53 by means of metal rings 54, each of which have a threaded hole 55 for receiving a set screw in order to hold the rings 54 and the tubes 50, 51, etc., in place. The ends of the tubes 50, 51, etc., are clamped against the rings 54 by means of rubber washers 57. The outside electrode of the ceramic tubes 50, 51, etc., are connected together by means of leads 59 and the inside electrodes of the ceramic tubes are connected to the metal tube 53 by means of connectors 60, 61, etc. The tubes 50, 51, etc. are thus connected in parallel and the terminal connections for the device are not illustrated. The device of Figs. 5 and 6 is preferably oil-filled and, for the purpose of retaining the oil around the device, there is provided a housing which comprises metallic end sections 62 and 63 adapted to be clamped to the tube 53 by means of set screws in the threaded holes 64 and 65. A fitting 66 to receive an electrical connector for the device is provided and an acoustically transparent rubber housing or tube 67 between the end plugs 62 and 63 effectively retains the oil inside. The housing 67 is held on the end plugs 62 and 63 by means of clamps 68 and 69. In order to allow free access of the oil to all parts of the device, holes 70, 71, 72 and 73 are provided in the tube 53 but a pressure-release covering 74 is provided for the inside of each of the cylinders. This covering may be of closed-cell sponge rubber. A plug is inserted in the threaded hole 75 and the connector containing the leads is inserted in the threaded hole 76 in the member 66 to hold the oil inside the device. Threaded holes 77 and 78 are provided for making connections (not shown) with the leads to the electrodes on electromechanically sensitive tubes 50 and 51, etc.

In considering the operation of the device of Figs. 5 and 6, it will first be understood that its operation is generally similar to that of Fig. 3 and that it has the same general type of response characteristic. However, the directional response characteristic of the device of Figs. 5 and 6 is very much sharper due to its increased length. This sharp response characteristic is retained even though the mechanically sensitive cylinders 50 and 51, etc., have a substantial space between them. Actually, it has been found that the spacing of the cylinders 50, 51, etc., does not substantially upset the sharp-response characteristic over a wide range of wave-lengths providing that the spacing between the cylinders, center to center, is not substantially greater than $\frac{3}{4}$ of the shortest wave-length in the range. This spacing of $\frac{3}{4}$ the shortest wave-length is, however, rather critical and if the spacing between the tubes 50, 51, etc., is increased to any extent beyond this amount the sharp directional pattern immediately breaks up into a series of narrow spikes and the response of the device becomes very much inferior for most applications.

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While there has been described what are at present considered to be the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy comprising: a hollow cylinder having a length not substantially greater than half its circumference and of electromechanically sensitive material; and means, including electrodes on said cylinder and provisions for causing one surface of said cylinder to be acoustically exposed to said medium and the other surface of said cylinder to be acoustically shielded from said medium when said cylinder is immersed in said medium, for applying one of said types of energy to said cylinder and for deriving the other of said types therefrom.

2. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy comprising: a hollow cylinder having a length not substantially greater than half its circumference and of electromechanically sensitive material; and means, including electrodes on said cylinder and provisions for causing the outer surface of said cylinder to be acoustically exposed to said medium and the inner surface of said cylinder to be acoustically shielded from said medium when said cylinder is immersed in said medium, for applying one of said types of energy to said cylinder and for deriving the other of said types therefrom.

3. A transducer for operation in a medium and for transducing therein mechanical energy to electrical energy comprising: a hollow cylinder having a length not substantially greater than half its circumference and of electromechanically sensitive material; means including provisions for causing the outer surface of said cylinder to be acoustically exposed to said medium and the inner surface of said cylinder to be acoustically shielded from said medium when said cylinder is immersed in said medium so that sound waves in said medium are effective to apply mechanical energy to said cylinder; and means comprising electrodes on said cylinder for deriving electrical energy from said cylinder in response to the application of said mechanical energy to said cylinder.

4. A transducer for operation in a medium and for transducing therein electrical energy to mechanical energy comprising: a hollow cylinder having a length not substantially greater than half its circumference and of electromechanically sensitive material; means including electrodes on said cylinder for applying electrical energy to said cylinder; and means including provisions for causing the outer surface of said cylinder to be acoustically exposed to said medium and the inner surface of said cylinder to be acoustically shielded from said medium when said medium is immersed in said water so that mechanical energy is propagated into said water in the form of sound waves in response to the application of said electrical energy to said electrodes.

5. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy comprising: a hollow cylinder having a length substantially equal to half its circumference and of electromechanically sensitive material having the property of expansions and contractions around its circumferential directions due to its electromechanical action when in operation which are associated with corresponding expansions and contractions in its length directions; and means, including electrodes on said cylinder and provisions for causing one surface of said cylinder to be acoustically exposed to said medium and the other surface of said cylinder to be acoustically shielded from said medium when said cylinder is immersed in said medium,

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for applying one of said types of energy to said cylinder and for deriving the other of said types therefrom.

6. A transducer for operation in a medium and for transducing therein mechanical energy to electrical energy comprising: a hollow cylinder having a length substantially equal to half its circumference and of electromechanically sensitive material having the properties of expansions and contractions around its circumferential directions due to its electromechanical action when in operation which are associated with corresponding expansions and contractions in its length directions; means including provisions for causing the outer surface of said cylinder to be acoustically exposed to said medium and the inner surface of said cylinder to be acoustically shielded from said medium when said cylinder is immersed in said medium for applying mechanical energy in the form of sound waves to said cylinder; and means including electrodes on said cylinder for deriving electrical energy from said cylinder in response to the application of said mechanical energy to said cylinder.

7. A transducer for operation in a medium and for transducing therein electrical energy to mechanical energy comprising: a hollow cylinder having a length substantially equal to half its circumference and of electromechanically sensitive material having the property of expansions and contractions around its circumferential directions due to its electromechanical action when in operation which are associated with corresponding expansions and contractions in its length directions; means including electrodes on said cylinder for applying electrical energy to said cylinder; and means including provisions for causing the outer surface of said cylinder to be acoustically exposed to said medium and the inner surface of said cylinder to be acoustically shielded from said medium when said cylinder is immersed in said medium for applying mechanical energy in the form of sound waves to said medium in response to the application of said electrical energy to said cylinder.

8. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy comprising: a plurality of similar axially aligned hollow cylinders each having a length not substantially greater than half its circumference; and means, including electrodes on each of said cylinders and provisions for causing a corresponding surface of each of said cylinders to be acoustically exposed to said medium and the other corresponding surfaces of each of said cylinders to be acoustically shielded from said medium when said transducer is immersed in said medium, for applying one of said types of energy to each of said cylinders and for deriving the other of said types therefrom.

9. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy comprising: a plurality of similar axially aligned hollow cylinders each having a length not substantially greater than half its circumference; and means, including electrodes on each of said cylinders and provisions for causing the outer surface of each of said cylinders to be acoustically exposed to said medium and the inner surface of each of said cylinders to be acoustically shielded from said medium when said transducer is immersed in said medium, for applying one of said types of energy to each of said cylinders and for deriving the other of said types therefrom.

10. A transducer for operation in a medium and for transducing therein mechanical energy to electrical energy comprising: a plurality of axially aligned hollow cylinders each having a length not substantially greater than its circumference; means including provisions for causing the outer surface of each of said cylinders to be acoustically exposed to said medium and the inner surface of each of said cylinders to be acoustically shielded from said medium when said transducer is immersed in said medium for applying mechanical energy in the form of sound waves in said medium to said cylinders; and means including electrodes on each of said cylinders for deriving elec-

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trical energy from said transducer in response to the application of said mechanical energy to said cylinders.

11. A transducer for operation in a medium and for transducing therein electrical energy to mechanical energy comprising: a plurality of similar axially aligned hollow cylinders each having a length not substantially greater than its circumference; means including electrodes on each of said cylinders for applying electrical energy to said cylinders; and means including provisions for causing the outer surface of each of said cylinders to be acoustically exposed to said medium and the inner surface of each of said cylinders to be acoustically shielded from said medium when said transducer is immersed in said medium for causing mechanical energy in the form of sound waves to be propagated into said medium in response to the application of said electrical energy to said cylinders.

12. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy comprising: a plurality of axially aligned similar hollow cylinders each having a length substantially equal to half its circumference and of electromechanically sensitive material having the property of expansions and contractions around its circumferential directions due to its electromechanical action when in operation which are associated with corresponding expansions and contractions in its length directions; and means, including electrodes on said cylinders and provisions for causing a corresponding surface of each of said cylinders to be acoustically exposed to said medium and the other corresponding surface of each of said cylinders to be acoustically shielded from said medium when said transducer is immersed in said medium, for applying one of said types of energy to said cylinder and for deriving the other of said types therefrom.

13. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy over a given range of wave-lengths; a plurality of similar axially aligned hollow cylinders each having a length not substantially greater than half its circumference and being spaced from any of the other of said cylinders by a distance not substantially greater than three-fourths of the shortest wave-length in said range; and means, including electrodes on said cylinders and provisions for causing the outer surface of each of said cylinders to be acoustically exposed to said medium and the inner surface of each of said cylinders to be acoustically shielded from said medium when said transducer is immersed in said medium, for applying one of said types of energy to said cylinder and for deriving the other of said types therefrom.

14. A transducer for operation in a medium and for transducing therein between electrical and mechanical types of energy over a given range of wave-length; a plurality of similar axially aligned hollow cylinders each having a length not substantially greater than half its circumference and being spaced from any of the other of said cylinders by a distance not substantially greater than three-fourths of the shortest wave-length in said range and of electromechanically sensitive material having the property of expansions and contractions around its circumferential directions due to its electromechanical action when in operation which are associated with corresponding expansions and contractions in its length directions; and means, including electrodes on said cylinders and provisions for causing the outer surface of each of said cylinders to be acoustically exposed to said medium and the inner surface of said cylinder to be acoustically shielded from said medium when said transducer is immersed in said medium, for applying one of said types of energy to said cylinder and for deriving the other of said types therefrom.

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