

Dec. 14, 1948.

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2,456,294

UNDERWATER SOUND TRANSMITTER OR RECEIVER

Filed May 15, 1946

2 Sheets-Sheet 1

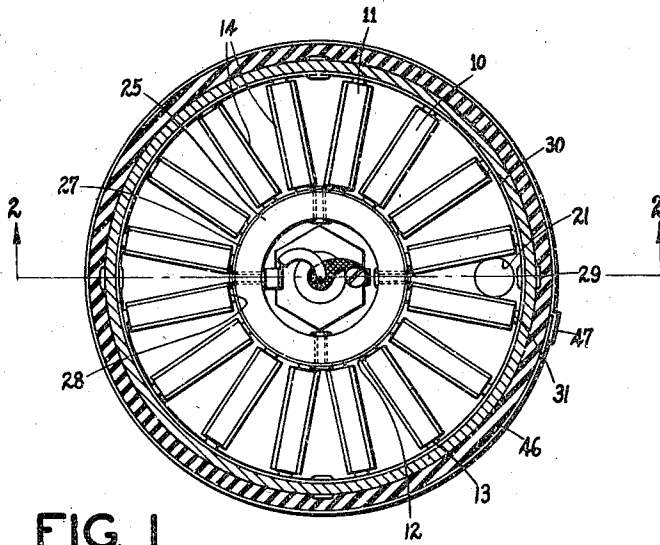


FIG. 1

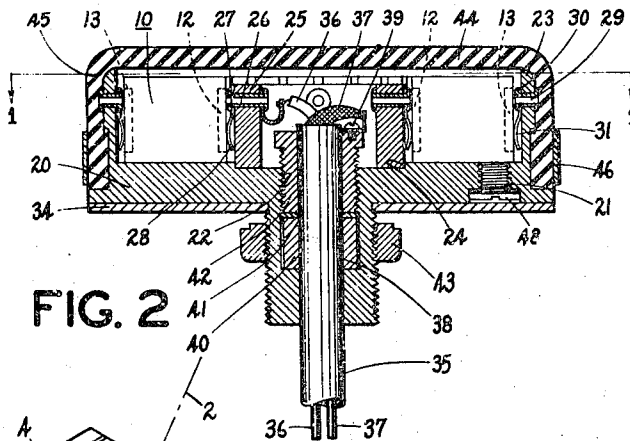


FIG. 2

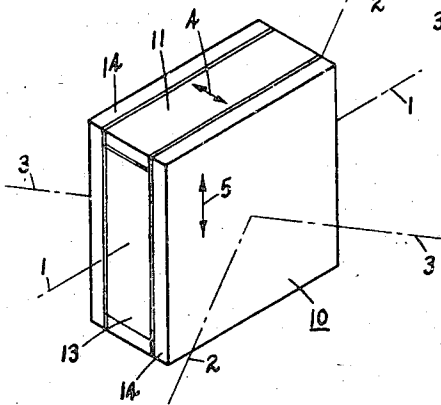


FIG. 3

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2 Sheets-Sheet 2

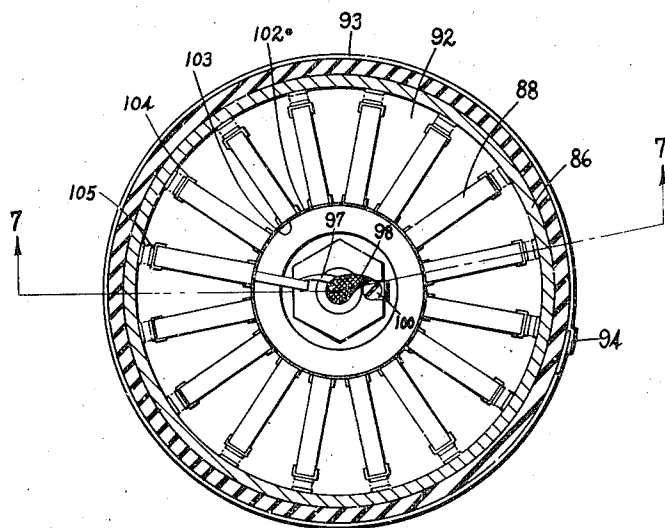


FIG. 6

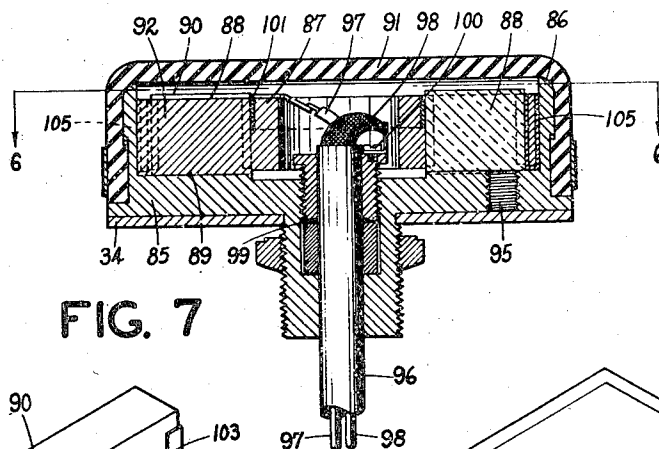


FIG. 7

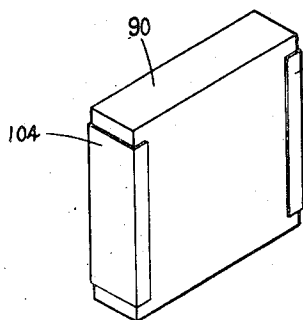


FIG. 4

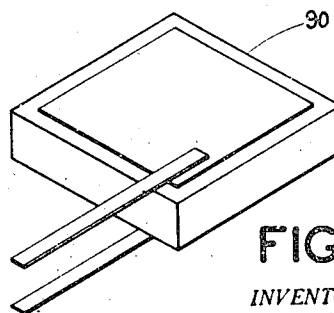


FIG. 5

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UNDERWATER SOUND TRANSMITTER
OR RECEIVER

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Application May 15, 1946, Serial No. 669,761

2 Claims. (Cl. 177—386)

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My invention pertains to transducers of transmitting and/or receiving types utilizing piezoelectric crystals wherein the crystal assemblies are mounted in the transducer with particular orientation.

This application is a continuation-in-part of my previous application Serial No. 436,304, now abandoned, and is related to my application Serial No. 519,069, which is a division of Serial No. 436,304, and which claims the crystal unit per se.

An object of my invention is to provide a piezoelectric crystal assembly capable of being used with greater efficiency.

Another object of my invention is to provide a piezoelectric crystal assembly which will not transmit certain undesired low frequency sound pressures.

A further object of my invention is to provide a fluid-filled transducer device utilizing my piezoelectric crystal assembly, and in which certain undesirable low frequency sound pressures are substantially prevented from being hydrostatically transmitted.

Still another object of my invention is to provide a transducer device which is sensitive to certain desirable low frequency electric fields and/or pressure variations.

It is another object of my invention to provide a speaker device which has sharp directional characteristics.

It is another object of my invention to provide an underwater speaker and/or microphone which will withstand high pressures, and wherein low frequency signals will not cancel out within the speaker or microphone housing.

A further object of my invention is to so mount one or more of the crystal assemblies disclosed and claimed in Serial No. 519,069 that the maximum efficiency of transmission or reception is obtained.

And still another object of my invention is to provide a piezoelectric crystal transducer wherein each individual crystal is subjected to substantially uniform static pressure on all of its faces and to alternating pressures on some only of its faces.

Other objects and a fuller understanding of my invention will be had by referring to the following description and claims read in conjunction with the drawing wherein:

Figure 1 is a sectional view taken along line 1—1 of Figure 2 showing a transducer utilizing a number of the crystal units of Figure 3.

Figure 2 is a sectional view taken along line 2—2 of Figure 1.

Figure 3 is an isometric view of a crystal unit constructed in accordance with the teachings of my application Serial No. 519,069.

Figures 4 and 5 are isometric views of two crystal elements, and

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Figures 6 and 7 are sectional views taken along lines 6—6 and 7—7 of Figures 7 and 6, respectively, of a transducer which utilizes the crystals shown in Figures 4 and 5.

In the use of piezoelectric crystals for underwater microphones and speakers it is desirable to fill the housing surrounding the crystal with oil, such as castor oil, in order to seal the housing against ingress of humidity and in order to couple the crystals through a vibration transmitting portion of the housing to the water outside.

Crystals which may be used are quartz, Rochelle salt, primary ammonium phosphate, primary potassium phosphate and the like. In fact, any crystal cut which has more than one face which vibrates may be treated in accordance with my invention.

Rochelle salt and primary ammonium and potassium phosphate crystals in the expander plate form have two pairs of parallel faces which vibrate, and, inasmuch as this type of crystal is used extensively in underwater transducers the detailed description which follows will refer thereto. It is to be remembered, however, that the principle involved is applicable to all crystalline materials and cuts therefrom which exhibit more than one face which vibrates in accordance with a properly applied alternating voltage, and is applicable to all crystalline materials and cuts therefrom which produce an alternating voltage upon the proper application of an alternating pressure.

The piezoelectric expander crystal shown in Figure 3 may be Rochelle salt, primary ammonium phosphate, or primary potassium phosphate, and it has the characteristic that four faces move with piezoelectric effect. For a given applied polarity, two of the faces move toward each other and the other two faces move away from each other, and there is substantially no change in the volume of the crystal. Accordingly, in a speaker having an oil-filled chamber containing operating piezoelectric crystals in which the oil is in contact with all four faces which operate piezoelectrically, there may be substantially no change in fluid pressure; and in a microphone if the oil surrounds the crystal completely, any pressure change on one pair of crystal faces will generate a voltage, and the same pressure change on the other pair of faces will generate a cancelling voltage thus greatly reducing sensitivity of the device. A single crystal or multiple separated crystals completely surrounded by oil may be inoperative particularly in the region of frequencies in which the wave length is large compared to the size of the crystal.

To eliminate or reduce the transfer of undesired alternating pressures to certain of the piezoelectrically active faces of the crystal, I have found that it is desirable that there exist adjacent

to these faces, a material or a structure that is relatively compressible compared to the crystal material. This substantially eliminates alternating pressures on the certain crystal sides but applies the static pressure, thereby maintaining the sensitivity of the device at a higher level than would be obtained if a differential static pressure were present on only two of the faces of the crystal.

The use of oil inside the transducer housing establishes under high water pressures an internal pressure on the housing which enables the transducer to withstand higher water pressures. In other words, the housing being fluid filled is in effect substantially solid and can withstand high external pressures.

With reference to Figure 1 my invention comprises a plurality of crystal units 10 positioned in a housing of a speaker or microphone adapted to operate underwater. Each crystal unit is made of an expander slab 11 of piezoelectrically active material with an electrode 12 at one end of the slab, an electrode 13 at the other end of the slab, and two pieces of sheet cork 14, or other such material cemented on or held closely adjacent to two of the side faces which vibrate piezoelectrically. A very suitable material has been found to be a molded composition of cork and rubber known as corprene. However, any material having a mechanical impedance which is low compared to the mechanical impedance of the crystal and the liquid and which will not absorb substantial quantities of the oil will operate successfully. Sponge rubber will also serve the purpose.

The slab of crystal 11 and the electrodes 12 and 13 are adapted to be connected into an electric circuit in the well-known manner, and are operable when subjected to an alternating current to establish an alternating mechanical pressure. The units are also operable when subjected to an alternating mechanical pressure to establish an alternating electric potential. Thus the units may be utilized as motors such as in a loud-speaker, or as generators such as in a microphone.

My invention is applicable to both motor and generator devices but because it has found wide use as a generator device for underwater microphones, I will describe it in detail with reference to such a device. It is to be understood, however, that it is not limited to such microphone devices.

When a crystal speaker device is subjected to an alternating current, the piezoelectric crystal has the property of vibrating in two directions. Accordingly, there are four vibrating faces. In the usual air-filled speaker the relative movement between any two vibrating parallel faces is transmitted to a diaphragm and utilized to send out pressure waves, and the vibration of the other two parallel faces does not interfere with the signal. In a substantially incompressible fluid such as oil, however, the vibration of the other two faces may cause considerable distortion in the directional pattern of the transmitted signal, and may cause a reduction in output. It is the nature of the crystals that at any instant, upon being subjected to an alternating electric signal, one pair of parallel faces will tend to establish an increase in pressure to the surrounding fluid, while the other pair of parallel faces will tend to establish a decrease in pressure to the surrounding fluid. When the surrounding fluid is oil which readily transmits the slightest variation in pressure, the oil coupling of all four vibrating faces to the external transmitting fluid (such as water) causes loss of

low frequencies and loss of desired directional characteristics.

I obviate these undesirable characteristics by fastening decoupling means to one pair of parallel vibrating faces to decouple substantially those faces from the oil in the speaker, thereby substantially preventing the transmission of a signal from those faces, and I orient each crystal within the housing so that the other pair of parallel vibrating faces is parallel to the base upon which the crystal is mounted. Thus the plane of the decoupling means is substantially perpendicular to the base of the transducer, and one of the vibrating faces which is not covered by a decoupling member is cemented to the housing base and the other uncovered vibrating face faces the vibration transmitting portion of the housing whereby directional vibrational waves are beamed out of the housing.

When a crystal microphone device of the oil-filled type is submerged in water and subjected to alternating pressures due to audio or super-audio waves, the piezoelectric crystal has the property of being vibrated in two directions, and has two faces perpendicular to each of the two directions. Accordingly, as in the speaker, there are four vibrating faces. In the usual air-filled microphone the relative movement between any two vibrating parallel faces is utilized to establish an alternating potential, and the vibration of the other two parallel faces does not interfere with the alternating potential. When the microphone is filled with a substantially incompressible fluid such as oil, however, and a pressure wave hits all four crystal faces, the vibration of two faces generates a voltage, and the vibration of the other two faces generates a cancelling voltage. This is due to the oil transmitting substantially equal pressures to all four vibrating faces and materially reduces the sensitivity of the microphone. It is the nature of these piezoelectric crystals that at any instant upon being subjected to a pressure on one pair of parallel faces the crystal will tend to establish a potential of a first polarity and when that same instantaneous pressure is applied to the other pair of parallel faces the crystal will tend to establish a potential of a polarity opposite the first polarity. When the microphone operates in a fluid such as oil which transmits pressures substantially instantaneously and equally in all directions, the instantaneous pressure on all four piezoelectrically active faces may cause loss of signal especially in the low frequency range, and loss of the directional pattern in the high frequency range.

The microphone shown in Figures 1 and 2 is comprised of a metal base portion 20 which has two threaded openings 21 and 22. The base portion 20 may be circular and has an upstanding peripheral edge portion 23, and an annular shoulder 24 near its center. Positioned against the base 20 and against the shoulder 24 is a contact ring 25, and connected to the contact ring 25 by means of rivets 26 is an inside contact strip 27 which has a plurality of contact fingers 28, one for each crystal unit. Connected to the upstanding edge 23 of the base portion 20 by means of rivets 29 is a somewhat similar outside contact strip 30 having a plurality of contact fingers 31, one for each crystal unit 10. The plurality of piezoelectric vibrating faces against the base 20, and with electrode 13 against an outside contact

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finger 31, and with electrode 12 against an inside contact finger 28.

A cable 35 composed of two wires 36 and 37 is brought into the microphone through the threaded opening 22, and waterproof connection means 38 are provided for preventing the ingress of moisture around the cable 35. The wires 36 and 37 are connected at one end to an amplifier, and wire 36 is connected at its other end to inner contact strip 27 by means of one of the rivets 26. The wire 37 is connected at its other end to the base 20 of the microphone by means of a screw 39. The electrical path may, therefore, be traced from wire 37 through the base 20 to the upstanding edge 23, to rivets 29, to contactor strip 30, and through contact fingers 31, to the electrode 13 of each crystal unit 10. The contact ring 25 as shown is made of an insulating material, or it may be made of metal and insulated from the base 20 to prevent a shunt circuit.

The waterproof connection means 38 is comprised of a cable clamp bushing 40, a washer 41, and a cable clamp nut 42. The nut 42 threads into the threaded opening 22 and presses the washer 41 against the bushing 40 to effect the waterproof seal. A nut 43 may be provided on a threaded extension of the base 20 for attaching the microphone to a support, and a layer of cork 34 or other vibration absorbing material may be applied to the bottom of the microphone (or speaker) to isolate it from vibrations in the support.

After the microphone has been assembled a rubber cover 44 having a downwardly extending edge portion 45 is placed over the top of the crystal units 10 with the edge portion 45 outside of the upwardly extending edge portion 23 of the metal base 20. A clamping ring 46 is placed around the outside of the edge portion 45 of the cover 44 and is pulled tight and clamped by means of a clamp 47.

After the cover 44 has been connected to the upstanding edge 23 to prevent the ingress of moisture, the air within the speaker is evacuated and the air is replaced by castor oil admitted through the threaded opening 21. This is preferably done in a position with the rubber cover 44 downward, and by using a vacuum pump. When all of the air is out and oil has replaced it, a threaded plug 48 is used to close the opening 21.

Upon an alternating pressure signal of one potential being applied to two parallel and piezoelectrically active faces of a crystal in a microphone, a voltage is generated. When the same pressure is applied to the other two parallel and piezoelectrically active faces a voltage is generated. If these pressures are applied at the same time the two voltages tend to cancel each other thereby reducing the signal output. Except for the presence of the decoupling means 14 on one pair of moving faces the fluid within the microphone would apply substantially equal pressures on all four piezoelectrically active faces at substantially the same instant. This is not desirable. Accordingly, I provide decoupling means such as cork, corprene, or sponge rubber 14 to prevent the pressures (both positive and negative) from being applied to more than one pair of piezoelectrically active faces. The "piezoelectrically active faces" of a crystal plate are those faces which are perpendicular to a direction of direct crystalline expansion and contraction when the crystal plate is properly subjected to an alternating electric field.

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pander crystals made according to my invention, and shows the decoupler 14 connected to two of the four faces which vibrate piezoelectrically when the crystal is subjected to alternating mechanical pressures, or when the crystal is subjected to alternating potentials. The electrode 13 is shown connected to one of the uncovered faces and another electrode 12 (not shown in Figure 3) is connected to the uncovered face which is parallel to the face upon which electrode 13 is placed.

For operation as a microphone, the alternating pressure is applied to two parallel faces which are piezoelectrically active, that is to two faces which cause the generation of an electromotive force upon being moved toward or away from each other, and the voltage appears between the electrodes 12, 13. The other two parallel faces which are piezoelectrically active are decoupled from the surrounding medium by a rubber impregnated cork material 14.

For operation as a speaker, the alternating voltage is applied to the two electrodes 12, 13 thereby causing the two pairs of piezoelectrically active faces to move. One pair of piezoelectrically active faces is covered with the rubber impregnated cork 14 and is therefore uncoupled from the surrounding medium. The other pair of piezoelectrically active faces is not covered with the rubber impregnated cork 14, and accordingly is closely coupled to the surrounding medium. When an alternating voltage is applied to the electrodes 12, 13, the uncovered faces transmit an alternating signal pressure to the surrounding fluid, and the covering on the other faces serves to prevent the vibrations from sending a signal into the surrounding fluid.

The lines 1-1, 2-2, and 3-3 in Figure 3 illustrate the direction of the crystallographic axes of the unit. If the line 1-1 is the x (or A) axis, then line 2-2 may be the y (or B) axis and line 3-3 may be the z (or C) axis. If the line 1-1 is the y axis, then lines 2-2 and 3-3 become the other two axes and the piezoelectrically active faces are at 45 degrees with respect to them. If line 1-1 is the z axis, then lines 2-2 and 3-3 represent the other two axes of the crystal. In any expander cut of crystal of Rochelle salt or primary ammonium phosphate types the directions of piezoelectric expansion are at 45 degrees with respect to two of the axes. The arrow 4 indicates one direction of expansion and contraction of the crystal, and arrow 5 indicates the other direction of expansion and contraction. It is desired that the amplitude of movement of the crystal faces in direction 4 be as small as possible, and that the amplitude of movement in direction 5 be as large as possible.

If it is desired that the pattern of the transducer be directional and in order that a good signal output be obtained the crystal unit shown in Figure 3 should be mounted within the housing with one of its directions of expansion and contraction extending in a direction out through the vibration transmitting portion of the housing, and with the parallel vibration transmitting face against a massive base, as is shown in Figure 2. The other two vibrational faces are covered with a body of material which decouples them from the surrounding liquid medium. In order for the transducer device to be directional the wave length of the signal in the liquid medium should be small compared to the diameter thereof. For example, in Figure 1, if the device is four inches in diameter it will be directional at about 60 kc. in water, if one of the directions of expansion and contrac-

Figure 3 is an enlarged view of one of the ex-

tion extends out through the vibration transmitting portion of the housing.

It is not essential in order to practice my invention to affix the sheet of decoupling material directly to certain faces of a crystal as the same result may be achieved by the means shown in Figures 6 and 7, which is described as a speaker but which will also operate as a microphone.

The loudspeaker comprises a base portion 85 having a raised outside edge portion 86. Positioned between the edges 86, and resting against the base 85, there is a circular spider 92 which has a plurality of openings into which a plurality of electroded crystals fit. The crystals 88 are arranged in a ring with one of the two unelectroded narrow faces 89 or 90 in engagement with the base 85 and the other unelectroded narrow face extending slightly above the top of the spider 92. The spider 92 is made of some material such as a molded mixture of rubber and cork, or other such material which will serve to decouple the broad faces of the crystal units 88 from the oil in the speaker. A cover 91 is connected at its downwardly extending outside edges to the raised edge portion 86 of the base by means of a clamping ring 93 and a clamp 94 to establish a seal. A threaded opening is provided in the base 85 through which all of the air in the speaker may be withdrawn and replaced by a fluid such as oil which will transmit fluid pressure to the crystals 88 but which will not affect the crystalline substance. The threaded plug 95 seals the oil within the speaker. A cable 96 comprised of two wires 97 and 98 is brought into the speaker through sealing means 99, and wire 98 is electrically connected to the base 85 of the speaker by means of the screw 100. The wire 97 is connected to a spring contactor strip 101. The contactor strip fits in a slit 102 in the top surface of the spider 92 and electrically engages each of the electrodes 103 on the inner ends of all of the crystals 88. The outer crystal electrodes 104 each engage one of a plurality of U-shaped spring clips 105. Each clip 105 has two legs and one of the legs is in engagement with a crystal electrode 104 and the other leg is in engagement with the raised edge portion of the base 85. Accordingly, an electric circuit is established from wire 97 to the spring contactor strip 101, to the inner end of each of the crystals 88 through the crystals 88 to each of the U-shaped clips 105, thence to the speaker edge 86 and base 85, and then to the wire 98. Upon an alternating potential being applied across the crystals 88, the crystals will expand and contract in a direction substantially normal to the base 85, and in a direction substantially normal to the planes of the large crystal faces. The expansion in the latter direction will not materially affect the pressure in the surrounding fluid as the two large crystal faces are in engagement with the spider and accordingly are decoupled from the fluid. The expansion and contraction in the direction normal to the base 85 will cause an alternating pressure to be established in the oil unit within the speaker, and the cover 91 will transmit the pressures to the water outside the speaker. The waterproof cable connection means 99 may be the same type as used in Figure 1, and cork insulating means 34 may be positioned on the bottom of the speaker if it is so desired to isolate any transmission through the base of the speaker housing.

From my description, it will be seen that in a

fluid-filled transducer the operating characteristics may be improved by providing certain of the crystal faces with an adjacent compressible material, and by orienting the crystal to obtain the maximum beneficial results. If the compressible material contains trapped air such as in sponge rubber, cork, or similar material, then the sensitivity of the device at low frequencies may be substantially the sensitivity of an air-filled unit. The structure may be oil filled but the decoupling means prevents sound pressures from being transmitted to all of the piezoelectrically active faces, especially at the lower frequencies. Because of the decoupling means each unit should be more sensitive to lower frequencies, the directional characteristics should be sharper, and the characteristics should be more uniform among various units of the same type which are made by mass production methods. Further, because the decoupling means is effective to transmit direct hydrostatic pressure such as that caused by the device being submerged in water, it permits the use of the devices at greater depths without the loss of sensitivity which would arise if the hydrostatic pressure were only present on one or two of the piezoelectrically active faces.

Although I have described my invention with a certain degree of particularity, it is to be understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangements of parts may be made without departing from the spirit and scope of the invention as hereinafter claimed.

I claim as my invention:

1. In a piezoelectric transducer device adapted to operate underwater, a water-tight enclosure having a vibration transmitting portion, a liquid medium within said housing having a mechanical impedance comparable to the mechanical impedance of the water in which said piezoelectric device is adapted to operate, a compressible body having a slot therein mounted within said water-tight enclosure and in contact with said liquid medium, said body having lower mechanical impedance than said liquid medium, and piezoelectric expander crystal means having at least two faces which vibrate with piezoelectric action mounted in the slot with one but not all of said faces directly against said compressible means to decouple said face from the surrounding liquid medium, said other face which vibrates being substantially coupled to said liquid medium to effect a differential alternating pressure of the liquid medium on the said two faces when the crystal unit operates piezoelectrically.

2. A piezoelectric transducer device as set forth in claim 1, further characterized by said compressible body having a plurality of radially extending slots and by a plurality of expander crystal means, one of said crystal means being mounted in each of said slots.

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The following references are of record in the file of this patent:

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