

United States Patent

Schweitzer et al.

[15] 3,704,385

[45] Nov. 28, 1972

[54] **PIEZOELECTRIC TRANSDUCER
ASSEMBLY WITH PHASE SHIFTING
ACCOUSTICAL PARTS**[72] Inventors: **John C. Schweitzer; Edward M. Junak**, both of Grand Junction, Colo.[73] Assignee: **Delta Products, Inc.**, Grand Junction, Colo.[22] Filed: **March 2, 1971**[21] Appl. No.: **120,252**[52] U.S. Cl. **310/8.2, 310/8.5, 310/9.1**[51] Int. Cl. **H01v 7/00**[58] Field of Search.....310/8.5, 8.6, 8.8, 9.1, 9.2,
310/9.5, 8.2; 340/10; 179/110 A, 110 D, 110 F[56] **References Cited****UNITED STATES PATENTS**

3,109,111	10/1963	Wiggins.....	310/8.2
3,518,460	6/1970	Wood et al.	310/8.6
3,085,167	4/1963	Kritz.....	310/8.6 X
3,299,301	1/1967	Heilmann et al.	310/9.1

3,331,970	7/1967	Dundon et al.....	310/9.1
3,123,727	3/1964	Kritz.....	310/9.1 X

Primary Examiner—J. V. Truhe

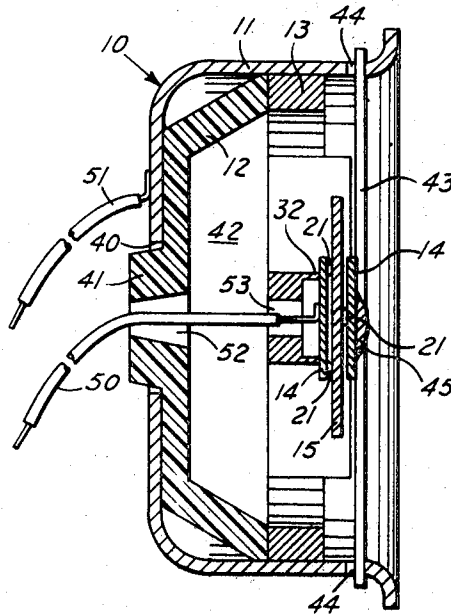
Assistant Examiner—B. A. Reynolds

Attorney—Anderson, Spangler & Wymore

[57]

ABSTRACT

A piezoelectric element which resonates at a predetermined ultrasonic frequency is mounted in a housing structure formed by a cup and insert structure. A resonant cavity is defined in the cup and the element is held adjacent thereto by bosses formed on a pair of mounting chips. The bosses contact the element along its node so that it may vibrate in an unrestrained manner and the mounting chips define acoustical ports therewith on each side of the element which function to delay and thereby phase shift acoustical waves as they pass therethrough so that acoustical waves at the element's resonant frequency combine in phase at the element's surface. The mounting chips and bosses also function as electrodes and electrical leads are electrically connected thereto for connecting the transducer assembly formed to external circuitry.

13 Claims, 7 Drawing Figures

PATENTED NOV 28 1972

3,704,385

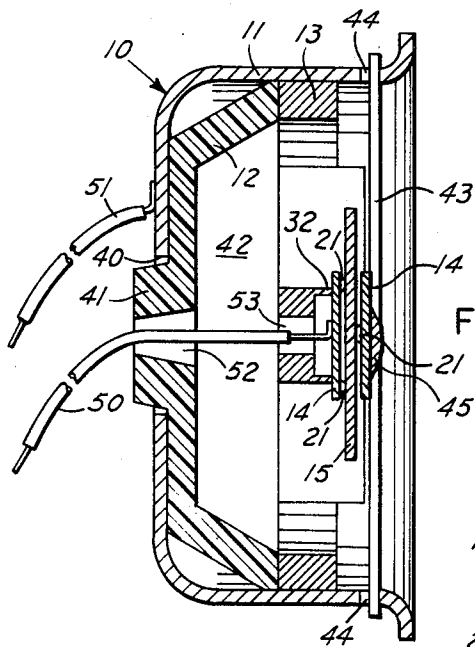
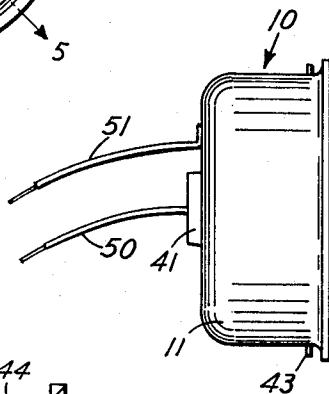
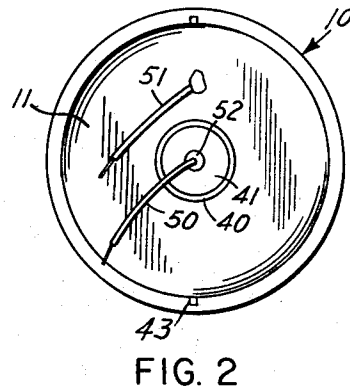
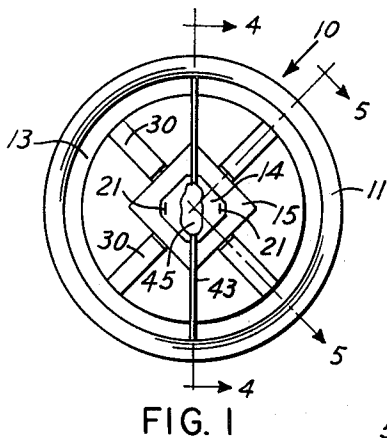


FIG. 4

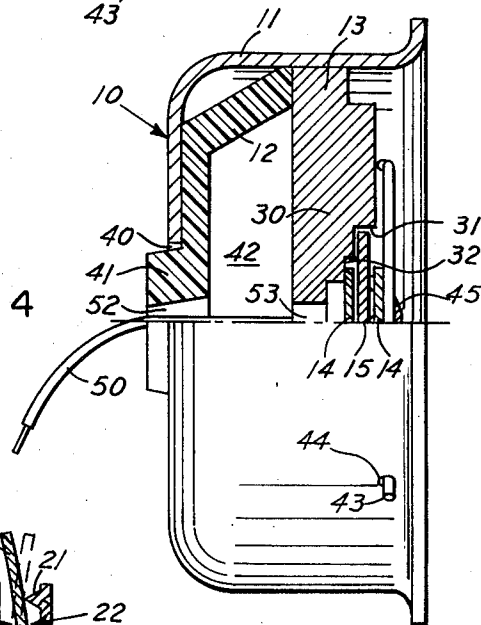


FIG. 5

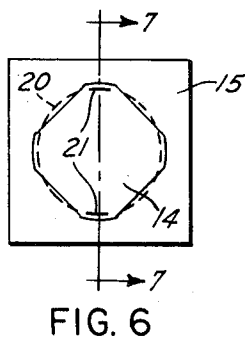


FIG. 6

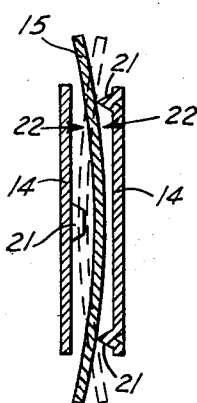


FIG. 7

INVENTORS
JOHN C. SCHWEITZER
EDWARD M. JUNAK
BY

Anderson, Spangler & Wynne
ATTORNEYS

PIEZOELECTRIC TRANSDUCER ASSEMBLY WITH PHASE SHIFTING ACOUSTICAL PARTS

The present invention relates to transducers and more particularly to an improved piezoelectric transducer assembly which is highly sensitive and may be employed as an ultrasonic transducer for converting electrical signals to high frequency inaudible sound waves or vice versa.

Piezoelectricity is pressure electricity and piezoelectric behavior is the characteristic of materials to deform upon the application of electrical signals or conversely to develop electricity whenever deformed by the application of pressure. Certain natural occurring crystals are known to exhibit piezoelectric behavior. Also, it is known that piezoelectric behavior may be induced in ceramic materials by use of a polarizing treatment. Piezoelectric materials whether naturally occurring or man created are anisotropic, i.e., the magnitude of the piezoelectric properties they exhibit vary with direction in the materials. For example, a ceramic crystal may be polarized in a given direction so that application of an electrical field of one polarity along this direction causes expansion and application of a field of opposite polarity causes contraction while application of an electrical field perpendicularly to the direction of polarization has substantially no effect on the piezoelectric material.

Heretofore, piezoelectric materials have been utilized in ultrasonic transducer assemblies. One type of piezoelectric element which has been employed in ultrasonic applications is a flexing type of piezoelectric material which bends along a given plane or dimension about a node in response to an electric field applied perpendicularly to the material's given plane or dimension. An inherent disadvantage with the use of such a piezoelectric element in ultrasonic applications is that as the portion of the element on one side of the node vibrates in one direction the portion of the element on the other side of the node always vibrates in an opposite direction. Thus, as a compression wave is being created on one side of the node a rarefaction wave is always being created on the other side of the node. As a result, the compression and rarefaction waves created on opposite sides of the element's node tend to destructively interfere with each other and cancel out the acoustical output of such piezoelectric elements. Thus, the response and sensitivity of such a piezoelectric element is significantly decreased by this destructive interference effect and its effectiveness in ultrasonic applications whether for converting acoustical to electrical energy or vice versa is severely limited.

It is, accordingly, an object of the present invention to provide an improved piezoelectric transducer assembly which is constructed so as to not be subject to destructive interference whereby to obviate the aforementioned disadvantage inherent with prior art piezoelectric transducer assemblies.

It is, further, an object of the present invention to provide an improved piezoelectric ultrasonic transducer which is characterized by having a relatively high sensitivity and response both for converting acoustical energy to electrical energy and vice versa.

It is, also, an object of the present invention to provide an improved piezoelectric ultrasonic transducer assembly which employs a type of piezoelectric element which bends or flexes about a node and which is

characterized by being constructed so as to not be subject to destructive acoustical interference whereby to have relatively high sensitivity and response characteristics.

It is, additionally, an object of the present invention to provide an improved piezoelectric ultrasonic transducer assembly which employs a type of piezoelectric element which bends or flexes about a node and which is constructed to phase shift acoustical waves generated on different sides of the node so as to eliminate destructive acoustical interference.

Additional objects of the present invention reside in the specific construction of the exemplary transducer assembly hereinafter particularly described in the specification and shown in the several drawings.

In accomplishing these and other objects, there is provided in accordance with the present invention a transducer assembly formed by a piezoelectric element having a predetermined ultrasonic resonant frequency at which it vibrates by bending along its sides. The element has a node which is substantially free from vibratory motion so that the element portion on one side of the node always vibrates in a direction opposite to the direction of vibration of the element portion on the other side of the node. Structure is provided which mounts the element for substantially unrestricted vibration and electrodes are positioned to sense an electrical signal on the element or apply an electrical signal thereto. Electrical leads are connected to the electrodes for connecting the transducer assembly to external electrical circuitry and a resonant cavity is defined in the transducer assembly which amplifies vibrations at the resonant frequency of the piezoelectric element. Acoustical parts are formed adjacent each side of the piezoelectric element to phase shift acoustical waves at the resonant frequency traveling from one side of the node to the other so that acoustical waves at the resonant frequency combine in phase on each side of the element instead of destructively interfering with each other. Thus, there is provided an improved piezoelectric transducer assembly which is constructed to eliminate destructive acoustical interference so as to have relatively high sensitivity and response characteristics both for converting acoustical to electrical energy and vice versa.

A better understanding of the present invention may be had from the following detailed description when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a top plan view of a transducer assembly according to the present invention;

FIG. 2 is a bottom view of the transducer assembly of FIG. 1;

FIG. 3 is a side view of the transducer assembly of FIG. 1;

FIG. 4 is a sectional view taken along the line 4—4 of FIG. 1;

FIG. 5 is a sectional view taken along the line 5—5 of FIG. 1;

FIG. 6 is a top plan view of the piezoelectric element of FIG. 1 with the position of its node indicated thereon in a dashed line and illustrating a mounting chip positioned to contact the piezoelectric element along its node; and

FIG. 7 is a sectional view taken along the line 7—7 of FIG. 6.

Referring to the drawings in more detail, there is shown a transducer assembly generally designated by the numeral 10 made up of an outer cup portion 11, a cup insert 12, a support ring 13, a pair of mounting chips 14 and a piezoelectric element 15. The piezoelectric element 15 is in the form of a thin flat layer arrangement and is preferably rectangular in shape. The piezoelectric element is of the so called bender type which in response to an electrical field applied perpendicularly to its flat surfaces it flexes or bends as shown in FIG. 7 about its node. The element 15 may be made from any suitable crystal, ceramic or other piezoelectric material and can be a "BIMORPH" bender type of piezoelectric element made by the Clevite Corporation. "BIMORPH" is a trade name of the Clevite Corporation and such "BIMORPH" bender type piezoelectric elements are generally made by securing together two transverse-expander plates in a sandwich type layer construction.

The piezoelectric element 15 is designed to resonate at a frequency in the ultrasonic range and have a node located on its surface at a predetermined and known location between its center and its outer peripheral edge. As shown in FIG. 6, the node is indicated by the dashed circular line 20. It is noted that the node on a vibrating element, such as vibrating piezoelectric element, is the point, line or surface on the element which is always free or relatively free of vibratory motion, and that the node line 20 divides each side of the piezoelectric element 15 into a center area within the node line 20 and an edge area outside of the line 20. FIG. 7 illustrates the vibratory motion of the element 15 in two different positions, with one position being shown in dashed lines while the other position is shown in solid lines.

The piezoelectric element 15 is mounted in the transducer assembly 10 by means of the mounting chips 14. The mounting chips 14 are made of an electrical conductive material, such as a suitable metal, and also serve as electrode plates for picking off or applying electrical signals to the piezoelectric element 15. Pairs of similarly shaped bosses 21 made of electrically conductive material are formed on one side of each of the mounting chips 14 for contacting the element 15. The bosses 21 are preferably spaced apart a distance equal to the diameter of the circle defined by the node line 20 and are shaped and positioned for making point contacts with the element 15 exactly along the node line 20. The bosses 21 serve dual purposes first, providing electrical contact points for picking off or applying electrical signals to the piezoelectric element 15 and secondly, holding the mounting chips 14 and the element 15 in a predetermined spaced apart layer relationship so as to define air vents or acoustical ports 22 along each side of the piezoelectric element 15. It is noted that by mounting the piezoelectric element 15 between the mounting chips 14 by means of bosses 21 formed on the chips 14 which contact the node of the element 15, the element 15 is held so that it is free to vibrate in a substantially unrestricted manner since the bosses 21 only contact the element 15 at points which are substantially free of vibratory motion.

As mentioned, acoustical or air ports 22 are formed along each side of the piezoelectric element 15 by the spaced apart mounting arrangement of the element 15 between the mounting chips 14. The effective size of these air ports 22 is determined by the shaping and

dimensioning of the element 15, the chips 14 and the bosses 21. The function of the air ports 22 is to physically restrict and thereby delay to a predetermined extent acoustical waves generated by a portion of the piezoelectric element 17 so that the acoustical waves generated by the portion of the element 17 within the node defined by dashed line 20 reinforce the acoustical waves generated by the edges of the element 17 instead of destructively interfering therewith. As before mentioned, the reason such a phase shift is necessary is that when the portion of the piezoelectric element 17 within the nodal line 20 is moving in one direction its edges are moving in the opposite direction so that while a compression wave is being generated by the center portion of the element 15 a rarefaction wave is being generated by its edges and vice versa. These simultaneously generated compression and rarefaction waves on the same side of the element 15 will destructively interfere and cause cancellation of the acoustic output unless they are phase shifted relative to each other so as to combine in phase.

In the exemplary transducer herein described, the mounting chips 14 are designed to be substantially flat and are positioned adjacent the center portion of the element 15 in a spaced apart parallel relationship to the at rest position of the piezoelectric element 15. Thereby, the air ports 22 are designed to physically restrict and delay the movement of acoustical waves out from and into the center of the element 15 so that the acoustical waves generated or sensed by the edges of the element 15 reinforce and add with the acoustical waves generated or sensed by the center of the element 15. For example, as a compression wave generated by one side of the center portion of the element 15 travels outward to the edges of the element 15, the compression wave is time delayed by one-half wave length by the physical restriction provided by the air ports 22 so that by the time the compression wave arrives at the element edges the edges on the same side of the element 15 are also moving in a direction which generates a compression wave. Thus, the acoustical waves generated by the center portion of the piezoelectric element 15 and its edges are in phase and consequently combine to produce a reinforced, strong acoustical output signal.

The appropriate sizing and shaping for the air or acoustical ports 22 depends on the size of the piezoelectric element 15 and its natural resonant frequency. In an exemplary transducer assembly constructed, the piezoelectric element 15 was square shaped having a side dimension of 0.317 inches, a width of 0.024 inches, and a resonant frequency of 36 kilo herz (KHz). To form appropriate air ports 22 which were operable to delay and hence phase shift a 36 KHz acoustic wave one-half wave length as it passed therethrough, the mounting chips 14 were made to be flat substantially square shaped metallic members having side dimensions of 0.2 inches, width of 0.015 inches, and having rounded ro coin corners with a diagonal dimension of 0.232 inches between opposite corners. The pointed bosses 21 formed on the chips 14 had a height of 0.008 inches, a width of 0.031 inches and were spaced apart to contact the element 15 at its node on opposite sides of a diameter drawn through the center of the element 15. The element 15 employed

was designed to have a circular node having an 0.216 inch diameter and thus the spacing of the bosses 21 were 0.216 inches apart. The point contacts of the pairs of bosses 21 formed on each mounting chip 14 further were positioned along a diagonal drawn through opposite corners of the chip 14 and were positioned 0.008 inches in from the corner edge of the chip 14. It is pointed out that various other structural arrangements having other dimensions may be employed to define appropriate acoustical ports 22 and that such other arrangements are merely equivalent arrangements of the detailed arrangement here described. The detailed description above given is provided for the purpose of illustrating one suitable arrangement for use with a piezoelectric element having a 36 KHz resonant frequency. It is noted that a piezoelectric element having a resonant frequency other than 36 KHz may be employed and that in such a case the dimensioning of the chips 14 and bosses 21 would be changed to provide suitable ports 22 for use with the specific piezoelectric element employed.

As before mentioned, the piezoelectric element 15 is mounted in the transducer assembly 10 by means of the mounting chips 14. This is accomplished by including cross members 30 in the support ring structure 13 which intersect preferably at right angles to each other in the center of the ring 13. The cross members 30 are notched at their center to define a square shaped recessed portion 31 slightly larger than the element 15 so as to provide clearance for the vibrating element 15. The cross members 30 also form a centrally located seat means 32 for one mounting chip 14 so that the chips 14 and element 15 may be mounted in the ring 13 by the following procedure: seating one chip 14 centrally in the seat 32 with the bosses 21 formed thereon extending outward, positioning the element 15 on these bosses 21 with the bosses 21 contacting the element node line 20, and then positioning the other chip 14 adjacent the element 15 with its bosses 21 contacting the element 15 along its node line 20. Thereby, the piezoelectric element 15 is supported in the ring 13 in such a way that it is free to vibrate in an unrestrained manner since its only contacts with mounting structure are the contacts made by the bosses 21 along the element's node. It is noted that the mounting chips 14 are preferably mounted relative to each other so that imaginary lines drawn through the bosses 21 on each of the chip 14 are perpendicular to each other. Thereby, the element 15 is supported between the chips 14 in a saddle type mounting construction as shown.

The cup 11 of the transducer assembly 10 forms the housing portion of the assembly and has an outward extending rim formed on its open end. A hole 40 is formed centrally in the other end of the cup for receiving an annular projecting portion 41 of the cup insert 12. The cup insert 12 is fitted in the bottom of the cup 11 with its annular portion 41 extending through the hole 40. The cup insert 12 is shaped to define a resonant cavity 42 which is appropriately sized to correspond with the resonant frequency of the piezoelectric element 15. With the cup insert 12 in position, the support ring 13 with the chips 14 and the element 15 correctly positioned thereon is fitted in the cup 11 with its annular ring portion positioned against the cup insert 12. Adhesive or cement may then be applied to secure the cup insert 12 and support ring 13 in place.

To hold the mounting chips 14 and the element 15 in place in their stacked relationship, a straight piece of rigid wire 43, such as spring or music wire, is passed through matching holes 44 formed in the cup 11 and secured at point 45, such as by soldering, to the outer mounting chip 14 as shown. At least one of the ends of the wire 43 is then cemented or otherwise secured to the side of the cup 11 at the point it passes through a hole 44.

To complete the assembly of the transducer assembly 10, electrical leads 50 and 51 are electrically connected to the electrodes provided by the electrically conductive mounting chips 14. The lead 50 is connected to the inner chip 14 by passing the lead 50 through holes 52 and 53 formed, respectively, in the cup insert projection 41 and the cross members 30, and soldering or otherwise electrically connecting the lead 50 to the inner chip 14. The lead 51 is soldered or otherwise electrically connected directly to the cup 11. An electrical connection is, thus, made to the outer chip 14 through the cup 11 which is made of an electrically conductive material, such as metal, and the electrically conductive wire 43 which connects both the cup 11 and the outer mounting chip 14. It is noted that in order to electrically isolate the lower chip electrode 14 from the cup 11, and thus from the upper electrode chip 14, the cup insert 12 and the support ring 13 are made of an electrical insulating material or are otherwise electrically isolated from the cup 11. Additionally, an adhesive may be applied across the inside opening of the hole 52 in the cup insert projection 41, first to secure the lead 50 in place so that it does not move the lower mounting chip 14 and secondly, to seal this hole 52 in the resonant cavity 42.

In use and operation of the transducer assembly 10, the cup 13 is preferably mounted in a shock absorbent material, such as foam rubber, so as to be unaffected by extraneous vibrations. In use as an acoustic to electric energy transducer, the leads 50 and 51 are connected to an electrical measuring instrument, such as an extremely accurate voltmeter. The transducer assembly 10 then operates to sense acoustic vibrations at the resonant frequency for which it is designed. For example, if the transducer assembly 10 is designed to sense 36 KHz acoustic waves, the piezoelectric element 15 vibrates at 36 KHz upon sensing a 36 KHz acoustical wave and this vibration causes a voltage signal to appear across the width of the element 15 which is picked off by the leads 50 and 51 through the electrical contacts provided by the bosses 21. It is noted that since the phase shift means provided by the air ports 22 appropriately phase shifts the 36 KHz acoustical signal being sensed so that no destructive interference of the signal occurs at the vibrating surface of the element 15 that the transducer assembly 10 is highly sensitive and produces a readily measurable electrical output which is transmitted by the leads 50 and 51 to the electrical measuring device.

In the case where the transducer assembly 10 is employed as an electric to acoustic energy transducer, the leads 50 and 51 are connected to an electrical device which produces or generates an electrical output at approximately the resonant frequency of the piezoelectric element 15. If the element 15 has a resonant frequency of 36 KHz, 36 KHz electrical signals applied across its width cause the element 15 to vibrate at its resonant

frequency. Thereby, the element 15 generates an acoustical output at its resonant frequency. Since the air ports 22 are designed to phase shift by one-half wave length the acoustical waves generated by the center portion of the element 15 with respect to the acoustical waves generated by its outer edge, the acoustical waves generated reinforce each other, instead of destructively interfering, to produce a strong acoustical output.

Thus, there is provided an improved piezoelectric device suitable for use as an ultrasonic transducer which is constructed to eliminate destructive acoustical interference so as to have relatively high sensitivity and response characteristics both for converting acoustical energy to electrical energy and vice versa. The destructive interference is eliminated by providing means for physically delaying acoustical waves generated or received so that they combine in phase at the surface of the piezoelectric element to reinforce the acoustical signal. It is to be understood that in accordance with the spirit of the present invention various changes in shaping and dimensioning may be made in constructing the means which provide the acoustical phase shift or delay.

What is claimed is:

1. A transducer assembly, comprising:

a piezoelectric element having a predetermined resonant frequency at which it vibrates, said element being substantially flat and having a node which is substantially free of vibratory motion;

structure means mounting said element for substantially unrestricted vibration, said structure means including a pair of flat mounting chips positioned on opposite sides of said flat element and having electrically conductive contact points formed thereon which contact said element along its node and hold said mounting chips and said element in a mutually parallel spaced apart relationship, said contact points providing electrode means to pick up an electrical signal generated by vibration of said element or to apply an electrical signal to said element to cause vibration thereof; and

acoustical port means formed adjacent said element for delaying and thereby shifting into phase acoustical waves generated and sensed by said element which are at said predetermined resonant frequency so that acoustical waves at said predetermined resonant frequency combine in phase at the surface of said element, said acoustical port means being formed adjacent said element by the surfaces of said spaced apart mounting chips and element and being sized as a function of said predetermined resonant frequency.

2. The invention recited in claim 1, wherein each of said mounting chips is electrically conductive and including electrical leads connected to said mounting chips for connecting said transducer assembly to external electrical circuitry.

3. The invention recited in claim 1, wherein the node of said element which is substantially free of vibratory motion divides said element into two portions and the portion of said element to one side of said node always vibrates in a direction opposite to the direction of vibration of the portion of said element to the other side of said node, and said acoustical port means are

operable to phase shift an acoustical wave at said predetermined resonant frequency as it travels from one side of said node to the other by one-half wave length so that acoustical waves generated or sensed at said resonant frequency reinforce each other.

4. The invention recited in claim 1, wherein said element vibrates at a resonant frequency in the ultrasonic range.

5. The invention recited in claim 4, wherein said element is a bender type piezoelectric element.

6. The invention recited in claim 4, wherein said element is a bender type piezoelectric element formed by two transverse expander plates secured together.

7. An ultrasonic transducer assembly, comprising: a piezoelectric element having a predetermined ultrasonic resonant frequency at which it vibrates, said element being substantially flat and having a node which is substantially free of vibratory motion;

first structure means defining a resonant cavity which is designed to amplify vibrations at said resonant frequency;

second structure means counting said element for substantially unrestricted vibration adjacent said resonant cavity, said second structure means including a pair of electrically conductive flat mounting chips positioned on opposite sides of said flat element and having electrically conductive contact points formed thereon which contact said element along its node and hold said mounting chips and said element in a mutually parallel spaced apart relationship, said contact points providing electrode means to pick up an electrical signal generated on said element or apply an electrical signal thereto;

electrical leads connected to said mounting chips for connecting said transducer assembly to external electrical circuitry; and

acoustical port means formed adjacent said element for delaying and thereby shifting into phase acoustical waves generated and sensed by said element which are at said predetermined resonant frequency so that acoustical waves at said predetermined resonant frequency combine in phase at the surface of said element, said acoustical port means being formed adjacent said element by the surfaces of said spaced apart mounting chips and element.

8. The invention recited in claim 7, wherein the node of said element which is substantially free of vibratory motion divides said element into two portions and the portion of said element on one side of said node always vibrates in a direction opposite to the direction of vibration of the portion of said element on the other side of said node, and said acoustical port means are operable to phase shift an acoustical wave at said predetermined resonant frequency as it travels from one side of said node to the other by one-half wave length so that acoustical waves generated or sensed at said resonant frequency reinforce each other.

9. The invention recited in claim 8, wherein said element is a bender type piezoelectric element formed by two transverse expander plates secured together.

10. An ultrasonic transducer assembly, comprising:

a bender type piezoelectric element having two sides, said element having a predetermined ultrasonic resonant frequency at which it vibrates by bending along its sides, said element having a node which is substantially free from vibratory motion and which divides each side of said element into a center area within said node and an edge area outside of said node so that said center element area always vibrates in a direction opposite to the direction of vibration of said edge element area;

structure means mounting said element for substantially unrestricted vibration, said structure means including electrode means positioned to pick up an electrical signal on said element or apply an electrical signal thereto;

electrical leads connected to said electrode means for connecting said transducer assembly to external electrical circuitry; and,

acoustical port means adjacent each side of said element for delaying and thereby phase shifting acoustical waves generated and sensed by said element, each of said acoustical port means being operable to phase shift an acoustical wave at said predetermined resonant frequency as it travels between said center and edge element areas one-half wave length so that acoustical waves at said predetermined resonant frequency combine in phase on each side of said element.

11. the invention recited in claim 10, including second structure means defining a resonant cavity, said resonant cavity being formed adjacent said element and being designed to amplify vibrations at said resonant frequency.

12. The invention recited in claim 10, wherein said structure means comprises a pair of flat mounting chips positioned on opposite sides of said element and having electrically conductive contact points thereon which contact said element along its node and hold said mounting chips and said element in a mutually parallel spaced apart relationship, said contact means providing said electrode means, said acoustical port means being formed adjacent each side of said element by the surfaces of said spaced apart mounting chips and element.

13. An ultrasonic transducer assembly, comprising:

a piezoelectric element having a predetermined resonant frequency at which it vibrates, said element having a node substantially free from vibratory motion which divides said element into two portions and the portion of said element to one side of said node always vibrating in a direction opposite to the direction of vibration of the portion of said element to the other side of said node;

structure means mounting said element for substantially unrestricted vibration, said structure means including electrode means positioned to pick up an electrical signal on said element or apply an electrical signal thereto; and

acoustical port means adjacent said element for delaying and thereby phase shifting acoustical waves generated and sensed by said element, said acoustical port means being operable to phase shift an acoustical wave at said predetermined resonant frequency as it travels from one side of said node to the other by one-half wave length so that acoustical waves at said predetermined resonant frequency combine in phase at said element.

35

40

45

50

55

60

65