United States Patent [19]

Cook

[11] **3,851,300**

[45] **Nov. 26, 1974**

[54] **TRANSDUCER**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

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[21] Appl. No.: **196,848**

[52] **U.S. Cl.** .... **340/8 R,** 310/8.2
[51] **Int. Cl.** **H04b 13/00**
[58] **Field of Search** 340/8, 9, 10, 12, 13; 310/8.2

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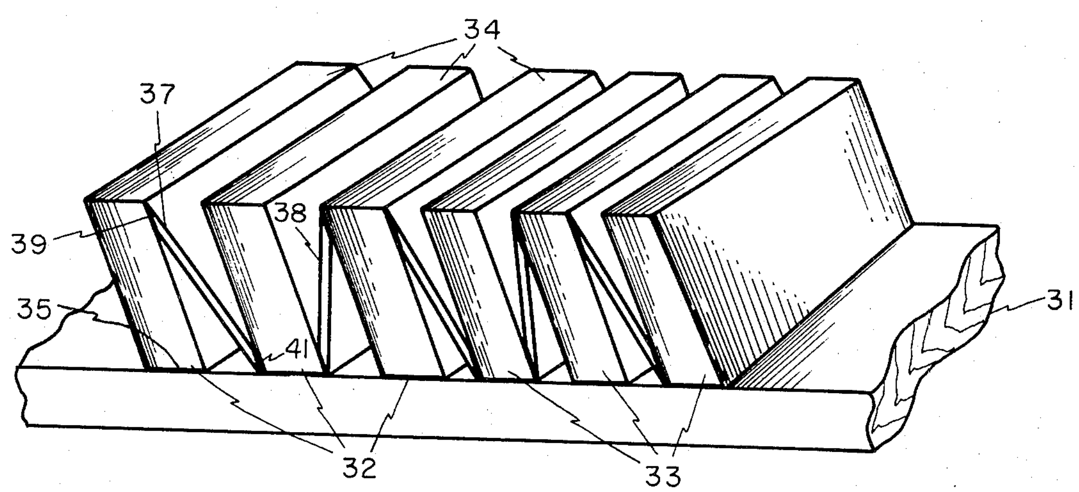
[57] **ABSTRACT**

An electroacoustical transducer is disclosed which incorporates an array of reversible electroacoustical energy converters. Disposed between opposite ends of adjacent ones of said converters is one or more balsa wood struts or wafers which effect predetermined lateral mechanical decoupling therebetween whenever they are energized either by electrical or acoustical energy.

16 Claims, 10 Drawing Figures



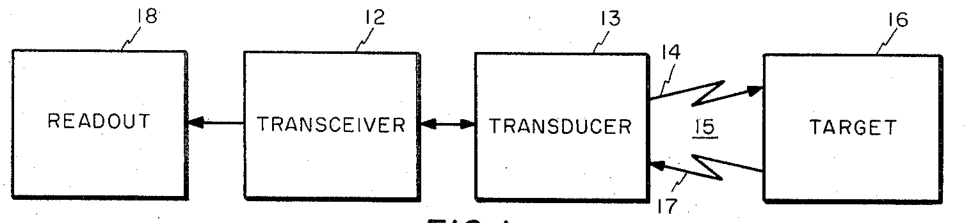


FIG. 1

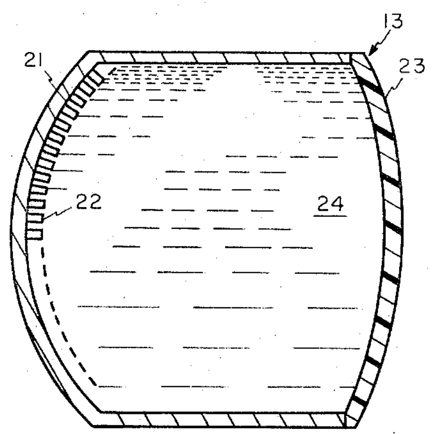


FIG. 2

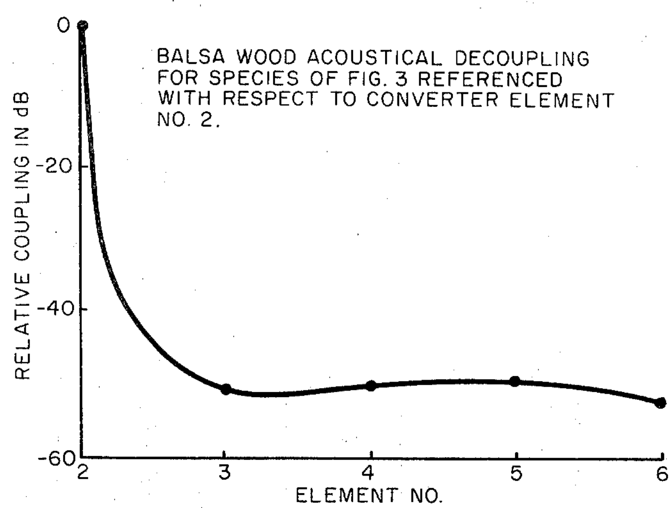


FIG. 9

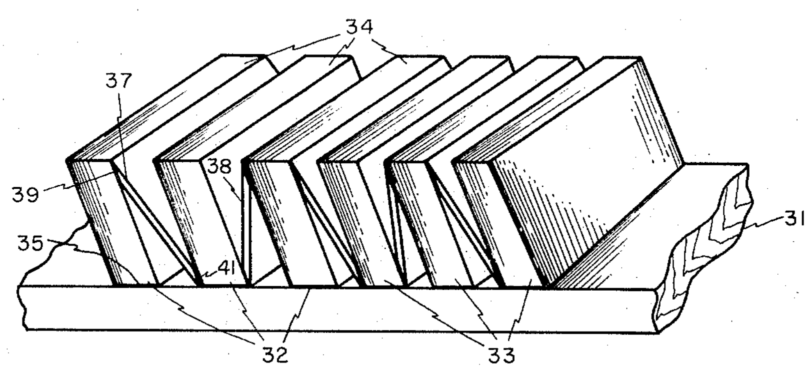
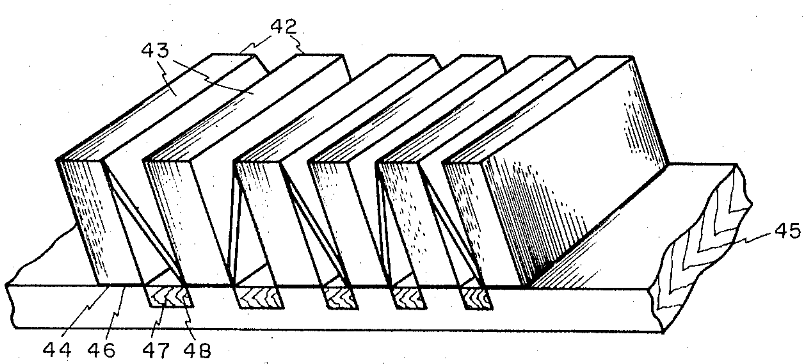


FIG. 3



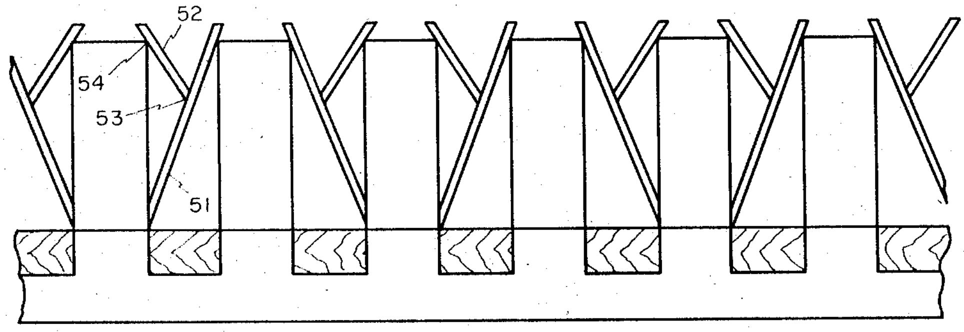


FIG. 5

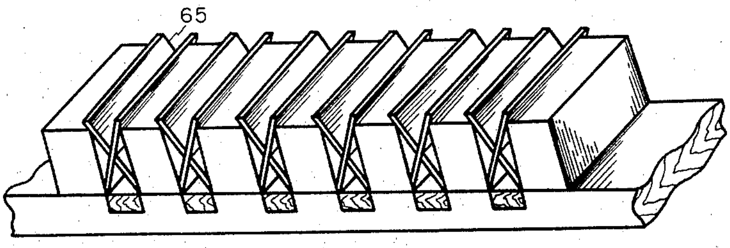


FIG. 6

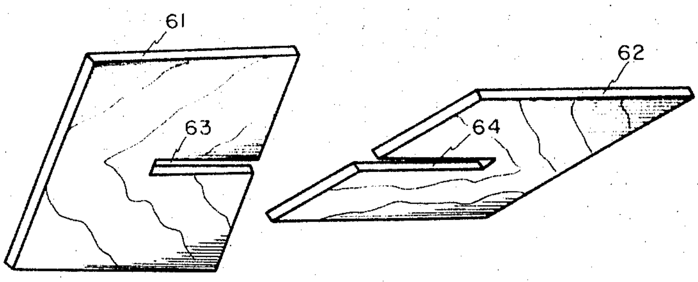


FIG. 7

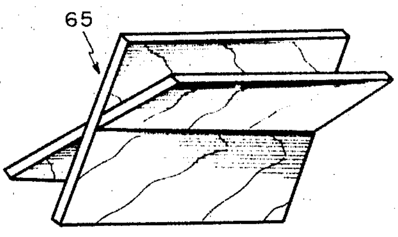


FIG. 8

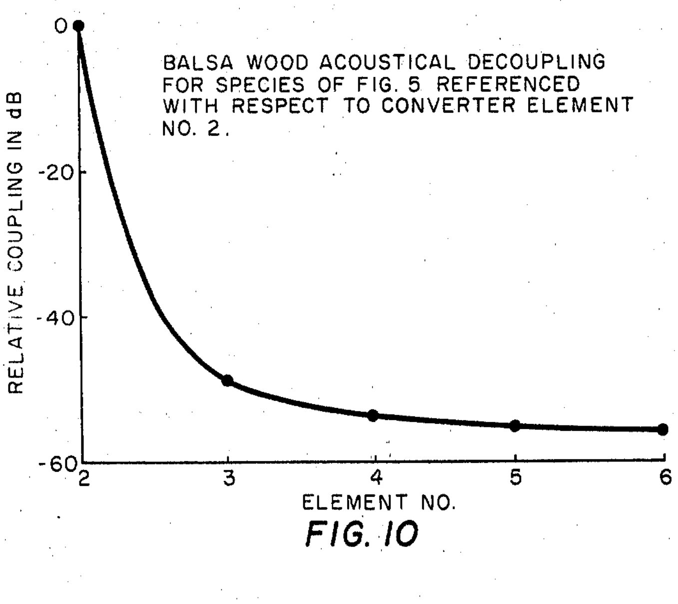


FIG. 10

TRANSDUCER

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 pertains, in general, to electroacoustical transducers and, in particular, is an electroacoustic transducer incorporating an array of substantially pressure decoupled piezoelectric energy converters or crystals, the decoupling of which is accomplished in a relatively simple but unique manner.

DESCRIPTION OF THE PRIOR ART

Heretofore, numerous prior art electroacoustical transducers have been invented, some with means for decoupling the various and sundry energy converters incorporated therein. For example, some prior art transducers have arrays of energy converter elements that are sufficiently spaced from one another to minimize cross-coupling of acoustical energy therebetween; others, have shaped the individual energy converter elements in an attempt to make them more directional in their response to excitation. Still other prior art transducers use mass loading techniques in the construction thereof, so as to reduce vibrations in unwanted directions which, in turn, induce spurious excitations in adjacent energy converter elements. In addition, others have included solid pressure release materials between energy converter elements which, to some extent, act as pressure insulators therebetween.

All of the known prior art decoupling structures and methods, including those mentioned above, leave a great deal to be desired, in that they reduced the sensitivity and/or efficiency thereof, they reduce the resolution thereof, and they increase associated adverse side effects, such as, for instance, the cooling difficulties encountered in those transducers intended to be operated at high power.

SUMMARY OF THE INVENTION

The instant invention overcomes many of the aforementioned problems attributable to prior art electroacoustical transducers, in that it incorporates structures that effect improved image resolution characteristics without excessive loss of cooling capabilities. These beneficial results are obtained by means of uniquely configured, grain oriented balsa wood members disposed between and interconnecting substantially opposite ends of adjacent piezoelectric energy converter elements of an array of such elements. Moreover, the mounting and structural configuration of said balsa wood members are such as allows cooling and insulating oils and other refractive acoustical fluids to be in direct contact with maximum areas of the individual energy converter elements, while at the same time causing the radiating faces thereof to be shaded in such manner as to improve the directivity characteristics thereof.

It is, therefore, an object of this invention to provide an improved electroacoustical transducer.

Another object of this invention is to provide an electroacoustic transducer array having improved sonic

isolation between the adjacent energy converter elements thereof.

Still another object of this invention is to provide an electroacoustic transducer having improved acoustic decoupling between the energy converters thereof, while allowing optimum interaction thereof with lens and cooling liquds, other fluids, and the like.

Another object of this invention is to provide an improved method and means for sonically decoupling predetermined electroacoustical energy converter elements in a given array of such elements.

Antoher object of this invention is to provide an improved method and means for supporting vibrating members in an array of two or more vibrating members, so as to minimize the spurious resonance coupling of forces therebetween.

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 DRAWINGS

FIG. **1** is a block diagram of a sonar system which incorporates the subject invention to an advantage;

FIG. **2** is a representative embodiment of an electroacoustical transducer incorporating an array of sonically decoupled energy converters, in accordance with the subject invention;

FIG. **3** is a perspective view of one species of the energy converter array of the transducer of FIG. **1**;

FIG. **4** is a perspective view of another species of the energy converter array of the transducer of FIG. **1**;

FIG. **5** is an elevational view of still another species of the energy converter assembly of the subject invention;

FIG. **6** is a perspective view of still another species of the energy converter assembly of the invention;

FIG. **7** is an exploded view of an improved acoustic separator according to the invention;

FIG. **8** is a perspective view of the assembled acoustic separator of FIG. **7**;

FIGS. **9** and **10** are graphical representations of the decoupling characteristics effected by the species of FIGS. **3** and **5**, respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown a sonar system **11** of the type that may incorporate the subject invention to an advantage. Included therein is a transceiver **12** that is connected to an electroacoustical transducer **13**. In response to electrical energy supplied to transducer **13** by the transmitter portion of transceiver **12**, acoustical energy **14** is broadcast throughout aqueous or other ambient environmental medium **15**, and after reflection from a target **16**, the echo **17** thereof is sensed by transducer **13** and coupled to the receiver portion of transceiver **12** for suitable processing before display thereof by a readout **18**.

The foregoing sonar system **11** has been presented herewith by way of introduction and example to emphasize the usefulness and significance of the contribution made thereto - and, indeed, to numerous other similar sonar systems, as well - by the subject invention.

FIG. 2 depicts an exemplary electroacoustical transducer of the type that may be used in the sonar system of FIG. 1 as transducer **13.** Because it is merely representative of the several liquid lens type transducers presently available, with the exception of the decoupled electroacoustical energy converter array - to be described subsequently - it is herewith disclosed quasi-schematically for simplicity of disclosure purposes. Thus, it may readily be seen that it incorporates a housing **21** which, at one inner end thereof has an array of decoupled piezoelectric crystal, electroacoustical energy converter elements **22** configured according to the invention. At the other end of housing **21** is an acoustically clear membrane or wall **23** which effects the closure of housing **21,** so as to make it a leak-proof container-like configuration. Disposed within the non-occupied portion of housing **21** is any suitable acoustical energy refracting fluid **24,** such as, for example, a Flurolube and FC-75 mixture, manufactured by Hooker Chemical Co. of Niagara Falls, N.Y.

The aforementioned acoustically clear wall **23** in combination with fluid **24** comprises an acoustic lens which refracts incoming sonic energy in such manner as to cause it to be focused on energy converter array **22.** Of course, said combination would constitute a refractive lens during the broadcast of acoustical energy by the converters of array **22,** too, inasmuch as for most practical purposes transducer **13** may be considered to be a reversible transducer.

A detailed portion of one species of an electroacoustical energy converter array of the type that may be used as array **22** of FIG. **2** is illustrated in FIG. **3.** As may be seen, it contains a base **31** which is preferably made of a relatively flexible acoustic release material, such as, for instance, corprene, balsa wood, or the like, or any other rigid, resilient, or piezoelectric material. Attached thereto, as by an appropriate conventional cement **32** (or any other suitable attachment means) is a plurality of spatially disposed piezoelectric elements **33,** herewith geometrically configured as oblong blocks, although square blocks, round posts, tapered posts, or any other configurations warranted by operational circumstances may also be so attached. Obviously, it would be well within the purview of the artisan having the benefit of the teachings presented herein to design the acoustical energy converter elements of array **22** to have whatever structural configuration is desired, either individually or in concert, including the making of them in the form of single or double diced or serrated crystal elements.

At this time, it would perhaps be noteworthy that the appropriate faces or surfaces of piezoelectric energy converters also have suitable electrodes **34** and **35** attached to them, with electrical lead wires (not shown) connected thereto, as is conventional in the electroacoustical transducer art, so that the energy converters will be energized in response to the electrical energy supplied to said electrodes and vice versa.

Moreover, it is also noteworthy that said energy converters **33** are at least partially immersed in the aforementioned refractive fluid **24,** so that said fluid is in contact with the adjacent sides of all of the individual elements of array **22,** as well as with the active-responsive surfaces thereof.

The uniqueness of the subject invention, as previously suggested, lies in the method and means of mechanically decoupling the energy converter elements of an array and especially adjacent ones thereof, so as to provide optimum acoustical isolation for each thereof which, in turn, permits high signal discrimination to occur between adjacent crystal elements. Of course, the better the signal discrimination, the better the image resolution of any acquired target object; moreover, this is especially true with respect to the imaging of marine mines that are buried within the sea floor.

To effect the aforementioned decoupling of electroacoustical energy converter elements - that is, piezoelectric crystals **33** - thin struts or wafers **37** and **38** are respectively located between adjacent ones thereof in such manner that they have angular bracing dispositions between substantially one end of one and substantially the other end of an adjacent one. Hence, said wafers are physically connected to the tops and bottoms of said energy converters, respectively, and they are so connected by any suitable means, such as conventional cement **39** and **41,** or the like.

Wafers **37** and **38** may be made of any appropriate impedance mismatching material; however, it has been found that balsa wood with the grain thereof properly oriented is an eminently satisfactory material therefor.

FIGS. **4** through **6** are additional species of the subject invention and, for the most part, only differ from the species of Fig. **3** and each other by the respective decoupling configurations of the wafers and depths of serrations between crystals. Therefore, extraneous details of each thereof will be omitted, unless they are necessary for the disclosure of different structural decoupling configurations. So doing, of course, will facilitate the disclosure of the inventive aspects thereof, without belaboring the conventional aspects and, therefore, will simplify this case.

FIG. **4,** like FIG. **3,** contains a plurality of acoustical energy converter elements **42,** each of which are conventionally energized by electrodes **43** and **44** attached thereto. Said converter elements are mounted on a base **45,** as by cement **46** or the like. In this particular embodiment, however, the slots or serrations between converters have extensions **47** into base **45** which are filled with solid decoupling material **48,** such as balsa wood, rubber, or the like. Wafers **49** and **50,** likewise preferably of balsa wood, are respectively disposed in such manner between adjacent converters that they extend from the top of one to the bottom of an adjacent one and vice versa, preferably without extending into the balsa wood filled serrations of base **45.**

The embodiment of the invention of FIG. **5** is similar to that of FIG. **4,** except that it has differently that is, Y-configured decoupling balsa wood wafer assemblies **51,** each of which extends from the bottom of one converter to the top of an adjacent converter, and each of which includes another support wafer **52** which is attached to and extends from approximately an intermediate position **53** of wafer **51** to the top **54** an adjacent converter element. Again, all connections between wafer sections and electroacoustical energy converters may be made by any conventional means, such as cement or the like.

FIG. **6** is substantially similar to the assembly of FIGS. **4** and **5,** except that it includes still another decoupling wafer configuration, herewith defined as an X configuration. As may readily be seen from FIG. **7,** such an X configuration may be made of two plates of balsa wood **61** and **62,** each of which have slots **63** and

64, respectively. When assembled, as by mating slots 63 and 64, said X configured wafer acquires the appearance of that referenced as 65 in FIG. 8. Hence, if balsa wood wafers 65 having the X geometrical configuration of the one of FIG. 8 are respectively inserted between adjacent energy converter elements that are likewise otherwise constructed essentially as those shown in FIGS. 3, 4, or 5, the result is the decoupled array of energy converters shown in the aforementioned FIG. 6.

Again, it should perhaps be emphasized that the subject invention consists of a new combination of old elements; accordingly, it is to be understood that portions of the electroacoustical energy converter arrays of the type shown in FIGS. 2 through 6 are well known in the art. For instance, the energy converter elements of all of the above described species of the invention may be of any conventional types. Thus, they may comprise electroded piezoelectric crystal elements, such as barium titanate, lead zirconate, or the like; or, in the alternative, they may be of such structural configurations as to be electrostrictively responsive in nature, if so desired. Obviously, one of ordinary skill in the art having the benefit of the teachings herewith presented could select any one of many well known electroacoustical energy converter designs and incorporate them as the energy converter array portions of the otherwise unique combinations of elements constituting this invention without violating the spirit and scope thereof. Therefore, it should also be noted that when the various species of converter decoupling methods and means are incorporated in such assembled arrays, structural combinations are effected which have been heretofore unknown and which produce decoupling results that are new, different, and, for many practical purposes, better than those of the prior art, as evidenced by the decoupling curves depicted in FIGS. 9 and 10.

MODE OF OPERATION

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

When the liquid lens transducer of FIG. 2 incorporates any or all of the electroacoustical, piezoelectric energy converter element assemblies of FIGS. 3 through 8 and is included in a sonar system of the type exemplarily illustrated in FIG. 1, it becomes a relatively high image resolution device which may be used to broadcast acoustical energy in search of an underwater target and respond, with considerable accuracy, to acoustical echoes therefrom. As such, the sonar system of FIG. 1 facilitates the location, range-finding, and identification of various and sundry target objects, including buried marine mines of the type that are used to mine harbors and other places during warfare. Of course, the improved target imaging or resolution is effected as a result of the aforesaid energy converter piezoelectric crystal decoupling.

When an energy converter crystal is excited, either from a varying acoustic pressure or by an electrical signal, all faces thereof undergo a change in dimensions. These changes in crystal dimensions produce a pressure in a lateral direction that can set adjacent crystal elements into mechanical motion. Such operational sequence may, of course, occur several times and at several places in an energy converter array, which, in turn, causes deleterious image distortions to occur therein. To prevent such occurrences of mechanical motion transfer between crystal elements, one or more struts or thin wafers of balsa wood are inserted and connected between the crystal elements in an angular position - that is, top to bottom or between opposite ends of adjacent elements - in order to reduce the level of lateral pressure energy coupling therebetween.

As shown in FIGS. 9 and 10, it has been determined that the use of balsa wood as the material of which the decoupling wafers are made causes the lowering of the acoustical coupling level between adjacent converter elements - such as, for example, between acoustical energy converter elements 2 and 3 - by as much as 50 db, which is indeed significant from a target image resolution standpoint. Such improved results are effected, of course, because balsa wood is ordinarily of such grain and consistency as to cause it to provide boundary conditions that have a different characteristic impedance from that of the fluid or liquid ordinarily disposed between energy elements in an electroacoustical transducer, thereby establishing sufficient impedance mismatch to lower the intercoupling level throughout the entire energy converter array thereof. As a result, each energy converter element responds more nearly to its respective electrical or acoustical excitation, regardless of what is happening to adjacent or contiguous ones thereof. Of course, such individual response improves the image resolution thereof to a considerable extent.

From the foregoing, it may readily be seen that the disclosed use of balsa wood or other similar decoupling means between electroacoustical energy converters of an array of electroacoustical energy converters of a sonar transducer produces an advance in the art which is significantly new and useful to be of patentable significance.

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. In a reversible electroacoustical transducer:

a plurality of electroacoustical energy converters, each of which has an active-response surface and a mounting surface in opposite disposition therewith, and each of which is spatially disposed from the others;

a plurality of electrodes respectively connected to the active-response surfaces and the mounting surfaces of said plurality of electroacoustical energy converters;

base means connected to the mounting surface electrode ends of each of said plurality of electroacoustical energy converters for the supporting thereof in a predetermined array within said electroacoustical transducer; and

substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-responsive surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters, without further contact with the remainder of the sides thereof.

2. The device of claim **1** wherein each of the plurality of electroacoustical energy converters comprises a piezoelectric crystal element.

3. The device of claim **1** wherein said space means connected to the mounting surface electrode ends of each of said plurality of electroacoustical energy converters for the supporting thereof in a predetermined array within said electroacoustical transducer comprises a flexible, resilient, pressure release base.

4. The device of claim **1** wherein said base means connected to the mounting surface electrode ends of each of said plurality of electroacoustical energy converters for the supporting thereof in a predetermined array within said electroacoustical transducer comprises a balsa wood base.

5. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises strut means.

6. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surface of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises a balsa wood strut.

7. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises a wafer.

8. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises a balsa wood wafer.

9. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises a plurality of rigid decoupling wafers.

10. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises a plurality of balsa wood wafers.

11. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises:

a first plurality of decoupling wafers effectively connected between opposite ends of adjacent sides of adjacent ones of said plurality of electroacoustical energy converters; and

a second plurality of decoupling wafers effectively connected between intermediate locations of predetermined sides of said first plurality of decoupling wafers and the sides of adjacent ones of said plurality of electroacoustical energy converters in such manner respectively as to effect a Y-cross-sectional configuration for each combination thereof.

12. The invention of claim **11,** wherein each of said first and second plurality of decoupling wafers is a balsa wood wafer.

13. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises:

a first wafer having a first wall of predetermined thickness and a first slot located therein that runs partially therethrough in a direction that is substantially parallel to the aforesaid electroacoustical energy converter support means;

a second wafer having a second wall of a thickness that is sufficiently complementary with said first slot to be slidably inserted therein and a second slot partially running therethrough in a direction that is parallel to said first slot and of such dimension as to be sufficiently complementary with said first wall to be slidable thereover, with said first and second slots of said first and second wafers slided together in such manner as to cause an overlapping and interweaving of said first and second wafers, so as to effect an X-cross-sectional geometrical configuration of the combination thereof.

14. The device of claim **13,** wherein said first and second slotted wafers are balsa wood wafers.

15. The device of claim **1,** wherein said substantially rigid, impedance mismatching, bracing means respectively angularly connected only between the sides contiguous with the active-response surfaces of predetermined ones of said plurality of electroacoustical energy converters and the sides contiguous with the base mounting surfaces of predetermined adjacent others thereof for effecting the lateral mechanical and pressure energy decoupling between predetermined ones of said plurality of electroacoustical energy converters without further contact with the remainder of the sides thereof comprises:

a first plurality of decoupling wafers effectively connected between opposite ends of adjacent sides of adjacent ones of said plurality of electroacoustical energy converters, respectively;

a second plurality of decoupling wafers effectively connected between intermediate locations of predetermined sides of said first plurality of decoupling wafers and the sides of adjacent ones of said plurality of electroacoustical energy converters, respectively; and

a third plurality of decoupling wafers effectively connected between intermediate locations of the sides of said first plurality of decoupling wafers that are opposite those to which said second plurality of decoupling wafers are effectively connected and the sides of adjacent ones of said plurality of electroacoustical energy converters in such manner respectively as to cause said first, second, and third plurality of decoupling wafers to effect a predetermined configuration for each combination thereof.

16. The invention of claim **15** wherein said first, second, and third plurality of decoupling wafers are balsa wood decoupling wafers.

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