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Haan

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[54] **WIDE-BAND ELECTROACOUSTIC TRANSDUCER**

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[52] **U.S. Cl.** **310/9.5**, 310/9.6, 340/10

[51] **Int. Cl.** **H01j 7/00**

[58] **Field of Search** .... 310/8, 8.2, 9.6, 9.5; 340/10; 73/67.5 R

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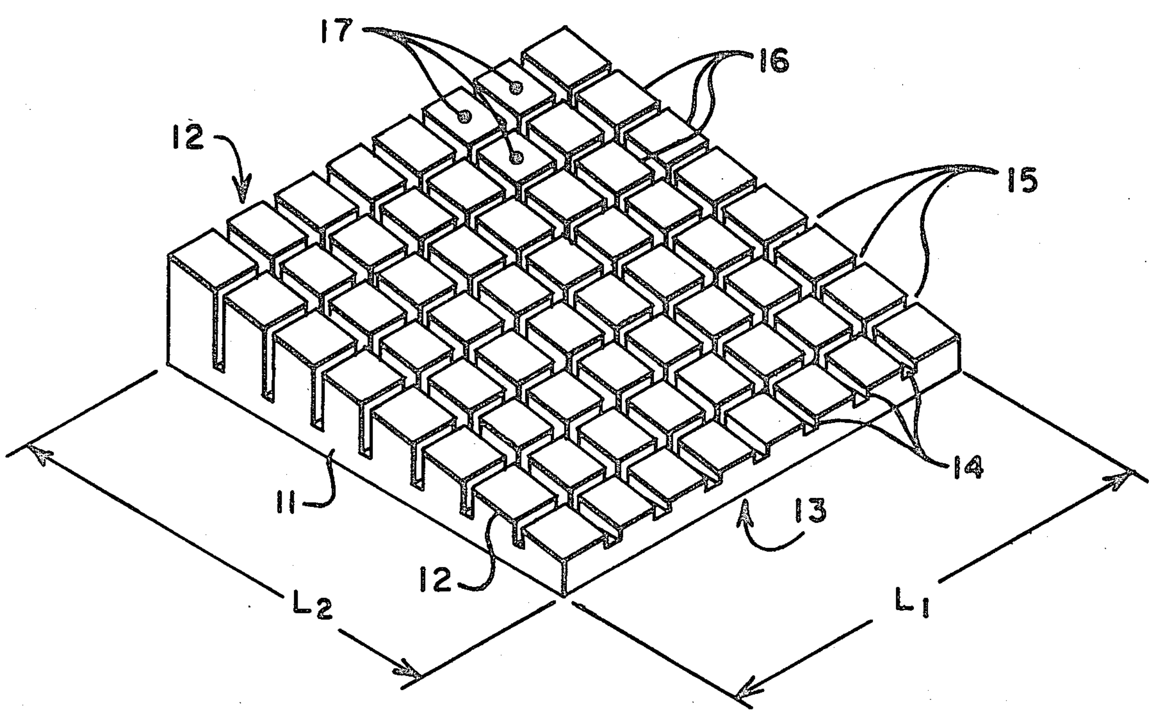
Primary Examiner—Mark O. Budd

[57] **ABSTRACT**

A thickness-mode electroacoustic transducer wherein an active body of non-uniform thickness is employed to provide uniform wide-band frequency response. The body may be wedge-shaped, having non-parallel planar major surfaces. At least one of the major surfaces is subdivided into a two-dimensional array of poles by means of grooves formed in the surface for the purpose of providing improved frequency and directional response.

9 Claims, 3 Drawing Figures



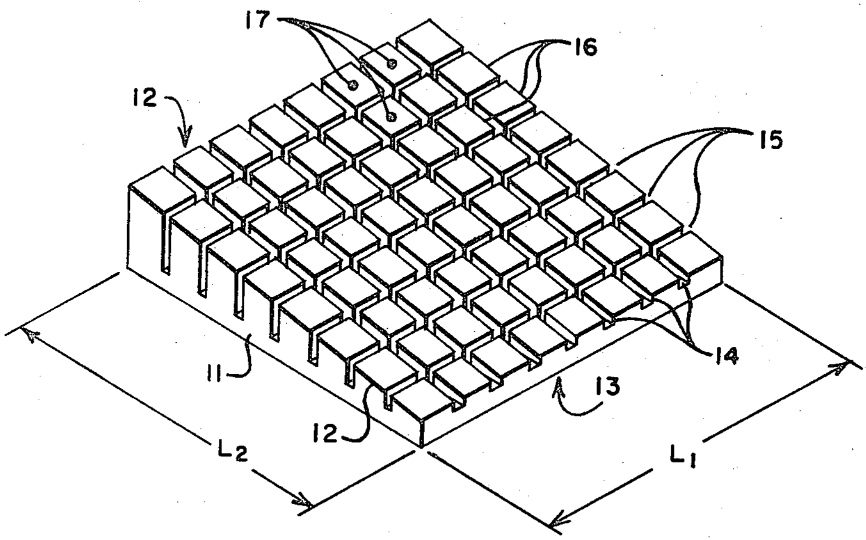


FIG. 1

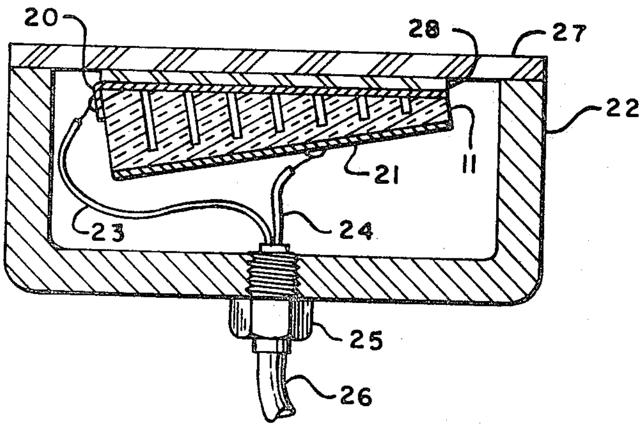


FIG. 2

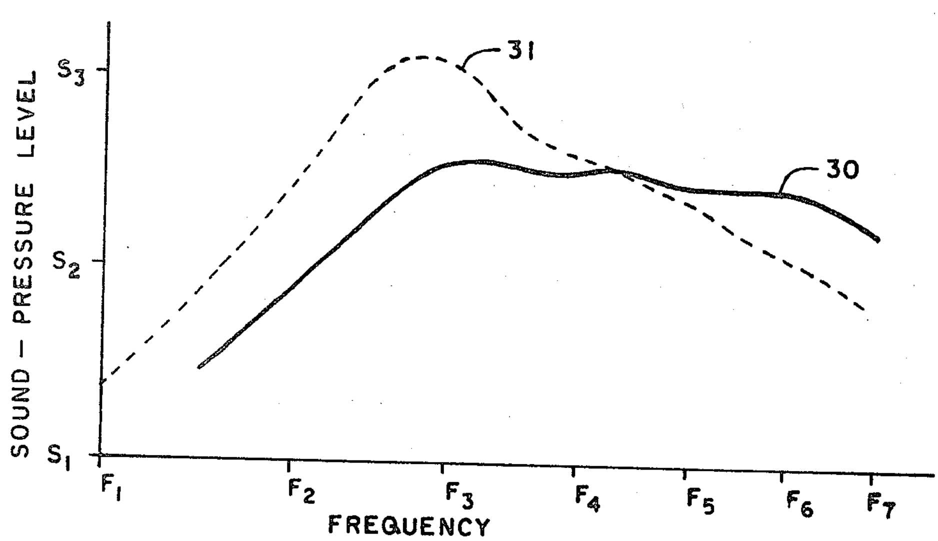


FIG. 3

and does not require critical design of the transducer housing and/or electrical signal processing circuitry.

Additional objects of the present invention may be ascertained from a study of the drawings, specification, and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of the applicant's uniquely configured active body for an electroacoustic transducer;

FIG. **2** is a sectional view of a wide-band sonar transducer including the active body shown in FIG. **1** with electrodes attached and mounted in a water tight housing; and

FIG. **3** is a pair of operational curves for illustrating relative bandwidths of the applicant's transducer and a typical prior art wide-band transducer.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The transducing element shown in FIG. **1** comprises a body **11** formed from a thick sheet or plate of piezoelectric ceramic material. Suitable ceramic materials for this purpose include barium titanate and lead zirconate titanate. Body **11** has opposing nonparallel major surfaces **12** and **13.** Surfaces **12** and **13** may be planar, thus providing for a body of wedge-shaped or tapered configuration. Sets of grooves **14** and **15** are formed in surface **12** to subdivide the surface into a two-dimensional array of poles **16.** Each pole has a face **17** which lies in surface **12.**

Sets of grooves **14** and **15** may be located along two sets of equally-spaced parallel lines, each set intersecting the other so as to form a regular pattern. As shown in FIG. **1,** sets of grooves **14** and **15** are at right angles to one another. However, such a geometric relationship is not required for proper operation. The grooves may, for example, be located along unequally spaced lines. Further, grooves **14** may be oriented at an acute angle relative to grooves **15.**

Theoretically, the spacing between adjacent grooves should be such that the maximum cross-sectional dimension of each pole is less than one wave length at the resonant frequency of that pole. Thus, the spacings between adjacent grooves may vary depending on the location of the grooves between the thick and thin edges of the piezoelectric body. However, from a production viewpoint, it has been found more practical to evenly space the grooves. Also, it has been found more effective to space the grooves so that maximum cross-sectional dimensions of the poles are approximately one-half wave length at the highest operating frequency of the transducer.

Operational transducers have been constructed with spacing between adjacent grooves as small as one millimeter. The width of the grooves should be as small as possible to minimize the volume of ceramic material removed, and thereby maximize the power-handling capabilities of the transducing element. Minimum groove width is determined by the width of the cutting or forming tool, and may be in the order of a few thousandths of an inch.

The ceramic material from which body **11** is formed is polarized to operate in a thickness mode. Stated otherwise, an alternating electrical potential applied between surfaces **12** and **13** causes alternating changes in the thickness of body **11.** Conversely, mechanical forces which cause alternating thickness changes result in generation of an alternating potential between surfaces **12** and **13.**

One of the functions of grooves **14** and **15** is to minimize mechanical coupling between poles **16.** Since any solid material connecting individual poles results in mechanical intercoupling, optimum operation is achieved if the grooves are as deep as possible. However, it is also necessary to maintain the structural integrity of body **11.** For operational purposes, the depth of grooves should be at least 75 percent of the body thickness. It has been found that forming the grooves to a depth of 85 percent of the minimum body thickness leaves sufficient material beneath the grooves to prevent fracture during normal handling and operation. In the preferred embodiment shown in FIG. **1,** the grooves extend to a uniform distance from surface **13,** forming rows of poles of increasing (or decreasing) height.

From an operational viewpoint, lateral dimensions L_1 and L_2 of body **11** are dictated by directional response or beam width requirements. Practical considerations presently limit dimensions L_1 and L_2 to a maximum of approximately **2** inches. However, the effect of a larger bady can be achieved by mounting individual bodies side by side and energizing them in parallel.

Beam width in a given plane is inversely proportional to the lateral dimension in that plane. Hence, beam width in a plane parallel with indicated dimension L_1 is inversely proportional to the magnitude of L_1. The beam width in a plane parallel with indicated dimension L_2 tends to be inversely proportional to the magnitude of L_2. However, the asymmetry of body **11** in planes parallel with dimension L_2 complicates the relationship between the magnitude of dimension L_2 and beam width in planes parallel therewith. It has been found that for a thickness taper of **4** degrees, the effective radiating aperture is approximately 0.82 L_2. The multiplying factor is believed to vary inversely with taper angle.

FIG. **2** shows a complete sonar transducer in which previously described body **11** is provided with electrodes **20** and **21** and mounted within a fluid tight housing **22.** Surfaces **12** and **13** may be prepared in a conventional manner for attachment of electrodes **20** and **21.** For example, a silver paste may be screened on the surfaces and fired, or the surfaces may be sprayed with a silver paint. Electrodes **20** and **21** are then secured to the prepared surfaces.

In order to achieve optimum operation, there must be uniform mechanical loading of the poles and minimum mechanical coupling between poles. It is also important that the electrode on the pole faces have a smooth and flat exterior surface for mounting against a flat acoustic window or radiation into a fluid medium. These requirements impose certain restrictions on electrode **20.** One improved electrode configuration which has been found quite satisfactory comprises metal foil bonded to the pole faces by means of an adhesive. Foil tape having a pressure sensitive adhesive backing has been found satisfactory for this purpose.

Electrode **21** may be of the same type as electrode **20.** Alternatively, if body **11** is of the illustrated configuration wherein grooves are formed in only one major surface, electrode **21** may be any one of various suitable prior art types of electrodes, or a simple soldered wire connection.

WIDE-BAND ELECTROACOUSTIC TRANSDUCER

BACKGROUND OF THE INVENTION

The invention herein described was made in the course of or under a contract, or subcontract thereunder, with the Department of the Navy.

This invention pertains generally to acoustic transducers, and more specifically to thickness-mode electroacoustic transducers having relatively uniform frequency and directional response over a wide band of frequencies.

For purposes of the following discussion, it is pointed out that certain terms used as a matter of convenience are most commonly associated with projection of acoustic energy. However, the discussion applies to both acoustic projectors and hydrophones.

Commercial and military interest in transmitting and receiving underwater acoustic signals has increased rapidly in recent years. One of the most widely used items of equipment for this purpose is the electroacoustic transducer. Most prior art electroacoustic transducers are inherently relatively narrow frequency band devices. A basic reason for this is that each transducer, including its transducing element and associated electrodes, acoustic decouplers and housing, comprises a dynamic structural system having a fundamental resonant frequency and other dynamic characteristics which limit its frequency response.

One common type of electroacoustic transducer, known as a thickness-mode transducer, employs a transducing element of which the lateral dimensions are larger than the thickness. The transducing element is polarized so that its thickness changes in response to a changing electrical potential applied across the element. Conversely, any mechanical force which changes the thickness of the element results in generation of a changing electrical potential thereacross.

Thickness-mode transducers as described above are entirely adequate for many underwater electroacoustic transducer applications. Further, such transducers of conventional narrow frequency band design have the added advantage that problems in achieving satisfactory frequency and directional response are generally minimized. Nevertheless, they frequently exhibit somewhat anomalous frequency and directional response characteristics. Such characteristics become increasingly pronounced and troublesome in transducers designed for operation over wider bands of frequencies.

A variety of techniques have been devised in attempts to minimize side lobes and other unwanted forms of radiation which to some degree, degrade the response patterns of all transducers. One such technique involves forming grooves in a face of the transducing element. The grooves have the effect of interrupting the propagation of unwanted (typically radial or lateral) modes of vibration in the element, thereby minimizing undesired patterns of radiation. Transducers employing this technique are described in greater detail in U.S. Pat. Nos. 2,956,184 and 3,470,394 issued respectively to Hyman Pollack on Oct. 11, 1960 and Rufus Cook et al. on Sept. 30, 1969.

Another prior art technique (also described in U.S. Pat. No. 2,956,184) involves contouring the transducing element so that an electrical signal applied between opposing faces thereof subjects the center of the element to a higher electrical gradient than that near its outer edge. According to the patent, the outer edge of the element is believed to be principally responsible for radiating side lobes. Hence, by differentially polarizing the transducing element so that its outer edge is driven less vigorously than its central portion, directional response is improved.

Yet other techniques which have been attempted for minimizing unwanted transducer radiation include mechanical tuning of the transducing element-housing assembly, the use of electrical signal shaping circuitry, and the use of acoustical baffles for defining a window through which radiation is permitted.

Whereas conventional narrow-band transducers have been generally satisfactory for many past transducer applications, an increasing number of requirements are now developing for transducers capable of efficient operation over an extended band of frequencies. Wide-band operation greatly increases the severity of problems involved in achieving acceptable directional response, and necessitates the use of special features to minimize such problems. The transducer disclosed in previously identified U.S. Pat. No. 3,470,394 employs a transducing element of which opposite faces are cross serrated or diced to permit operation over a somewhat wider band of frequencies than prior art transducers. Although transducers of this design provide somewhat improved wide-band performance, they have not been found capable of acceptable operation over bands of frequencies which are sufficiently wide to meet various present transducer requirements.

The applicant has discovered an electroacoustic transducer element of unique design which provides uniform response over a substantially increased band of frequencies. The design includes features for minimizing radiated side lobes and other unwanted response characteristics. Thus, the broad band capabilities may be effectively used to maximum advantage.

SUMMARY OF THE INVENTION

The invention herein described is a thickness-mode electroacoustic transducer comprising an active body having non-parallel major surfaces for transmitting or receiving acoustic energy. At least one of the major surfaces is subdivided by means of grooves to form a two-dimensional array of poles. The major surfaces are provided with electrode means for carrying electrical signals to or from the poles.

In a preferred embodiment, the non-parallel major surfaces are planar so that the body is of a generally wedge-shaped configuration. The grooves may be located along two intersecting sets of parallel lines so as to form a regular pattern, and may extend to a uniform distance from the surface opposite the grooved surface, thereby forming poles of varying heights. The electrode means may comprise conductive foil bonded to the major surfaces by means of an adhesive.

A principle object of this invention is to provide an improved electroacoustic transducer which is capable of efficient operation over a wide frequency band.

A further object is to provide a wide-band electroacoustic transducer capable of producing a satisfactory directional response pattern at all frequencies within its operating frequency band.

Yet a further object is to provide a uniquely configured transducing element which is suitable for wide-band operation; is simple and economical to produce;

Electrodes **20** and **21** are attached to insulated conductors **23** and **24** respectively. Conductors **23** and **24** pass through a fluid tight feedthrough fitting **25** in housing **22** and into a cable **26** which carries electrical signals between electrodes **20, 21** and conventional electrical signal processing circuitry not shown in FIG. **2.**

Housing **22** is provided with a window **27** which is suitable for the transmission of acoustic energy. The transducer embodiment shown in FIG. **2** is air filled. In such an embodiment, structural acoustic decouplers are not required. In addition, the assembly comprising body **11** and electrodes **20, 21** may be secured directly to window **27.** As shown, the assembly is bonded to window **27** by means of a layer of adhesive **28** between the window and electrode **20.** It is, however, pointed out that the present invention may be equally advantageously employed in connection with fluid filled transducers, and in connection with transducers wherein the body - electrode assembly is not secured to the window, but is mounted within the housing by methods which may require the use of structural acoustic decouplers.

The improvement in wide-band response afforded by the applicant's unique transducer configuration is evident in FIG. **3.** Curve **30** represents the sound-pressure level versus frequency characteristic of a typical transducer in accordance with the present invention. Curve **31** represents the sound-pressure level versus frequency characteristic of a typical prior art transducer designed to operate over substantially the same frequency range. It can be observed from curve **31** that the prior art transducer has a definite resonance at a frequency between F_2 and F_3. The sound-pressure level decreases relatively rapidly at frequencies below and above the resonant frequency.

Since a relatively constant voltage level versus frequency relationship is required for practical sonar operation, it can be observed that the operational frequency range of the prior art transducer is limited. The useful frequency range can be somewhat extended by employing electronic compensation to boost voltages having values below a desired level, and by employing damping to reduce voltages having values above the desired level. These techniques obviously involve critical design considerations, and require additional equipment which increases the complexity of resulting transducer installations. Further, although some increase in useful bandwidth can be achieved, the total available improvement is limited.

As shown by curve **30,** the sound-pressure level versus frequency response of a transducer in accordance with the present invention is relatively constant, for a constant applied voltage, over a range of frequencies extending from below F_3 to approximately F_6. This relationship extends over a considerably greater range of frequencies than that over which useful operation can be obtained from a transducer of prior art design. If re-

quired, the operational frequency range can be somewhat further extended by employing electronic compensation.

Although a single embodiment of the applicant's invention has been shown and described in detail, a variety of other embodiments and modifications are within the applicant's contemplation and teaching. Such embodiments and modifications will be readily apparent to one skilled in the art having the benefit of the teachings presented in the foregoing description and drawings. Accordingly, the applicant does not intend to be limited to the disclosed embodiment, but only by the terms of the appended claims.

What is claimed is:

1. In a thickness-mode electroacoustic transducer of the type including an active body having two major surfaces, at least one of which is subdivided by means of grooves to form a two-dimensional array of poles, and electrode means for carrying electrical signals to or from the poles, the improvement which comprises an active body wherein the major surfaces are non-parallel so that said body is of non-uniform thickness.

2. The transducer of claim **1** further including a fluid tight housing having a window transparent to acoustic energy, and means for securing the assembly comprising said body and said electrode means within said housing.

3. The transducer of claim **2** wherein said body is positioned within said housing so that said poles are generally directed toward the window, said assembly being bonded to the window.

4. A wide-band thickness-mode electroacoustic transducer comprising an active body having two non-parallel major surfaces at least one of which is subdivided by means of grooves to form a two-dimensional array of poles, and electrode means for carrying electrical signals to or from said poles.

5. The transducer of claim **4** wherein said body is of tapered configuration having planar major surfaces.

6. The transducer of claim **5** wherein the grooves in one major surface of said body extend to a uniform distance from the other major surface, thereby forming poles of varying heights.

7. The transducer of claim **6** wherein the grooves are located along two sets of equally-spaced parallel lines, each set intersecting the other so as to form a regular pattern.

8. The transducer of claim **7** wherein said electrode means comprises metal foil bonded to the major surfaces of said body by means of an adhesive.

9. The transducer of claim **8** wherein the assembly comprising said body and said electrode means is contained within a water tight housing having a window transparent to acoustic energy, said body being positioned so that the poles thereof are generally oriented toward the window, said assembly being bonded to the window.

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