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Paddock

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[54] **AUDIO TRANSDUCER WITH FLEXIBLE FOAM ENCLOSURE**

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[73] Assignee: **Lineaum Corporation**, Portland, Oreg.

[21] Appl. No.: **384,380**

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Related U.S. Application Data

[63] Continuation of Ser. No. 986,803, Dec. 8, 1992, abandoned.

[51] **Int. Cl.**^{6} **H04R 25/00**

[52] **U.S. Cl.** **381/202**; 381/193

[58] **Field of Search** 381/188, 192, 381/193, 194, 197, 199, 202, 204, 182, 186; 181/153, 166, 169, 171, 172, 173

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,821,469	9/1931	Hicks	181/169
3,612,783	10/1971	Schneider	381/204
4,584,439	4/1986	Paddock	179/115.5
4,903,308	2/1990	Paddock et al.	381/202
4,939,783	7/1990	Dunning	381/188
5,127,060	6/1992	Paddock	381/197
5,198,624	3/1993	Paddock et al.	181/166

FOREIGN PATENT DOCUMENTS

0159831	6/1983	Germany	181/171
8903160	4/1989	WIPO	381/202

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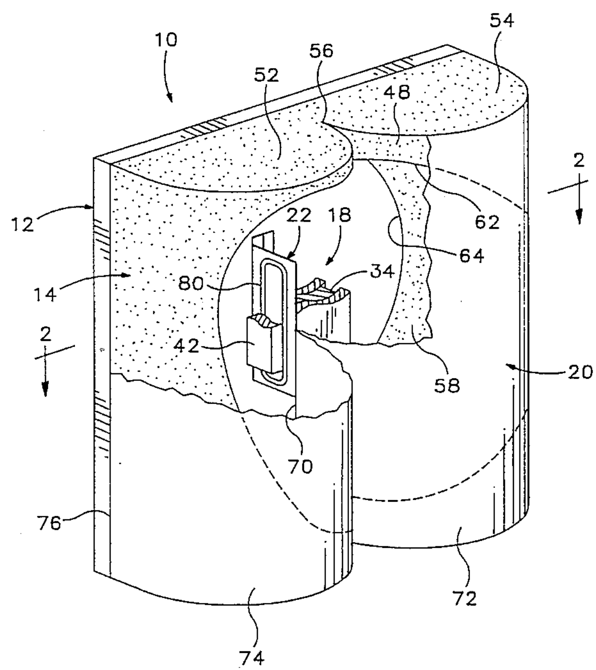
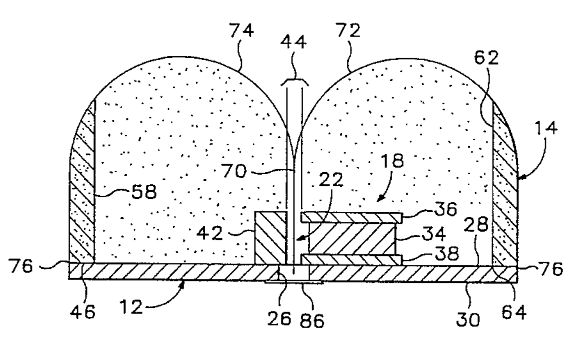
[57] **ABSTRACT**

An audio transducer includes a rigid base plate and a flexible foam element attached to the plate. The foam element has a "B" shaped cross section, with a plastic film diaphragm conformally attached to the dual semi-cylindrical front surface of the foam element. The foam element defines a large circular bore for receiving a magnet assembly attached to the plate, with a electrical coil attached to the diaphragm and received within a gap defined within the magnet assembly. The plate and diaphragm are sealed to the foam element to provide an environmentally sealed chamber within the bore.

28 Claims, 3 Drawing Sheets





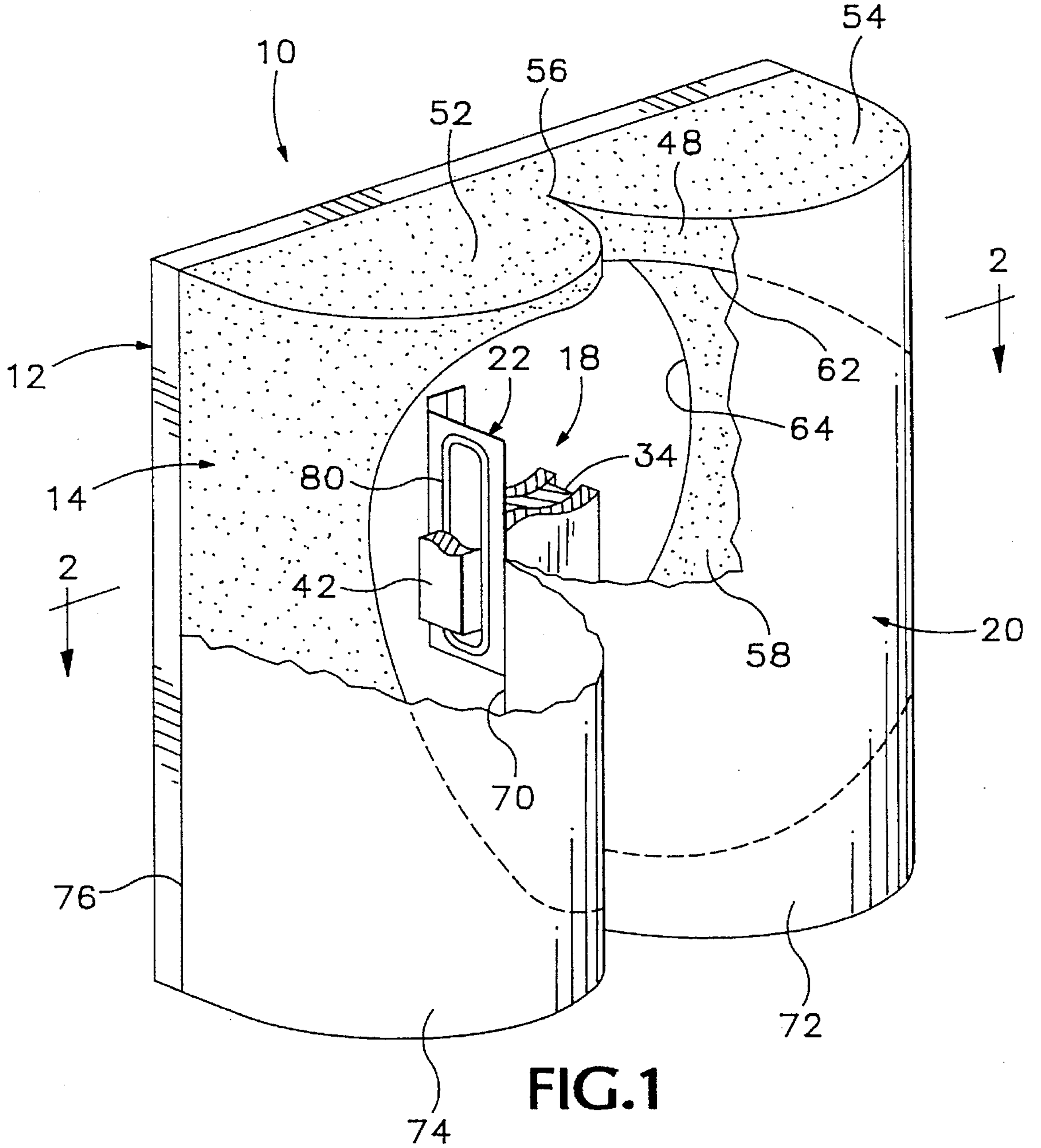


FIG.1

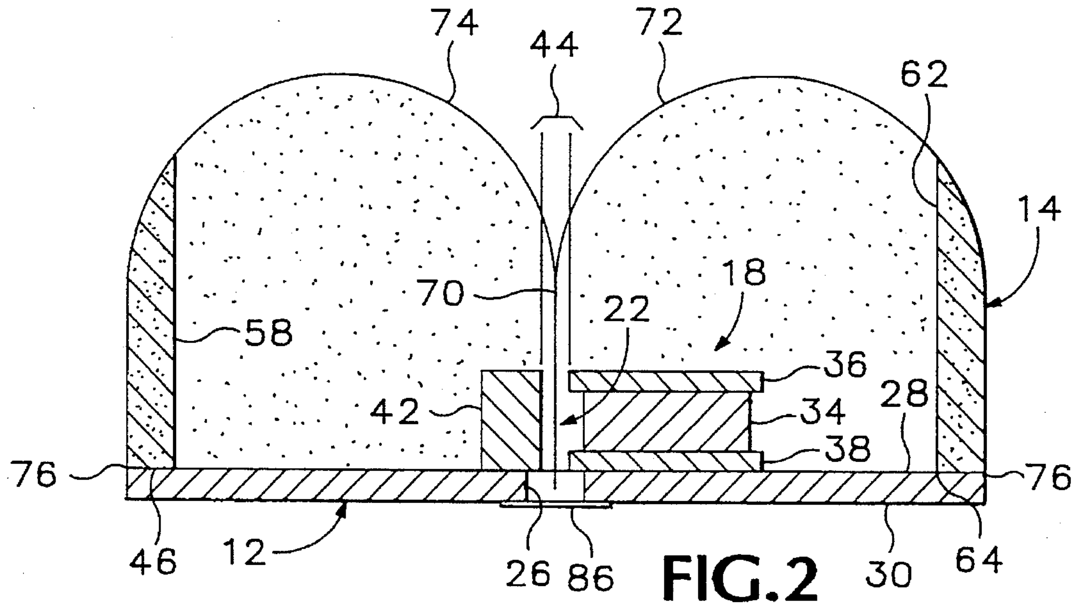

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FIG.2

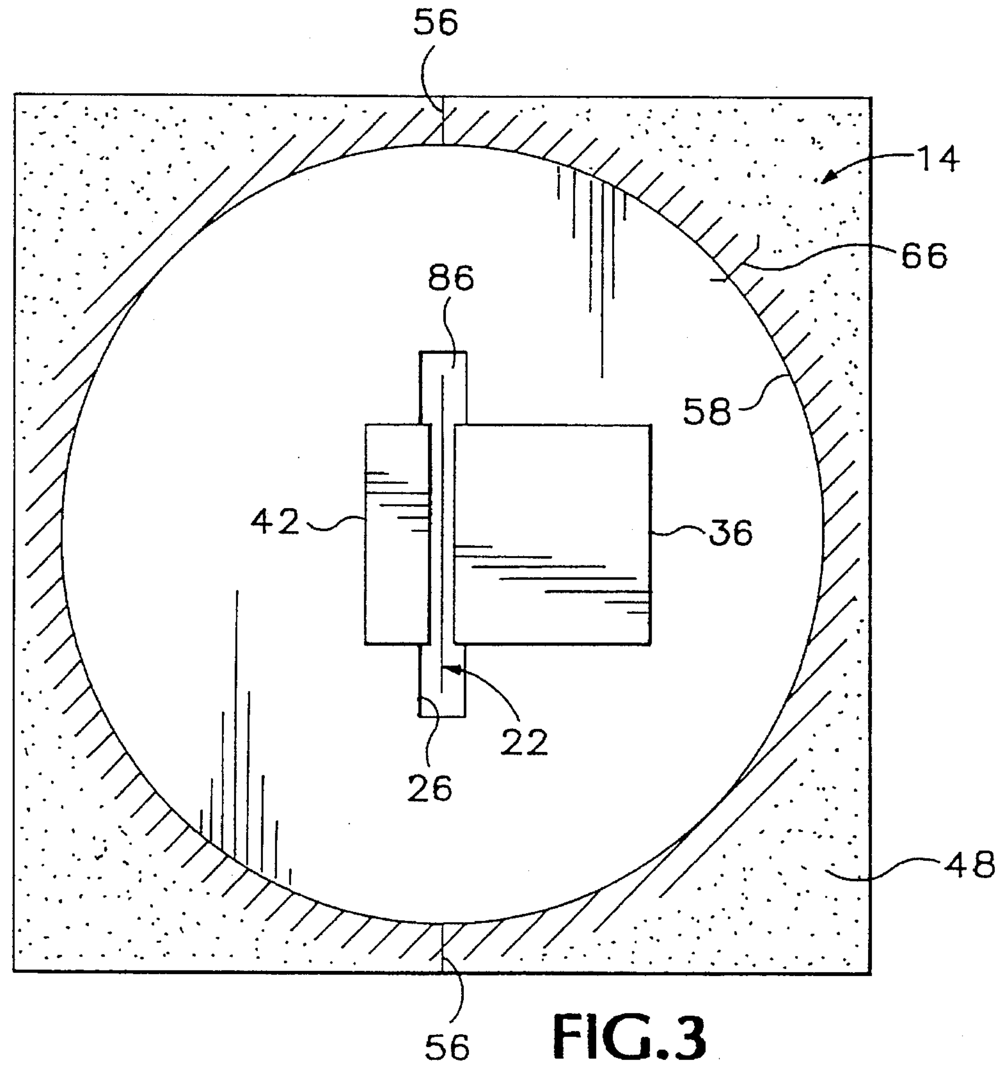
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FIG.3

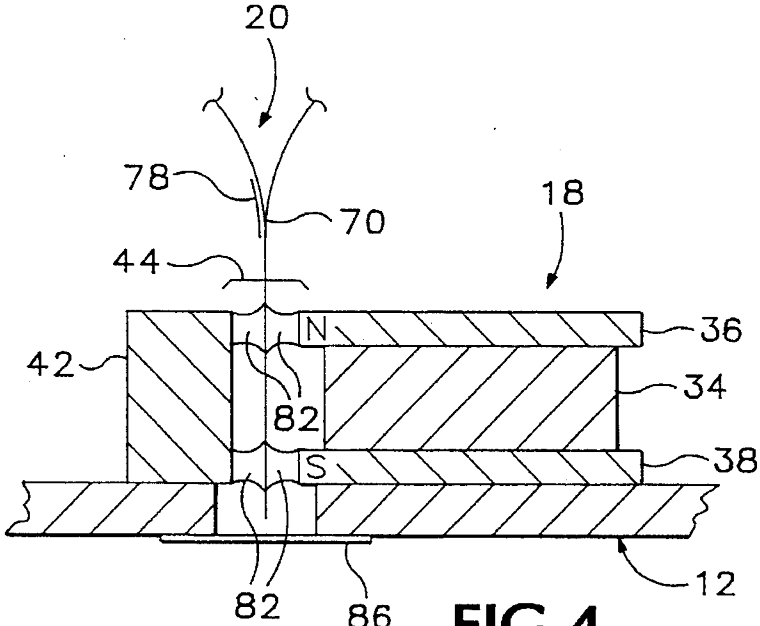

FIG.4

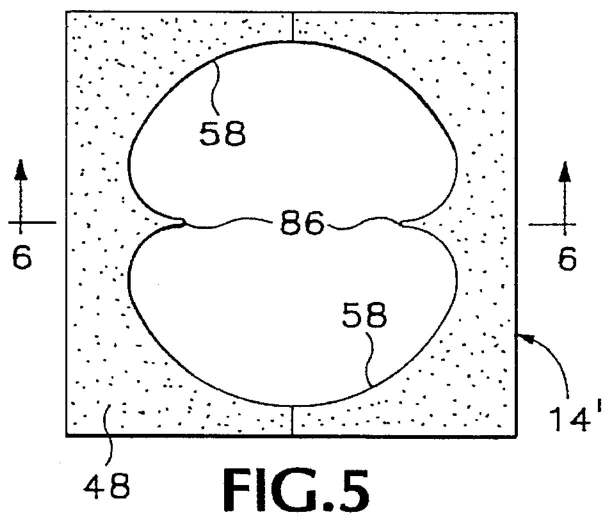

FIG.5

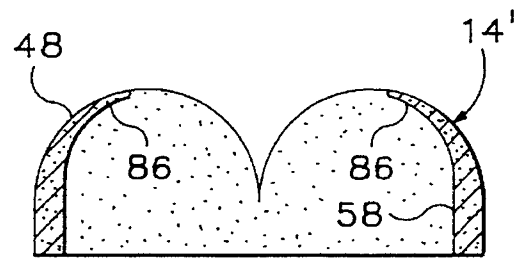

FIG.6

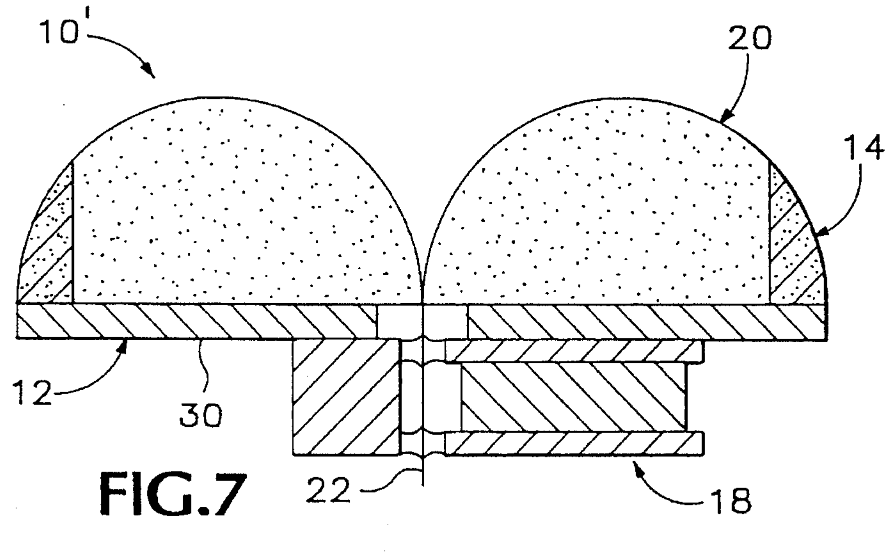

FIG.7

AUDIO TRANSDUCER WITH FLEXIBLE FOAM ENCLOSURE

This application is a continuation of application Ser. No 07/986,803, filed on Dec. 8, 1992, now abandoned.

TECHNICAL FIELD

This invention generally relates to audio transducers. More particularly, the invention relates to improvements in the design of a transducer having a flexible diaphragm.

BACKGROUND OF THE ART

U.S. Pat. Nos. 4,584,439, 4,903,308, 5,127,060, and pending U.S. patent applications Ser. Nos. 07/436,914 filed Nov. 14, 1989, now issued as U.S. Pat. No. 5,198,624; No. 07/730,172 filed Jul. 12, 1991, now issued as U.S. Pat. No. 5,230,021; No. 07/916,038 filed Jul. 17, 1992, No. 07/882,144 filed May 11, 1992, and No. 07/962,988, filed Oct. 15, 1992, are incorporated herein by reference. These references disclose variations and refinements of audio transducers having flexible diaphragms that can be generally described as "cylindrical" in the broadest sense of the term. That is, the diaphragm is defined by a two dimensional cross-sectional profile that is projected on an axis to form a three-dimensional diaphragm having a constant cross section. Typically, this profile is in the form of a "figure-eight" or a "figure-three" shape having two adjacent parallel semi-cylindrical lobes facing forward toward the listener.

In operation, these disclosed transducers generate sound by a "rolling motion" in which an electromagnetic coil attached to the diaphragm interacts with a fixed magnetic field to move in a direction perpendicular to the vertical axis of projection of the diaphragm, oscillating toward and away from the listener in a forward and rearward direction. While the transducers of the above-referenced applications and patents are quite effective, there remains a need for additional improvements to improve performance and reduce manufacturing costs.

Existing transducers have variations in efficiency over the useful frequency range. One variation may be generated by internal reflections of acoustic waves within the diaphragm at the top and bottom free edges of the diaphragm. A loss of efficiency may also occur at the top and bottom free edges of the diaphragm; acoustic pressure generated at the front of the diaphragm may be dissipated by the flow of some air over the edges of the diaphragm to the low-pressure region behind the diaphragm.

A further need in the prior art is to provide a simplified means for centering or positioning the diaphragm relative to the magnet structure during manufacturing. In addition, there is a need to reduce manufacturing costs by reducing the quantity and cost of components, and to reduce the need for precision and skilled labor to perform various manufacturing steps. Also, it is desirable to reduce the size and weight of existing transducers.

SUMMARY OF THE INVENTION

The primary object of this invention is to provide an improved transducer having features that independently and in concert overcome the difficulties and shortcoming of the prior art, and which fulfills the aforementioned needs.

This object may be satisfied by providing a transducer having a base plate with a magnet assembly forming a magnet gap, a flexible foam element attached to the base plate and having a "figure-three"-shaped front surface for supporting a similarly shaped flexible diaphragm, which is attached to the foam element. The foam element defines a chamber in which a coil centrally attached to the diaphragm is suspended within the magnet gap. The entire chamber may be sealed to prevent entry of dirt particles.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cutaway perspective view of a transducer in accordance with a first embodiment of the present invention.

FIG. **2** is a sectional bottom view of the transducer of FIG. **1** taken along line **2—2**.

FIG. **3** is a front view of the transducer of FIG. **1** with the diaphragm removed.

FIG. **4** is an enlarged sectional bottom view of the transducer of FIG. **1**.

FIG. **5** is a front view of a foam element of an alternative embodiment.

FIG. **6** is a sectional bottom view of the element of claim **5** taken along line **6—6**.

FIG. **7** is a sectional bottom view of a transducer in accordance with a second embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** illustrates an audio transducer **10** having a rigid base plate **12** to which a flexible foam frame element **14** is attached. A magnet assembly **18** is centrally attached to the plate **12**. A flexible cylindrical diaphragm **20** is attached to the front of the foam element **14** to conform thereto. A coil **22** is centrally attached to the diaphragm to be positioned near the magnet assembly **18**.

The plate **12** is a rigid metal plate, preferably of aluminum, although steel plate having weak magnetic properties or any other nonmetallic rigid structure may be substituted. The plate defines a rectangular slot **26** parallel to a major edge of the plate and centrally located therein. As shown in FIG. **2**, the plate has a front surface **28** and rear surface **30**.

The plate **12** need not be a flat sheet, although this is preferred as the lowest cost alternative. The plate may be an extruded rail having perpendicular side flanges for extending forward to capture the foam element **14** or extending rearward away from the foam element. Alternatively, the plate may be a deep drawn cup shape entirely surrounding the periphery of the foam element **14**. If desired, for certain applications, the entire transducer **10** may have a circular profile instead of square, with the corners being rounded off. The plate may further include flanges or attachment holes at the rear plane of the speaker, or extending forward beyond the front surface of the diaphragm **20** to provide a recessed or flush mounting in a panel.

As further shown in FIG. **2**, the magnet assembly **18** is attached at a central location on the front surface **28** of the plate **12**. The magnet assembly includes a magnet **34** having a front pole plate **36** and a rear pole plate **38**, with the rear pole plate being adhered directly to the base plate **12**. An iron return bar **42** is positioned adjacent the pole plates to form a magnet gap **44**. The magnet assembly **18** is positioned so that the magnet gap **44** is centrally registered with the slot **26** in the plate **12**. Accordingly, a first magnetic field spans between the front pole plate **36** and a front portion of the return bar **42**, while a second magnetic field of opposite direction and polarity spans between a rear portion of the return bar **42** and the rear pole plate **38**.

The foam frame element **14** has a B-shaped exterior profile as viewed from the top or bottom as shown in FIG. **2**. This provides a flat rear surface **46** adhered to and coextensive with the front surface **28** of plate **12**. As best shown in FIG. **1**, the foam element **14** has a front surface **48** in the shape of two semi-cylindrical lobes **52** and **54**, which are positioned side by side in nearly tangential contact to define a groove **56**. As shown in FIG. **3**, the foam element **14** defines a large circular bore **58** passing entirely through the foam element **14** from front to rear, on an axis perpendicular to the rear surface **46**. The bore **58** terminates at a front aperture **62** in the front surface **48**, and at a rear aperture **64** in the rear surface **46**. The front surface **48** includes a rim portion **66** entirely encompassing and immediately adjacent the front aperture **62**, providing a continuous band to which adhesive will be applied. The frame element is preferably formed of a medium-weight, open-cell polyether foam, although a wide variety of flexible materials may potentially be substituted. The element may be molded, extruded, die cut, or hot wire cut, or fabricated by a combination of these processes. Preferably, the foam element **14** is a single integral unit to facilitate simple assembly of the transducer **10**, with the groove **56** centrally aligned with the magnet gap **44**.

The diaphragm **20**, as shown in FIGS. **1** and **2**, is a single thin flexible plastic sheet having a central fold **70** that is received within the foam element groove **56**, with a pair of curved expanses **72** and **74** conforming to the semi-cylindrical front surface **48** of the foam element **14**. Thus, it is apparent that the foam element **14** serves a form function to support and shape the diaphragm **20**. The distal edge **76** of each expanse is attached to or near a respective edge of the base plate **12**. Consequently, the distal edges **76** are effectively fixed in position so that they do not normally move when the central portion of the diaphragm oscillates. The diaphragm may be adhered to the entire front surface of the foam element **14**, although it is only necessary that the diaphragm be adhered to the entire rim portion **66**. It is important that the rim portion **66** of the foam element **14** adjacent the front aperture **62** be coupled with the diaphragm so that motion in the central portion of the diaphragm does not cause relative sliding between the diaphragm and the foam element, which would generate unwanted buzzing in the transducer. All diaphragm motion is to be accommodated by flexing of the foam element **14**.

As best shown in FIG. **4**, the coil **22** is attached at one edge to the fold **70** of the diaphragm **20** so that it resides within the magnet gap **44**. A strip of tape **78** on one or both sides of the junction between the coil **22** and diaphragm provides secure attachment. As shown in FIG. **1**, the coil includes a spiral trace **80** arranged in an oblong racetrack shape to function in the manner disclosed in the art incorporated by reference above. The coil **22** preferably includes a spiral trace on each side for heat dissipation and efficiency.

Oscillation of the coil toward and away from the listener is accommodated by the slot **26** formed in the base plate **12**. The slot **26** is sufficiently large to provide clearance of the coil **22**. Oscillation is transmitted to the diaphragm **20**, which moves relatively freely at the small displacements associated with high frequencies over 2500 Hz. This is due to the flexibility of the foam element **14**, particularly because of the thin cross-section of the foam near the groove **56** at the lower and upper portions of the foam element. Additional flexibility may be provided, if necessary, by slitting the diaphragm **20** along the fold **70** at each end thereof, and

resealing the slits with a flexible adhesive tape strip (not shown).

As shown in FIG. **4**, to further facilitate heat dissipation, efficiency, and accurate centering of the coil **22** within the magnet gap **44**, a small quantity of ferrofluid **82** is provided in the magnet gap **44**. The ferrofluid **82** contains suspended magnetic particles and wicks into the magnet gap **44** on either side of the coil **22** at positions adjacent the edges of the pole plates **36**, **38**.

Suitable ferrofluid may be obtained from Ferrofluidics of Nashua, N.H. A viscosity of 200 to 300 centipoids is preferred, although a wide range of viscosities has proven suitable.

FIGS. **5** and **6** show an alternative embodiment of the foam frame element **14** in which a pair of damping fingers **86** extend into the bore **58** along the front surface **48**. These are intended to be adhered to the diaphragm **20** to damp any unwanted vibrations or resonances. The shape, size, location, and quantity of the fingers may be adjusted to optimize the performance for a variety of transducer embodiments. It should be further noted that the circular shape of the bore **58** is preferred because its geometry provides a varying width to avoid resonances at particular frequencies. Alternatively, the bore may be formed of an elliptical or other shape, and may have irregular edges.

When assembled, as shown in FIG. **2**, the plate **12**, frame **14**, and diaphragm **20** enclose a chamber **84** in which the coil **22** and magnet assembly **18** reside. The components are adhered together so that particles may not enter the chamber after assembly. A tape strip **86** is adhered to the rear surface of the base plate **12** to cover the slot **26**, providing a completely enclosed chamber. This permits the transducer to be completely assembled and sealed before the magnet **34** is magnetized by application of an external magnetic field.

FIG. **7** shows an alternate transducer **10'** in which the magnet assembly **18** is attached to the rear surface **30** of the base plate **12**. Consequently, the magnet assembly **18** is positioned outside of the sealed chamber **84**. A rear enclosure (not shown) may be attached to the base plate to protect and seal the magnet assembly **18** and coil **22**.

Although the illustrated embodiments are intended for use as "tweeters" with a low frequency limit of about 2500–3000 Hz and a high frequency limit of 20–30 kHz, the disclosed structures may be applied in transducers having different frequency limits. The preferred embodiment has a square profile between two to three inches on a side. Smaller transducers one inch on a side may be used as "super tweeters" with a useful range above 5 kHz. Such small sizes also enjoy the added benefit of improved dispersion, functioning effectively as a point source without an appreciable reduction in sound pressure levels 90 degrees off axis.

Having illustrated and described the principles of my invention by what is presently a preferred embodiment, it should be apparent to those persons skilled in the art that the illustrated embodiment may be modified without departing from such principles. I claim as my invention not only the illustrated embodiment, but all such modifications, variations and equivalents thereof as fall within the true spirit and scope of the following claims.

I claim:

1. An audio transducer comprising:

a rigid frame;

a magnetic assembly attached to the frame and defining a magnet gap;

a flexible sheet diaphragm having a pair of curved expanses;

a coil attached to the diaphragm, at least a portion of the coil being suspended within the magnet gap such that current flowing through the coil generates motion of the coil and at least a portion of the diaphragm relative to the frame; and

a flexible diaphragm form attached to the frame and having a form function to support and shape the flexible diaphragm, the diaphragm form having a front curvilinear surface including a middle portion from which said curved expanses extend and to which the diaphragm is attached so that the diaphragm conforms to the curvilinear surface.

2. The apparatus of claim **1** wherein the diaphragm form is formed at least in part of open cell foam.

3. The apparatus of claim **1** wherein the front surface comprises a pair of adjacent, convexly curved cylindrical portions.

4. The apparatus of claim **1** wherein the diaphragm form has a B-shaped cross sectional profile.

5. The apparatus of claim **1** wherein after conforming to the diaphragm form the diaphragm includes a pair of adjacent curvilinear portions joined at a fold therebetween.

6. The apparatus of claim **5** wherein the diaphragm form defines a groove at the middle portion and the fold is received within the groove.

7. The apparatus of claim **6** wherein the groove is complanar with the magnet gap.

8. An audio transducer comprising:

a rigid frame;

a magnetic assembly supported by the frame and defining a magnet gap;

a flexible sheet diaphragm;

a coil attached to the diaphragm, at least a portion of the coil being suspended within the magnet gap such that current flowing through the coil generates motion of the coil and diaphragm relative to the frame; and

a flexible diaphragm form attached to the frame and having a form function to support and shape the flexible diaphragm, the diaphragm form having a front curvilinear surface, portions of which lie in respective curvilinear planes and to which the diaphragm is attached thereby forming tangential curvilinear lobes.

9. An audio transducer comprising:

a frame;

a flexible sheet diaphragm;

an electrically actuated drive mechanism cooperative with the diaphragm to move same in a substantially planar manner; and

a contoured diaphragm form having at least two curvilinear, adjacent lobes to which the diaphragm is affixed, the diaphragm form serving a form function to support and shape the diaphragm into a curvilinear configuration.

10. The transducer of claim **9** wherein the diaphragm is formed from a single sheet of material having a central fold.

11. The transducer of claim **9** wherein the drive mechanism includes a coil sandwiched between the respective planar surface portions of the lobes and a magnet assembly supported by the frame, which defines a magnetic gap wherein the coil is located.

12. An audio transducer, comprising:

(a) a frame;

(b) a diaphragm support member having a rear surface attached to the frame, and a curvilinear front surface shaped as two tangential semi-cylinders, the support member further defining an opening extending from the front surface to the rear surface thereof;

(c) a diaphragm substantially covering the front surface and covering the opening the support member serving a form function to support and configure the diaphragm; and

(d) an electromagnetic transducer that movably responds to electrical signals that is connected to the diaphragm for moving the diaphragm to produce sound.

13. The audio transducer of claim **12** wherein the opening is substantially circular.

14. The audio transducer of claim **12** wherein the opening is substantially rectangular.

15. The audio transducer of claim **12** wherein the support member includes an end surface having a substantially B-shaped profile.

16. The audio transducer of claim **12** wherein the diaphragm, when attached to the support member, is shaped as two substantially semi-tubes tangentially joined.

17. The audio transducer of claim **12** wherein the electromechanical transducer comprises a magnetic assembly defining a magnet gap, and a coil that is at least partially suspended in the gap and that is attached to the diaphragm so that current flowing in the coil causes the coil, and thus the diaphragm, to move.

18. The audio transducer of claim **12** wherein the diaphragm is adhered to the front surface of the support member proximate the opening.

19. The audio transducer of claim **12** further comprising at least one damping finger located within the opening.

20. The audio transducer of claim **12** further comprising at least one damping finger integrally formed of the support member.

21. The audio transducer of claim **12** wherein the support member defines a groove and the diaphragm includes a fold that is received in the groove when the diaphragm is attached to the support member.

22. An audio transducer, comprising:

(a) a diaphragm support member having a substantially planar rear surface that defines a rear aperture and a curved front surface that defines a front aperture, an opening extending between the front and rear apertures, wherein the front surface has a shape resembling two substantially tangential semi-cylindrical lobes;

(b) a diaphragm attached to the support member along the front surface and covering the front aperture wherein the support member serves a form function to support and shape the diaphragm; and

(c) an electromagnetic transducer attached to the diaphragm for moving the diaphragm in response to electrical signals.

23. The audio transducer of claim **22** wherein the support member is foam.

24. The audio transducer of claim **22** further comprising damping fingers extending into the opening and in contact with the diaphragm.

25. The audio transducer of claim **22** wherein the diaphragm is a sheet having a central fold.

26. The audio transducer of claim **22** wherein the support member includes a groove between the semi-cylindrical lobes and the diaphragm is a sheet having a fold and the fold is located in the groove when the diaphragm is connected to the support member.

27. The audio transducer of claim **22** further comprising a rim portion circumscribing the front aperture and wherein the diaphragm is attached to the rim portion.

28. The audio transducer of claim **22** wherein the electromechanical transducer comprises a magnetic assembly defining a magnet gap and a coil located at least partially within the gap, the coil being connected to the diaphragm.

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