

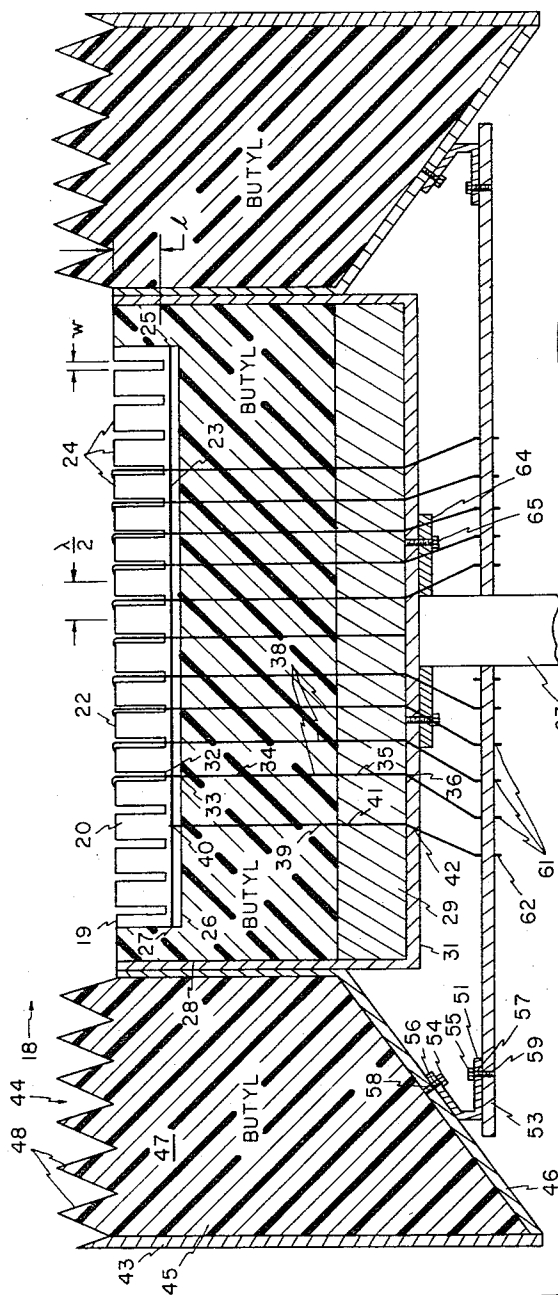


FIG. 2

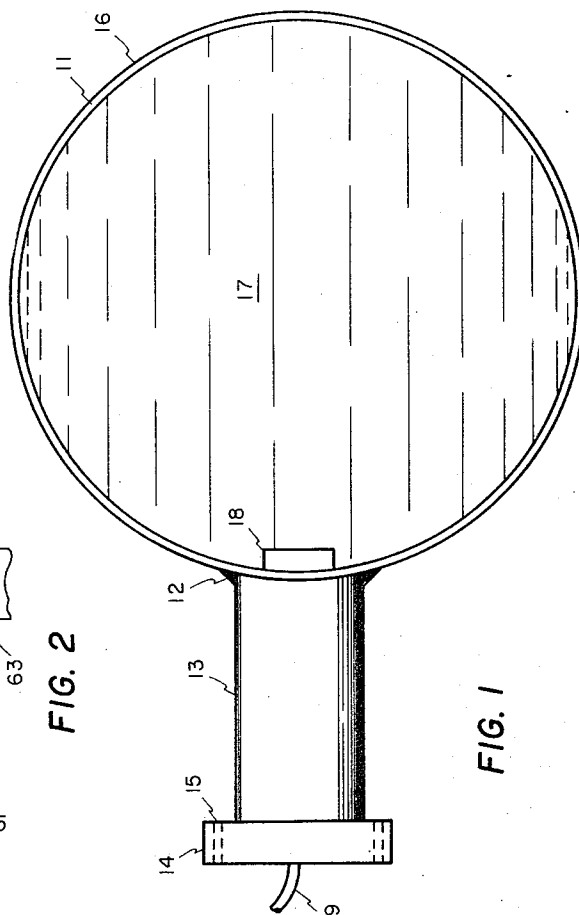


FIG. 1

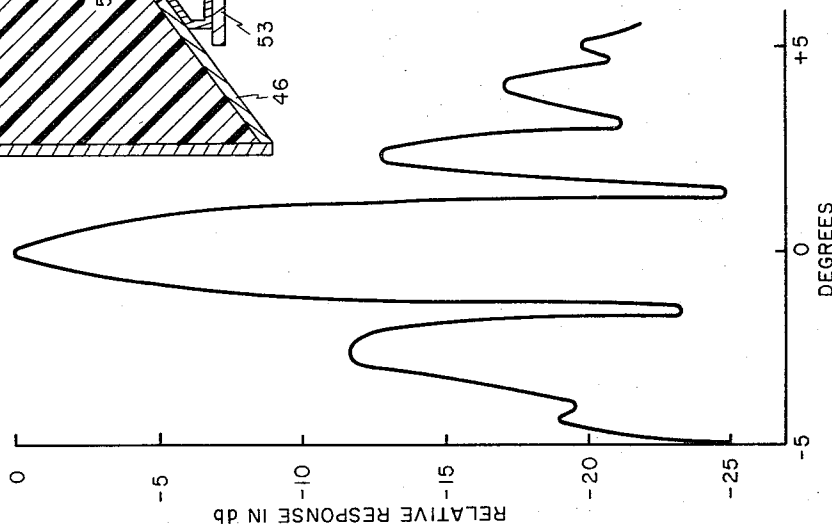


FIG. 6

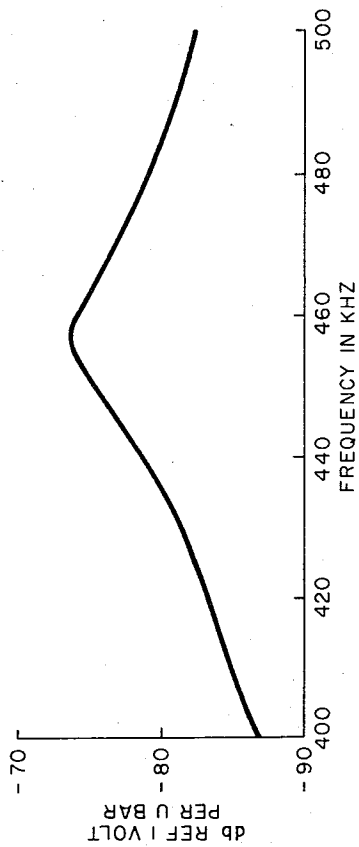


FIG. 5

91	92	93	94	95	96	97	98	99	100
81	82	83	84	85	86	87	88	89	90
71	72	73	74	75	76	77	78	79	80
61	62	63	64	65	66	67	68	69	70
51	52	53	54	55	56	57	58	59	60
41	42	43	44	45	46	47	48	49	50
31	32	33	34	35	36	37	38	39	40
21	22	23	24	25	26	27	28	29	30
11	12	13	14	15	16	17	18	19	20
1	2	3	4	5	6	7	8	9	10

FIG. 4

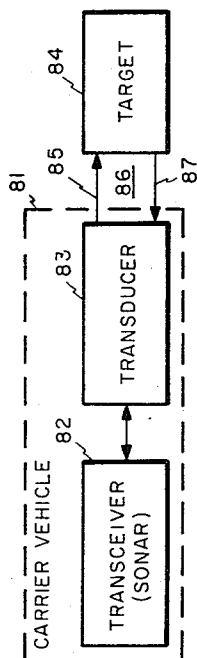


FIG. 7

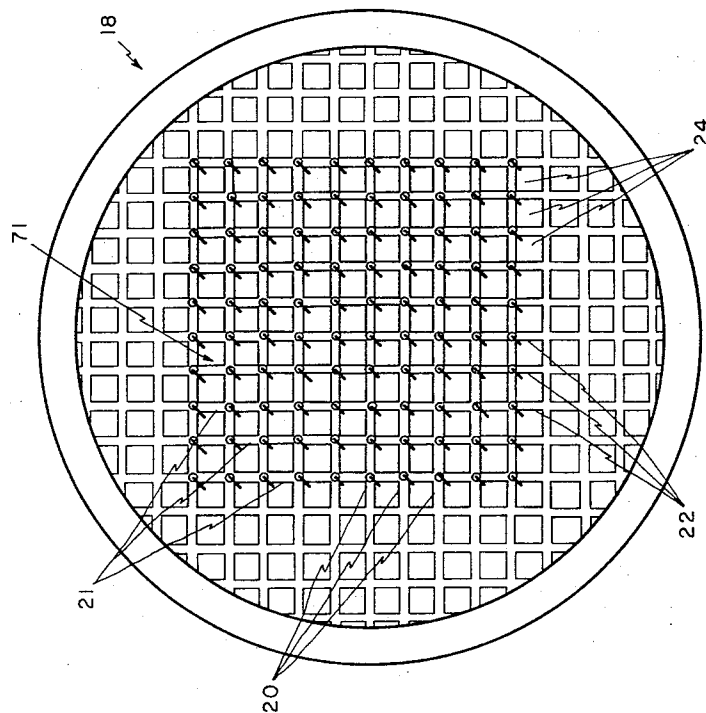


FIG. 3

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3,718,898
TRANSDUCER

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assignors to the United States of America as repre-
sented by the Secretary of the Navy
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12 Claims

ABSTRACT OF THE DISCLOSURE

An electroacoustical transducer is disclosed which incorporates a diced piezoelectric crystal backed by a phenolic disc, a resilient pressure release Butyl rubber cup, an aluminum block, and a metallic cup that contains said crystal, disc, rubber cup, and aluminum block. Electrodes are connected to all of the active end faces and the base of said diced piezoelectric crystal, and electrical wire conductors are connected to each of said face electrodes and said base electrode. A Butyl rubber baffle extends around and radially from said diced piezoelectric crystal, and a liquid acoustical lens is effectively associated therewith. A mounting pipe and flange are effectively connected to said lens and metallic cup for the mounting thereof on a utilization apparatus.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

FIELD OF THE INVENTION

The present invention relates, in general, to electro-mechanical transducers, and, in particular, it is an underwater electroacoustical imaging transducer having multiple, substantially independent, piezoelectric energy converters separated and configured in such manner as to provide signals representing predetermined discrete acoustical pressures occurring within a sensed composite distribution of acoustical pressures.

DESCRIPTION OF THE PRIOR ART

Heretofore, numerous electroacoustical transducers have been employed for converting electrical energy to acoustical energy and vice versa. For many practical purposes, they have been eminently satisfactory, but for some purposes they leave a great deal to be desired. In those instances where the image resolution of acquired underwater targets is less than desired, it is often the result of insufficient mechanical decoupling occurring between adjacent operative posts of a piezoelectric crystal that is diced to have a mosaic configuration.

SUMMARY OF THE INVENTION

The instant invention includes a diced piezoelectric crystal having operative posts which are spaced in such manner as to have a distance of $\lambda/2$ between the center longitudinal axes of adjacent ones thereof, where λ is the wave length of the optimum operative design frequency of the entire transducer. Suitable pressure release material is employed as a backing for the diced ceramic piezoelectric crystal. The entire periphery of the diced piezoelectric crystal array is surrounded by a butyl baffle having pyramidal shaped wedges, in order to promote acoustic isolation thereof from the directions substantially normal

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to the propagation and response directions thereof and, hence, thereby reduce internal reflections therein. In addition, the crystal array is disposed within a liquid lens in such manner that the liquid thereof floods the spaces between all of the crystal elements, thereby allowing each element or post to operate in a substantially independent manner without acoustic energy being coupled therebetween.

Of course, as is usual with electroacoustical transducers, the transducer constituting the subject invention is reversible—that is, it broadcasts acoustical energy in response to electrical excitation and produces electrical energy in response to acoustical energy excitation.

Due to the unique structural configuration of the invention, it overcomes many of the disadvantages of the prior art and, thus, in some respects, constitutes an improvement thereover.

Therefore, it is an object of this invention to provide an improved reversible electromechanical transducer.

Another object of this invention is to provide an improved reversible electroacoustical transducer.

Another object of this invention is to provide an improved acoustic imaging sensor.

Still another object of this invention is to provide a transducer having independent multiple electroacoustical energy converters which are capable of selectively taking discrete electrical samples of a composite acoustic pressure distribution.

A further object of this invention is to provide an improved method and means for mapping a pressure distribution of the type that would be present at the image surface of an acoustic imaging element, such as a lens.

Another object of this invention is to provide an improved method and means for effecting a two-dimensional spatial sampling of a given pressure field, such as a given acoustic pressure distribution over a predetermined area.

A further object of this invention is to provide a matrix of piezoelectric crystal elements, each of which has frequency response and impedance characteristics that are similar to those of the others.

A further object of this invention is to provide a matrix of piezoelectric crystal elements, each of which exhibits a free field voltage response that is essentially similar to that of the others.

Other objects and many of the attendant advantages will be readily appreciated as the subject invention becomes better understood by reference to the following detailed description, when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic illustration of the invention, partly in cross-section, and partly in elevational view;

FIG. 2 is a cross-sectional view of the unique energy converter assembly of FIG. 1;

FIG. 3 is a front elevational view of the energy converter assembly of FIGS. 1 and 2;

FIG. 4 is a diagram of a centered, square-configured matrix of piezoelectric sensor elements which are illustrated as being numbered in a preferred operational sequence within the subject invention;

FIG. 5 is a graphical representation of the reception sensitivity versus frequency of a typical piezoelectric electroacoustical energy converter element of the type incorporated in the subject invention;

FIG. 6 is a graphical representation of the response directivity pattern effected by each of the electroacoustical energy converter elements of the energy converter assembly of FIGS. 1 and 2; and

FIG. 7 is a block diagram of a typical system which may incorporate the transducer constituting this invention to an advantage.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, the transducer constituting this invention is shown as having a spherical liquid lens 11 that is connected by any conventional means (such as cementing 12) to one end of an extension pipe 13, the other end of which is secured to a mounting flange 14 having bolt holes 15 extending therethrough. Said lens 11, pipe 13, and flange 14 may also be connected to their respective elements in any suitable, conventional manner that will provide a fixed relationship therebetween.

The outer peripheral boundary of lens 11 is, in fact, effected by an acoustically clear shell 16 constructed, for example, of an acrylonitrile-butadiene-styrene, a polypropylene material, a polyethylene material, or the like. Preferably, the ρc —that is, the density times sound velocity—of the shell material should be such that its acoustical characteristics closely approximate that of sea water or the ambient environmental medium thereof, in the event the subject transducer is used in some other medium.

An acoustical energy refracting fluid 17, such as Freon, fluorocarbon, fluorolube, or the like, is used to fill shell 16. Such fluid, of course, is intended to refract sound waves that pass through it and shell 16, so that incoming acoustic energy will be focused within a predetermined focal area for a given distance. It should also be selected so that the wavelength of sound therein is about $\frac{1}{2}$ the value of the wavelength of sound in sea water. An electroacoustical imaging sensor assembly 18 is mounted within shell 16 and fluid 17 in such manner that it is in direct contact with said fluid 17 and also located within the aforesaid focal area thereof. Consequently, incoming sonic energy will tend to be focused thereon. Because imaging sensor assembly 18 is of considerable importance in the invention, it will be discussed more fully subsequently.

An electrical cable 9 containing a plurality of insulated electrical conductors is connected to sensor assembly 18 and extends out of pipe 13. It is, of course, suitable for being connected to any appropriate utilization apparatus. Obviously, imaging sensor assembly 18 and electrical cable 9 should be mounted in such manner as to prevent liquid or fluid 17 from leaking from shell 16. Hence, the joining surface of sensor assembly 18 and shell 16 should be made fluid tight by any convenient conventional means.

FIG. 2 shows the structure comprising the aforementioned electroacoustical imaging sensor assembly 18.

In this particular embodiment, a piezoelectric ceramic disc 19, made of a lead zirconate-titanate composition or any other suitable piezoelectric material, is serrated in 90° directions in such manner as to have a plurality of slots 20 and 21 (see FIG. 3 for better view) of width w and depth l , thereby effecting a multiplicity of square or rectangular piezoelectric crystal elements 22 having the longitudinal axes of adjacent ones one-half wavelength ($\lambda/2$) apart (based on the velocity of sound in water) for the intended operational frequency and, in addition, having a common piezoelectric crystal base 23. A plurality of metallic electrodes 24 are respectively attached to the active front end faces of said piezoelectric crystal elements 22, and a single electrode 25 is attached to the back of base 23 in such manner as to cover the entire area thereof that is opposite the active end faces of the aforesaid rectangular piezoelectric crystal elements 22.

A thin phenolic sheet 26, say of the order of .002 inch thick, is attached to the back of said base electrode 25, as by an epoxy or other adhesive 27. A cup shaped resilient pressure releasing material 28, preferably made of Butyl rubber, is disposed around and back of the diced piezoelectric element 19 and phenolic backing sheet 26 connected thereto. The lip thereof is preferably flush with

the active face of the peripheral ones of said rectangular piezoelectric crystal elements.

In abutment with the back surface of rubber cup 28 is an aluminum block-like disc 29, and surrounding the assembly described so far, is an aluminum metal cup 31, with the lip thereof likewise flush with the lip of rubber cup 28.

Through a plurality of in-line holes 32 through 36 respectively located through crystal base 23, phenolic disc 26, backing butyl rubber cup 28, aluminum disc 29, and metallic cup 31, are a plurality of size #37 enameled wires 38, the ends of which are respectively soldered to electrodes 24. Likewise, a wire 39 is threaded through in-line holes 40 through 42 located in phenolic disc 27, rubber cup 28, aluminum disc 29, and metallic cup 31, respectively.

Surrounding the periphery of metallic cup 31 is a ring-like metallic frame 43 having an open front end 44, a recess 45, and a closed rear end 46, and disposed within the recess thereof is a resilient butyl rubber ring-like baffle 47. At the end of butyl ring baffle 47 which is adjacent to the active front end faces piezoelectric elements 22, said baffle is configured to have a plurality of radially spaced pyramidal shaped wedges 48 that protrude in the forward direction, so as to extend beyond said active front end faces at least an amount equal to the depth of the wedges. In this preferred embodiment, baffle wedges 48 have pointed apexes at the forward ends thereof; however, it should be understood that other geometrical configurations may be employed, if operational circumstances so warrant. Obviously, it would be well within the purview of one skilled in the art having the benefit of the teachings presented herewith to properly size and shape wedges 48, as well as baffle 47 and the aforesaid piezoelectric crystal elements 22, in order to optimize the subject invention for any intended operational signal frequencies or to have any other desired operational characteristics.

By means of a plurality of brackets 51, a rear bus bar 53 is connected to the rear surface of frame 43. Preferably, bolts 54 and 55 extending through holes 56 and 57 in brackets 51 are screwed into threaded holes 58 and 59 of frame 43 and bus bar 53, respectively. Any number of such brackets may, of course, be used; hence, only the particulars of one bracket, viz, bracket 51 are disclosed here, in order to simplify this case as much as possible.

A plurality of electrical terminals 61 are respectively connected to wires 38 that, in turn, are connected to the forward electrodes 24 of piezoelectric elements 22. Said terminals 61 are, in turn, connected to a like number of electrical conductors incorporated in the aforementioned cable 9, illustrated in FIG. 1. Likewise, another electrical terminal 62 is connected to the wire connected to rear electrode 25. As may readily be seen, terminals 61 and 62 all extend through and are, thus, mounted on bus bar 53.

A support shaft 63 having a flange 64 which is, in turn, connected to metallic cup 31 by bolts 65 (or any other conventional connection means) and may be optionally used as a mounting means for the entire energy converter imaging sensor assembly 18. If used, it may be connected as desirable to the aforesaid pipe 13 of FIG. 1, or it may be connected directly to any other suitable mounting means (not shown) warranted by operational circumstances.

FIG. 3 depicts a front view of electroacoustical sensor assembly 18 without frame 43 and baffle 47 being attached thereto. As may readily be seen, it is preferably circular in shape; but, it has been determined that, although the entire circular area may contain piezoelectric crystal posts or elements 22, only a particular, centered square configuration 71 thereof provides optimum independent action or acoustic image sensing by each element.

For convenience in understanding data to be presented subsequently, the individual ones of piezoelectric energy

converted posts 22 in the square configuration are numbered in the diagram of FIG. 4. They are numbered consecutively from 1 to 100 starting at the lower left hand corner and working across the bottom row and then working up in rows.

With a configuration of sensor posts 22 as shown in FIG. 4, it has been determined that the free field sensitivity for each post is substantially similar to that shown in FIG. 5 for frequencies between 400 and 500 kilocycles per second.

In addition, due to the acoustic isolation of each post (as a result of its configuration, spacing, and disposition within the liquid lens) of the square configuration of FIG. 4, it has been determined, for example, that post 46 has a receiving directivity pattern similar to that shown in FIG. 6, and that the directivity response patterns of the others are substantially similar thereto. Hence, with such response patterns effected by practically all of the piezoelectric posts, it may also be seen that to a considerable extent each thereof is acoustically isolated from its neighbors and, therefore, the combination thereof effects high response image resolution while "viewing" any particular incoming acoustical signal, say, that which has been reflected from an acquired underwater target. For example, the coupling levels between piezoelectric elements 45 and 46 and the coupling levels between piezoelectric elements 55 and 56—element pairs which ordinarily would be subject to the maximum coupling conditions due to their central location in the piezoelectric element matrix—have been determined to be of the order of -25 db or less, a very worthwhile achievement, indeed.

FIG. 7 illustrates a carrier vehicle 81 containing a typical echo-search-ranging system that may incorporate the subject invention to an advantage. In this particular instance said carrier vehicle will be considered to be a ship and said echo-search-ranging system will herewith be defined as a sonar system adapted for locating and identifying underwater targets. Accordingly, a transceiver 82, preferably of the sonar type, is connected to a transducer 83 of the type constituting this invention which, in turn, is well suited to acquire and identify a target 84, as will now be discussed more fully below during the discussion of the mode of operation of the invention.

MODE OF OPERATION

The operation of the invention will now be discussed briefly in conjunction with all of the figures of the drawing.

As previously suggested, the entire transducer of substantially the type pictured in FIG. 1 is ordinarily mounted on a marine or submarine vehicle 81 in such manner that it is physically directed toward an area where it is desired to search for various and sundry targets. For example, if it is assumed that vehicle 81 of FIG. 7 is a marine vehicle, such as a ship or the like, and target 84 is an object laying on the sea floor, the subject transducer 83 would probably be mounted on vehicle 81 in such manner as to look forward and downward. Then the transmitter portion of transceiver 82 would electrically energize transducer 83, thereby causing it to broadcast an acoustical energy search signal 85 through water 86. Upon acquiring target 84, an echo 87 of said search signal would be reflected therefrom back to transducer 83. Of course, if so desired, a separate electroacoustical transducer could be used to initially broadcast search signal 85, and it then may be mounted on vehicle 81, on some other vehicle, or on some other suitable mounting platform disposed at any place that would facilitate the searching for known or unknown targets with acoustical search signals.

In order to effect search signal transmission, electrical energy is supplied to terminals 61 and 62 of FIG. 2, which, in turn, conduct it is so as to be applied across face electrodes 24 and base electrode 25. As a result of the inherent piezoelectric characteristics existing in diced crys-

tal 19, said electrical energy is converted to acoustical energy proportional thereto which is then broadcast in a forward direction as pressure waves from the front faces of all of the crystal elements being energized at any given instant. Said pressure waves are ordinarily refracted by fluid 17 as they pass therethrough before the sonification of the ambient medium.

The reception process of transducer 83, is just the opposite of that mentioned above. Incoming waves of acoustic pressure energy are refracted by fluid or liquid 17 in such manner as to be focused on the active front faces of piezoelectric elements 22. Due to the incorporation of the various pressure release backing materials and baffle 44 having wedges 48, said crystal elements 22 are not subject to stray or spurious inputs that might otherwise impinge thereon from directions other than that of the intended "sight" or forward direction. In other words, the unique construction of the sensor assembly depicted in FIG. 2 improves the efficiency and resolution of the subject invention to a considerable extent as a result of either eliminating or isolating unwanted image distorting noise signals.

When the acoustic target echo signals are received by transducer 83, there are any number of ways of processing the data emanating therefrom, as the result of each active piezoelectric crystal element thereof converting that portion of said echo signal received thereby into an electrical signal proportional thereto. Hence, transducer 83, in effect, produces, say, 100 bit signals each of which, for most practical purposes, are substantially independent of the others, as a result of their respectively having response patterns like that shown in FIG. 6 and, thus, having a minimum of cross-coupling between adjacent one thereof. Accordingly, it may be said that discrete samples of target reflected acoustical signals are selected by and within the subject transducer. Whether said discrete samples are scanned consecutively, say, from elements 1 through 100, or whether they are data processed simultaneously depends upon the type of transceiver employed and the type of readout incorporated therein. Obviously, it would be well within the purview of the artisan having the benefit of the teachings presented herewith to design and/or select whatever type of transceiver would be optimum for any given operational circumstances.

As shown in FIG. 5, the free field sensitivity of each piezoelectric element is sufficient between 400 and 500 kHz to provide good target resolution, regardless of the data processing and readout employed in sonar transceiver 82.

It would perhaps be noteworthy that the subject invention is primarily intended to be used in sonar systems for detection of underwater targets; however, it should be understood that it may also be used in or in conjunction with any other appropriate environmental medium for detection and determination of various and sundry parameters of objects and materials existing therein.

Obviously, other embodiments and modifications of the subject invention will readily come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing description and the drawings. It is, therefore, to be understood that this invention is not to be limited thereto and that said modifications and embodiments are intended to be included within the scope of the appended claims.

What is claimed is:

1. A transducer, comprising in combination:

a piezoelectric crystal disc having a mosaic configuration of slots extending partially therethrough in such manner as to effect a plurality of predetermined electroacoustical energy converter elements having a like plurality of forward active end faces and a common base at the back thereof;

a plurality of electrodes attached to said plurality of electroacoustical energy converter elements, respectively;

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another electrode connected to the back of said common base;

a thin phenolic disc connected to the back of the base electrode side of said piezoelectric crystal disc;

a resilient pressure release cup disposed around said piezoelectric crystal disc and the thin phenolic disc connected thereto in such manner as to be in contact with the periphery and back thereof, respectively;

a metallic disc connected to the back of said resilient pressure release cup;

a metallic cup holding said piezoelectric crystal disc, said phenolic disc, said resilient pressure release cup, and said metallic disc as a unitary means;

a plurality of insulated electrical conductors threaded through said metallic cup, said metallic disc, said resilient pressure release cup, said phenolic disc, the common base of said mosaiced piezoelectric crystal disc, and connected to the forward active faces of said plurality of predetermined electroacoustical energy converter elements, respectively; and

another insulated electrical conductor threaded through said metallic cup, said metallic disc, said resilient pressure release cup, and said phenolic disc, and connected to the aforesaid another electrode.

2. The device of claim 1, wherein said piezoelectric crystal disc is made of lead zirconate and the mosaicing slots extending therethrough are disposed at such angles, respectively, as to cause the forward active faces of said plurality of predetermined electroacoustical energy converter elements to have substantially square geometrical configurations.

3. The device of claim 1, wherein said thin phenolic disc has a thickness of .002 inch.

4. The device of claim 1, wherein said resilient pressure release cup disposed around said piezoelectric crystal disc and the thin phenolic disc connected thereto in such manner as to be in contact with the periphery and back thereof, respectively, is constructed of Butyl rubber.

5. The device of claim 1, wherein said metallic disc connected to the back of said resilient pressure release cup is constructed of aluminum.

6. The invention of claim 1, further comprising:

a hollow shell of acoustically clear material effectively connected to said transducer in such manner that said unitary means is located in the hollow thereof and said electrical conductors extend in fluid tight arrangement through the wall thereof; and

a predetermined acoustic energy refracting fluid filling the hollow of said shell in such manner as to be in constant contact with the active external surfaces of said plurality of predetermined electroacoustical

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energy converter elements, including the slots therebetween and the forward active end faces thereof.

7. The invention of claim 6, further comprising means effectively connected to said hollow shell and the transducer disposed therein for the mounting thereof on a predetermined carrier vehicle, so as to have a predetermined attitude relationship therewith.

8. The invention of claim 1, further comprising a baffle surrounding the periphery of said metallic cup in such manner as to extend a predetermined radial distance therefrom.

9. The device of claim 8, wherein said baffle is constructed of rubber and includes a predetermined plurality of radially spaced, pyramidal shaped wedges that protrude sufficiently in the forward direction to extend beyond the forward active end faces of said plurality of predetermined electroacoustical energy converter elements.

10. The device of claim 8, wherein said baffle comprises:

a ring-like metallic frame having an open front end, a recess of predetermined configuration and depth, and a closed rear end contiguously disposed around the periphery of said metallic cup; and

a filler of rubber disposed within the recess of said frame.

11. The invention of claim 10, further comprising a predetermined plurality of radially spaced, pyramidal shaped rubber wedges integrally connected to the forward surface of said filler in such manner as to protrude sufficiently in the forward direction to extend beyond the forward active end faces of said plurality of predetermined electroacoustical energy converter elements.

12. The invention of claim 11, further comprising:

a bus bar effectively connected to the rear end of said ring-like metallic frame; and

a plurality of terminals extending through said bus bar and respectively connected to the aforesaid electrical conductors.

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U.S. Cl. X.R.

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