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[54] **ELECTROACOUSTIC TRANSDUCER
HAVING IMPROVED TRANSDUCING
ELEMENT SUPPORTING MEANS**

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[51] Int. Cl. **H04r 17/00**

[58] Field of Search **310/8.2, 8.3, 9.1-9.4**

[56] **References Cited**

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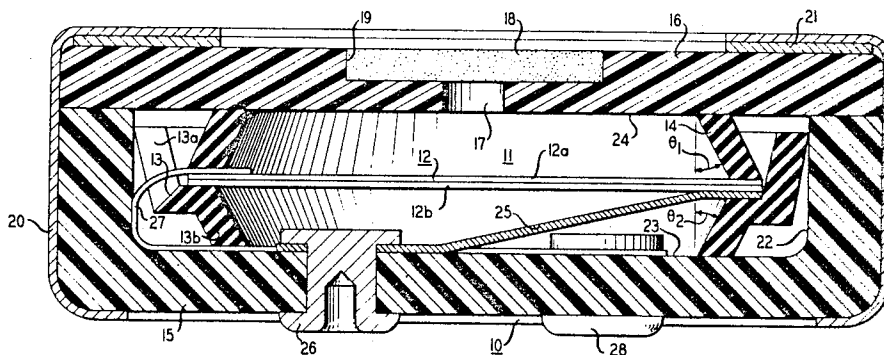
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Primary Examiner—J. D. Miller
Assistant Examiner—Mark O. Budd
Attorney—W. L. Keefauver

[57] **ABSTRACT**

A planar transducing element is supported within a transducer housing by a pair of specially dimensioned generally conical rubber washers. The first washer includes a first portion comprising a hollow frustum of a cone for spacing the element from the side walls of the housing, and a second generally conical portion integral with the first portion for seating the element and spacing it from the housing bottom. The second washer also includes a hollow frustum of a cone for spacing the element from the top of the housing. The washer design provides a relatively uniform support stiffness, independent of washer compression, enabling mass production of transducers having a desired frequency response characteristic. Additionally, the washers serve to prevent element damage due to shock and moisture condensation.

11 Claims, 7 Drawing Figures



2 Sheets-Sheet 1

FIG. 1

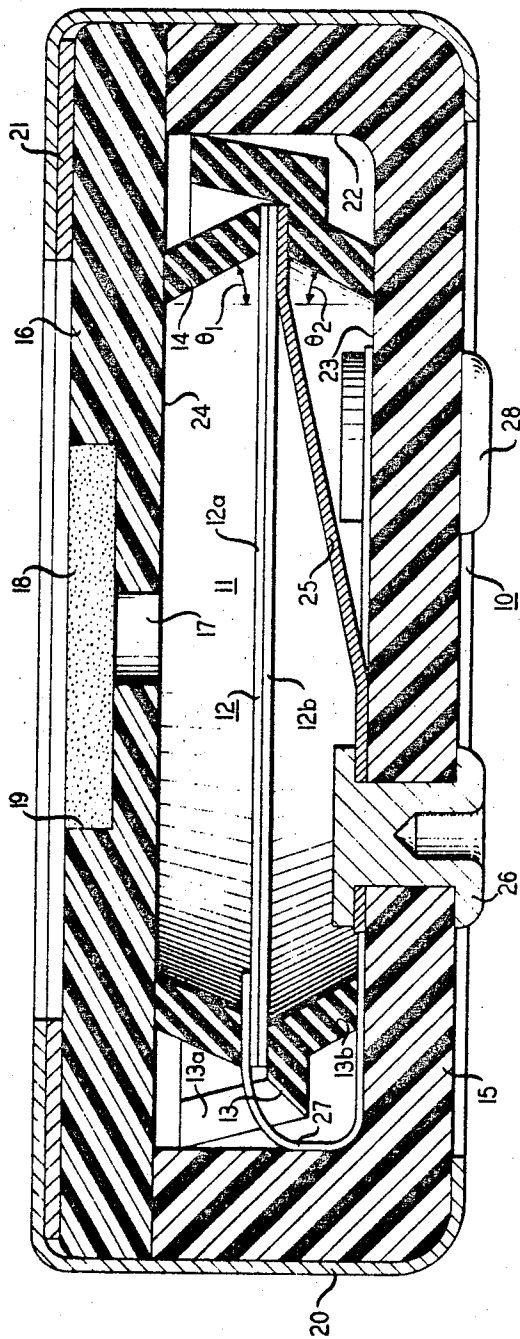


FIG. 2

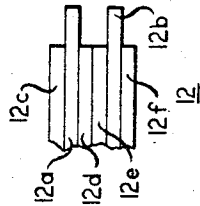


FIG. 5

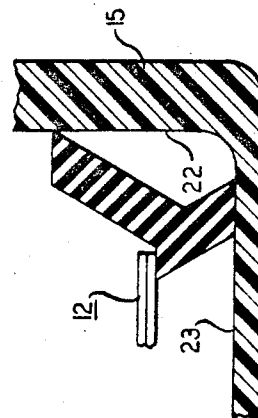


FIG. 6

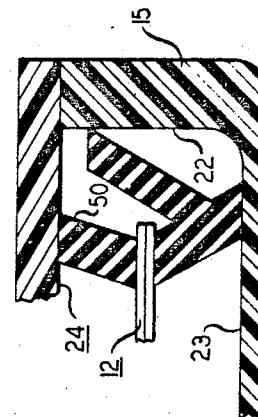


FIG. 7

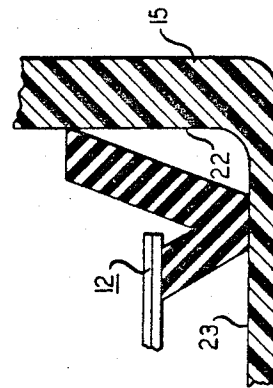


FIG. 3

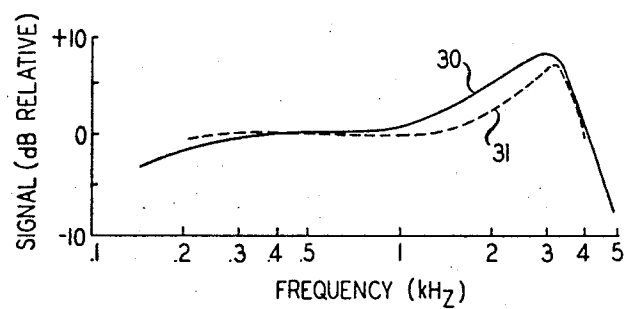
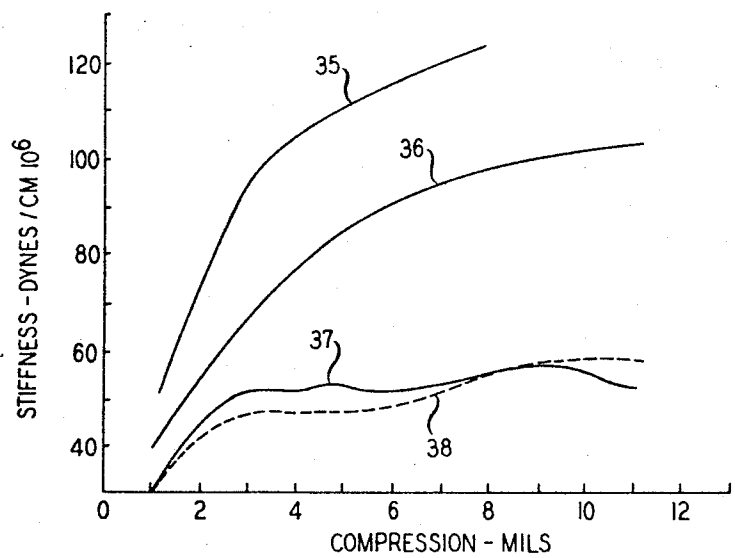


FIG. 4



ELECTROACOUSTIC TRANSDUCER HAVING IMPROVED TRANSDUCING ELEMENT SUPPORTING MEANS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to electroacoustic transducers utilized to convert sound energy into electrical energy, and vice versa, and, more particularly, to such transducers having an improved means for supporting the transducing element within the transducer housing.

2. Description of the Prior Art

While the carbon microphone has faithfully served the electronics industry for many years, recent advances in technology call for a higher degree of stability and a generally smaller size than is afforded by the carbon instrument. This is especially true in the telephone art, where new compactness and efficiency in components and circuitry, as well as more streamlined customer equipment, necessitate a corresponding improvement in transducer design. An attractive substitute for the carbon microphone is the piezoelectric ceramic transducer, by virtue of its reduced volume requirements and its low manufacturing costs. Besides its use as a microphone, such a transducer may also be employed as a receiver or speaker.

In order to make effective use of the piezoelectric ceramic transducer, or most other electromechanical transducing devices, however, a number of design problems must be overcome, outstanding among which is the provision of a suitable means for supporting the transducing element within the transducer housing. Conventional element supports have typically included a pair of gaskets, at least one of which is rubber, for supporting opposite faces of the element, as illustrated in U.S. Pat. No. 3,137,836, issued to C. P. Glover on June 16, 1964. These gaskets, or O-rings as they are sometimes called, are compressed against the periphery of the faces, so that a pressure seal is provided, and the element held in the desired position. Unfortunately, the use of such a supporting means has several disadvantages. First, and most importantly, the stiffness of the vibratory system is closely tied to the amount of compression applied to the rings. As a result, small changes in manufacturing tolerances or assembly techniques produce varying amounts of compression, which, in turn, may often adversely affect the transducer frequency response characteristics, or, at least cause unwanted variations in such characteristics between individual transducers of the same lot. Second, the use of such gaskets leads to the possibility of element damage due to overcompression either in manufacture or assembly, or to fracture of the element if an overly unyielding system is dropped or subject to impact. Additionally, simple O-rings do not provide a convenient means for transversely seating the transducing element in proper position during assembly, and if insufficient compression force is applied, lateral movement of the element and consequent misalignment may result; if the transducing element is allowed to touch the transducer housing, breakage is possible should the assembly be dropped.

Accordingly, it is the broad object of the present invention to provide an electroacoustic transducer preferably of the piezoelectric ceramic type having an im-

proved means for supporting the transducing element within the transducer housing.

An additional object of the invention is to provide a supporting means for an electromechanical transducing element wherein the stiffness of the vibratory system is relatively uniform and independent of variations in compression, so that a desired transducer frequency response characteristic may be achieved despite nonuniformities inherent in mass manufacturing and assembly techniques.

Additional objects of this invention include the provision of an improved transducing element supporting means that facilitates transverse positioning of the element within the transducer housing, and that at the same time provides protection against element damage due to impact and to moisture condensation.

SUMMARY OF THE INVENTION

Each of the foregoing and additional objects are achieved in accordance with the principles of the invention by the provision in an electroacoustic transducer of an improved means for supporting the transducing element within a housing which includes a pair of specially dimensioned generally conical rubber washers. Briefly, the first washer includes a first portion comprising a hollow frustum of a cone for spacing the element from the side walls of the housing, and a second generally conical portion integral with the first for seating the element and for spacing it from the housing bottom. The second washer includes a hollow frustum of a cone for spacing the element from the top of the housing. The first portion is arranged to contact the side walls in a plane substantially removed from the plane of the transducing element.

By virtue of the advantageous provision of washers having a general conical shape, the stiffness of the element supporting system has been found to be substantially independent of washer compression, thereby enabling the mass production of transducers having a uniformly desirable frequency response characteristic. Furthermore, since contact between the housing side walls and the first washer is confined to a plane substantially removed from the plane of the transducing element, this necessary contact is prevented from adding varying amounts of stiffness to the vibratory support system. In addition, the aforesaid first portion of the first washer acts as a "bumper" in preventing element damage due to impact. Since a seating surface is also provided by the first washer, location of the element within the housing during transducer assembly is facilitated, and the element is constrained from lateral movement. Also, the washers provide a rubber seal on both sides of the element, protecting it from moisture condensation which could otherwise shunt the element as a leakage resistance.

BRIEF DESCRIPTION OF THE DRAWING

The aforementioned and other features and advantages of the invention will become more apparent to those skilled in the art by reference to the following detailed description, when read in light of the accompanying drawing, in which:

FIG. 1 is a central cross-sectional view of an electroacoustic transducer constructed in accordance with the principles of the invention;

FIG. 2 is a fragmentary cross-sectional view of a piezoelectric ceramic transducing element for use in the transducer of FIG. 1;

FIG. 3 is a graph comparing the frequency response characteristic of a piezoelectric ceramic transducer constructed in accordance with FIG. 1 with an idealized characteristic curve for a microphone suitable for use in telephony;

FIG. 4 is a graph representing the stiffness vs. compression characteristics of various transducing element supporting structures, including the specially dimensioned washers of FIG. 1;

FIG. 5 is a fragmentary view, in cross section, of an alternate support system, in accordance with the invention, for use in the transducer of FIG. 1;

FIG. 6 is a fragmentary view, in cross section, of another alternate support system similar to that of FIG. 5; and

FIG. 7 is still another cross-sectional fragmentary view similar to FIGS. 5 and 6.

Referring now to FIG. 1, there is shown in central cross-sectional view an electroacoustic transducer constructed in accordance with the principles of the invention. The transducer comprises a housing, designated generally at 10, defining an internal chamber 11, and a planar electromechanical transducing element 12 within the chamber. Means for supporting the element 12 within the chamber 11 include first and second annular washers 13 and 14, respectively.

Structurally, transducing element 12 of the piezoelectric ceramic type, may include a pair of oppositely poled lead zirconate-lead titanate discs 12a, 12b, bonded together to form a composite element, as shown in FIG. 2. While the discs may be formed in various ways, one method found advantageous is to sinter a niobium-doped compound of lead zirconate and lead titanate having a tetragonal crystal structure in a lead oxide atmosphere at a temperature below the compound melting point, resulting in a rather dense body. After cooling, electrodes such as electrodes 12c and 12d on disc 12a and electrodes 12e and 12f on disc 12b, shown in FIG. 2 greatly exaggerated in thickness for the purposes of illustration may be applied to each face of the ceramic material, and poling accomplished in either bulk or final form by applying a DC voltage of 50v/mil at a temperature of 130° C. in a silicone oil bath or an atmosphere of inert gas, in order to avoid arcing. The resulting element, which is quite stable thermally and has excellent aging properties, has a relatively high piezoelectric coupling coefficient and dielectric constant. Of course, other polarizable ferroelectric ceramic materials, for example, barium titanate, and other forming techniques, may also be practiced with equal success.

Functionally, the processed ceramic, heretofore described, will generate a voltage proportional to the dynamic compression or expansion forces applied thereto. However, for the bending mode utilized in the transducer of FIG. 1, the compressive and expansive stresses created on either side of a central neutral axis in a single ceramic disc are opposite in sense, producing equal but opposite voltages within the ceramic, and therefore zero output. Accordingly, two oppositely poled discs 12a, 12b are bonded together to obtain bilaminar transducer element 12, thereby locating each ceramic outside of the neutral bending plane. When connected in series, the elements thus produce an out-

put voltage equal to the sum of their individual voltages.

While various methods may be utilized to bond the ceramic discs into the bilaminar element of FIG. 2, it is to be noted that for proper generator action, the two discs should be securely and rigidly fastened together, so that the resulting element possesses sufficient characteristics of structural strength, impedance and output uniformity. One such method that has proven successful is to deposit a very thin coating of a nonconducting cement or epoxy on one electroded face of each disc 12a and 12b, to then bring the coated faces into alignment and to apply pressure to the assembled element 12 so that a metal-to-metal contact between inner electrodes 12d and 12e through the intervening cement is assured. With this arrangement, the output and impedance uniformities of the assembled element are satisfactory, as is its physical strength. In addition, the use of electrically conducting cement, which sometimes results in an undesirably stiff element, is avoided.

As an alternative to the bilaminar transducing element 12 of FIG. 2, it may in certain instances be advantageous to employ a metal-ceramic element. In this construction, a single ceramic body, electroded on both faces, is bonded onto a larger metal plate. The thickness, density and modulus of elasticity of the metal plate are chosen so that the neutral bending plane of the composite transducing element is located at the metal-ceramic interface, thus producing a uniaxial stress within the ceramic body. In this configuration, the metal plate is circumferentially edge clamped within the transducer housing, as is discussed more fully hereinafter. In certain cases, it may be advantageous to utilize a square or rectangular shaped ceramic bonded to a circular plate.

The overall electrical response characteristics of the transducer of FIG. 1 depend on both the geometry of the housing 10 and the means utilized to support the transducing element 12 within the chamber 11 formed thereby. The general shape of a desirable frequency response curve of a microphone for use in a telephone system is shown as curve 30 in FIG. 3, although it is to be clearly understood, especially by those skilled in the art, that other characteristics can similarly be achieved by modifications intended to be within the scope of this invention. The low frequency end of curve 30 is relatively easy to obtain, in the case of a piezoelectric ceramic transducer, when it is realized that the ceramic element 12 largely represents a capacitance. Accordingly, by approximately choosing the value of resistance connected across the element, as, for example, the input resistance of a preamplifier stage following the transducer, the corresponding low frequency roll off may be appropriately located at about 150 Hz. The peak at the high frequency end (about 3.3 KHz) is obtained by locating the first natural resonance of transducing element 12 in this vicinity, as will be explained in more detail hereinafter. However, the resonance thus produced is quite sharp (as much as 35 db) and includes higher frequency overtones, all of which must be suppressed in order to obtain satisfactory performance. This suppression is provided by the design of housing 10, which, as depicted in FIG. 1, includes a cup-shaped body member 15 and a disc-like frontal plate 16, both of which may be fabricated from a plastic material possessing suitable qualities of heat and moisture resistance. Frontal plate 16 has centrally drilled there-

through a port or center hole, such as port 17, which is covered by an acoustic damping member 18 either fastened across the hole atop the plate 16 or nested and fastened within a centrally bored recess 19 provided in plate 16, as shown in FIG. 1. Port 17 serves as a low-pass filter, and when suitably dimensioned, selectively suppresses the high frequency overtones noted above. The acoustic resistance or damping member 18, which may conveniently be fabricated from porous sintered steel, helps to reduce the primary resonance to an acceptable level. In assembled form, frontal plate 16 and body member 15 are encased by a thin metal shell 20 having a generally U-shaped cross section. A coned metal spring washer 21 may be used to supply the pressure necessary to ensure positive contact between member 15 and plate 16 and to hold the unit in proper alignment.

As stated above, the proper design of means to support transducing element 12 within chamber 11 of housing 10 is extremely critical to the attainment of the desired transducer frequency response characteristic. Functionally, the means chosen, in order to be effective, must provide a first natural resonance of the mounted element at a desired frequency, and in addition provide a semirigid clamping action around the element periphery that serves to minimize planar or piston-like motion of the element while allowing a cupping or spherical bending action in the element, the latter being the only source of electrical output. Practically, the supporting means must be capable of providing a desired system stiffness that is relatively independent of supporting means compression, since minor variations in the internal dimensions of chamber 11 and the thickness of washers 13 and 14 are to be expected in the production and assembly of a large number of units. In addition, it is desirable that the supporting means provide a surface on which element 12 can be easily seated during manufacture, and at the same time provide protection against transducer damage caused by shock and moisture.

In accordance with the principles of the instant invention, means for supporting element 12 within chamber 11 of housing 10 that meet the above requirements include a pair of specially dimensioned conical rubber washers 13 and 14 as depicted in FIG. 1. The first washer 13 includes a first portion 13a comprising a hollow frustum of a cone for spacing element 12 from the side walls 22 of chamber 11 and a second generally conical portion 13b integral with the first portion for seating the element and spacing it from the chamber bottom 23. The first portion is advantageously arranged to contact side walls 22 in a plane substantially removed from the plane of element 12. The second washer 14 also includes a hollow frustum of a cone having a base parallel with the plane of transducing element 12 for spacing that element from the top 24 of chamber 11. The slopes of second portion 13b and washer 14 are preferably adjusted to form angles θ_2 and θ_1 , respectively, of approximately 25° with the vertical, as defined by the side wall 22.

During assembly, the smaller diameter face of washer 13 is seated upon the inner face of cup-shaped body member 15 which forms the bottom wall 23 of chamber 11. One end of a first strip 25 of gold plated copper foil or other conducting material is then attached to an electrically conductive terminal rivet 26 extending through the bottom portion of cup-shaped housing

member 15, and the other end thereof placed on the seating surface of the second portion 13b of washer 13. Transducing element 12 is next seated on washer 13 so that a portion of electrode 12f is brought into electrical contact with strip 25. One end of a second conductive strip 27, similar to strip 25, is then placed in contact with a portion of the outer periphery of electrode 12c, the remaining end having been previously extended through a slit in the first portion 13a of washer 13, and connected to a terminal rivet 28 similar to terminal rivet 26, but electrically isolated therefrom. The larger diameter face of washer 14 is next seated on the upper face of transducing element 12, so that strip 27 is held in close electrical contact with electrode 12c. To complete assembly, frontal plate 16 is next aligned with body member 15, and spring washer 21 is placed thereupon. Finally, the entire transducer is clamped together by appropriately bending shell 20, as shown in FIG. 1. Electrical connection between the transducer and an external load or source is accomplished by appropriately connecting leads to the external portions of terminals 26 and 28.

In the event that a metal-ceramic transducing element is utilized in lieu of the bilaminar transducing element 12 of FIG. 2, the metal plate, which is in electrical contact with the lower electrode face of the ceramic disc, is seated on the surface provided by the second portion 13b of washer 13 in much the same way as previously described, thereby providing electrical continuity between that electrode and strip 25. However, since the larger diameter face of washer 14, when properly positioned, contacts only the upper periphery of the metal plate and not the upper electrode face of the ceramic element, strip 27 must be suitably extended to make electrical contact with the upper electrode and fastened thereto, and in addition, must be suitably insulated from electrical contact with the plate. Various means for attaching strip 27 to the upper electrode and for insulating it from the plate will be readily apparent to those skilled in the art, and need not be further explained.

From the above description of the transducer of FIG. 1 and its construction technique, it can be seen that rapid and virtually foolproof mass assembly of the instrument is enabled by the unique design of washers 13 and 14. Furthermore, it should be readily apparent that moisture entering the transducer via port 17, or otherwise, is prevented from shunting the edges of transducing element 12 by virtue of the complete rubber seal around the periphery thereof provided by washer 14. Additionally, the first portion 13a of washer 13 advantageously serves as a rubber "bumper," preventing element damage due to impact on the side of housing 10, while both washers 13 and 14 generally prevent injury caused by mechanical shock.

Other advantages of the means utilized to support transducing element 12 within chamber 11 will be more readily apparent by reference to FIG. 4, which depicts the stiffness vs. compression characteristics of washers 13 and 14 as well as conventional O-rings. As can be seen therefrom, curve 35, which represents the stiffness vs. compression of commercial O-rings fabricated from a standard rubber composition, indicates a marked and undesirable change in stiffness with differing degrees of compression. If a special rubber composition is employed, to be discussed more fully hereinafter, the slope of the compression-stiffness curve 36 is

somewhat reduced, but is still not uniform. However, the specially shaped rings of FIG. 1, in accordance with the invention, when fabricated from the aforesaid rubber composition and designed so that frustum angles θ_1 and θ_2 are approximately 25° to the vertical, exhibit a nearby uniform compression-stiffness characteristic, as is evidenced by curves 37 and 38, which correspond to rings 13 and 14, respectively. As a result of the independence of stiffness with compression of washers 13 and 14, manufacturing and assembly tolerances on the inner dimensions of chamber 11 and the height of washers 13 and 14 can be wide enough to allow ring compression of between approximately 2 and 11 mils, without materially affecting transducer performance. The frequency response characteristics of a transducer as shown in FIG. 1, adjusted to curve 30 of FIG. 3 at 1 KHz, is shown as curve 31. The correspondence between the desired and actual curves can be seen to be quite good.

Returning to FIG. 4, it is to be noted that while the use of a special rubber formulation aids in achieving a desired flatness in the compression-stiffness curve, the unique shape of the washers, as previously described, is the sine qua non to proper transducer performance. In certain instances, it may even be possible to fabricate washers 13 and 14 from a soft plastic material. However, for the sake of completeness, the rubber composition found to be suitable for fabrication of washers 13 and 14 is essentially constituted of the following ingredients, the amounts of each being given in parts per hundred of rubber, by weight:

INGREDIENT	PPHR
Cis-1,4 - Polybutadiene	50.0
75/25 Copolymer of polybutadiene and styrene (37.5% oil extended)	68.75
Semireinforcing furnace black	80.0
Zinc Oxide	5.0
Phenyl-beta-naphthylamine	1.0
Stearic Acid	1.0
Paraffin Wax	3.0
Naphthenic Process Oil	18.75
N-isopropyl-N'-phenyl-p-phenylene diamine	0.50
N-cyclohexyl-2-benzothiazole-sulfenamide	0.2
Sulfur	2.25

Referring now to FIGS. 5, 6 and 7, there are shown in fragmentary cross-sectional view several alternate designs which may be used in lieu of washer 13 of FIG. 1, each of which possesses the previously described advantages inherent in the design of that washer. As can be seen therefrom, each of the washers includes a first portion comprising a hollow frustum of a cone for spacing the transducing element 12 from the inner side walls 22 of housing 10, and a second generally conical portion integral with the first portion for seating the element and spacing it from the bottom 23 of chamber 11. In the embodiment of FIG. 5 the conical taper of the second portion is reversed with respect to that shown in FIG. 1, so that the greater diameter face of the first portion of the washer abuts with the bottom 23 of chamber 11. In the embodiment of FIG. 6, the junction between the first and second portions shown in FIG. 5 is removed to a point somewhat below the seating surface of the second portion, so that a portion of the periphery of transducing element 12 may overhang the seating surface. In this configuration, clamping of the transducing element at the nodal circle may be possible, depending upon element geometry, further en-

hancing transducer performance. In the embodiment of FIG. 7, the first and second portions are jointed at the bottommost ends of both portions, again enabling transducing element overhang and nodal circle clamping.

Also illustrated in FIG. 6 is a second washer 50 comprising a hollow frustum of a cone for spacing transducing element 12 from the top 24 of chamber 11. While washer 50 may be physically identical to washer 14 of FIG. 1, it is to be observed that, unlike washer 14, its larger diameter face abuts with the top face of element 12. This arrangement may, on occasion, be desirable, and can be utilized in conjunction with any of the previously described supporting means arrangements with equal success.

In order to more fully appreciate the degree of compactness of a transducer of the type depicted in FIG. 1, the following typical dimensions are given by way of illustration only, the instant invention not being limited to the sizes stated:

Outside diameter of housing 10	0.822 inches
Thickness of housing 10	0.302 inches
Diameter of transducing element 12	0.59 inches
Thickness of transducing element 12	0.012 inches

Many modifications and adaptations of this invention will readily become apparent to persons skilled in the art. For this reason, it is intended that the invention be limited only by the appended claims. For example, it should be apparent that the heretofore described electroacoustic transducer may function equally well as a receiver for converting electrical energy into sound energy, or as a microphone. Additionally, the means employed for supporting transducing element 12 may, on occasion, be useful in an instrument wherein said element is of an electromechanical transducer type other than a piezoelectric ceramic. Still further, while the shape of the transducing element has heretofore been described as round, or disc like, it should be clearly understood that appropriate modifications to the peripheral shape of the transducer and/or its internal components may sometimes be required.

What is claimed is:

1. An electroacoustic transducer for converting sound energy into electrical energy and vice versa, comprising
 - a planar electromechanical transducing element operating in the audio frequency range,
 - a housing defining a chamber for containing said element, said chamber having a bottom, a top, and a side wall, and
 - means for peripherally supporting said element within said chamber and for damping the vibratory motion of said transducing element, said supporting means including,
 - a first annular member having a first portion comprising a hollow frustum of a cone for spacing said element from said side wall and a second generally conical portion integral with said first portion for seating said element and for spacing said element from said bottom, and
 - a second annular member comprising a hollow frustum of a cone for spacing said element from said top.
2. The invention defined in claim 1 wherein said transducing element includes a polarizable ferroelectric ceramic material.

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3. The invention defined in claim 2 wherein said ceramic material is selected from the group consisting of barium titanate and lead zirconate-lead titanate.

4. The invention defined in claim 1 wherein said second generally conical portion forms an angle of approximately 25° with said side wall, and said second annular member forms an angle of approximately 25° with said side wall.

5. The invention defined in claim 1 wherein said first and second annular members are rubber.

6. The invention defined in claim 1 wherein said transducing element includes,
a first piezoelectric ceramic disc having a pair of electrodes on each face thereof,
a second piezoelectric ceramic disc having a pair of electrodes on each face thereof bonded to said first disc, and
a layer of electrically nonconducting cement intervening between said discs.

7. The invention defined in claim 1 wherein said transducing element includes,
a piezoelectric ceramic body having a pair of electrodes on each face thereof, and

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a larger metal plate bonded to said body.

8. The invention defined in claim 7 wherein said ceramic body is rectangular and said metal plate is round.

9. An electroacoustic transducer comprising:

a planar piezoelectric ceramic transducing element,
a housing defining a chamber having a top, a bottom and side walls for containing said element, and
means for peripherally supporting said element within said chamber and for damping the vibratory motion of said transducing element, said supporting means including,

a first annular member comprising a frustum of a cone for spacing said element from said bottom, and

a second annular member comprising a frustum of a cone for spacing said element from said top.

10. The invention defined in claim 9 wherein said first and second members form an angle of approximately 25° with said side walls.

11. The invention defined in claim 9 wherein said first annular member further includes means for spacing said element from said side walls.

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