US005455396A

United States Patent [19]

Willard et al.

[11] Patent Number: 5,455,396

[45] Date of Patent: Oct. 3, 1995

[54] **TEMPERATURE/ENVIRONMENT-RESISTANT TRANSDUCER SUSPENSION**

[75] Inventors: **Charles L. Willard**, Castaic, Calif.; **Earl R. Geddes**, Livonia; **Robert H. Benedict**, Ann Arbor, both of Mich.

[73] Assignees: **JBL Incoporated**, Northridge, Calif.; **Ford Motor Company**, Dearborn, Mich.

[21] Appl. No.: **327,441**

[22] Filed: **Oct. 21, 1994**

Related U.S. Application Data

[63] Continuation of Ser. No. 36,959, Mar. 25, 1993, abandoned.

[51] **Int. Cl.**[6] **H04R 7/00**; F01N 1/06

[52] **U.S. Cl.** **181/172**; 181/206

[58] **Field of Search** 181/167, 169, 181/171, 172, 173, 174, 206; 381/71, 162, 188, 193, 205

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,891,566	12/1932	McKellip	181/172
3,767,004	10/1973	Liebcher	181/171
3,997,023	12/1976	White	181/171
4,122,314	10/1978	Matsuda et al.	181/172 X
4,676,853	6/1987	Lerma	156/87
5,099,949	3/1992	Mitobe	181/171
5,111,510	5/1992	Mitobe	181/172 X
5,115,474	5/1992	Tsuchiya et al.	181/172 X
5,233,137	8/1993	Geddes	181/206

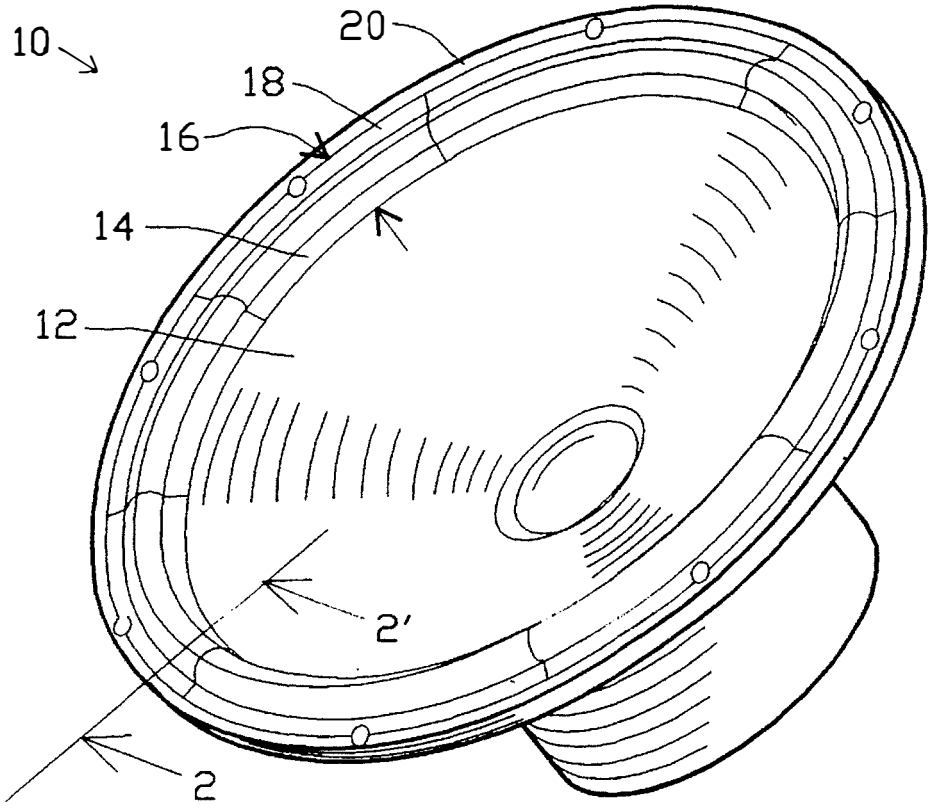
Primary Examiner—Khanh Dang

Attorney, Agent, or Firm—J. E. McTaggart

[57] **ABSTRACT**

For transducers such as loudspeakers and actuators which must operate at unusually low or high ambient temperatures, a robust resilient annular support member for mounting the vibratable diaphragm extends outwardly therefrom to the main frame. The support member is formed from silicone elastomer or a silicone rubber composite in a molding process which may be a constant temperature process, preferably transfer molding. A diaphragm and a surround member may be bonded together in the molding process by inserting the edge of the diaphragm into the cavity mold. The molding techniques of silicone rubber composites containing pulp and weave fiber grades of commercially available mix materials allow transfer, compression or injection molding of diaphragm suspension system members with good control of the mechanical properties and thickness. Particularly with regard to surround suspensions, the ability to mold silicone rubber composite in thin cross sections and to vary the thickness and undulation pattern in the resilient region adds a great degree of design freedom.

19 Claims, 2 Drawing Sheets



TEMPERATURE/ENVIRONMENT-RESISTANT TRANSDUCER SUSPENSION

This application is a continuation of application Ser. No. 08/036,959, filed Mar. 25, 1993, now abandoned.

FIELD OF THE INVENTION

The present invention relates to acoustic transducers and more particularly it relates to improvements in the structure and manufacture of diaphragm-suspension members of actuators and loudspeakers of the moving voice coil/diaphragm type for use in harsh environments at unusually low and high ambient temperatures.

BACKGROUND OF THE INVENTION

The moving voice coil/diaphragm type transducer configuration has been utilized widely in loudspeakers, where the main moving diaphragm is typically but not necessarily conical in shape with its inner edge attached to a voice coil bobbin. Typically there are two resilient suspension members: a spider attached to the voice coil bobbin generally near the region where the bobbin is attached to the cone, and a surround member forming an annular border strip having its inner edge attached around the outer edge of the cone and its outer edge attached to a peripheral flange of the speaker frame. Both of these suspension members are required to provide the cone/voice coil assembly with elastic freedom to move back and forth over large excursions along the central axis while at the same time providing sufficient lateral stiffness to hold the voice coil and bobbin concentrically aligned within the gap between the magnetic poles.

It is quite difficult to find suitable materials that will act satisfactorily as suspension members in a hostile environment such as an automotive exhaust pipe where the temperature can range from −40 to +600 deg. F. (−40 to 316 deg. C.), compared to a much narrower range, typically 0 to 150 deg. F. (−18 to 66 deg. C.) over which ordinary loudspeakers are designed to operate.

For this severe duty, generally most materials will be found unsuitable in either fatigue endurance, acoustic properties or flexural properties, when subjected to extreme heat and cold.

RELATED PRIOR ART

U.S. Pat. No. 3,767,004 to Liebscher discloses a loudspeaker utilizing a thin flat surround member around the outside of the cone, which receives its full support from a double spider rear suspension system, thus removing all stresses from the surround member so that it serves merely as an air separator rather than as a suspension member. In Liebscher's flat surround configuration, the material is unstressed in an inactive condition, and is required to stretch isotropically, i.e. omnidirectionally, with cone displacement.

The foam material utilized by Liebscher is specified to be of the closed cell type (i.e. containing bubbles); such material is essentially not moldable into a required shape because necessary pressurization would make it impossible to control the resulting thickness of the surround material when the pressure is released. Thus the usefulness of foam material in loudspeaker surrounds is limited to flat non-supportive members such as the Liebscher surround which requires no lateral stiffness and thus can be made inexpensively from sheet foam stock cut to the required outline and used in flat form.

Many loudspeakers of known art use a type of surround suspension which is cut from a sheet of fibrous material such as soft paper and press-formed to have annular corrugations so as to provide some degree of lateral stiffness along with flexibility to vibrate axially; however such suspensions are well known to be fragile and tend to have short life expectancy especially under harsh environmental conditions including temperature extremes.

OBJECTS OF THE INVENTION

It is a primary object of the present invention to provide a robust loudspeaker surround suspension member in which a specially selected material is particularly configured to provide uniform resilience in the direction of vibration and sufficient lateral stiffness to provide concentric control of the voice coil, and which can withstand large temperature variations while providing the required amount of excursion without sacrificing fatigue resistance and/or acoustic efficiency.

It is a further object of the invention that the material selected for the surround suspension member be suitable for manufacturing methods which allow freedom and flexibility in shaping the selected material to optimal form for best realization of the primary object of the invention.

SUMMARY OF THE INVENTION

The above objects have been met in the present invention of voice coil/cone suspension members made from silicone rubber or a silicone rubber composite of dense non-cellular structure as distinguished from an open porous or cellular structure such as is found in foam rubber materials, that is molded into the shape of a suspension member in a constant temperature molding process, preferably transfer molding. The ability to mold silicone rubber composite in thin cross sections adds a great degree of freedom in designing a surround system. The molding techniques of this material allow injection, transfer and compression molding of a suspension member with good control of the shape, mechanical properties and thickness, particularly with regard to the surround suspension member. Molding enables the cross-section of the surround to be made in the shape of one or more arcuate half-rolls which operate on the principle of anisotropic hoop tension to hold the voice coil well centered while allowing freedom to vibrate.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and further objects, features and advantages of the present invention will be more fully understood from the following description taken with the accompanying drawings in which:

FIG. **1** is a perspective view of a typical transducer showing the location of the surround member.

FIGS. **2–5** are cross sectional views of the surround support region of a transducer as implemented in different embodiments of the present invention:

FIG. **2** shows a half-roll surround member molded onto a diaphragm edge.

FIG. **3** shows a half-roll surround member adhesively attached to the diaphragm edge.

FIG. **4** shows a half-roll surround member formed with variations in thickness.

FIG. **5** shows a multiple roll surround member molded onto a diaphragm edge.

DETAILED DESCRIPTION

In FIG. Is a typical transducer **10** is depicted in a perspective frontal view showing the cone shaped diaphragm **12** attached around its outer edge to the inner edge **14** of a surround member **16** which is in turn attached by its outer edge **18** to the peripheral flange **20** of the frame of transducer **10**.

FIG. **2** is a cross sectional view of an edge region of transducer **10** as viewed at radial axis **2—2'** of FIG. **1**. In this embodiment of the invention, a surround member **16*a*** is molded from silicone rubber or a composition thereof; the inner edge bifurcated to form two lips **14*a*** and **14*b***, between which diaphragm **12** is sandwiched and bonded in place by a molding process or by an adhesive.

The surround member **16*a*** is seen to have a half-roll arched portion **22*a*** which provides the main axial compliance, and a flat outer edge **18** by which it is attached to flange **20** of the transducer **10**, typically by adhesive bonding.

FIG. **3** shows a surround member **16*b*** having a half roll arched portion **22** similar to that of FIG. **2**, however in this embodiment the inner edge **14** is made flat and attached on its lower surface to diaphragm **12** by adhesive bonding.

FIG. **4** illustrates another embodiment of the invention wherein the surround member **16*c*** is made to have different thickness at different regions of the cross section. The thickness dimension B in a central region of arched portion **22** is made less than the thickness dimension A at outer edge **18**; also the arched portion **22** is made thicker at dimension C near the bifurcated inner edge **14*a***, **14*b***. In this example the inner edge is shown as in FIG. **2**, i.e. bifurcated with lips **14*a*** and **14*b*** for molded attachment to the diaphragm **12**; however, the concept of varying the thickness is also applicable in the case of one-sided adhesive edge attachment as shown in FIG. **3**. As an example of varying the thickness of the surround member **16*c***, for a 6" round loudspeaker, dimensions A and C may be made 0.03" (0.76 mm) while dimension B is made to be 0.015" (0.38 mm). The values selected will depend on several design parameters such as the size of the transducer, the molding process and the composition of the silicone rubber material. This variation in thickness, which is readily implemented in a molding process by shaping the cavities as required, provides design flexibility to increase the axial compliance and its linearity while preserving lateral stiffness for centering purposes and providing a robust region for attachment at the outer edge **18** and the inner edge **14**.

FIG. **5** shows an example of an alternative configuration for the surround member **16*d*** in which the resilient portion **22*d*** is made with multiple rolls as shown in place of the half roll configuration of the foregoing embodiments. In this instance there are three half rolls approximating three adjacent semicircles: this concept can be extended to any number of multiple rolls, typically there will be an odd number of half rolls. The concept of multiple rolls may be applied in the same manner as described above for a single half roll: i.e. in combination with molded attachment, adhesive attachment and/or thickness variation.

In implementing this invention silicone rubber alone will provide improvements over prior art. Further enhancement may be obtained by adding other material to the silicone to form a composite silicone molding material, typically pulp and weave fiber grades of the mix materials such as those sold under Kevlar, Nylon, Nomex and Fiberglass, as selected to provide desired mechanical, acoustic and fatigue resistant properties of the silicone suspension member. In an example of a viable composite material for this purpose, fiber pulp sold under Kevlar is added to the silicone elastomer material in an amount of 1.5% by weight.

Regarding molding processes, transfer molding has been found most satisfactory and economical, and is typically performed at a pressure of 200 to 300 psi and a temperature around 350 degrees F. (177 deg. C.). As an alternative constant temperature molding process, compression molding could be utilized. It would also be possible to injection mold preheated material in a thermal cycle process. Material thickness typically ranges from 0.017" (0.43 mm) to 0.025" (0.63 mm).

A round speaker configuration is shown in FIG. **1** as illustrative: the invention is equally applicable to other speaker shapes such as elliptical or rectangular.

The invention may be embodied and practiced in other specific forms without departing from the spirit and essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description; and all variations, substitutions and changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. In an acoustical transducer for extreme temperature usage in an unusually harsh environment, said transducer being of the type having a main body and a diaphragm that is vibratable relative to the main body, an improved resilient support structure, for supporting the diaphragm from the main body, comprising:

a suspension member, composed of a dense non-cellular silicone rubber material such that said suspension member operates reliably over an extremely wide temperature range, having an outer edge portion attached to the main body, an inner edge portion attached to the diaphragm, and a resilient region extending between the outer and inner edge portions.

2. The improved resilient support structure as defined in claim **1** wherein said suspension member is uniformly composed of a dense silicone rubber material that has been formed from a silicone molding composition containing up to 10% by weight of commercial fibrous mix material in a substantially constant temperature molding process.

3. The improved resilient support structure as defined in claim **1** wherein said suspension member is uniformly composed of a dense silicone rubber material that has been formed from a silicone molding composition containing up to 10% by weight of commercial fibrous mix material in a transfer molding process.

4. The improved resilient support structure as defined in claim **1** wherein said suspension member is uniformly composed of a dense silicone rubber material that has been formed from a silicone molding composition containing up to 10% by weight of commercial fibrous mix material in a compression molding process.

5. The improved resilient support structure as defined in claim **1** wherein said suspension member is uniformly composed of a dense silicone rubber material that has been formed from a silicone molding composition containing up to 10% by weight of commercial fibrous mix material in an injection molding process.

6. The improved resilient support structure as defined in claim **1** wherein the main body of the transducer is provided with a circumferential flat mounting surface, and wherein the outer edge of said suspension member is adhesively bonded to the mounting surface.

7. The improved resilient support structure as defined in

claim **1** wherein the diaphragm is provided with a circumferential attachment region and the inner edge portion of said suspension member is adhesively bonded to the attachment region.

8. The improved resilient support structure as defined in claim **1** wherein the diaphragm is provided with a double-sided circumferential flat attachment region, the inner edge portion of said suspension member is configured With a parallel pair of edge flaps, and the flaps, being disposed so as to flank the attachment region of the diaphragm, are moldedly bonded thereto.

9. The improved resilient support structure as defined in claim **1** wherein said suspension member is molded to have a shape, at a radial cross section, defining an arch in the resilient region.

10. The improved resilient support structure as defined in claim **9** wherein the shape of said suspension member, as formed in a mold, is made to have a graduated thickness variation such that a central portion of the arch is made thinner than the outer edge portion and thinner than an end region of the arch adjacent the inner edge portion.

11. The improved resilient support structure as defined in claim **1** wherein said suspension member is molded to have a radial cross sectional shape defining a series of undulations in the resilient region.

12. The improved resilient support structure as defined in claim **11** wherein the shape of said suspension member as molded is made to have a predetermined pattern of graduated thickness variations in the resilient region.

13. The improved resilient support structure as defined in claim **1** wherein the diaphragm is provided with a circumferential attachment region and the suspension member is moldedly bonded to the attachment region of the diaphragm.

14. The improved resilient support structure as defined in claim **13** wherein said suspension member is composed of a dense silicone rubber material formed in a constant temperature molding process from a silicone molding material containing up to 10% by weight of commercial fibrous mix material.

15. The improved resilient support structure as defined in claim **1** wherein said suspension member is composed of a dense silicone rubber formed in a transfer molding process from a silicone molding material containing up to 10% by weight of commercial fibrous mix material.

16. In an acoustical transducer that is required to operate reliably over an extremely wide temperature range in an usually harsh environment, said transducer being of the type having a main body and a diaphragm that is vibratable relative to the main body, the diaphragm having a circumferential attachment portion, an improved resilient support structure for supporting the diaphragm from the main body, said support structure comprising:

an annular suspension member, composed of dense non-cellular silicone rubber material formed from a silicone molding composition containing up to 10% by weight of commercial fibrous mix material, the composition being such that said suspension member operates reliably over an ambient temperature range of at least –40° F. to +600° F., i.e. –40° C. to +316° C., said suspension member having a circumferential outer edge portion attached to the main body, an inner edge portion attached to the circumferential attachment portion of the diaphragm, and a concentrically-undulated resilient region extending between the outer and inner edge portions of said suspension member.

17. The improved resilient support structure as defined in claim **16** wherein the resilient region is made to have a radial cross-section shaped as an arch, and wherein said support structure is molded in a process selected from a group consisting of constant temperature molding, transfer molding, compression molding and injection molding.

18. The improved resilient support structure as defined in claim **16** wherein the circumferential outer edge portion thereof is adhesively attached to the main body, and the inner edge portion thereof is moldedly bonded to the circumferential attachment portion of the diaphragm.

19. In an acoustical transducer, for use in harsh environments, having a diaphragm that is vibratable relative to a main body of the transducer and that is provided with a pair of attachment surfaces one on each side of a circumferential portion thereof, an improved resilient support structure, for supporting the diaphragm from the main body, comprising:

an annular suspension member, composed of dense non-cellular silicone rubber material formed from a silicone molding composition containing up to 10% by weight of commercial fibrous mix material, the composition being such that said suspension member operates reliably over an ambient temperature range of at least –40° F. to +600° F., i.e. –40° C. to +316° C., said suspension member having a circumferential outer edge portion adhesively attached to the main body, an inner edge portion configured with a pair of flaps flanking the circumferential portion of the diaphragm and moldedly bonded to the attachment surfaces thereof, and a resilient region extending between the outer and inner edge portions thereof, the resilient region being made to have a radial cross section shaped as an arch of graduated varying thickness that decreases from each end thereof to a minimum thickness in a central region thereof.

* * * * *

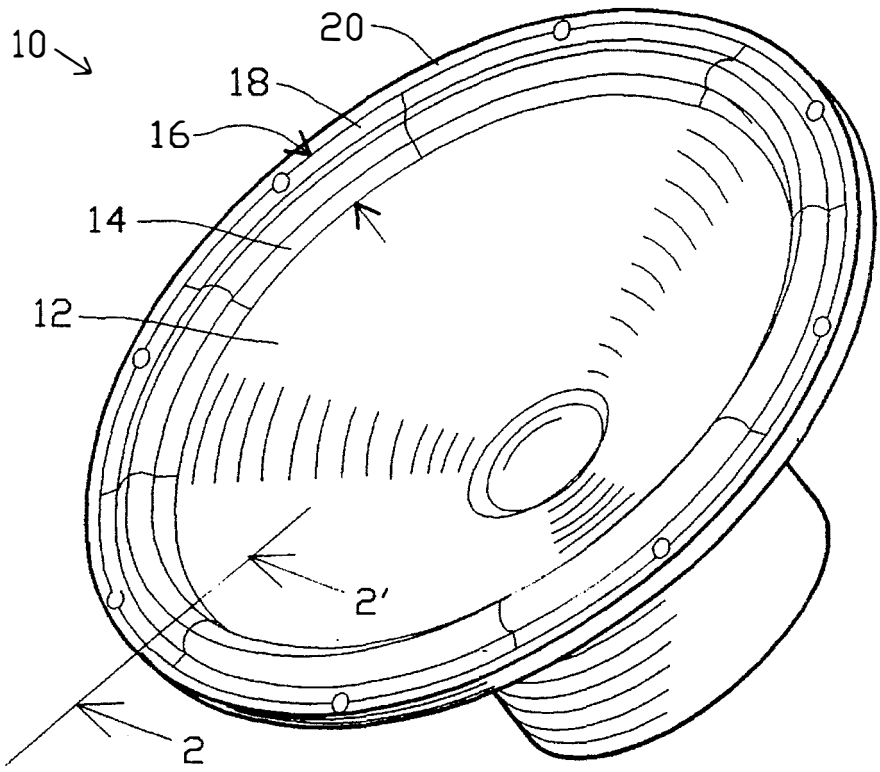


FIG. 1

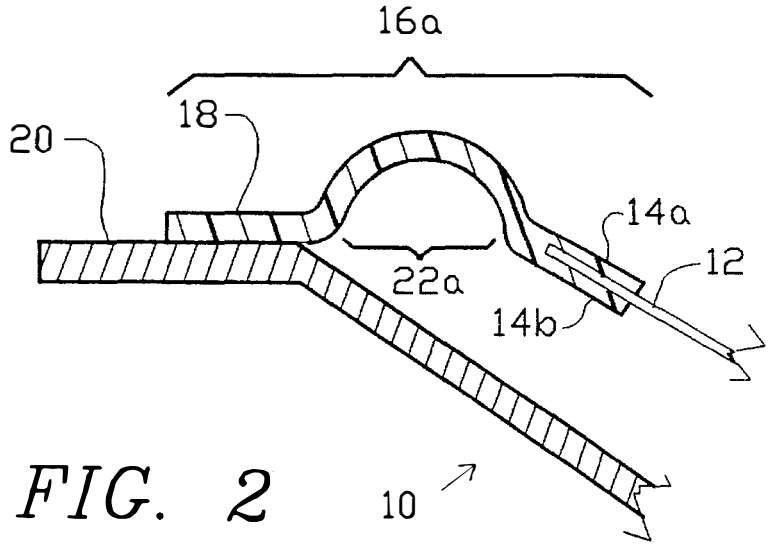


FIG. 2

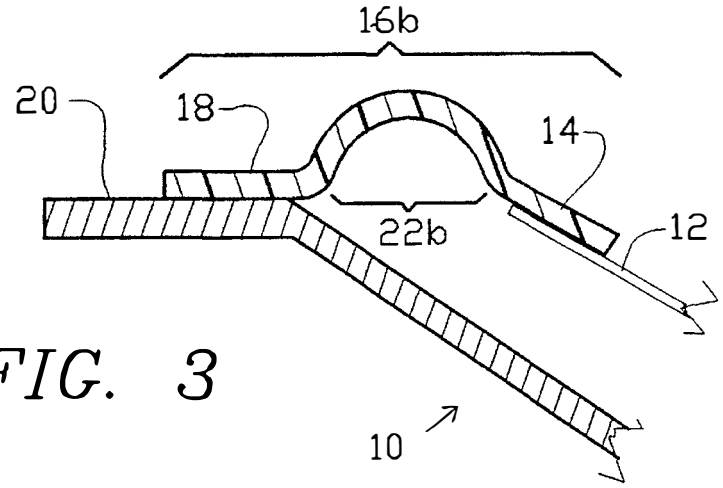


FIG. 3

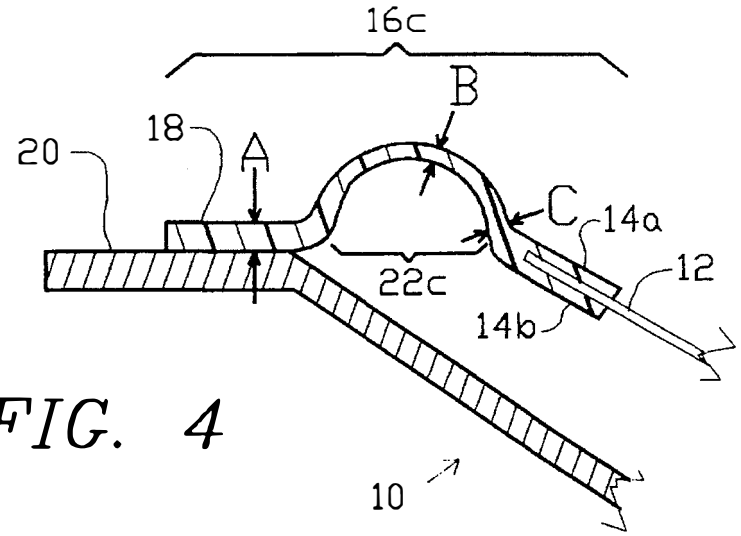


FIG. 4

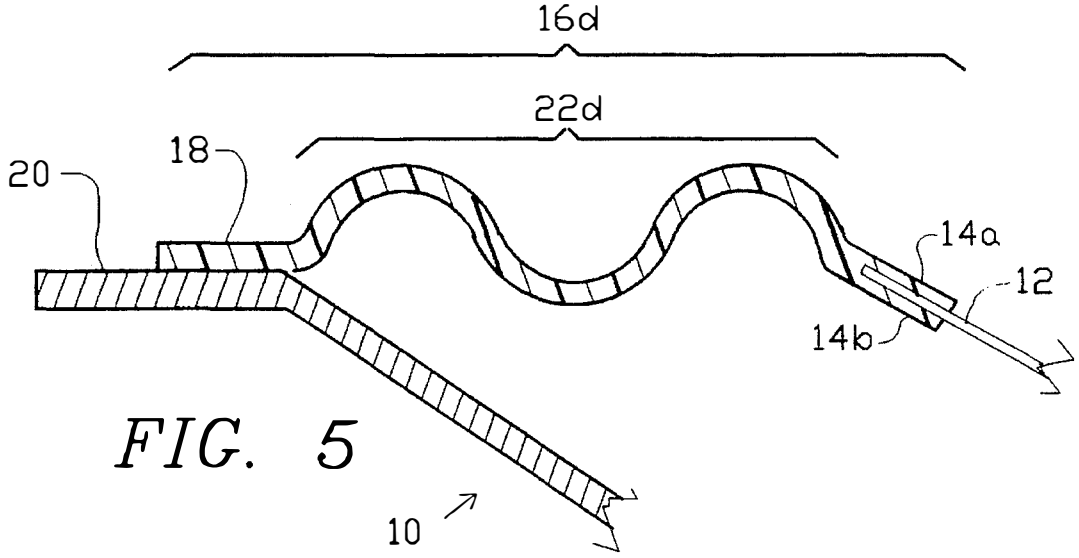


FIG. 5

US006782112B1

(12) **United States Patent**
Geddes

(10) **Patent No.: US 6,782,112 B1**
(45) **Date of Patent: Aug. 24, 2004**

(54) **LOW FREQUENCY TRANSDUCER ENCLOSURE**

(76) Inventor: **Earl R. Geddes**, 43516 Scenic La., Northville, MI (US) 48167

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/508,790**

(22) PCT Filed: **Oct. 1, 1998**

(86) PCT No.: **PCT/US98/20817**

§ 371 (c)(1),
(2), (4) Date: **Mar. 16, 2000**

(87) PCT Pub. No.: **WO99/18755**

PCT Pub. Date: **Apr. 15, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/060,546, filed on Oct. 2, 1997.

(51) **Int. Cl.**[7] **H04R 25/00**

(52) **U.S. Cl.** **381/351**; 381/345; 381/186; 381/349; 381/353; 181/145; 181/163

(58) **Field of Search** 381/89, 182, 184, 381/186, 345, 346, 347, 348, 349, 350, 351, 353, 335; 181/144, 145, 147, 163, 166, 155, 156

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,805,514 A	*	4/1974	Bodine	60/698
4,076,097 A		2/1978	Clarke	
4,182,937 A	*	1/1980	Greenwood	381/162
4,301,332 A		11/1981	Dusanek	
4,379,951 A	*	4/1983	Gabr	381/186
4,547,631 A		10/1985	Nieuwendijk et al.	
5,327,504 A	*	7/1994	Hobelsberger	381/350
5,812,686 A	*	9/1998	Hobelsberger	381/345
5,850,460 A	*	12/1998	Tanaka et al.	381/186

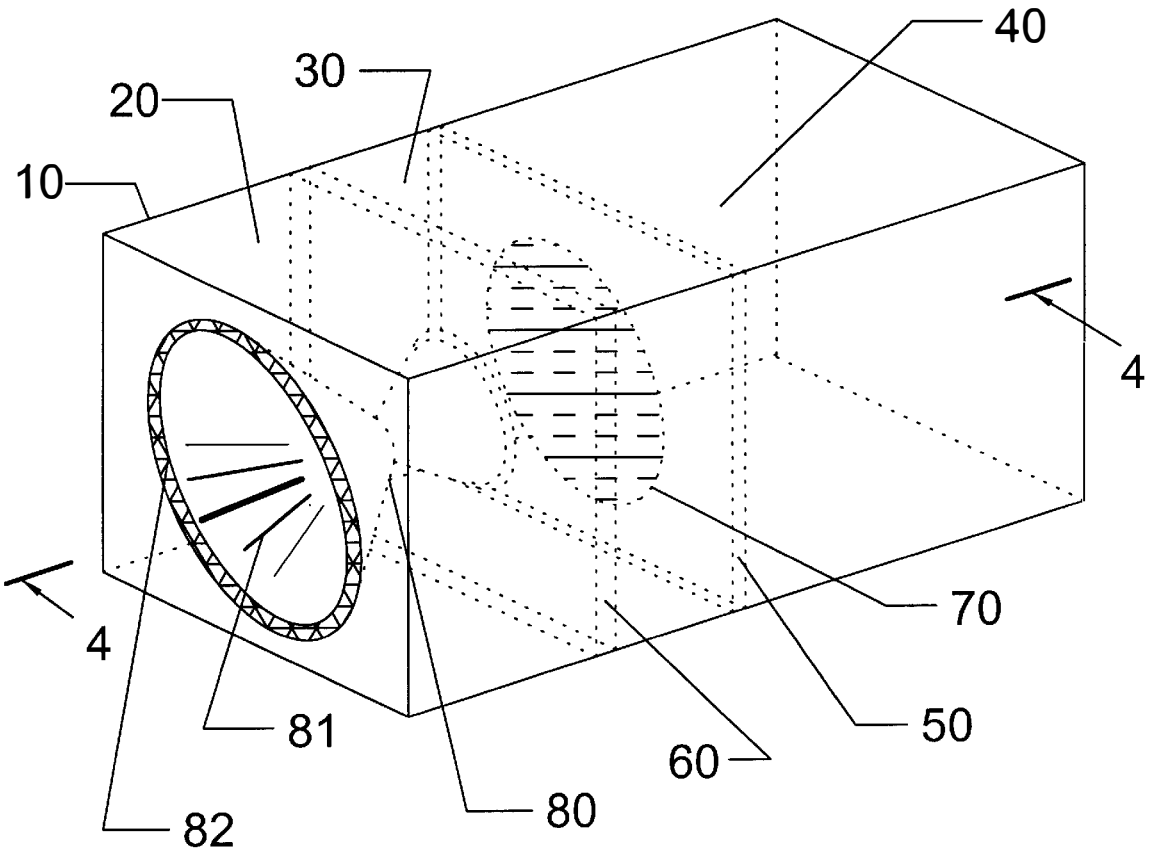
* cited by examiner

Primary Examiner—Suhan Ni

(57) **ABSTRACT**

An acoustical transducer enclosure has an acoustic lever acoustically coupled to an electro-acoustical transducer so as to force all radiated sound through the lever.

8 Claims, 9 Drawing Sheets



LOW FREQUENCY TRANSDUCER ENCLOSURE

This application claims the benefit of Provisional application No. 60/060,546 filed Oct. 2, 1997.

BACKGROUND

1. Field of the Invention

The present invention relates to acoustical transducer enclosure methodologies and ways to improve their efficiency.

2. Description of Prior Art

Transducer enclosure design for audio loudspeaker reproduction is a highly evolved science. The art of these designs goes back nearly one hundred years and yet there have been numerous recent advances in this art. The basic design methodologies are well described in the classical works of Novak "Performance of Enclosures for Low Resonance High Compliance Loudspeakers", Thiele "Loudspeakers in Vented Boxes" Parts I and II, Small "Vented-Box Loudspeaker Systems" Parts I, II, III, and IV, and Geddes "An Introduction to Bandpass Loudspeaker Enclosures". All of these articles can be found in the Loudspeaker Anthology series available from the Audio Engineering Society, New York, N.Y. A combined reference to these works would encompasses most of the current state-of-the-art in commercial loudspeaker enclosure design.

The recent trend towards the bandpass type of enclosure stems from the desire to produce more output with less energy i.e.—improved efficiency. By tuning single or multiple resonant acoustical systems the loading presented to the loudspeaker can be increased with a corresponding increase in efficiency. A rule of thumb for these designs is that the narrower the bandwidth of the bandpass system the higher the acoustic gain and the greater the efficiency improvement. This limitation of high efficiency—low bandwidth or low efficiency—high bandwidth is sometimes stated as—the efficiency bandwidth product for a bandpass loudspeaker system must remain constant. Mathematically this is not exactly true, but practically speaking it is.

It would be highly desirable to be able to increase the acoustic load presented to the loudspeaker without a corresponding decrease in the bandwidth of the resulting system.

Other novel attempts at increasing the radiating efficiency have been attempted by such inventors as Dusanek in his 1981 patent "Woofer Loudspeaker" U.S. Pat. No. 4,301,332. In this patent the rear of a loudspeaker is attached to "an inner and an outer passive speaker cone" such that the outer radiating cone is larger than the inner cone. An example from this patent is shown in FIG. **1**. A mechanical amplification of the loudspeaker cone motion is thus created. The inventor claims that this results in "a combination of lower frequency response and higher efficiency from a . . . small enclosure . . . ". The frequency response of the system may be lower, but the efficiency in the passband cannot be increased with this design. This is because the larger cone motion of the passive radiator will increase the sound radiation only in a very narrow range of frequencies around box resonance. Below this resonance the front and rear radiation will cancel one another (as in any ported enclosure) defeating any gains in radiation efficiency that might otherwise have been produced by a mechanical amplifier. Above resonance a passive radiator becomes decoupled from the loudspeaker and the pass band efficiency of the system must remain that of the direct radiator since there is no output from the passive radiator. At resonance an increase in efficiency will be evident and this improved efficiency can be utilized only by tuning the box lower than otherwise would be the case. Dusanek failed to realize that to be truly effective all of the radiating sound must be directed through the dual cone mechanical amplifier. This design has never seen commercial success.

Other forms of mechanical advantage have been tried. Niewendijk, et. al (1985) disclosed in U.S. Pat. No. 4,547,631, the use of a mechanical arm acting as a lever between a traditional voice coil and a bellows. The idea is to create a large volume displacement of the radiating surface from a much smaller motion of the voice coil or other actuating motor. The disadvantages of this design are extreme complexity in design and manufacturing and highly questionable reliability. This design has also never seen commercial implementation.

A similar (identical?) design to that of Dusanek was disclosed by Clarke in U.S. Pat. No. 4,076,097, "Augmented Passive-Radiator Loudspeaker Systems" (1979). In this invention a dual cone unit is again coupled to the back of a freely radiating driver except that the sound energy is directed to the junction between two passive radiator cones. An example from this patent is shown as FIG. **2**. The inventor claims that this new design offers an improved response over a standard passive radiator design due to the possibility of controlling the net compliance of the passive radiator by the addition of the second box. This "improvement" is of little consequence since any effect of a passive radiator's compliance would take place below resonance where the acoustical output is negligible. In practice the compliance of a passive radiator is not very important—thus controlling it is of little interest. This design never saw commercialization.

Referring now to FIG. **5**, transducer **70** is energized by connecting its motor to an amplifier (not shown) via wires **95**. In this manner acoustic energy from the transducer is introduced into chamber **30**. The sound pressure that results from this acoustic energy acts on the driven area of the lever **85**, which faces the transducer. Lever **80** will be displaced by this action in an amount that is substantially equal to the ratio of the transducer radiating area to the driven area of the acoustic lever multiplied by the transducers cone displacement. That is, if x_d is the displacement of a transducer having area A_d and x_1 is the displacement of the driven surface of an acoustic lever having area A_{ld} then:

$$x_1 = \frac{A_d}{S_d} \cdot x_d$$

An acoustic lever moves as a unit and thus the displacement of the radiating area of the acoustic lever is also x_1. The radiating area, A_{lr}, faces the exterior fluid medium. The volume of air displaced (displacement times area) by the radiating area of the acoustic lever, A_{lr}, will be:

$$A_{lr} = A_{lr} \cdot x_1 = A_{lr} \cdot \frac{A_d}{A_{ld}} \cdot x_d = \frac{A_{lr}}{A_{ld}} \cdot A_d \cdot x_d = \frac{A_{lr}}{A_{ld}} \cdot V_d$$

where V_d is the volume of air displaced by the transducer. If the radiating area is greater than the driven area then the volume velocity of air radiated by the acoustic lever will be greater than that of the transducer by the ratio of the acoustic levers radiating area to its driven area. This transformation of radiating volume velocity is very similar to the function of a transformer in electrical terms or a lever in mechanical terms. Hence the name acoustic lever.

As an example of the relationship given above, consider an acoustic lever made from two cones, the driven side is constructed with a projected area of 200 $cm.^2$ and the radiating side is constructed with a projected area of 400 $cm.^2$. From the above equation it is shown that the radiated volume displacement will be twice that of the electro-acoustic transducers cone displacement. This means that the radiated volume velocity will also be twice that of the electro-acoustic transducer and that the Sound Pressure Level (SPL) resulting from this sound radiation will be increased by approximately 6 dB as a result of the presence of the acoustic lever.

The above derived relationship will not hold at all frequencies. At frequencies above the frequency of resonance defined by the volume of chamber **30** and the acoustic mass of lever **80** the amplification effect will disappear and the radiated sound will diminish. This roll-off can be made steeper, if desired, by making the connection between the radiating surface and driven surface of lever **80** flexible instead of rigid. The volume of chamber **30** and or the acoustic mass of lever **80** can be determined from this relationship and the desired upper frequency of operation.

Chamber **20** will act so as to decrease the compliance of the acoustic lever. The acoustic compliance of chamber **20** will add (in parallel) to the acoustic lever compliance to form a single lumped compliance for this component. In most designs this compliance is assumed to be high enough so that the resonance created by the lumped compliance of the acoustic lever and its physical mass is well below the operating bandwidth of the desired system. This can always be made to be the case by making the volume of chamber **20** larger, the acoustic mass of lever **80** larger and or by increasing the acoustic lever compliance. In practice the lumped acoustic lever will not effect the system performance to a large extent unless this lumped compliance becomes mall compared to the combined compliance of transducer **70** and chamber **40**. In the event that the lumped acoustic lever compliance is not a sufficiently large compliance the result will be a de-tuning of the system, lowering its overall efficiency, primarily at the lower frequencies. This de-tuning can, to a certain extent, be compensated for by changes in the tuning of the other components of the system.

Physically the apparent acoustic compliance added by chamber **20** will be the normal acoustic compliance of this volume of air but acted upon by the acoustic lever as the difference in the projected areas of surfaces **81** and **85**, since the two surfaces of the acoustic lever move in opposite directions relative to the volume between them.

The above equation for the net gain in acoustically radiated volume velocity predicts that the gain can be increased indefinitely by increasing acoustic lever surface ratio, the ratio of the driven area of the acoustic lever to its radiating area. The above discussion regarding the lumped acoustic lever compliance indicates that there will be a practical upper limit to this amplification. The apparent acoustic compliance of chamber **20** and the acoustic lever compliance will both decrease as one attempts to increase the acoustical gain by increasing the acoustic lever surface ratio. The lumped acoustic lever compliance will eventually become so small as to limit the effective gain at a rate faster than the gain is increased by increasing acoustic lever surface ratio.

Good results have been obtained for an acoustic lever whose radiating area is somewhat larger than that of the transducer and whose driven area is somewhat smaller than that of the transducer. A radiating area of about 1.4 times that of the transducer and a driven that is about 0.7 times that of the transducer will produce a volume velocity increase of two, and a theoretical improvement in the radiated pressure of six dB. These construction parameters result in an acoustic lever with surfaces that are not too different from that of the electro-acoustical transducer thus facilitating an easy construction while yielding an impressive six dB of increased output.

Referring now to FIG. **6** in detail, a chart is illustrated which shows the theoretical improvement in radiated pressure that is to be expected from my invention. This figure compares a standard bandpass tuning of the fourth order variety with a Q of about 0.7 (as described in my paper "An Introduction to Bandpass Loudspeaker Systems")(lower curve) with an enclosure system utilizing an acoustic lever (upper curve). The transducer and enclosure volumes in this figure have been held constant. The specific design of the acoustic lever shown in FIG. **5** operates in a bandpass mode wherein the acoustic mass of lever **80** and the volume of the chamber **30** are adjusted so as to resonant at the resonance frequency of transducer **70** when placed in chamber **40**. The acoustic mass of the lever is made to be 1.414 times the acoustic mass of the transducer. This alignment is identical to that discussed in my paper above except that here the lumped acoustical lever has been ignored. This is valid so long as this compliance is not too small, as described above. The acoustic mass of the acoustic lever is its moving mass divided by its radiating area

In general, all of the designs described in my "Bandpass" paper are applicable here wherein substantial improvements in output can be obtained through the use of acoustic levers as opposed to the "ports" described in that paper. This is true as long as the lumped acoustic lever compliance is not too small as described above.

Referring now to FIG. **7** in detail, a perspective drawing is shown which highlights an alternate form of my invention. Dual acoustic lever system enclosure **100** is partitioned into front acoustic lever to electro-acoustic transducer coupling chamber **110**, rear acoustic lever to electro-acoustic transducer coupling chamber **120** and acoustic lever chamber **130** by interior acoustic lever partition **140** and electro-acoustic transducer partition **50**. Front acoustic lever **150** is coupled to the front of transducer **70** through chamber **110**. Rear acoustic lever **160** is coupled to the rear of transducer **70** through chamber **120**. An acoustic lever separating partition **145** in chamber **130** may be required to avoid interference between levers **150** and **160**. This partition is not shown in the perspective view but is shown in the cross sectional view of FIG. **8**. In this manner both radiating sides of transducer **70** can be utilized for an even greater increase in radiated output.

Determining the correct volumes of chambers **110** and **120** and the correct acoustic masses for the levers **160** and **150** would follow along analogous lines to the design of a six order non-symmetric bandpass enclosure described in my paper "An Introduction to Bandpass Enclosure Designs". This is true as long as the lumped acoustic lever compliance is not too small, as described above.

In some applications it may be undesirable, due to phase interference effects, to use two acoustic levers. This problem can be circumvented by using an acoustic duct, **170**, essentially a hollow tube of standard construction, often used in "ported" loudspeaker enclosures, as the acoustical mass in the lower frequency box resonance tuning. When this is done an improved pass band efficiency can be obtained without the degradation in the low frequency output which will result from phase interference if two acoustical levers are used. This construction is shown in FIG. **9**.

In any of the designs disclosed here the effective acoustic lever can be made up of several acoustic levers. In this case the sum of the acoustic masses of the individual levers would yield a single effective acoustic mass to be used in the design. These multiple levers would facilitate alternate constructions and polar responses for the system and reflect yet another design degree of freedom.

In my invention it should be noted that the fluid medium acting between the transducer and the acoustic lever can be any fluid substance including air, a gas or a liquid. In some applications the use of liquid as the coupling medium will be advantageous due to its incompressible nature. This would allow for a much wider bandwidth of the device than would otherwise be possible if a more compressible fluid, such as air, were used. This feature would be useful, for example, in an application where it is impractical to use more than a single transducer because of space issues. Examples of this type of application are hearing aid transducers and earphone transducers.

It is a further feature of my invention that the acoustic distortion of the system would be lowered. It is a well known effect of nonlinear distortion in transducers that a non-symmetric nonlinearity will cause the diaphragm to exhibit a static displacement, thus moving the cone into regions of even higher non-linearity. This static force is opposed by the system stiffness seen by the transducer at zero frequency. In a transducer system with air as the acoustic mass, such as ports, the zero frequency stiffness of the system is simply that of the transducer diaphragm support. When an acoustic lever is used the zero frequency stiffness opposing the static force is substantially higher due to the stiffness of the acoustic lever. Thus the diaphragm will not displace as much from the static force and the net distortion of the system will be lowered.

Other novel and unique modifications to the above description will be evident to those proficient in the art.

In the vein of the pure acoustical implementation of a bandpass system there are several patents on numerous configurations of ducts and enclosures all aimed at improved efficiency. Each of these acoustical implementations suffer from the efficiency—bandwidth tradeoff described above. While some are very efficient in terms of output and construction it would still be desirable to improve on these designs in a manner which does not degrade the bandwidth and is yet easy to construct.

SUMMARY OF THE INVENTION

The present invention provides for a novel use of an "acoustic lever". Both Dusanek and Clarke used acoustic levers in their inventions, although they did not call them as such and they were used in different configurations than in the invention disclosed here.

An acoustic lever, see FIG.(**3**), which shows several embodiments, is a passive mechanical device constructed of two rigid diaphragms (**14**, **16**) mechanically connected together and compliantly supported in a manner so as to allow motion along a line (**18**) The line of motion is normal to two baffles (**11**, **12**) into which the compliantly supported diaphragms have been installed. It should be noted that the baffles need not be flat planes as shown in the drawing, although this is the easiest and most logical form for these baffles. It would be obvious, to one skilled in the art, how to define and construct an acoustic lever for non-planar baffles. Effective surface areas of the diaphragms are defined as the projection of the diaphragm surfaces onto a plane normal to the axis of motion. These surfaces have areas denoted as the driven area A_{ld} and the radiating area A_{lr}. In one embodiment of an acoustic lever, flat circular diagrams are connected together by a rigid rod as shown in FIG.(**3**A). The rod need not-be perfectly rigid however, and one skilled in the art could see how this would effect the systems performance.

In another embodiment one or both of the diaphragm members can be a section of a cone, like a passive radiator diaphragm. When two cones are used they are placed apex to apex and fastened together as shown in FIG.(**3**B). There are no holes within an acoustic lever through which air can pass, i.e. through the apex's of the cone sections.

In another embodiment the apex of the cone section can be attached to a round plate (the driven diaphragm as shown in FIG.(**3**C).

The defining characteristic of an acoustic level is that it always has three distinct surfaces and is installed between two baffles. The acoustic lever surfaces are; a radiating surface which lies in that side of one of the baffles that does not oppose the other baffle; a driven surface which lies in that side of the other baffle which does not opposed the other baffle; and an inner surface that is composed of those surfaces which move and that lie between the two baffles. The area of the driven surface is generally smaller than the radiating area. The radiating area, in the context of this invention always faces the exterior of the enclosure and the driven surface is always located on an interior baffle. The inner surface always has an effective area which is the difference of the driven and radiating areas. When two passive radiators are connected together to form an acoustic lever, FIG.(**3**B) one of the surfaces of each of the passive radiators is combined with one of the surfaces of the other passive radiators to form the inner surface of the acoustic lever. If the driven area and the radiating area of an acoustic lever are equal then the inner area becomes zero and the acoustic lever is in essence a passive radiator. Thus a passive radiator is a special case of an acoustic lever, which is of no interest in this invention.

When an acoustic lever is acoustically coupled to a electro-acoustic transducer in a manner which forces all radiated sound to go through the acoustic lever, i.e. acoustically in series, then the resulting system can be made to cause a many-fold increase in the radiated volume velocity of the transducer, throughout the operating pass band of the system. This results in a significant increase in the efficiency of the transducer enclosure combination when compared to the same transducer used without the lever.

A novel transducer enclosure can also be assembled by utilizing two acoustic levers, one on each side of the electro-acoustic transducer which will further enhance the radiated sound output of this design. One of the levers can be replaced by a standard duct or passive radiator system for even more design flexibility.

The acoustic lever enclosure design will also lower the distortion radiated from the transducer.

DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a drawing of the preferred embodiment of the prior art of Dusanek;

FIG. **2** shows a drawing of the preferred embodiment of the prior art of Clarke;

FIG. **3** is a perspective view of three possible acoustic lever implementations, in A the baffles are explicitly shown;

FIG. **4** is a perspective view of the novel enclosure utilizing a single acoustic lever;

FIG. **5** is a cross sectional view of the transducer enclosure shown in FIG. **3** as taken in the direction of **2**—**2** thereof;

FIG. **6** shows a frequency response comparison of a standard bandpass enclosure design and the novel design incorporating an acoustic lever;

FIG. **7** shows a perspective view of the novel enclosure design which incorporates two acoustic levers; and

FIG. **8** shows a cross sectional view of the transducer enclosure shown in FIG. **6** as taken in the direction of **3**—**3** thereof.

FIG. **9** shows a cross sectional view of a transducer enclosure with the front chamber (low frequency tuning) acoustical mass implemented with a duct.

Reference Numerals in Drawings

10	system enclosure
11	baffle containing driven diaphragm
12	baffle containing radiating diaphragm
14	acoustic lever driven compliantly supported diaphragm
16	acoustic lever radiating compliantly supported diaphragm (underside)
18	axis of motion
20	acoustic lever chamber
30	acoustic lever to electro-acoustic transducer coupling chamber
40	electro-acoustic transducer rear chamber volume
50	electro-acoustic transducer partition
60	interior acoustic lever partition
70	electro-acoustic transducer
80	acoustic lever
81	acoustic lever radiating surface
82	acoustic lever radiating surface compliant support
85	acoustic lever driven surface
86	acoustic lever driven surface compliant support
95	electro-acoustic transducer energizing wires
100	dual acoustic lever enclosure
110	front acoustic lever to electro-acoustic transducer coupling chamber
120	rear acoustic lever to electro-acoustic transducer coupling chamber
130	acoustic lever chamber
140	interior acoustic lever partition
145	dual acoustic lever isolation baffle
150	front acoustic lever
160	rear acoustic lever
170	acoustical duct

DESCRIPTION OF THE PREFERRED EMBODIMENT

A preferred embodiment of the enclosure is illustrated in FIGS. **4** and **5**. An external enclosure **10** is subdivided into at least three internal chambers; a acoustic lever chamber **20**, an acoustic lever to electro-acoustic transducer coupling chamber **30** and a rigid closed electro-acoustic transducer rear chamber **40** by electro-acoustic transducer partition **50** and an interior acoustic lever partition **60**. The enclosure and the internal partitions are of standard construction. An electro-acoustic transducer **70**, of standard construction, is securely attached to partition **50** and sealed so that negligible air flow exists between chamber **40** and chamber **70**.

An acoustic lever **80** is mounted such that it has its radiating surface **81** along with its compliant surround **82** are sealingly mounted in one exterior wall of enclosure **10** and its driven surface **85** along with its compliant surround **86** are sealingly mounted on partition **60**. The two compliant surrounds, **82** and **86** will act together to create a single acoustic lever compliance.

I claim:

1. An enclosure for housing an acoustic transducer comprising:

an external rigid shell with first and second interior baffles partitioning the interior of said enclosure into three chambers;

at least one active acoustic transducer mounted on said first interior baffle, and;

at least one passive acoustic lever, comprising;

two passive radiators, of different areas, which are mechanically joined together so as to move as a single unit,

connected between one of said first and second interior baffles and said external rigid shell.

2. An enclosure for housing an acoustic transducer as in claim **1** wherein:

said passive acoustic lever is connected between said second interior baffle and said external rigid shell.

3. An enclosure for housing an acoustic transducer as in claim **1** including:

at least one port which contains an acoustic duct or passive radiator, on said interior baffles.

4. An enclosure for housing an acoustic transducer of claim **1** including:

at least one port which contains an acoustic duct or passive radiator, on said external rigid shell.

5. An enclosure for housing an acoustic transducer comprising:

an external rigid shell with first and second interior baffles partitioning the interior of said enclosure into chambers one, two and three;

at least one acoustic transducer mounted on said first interior baffle between said chambers one and two; and

at least two passive acoustic levers, one and two,

each acoustic lever comprising two passive radiators, of different areas, which are mechanically joined so as to move as a single unit,

connected between said first or second interior baffles and said external rigid shell.

6. An enclosure for housing an acoustic transducer as in claim **5** wherein:

said passive acoustic lever one is connected between said second interior baffle and said external rigid shell.

7. An enclosure for housing an acoustic transducer as in claim **6** wherein:

said passive acoustic lever two is connected between said second interior baffle and said external rigid shell.

8. An enclosure for housing an acoustic transducer as in claim **5** including:

an additional interior baffle partitioning said interior chamber three such that said acoustic levers one and two are each in their own chamber.

* * * * *

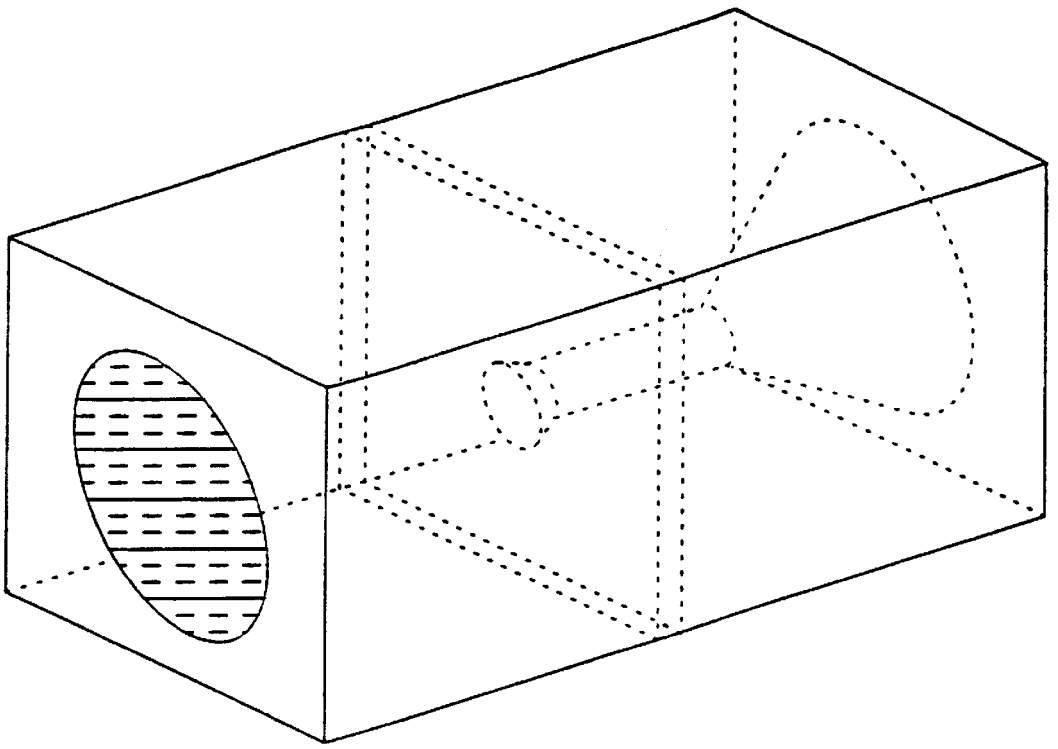


Fig. 1 - *Prior Art*

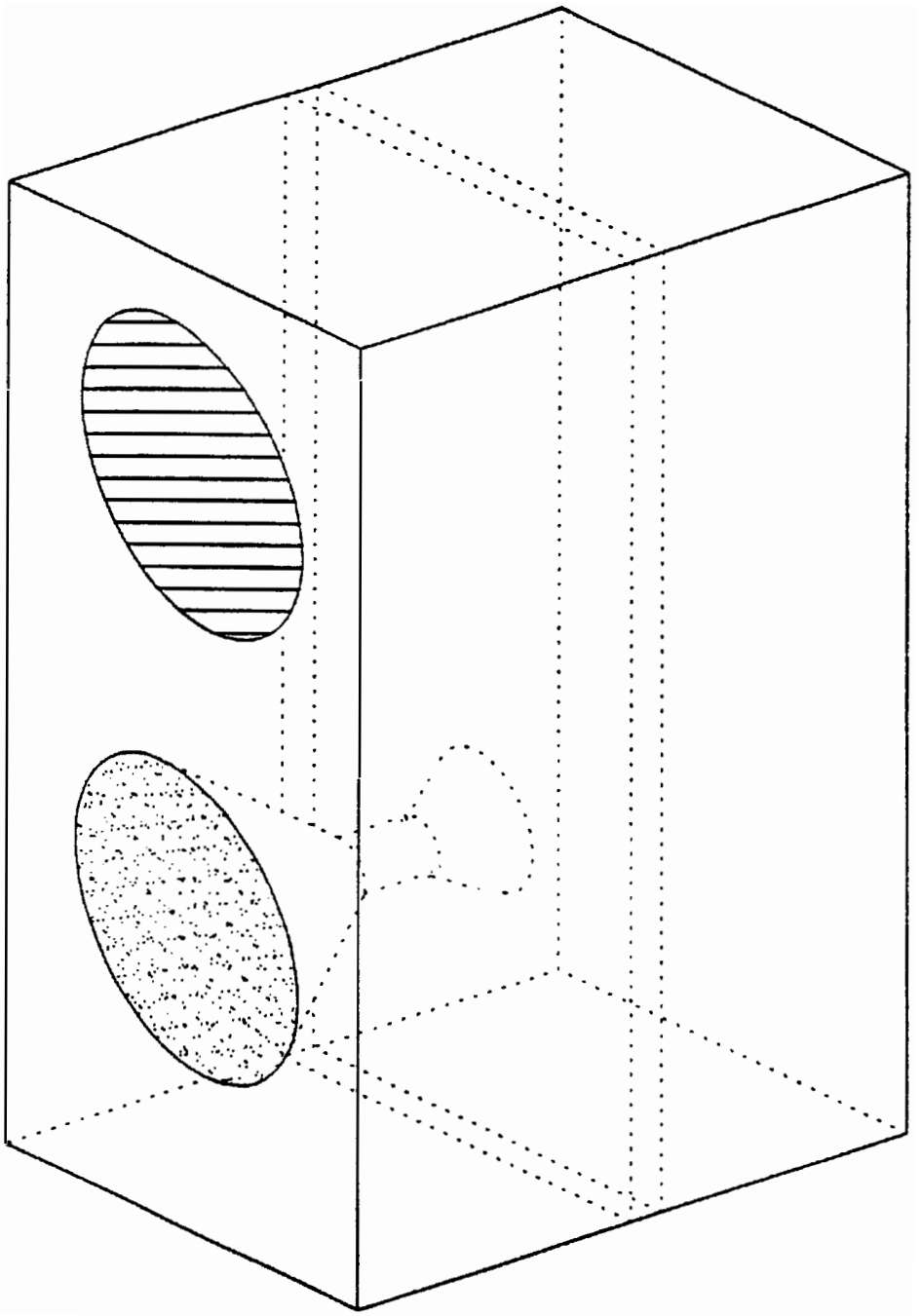


Fig. 2 - *Prior Art*

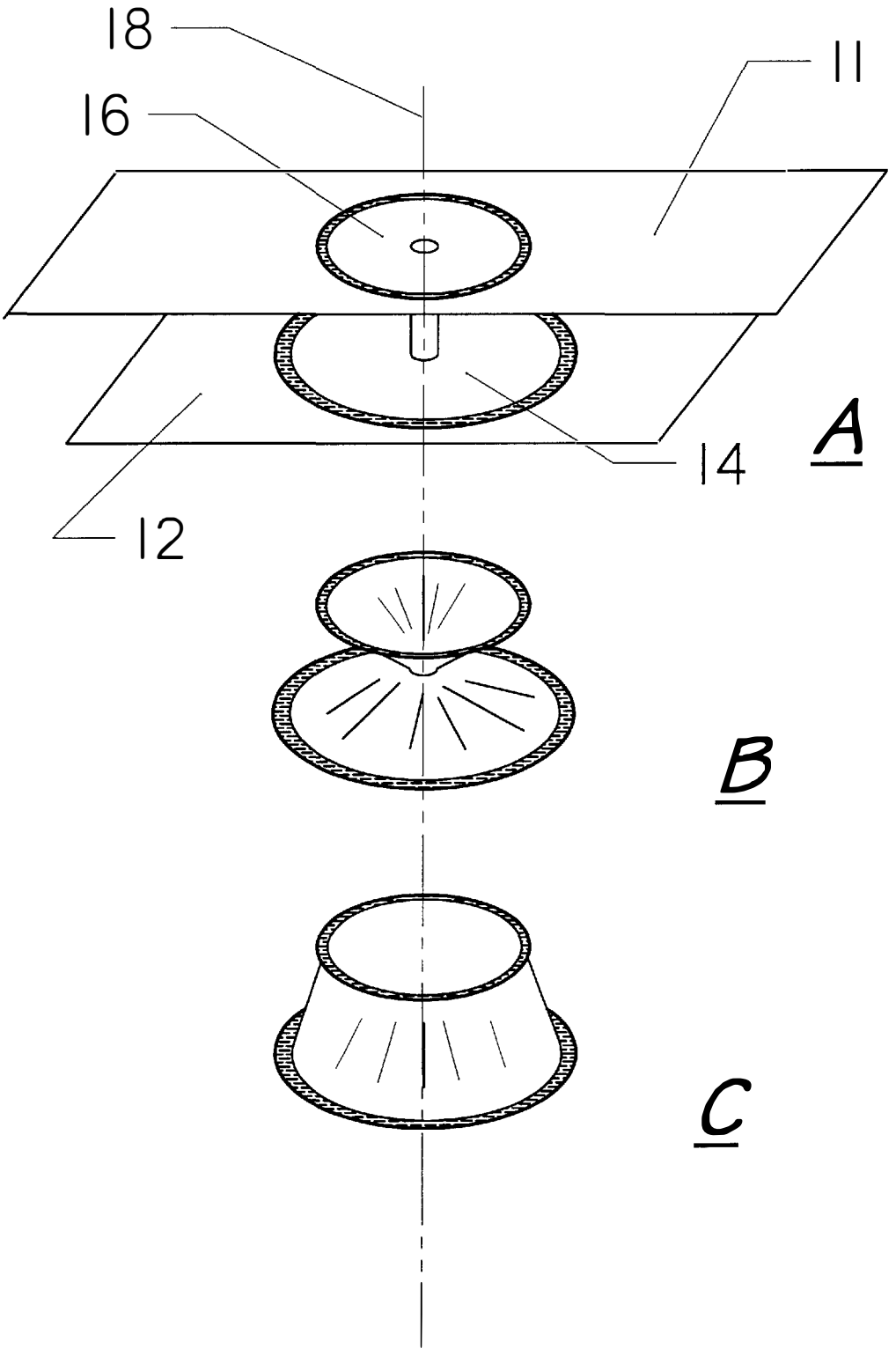


Fig. 3

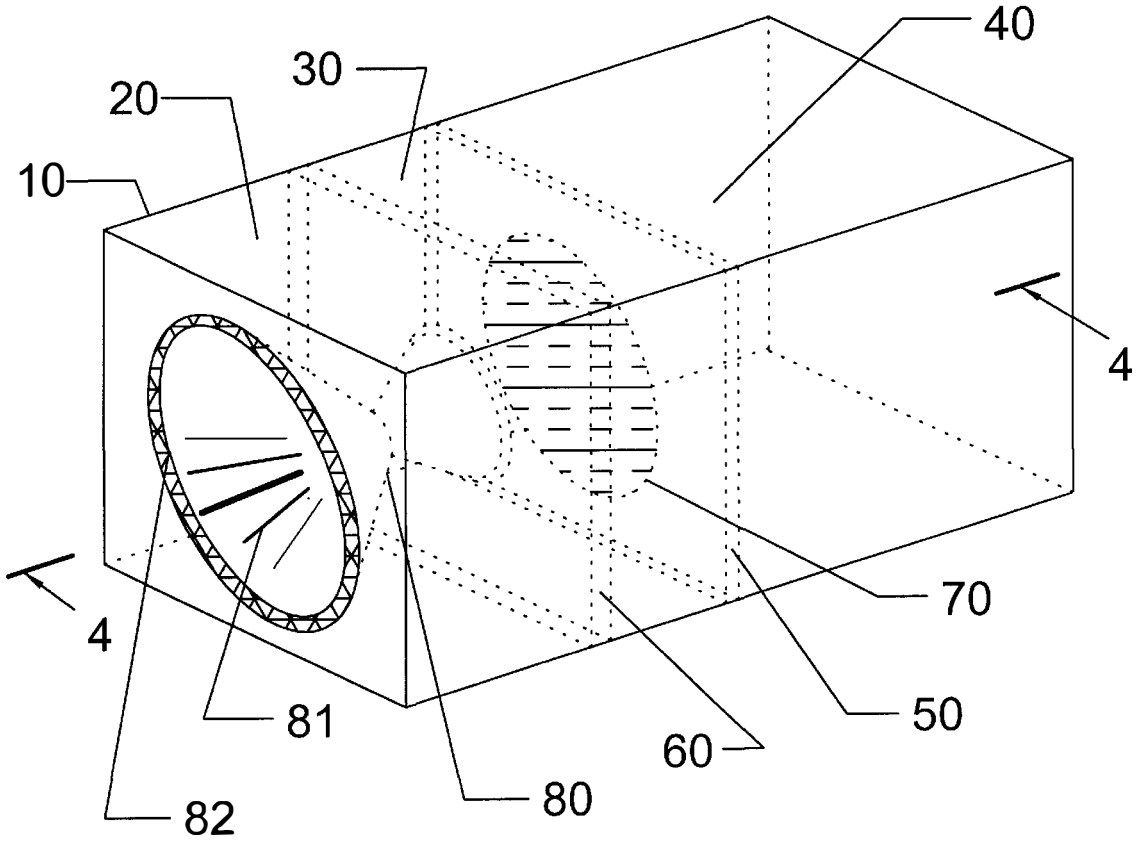


Fig. 4

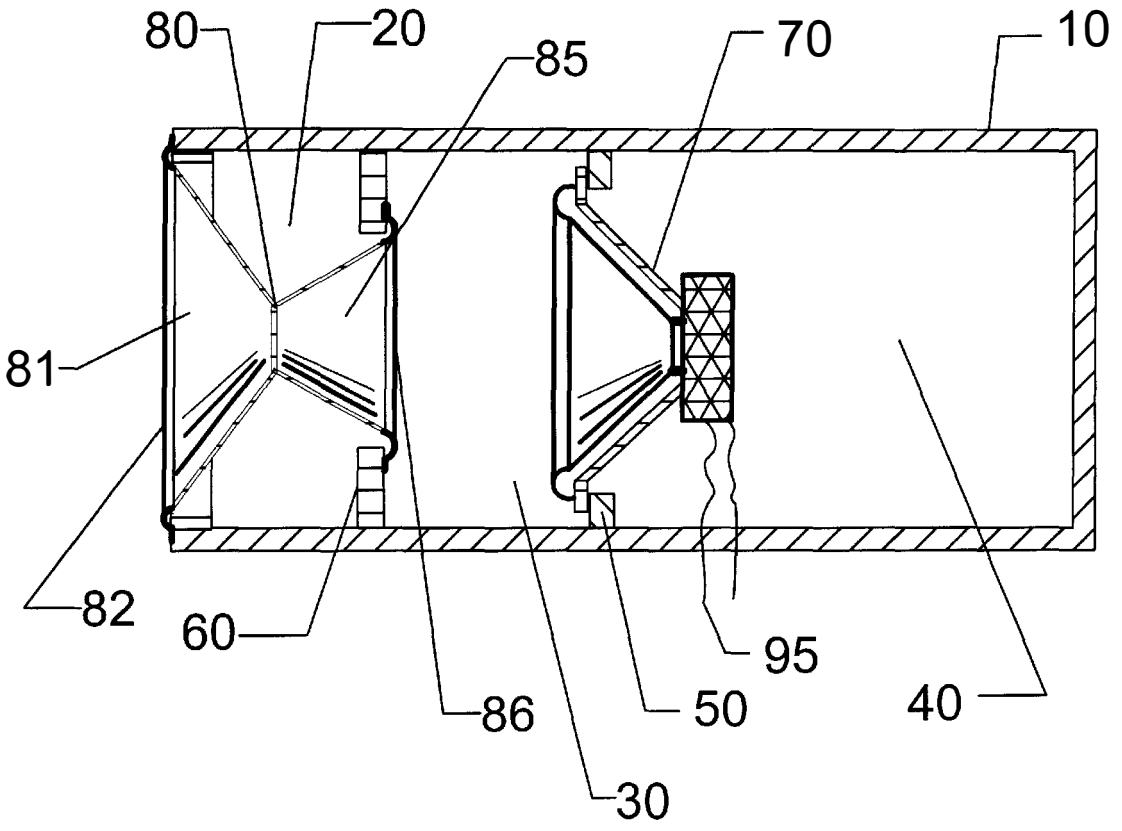


Fig. 5

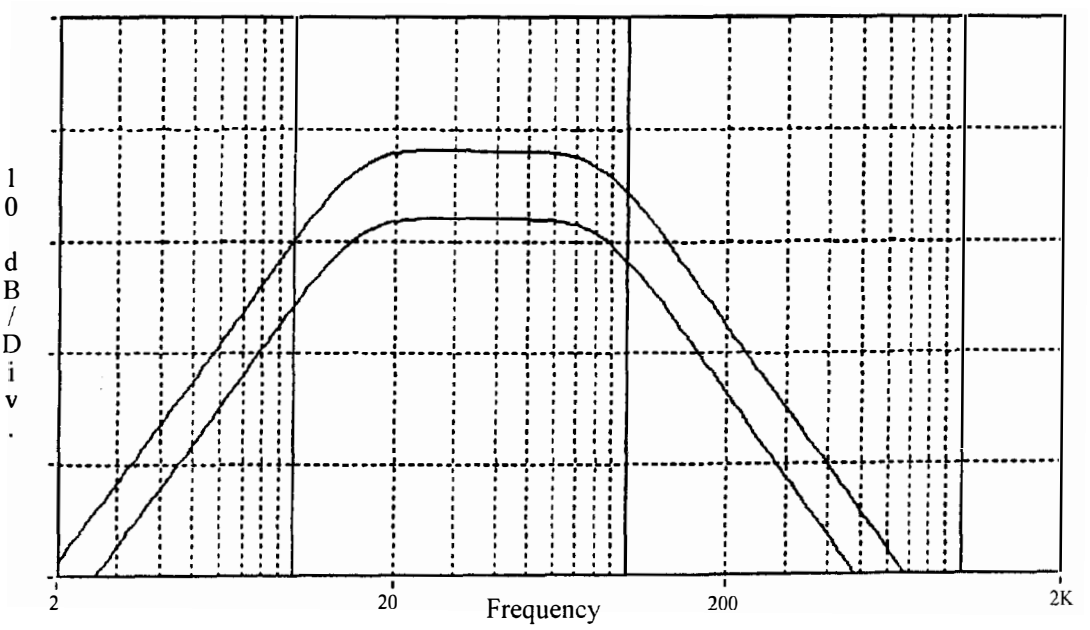


Fig. 6

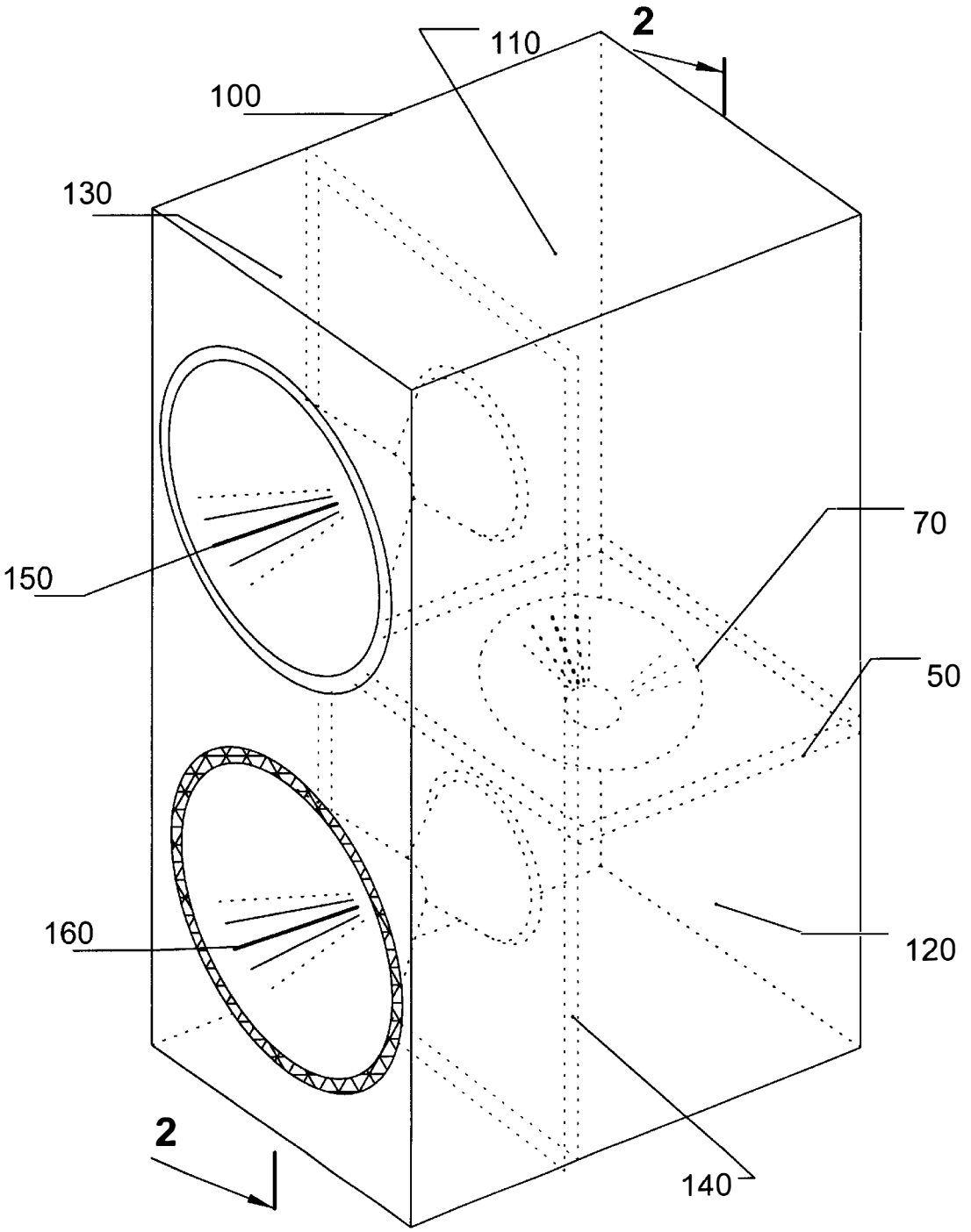


Fig. 7

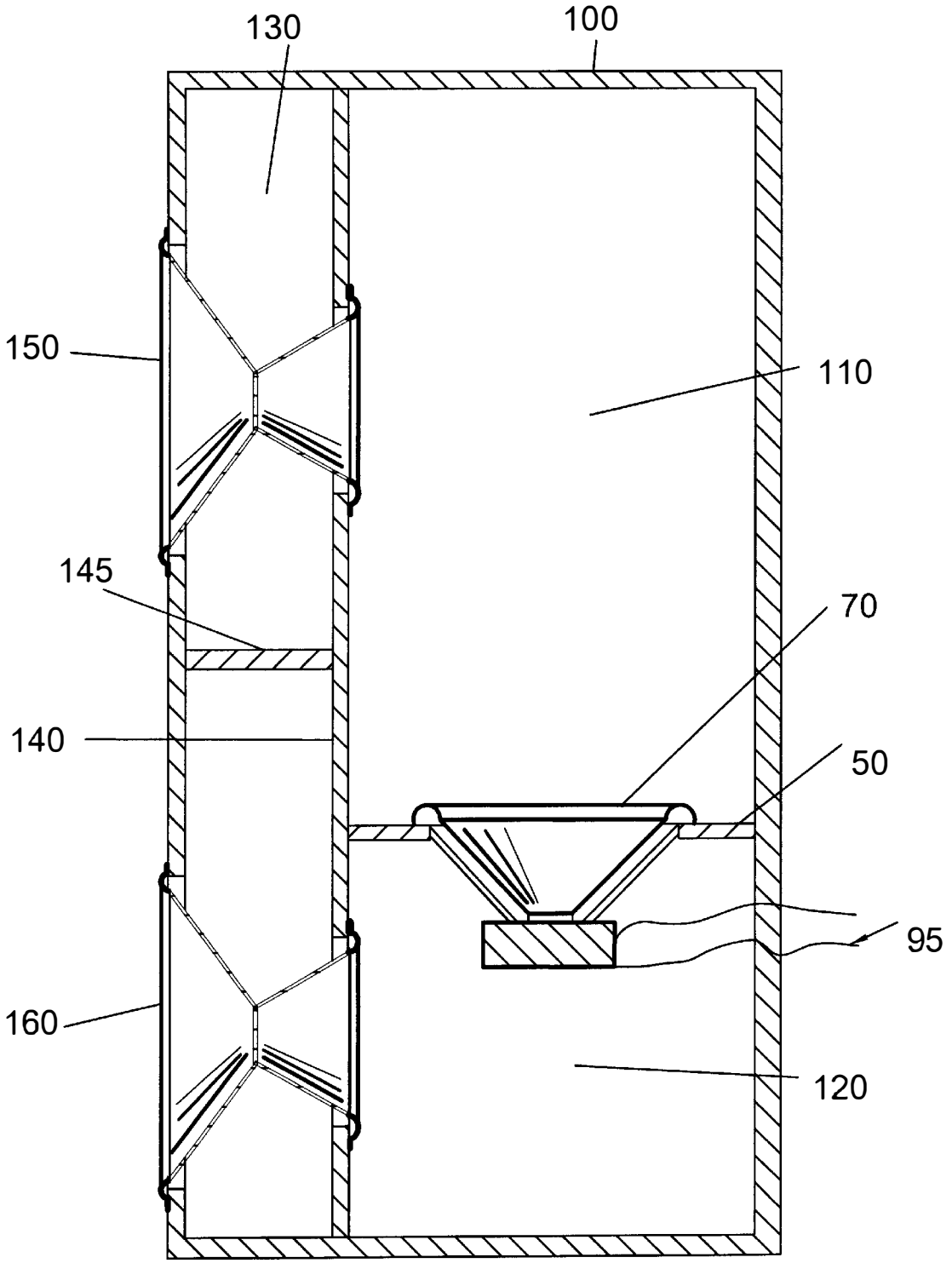


Fig. 8

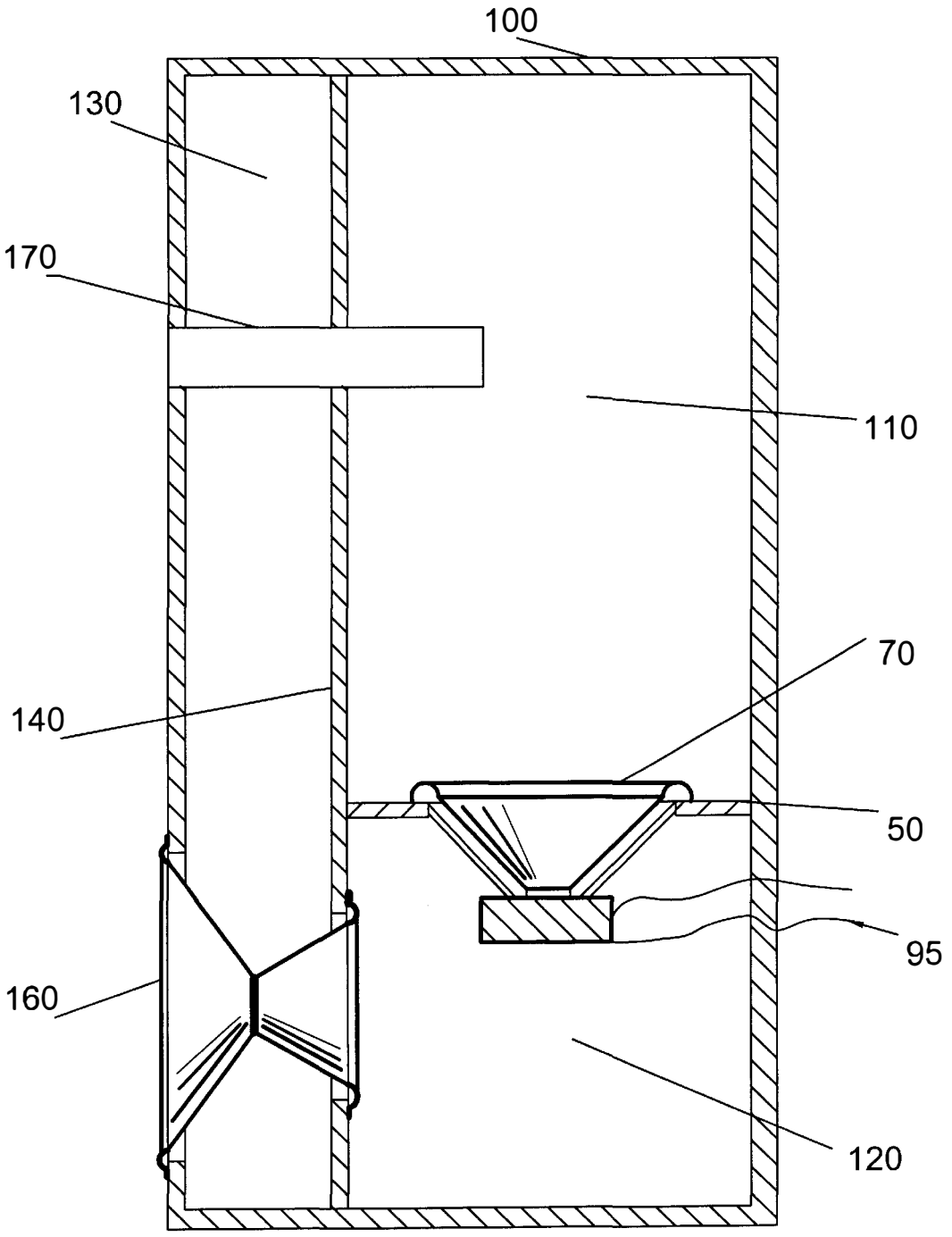


Fig. 9

US 20040066947A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2004/0066947 A1

Geddes (43) Pub. Date: Apr. 8, 2004

(54) TRANSDUCER WITH MULTIPLE PHASE PLUGS

(76) Inventor: Earl Rossell Geddes, Northville, MI (US)

Correspondence Address:
Earl Geddes
43516 Scenic Lane
Northville, MI 48167 (US)

(21) Appl. No.: 10/265,476

(22) Filed: Oct. 4, 2002

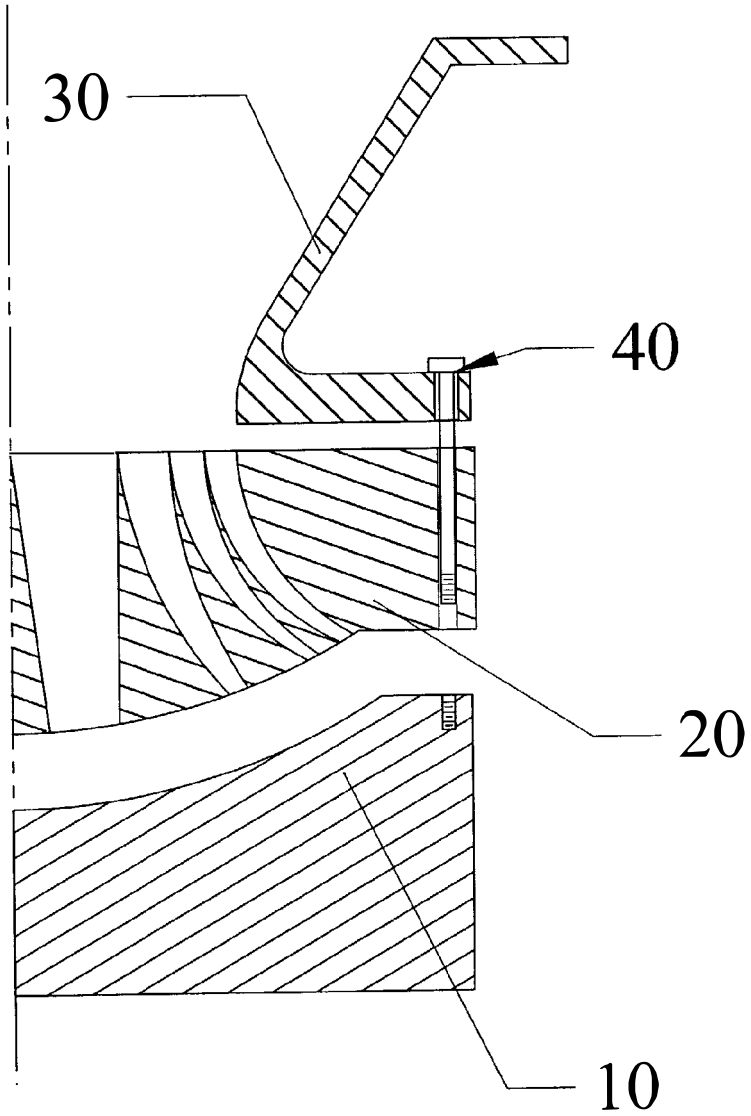
Publication Classification

(51) Int. Cl.[7] H04R 1/02; H04R 1/20

(52) U.S. Cl. 381/343

(57) ABSTRACT

An acoustic transducer which can have a multiplicity of different phasing plugs is disclosed.



Section 0-A

TRANSDUCER WITH MULTIPLE PHASE PLUGS

BACKGROUND

[0001] 1. Field of the Invention

[0002] The present invention relates to the use of interchangeable phase plugs in an electro-acoustic transducer composed of drive-unit and waveguide assemblies.

[0003] 2. Description of Prior Art

[0004] In high performance audio playback systems it is common practice to use wave guiding devices coupled to an electro-acoustic transducer drive-unit (that portion of an electro-acoustic transducer that does the direct electrical to acoustical transduction) that act to both amplify and direct the sound energy created therein. These devices go by many names, the most common being "waveguides" and "horns". I will use the term waveguide to mean any and all devices performing such tasks.

[0005] The "shape" (magnitude and phase) of the wavefront presented to the waveguide at its input end (the throat) has a great influence on how the device radiates sound from the open end (the mouth), particularly at the higher frequencies. In order to control the formation of the throat wavefront it is common practice to place a plug containing multiple sound paths between the audio transducer and the throat of the waveguide. This plug is designed so as to direct the sound waves emitted from the drive-unit into the throat in a prescribed shape. This plug is also know by various names, the most common being "phase plug", "phasing plug" or "equalizer".

[0006] The art of phase plug design is well advanced. The first significant disclosure of the function of a phase plug is provided by Wente, U.S. Pat. No. 2,037,187 (1936). Wente notes that the goal is to provide an essentially planar wavefront at the horn throat and he achieves this task by directing the sound through channels of essentially equal length, thereby ensuring that the contributions all add in phase.

[0007] In Henricksen, U.S. Pat. No. 4,050,541 (1977), an alternate type of phase plug wherein the sound directing channels are radial, as opposed to circumferential, is disclosed.

[0008] Carlson, U.S. Pat. No. 4,718,517 (1988), discloses a phase plug which has a rectangular exit aperture at the throat and couples to a circular drive-unit diaphragm.

[0009] Adamson, U.S. Pat. No. 4,975,965 (1990) discloses a loudspeaker with a phase plug which is coupled to a drive-unit diaphragm that has both convex spherical and concave conical sections. Of note in this patent is the fact that the phase plug is a separate part of the assembly. Adamson does not discuss, nor has he ever made available to the public more than the singular phase plug that is distributed with the product.

[0010] Bie, U.S. Pat. No. 5,117,462 (1992), utilizes the voice coil motion as part of the radiating surface of the drive-unit and adds a sound channel to said radiating region.

[0011] Finally, Keith, U.S. Pat. No. 6,064,745 (2000), discloses an improved radial type of phase plug which is easier to manufacture than previous designs.

[0012] Each of these inventions claims a distinct improvement over the others in regard to performance, manufacturability and/or some other comparable, however, non of them recognizes the possibility of using more than one design for a given drive-unit. The Adamson invention would allow for such a possibility, although he did not disclose any recognition of this possibility, nor has he ever utilized it in practice.

[0013] Adamson acknowledged in U.S. Pat. No. 4,975,965 (column 5, lines 56-64) that his phase plug "has been found to be particularly useful when applied to acoustic waveguide speakers of the variety developed by Dr. E. R. Geddes . . ."—the current inventor. The waveguide referred to by Adamson was based on the oblate spheroidal coordinate system. In Chapter 6 of my book *Audio Transducers,* (GedLee Publishing, July, 2002), I discuss the fact that there are several different coordinate systems which yield useful waveguides (see table 6.1 in the text) and that each one has a different set of radiation characteristics. As discussed in this text, these different waveguides require different wavefront shapes at the throat ("source aperture" and "curvature" in the table of my text) for optimum performance. This means that a drive-unit which is intended to utilize different waveguides—i.e. when different polar patterns are desired—should have different phase plugs if it is to be optimally matched to the waveguide.

[0014] In none of the prior art disclosures is it recognized that one might want to use different phase plugs with a given drive-unit for use with different waveguides. It was generally assumed that the phase plug should create a planar (uniform phase and magnitude) wavefront at a circular exit aperture (i.e. the throat of the waveguide) and that the waveguide throat is adapted to match the phase plug's exit aperture—not the other way around. Not only is a plane wavefront in a circular aperture at the exit of the phase plug not always optimum for a waveguide, the optimum wavefront and exit aperture is different for different waveguides.

[0015] In order to allow for an optimal matching of a drive-unit to a waveguide, it would be desirable to be able to use different phase plugs when different waveguides are used.

OBJECTS AND ADVANTAGES

[0016] It is the primary object of this invention to disclose a mechanism whereby a given drive-unit can have multiple interchangeable phase plug options. The advantage of this invention is to provide a means for optimally matching a given drive-unit to different waveguides by the use of interchangeable phase plugs which provide this optimal match. This is a distinct advantage over a drive-unit with a fixed phase plug.

DRAWING FIGURES

[0017] **FIG. 1** shows a top view of a phase plug of conventional design;

[0018] **FIG. 2** shows an exploded view of the axi-symmetric cross section **0**-A of a phase plug and the preferred embodiment for the attachment of the phase plug to the waveguide and drive-unit;

[0019] **FIG. 3** shows a top view of a phase plug with an elliptical exit aperture for use on an ellipsoidal coordinate system waveguide;

[0020] **FIG. 4** shows a top view of a phase plug with a rectangular exit aperture for use on an prolate spheroidal or elliptic cylinder coordinate system waveguide.

REFERENCE NUMERALS IN DRAWINGS

[0021]

10 generic drive-unit	30 waveguide
20 interchangeable phase plug	40 attachment bolt

SUMMARY

[0022] In accordance with the present invention, the ability to optimally adapt a given drive-unit to an assortment of waveguides by using interchangeable phase plugs is disclosed.

Description FIGS. **1** to **4**

[0023] Since there can be many ways to assemble a drive-unit, phase plug and waveguide together only a typical structure will be shown.

[0024] In the prior art a circular exit aperture from the phase plug (**20**) is coupled to the circular input of a waveguide as shown in **FIG. 1**.

[0025] In **FIG. 2 a** means for connecting a waveguide (**30**) to a drive-unit (**10**) can be seen. The phase plug (**20**) is held in place by a compression connection created by the joining of the waveguide and the drive-unit with bolts (**40**). It is equally feasible to connect the phase plug directly to the drive-unit and then connecting the waveguide to the phase plug or again, directly to the drive-unit. The details of the phase plug design, as shown in the figure are not significant. It is the ability to connect alternate designs that is the key invention of this application.

[0026] **FIG. 3** and **FIG. 4** show alternate phase plug exit aperture configurations that one might use in the context of this disclosure.

[0027] One skilled in the art will recognize that there are many ways to assemble an electro-acoustic transducer composed of a drive-unit, phase plug and waveguide and that the method of assembly shown here is but one. For example, the diaphragm could also be placed convex side out (as opposed to that shown in **FIG. 2**), or the voice coil and magnet structure might be opposite to that implied by the figures. So long as there is more than one phase plug utilized in the design, these details do not affect the significance of the disclosure presented here in any way.

I claim:

1) An electro-acoustic transducer for creating sound comprising:

a drive-unit;

a waveguide and;

at least two interchangeable phase plugs.

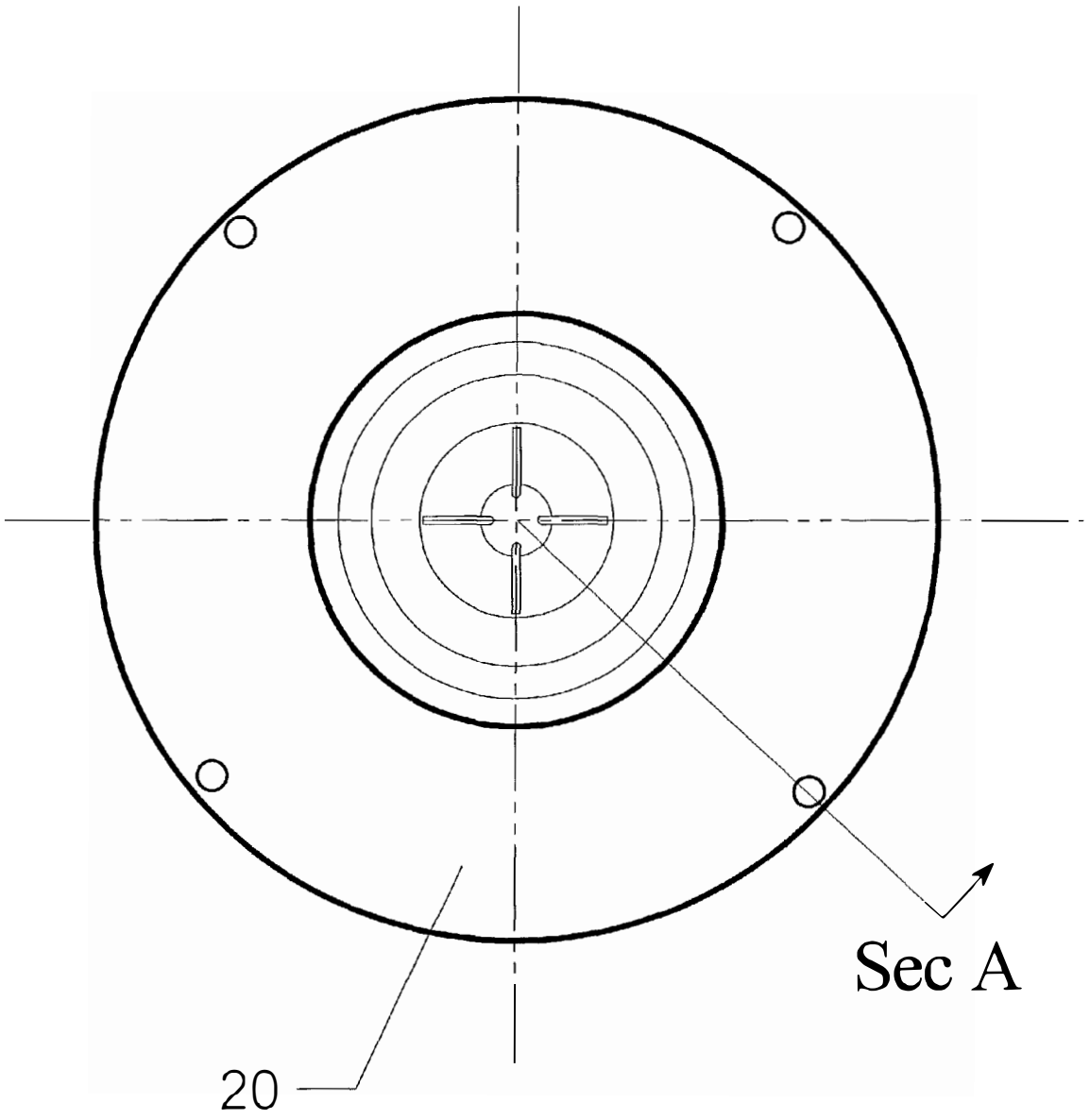
2) An electro-acoustic transducer as defined in claim 1 wherein:

one of said interchangeable phase plugs has an elliptical exit aperture.

3) An electro-acoustic transducer as defined in claim 1 wherein:

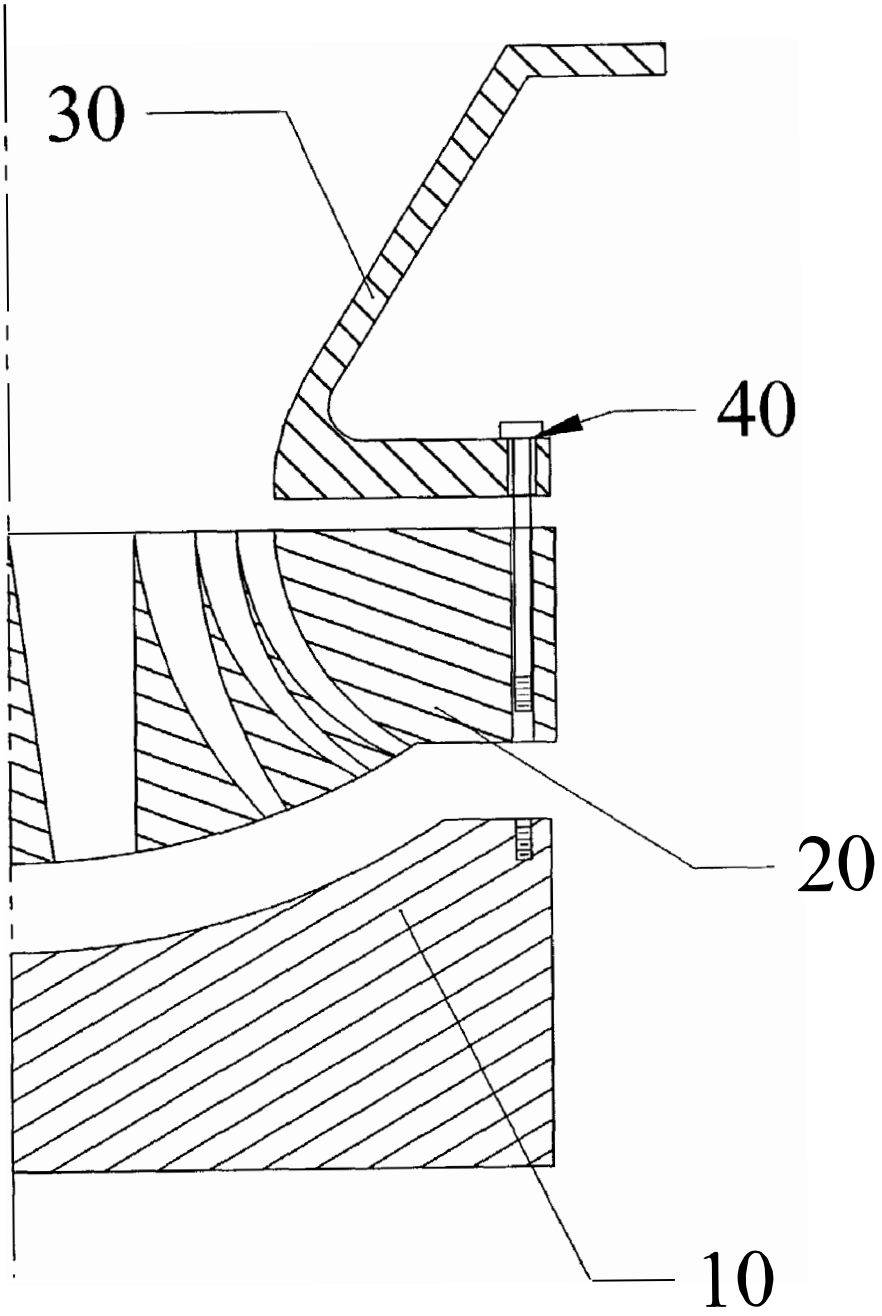
one of said interchangeable phase plugs has a rectangular exit aperture.

* * * * *



Prior Art

Fig. 1



Section 0-A

Fig. 2

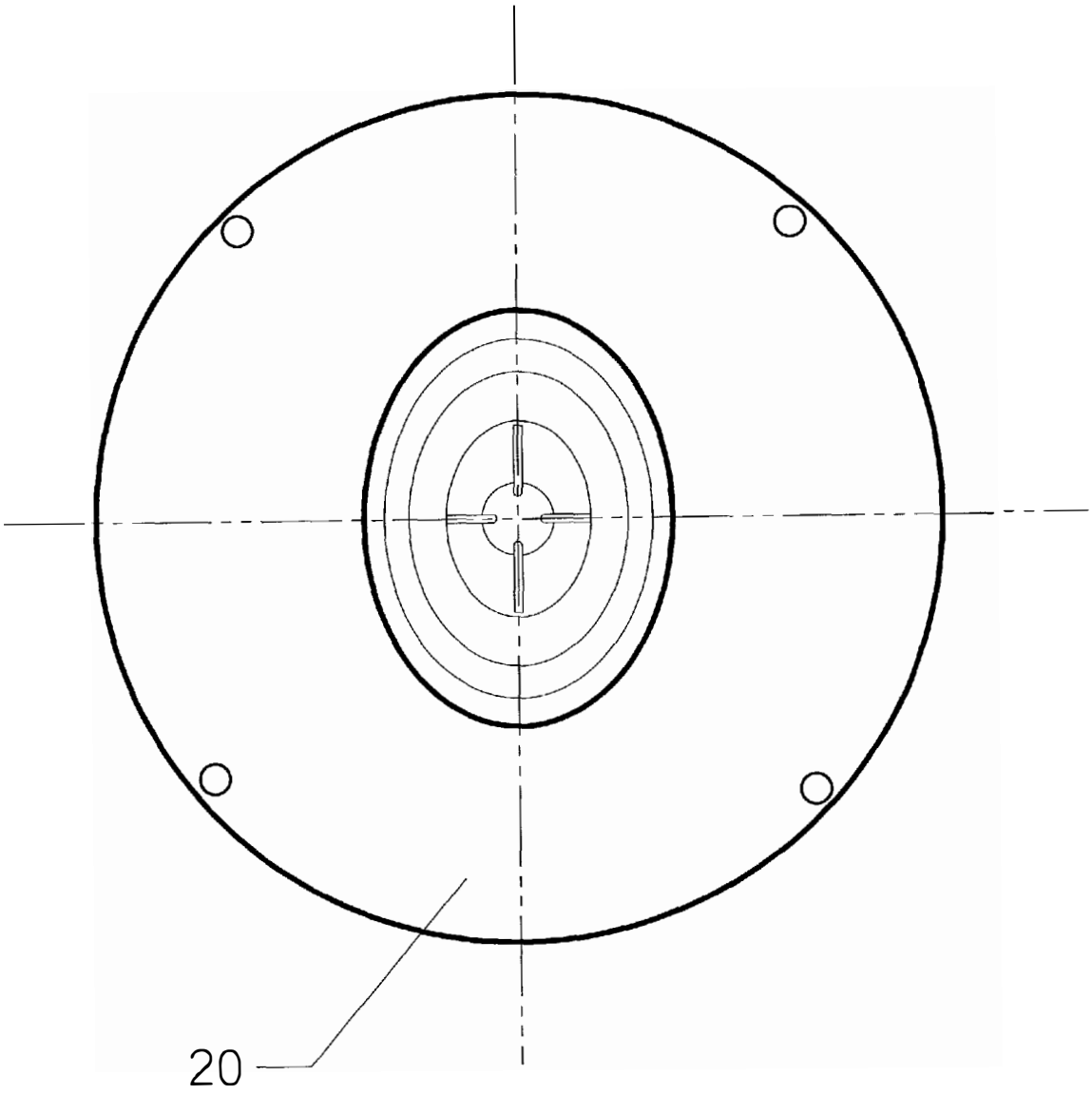


Fig. 3

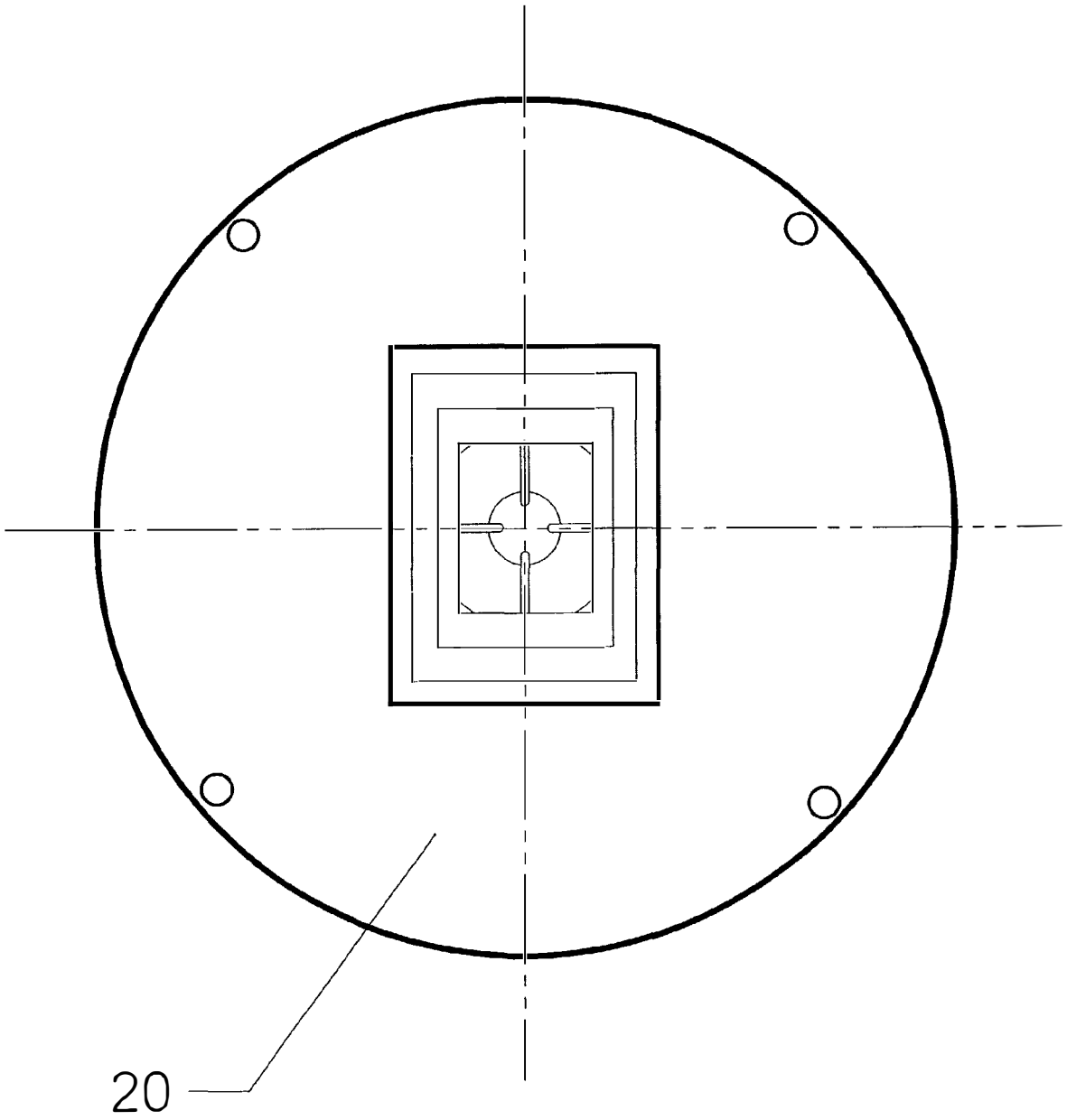


Fig. 4

US 20060034475A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0034475 A1**

Geddes (43) **Pub. Date: Feb. 16, 2006**

(54) **COMPRESSION DRIVER PLUG**

(76) Inventor: **Earl Rossell Geddes**, Northville, MI (US)

Correspondence Address:
Earl Geddes
43516 Scenic LN.
Northville, MI 48167 (US)

(21) Appl. No.: **10/919,145**

(22) Filed: **Aug. 16, 2004**

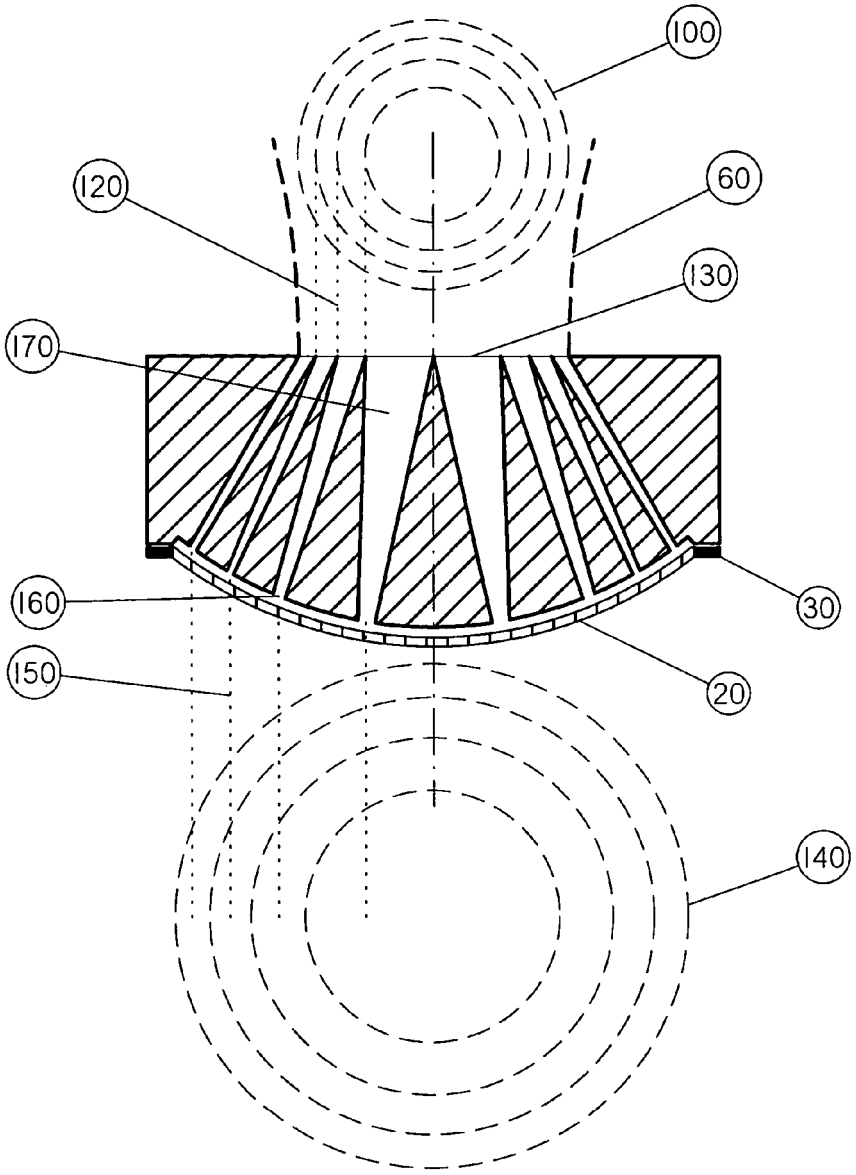
Publication Classification

(51) **Int. Cl.**
H04R 1/02 (2006.01)
H04R 1/20 (2006.01)

(52) **U.S. Cl.** **381/343**; 381/337

(57) **ABSTRACT**

An improved phase plug for a compression driver which has a wavefront at its exit aperture that is uniform in both amplitude and phase. An alternative phase plug wherein the velocity distribution in the exit aperture is specified in both magnitude and phase. The improved phase plug results in an improved coupling to the waveguide for better directivity control.



COMPRESSION DRIVER PLUG

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional application Ser. No. 60/_____ filed Aug. 16, 2003.

FIELD OF THE INVENTION

[0002] The present invention pertains to the phase plug in a compression driver placed between the diaphragm and the waveguide or horn whose function is to provide for equal path lengths from the diaphragm to the exit aperture of the phase plug—the input aperture to the waveguide.

BACKGROUND OF THE INVENTION

[0003] In the area of audio loudspeakers it is not uncommon to use compression drivers for mid to upper frequencies. There are two main reasons for this. First, the compression driver, when coupled to a waveguide (in this application the terms waveguide and horn are synonymous), provides for much higher electro-acoustical efficiency than a direct radiating loudspeaker can achieve. Second, the waveguide provides for a better control over the directional characteristics of the sound radiation than can be achieved with a direct radiator loudspeaker. In both cases at higher frequencies, where the wavelength of the sound begins to approach the dimensions of the throat of the waveguide, it is important for the wavefront presented to the waveguide to be approximately flat (uniform in phase), otherwise frequency response aberrations and poor directivity control will result.

[0004] The usual goal of a phasing plug is to create a flat wavefront at its exit aperture. This was most elegantly stated by Wente in his hallmark U.S. Pat. No. 2,037,187: "In order to insure uniform reproduction of a wide range of frequencies . . . means are provided . . . for preventing suppression of . . . higher frequencies. To this end a multi-sectional acoustic transducer or plug is provided intermediate one surface of the diaphragm and the end of the horn in acoustic communication with the surface." Later in the patent He goes on to state, "The several elements noted are so proportioned that the passageways formed thereby are of substantially equal length and are equally spaced at the ends towards the diaphragm. This construction provides a plurality of paths of substantially equal length so that sound waves emanating from all points of the central portion of the diaphragm traverse paths substantially the same length in passing to the throat of the horn and hence arrive at the throat of the horn substantially in phase. Another feature of this construction is that a substantially plane wave front is obtained at the end of the bore directed toward the diaphragm." This design philosophy has remained the principle one in virtually every circumferential phase plug design in use today and was even recently reinforced by Bie in U.S. Pat. No. 5,117,462 where he references the Wente design as "perhaps the most frequently used . . . "

[0005] Modifications to the Wente design have been seen, primarily in the use of holes as equalizing paths, or radial slots, see Henrickson, U.S. Pat. No. 4,050,541. The present application is concerned with improvements and corrections to phase plug designs of the annular ring variety.

[0006] The single most significant contribution to phase plug design after Wente was put forth by Smith ("An Investigation of the Air Chamber of Horn Type Loudspeakers", Jour. Of the Acoustical Soc. of Amer., Vol. 25 no. 2, Mar. 1953) and later adopted by Murray (Audio Engineering Society Preprint no. 1384, November 1978). Smith developed a design approach whose goal was the suppression of radial modes in the circular chamber in front of the diaphragm. Following his design approach, the ring areas and their radial location at the diaphragm are variables in the equations that Smith uses and they can therefore be of any value. However, one will obtain areas and radii of the sound channel entrances at the diaphragm which will tend to be nearly equally spaced and will appear to have approximately equal gap widths. This means that the sound channel entrance areas will actually vary from the inner ring to the outer ring, and these areas tend to get larger as they move away from the axis. In the Smith design approach no mention is made of how to place the ends of the annular rings at the exit aperture of the phase plug. This is left to the designer's discretion.

[0007] There is a serious error in all of the prior art as regards the phase plug design, which has heretofore gone unchallenged, and it is to be found in the statements of Wente. Wente concludes that making sound channels of equal length will yield a plane wave front at the exit aperture of the phase plug, but this is incorrect. The prior art approachs will generally yield a wavefront of constant phase angle across this surface, but placing the "passageways . . . equally spaced at the ends towards the diaphragm" will cause the wavefront to have a non-uniform volume velocity across this equal phase surface unless extreme care is taken at the exit aperture to allow for the different volume velocities that will occur in each channel when this approach is taken.

[0008] Indeed, what Wente and the others have missed is the fact that to be a true plane wave one must have both a uniform phase and uniform velocity amplitude in the surface. Wente's discussion and his design approach will only ensure, or allow for, the phase to be uniform, but not the velocity magnitude. Neither Smith nor Murray offer any method for making the wavefront at the exit aperture uniform in velocity magnitude and no indication is made that they even recognized this to be important. Of course for low frequencies, where the wavelengths are large compared to the exit aperture there cannot be anything but uniform velocity in the surface, so the traditional approach is perfectly correct. However, at higher frequencies, where the wavelengths are comparable to the exit aperture's dimensions, there can be a substantial deviation of the velocity magnitude from uniform across the exit aperture.

[0009] Further to this discussion, the entire prior art relied on the prevailing theory of horns attributed to Webster and known as Webster's Horn Equation. This theory makes the assumption of uniform velocity across the horn device throughout its length so it is natural not to take into consideration any deviation of the velocity amplitude from uniform at the horns throat, usually the phase plugs exit aperture.

[0010] Not until Geddes showed through his work on waveguides (see Chapter 6 of *Audio Transducers,* GedLee Publishing, 2002 ISBN 0-9722085-0-X) was the importance

of the velocity amplitude distribution (in addition to the phase) at the throat of the waveguide recognized. Geddes showed that higher order modes exist in all waveguides and that they play a dominate role in wave propagation in a waveguide at the higher frequencies. In order to control the high frequency polar response one has to control the excitation and propagation of the higher order modes and hence the distribution of these modes at the throat. Clearly the wavefront at the exit aperture of the phase plug, which becomes the throats input wavefront, must be controlled more precisely than by just adjusting the phase across this wavefront. This significant point is missing from the entire body of prior art designs for phase plugs.

[0011] **FIG. 1** shows a simplified drawing of a typical phase plug **(40)** in the current art. A diaphragm **(20)** is shown along with a means of flexible support **(30)**. A means for driving this diaphragm is not shown since these are not germane to the discussion, but one would have to be applied to a functional compression driver. Four annular sound channels **(50)** are shown terminating at the diaphragm and the exit aperture **(70)**. The entrances of the sound channels at the diaphragm **(10)** are radially spaced either equally (according to Wente) or as solutions of a Bessel function matrix (according to the Smith approach). The widths of the entrances of the sound channels are substantially equal for all of the channels, but the areas vary according to Smith. The lengths should be substantially equal. The phase plug terminates at the entrance to the horn or waveguide **(60)** at the exit aperture. The details of the sound channels exits **(15)** are not specified by either the Wente or the Smith design procedures. They are usually equally spaced, but are never spaced in a manner which gives a controlled complex velocity distribution in the exit aperture.

[0012] It is the purpose of this invention to disclose an improved circumferential phase plug design which has the ability to create a wavefront in the exit aperture which can be manipulated in both amplitude and phase.

SUMMARY OF THE INVENTION

[0013] The present invention is a compression driver phase plug of the concentric annulus channel variety which has the locations and the width of the inlet of these channels specified in such a way so as to create a wavefront in the exit aperture of this phase plug that has a prescribed amplitude and phase of the velocity in this surface. These design constraints are accomplished by considering the diaphragm and the exit aperture to be composed of Fresnel zones. In the Fresnel zone concept, each zone is of equal area. The number of zones is arbitrary except that there should be the same number at the diaphragm and the exit aperture and there are the same numbers of concentric annulus channels as Fresnel zones.

[0014] This application is concerned with the details of the acoustic wave generated by the compression driver's diaphragm as it passes through what will be called the phase plugs exit aperture. This surface is usually of circular or circular annular cross section, although it can be any other shapes as well, most notably elliptical or rectangular. In this application the exit aperture will always be refereed to as being of circular cross section although the extension of the techniques disclosed herein to other shapes would be obvious. Usually, the phase plugs exit aperture is identical to the waveguides throat, or entrance, the two devices join these two mating surfaces together in actual usage. Although, it can be the case that the waveguide contour actually extends down into the phase plug and in this case the phase plugs exit aperture is actually within the body of the waveguide and the waveguides throat would lie at of near the driver's diaphragm. This detail has no effect on the techniques that will be disclosed herein, except to alter the locations of where the exit aperture of the phase plug and the throat of the waveguide reside relative to one another.

[0015] When the diaphragm is moving with a uniform velocity then each Fresnel zone at the diaphragm with have the same volume velocity. Each annular channel couples a corresponding input Fresnel zone, on the diaphragm with an output Fresnel zone in the exit aperture. The Fresnel zones correspondence between the diaphragm and the exit aperture identically from the inner to outer zone. That is, the inner zone on the diaphragm couples to the inner zone in the exit aperture, the next one to the next one and so forth out to the outer most zone. The simplicity and usefulness of this approach are obvious.

[0016] Each channel carries an identical volume velocity from the diaphragm to the exit aperture and when the channel outlets correspond to Fresnel zones then each Fresnel zone in the exit aperture will carry an identical volume velocity and hence a uniform velocity distribution in the aperture. A slight modification of these same techniques allows for the specification of a close approximation to any velocity distribution in the exit aperture.

[0017] If the exit aperture is a rectangle then the Fresnel zones are nested rectangles and if it is elliptical then they are concentric ellipses, but otherwise the techniques are invariant with the shape of the exit aperture.

[0018] In one preferred embodiment, the location of an annular channels inlet, at the diaphragm, is placed essentially at the centroid of its corresponding Fresnel zone. The centroid line of a zone which divides the zone into two equal area parts.

[0019] In one preferred embodiment, the areas of all the channels are equal from the diaphragm to the exit aperture, but this area need not be constant. The channels area can change along their length and this would be desirable if it is done in a manner which makes the total channel area continuous from the waveguide that will be attached to the exit aperture back to the diaphragm.

[0020] According to the present invention, a compression driver phase plug is provided. The driver plug compromises a first surface having a plurality of apertures facing a compression driver diaphragm, a second surface having a respective plurality of apertures facing a horn or waveguide and a respective plurality of channels. The apertures of the first surface are in fluid communication with the respective plurality of apertures of the second surface via the channels. The apertures of the first surface, the apertures of the second surface, and the channels are sized such that the driver plug provides a controlled phase and velocity amplitude of the wavefronts that are presented to the horn or waveguide.

[0021] The channels areas can also remain constant along their length. The lengths of the channels are adjusted to remain substantially constant from channel to channel although variables channel lengths can be used to modify the

phase of the velocity distribution in the exit aperture in an obvious way. In this preferred embodiment, equal areas of the diaphragm are coupled through the annular sound channels to equal areas in the exit aperture, in phase, thus ensuring that a uniform complex (magnitude and phase) velocity distribution will exist in the exit aperture, so long as a uniform complex velocity exits at the diaphragm (which is the design goal of a compression driver diaphragm).

[0022] In another preferred embodiment a non-uniform velocity is created in the exit aperture by adjusting the input Fresnel zone areas and the channel lengths to yield the desired velocity distribution. The procedure is a slight modification of the procedure given above.

DRAWING FIGURES

[0023] **FIG. 1** shows a drawing of the prior art in phase plug design.

[0024] **FIG. 2** shows a layout of Fresnel zones with a unit area for four zones.

[0025] **FIG. 3** shows a table of Fresnel rings and centroid values for three values of N, the number of annular rings.

[0026] **FIG. 4** shows a drawing of the new phase plug design along with the Fresnel zones and the layout lines.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0027] It is the purpose of this invention to disclose an improved circumferential phase plug design which has the ability to create a wavefront in the exit aperture which can be manipulated in both amplitude and phase.

[0028] FIG. (**2**) shows an example of Fresnel zones laid out on a circle of unit area. There are four zones in this example and each zone is therefore one quarter of the total circular area. The radiuses of the four zones are shown (**80**), as well as the zone centroid radiuses (**90**). These values can also be found in the table of FIG. (**3**), along with values for three and five zones. The layouts of the Fresnel zones form the starting point for the layout of a phase plug of the new design.

[0029] FIG. (**4**) shows the design approach according to the new invention. Both the exit aperture (**130**) and the diaphragm (**20**) are aligned with Fresnel zone layouts, (**100**) and (**140**) respectively. Note that the Fresnel zones for the diaphragm are based on the projected areas and not on the areas in the diaphragms spherical surface. Each Fresnel zone in the diaphragm is matched to a Fresnel zone in the exit aperture.

[0030] The location of the entrance to the sound channels (**160**) is found by using the zone centroids from the table projected to the diaphragm (**150**). The width of the sound channel entrances is such that the area of each entrance is identical and the sum of the areas of all of the channels is equal to the area of the diaphragm divided by the desired compression ratio.

[0031] The locations of the sound channel exits is such that a projection of the Fresnel zones (**120**) from the Fresnel zone layout (**100**) will exactly place the junctions between successive channels. In this way each Fresnel zone projected onto the diaphragm area is mapped to a Fresnel zone in the phase plugs exit aperture.

[0032] In another preferred embodiment, variations on the above design procedure are also possible and advantageous. In his book *Audio Transducers,* (**FIG. 6-12**) Geddes shows how one might want to have a non-uniform velocity amplitude distribution in the exit aperture. An example target aperture velocity profile as a function of the normalized exit aperture radius is shown in FIG. (**5**).

[0033] According to the present invention, a compression driver phase plug is provided. The driver plug compromises a first surface having a plurality of apertures facing a compression driver diaphragm, a second surface having a respective plurality of apertures facing a horn or waveguide and a respective plurality of channels. The apertures of the first surface are in fluid communication with the respective plurality of apertures of the second surface via the channels. The apertures of the first surface, the apertures of the second surface, and the channels are sized such that the driver plug provides a controlled phase and velocity amplitude of the wavefronts that are presented to the horn or waveguide.

[0034] Using the number of channels as four (in this example), the desired velocity amplitudes for the four Fresnel zones are shown graphically as the boxes where the numbers in them represent the desired velocity values. These values represent the velocity in each Fresnel zone that most closely matches the value of the prescribed curve on the average across the box and such that the sum of the numbers adds up to be the number of annulus channels. These numbers represent the weights for a set of modified Fresnel zones that will be created at the diaphragm.

[0035] Using the weights, as calculated above, the Fresnel zones areas for the diaphragm Fresnel zone layout diagram (**140**) are modified as follows: the zone areas are no longer made equal, but instead they are proportional to the diaphragm area divided by the number of channels times the weight. This is a trivial calculation to perform and can be done with a calculator. These calculations result in new zone areas and centroids as shown in FIG. (**6**). This figure shows the new Fresnel layout required for the desired velocity modification. FIG. (**6**) should be compared to FIG. (**2**) where it can clearly be seen that the central zone areas have grown in size while the outer zone areas have decreased. The new areas and locations of the channel entrances will cause the volume velocity of the central zone at the exit aperture to increase since it now covers a larger diaphragm area (assuming that the diaphragm has a uniform velocity). Other modifications to this approach are possible and will be apparent to those proficient in the art.

I claim:

1) A compression driver phase plug, the driver plug compromising:

a first surface having a plurality of apertures facing a compression driver diaphragm;

a second surface having a respective plurality of apertures facing a horn or waveguide;

and a respective plurality of channels, wherein the apertures of the first surface are in fluid communication with the respective plurality of apertures of the second surface via the channels, and the apertures of the first surface, the apertures of the second surface, and the channels are sized such that the driver plug provides

control of the velocity amplitude and phase of the wavefronts that are presented to said horn or waveguide.

2) The compression driver phase plug of claim 1 wherein;

the channel lengths and areas are adjusted so as to yield a complex velocity in the plane of the exit aperture which is essentially uniform in magnitude and phase.

3) The compression driver phase plug of claim 1 wherein;

the channel lengths and areas are adjusted to yield a complex velocity in the plane of the exit aperture which is essentially uniform in magnitude but which has a phase delay that increases with the distance of the channel from said plugs central axis.

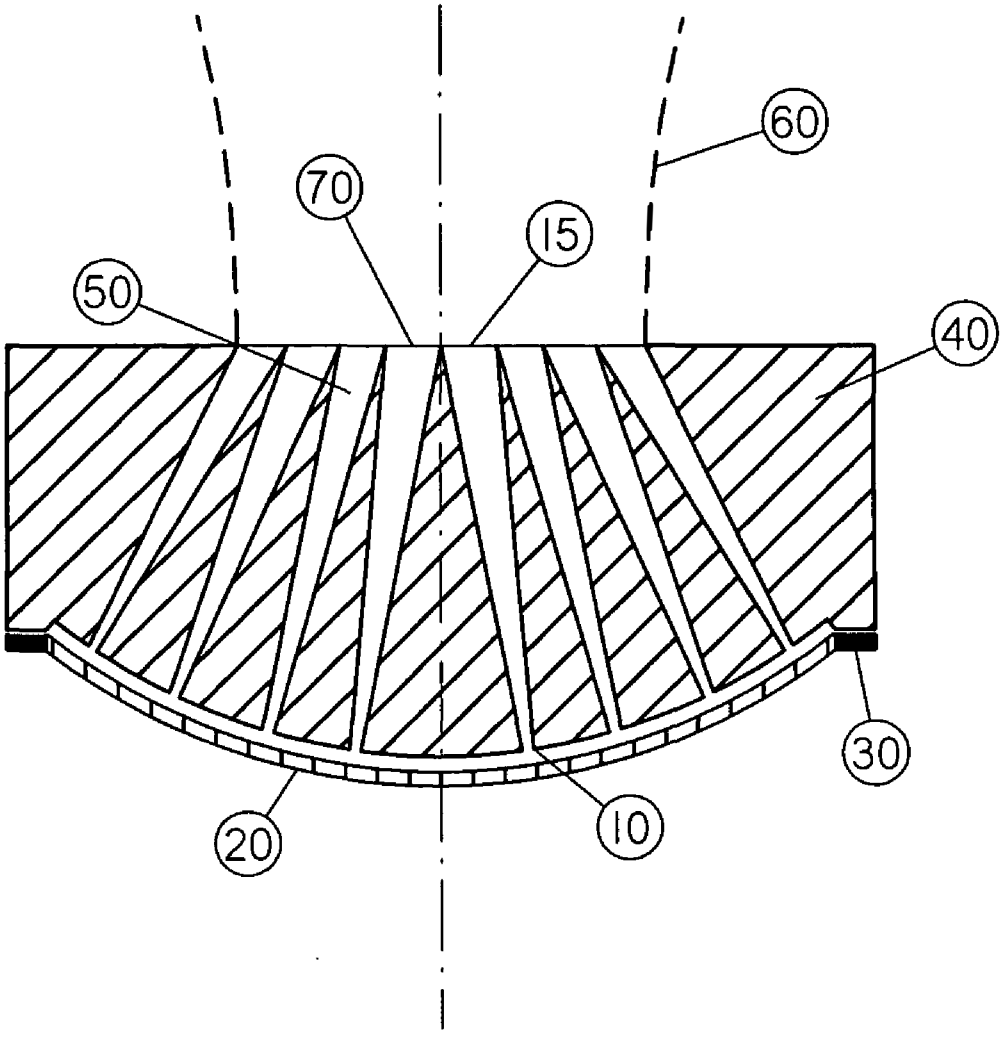
4) The compression driver phase plug of claim 1 wherein;

the channel lengths and areas are adjusted to yield a complex velocity in the plane of the exit aperture which is essentially uniform in phase but has a magnitude which varies within said plane.

5) The compression driver phase plug of claim 1 wherein;

the channel lengths and areas are adjusted to yield a complex velocity in the plane of the exit aperture that has a magnitude and phase which varies in a prescribed manner within said plane.

* * * * *



Prior Art

Fig. 1

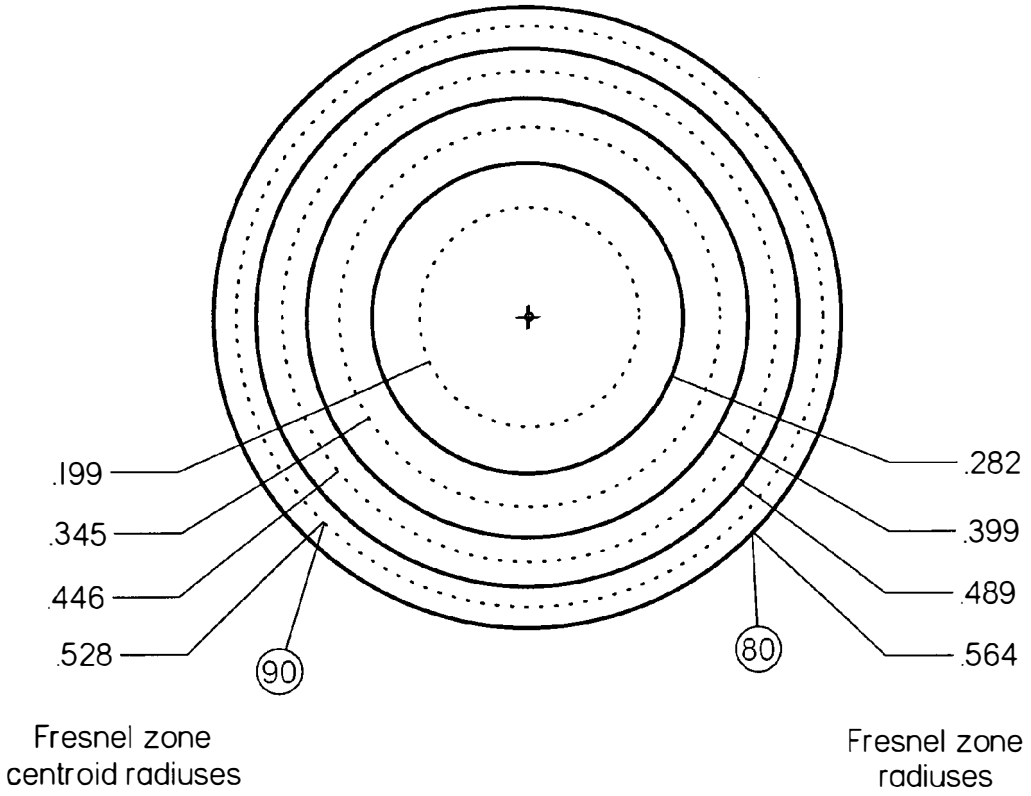

.199
.345
.446
.528
90
80
.282
.399
.489
.564
Fresnel zone centroid radiuses
Fresnel zone radiuses

Fig. 2

Number of Rings	3		4		5	
Ring number	Ring	Centroid	Ring	Centroid	Ring	Centroid
1	.326	.23	.282	.199	.252	.178
2	.461	.399	.399	.345	.357	.309
3	.564	.515	.489	.446	.437	.399
4			.564	.528	.505	.472
5					.564	.535

Fig. 3

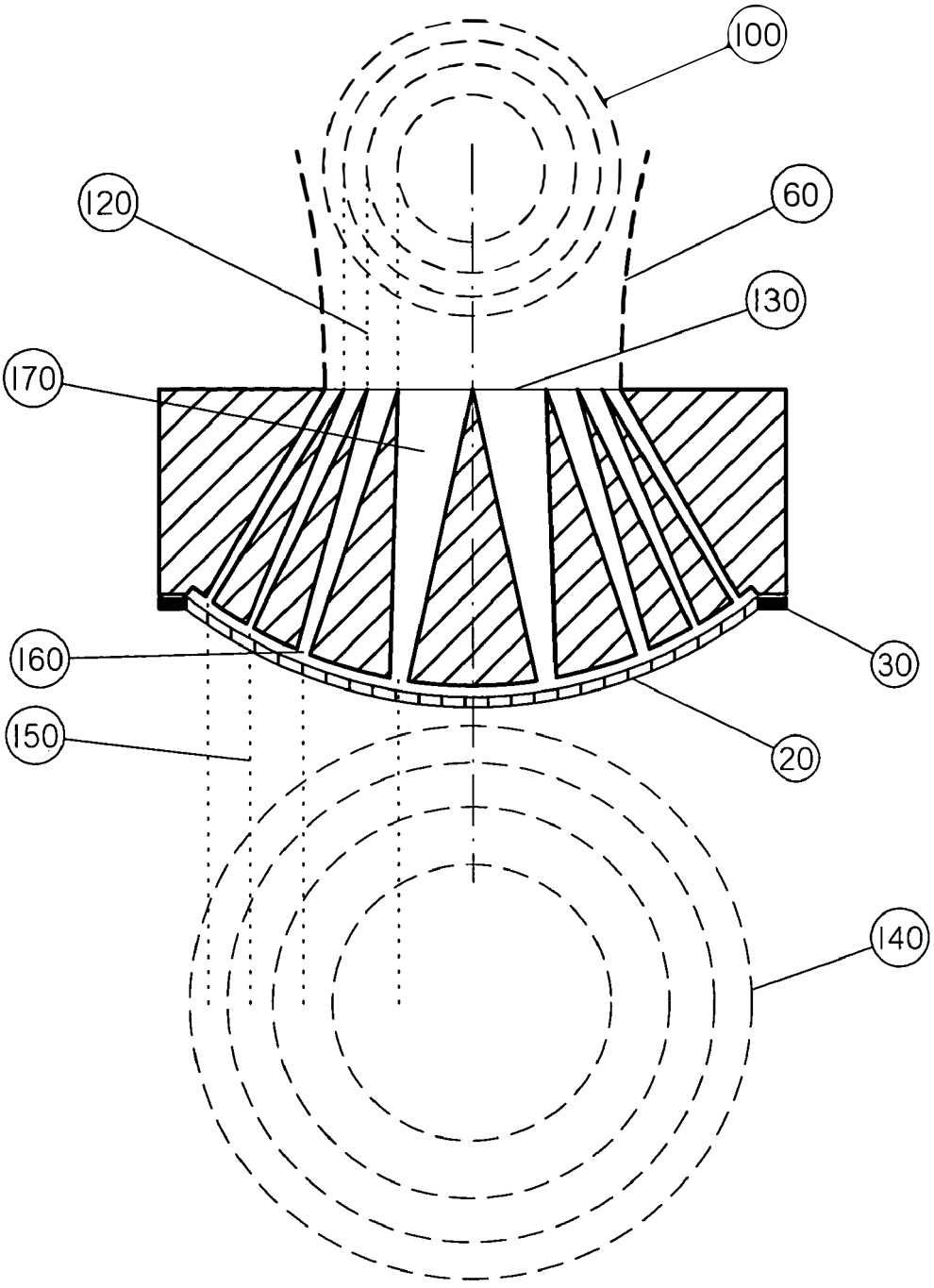


Fig. 4

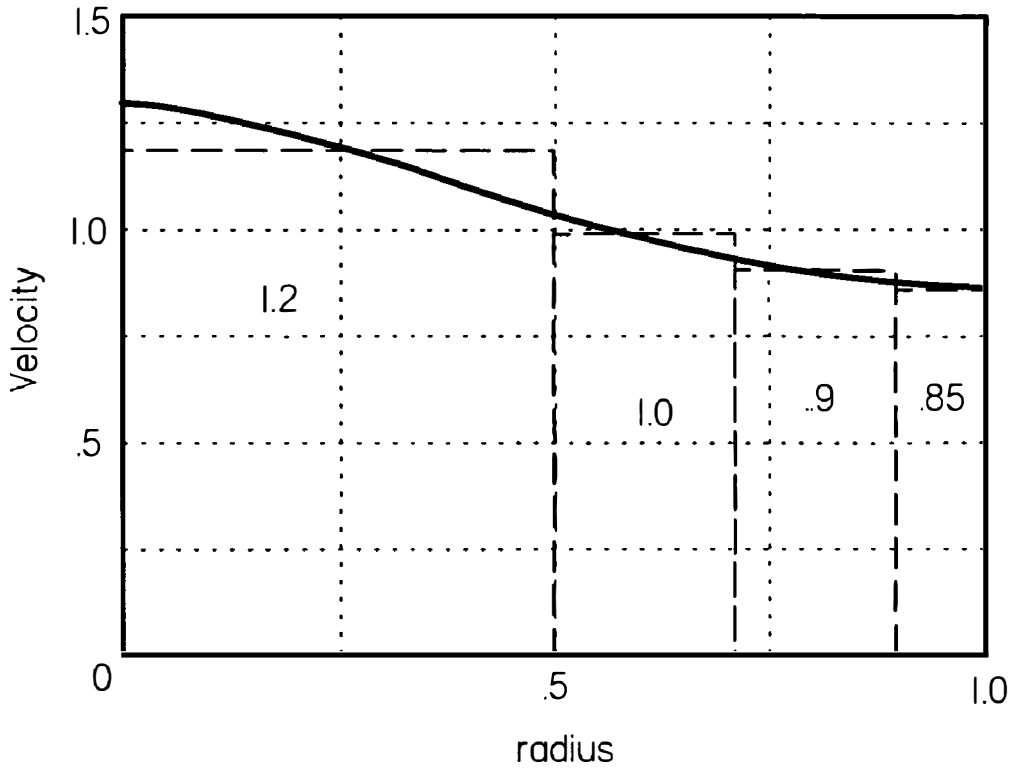


Fig. 5

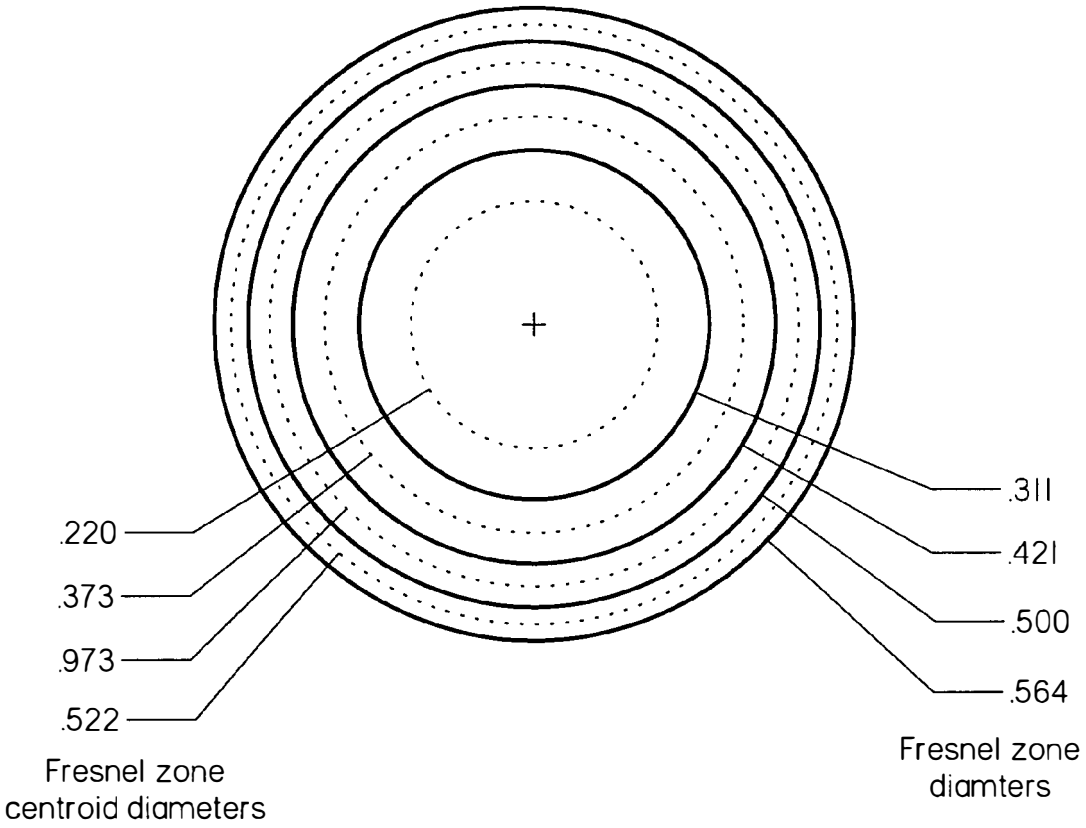

.220
.373
.973
.522
Fresnel zone centroid diameters
.311
.421
.500
.564
Fresnel zone diamters

Fig. 6

US007068805B2

(12) **United States Patent**
Geddes

(10) **Patent No.: US 7,068,805 B2**
(45) **Date of Patent: Jun. 27, 2006**

(54) **ACOUSTIC WAVEGUIDE FOR CONTROLLED SOUND RADIATION**

(76) Inventor: **Earl Russell Geddes**, 43516 Scenic La., Northville, MI (US) 48167

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/616,570**

(22) Filed: **Jul. 11, 2003**

(65) **Prior Publication Data**

US 2005/0008181 A1 Jan. 13, 2005

(51) **Int. Cl.**
H04R 1/30 (2006.01)

(52) **U.S. Cl.** **381/340**; 181/187

(58) **Field of Classification Search** 381/338–341, 381/342, 343; 181/152, 159, 175, 177, 178, 181/185, 187–189, 192, 195
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,324,313 A * 4/1982 Nakagawa 181/192
4,469,921 A * 9/1984 Kinoshita 381/340
5,163,167 A * 11/1992 Heil 181/152
6,059,069 A * 5/2000 Hughes, II 181/152
6,581,719 B1 * 6/2003 Adamson 181/182
6,585,077 B1 * 7/2003 Vincenot et al. 181/192

OTHER PUBLICATIONS

Geddes, Audio Transducers, Chapter 6 Aug. 2002, 6 ed Lee publishing, Novi, Mi, US.
Geddes, "Acoustic Waveguide Theory" J. Audio Eng. Soc. vol. 37 # 7/8 Jul. 1989.
Geddes, "Acoustic Waveguide Theory Revisited" J. Audio Eng. Soc., vol. 41, #6 Jun. 1993.

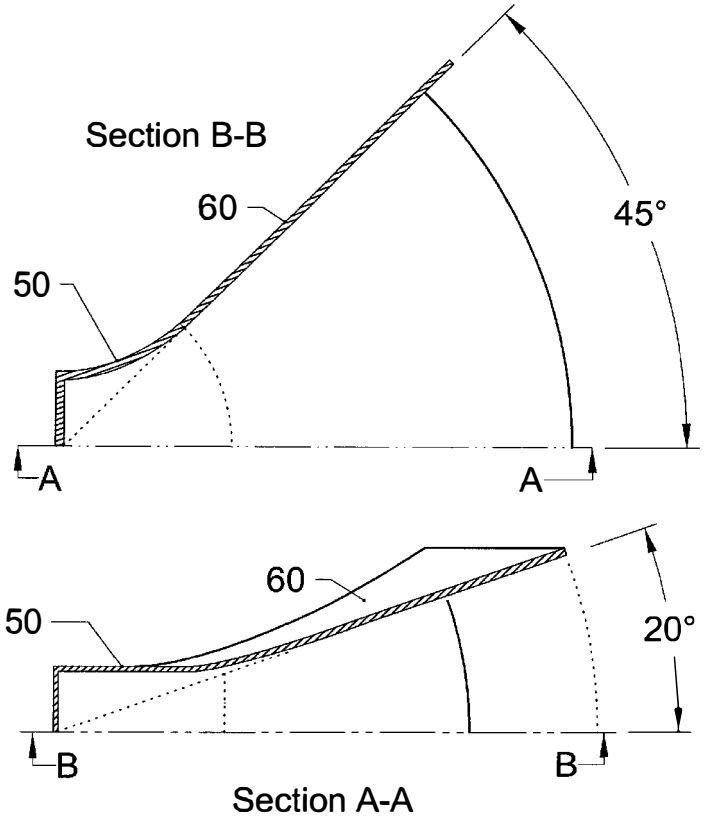
* cited by examiner

Primary Examiner—Sinh Tran
Assistant Examiner—Walter F Briney, III

(57) **ABSTRACT**

Acoustic waveguide contours that approximate either or both of the Elliptic Cylinder and the Prolate Spheroidal coordinate systems that allows for a more accurate prediction and control over the sound radiation polar pattern are disclosed.

2 Claims, 5 Drawing Sheets



ACOUSTIC WAVEGUIDE FOR CONTROLLED SOUND RADIATION

BACKGROUND—FIELD OF THE INVENTION

The present invention relates to acoustical sound radiation and a technique for controlling the directional aspects of the radiated sound field via an acoustic waveguide.

BACKGROUND—DESCRIPTION OF PRIOR ART

There is much prior art relating to the control of sound radiated from waveguides, which are also know as horns in the audio sound reproduction field of art. The term waveguides is used here to refer to those contours that adhere to a stricter definition for their construction, as described herein. The concept of a device whose primary task is to control the directional response of the sound radiation, as opposed to a horn whose primary task was acoustic loading, is relatively new. The prior art in the area of horn theory was almost exclusively concerned with the acoustic loading characteristics of such devices and little attention was paid to an accurate definition the internal wavefront configuration or the directional response, which is highly dependent on this internal wavefront configuration.

Classical horn theory is based on the well known equation of Webster known as Webster's Horn Equation. This applicability of this equation suffers from the fact that it is only accurate for relatively small rates of change of the contours that define it or for contours that have very simple geometries (for example straight sided conical). This fact is well described in Chapter six of my text *Audio Transducers* available from GedLee Publishing at www.gedlee.com. The theory found in this work is fundamental to the understanding of this application. The background to the textbook chapter can be found in my papers on the subject of Waveguides, *Waveguide Theory* and *Waveguide Theory Revisited*, both of which are available from The Audio Engineering Society in their Anthology series.

Current practice in the art is to design a horn that has one or more diffraction apertures created by discontinuities in the conduits cross sectional rate of change of area at points along its axis. The wavefront, upon reaching this aperture, will be diffracted into a spherical (or sometimes a cylindrical) wavefront. If the aperture is not symmetric then this diffraction will occur only in the direction of the smallest dimension, for example a narrow slit will diffract the wave only in the direction across the width of the slit. Once the wavefront has been diffracted into a spherical or cylindrical wave, it is constrained to a specific angle by a basically straight side wall although sometimes there is a slight flaring in this section. The final section is sometimes flared more radically at the exit so as to avoid a second diffraction at the mouth. The diffraction technique does work for directivity control but is not without its detrimental consequences. The diffraction at the apertures causes a large amount of wavefront energy to be reflected from the discontinuity aperture back down the waveguide towards its input end, which causes a standing wave within the device. It is not possible to use diffraction as a wavefront control mechanism and not have this characteristic standing wave occur in the device. This standing wave creates the outgoing and incoming wavefronts to interfere resulting in periodic loading effects on the driver and a comb filter effect on the radiated response. This is a principle reason why horns of this type are often deemed to sound poorly.

Another problem with horns based on diffraction is that they exhibit an ambiguous acoustic center. That is, the wavefront that is created has at least two different centers of curvature for the vertical and horizontal patterns. The secondary diffraction at the aperture points creates secondary sources that are displaced in space from the first source—the driver. Two distinct acoustic centers are thus created. This problem is also well known.

It would be desirable to be able to control the wavefront curvature without the use of diffraction, which is the problem that is dealt with in this disclosure.

A direct result of the aforementioned publications on waveguides is a recent trend toward hom/waveguide designs that are derivatives of or minor contour modifications of the Oblate Spheroidal (OS) waveguide, shown in FIG. **1**. This geometry was first disclosed in my two earlier papers. The OS coordinates are generated from the Elliptical coordinates (shown in FIG. **2**) by rotating these two dimensional (2-D) coordinates about a line normal to this origin at its center. The semi-minor axes of the ellipses make up the lines of constant radial coordinate ξ. This creates a disk as the origin with the diameter of the disk equal to the length of the origin in the 2-D plot. The lines emanating from the origin are lines of constant angles η. The rotation angle is the ψ coordinate, the third coordinate in a three dimension coordinate system.

In an OS waveguide the external shell **10** lies along a coordinate surface for the angular coordinate η of the Oblate Spheroidal coordinate system. The specific angle is called η_0. In an OS waveguide the throat, **20**, is that portion of the origin disk that lies within the bounding contour defined by η_0. A mouth, **30**, results when the shell, **10**, is terminated at some finite length of the conduit. The wavefronts in this configuration will then correspond to the ξ coordinates in the OS waveguide.

To be mathematically correct, each cross section of a true OS waveguide would be round, however, satisfactory results have sometimes been obtained with waveguides which maintain the proper cross sectional area but are made to slowly form an ellipse at the mouth as these cross sections move from the throat to the mouth. The device contours are circular at the waveguide throat, to match the driver outlet shape, and are modified to become elliptical at the mouth in order to create a radiation pattern that is not axi-symmetric. This transition is done in a gradual manner so as to not unduly disturb the wavefront propagation.

Experience has shown that too much of this waveguide contour manipulation will yield a device with less than optimal performance. It has been found in practice that not much more than about a twenty to thirty degree difference in the radiated polar angles (vertical and horizontal) can be achieved with this technique. Thus a typical polar pattern of ninety by forty degrees, readily obtainable with diffraction based designs, would only be possible with this technique in a compromised design.

The prior art suffers from one or more of the following problems:

- The horn theory used to define the contour lacks the rigor required to predict the shape of the wavefront at the mouth thus limiting the predictive capability of devices that are based on this theory.
- In order to control the polar radiation pattern, diffraction within the device must be used which results comb filter effects and ambiguous acoustic centers.
- Waveguides based on Oblate Spheroidal or similar contours cannot achieve all desirable radiation characteristics.

Objects and Advantages

It is the object of the technique disclosed in this application to define a waveguide contour that is free from the use of diffraction and yet still allows for precise control of the radiated response. This is achieved by using a combination of two coordinate systems and matching the wavefront output of the first to the input of the second. A match between a flat aperture throat and a high aspect ratio mouth can thus be obtained. This new waveguide has characteristics which cannot be achieved with the prior art.

DRAWING FIGURES

FIG. **1** shows the prior art usage of the Oblate Spheroidal coordinate system in a waveguide;

FIG. **2** shows the two dimensional Elliptic coordinate system;

FIG. **3** shows the new Bi-Spheroidal waveguide in two cross sections;

FIG. **4** shows the Bi-Spheroidal Waveguide with a flared exit to minimize diffraction at the mouth.

REFERENCE NUMERALS IN DRAWINGS

10	OS Waveguide conduit
20	OS waveguide throat aperture
30	OS waveguide mouth aperture
40	origin line in 2-D Elliptical coordinates
50	Prolate Spheroidal section
60	Elliptic Cylinder section
70	Mouth flare
80	Mouth termination
90	Acoustic transducer

SUMMARY

In accordance with the present invention an acoustic waveguide design is disclosed that is based on a combination of the Elliptical Cylinder (EC) and the Prolate Spheroidal (PS) coordinate systems.

DESCRIPTION

A detailed study of the eleven coordinate systems for which the wave equation is separable reveals that only three of them allows for an input aperture at the throat that is flat (see Audio Transducers Table 6.1). For each of these coordinate systems the radial dimension yields a useful waveguide. A flat origin is desirable since virtually all sources of interest have unidirectional vibration, which creates an essentially a flat source irrespective of the fact that the vibrating surface itself may not be flat—such as a typical domed compression driver diaphragm. The three coordinate systems which allow flat sources are the Oblate Spheroidal (OS), which has a circle as its origin, the Elliptic Cylindrical, which has a rectangle as its origin and finally the Ellipsoidal, which has an ellipse as its origin. The OS devices are widely used and referenced in the prior art discussed above. In my first Waveguide paper, the use of any of the separable coordinate systems as waveguide contours was discussed, however, the possibility of combining two coordinate systems to yield the desired waveguide characteristics was not discussed, except for a simple matching of an OS Waveguide to a Spherical coordinate system waveguide as a way to match the throat size of the OS Waveguide to the driver exit aperture size. No other geometries were discussed and no general technique for matching throat configurations to desired mouth configurations was expounded.

In this application I will describe a means for combining an EC section with a PS section to obtain a device that can have very different directional characteristics in two perpendicular planes, the horizontal and the vertical, a very desirable characteristic.

FIG. **2** shows a two dimensional map of the Elliptic coordinate system. When extended into and out of the page the EC coordinates are generated. When rotated about the semi-major axis of the ellipse then the PS coordinates are generated and when rotated about the ellipses semi-minor axis the OS coordinates are generated, as described above. The two dimensional coordinates for each of these coordinate systems are characterized by an angle η and the radius ξ with the third coordinate being the angle ψ. In waveguides constructed in each of these coordinate systems the wavefronts correspond to the constant ξ surfaces.

When the two foci coalesce into a single point in the above coordinates, then the Circular Cylindrical coordinates are generated for the 2-D case and the Spherical coordinates for the 3-D case.

A PS waveguide has cross sections that are everywhere rectangular. For small angles of η the wavefront surfaces that are generated for small radial coordinates in a PS Waveguide are very nearly a section of a cylinder, regardless of the size of the ψ angle. This means that the two angles of the walls of a PS waveguide are uncoupled—they are independent of one another—which is one of the goals. If the smaller of the two orthogonal wall design angles, the vertical and the horizontal, is limited to be small and this angle is allowed to correspond to the η direction, then with a very small error r the wavefront required to feed this device can be assumed to be cylindrical. For non-zero values of ξ this section is a finite section of a cylinder. This still poses us a problem since this is not the source wavefront that I want to match. However, as can be seen, again from FIG. **2**, an EC waveguide would generate a finite section of a cylinder from a finite source of rectangular cross section with axial vibration. Proper matching of the output of an EC section to the input of a PS section would allow for a flat rectangular source to develop into a non-axi-symmetric section of a sphere at the mouth of the PS waveguide. This is the goal.

The throat of an EC waveguide can be feed by several varieties of sources. First, an actual rectangular source could be used, a phase plug could be made which had a square outlet instead of the usual round one, or a round source could also simply feed the square opening. It is also quite reasonable to assume that a gradual transition from the normal round outlet of a compression driver or speaker to the square section of the EC Waveguide would function without undue degradation of the devices performance, so long as the same cross sectional areas are maintained or grow at a slow rate.

The outlet of the EC waveguide is a section of a cylinder whose dimensions depend on the specifics of this section of the waveguide. If a transition to a PS waveguide is made at a ξ value such that the input shape of the PS waveguide matches the output shape of the EC waveguide then an almost perfect matching of the wavefronts can be achieved. There are many specific angles and locations where this matching can be done and the preferred embodiment is one which minimizes discontinuities in the angles of the walls at the matching location while allowing for the elliptical section to have progressed far enough to have created the nearly cylindrical wavefront required by the PS input. Thus the

joining of the two sections is a compromise between two counter relationships. It is a straightforward task to manually determine this matching using typical drawing packages and finding the best fits of the wall angles and shapes graphically. There is no doubt that some mathematical approach could be developed, but in practice it has been found that drafting this transition graphically has been highly effective and efficient.

A preferred embodiment of this design is shown in FIG. **3**. The waveguide is drawn as two cross sectional drawings in two perpendicular planes which cross along the axis of the device. The EC section, 50, is shown in both views as is the PS section, 60. This new device is called a Bi-Spheroidal™ Waveguide, because it is composed of two waveguides, "Bi", with the outer section being "Spheroidal".

This new device is an improvement on the prior art in that it can achieve widely different directional patterns in two directions without the need for diffraction at any point. This will yield an improved sound quality through the minimization of internal standing waves and the resultant comb filter effect on the radiated response. This new device also does not exhibit an ambiguity as to the acoustic center since there is only a single apparent source with a single radius of wavefront curvature.

As is customary with a horn, this waveguide should have a flaring, a large radius, at the mouth to reduce diffraction and reflections from the mouth termination. A Bi-Spheroidal Waveguide with a flared mouth into a flat baffle is shown in FIG. **4**. The mouth can also be flared into a spherical surface if desired.

It should be noted that in some applications, such as line arrays, the vertical polar pattern will be dominated by the array and thus the vertical pattern for the individual waveguide in this array is not important. In this case it would be desirable not to have any vertical change in the conduits dimensions with length. This would correspond then to a purely EC coordinate system and the PS section would not be required. The waveguide would then be composed of a single EC section.

The preciseness with which one must match the coordinate systems as defined here has never been determined and it is to be noted that small deviations from the coordinate systems defined herein are still to be construed as being within the scope of the claims. For example simplifying the a hyperbolic coordinate curve by circles and lines that closely match said curve will still be within the scope of my invention as these small deviations are not significant in the end product. The EC and PS coordinate surfaces then are to be construed as ideals that can be deviated from without significant deviations from the positive features of these coordinate surfaces as defined within this application.

I claim as my invention:

1. An acoustic waveguide for propagating sound radiation from an acoustic transducer having a throat and a mouth termination, wherein two or more sections along the length of said waveguide have bounding surfaces that are substantially Elliptic Cylinder and Prolate Spheroidal coordinates from the throat to the mouth.

2. The waveguide of claim **1** wherein;

a mouth termination has a radius.

* * * * *

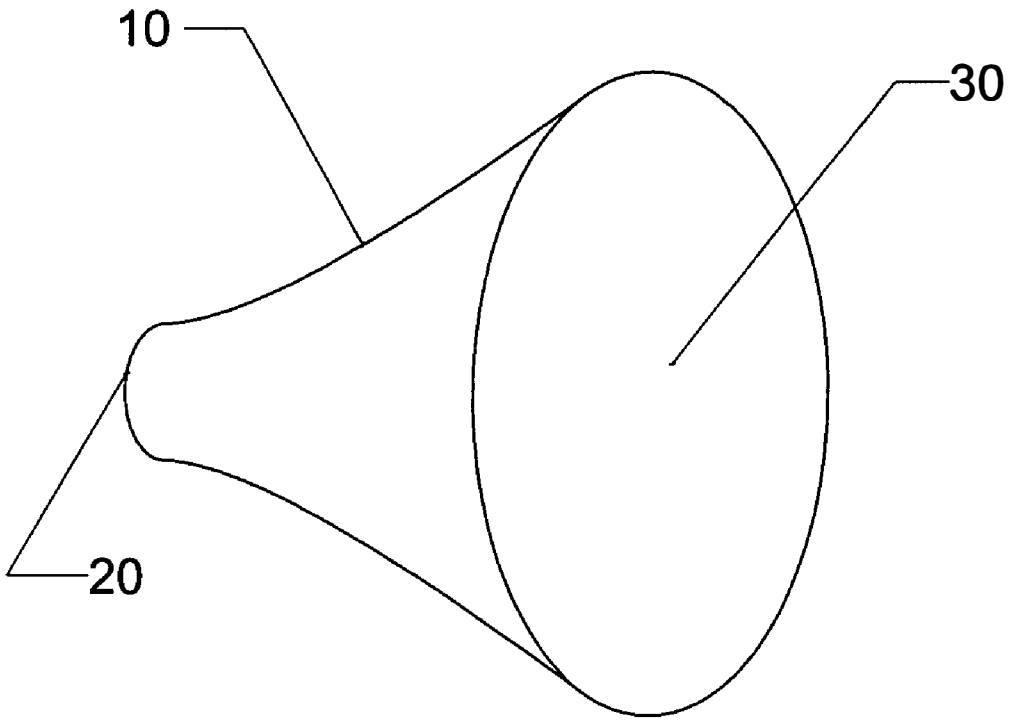


FIG. 1

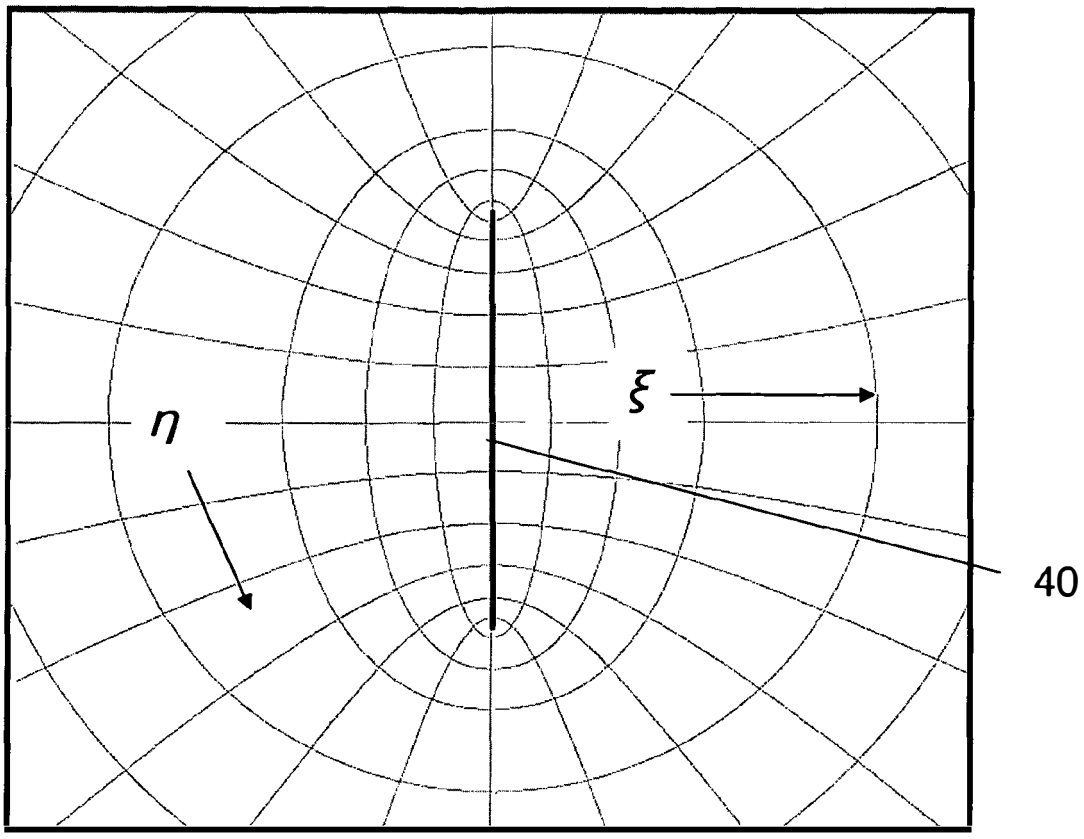


FIG. 2

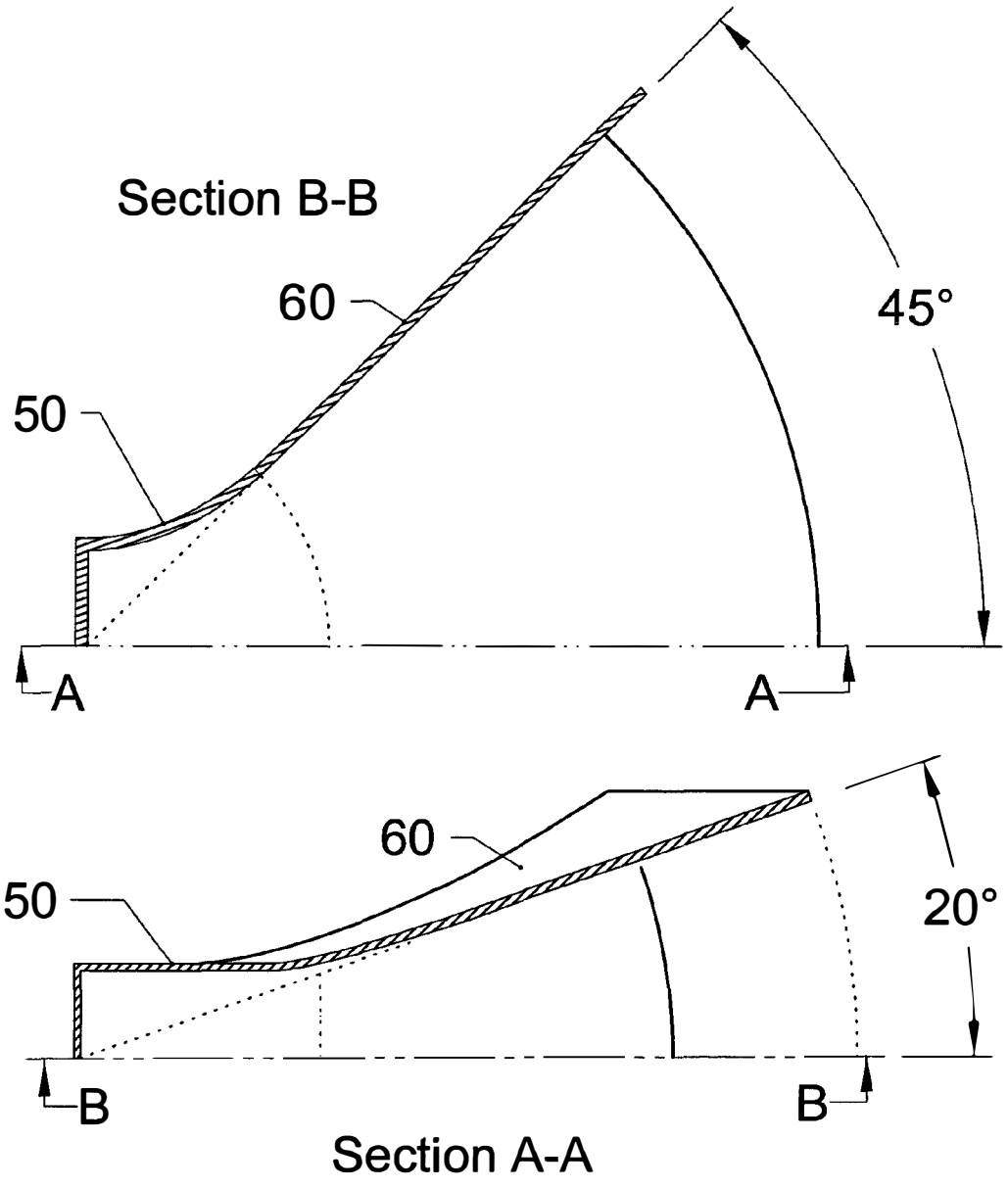


FIG. 3

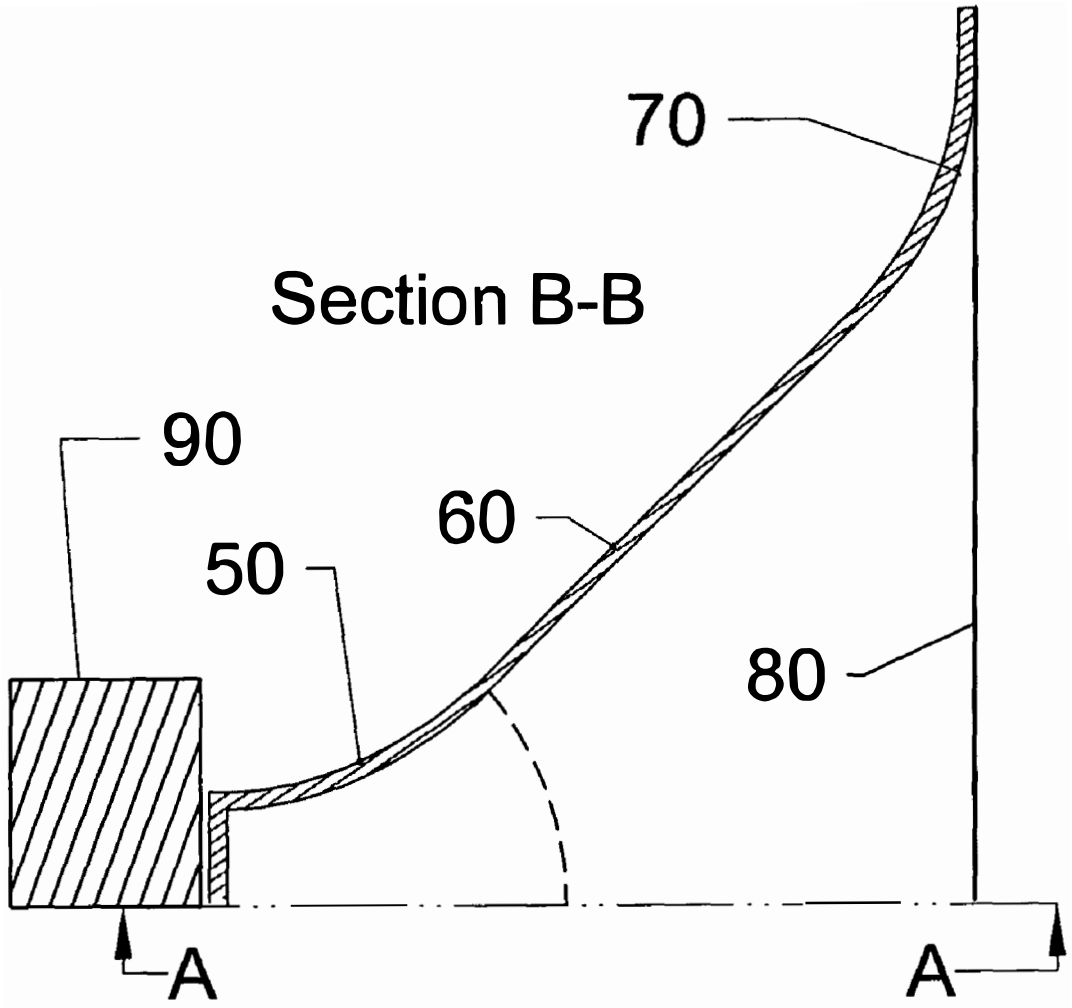
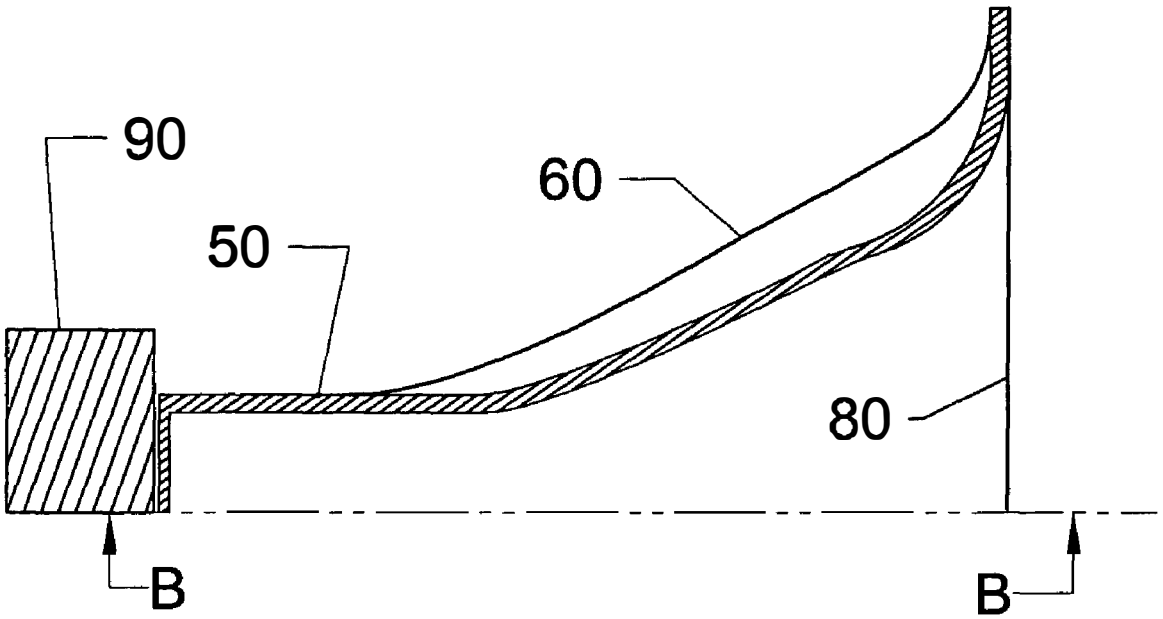


FIG. 4A



Section A-A

FIG. 4B

US007095868B2

(12) **United States Patent**
Geddes

(10) **Patent No.: US 7,095,868 B2**
(45) **Date of Patent: Aug. 22, 2006**

(54) **PHASE PLUG WITH OPTIMUM APERTURE SHAPES**

(76) Inventor: **Earl Geddes**, 43516 Scenic La., Northville, MI (US) 48167

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 179 days.

(21) Appl. No.: **10/361,327**

(22) Filed: **Feb. 10, 2003**

(65) **Prior Publication Data**

US 2004/0156519 A1 Aug. 12, 2004

(51) **Int. Cl.**
H04R 25/00 (2006.01)

(52) **U.S. Cl.** **381/343**; 381/337; 381/339; 381/340; 181/177; 181/185; 181/187; 181/189; 181/192

(58) **Field of Classification Search** 381/340–343, 381/182, 186, 335, 351, 386, 337–339, 428; 181/152, 144, 148, 159, 160, 185, 192–195, 181/186, 177, 184, 187, 188, 191, 199
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,037,187 A 4/1936 Weate
3,852,529 A * 12/1974 Schafft 381/75
4,050,541 A * 9/1977 Henricksen 181/159
4,091,891 A * 5/1978 Hino et al. 181/185
4,718,517 A * 1/1988 Carlson 181/159
4,975,965 A * 12/1990 Adamson 381/343
5,117,462 A 5/1992 Bie
6,026,928 A * 2/2000 Maharaj 181/152
6,064,745 A * 5/2000 Avera 381/343
6,628,796 B1 * 9/2003 Adamson 381/342
6,744,899 B1 * 6/2004 Grunberg 381/343
2002/0021815 A1 * 2/2002 Button et al. 381/343

OTHER PUBLICATIONS

Earl Geddes, Audio Transducers (Book) Jul. 2002, pp. 126-164, Gedlee Publishing www.Gedlee.com.

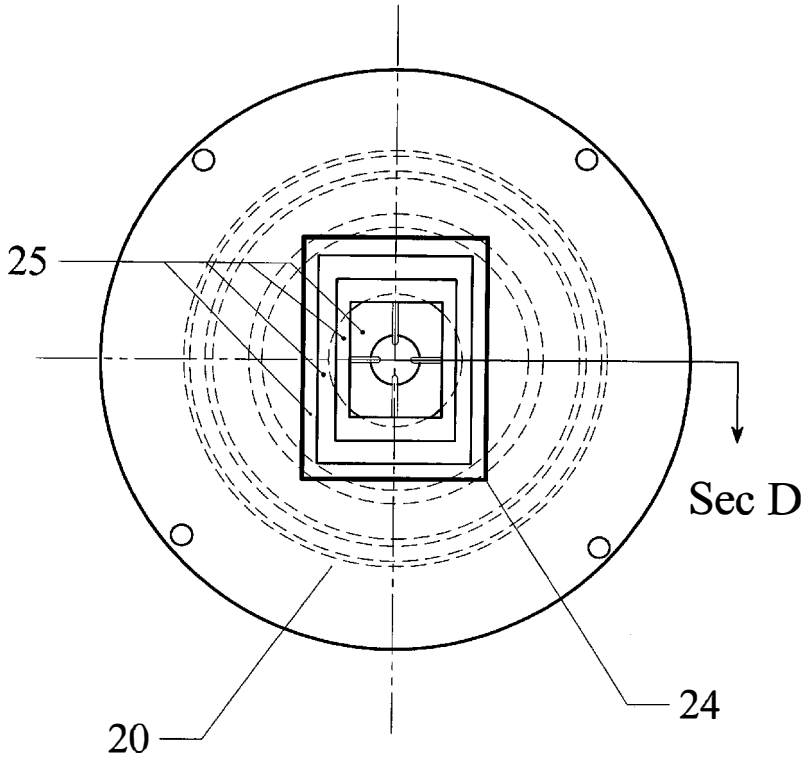
* cited by examiner

Primary Examiner—Suhan Ni
Assistant Examiner—Dionne Harvey

(57) **ABSTRACT**

A phase plug for optimally matching a drive-unit's diaphragm to the throat of a waveguide is disclosed. Specific embodiments of a circular diaphragm matched to an elliptical waveguide and a circular diaphragm to a rectangular waveguide are disclosed.

6 Claims, 15 Drawing Sheets



PHASE PLUG WITH OPTIMUM APERTURE SHAPES

BACKGROUND

1. Field of the Invention

The present invention relates to the design of the phase plug in an electro-acoustic transducer composed of the phase plug and drive-unit, and waveguide assemblies.

2. Description of Prior Art

In high performance audio playback systems it is common practice to use wave guiding devices coupled to an electro-acoustic transducer drive-unit (that portion of an electro-acoustic transducer that does the direct electrical to acoustical transduction) that act to both amplify and direct the sound energy created therein. These devices go by many names, the most common being "horns" and "waveguides", waveguides—a newer term—implies that more importance is given to the directivity controlling aspects of these devices than the loading ones. I will use the term waveguide consistent with its new meaning, but it is also my intention to mean any and all devices performing such tasks regardless of name.

The "shape" of the wavefront presented to the input aperture of the waveguide (the throat) has a great influence on how the device radiates sound from the open end (the mouth), particularly at the higher frequencies. Shape in the context of this application means the bounding area of a plane perpendicular to the sound channel propagation, it is a two dimensional surface, but it can also refer to the surface velocity distribution (complex number map) in that same surface. In order to control the formation of the throat wavefront it is common practice to place a plug containing multiple phase equalizing channels between the drive-unit diaphragm and the throat of the waveguide. This plug is usually designed so as to direct the sound waves emitted from the drive-unit diaphragm into the waveguide throat aperture in a prescribed shape. This plug is also know by various names, the most common being "phase plug", "phasing plug" or "equalizer".

The art of phase plug design is well advanced. The first significant disclosure of the function of a phase plug is provided by Wente, U.S. Pat. No. 2,037,187 (1936). Wente notes that the goal is to provide an essentially planar wavefront at the horn throat and he achieves this task by directing the sound through phase equalizing channels of essentially equal length, thereby ensuring that the contributions all add in phase.

In Henricksen, U.S. Pat. No. 4,050,541 (1977), discloses an alternate type of phase plug wherein the phase equalizing channels are radial, as opposed to more common circumferential.

Carlson, U.S. Pat. No. 4,718,517 (1988), discloses a phase plug which has a rectangular exit aperture at the throat end to better match the waveguide throat, but at the input end at the drive-unit diaphragm, the phase equalizing channels are also rectangular which is not ideal. Carlson recognizes the need for a phase plug when transitioning from a circular source to a non-circular one but does so utilizing only a single channel of non-varying cross section (obviously easy to fabricate) or he uses two phase equalizing channels which are still not ideally matched to the circular diaphragm. In the later case the phase equalizing channels vary only in size—not shape—as they progress, and they are not concentric. In terms of performance (but not necessarily so in terms of manufacturing case) Carlson's design is not optimal. The phase plug's phase equalizing channels entrance shape is not well matched to the diaphragm resulting in unequal phase propagation summation effects at the waveguide throat which will result in distortions of the sound.

Bie, U.S. Pat. No. 5,117,462 (1992), utilizes the voice coil motion as part of the radiating surface of the drive-unit and adds a sound channel to said radiating region. He also shows a phase plug with non-concentric round phase equalizing channels.

Finally, Keith, U.S. Pat. No. 6,064,745 (2000), discloses an improved radial type of phase plug which is easier to manufacture than previous designs. The input shapes are not circles, they are triangular.

Each of these inventions claims a distinct improvement over the others in regard to performance, manufacturability and/or some other comparable; however, none of them discloses a phase plug design which optimally matches a drive-unit's diaphragm shape to a waveguide throat of different shape (as can be required by waveguide theory). By using phase equalizing channels which transition gradually from circular at the diaphragm to non-circular at the exit an improved phase plug design can be implemented.

Adamson acknowledged in U.S. Pat. No. 4,975,965 (column 5, lines 56–64) that his phase plug "has been found to be particularly useful when applied to acoustic waveguide speakers of the variety developed by Dr. E. R. Geddes . . . "—the current inventor. The waveguide referred to by Adamson was based on the oblate spheroidal coordinate system. In Chapter 6 of my book *Audio Transducers*, (GedLee Publishing, July, 2002), I discuss the fact that there are several different coordinate systems which yield useful waveguides (see table 6.1 in the text) and that each one has a different set of radiation characteristics. As discussed in this text, these different waveguides require different wavefront shapes at the throat ("source aperture" and "curvature" in the table of my text) for optimum performance.

In order to optimally match a drive-unit to a waveguide, it is desirable to have a phase plug that adapts the motion of a generally circular diaphragm to a desired aperture shape in a manner which brings the velocities of various portions of the circular diaphragm to the exit aperture in a prescribed, but generally in-phase, manner. There are situations where the velocity distribution (the velocity shape) in the phase plug's exit aperture (the waveguides throat) may want to be non-uniform.

An preferred embodiment of the invention disclosed in this specification occurs when connecting a circular drive-unit to a waveguide that requires an elliptical throat aperture. The phase plug in this case should have a shape at the input end that is circular or annular such as concentric annular rings spaced so that each ring has the smallest path length to those diaphragm points which excite it, i.e. the shapes conform to the circular source. At the exit aperture the shapes are concentric elliptical rings, typically of equal area and arranged so that there combined shapes equal the shape required by the waveguides throat.

In none of the prior art is it recognized that the optimum phase plug would have the requirements highlighted above. It was generally assumed that the phase plug's exit aperture (the throat of the waveguide) should be circular, or one with an equally simple shape to fabricate so long as the shapes of the sound channels at the input and output ends remain constant. In most cases the waveguide throat is adapted to match the phase plug's exit aperture—not the other way around. The prior art generally conforms to a design approach where ease of manufacture is emphasized, steering away from more complicated sound channel shapes because of manufacturing concerns. Today, injection molding com-

plex phase plugs in plastic is a relatively easy manufacturing process and so complex shapes need no be avoided and more effective phase plugs can be readily fabricated.

OBJECTS AND ADVANTAGES

The primary object of this invention is a phase plug design which allows the drive-unit diagram shape to be optimally matched to a waveguide throat. The advantage of this optimum matching is that it creates a drive-unit/waveguide combination which has improved performance over one in which either; the waveguide shape is compromised to match the exit aperture from the drive-unit phase plug (usually circular in a "compression driver"—the usual name for a drive-unit phase plug combination), or; the phase plug input shape is not optimally matched to the diaphragms shape.

DRAWING FIGURES

FIG. **1** shows a top view of a phase plug horn combination of conventional design;

FIG. **2** shows an exploded view of the axi-symmetric cross section **0**–A of a phase plug and the attachment of the phase plug to the waveguide;

FIG. **3** shows a top view of a phase plug which has an elliptical exit aperture for use on a waveguide designed around the ellipsoidal coordinate system;

FIG. **4** shows a top view of a phase plug with a rectangular exit aperture for use on a waveguide designed around the prolate spheroidal or elliptic cylinder coordinate systems.

FIG. **5** shows a top view of a phase plug with a multiplicity of independent circular holes at the diaphragm and a rectangular layout of rectangular holes in the exit aperture plane.

REFERENCE NUMERALS IN DRAWINGS

10	generic drive-unit
20	phase plug
22	phase plug diaphragm end
24	phase plug exit aperture
25	sound equalizing channels
30	waveguide
40	attachment bolt

SUMMARY

In accordance with the present invention, a phase plug is disclosed which has the ability to optimally match a given drive-unit diaphragm shape to a chosen waveguide by utilizing sound equalizing channels that transition from the optimum shape at the diaphragm to the optimum shape at the waveguide.

DESCRIPTION FIGS. **1** TO **5**

There can be many ways to assemble a drive-unit, phase plug and waveguide, but only a typical structure will be shown here for brevity.

FIG. **1**. shows a typical prior art implementation of a phase plug where FIG. **2** is an axi-symmetric cross section along line **0**-A in FIG. **1**. A means for connecting a waveguide (**30**) to the phase plug (**20**) is shown as bolts (**40**). The phase plug (**20**) is placed over the diaphragm-motor structure (not shown) by some connection means (not shown). Annular rings at the diaphragm are brought out to annular rings in the throat aperture with the intention of making the distance traveled along the various sound channels (**25**) approximately equal. FIG. **1** shows each channel of equal length and constant cross section, although this is merely a convenience that is not always useful or desirable. Much prior art exists for placing and sizing the phase plug sound channels (**25**) but this art nearly always has a basically circular throat aperture. One notable exception is that described below for FIG. **5**.

FIG. **3** shows a preferred embodiment of the new phase plug design in which the phase equalizing channels of the design start out with exactly the same areas and shape as in FIG. **1**, but they are morphed along their path ending in ellipses at the exit aperture. This design will optimally match a circular diaphragm to the elliptical throat of an elliptically shaped waveguide, like that created in ellipsoidal coordinates according to Geddes. Allowing the phase plug sound channels to mimic the shape of the diaphragm at the diaphragm while having the shape of these channels match the entrance (throat) of the waveguide at the phase plug's exit aperture, is the key invention of this application.

FIG. **4** shows another preferred embodiment of the new phase plug design in which the phase equalizing channels of the design start out with exactly the same areas and shape as in FIG. **1**, but they are morphed along their path into nested rectangles at the exit aperture. This design will optimally match a circular diaphragm to the rectangular throat of a rectangular cross section waveguide like that required for an elliptic cylinder waveguide. The rectangular throat cross section would usually have a finite radius at the corners of the rectangles for various reasons, but t5he basic shape will be rectangular.

FIG. **5** shows another preferred embodiment of the new phase plug design in which the phase equalizing channels of the design start out as circular holes, but they are morphed along their path into rectangles at the exit aperture. The rectangular exit holes of the equalizing channels add up to yield the rectangular throat of an rectangular cross section waveguide. Likewise the exit exit holes of the equalizing channels could be made to add up to an elliptical aperture.

It should also be recognized that the early part of the waveguide increasing cross section may well be part of the phase plug in that the sound equalizing channels may expand in cross section as well as change shape.

One skilled in the art will recognize that there are many ways to assemble an electro-acoustic transducer composed of a drive-unit, phase plug and waveguide and that the method of assembly shown here is but one. They will also recognize that are many ways to design the phase plug equalizing channels and that the design shown here is but one example. For instance, the ratio of the diaphragm are to the area at the entrance of the phase plug (the compression ratio) could be varied, or the rate of area change along the phase equalizing channels could be varied. The invention described here relates to the change in the shape of the channels normal to the propagation direction as the channels progress from the diaphragm to the waveguide, the portion of the design usually called the phase plug.

I claim:

1. An electro-acoustic transducer for transmitting sound comprising:

a drive-unit;

a waveguide and;

a phase plug with a diaphragm end and an exit aperture, wherein:

said phase plug has sound path equalizing channels whose shapes normal to the wave propagation change from being multiple concentric annuluses at the diaphragm end, to being noncircular concentric at the exit aperture.

2. An electro-acoustic transducer as defined in claim **1** wherein:

said phase plugs sound path equalizing channels noncircular concentric shapes at the exit aperture, are ellipses.

3. An electro-acoustic transducer as defined in claim **1** wherein:

said phase plugs sound path equalizing channels noncircular concentric shapes at the exit aperture are essentially rectangular.

4. An electro-acoustic transducer as defined in claim **1** wherein:

said phase plugs sound path equalizing channels expand, along their length, corresponding to the cross sectional area expansion of the throat of a waveguide.

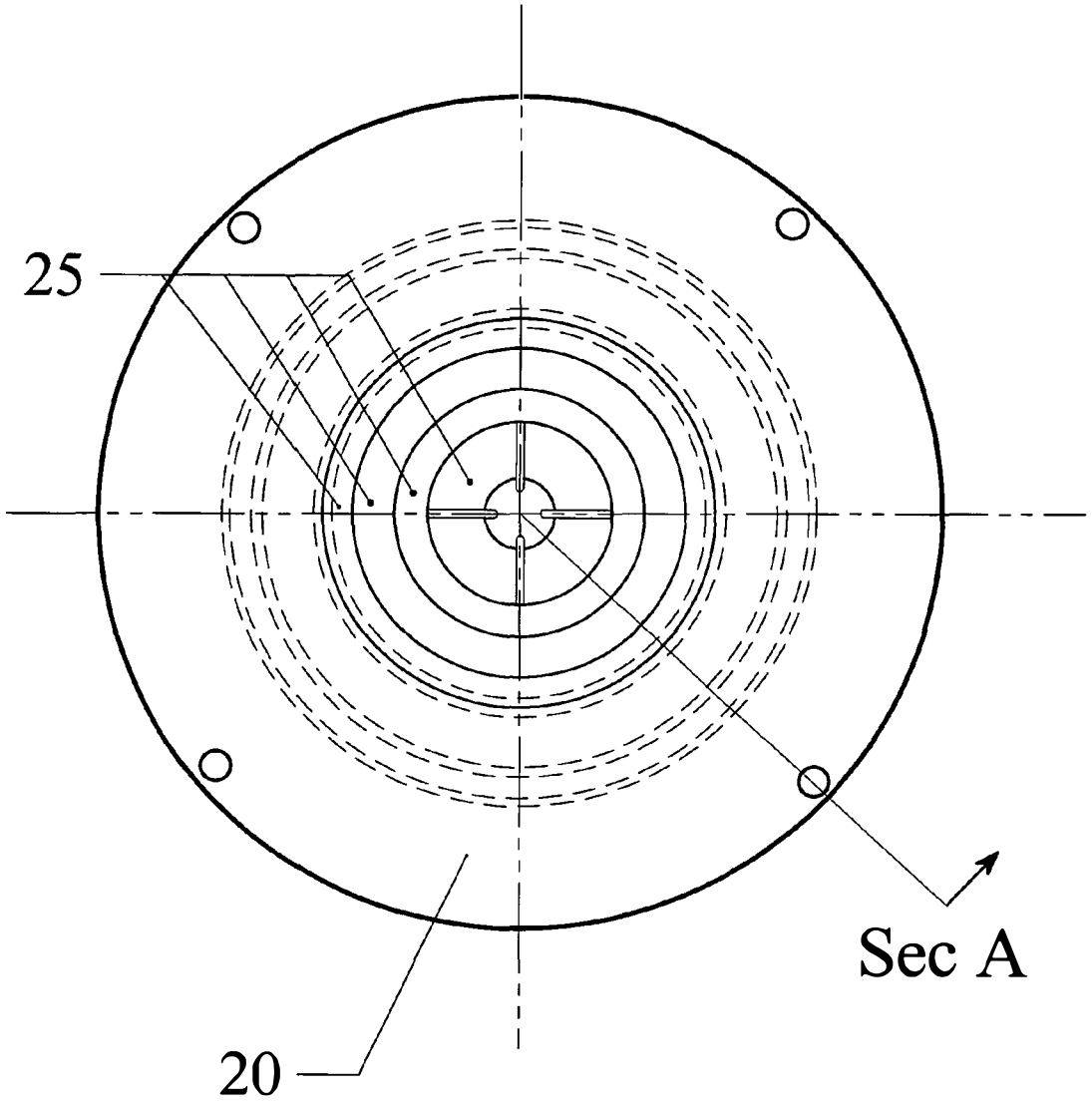
5. An electro-acoustic transducer as defined in claim **4** wherein:

said phase plugs sound path equalizing channels noncircular concentric shapes at the exit aperture are ellipses.

6. An electro-acoustic transducer as defined in claim **1** wherein:

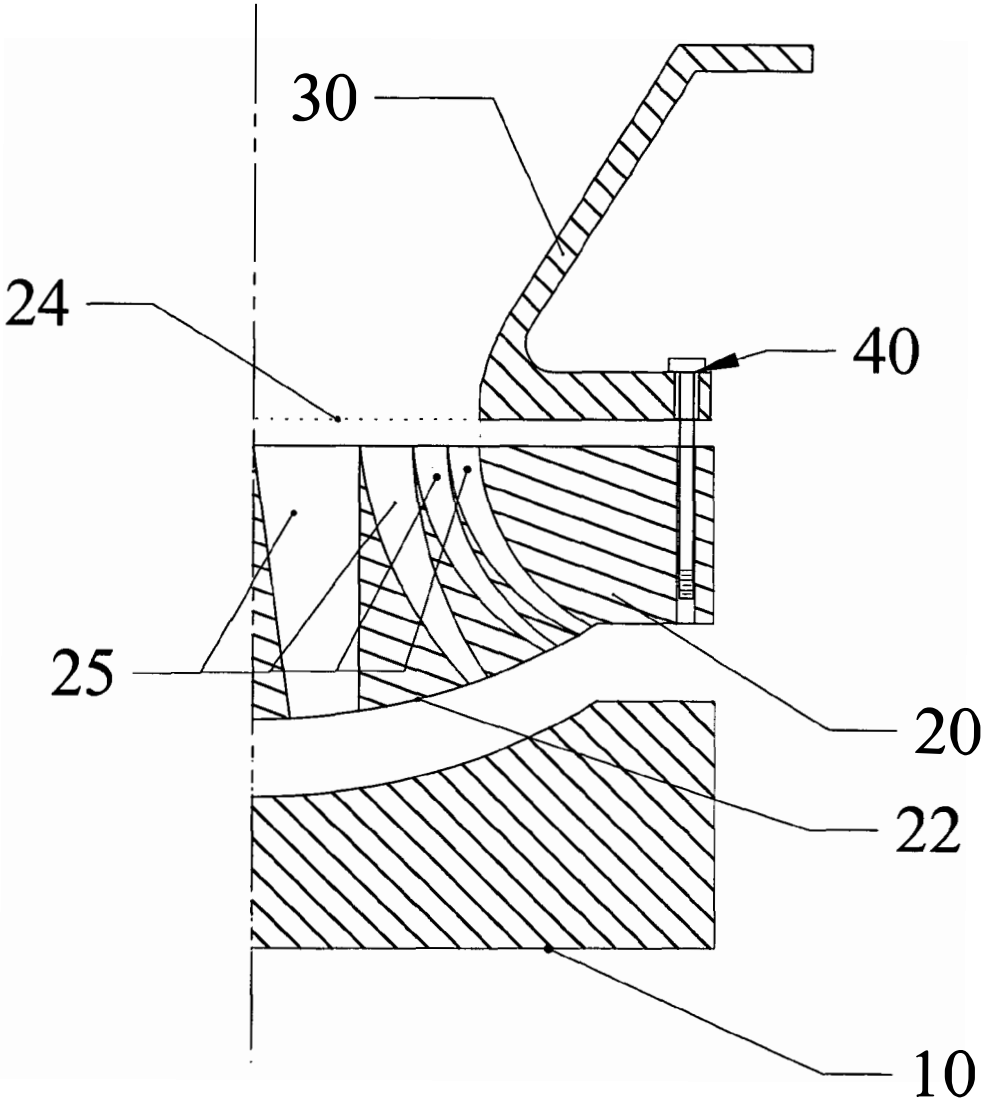
said phase plugs sound path equalizing channels noncircular concentric shapes at the exit aperture are essentially rectangular.

* * * * *



(Prior Art)

Fig. 1



Section 0-A

Fig. 2

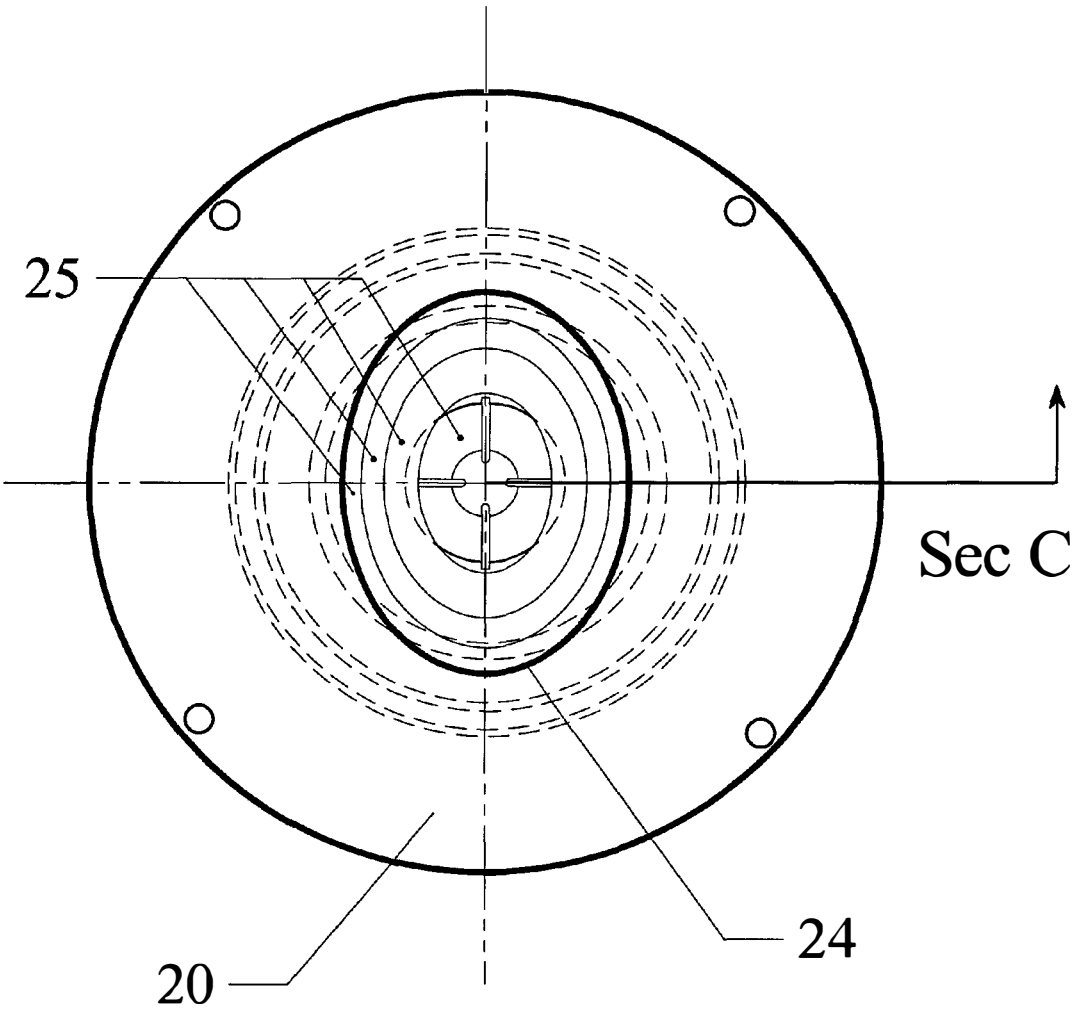
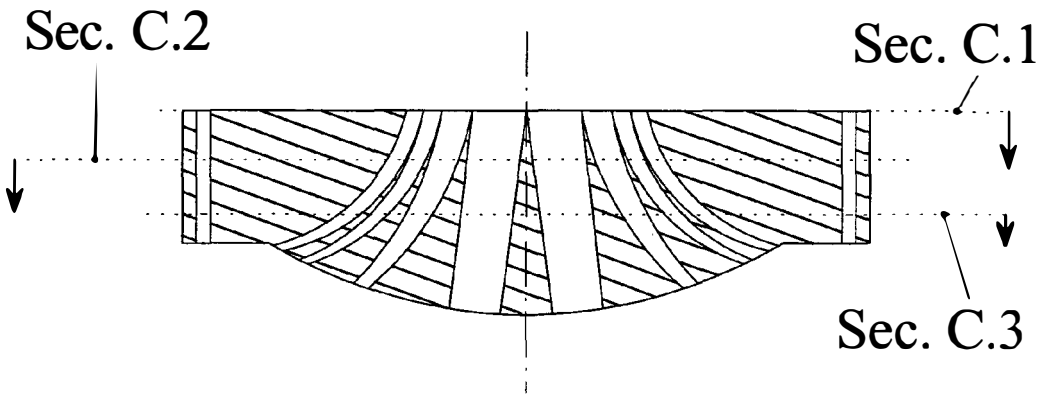
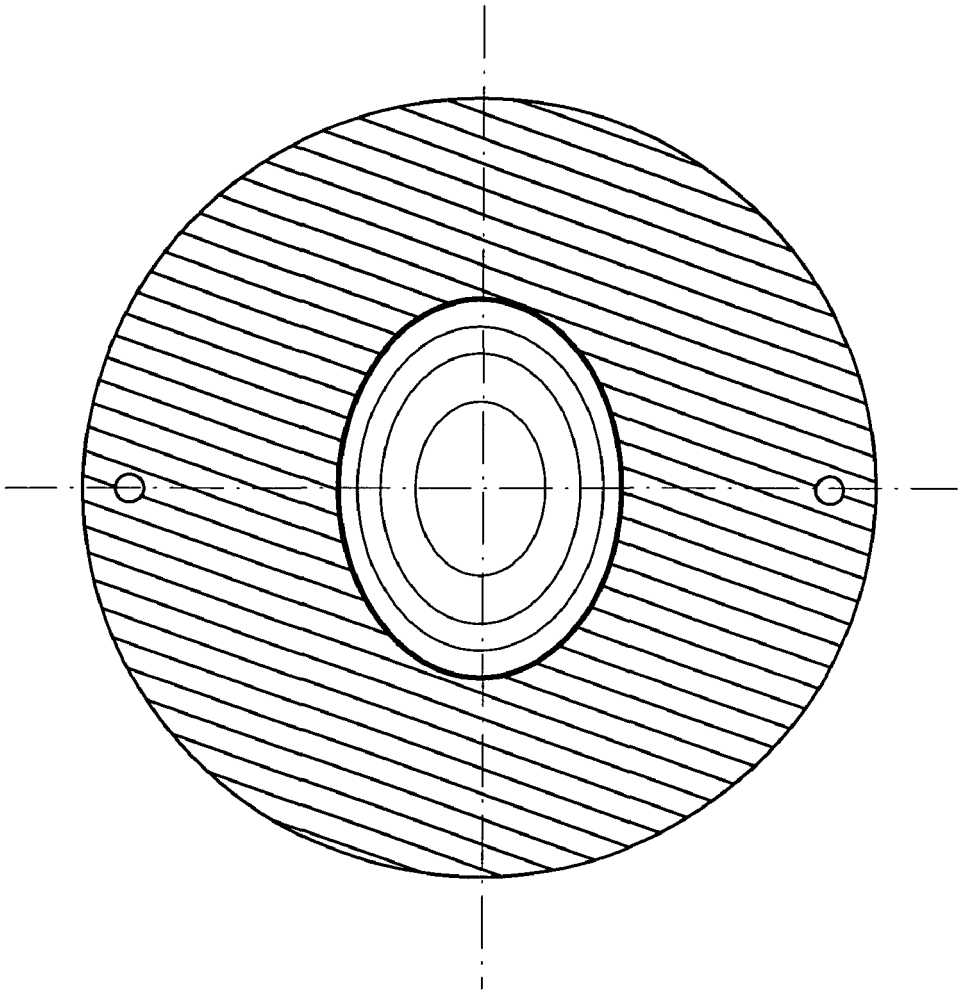


Fig. 3a



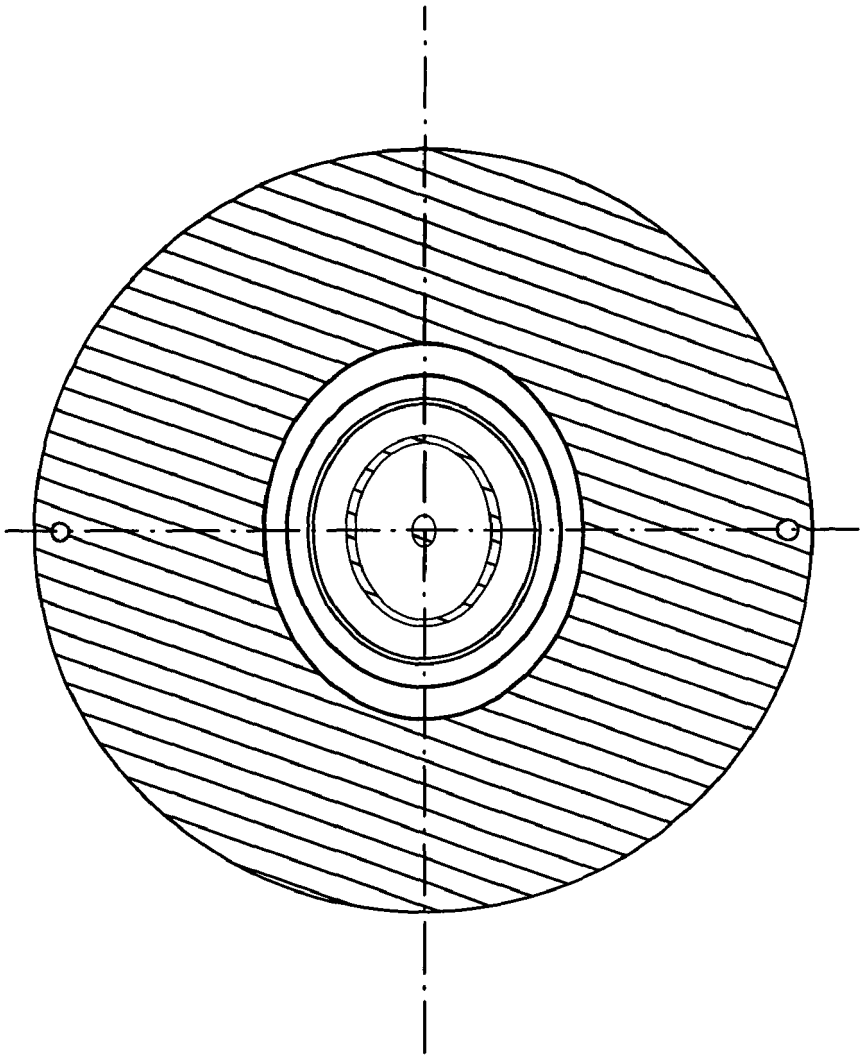
Section 0-C

Fig. 3b



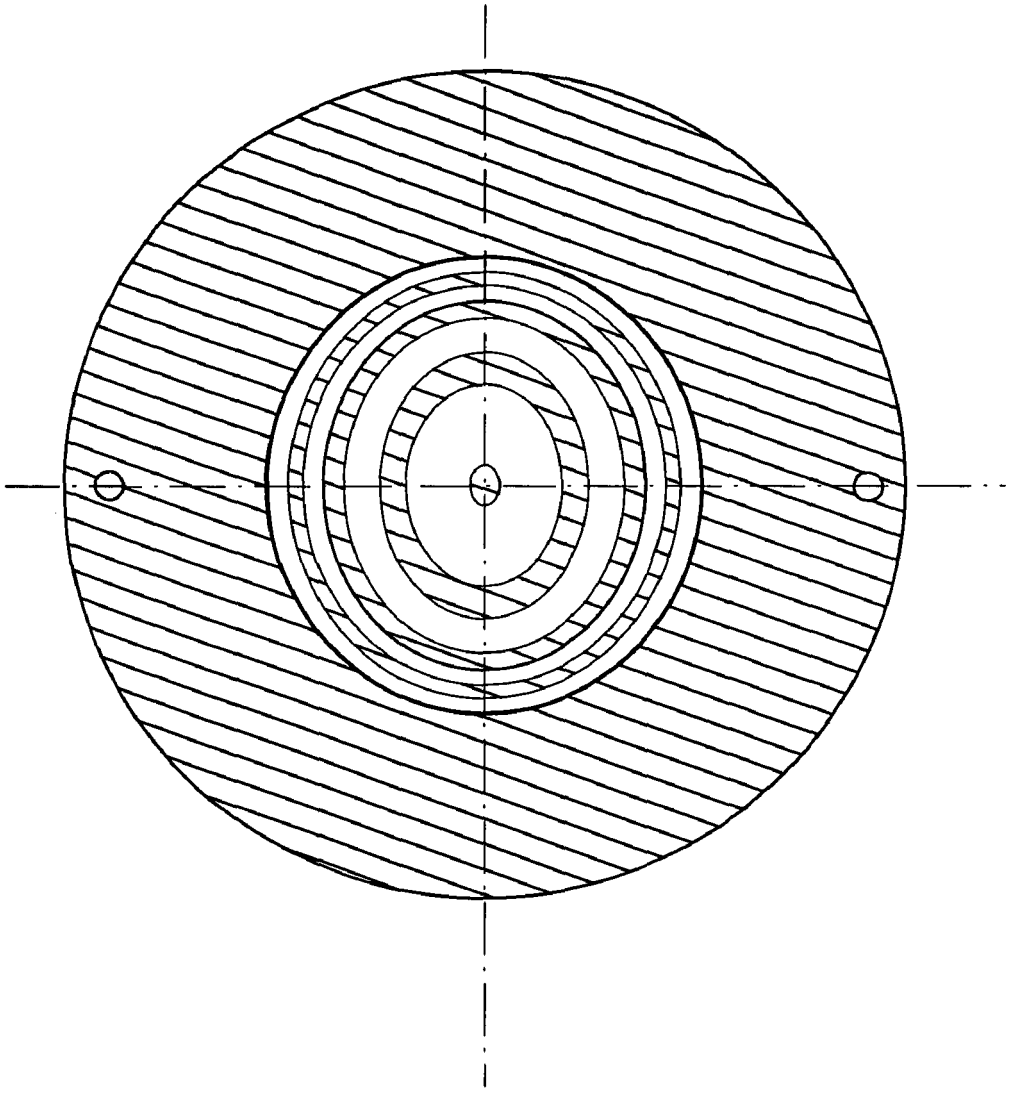
Section C.1

Fig. 3c



Section C.2

Fig. 3d



Section C.3

Fig. 3e

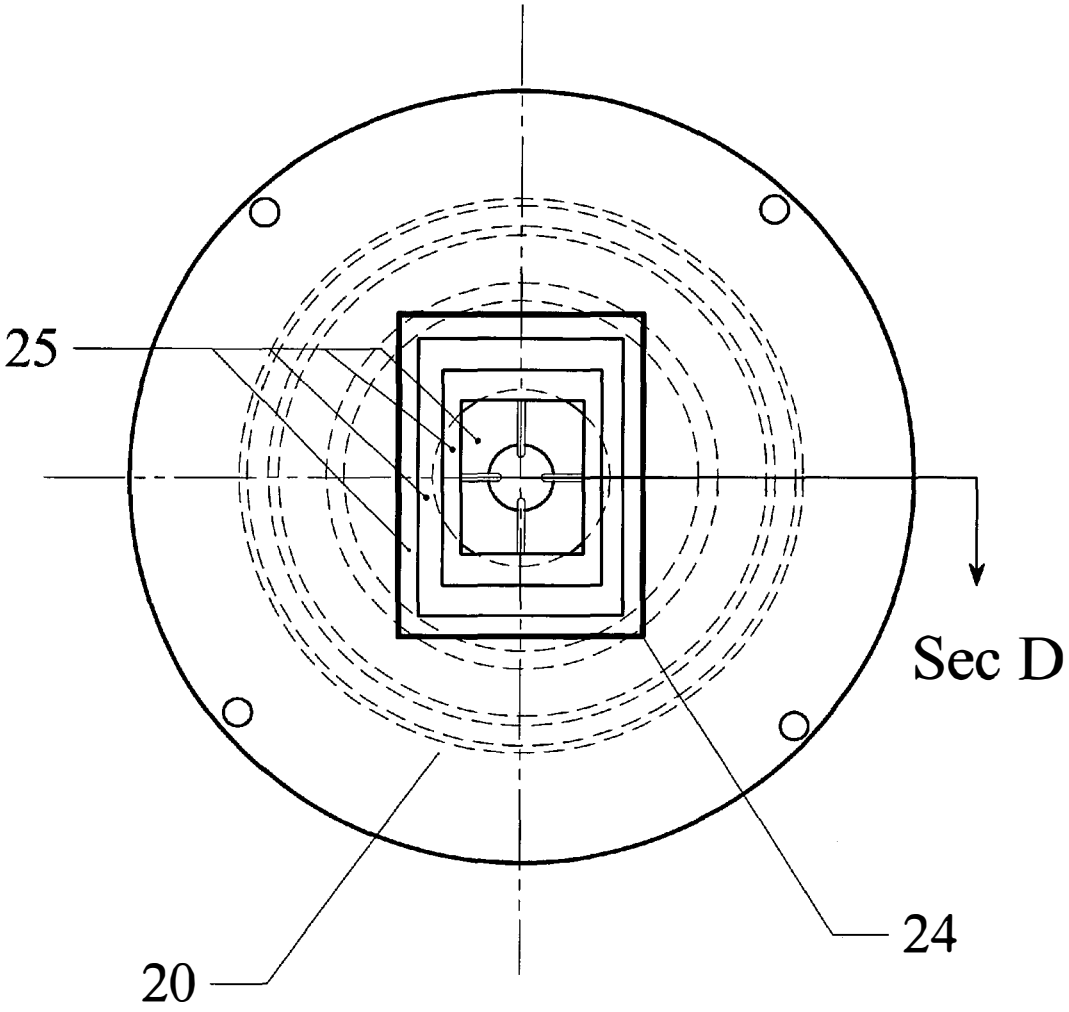
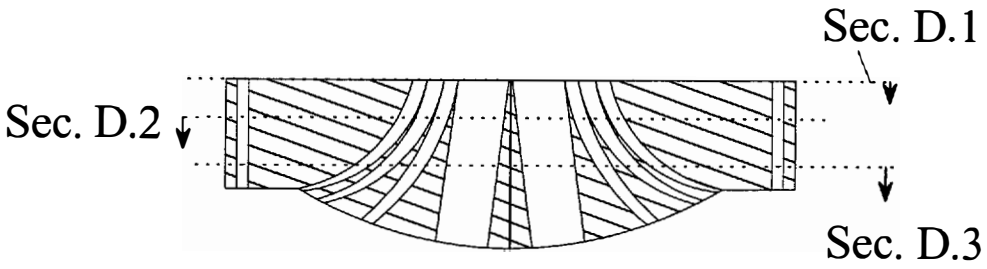
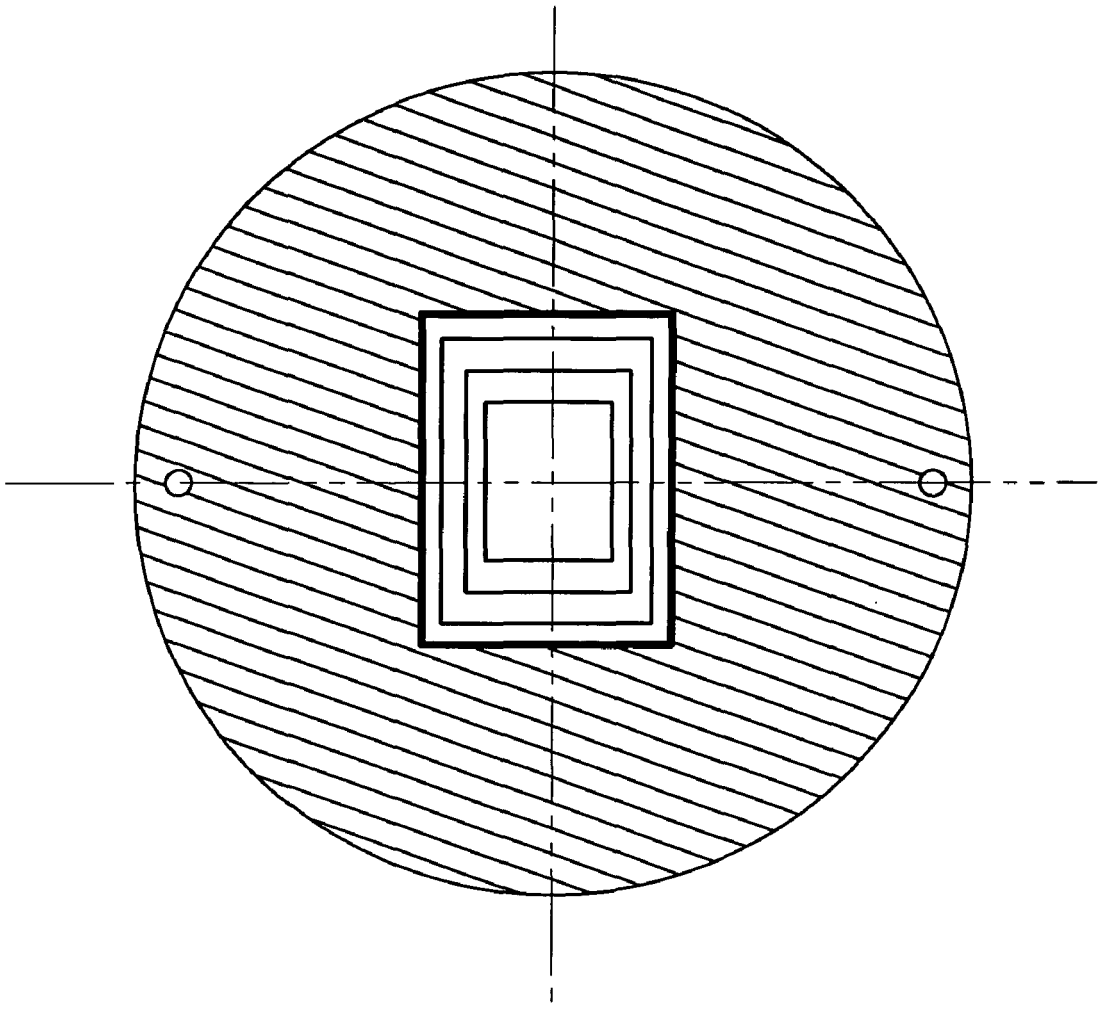


Fig. 4a



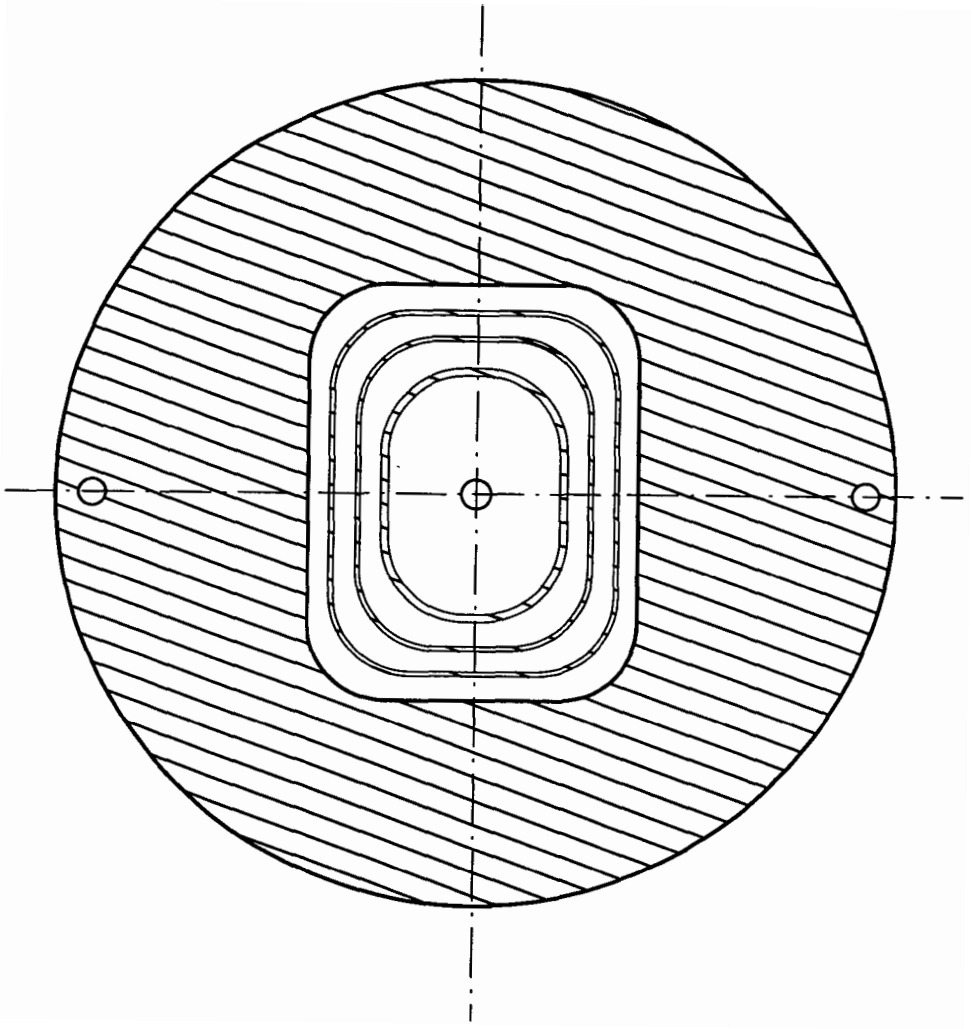
Section 0-D

Fig. 4b



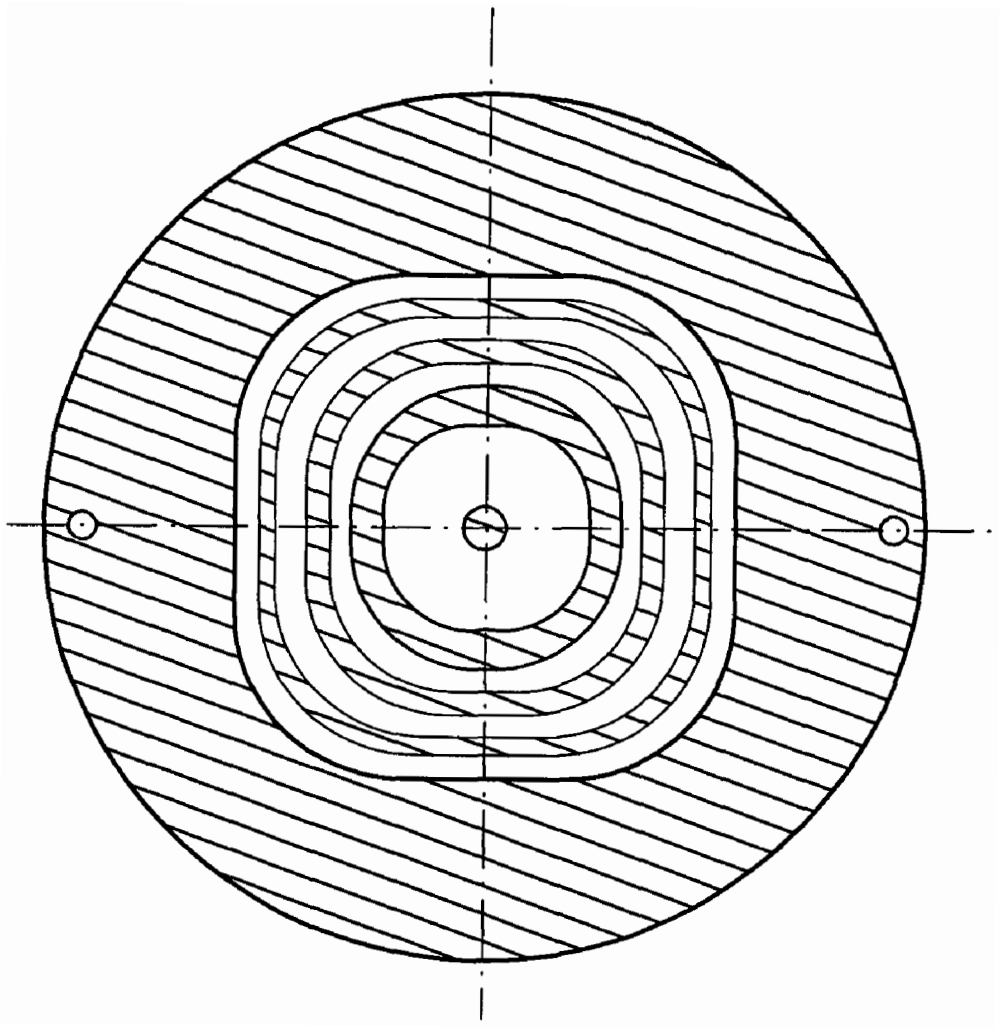
Section D.1

Fig. 4c



Section D.2

Fig. 4d



Section D.3

Fig. 4e

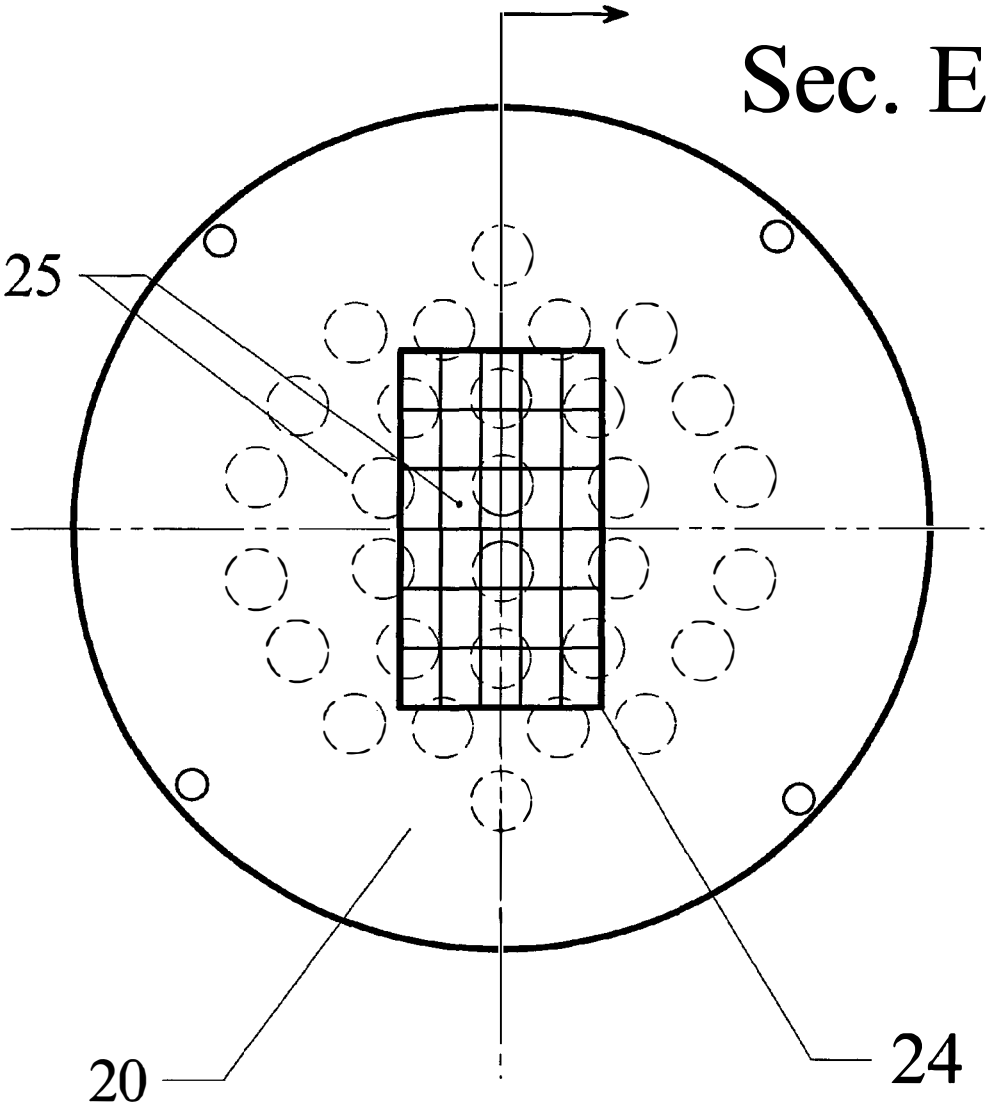
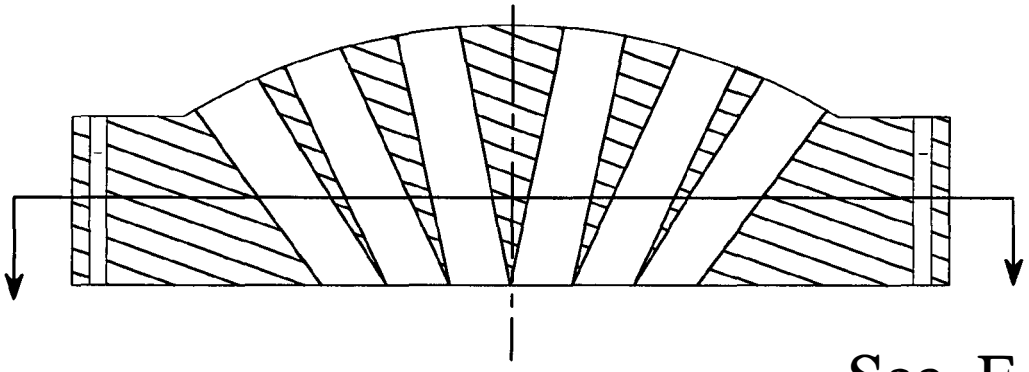


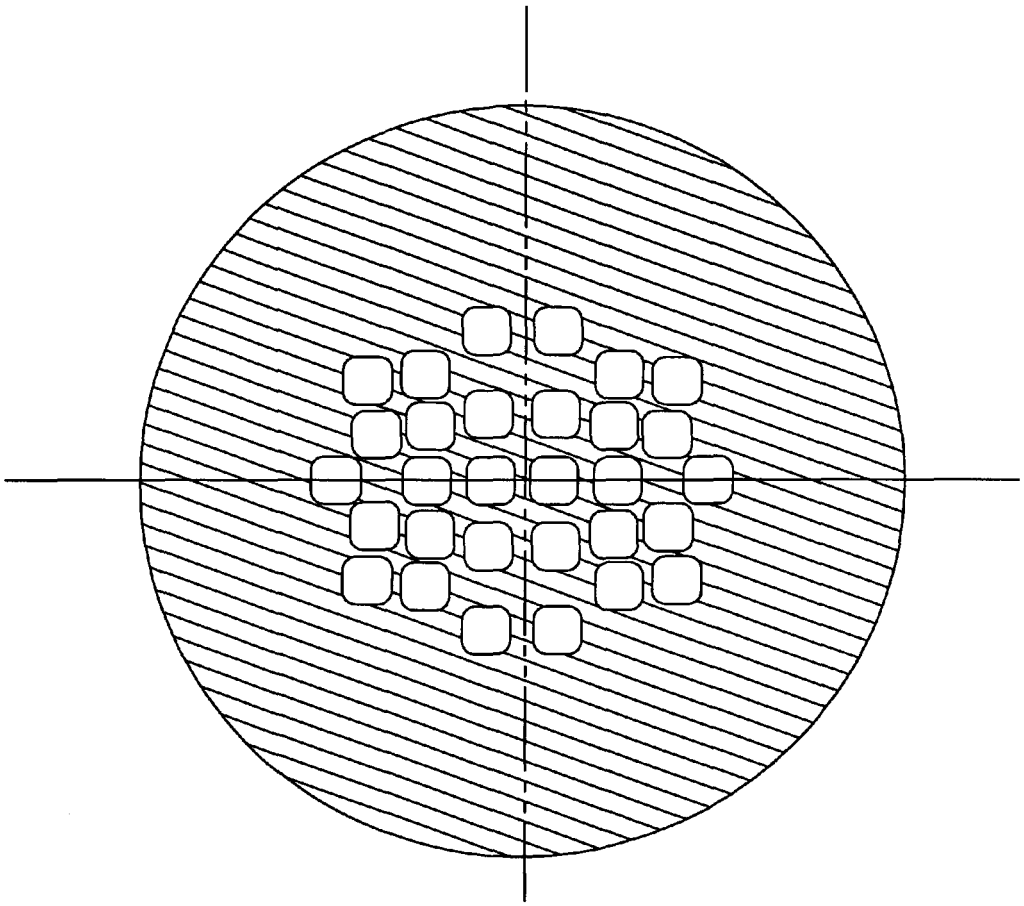
Fig. 5a



Sec. E.1

Section 0-E

Fig. 5b



Section E.1

Fig. 5b

Patented Apr. 14, 1936 2,037,187

UNITED STATES PATENT OFFICE

2,037,187

SOUND TRANSLATING DEVICE

Edward C. Wente, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application March 28, 1933, Serial No. 663,133

16 Claims. (Cl. 179—115.5)

This invention relates to sound translating devices and more particularly to loudspeakers of the horn type.

In the translation of sound, for example, in the transmission or reproduction of speech and music, it is desirable that the translating device be capable of transmitting or reproducing all the frequencies of importance in the audio frequency range with fidelity and with uniform intensity and efficiency. Horn type loudspeakers, in general, have a relatively low cut-off so that the higher sound frequencies and hamonics are in effect suppressed and high quality reproduction of speech and music, therefore, is not obtained. This cut-off characteristic is traceable in a large measure to the fact that the sound waves emanating from the various portions of the diaphragm of the loudspeaker traverse paths of unequal length in passing to the throat of the horn so that the sound waves propagated from all points of the diaphragm do not reach the throat of the horn in phase. For the low frequency waves the disparity in phase is not particularly detrimental but at the higher frequencies the phase difference is sufficient to cause a marked neturalization of the sound waves so that the high frequencies of speech and music are diminished in intensity or materially suppressed.

One object of this invention is to reproduce speech and music efficiently and faithfully throughout a wide range of frequencies.

In accordance with a feature of this invention, a plurality of sound ducts of substantially equal length are provided between one surface of a diaphragm in a loudspeaker and the throat of a horn acoustically coupled therewith, so that sound waves emanating from all parts of the radiating portion of the diaphragm traverse paths of substantially equal length in passing to the thoat of the horn and hence reach the throat substantially in phase.

In a specific embodiment of this invention, a loudspeaker comprises a magnet having coaxial pole pieces disposed one within the other, the inner of said pole pieces having a bore therein adapted to be coupled at one end to the throat of a horn. A diaphragm is mounted adjacent the other end of the bore and is provided with a dome-shaped portion in axial alignment with the bore. A tapered or conical and a plurality of hollow tapered or substantially frusto-conical members are disposed intermediate the dome-shaped portion of the diaphragm and the adjacent end of the bore in the inner pole piece and are spaced to provide a plurality of annular sound ducts extending from immediately adjacent the surface of the diaphragm directed toward the bore, and converging with respect to the axis of the bore. The conical members may be so designed that the area of the sound ducts increases exponentially toward the bore and preferably with the same taper as the horn.

The invention and the various features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings in which:

Fig. 1 is a side view partly in cross-section of a horn type loudspeaker illustrative of one embodiment of this invention;

Fig. 2 is an end view of the loudspeaker shown in Fig. 1 with portions broken away to show details of construction more clearly;

Fig. 3 is an enlarged detail view in cross-section illustrating the manner in which the leading-in conductors for the driving coil are brought out to external terminals; and

Fig. 4 is a fragmentary view showing another way in which the leading-in conductors for the driving coil may be brought out to external terminals.

Fig. 5 is an exploded view in persepctive showing the form of the members forming a plurality of sound ducts extending from adjacent one surface of the diaphragm to the sound passageway or bore in the magnet.

Referring now to the drawings, the loudspeaker shown therein comprises a magnet having inner and outer poles 10 and 11, the pole 10 having a cylindrical opening or bore 12 extending therethrough. The lateral cross-sectional area of the bore may increase exponentially toward the outer end, i. e., toward the right in Fig. 1. An excitation or field coil 13, which may be of a construction disclosed in a copending application of Albert L. Thuras, Serial No. 622,191, filed July 13, 1932, encircles the inner pole 10 and is insulated from the magnet by insulators 14. Metallic extensions 15 of the coil 14 are engaged by extensions 16 of the terminals 17 which are mounted on an insulating block 18 secured to the outer pole 11. The extensions 16 pass through apertures in the pole 11 and are insulated from the pole by bushings or sleeves 19. An annular pole piece 20 is provided with a shoulder 21 threaded into the pole 10. Another annular pole piece 22 is positioned on the outer pole 11 by dowel pins 23 and is secured thereto by screws 24. The pole pieces 20 and 22 are coaxially disposed and are spaced to form a narrow, annular air gap 25.

A diaphragm is mounted upon the magnet and comprises a central dished or dome-shaped portion 26, a flat peripheral portion 27, and a troughed flexible portion 28 intermediate the central and peripheral portions. The diaphragm may be of a single piece of lightweight material, such as duralumin. The peripheral portion 27 of the diaphragm is fixed on the outer pole piece 22 together with an insulating washer 29, by a

clamping ring 30 which is secured to the pole piece 22 by a plurality of screws 31.

The diaphragm is actuated by an annular driving coil 32 which is carried by a cylindrical sleeve 33 secured to the diaphragm at substantially the base of the dished or dome-shaped portion 26, and is disposed in the air gap 25. The driving coil 32 may be of the construction disclosed in Patent 1,707,544 granted April 2, 1929 to Albert L. Thuras. The diaphragm is provided with a pair of small apertures at substantially the intersection of the central and flexible portions 26 and 28, respectively in each of which an insulating bushing or sleeve 34 is secured. Leading-in conductors 35 for the driving coil, which may be integral extensions of the coil, extend loosely through a corresponding one of the sleeves 34 and outwardly to terminals 36 which are mounted on an insulating member 37 secured to the pole piece 22. This construction insures a distribution of the flexing stresses in the conductors 35, occasioned by the vibrations of the diaphragm, throughout a large portion of the conductors so that rupture of the conductors is prevented. To further insure against breakage of the conductors, damping means, for example thin vanes 59, of paper or the like, are provided to prevent local and resonant vibrations in the conductors. Breakage of the leads may be prevented also as shown in Fig. 4 by enclosing a portion of the leading-in conductors in an inflexible tubular member or sleeve 60 fixedly mounted adjacent a terminal 61. The inner diameter of the tubular member 60 is appreciably greater than the dimensions of the leading-in conductors so that the conductor will have limited freedom of movement.

In order to prevent the passage of sound waves through the air gap, the gap is sealed at the end remote from the diaphragm by an annular troughed member 38 of non-magnetic material such as brass which is secured to the pole piece 20 by a plurality of screws 39 and is spaced from the pole piece 22 by a washer or shim 40.

The surface of the diaphragm remote from the magnet may be encased by a dome-shaped cover 41 which is provided with a plurality of lugs or flanges 42 and is secured upon the pole piece 22 by screws 43 extending through the lugs or flanges. The cover is provided with a plurality of relatively large apertures 44 of sufficient area to prevent the air in the space between the cover and the diaphragm from materially affecting the vibrations of the diaphragm, and carries a protective screen 45.

A horn 46 abuts against the end of the pole 10 remote from the diaphragm and is secured to the magnet by a clamping ring 47 which is threaded to the magnet and is provided with a flange 48 which bears against a shoulder on a flange member 49 secured to the horn by screws 50.

In order to insure uniform reproduction of a wide range of frequencies of importance in speech and music, means are provided, in accordance with this invention, for preventing suppression of any, particularly the higher, frequencies. To this end, a multisection acoustic transducer or plug is provided intermediate one surface of the diaphragm and the end of the horn in acoustic communication with the surface.

As shown more clearly in Fig. 5, in one form, such a transducer or plug comprises a central substantially conical member 51 and a plurality of hollow substantially frusto-conical members 52, 53 and 54, disposed one within the other and coaxial with the conical member 51. The conical member 51 and frusto-conical members 52, 53 and 54 are rigidly secured together in spaced relationship by a plurality of keys 55 which fit into slots 56 in the several members. The inner surface of the pole piece 20 is dished to conform approximately to the outer surface of the frusto-conical member 54 and is provided with a plurality of slots 57 into which keys 58 may be fitted. The end of the conical and frusto-conical members toward the diaphragm is smoothly rounded to correspond accurately to the portions of the diaphragm in juxtaposition thereto. Preferably the conical and frusto-conical members are so positioned that the clearance between the diaphragm and the ends of the members thereadjacent is but slightly greater than the maximum displacement of the driving coil.

As will be seen more clearly from Fig. 2, the conical member 51 and the frusto-conical members 52, 53 and 54 together with the pole piece 20 provide a plurality of coaxial annular sound ducts extending from the diaphragm, toward the opening or bore 12 in the pole 10 and converging away from the diaphragm. The several elements noted are so proportioned that the passageways formed thereby are of substantially equal length and are equally spaced at the ends toward the diaphragm. Preferably these elements are so proportioned that the aggregate cross-sectional area thereof in planes at right angles to the sound paths increases exponentially away from the diaphragm. This construction provides a plurality of paths of substantially equal length so that sound waves emanating from all points of the central portion 26 of the diaphragm traverse paths of substantially the same length in passing to the throat of the horn 46 and hence arrive at the throat of the horn substantially in phase. Another feature of this construction is that a substantially plane wave front is obtained at the end of the bore 12 directed toward the diaphragm. Neutralization of the waves at the higher frequencies of speech and music is therefore prevented and speech and music may be reproduced with uniformity and fidelity throughout a wide range of frequencies.

Although a specific embodiment of the invention has been shown and described, it will be understood of course, that modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. A sound translating device comprising a diaphragm, and means adjacent one surface of said diaphragm forming a plurality of sound ducts of substantially equal length disposed one within another and converging away from said surface.

2. A sound translating device comprising a diaphragm, and at least three nested tapered members adjacent one surface of said diaphragm, spaced to form a plurality of annular sound passageways of substantially equal length disposed one within another and converging away from said surface.

3. A sound translating device comprising a diaphragm and at least three conical members disposed one within another each having one end adjacent said diaphragm, said ends jointly conforming to substantially one entire surface of said diaphragm, said members being spaced to form a plurality of coaxial sound passageways converging away from said diaphragm.

4. A sound translating device comprising a

diaphragm having a central radiating portion, and at least three spaced members adjacent said central portion having portions conforming to and substantially coextensive with said central portion forming a plurality of annular sound passageways disposed one within another and converging away from said central portion.

5. A sound translating device comprising a diaphragm having a dished central portion, and a plug member having one end in immediate juxtaposition to and substantially coextensive with one surface of said central portion and conforming thereto, said plug member including at least three sections spaced to form a plurality of tubular sound ducts acoustically associated with said central portion and converging away therefrom.

6. A sound translating device comprising a diaphragm having a dome-shaped central portion, and an acoustic transducer having one end conforming to and substantially coextensive with said central portion, said transducer including at least three nested tapered members spaced to form a plurality of coaxial sound passageways terminating adjacent said central portion and converging away therefrom.

7. A sound translating device comprising a diaphragm, means forming a sound duct having one end acoustically associated with one surface of said diaphragm, and a plurality of nested tapered members intermediate said one end and said surface, said members being spaced to form a plurality of tubular sound passageways of substantially equal length between said surface and said one end.

8. A sound translating device comprising a diaphragm, means forming a sound duct acoustically associated at one end with one surface of said diaphragm, and at least three nested conical members adjacent said one surface, said members being spaced to form a plurality of coaxial annular passageways of substantially equal length between said surface and the one end of said duct.

9. A sound translating device comprising a diaphragm, means forming a sound duct having one end acoustically associated with one surface of said diaphragm, and an acoustic transducer intermediate said one surface and said duct having a portion adjacent said one surface and substantially coextensive and in conformity with the radiating portion of said diaphragm, said transducer comprising at least three sections spaced to form a plurality of annular passageways disposed one within another and extending between said one surface and the one end of said duct.

10. A sound translating device comprising a diaphragm, means forming a sound duct acoustically associated with one surface of said diaphragm, and a plug member intermediate said one surface and said duct, said plug member including at least three nested conical members having their bases adjacent said diaphragm, said conical members being spaced to form a plurality of coaxial sound passageways of substantially equal length extending from said diaphragm and converging toward said duct.

11. A sound translating device comprisng a diaphragm having a dished central portion, means forming a sound duct having a tubular portion in axial alignment with said central portion, and a plug member intermediate said central portion and said duct, said plug member including a plurality of nested conical members having their bases in proximity to and conforming with said central portion, said conical members being spaced to form a plurality of tubular sound passageways of substantially equal length extending between said central portion and said duct and being coaxial therewith.

12. A sound translating device comprising a magnet having inner and outer poles, said inner pole having a bore extending therethrough, a diaphragm adjacent one end of said bore, and a plug member carried by said inner pole and disposed intermediate said diaphragm and said bore, said plug member comprising a plurality of sections spaced to form a plurality of tubular sound passageways disposed one within another, extending from said diaphragm and converging toward said bore.

13. A sound translating device comprising a magnet having inner and outer poles, said inner pole having a bore extending therethrough, a diaphragm adjacent one end of said bore, and at least three nested members carried by said inner pole and disposed adjacent said diaphragm, said members being spaced to form a plurality of annular sound passageways of substantially equal length extending between said diaphragm and the one end of said bore.

14. A loudspeaker comprising a magnet having inner and outer poles, said inner pole having a bore extending therethrough, a pair of pole pieces mounted on said poles and spaced to form an annular air gap, the inner of said pole pieces having an aperture therein in axial alignment with said bore, a diaphragm mounted on the outer of said pole pieces and having a central portion adjacent the aperture in said inner pole piece and substantially coextensive therewith, an actuating coil connected to said diaphragm and disposed in said air gap, and a plurality of conical members having one end in juxtaposition to said central portion, and extending into said aperture, said members being spaced to form a plurality of sound passageways of substantially equal length between said central portion and said bore and coaxial with said bore.

15. A sound translating device comprising a magnet having a bore extending therethrough, a horn connected to one end of said magnet and acoustically coupled to one end of said bore, a diaphragm mounted on the opposite end of said magnet and having one surface acoustically associated with the other end of said bore, and means including a plurality of nested members providing a plurality of sound passageways of substantially equal length between different portions of said surface of said diaphragm and a portion of said bore.

16. A sound translating device comprising a magnet having a sound passageway extending between opposite ends thereof, a horn connected to one end of said magnet and acoustically coupled to one end of said passageway, a diaphragm mounted on the opposite end of said magnet and having one surface acoustically associated with the other end of said passageway, means including a plurality of members disposed one within another and spaced to provide a plurality of sound ducts of substantially equal length between said one surface of said diaphragm and a portion of said bore, and a screen member mounted on said magnet and overlying said diaphragm.

EDWARD C. WENTE.

E. C. WENTE

April 14, 1936. SOUND TRANSLATING DEVICE 2,037,187

Filed March 28, 1933 2 Sheets-Sheet 1

FIG. 1

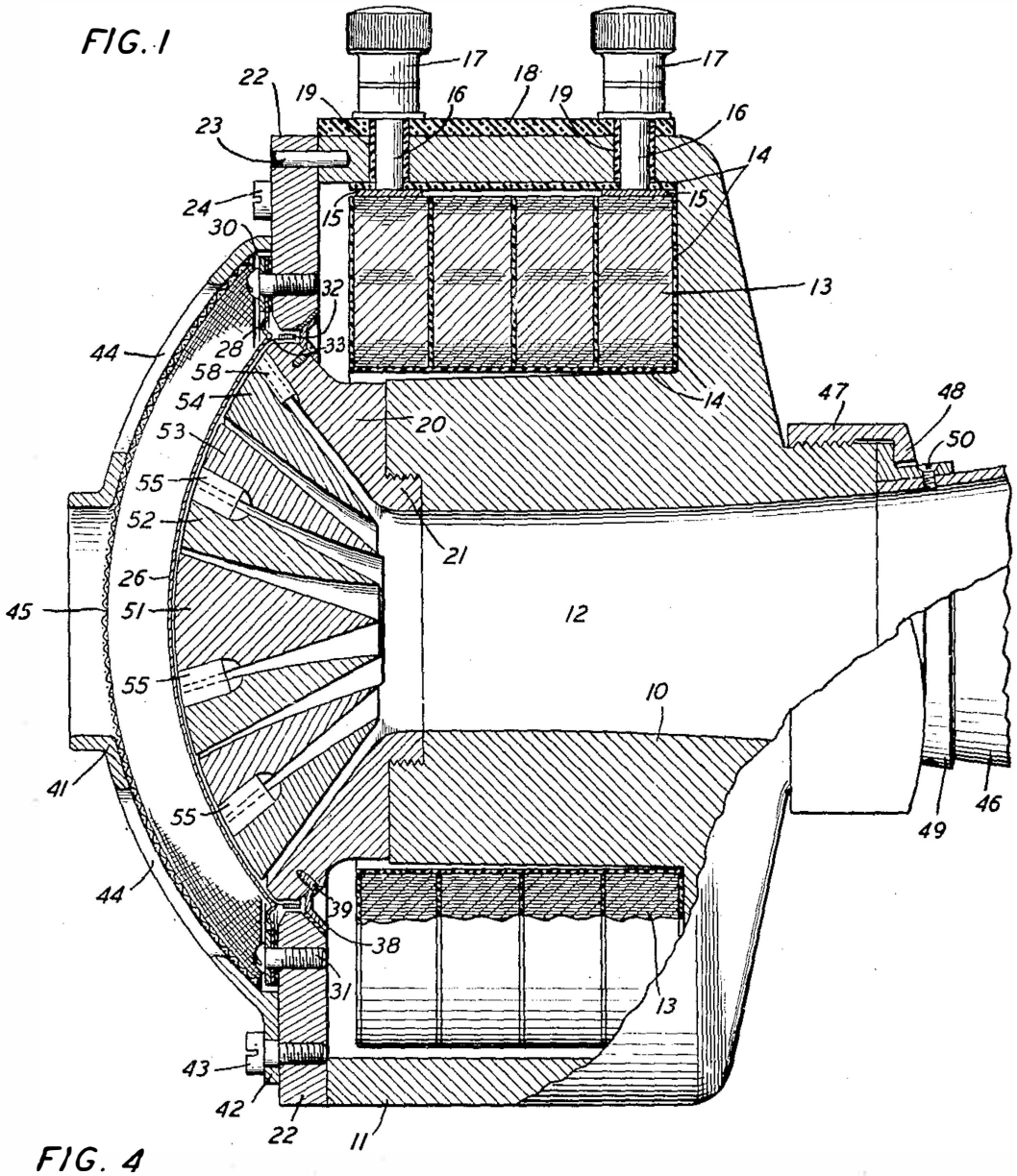
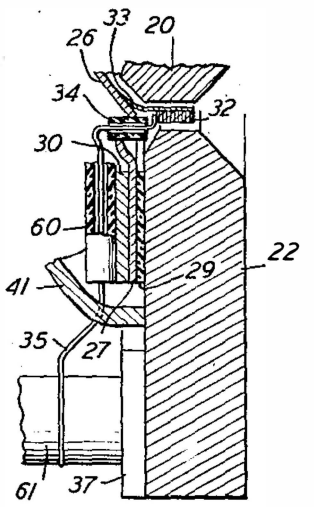


FIG. 4



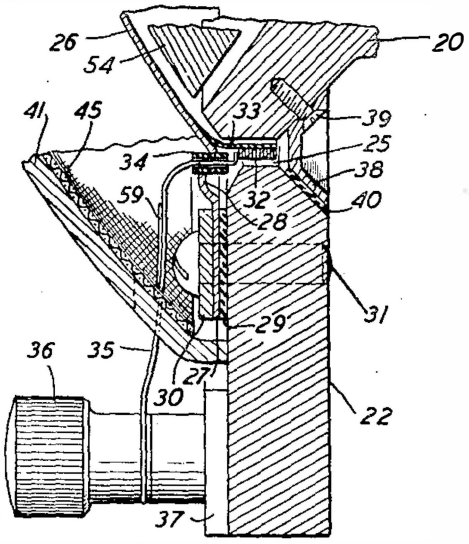


FIG. 3

INVENTOR
E. C. WENTE

BY
Walter C. Kiesel
ATTORNEY

E. C. WENTE

April 14, 1936. SOUND TRANSLATING DEVICE 2,037,187

Filed March 28, 1933 2 Sheets-Sheet 2

FIG. 2

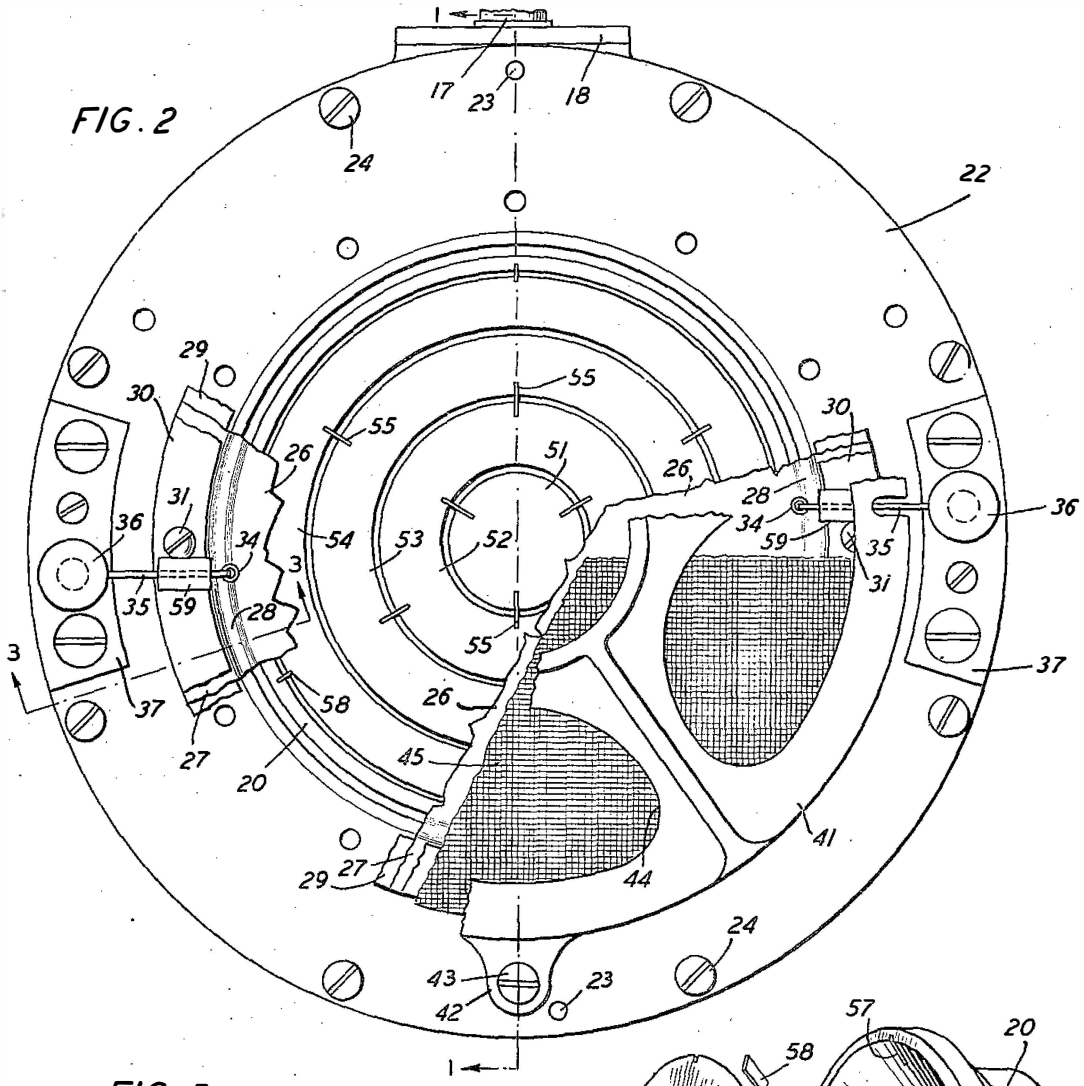
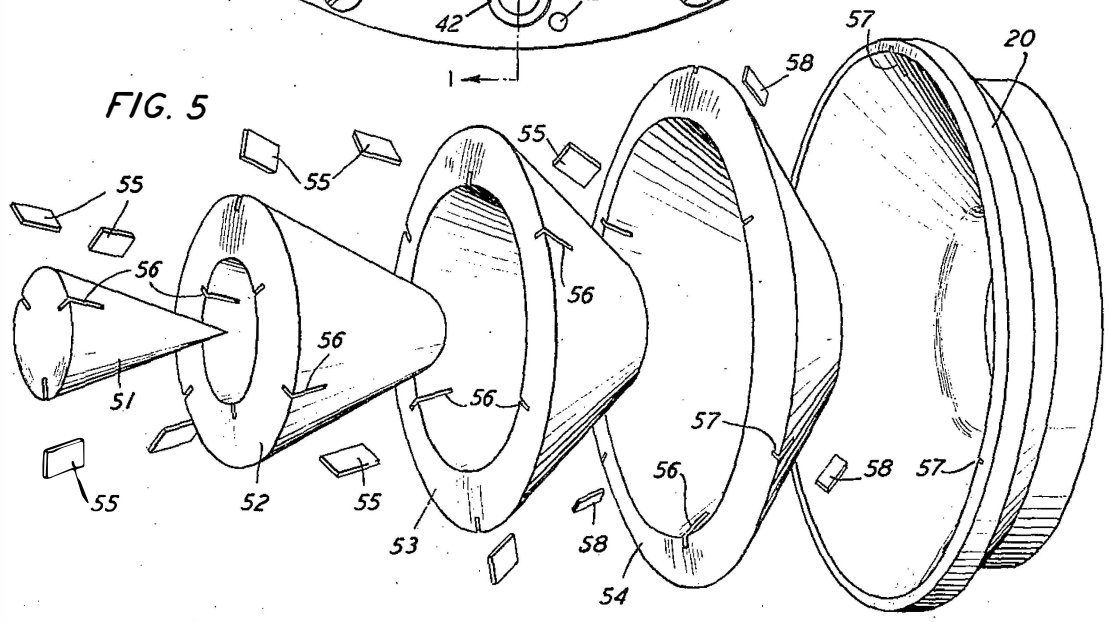


FIG. 5



INVENTOR
E.C.WENTE
BY Walter C. Kiesel
ATTORNEY

United States Patent [19]

Henricksen

[11] **4,050,541**

[45] **Sept. 27, 1977**

[54] **ACOUSTICAL TRANSFORMER FOR HORN-TYPE LOUDSPEAKER**

[75] Inventor: **Clifford A. Henricksen,** Yorba Linda, Calif.

[73] Assignee: **Altec Corporation,** Anaheim, Calif.

[21] Appl. No.: **678,873**

[22] Filed: **Apr. 21, 1976**

[51] **Int. Cl.**[2] **G10K 11/06**

[52] **U.S. Cl.** ..... **181/159;** 181/185; 179/115.5 H

[58] **Field of Search** ..... 181/159, 177, 184–188; 179/115.5 H

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,037,187	4/1936	Wente	181/159 X
2,183,528	12/1939	Blackburn	181/159
2,858,377	10/1958	Levy	181/159 X
2,942,071	6/1960	Witchey	181/159 X
3,852,529	12/1974	Schafft	179/1 MG

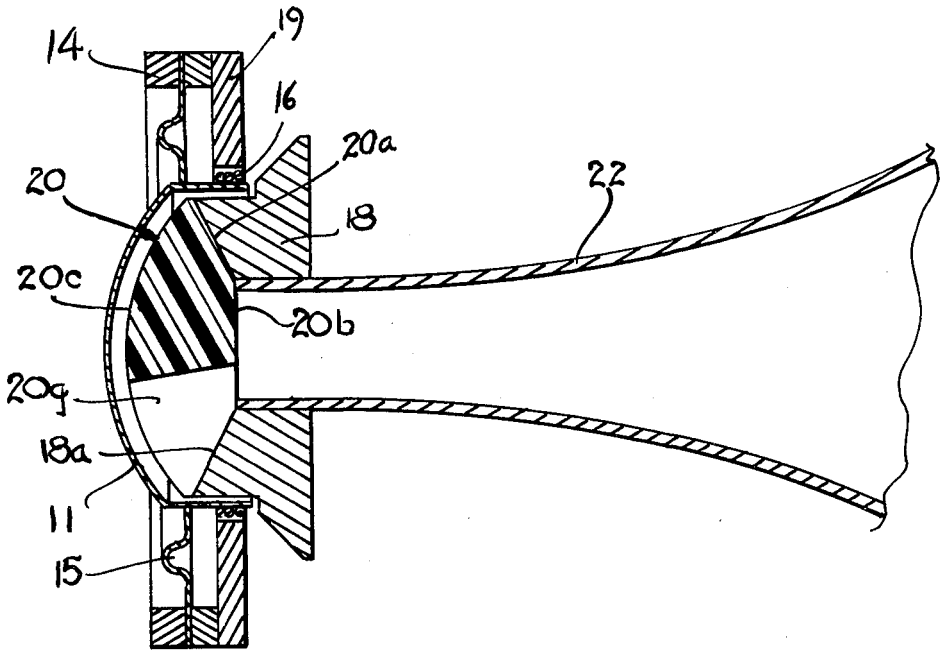
Primary Examiner—Lawrence R. Franklin

Attorney, Agent, or Firm—Edward A. Sokolski

[57] **ABSTRACT**

An acoustical transformer or "phasing plug" for coupling sound from a speaker diaphragm to the throat of a horn. The phasing plug of the invention is in the general shape of a dome on one side and a truncated cone on the other, and has evenly spaced radial slots or channels formed therein, these slots forming air passageways for propagation of the soundwaves. The walls of the slots are tapered exponentially from their inlet ends at the speaker diaphragm towards a flat plane outlet at the throat of the horn, to provide an optimum impedance match between the output of the diaphragm and the input of the horn; the sound channels formed by the slots exponentially increasing in area between their inlets and outlets. Transformation from a spherical wave front at the input to a plane wave front at the outlet is assured by the shaping of the channels to make the distances between corresponding points at the channel inlets and outlets equal to each other.

12 Claims, 9 Drawing Figures



ACOUSTICAL TRANSFORMER FOR HORN-TYPE LOUDSPEAKER

This invention relates to horn-type loudspeakers, and more particularly to an improved acoustical transformer or phasing plug for use in such loudspeakers.

In horn type loudspeakers, an acoustical transformer, commonly known as a "phasing plug", is used to impedance match the output of the speaker diaphragm to the throat of the horn. The design of this transformer is particularly important to assure good frequency response in the high frequency range (above 7 kHz). Generally a throat diameter which is small compared with that of the diaphragm is utilized.

In the prior art, acoustical transformers have generally taken the form of a plurality of annular concentric channels tapered outwardly from their inlets to their outlets. This type of transformer or phasing plug operates quite efficiently. However, it is somewhat difficult and expensive to construct in that it cannot be molded in one piece due to difficulties in removing this type of structure from a mold. to obviate this shortcoming, various attempts have been made to design speaker plugs utilizing radial slots or channels. Such prior art devices are described in U.S. Pat. No. 2,832,844 to Matsuoka, and U.S. Pat. No. 2,183,528 to Blackburn. In U.S. Pat. No. 2,832,844, the acoustic transformer has radial slots which are rectangular in cross-section. There is no coupling transition provided between the diaphragm output and the throat of the horn, as in the present invention. In U.S. Pat. No. 2,183,528, an attempt is made to impedance match the output of the diaphrgm to the horn throat by flaring the channels. In the device of U.S. Pat. No. 2,183,528, however, there is no exponential expansion of the channels to provide a smooth transition in coupling the sound between the diaphragm and the throat of the horn and for converting the spherical wave front of the sound waves radiated by the diaphragm to a planar wave front for coupling to the throat, as in the present invention. Further, in the device of this patent, an air space is left between the phasing plug and the sides of the pole piece at the output end of the plug, which is likely to produce distortion. In the device of the present invention, no such air space is allowed, i.e., the phasing plug matingly abuts against the pole piece thereby permitting full control of the airflow in each of the similar exponential channels, and avoiding the development of distortion compnents. To avoid loss of frequency response at higher frequencies of interest the spacing between adjacent channels is minimized. Further, in a preferred embodiment of the present invention, a prime number of channels is used which minimizes the generation of harmonic components in the diaphragm, this design parameter not being taught or suggested in either of these prior art patents.

It is therefore an object of this invention to provide a phasing plug which is easier and more economical to fabricate.

It is another object of this invention to provide a phasing plug utilizing radial sound channels having improved efficiency and lower distortion than prior art plugs utilizing radial channels.

It is still a further object of this invention to provide a phasing plug for loudspeakers using radial sound coupling channels capable of transforming a spherical wavefront at its input to a plane wavefront at its output.

Other objects of this invention will become apparent as the description proceeds in connection with the accompanying drawings, of which:

FIG. **1** is a cross-sectional view of a preferred embodiment of the invention as incorporated into a horn-type loudspeaker;

FIG. **2** is a plan view illustrating the input side of the preferred embodiment;

FIG. **3** is a plan view illustrating the output side of the preferred embodiment;

FIB. **4** is a diagrammatic view illustrating the walls of the channels of the preferred embodiment;

FIG. **5** is a diagrammatic view illustrating dimensional relationships of the channel separator "slices" of the preferred embodiment;

FIG. **6** is a side elevational view of the preferred embodiment installed in a pole piece unit;

FIGS. **7A** and **7B** are perspective views of the channel separator "slices" of the preferred embodiment; and

FIG. **8** is a plan view of the sound input end of an alternative embodiment of the invention.

Briefly described, the device of the invention is as follows: The phasing plug has a dome shaped surface on its sound input side and a truncated cone shaped surface on the opposite side. A plurality of radial slots or channels are formed between the two surfaces, there preferably being a prime number of such channels. Each of the channels is used to impedance match the output of the speaker diaphragm to the input of the horn and expands exponentially from its inlet, which receives sound from the speaker diaphragm, to its outlet which is in the form of a plane and which feeds the sound to the throat of the horn. The distances between corresponding points along the arcuate inlet of each channel and the flat outlet thereof are all equal to each other, to make for optimum transformation of the sound waves from a spherical to a planar wavefront. Further, the separation between adjacent channels of the plug is made small enough so that a resonant stading wave will not appear within the frequency range of desired operation. In an alternative embodiment of the invention, an aperture is placed in the central ("core") portion of the phasing plug to further prevent such a resonant condition at any frequency of interest. In the preferred embodiment, a prime number of channels is used to minimize the generation of harmonic signals.

Referring now to FIG. **1**, a preferred embodiment of the invention is shown as installed in a horn-type speaker. The speaker diaphragm **11** is resiliently supported on speaker frame **14** by means of spider **15.** A voice coil **16** is wound on the coil form portion of the diaphragm structure and is located in the magnetic gap formed between pole piece elements **18** and **19.** An acoustical transformer or phasing plug **20** is mounted with a portion of surface **20*a*** thereof, which is shaped in the form of a truncated cone, in abutment against the mating surface **18*a*** of pole piece **18.** The central portion of the inner periphery of the phasing plug is formed by sharp straight line edges **20*b*** and flat surfaced plug portion **20*f.*** The outer surface **20*c*** of the phasing plug is dome shaped and is positioned opposite diaphragm **11.** The sphericity of surface **20*c*** corresponds to that of the diaphragm. The straight line edges **20*b*** are positioned opposite the throat of horn **22.** Sound is coupled through the radial channels formed in phasing plug **20** from spherical diaphragm **11** which radiates sound having a spherical wave front, to the throat of horn **22,** the spherical wave front being transformed to a planar

wave front by the phasing plug, as to be described further on in the specification.

Referring now to FIGS. **2** and **3**, a preferred embodiment of the phasing plug of the invention is illustrated. The input side of the plug, as illustrated in FIG. **2**, has a dome shaped surface **20***c*, while the opposite formed by surfaces **20***a* along with central straight line edges **20***b* and central portion **20***f* is generally in the form of a truncated cone. A plurality of radial channels **24**, which extend between surfaces **20***c* and **20***a*, are formed between plug sections or "slices" **20***e*, the side wall portions **20***g* of the sections having an exponential curvature. The central or "core" portion **20***f* of the plug is conically shaped, the central portions **20***h* (see FIG **7B**) of the "slices" running along the sides of the cone.

For cnvenience of illustration, the plug sections or "slices" are shown in FIGS. **7A** and **7B** as separate elements. It is to be understood, however, that the plug is fabricated as an integral unit and there are no such separate pieces. Surface **20***g* is quadric, i.e., it has an exponential curvature. Surface **20***c* is spherical to match the sphericity of the speaker diaphragm. Surface **20***a* is conical to mate with the pole piece **18**. Surface **20***h* is conical to mate with conical plug section **20***f*. Edge **20***b* runs in a straight line.

Referring now to FIG. **6**, the preferred embodiment of the phasing plug as installed in pole piece **18** is illustrated. Surface portions **20***a* abut against the dished surface of the pole piece in mating relationship therewith, leaving no space therebetween, while the edge portions **20***b* are opposite the central apertured portion of pole piece **18**.

Referring now to FIGS. **4**, **7A** and **7B**, the exponential curvature of the side surfaces **20***g* of the channels is such that the straight line distances $\mathbf{1}_1$–$\mathbf{1}_n$ between corresponding points on curved surface **20***c* and straight edge **20***b* are all equal, i.e., if we divide surface **20***c* and edge **20***b* into the same number of equal parts, then, if line $\mathbf{1}_n$ is made equal to line $\mathbf{1}_1$, the lengths of the lines, $\mathbf{1}_2$, $\mathbf{1}_3$ . . . , $\mathbf{1}_{n-1}$ forming the edges of each of these parts will all be substantially equal to each other. This is illustrated in FIG. **4** where, as can clearly be seen by further reference to FIG. **6**, "*r*" is the length of the arc between the outer and inner top edge of each of plug sections **20***e* and "*z*" is the length of the edge portions of each of these sections. The straight lines "$\mathbf{1}_1$-$\mathbf{1}_n$" join together corresponding equispaced points along "*r*" and "*z*". The curvature of surface **20***g* is made such that lines $\mathbf{1}_1$-$\mathbf{1}_n$ are all equal to each other. As already noted, the curvature of surface **20***c* is made to match that of the speaker diaphragm, while edge **20***b* is made planar to match the throat of the horn. Flat surface **20***a* of the plug fits tightly against surface **18***a* of pole piece **18**, so that the sound energy is closely directed through channels **24** to the throat of the horn, there being no superfluous air spaces between adjacent channels.

In the preferred embodiment, a prime number of channels is provided, in the illustrative embodiment this number being **11**. This minimizes the development of harmonic signals on the diaphragm with its resultant distortion.

Referring now to FIG. **5**, certain dimensional relationships for optimum design of the plug are schematically illustrated. The dimension "$\mathbf{1}_d$" shown in FIG. **5** is the distance between the center of each of plug segments **20***e* and the center of each adjacent channel **24**, as measured at the outer periphery of each such segment. The dimension "$\mathbf{1}_d$" is preferably made as small as feasible and should in any event be less than a quarter-wave length at the highest frequency of interest. This is because the quarter-wave resonance provided by the dimension "$\mathbf{1}_d$" in effect operates as a turning stub which attenuates soundwaves at and near this resonant frequency.

Referring now to FIG. **8**, a modified embodiment of the invention is illustrated. This embodiment is the same as the previous embodiment except for the inclusion of an aperture **35** which is formed in the center portion **20***f* of the plug. The use of this aperture tends to prevent the formation of resonant acoustic paths and thus tends to improve the operation of the plug at the higher frequencies. The use of such an aperture is particularly helpful with larger sized phasing plugs.

While the invention has been described and illustrated in detail, it is to be clearly understood that this is intended by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the invention being limited only by terms of the following claims.

I claim:

1. An acoustical transformer for coupling sound from a dome shaped speaker diaphragm to the planar throat of a horn comprising a member having

a dome shaped surface having a curvature corresponding to that of said diaphragm,

a surface opposite said dome shaped surface having a truncated conical shape,

a central plug portion,

a plurality of radial slots formed in said member, said slots being spaced from each other around said member and extending through said member between the opposite surfaces thereof, running from said plug radially outwardly to the outer edges of said member,

sections of said member being formed between said slots, the opposite wall surfaces of adjacent member sections having an essentially exponential curvature, said slots forming essentially exponentially tapered sound channels, the sound entry end of said channels being along said dome shaped surface, the sound exit end of said channels being along the truncated end of said opposite surface, said truncated end being planar, the distances between corresponding points along the wall surfaces at the entry ends and the exit ends of said channels being substantially equal,

whereby sound waves generated by said diaphragm having a spherical wave front and entering the channels at the entry end thereof are transformed to waves having a planar wave front at the exit end thereof for coupling to the throat of said horn.

2. The acoustical transformer of claim **1** wherein said central plug portion has a truncated conical shape tapering inwardly between the dome shaped surface and the truncated end of said conical surface.

3. The acoustical transformer of claim **1** wherein the ends of the channel walls along the truncated end of said opposite surface have sharp edges.

4. The acoustical transformer of claim **1** wherein the plug portion has an aperture formed therethrough extending between said opposite surfaces.

5. The acoustical transformer of claim **1** wherein the distance between the centers of said sections at the outermost periphery thereof and the centers of said channels is less than a quarter-wavelength at the maximum frequency of the sound waves to be transformed.

6. The acoustical transformer of claim 1 wherein the number of said channels is a prime number.

7. In a horn type loudspeaker,

a dome shaped speaker diaphragm,

a horn having a planar throat,

a cylindrical member having an aperture formed through its center and having a conically dished portion surrounding said aperture, and

an acoustical transformer for coupling the sound output of said diaphragm to the throat of the horn, said transformer comprising a member having

a dome shaped surface with a curvature corresponding to that of said diaphragm and positioned directly opposite the diaphragm,

a truncated conical surface opposite said dome shaped surface, the truncated end of said truncated conical surface being planar and positioned directly opposite the horn throat and in a plane parallel to that of the throat, the sides of said conical surface fitting snugly in the conically dished portion of the cylindrical member,

a central plug portion extending between said opposite surfaces,

a plurality of radial slots formed around said member and extending therethrough between the opposite surfaces thereof, said slots running from said plug portion radially outwardly to the outer edges of said member,

sections of said member being formed between said slots, the opposing wall surfaces of adjacent sections forming said slots being essentially quadric said slots forming essentially exponential sound channels running between said diaphragm and said horn throat, the distances between corresponding points along each of said wall surfaces at the diaphram ends and the horn throat ends of said channels being substantially equal,

whereby the spherical wavefronts of waves generated by said diaphragm are transformed by the transformer to planar wavefronts for coupling to the horn throat.

8. The combination of claim 7 wherein said cylindrical member comprises a pole piece.

9. The combination of claim 7 wherein the ends of the channel walls along the truncated end of said truncated conical surfaces have sharp edges.

10. The combination of claim 7 wherein the plug portion has a truncated conical shape tapering inwardly from the dome shaped surface to the truncated portion of said truncated conical surface.

11. The combination of claim 7 wherein the number of said channels is a prime number.

12. The combination of claim 7 wherein said plug portion has an aperture extending therethrough extending between said opposite surfaces.

* * * * *

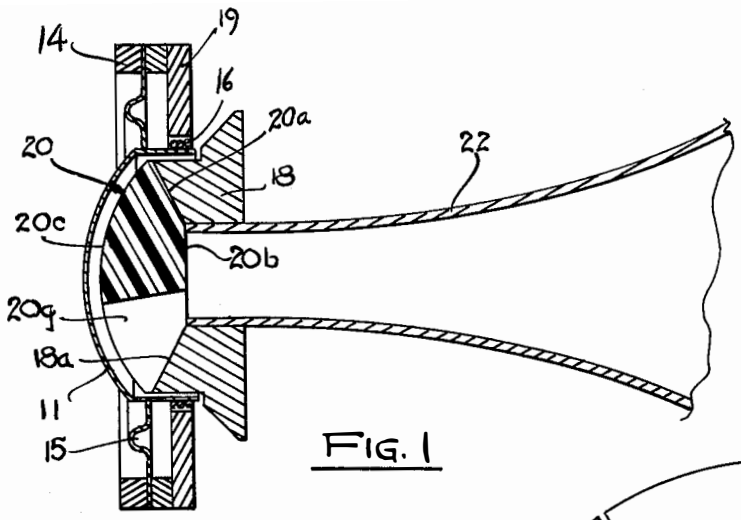


FIG. 1

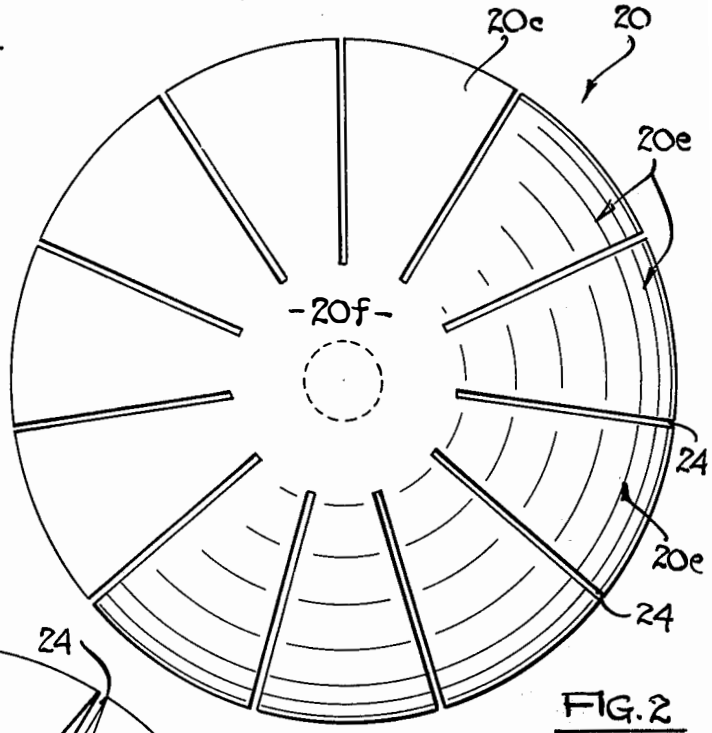


FIG. 2

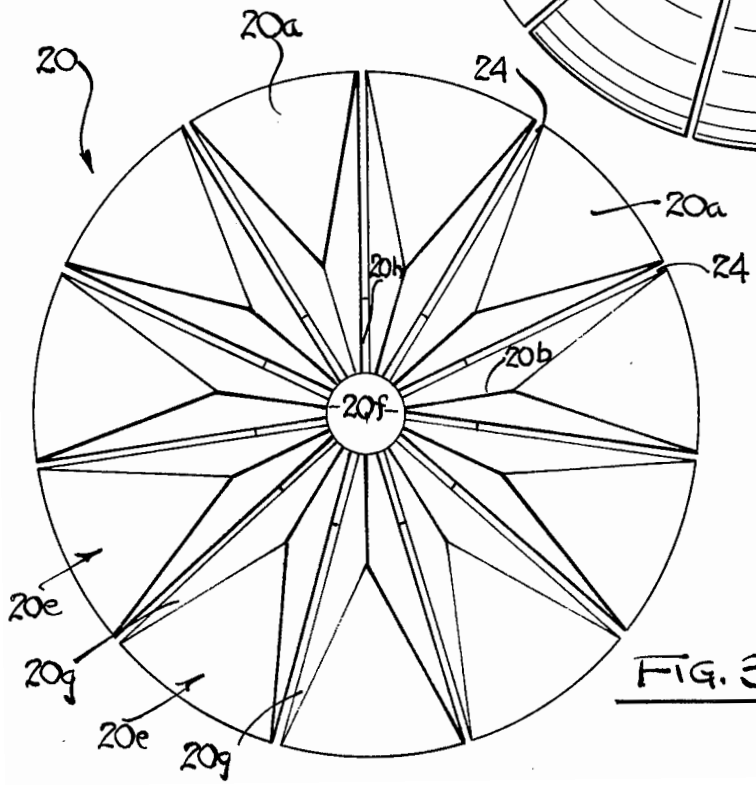


FIG. 3

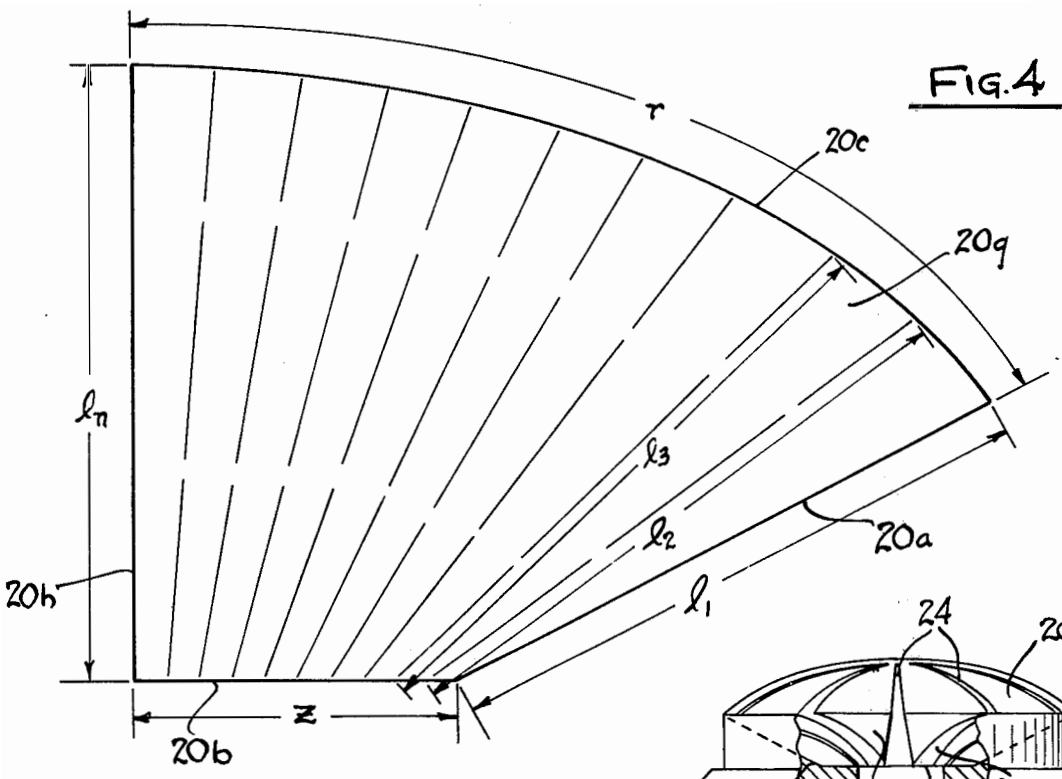


FIG. 4

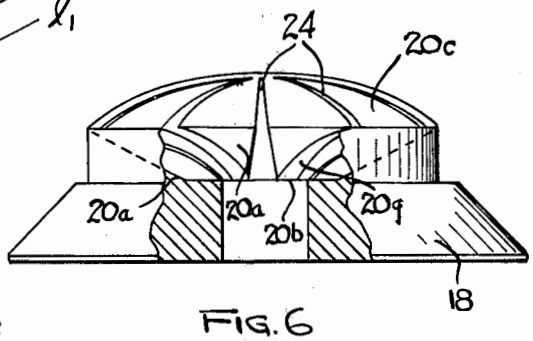


FIG. 6

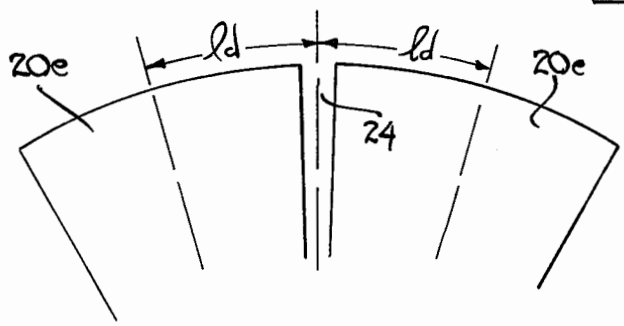


FIG. 5

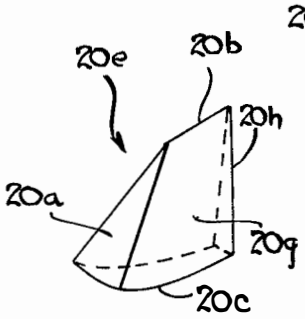


FIG. 7A

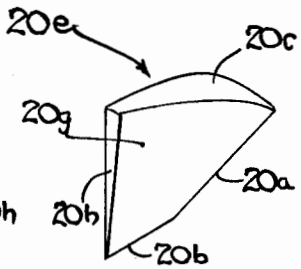


FIG. 7B

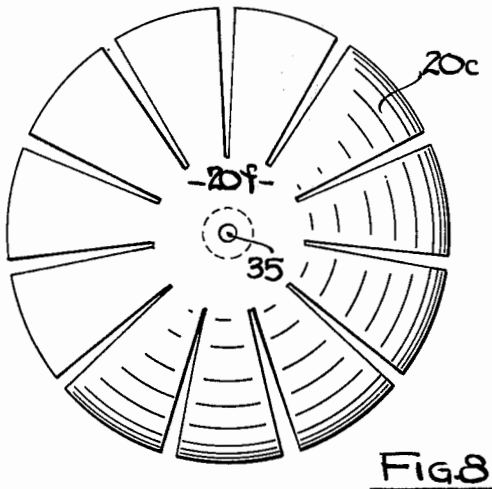


FIG. 8

United States Patent [19]

Carlson

[11] **Patent Number: 4,718,517**

[45] **Date of Patent: Jan. 12, 1988**

[54] **LOUDSPEAKER AND ACOUSTIC TRANSFORMER THEREFOR**

[75] Inventor: **David E. Carlson**, Niles, Mich.

[73] Assignee: **Electro-Voice, Inc.**, Buchanan, Mich.

[21] Appl. No.: **834,311**

[22] Filed: **Feb. 27, 1986**

[51] **Int. Cl.**[4] **G10K 13/00**; H04R 7/00

[52] **U.S. Cl.** **181/159**; 181/185; 381/156; 381/204

[58] **Field of Search** ..... 181/148, 155, 166, 171-174, 181/185, 186, 191, 199, DIG. 1, 159, 163; 381/153, 156, 158, 202, 204

[56] **References Cited**

U.S. PATENT DOCUMENTS

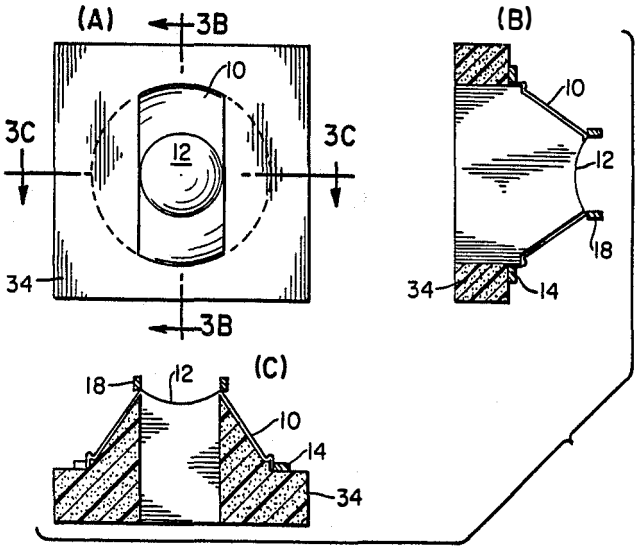
1,480,785	1/1924	Semple, Jr.	181/166
1,707,545	4/1929	Wente	181/159
1,930,915	10/1933	Wente	181/159
2,037,187	4/1936	Wente	381/156
2,107,757	2/1938	Kinsley	381/156
2,269,284	1/1942	Olson	381/204 X
2,717,047	9/1955	Buchmann	181/166
2,745,508	5/1956	Vadersen	181/171 X
2,763,333	9/1956	Schumann	381/204 X
2,845,135	7/1958	Cohen et al.	181/163 X
3,424,873	1/1969	Walsh	181/166 X
4,050,541	9/1977	Henricksen	181/159
4,157,741	6/1979	Goldwater	381/156
4,478,309	10/1984	Kawamura et al.	181/166 X

Primary Examiner—Benjamin R. Fuller
Attorney, Agent, or Firm—Darby & Darby

[57] **ABSTRACT**

A speaker system including a frusto-conical diaphragm, and a phase plug mounted within the volume formed by the diaphragm, the phase plug including a pair of substantially diametric open slots extending across the diaphragm and through the phase plug, with each of the slots having substantially rectangular cross sections transverse to the axis of the diaphragm.

13 Claims, 8 Drawing Figures



LOUDSPEAKER AND ACOUSTIC TRANSFORMER THEREFOR

BACKGROUND OF THE INVENTION

a. Field of the Invention

This invention relates to a design for loudspeakers, and more particularly relates to apex-driven woofer or cone-type loudspeakers with an improved acoustic transformer or phase plug.

b. Description of the Prior Art

In certain loudspeakers, particularly of the horn type, an acoustical transformer (commonly known as a "phase plug") is used to match the acoustic output from the speaker diaphragm to the surrounding listening area, either directly or through a horn, typically mounted in front of the phase plug/diaphragm combination. A phase plug is generally an insert fitted within the concavity defmed by a loudspeaker and positioned in proximity to the speaker diaphragm. It is used to attempt to bring all portions of the sound waves generated by the diaphragm into phase coherence at the outlet (usually the throat of a horn) and to minimize the volume of the air chamber between itself and the diaphragm.

In the prior art, phase plugs have had various configurations. One commonly used phase plug has been the "concentric" or annular type, illustrated in Goldwater U.S. Pat. No. 4,157,741 and the paper of Bob H. Smith entitled "An Investigation of the Air Chamber of Horn Type Loudspeakers", at page 305 of the March 1953 issue (Vol. 3, No. 2) of the Journal of the Acoustical Society of America. A second prior art type has been the radial or "tangerine" type, shown in Henrickson U.S. Pat. No. 4,050,541 entitled "Acoustical Transformer for Horn-Type Loudspeakers". Usual phase plug design theory requires that the phase plug be structured with one or a series of evenly spaced "loading slots" disposed across the sound-radiating diaphragm, such as those defmed by the concentric ring formation of the annular plug design or the pie-wedge-shaped formations of the radial plug design. To extend the high frequency performance of a loudspeaker (or compression driver), according to the standard concepts of phase plug theory, the phase plug should be closely spaced to the speaker diaphragm, the distance between the loading slots should be minimized, and the sound travel path lengths should be equal. These concepts have traditionally been thought to hold true for all speakers, and phase plug designs have been scaled accordingly to accommodate various sizes of speaker.

It was found that the traditional phase plug theory is not applicable over the entire frequency range of a woofer-type loudspeaker and in particular, an apex-driven woofer. For example, for a woofer speaker in one commonly used design, having a single, outwardly widening annular slot which is defined concentrically by an outer plug portion and an inner, centrally positioned "bullet" plug portion, instead of the theoretical frequency response with a peak in the output at 1.5 kHz and a "hole" (i.e., sharp dip) at 3 kHz, the actual measured response, indicated an unexplained peak at 3.2 kHz and two unexplained holes at 1.5 kHz and 5 kHz.

It is believed that this discrepancy is caused by the fact that standard phase plug theory assumes that the entire speaker diaphragm is vibrating as one piston. If the diaphragm was not vibrating as a piston (for example, if only the center portion of the diaphragm were vibrating) then concentric acoustic standing waves could exist between the faces of the diaphragm and the phase plug. The nulls in these standing waves could cause the appearance of previously unexpected holes or peaks.

Explained differently, when the entire diaphragm is vibrating, the boundary conditions are such that concentric standing waves in the air cavity or chamber between the diaphragm and the phase plug may be suppressed. If, however, there was a single driving point at the center of the speaker diaphragm with the outer portions of the diaphragm motionless, the boundary conditions would be proper for exciting concentric acoustic standing waves, producing the series of undesirable, well defmed nulls and peaks in the speaker's frequency response. This condition, where only the center of the diaphragm vibrates, occurs in the relatively higher frequency ranges of woofer or apex-driven cone-type loudspeakers, to which the standard phase plug theory appears no longer to apply.

OBJECTS AND SUMMARY OF THE INVENTION

An object of the present invention is to provide an improved phase plug design for use with woofer or cone-type loudspeakers that suppresses standing waves which may develop at higher operating frequencies, and improves the speaker response at the higher end of its frequency range.

Another object of the invention is to provide an improved phase plug design for use with woofer-type speakers that provides proper compression at higher frequencies and thus improves its higher frequency response.

A further object of the invention is to provide an improved phase plug that maintains phase coherency and a constant, non-shifting acoustic center at the outlet, over the entire frequency range of operation.

A still further object of the invention is to provide an improved phase plug design that is conveniently adapted for loading loudspeaker horns.

Yet another object of the invention is to provide an improved phase plug design for loudspeakers that overcomes the inherent disadvantages of prior proposed plug designs.

Still another object of the invention is to provide an improved driver, including a phase plug, for a rectangular acoustic horn.

In accordance with one embodiment of the invention, the usual phase plug for woofer-type loudspeakers is changed from its customary circular or annular sound transmission to a main portion positioned in close proximity to the diaphragm of the speaker, and having formed therein a rectangular channel or slot which extends diametrically across the diaphragm. This main plug portion includes a flat outer face and an inner face that conforms to the shape of the speaker to allow the plug to be closely positioned thereto. The periphery of the plug may conform in shape to the outer periphery of the loudspeaker. The main plug portion may also include a lip formed on the periphery of its inner surface, adapted for mounting the plug to the outer periphery of the speaker.

Preferably the width of the slot is dimensioned to be just slightly larger than the diameter of the dust dome at the center of the speaker cone. The main plug portion may be provided with outer sidewalls to extend the

outer face of the plug portion beyond the outermost face of the speaker diaphragm.

In an improved form, an inner plug portion is positioned within the rectangular slot. The inner plug portion is preferably wedge-shaped in transverse cross-section. It includes sidewalls which mutually converge at a position at or near the outer face of the main plug portion, to provide two channels of expanding cross-section leading away from the diaphragm.

Alternatively, the inner plug portion may be formed with a bottom face of circular cross-section (positioned approximately at the speaker diaphragm) which smoothly transforms through converging flattened sidewalls into a peaked wedge tip (positioned distally from the diaphragm) that extends diametrically across the speaker. In such an embodiment, the interior surface of the main plug section is formed with a complementary shape so that the slots or channels defined between the inner and main plug portions have substantially equal width over their entire extent to provide a substantially rectangular sound outlet.

The present invention is particularly adapted to take advantage of the desirable vertical and horizontal directivity characteristics of well-known acoustic horns by providing a direct acoustic coupling from a cone-type or apex-driven speaker to the entry of a rectangular horn.

Preferred forms of the phase plug, as well as other embodiments, objects, features and advantages of this invention, will become apparent from the following detailed description of illustrative embodiments thereof, which is to be read in connection with the accompanying drawings.

DETAILED DESCRIPTION OF THE DRAWINGS

FIGS. 1A, B and C are respective diagrammatic front, vertical section and horizontal section views of one form of prior art speaker system or compression driver with a substantially rectangular baffle plate, providing a rectangular sound exit from a circular cone-type speaker.

FIGS. 2A, B and C are respective diagrammatic front, vertical section and horizontal section views of a form of speaker system or compression driver with one form of phase plug according to the present invention.

FIGS. 3A, B and C are respective diagrammatic front, vertical section and horizontal section views of a modification of FIG. 2.

FIGS. 4A, B and C are respective diagrammatic front, vertical section and horizontal section views of a modification of FIGS. 2 and 3, with a phase plug including an interior wedge portion.

FIG. 5 is a perspective view, partly broken away, of phase plug of FIG. 4.

FIGS. 6A, 6B, and 6C are respective diagrammatic front, vertical section and horizontal section views, respectively, of a preferred embodiment of the invention coupled to a conventional speaker horn.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1A, 1B and 1C show diagrammatically a rudimentary speaker arrangement having a speaker diaphragm 10 with a dust dome 12. The diaphragm 10 is of conventional frusto-conical shape, and has its outer periphery 14 connected to a supporting frame 14 which is in turn fastened to a rigid panel or baffle 16. As usual, the inner portion of the diaphragm is caused to vibrate by a voice coil 18 or the apex of the dust dome may be driven by a conventional arrangement.

The baffle panel 16 has a generally rectangular aperture 22, extending diametrically and symmetrically across the face of the diaphragm 10. This form of speaker system, while adapted to be coupled to a rectangular horn, has the drawback that the sound waves created by the diaphragm are reflected from the inner surface of the baffle plate, which has the effect of producing standing waves which cause peaks and holes in the frequency characteristics, particularly for frequencies above 1.0 kHz (for a 10-inch speaker). Additionally relatively poor compression characteristics are provided.

FIGS. 2A, 2B and 2C show diagrammatically an improved arrangement according to one aspect of the invention, in which the baffle plate 16 is replaced by a phase plug 26. The plug 26 is formed or molded from lightweight sound impervious material, such as polyurethane foam or polystyrene foam or the like. It nearly fills the hollow space of the diaphragm and dust dome, except that it is spaced by a narrow gap (illustratively 0.2 inch) from the diaphragm 10 to allow vibration of the diaphragm 10 and to maintain good compression at the lower frequencies where the entire diaphragm vibrates, like a piston.

The phase plug 26 has a central diametral uniform width channel 28 extending from the dust dome 12 to the exit opening 22 which, like in FIG. 1A, is substantially rectangular and may be an entry aperture for a rectangular horn. The opening 28 may have a length substantially equal to the diaphragm diameter (e.g., about 9 inches long for a 10-inch woofer) with ends rounded to substantially conform to the outer edge of the diaphragm. As before, this aperture 22 has a width substantially equal to or slightly wider than the dust dome (and may be about 4 inches wide for a 10-inch woofer), so that at higher frequencies (illustratively about 1000 Hz) where only the dust dome area of the loudspeaker diaphragm vibrates, the channel 28 serves as a diverging wave guide for sound waves to couple the dust dome to a horn entry.

In this form, the characteristics are improved over FIG. 1, by eliminating the reflection, by the inner side of the baffle 16, of sound waves emanating from the dome or diaphragm, which might cause standing waves concentrically of the diaphragm with consequent undesirable peaks and holes in the frequency characteristics.

Improvement may be attained over the structure of FIG. 2 by increasing the thickness of the portion 32 of the phase plug outside the speaker, as shown at 34 in FIG. 3. This thickness may be lessened or increased depending on the desired exit geometry and wave expansion rate.

Still further improvement is attained by adding to the structure of FIG. 2 or 3 a central wedge 30, as shown in FIGS. 4 and 5. Wedge 30 may illustratively have an approximate thickness of about $1\frac{7}{8}$ inch for a $4\frac{1}{4}$ inch outlet width, and straddles the dust dome 10, from which it is closely spaced, illustratively by 0.20 inch to form an air chamber and compression space therebetween. The width of the wedge may be selected to achieve the desired compression ratio. The faces of wedge 30 converge toward the outlet aperture 22, and may form a narrow edge at the plane of the outer surface of the phase plug 26. Alternatively, the wedge may terminate in a narrow flat outer surface in the plane of

the plug outer surface, or may terminate either in a narrow flat surface or a sharp edge short of the plug outer surface. Typically the dimension "d" is determined by the mounting configuration used for the phase plug. The dimension "d" can be made deeper to accommodate a baffle board with a circular cutout, in order to provide for the baffle board supporting the weight of the speaker, and the phase plug.

The wedge thus forms two diverging channels **36, 38** between its respective side walls and the opposed wall of the main plug structure. These channels create a coherent phase for the sound waves exiting from the channels **36, 38**, and minimize the peaks and holes in the frequency characteristics up to the usual roll-off at the high frequency end of the operating range.

While the inner walls **42, 44** of the main phase plug structure are shown as parallel to each other and the central axis of the speaker, these walls may diverge or even slightly converge, as needed to create the desired sound wave pattern.

Also, although the plug inner walls have been shown and described as spaced substantially equal to or slightly larger than the dust dome diameter, the present invention may be practiced, with somewhat poorer results, with a narrower spacing, illustratively down to about 2½ inches.

The form of FIG. **4** is preferred, because it properly loads the diaphragm at higher frequencies, and provides a better controlled roll-off at higher frequencies, although the forms of FIGS. **2** and **3** provide a greater response at higher frequencies, at the expense of a slightly more irregular response at such frequencies due to beaming out of the higher frequencies. The form of FIG. **4** also provides an advantage in off-axis response due to the greater coherence of the wave front emerging from the phase plug, so that constant directivity characteristics are provided to beyond 2 kHz. It also affords the opportunity to better fill a wider horn and for use in manifolding several speakers.

The present invention particularly offers advantage for woofer, cone-type or apex-drive loudspeakers, although it can be used for higher range speakers. In the low-frequency region (where the diaphragm essentially moves as a rigid piston) there is compression throughout the entire phase plug/diaphragm interface. In the high frequency region, where essentially only the center portion of the speaker is vibrating (as determined by the voice coil, dust dome and cone), with proper selection of slot width the phase plug will channel nearly all of the acoustic energy out of the slot. There will be compression only under the wedge, and the region of the diaphragm closely juxtaposed to the phase plug will be essentially non-operating. In the mid-frequency region, the slot arrangement breaks up any concentric standing waves (in the radial modes) and directs the acoustic energy out of the slot in a smooth transition from the low to high frequency range.

The present phase plug thus compensates for the fact that the diaphragm ceases to act as a piston at higher frequencies. It eliminates parasitic acoustic waves that result from mechanical modes of diaphragm vibration by breaking up and inhibiting the acoustic standing waves, and directing the acoustic energy out of the slot. It extends high frequency response by utilizing the fact that a smaller portion and hence less mass of the diaphragm vibrates at higher frequency (for moving-mass roll-off) and by having a decreasing compression at increasing frequency. The wedge at the center provides a substantially constant path length for higher frequencies radiating from the diaphragm as well as for low frequencies, maintaining phase coherency and a fixed acoustic center throughout the region of operation. The rectangular exit provides for convenient application to a variety of horn loading. In FIG. **6A**, a conventional horn having side walls **50** and **52**, a bottom wall **54**, and a top wall **56** is mounted to the perimeter of the outlet aperture **22** of the phase plug embodiment of the invention shown in FIG. **4**. FIG. **6B** shows a vertcial sectional view of the mounting configuration thereof, whereas FIG. **6C** shows a horizontal sectional view of the mounting configuration.

It is to be understood that the forgoing description is to be deemed only illustrative of the invention, which is defined by the appended claims.

What is claimed is:

1. A speaker system comprising a substantially frusto-conical diaphragm having a hollow space in front of said diaphragm, a predetermined diameter, and an open face, and means for inhibiting the effect of an acoustic concentric standing wave pattern in the space in front of said diaphragm, said means comprising a substantially solid phase plug structure spaced closely to said diaphragm in non-touching relationship, and largely filling the volume of the hollow space associated with said diaphragm, said plug including a centrally located open slot for defining a substantially rectangular aperture leading away from the open face of said diaphragm to the frontmost portion of said phase plug.

2. A speaker system as in claim **1** wherein said phase plug structure includes said rectangular aperture having a length substantially equal to the diameter of said diaphragm.

3. A speaker system as in claim **2** wherein said diaphragm has a circular dust dome at the center thereof, and said aperture has a width at least equal to a diameter of said dust dome.

4. A speaker system as in claim **1** wherein said structure conforms to the shape of the open face of said diaphragm, and has a substantially frusto-conical surface closely juxtaposed to said diaphragm, and substantially uniformly spaced therefrom, and

said structure also having a channel extending from adjacent said dust dome to the open face of said diaphragm,

said aperture having a substantially rectangular exit opening.

5. A speaker system as in claim **4** wherein said channel has side walls parallel to a center axis of said diaphragm.

6. A speaker system as in claim **4** wherein said channel has side walls diverging from a center axis of said diaphragm.

7. A speaker system as in claim **1** wherein said phase plug structure has a substantially rectangular outlet aperture and substantially parallel side walls.

8. A speaker system as in claim **7** further including a wedge within said channel, spaced from said side walls and providing a pair of expanding sound channels extending from said diaphragm to the exterior of said speaker system.

9. A speaker system comprising:

a frusto-concical diaphragm with a concavity formed in front of said diaphragm,

a circular dust dome at the center of said diaphragm, and

a substantially solid phase plug insert shaped for mounting within and substantially filling the concavity of, and in close proximity to, said diaphragm,

said phase plug having a diametric slot therethrough forming a rectangular channel from said dome and diaphragm to an exterior surface of said speaker system,

and a wedge in said channel for dividing said channel into a pair of expanding sound channels to said speaker exterior.

10. A speaker system comprising:

a frusto-conical diaphragm,

and a substantially solid phase plug mounted therein, said phase plug including a pair of substantially diametric open slots extending across said diaphragm, said slots extending through said phase plug, and each of said slots having substantially rectangular cross sections transverse to the axis of said diaphragm.

11. A system as in claim **10** wherein said slots have progressively increasing cross-sectional area in the direction of sound propagation.

12. A system as in claim **11** wherein each of said slots has a pair of flat diverging walls.

13. A system as in claim **12** wherein said speaker has a substantially rectangular exit aperture adapted to be coupled to a rectangular horn.

* * * * *

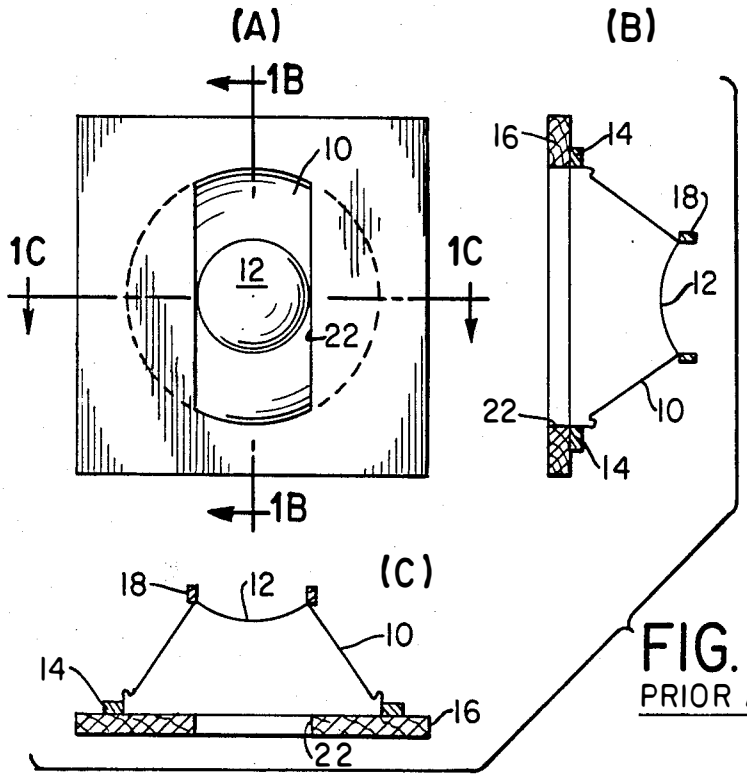


FIG. 1
PRIOR ART

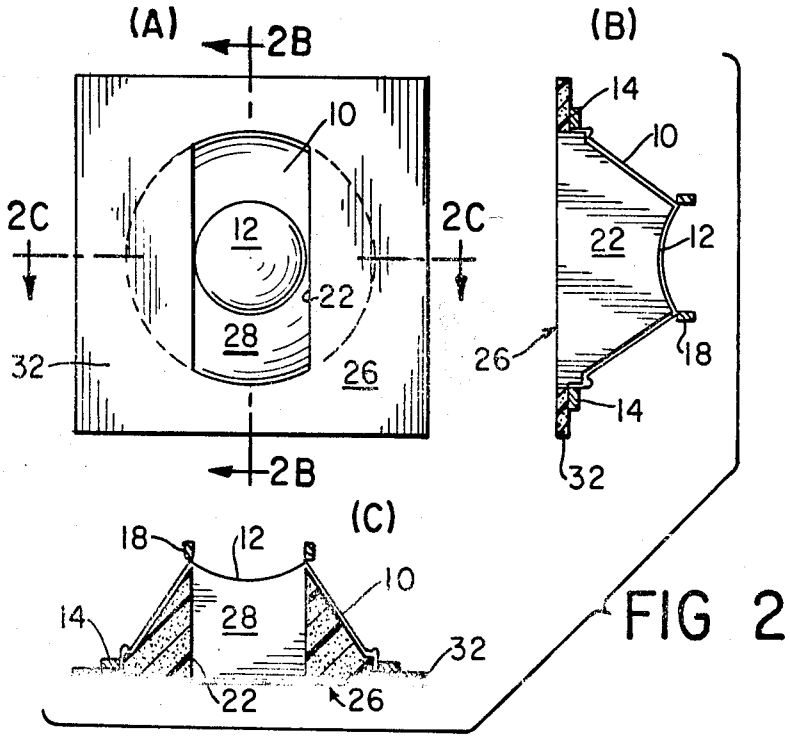


FIG 2

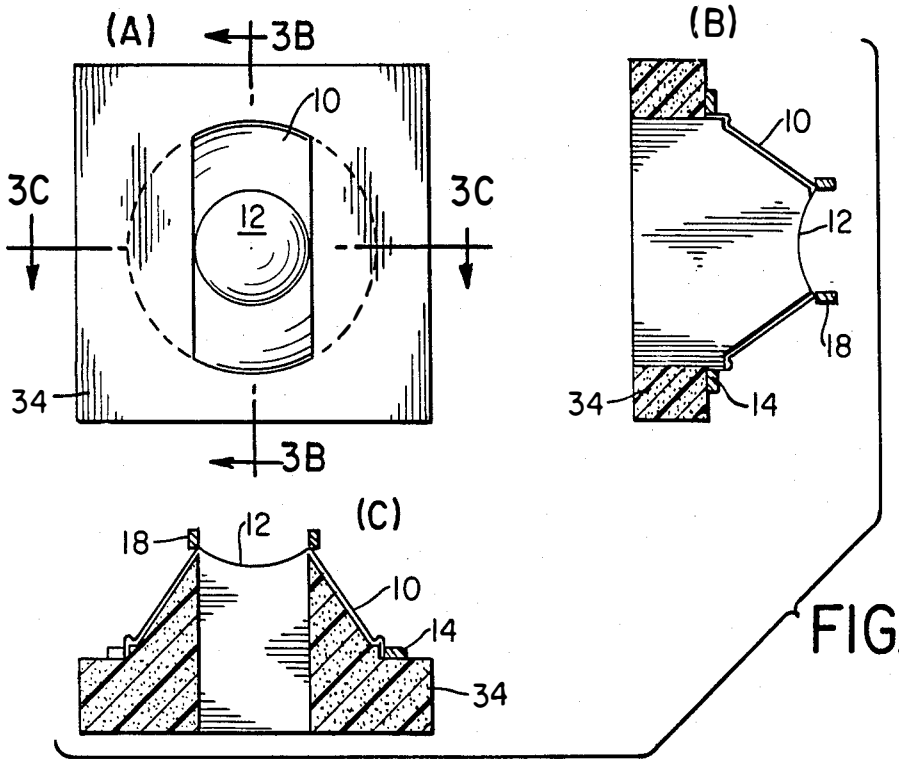

(A)
3B
10
3C
12
3C
34
3B
(B)
10
12
18
34
14
(C)
18
12
10
14
34

FIG. 3

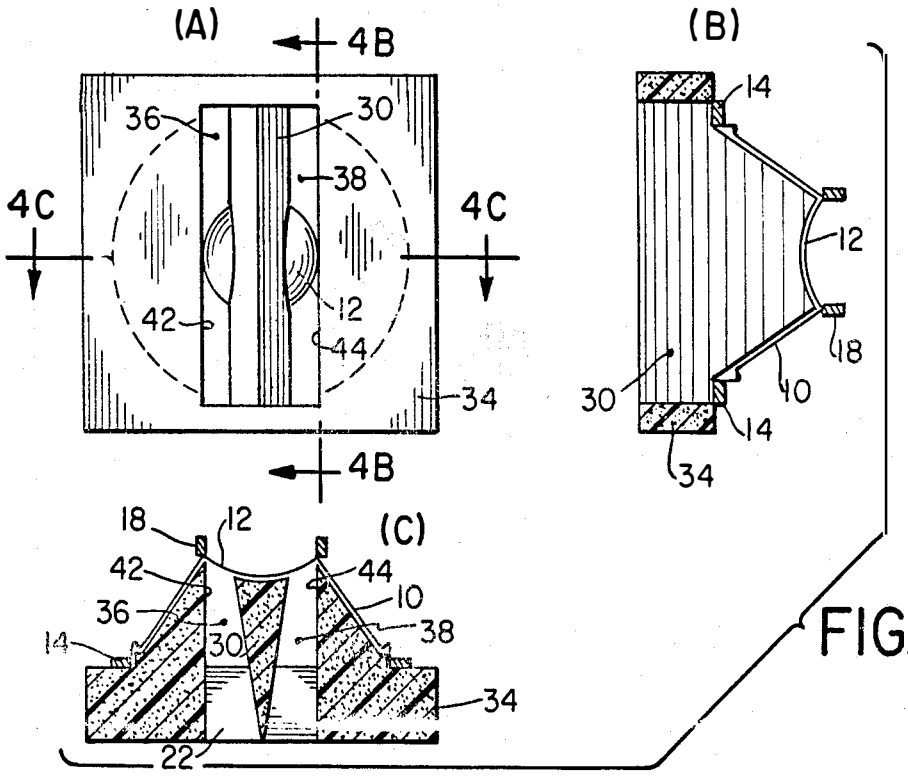
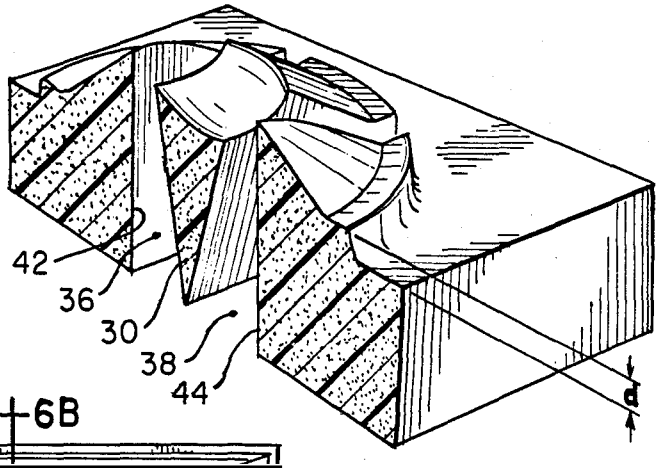

(A)
4B
36
30
38
4C
4C
42
12
44
34
4B
(B)
14
12
18
30
40
14
34
(C)
18
12
42
44
36
10
30
38
14
34
22

FIG. 4

FIG. 5



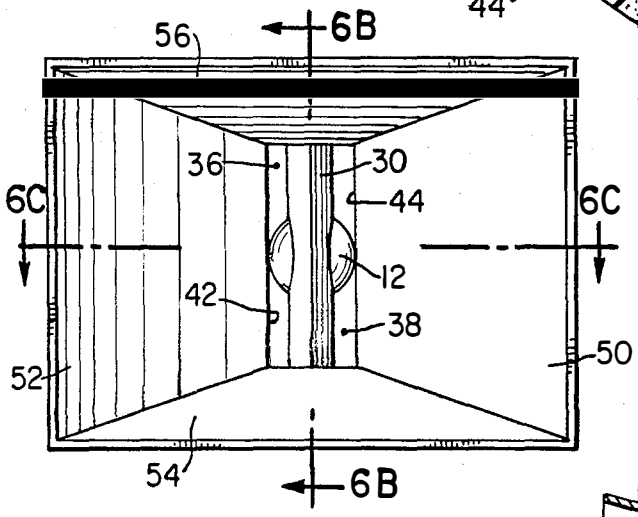


FIG. 6A

FIG. 6C

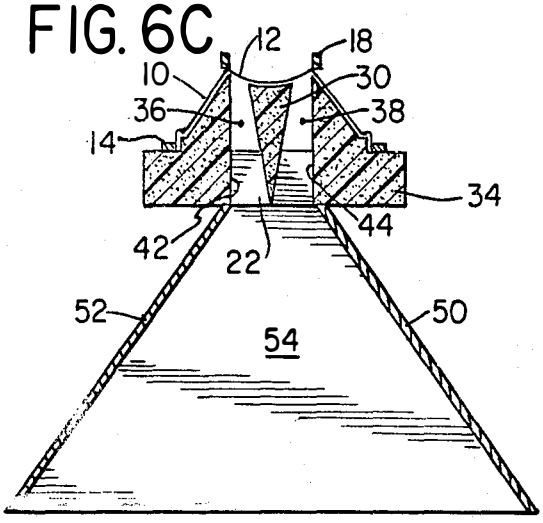
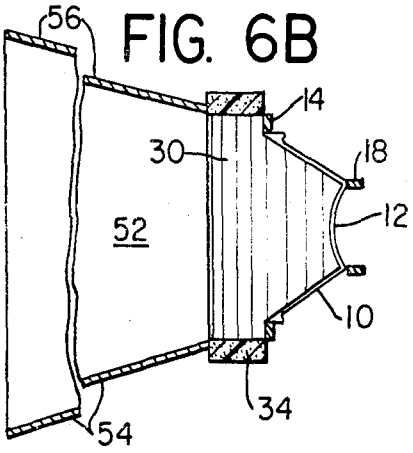


FIG. 6B



United States Patent [19]

Adamson

[11] **Patent Number: 4,975,965**

[45] **Date of Patent: Dec. 4, 1990**

[54] **LOUDSPEAKER DESIGN**

[76] Inventor: **Alan B. Adamson,** 817 Broch Road, Unit #9, Piceting, Ontario, Canada, L1W 3L9

[21] Appl. No.: **257,572**

[22] Filed: **Oct. 14, 1988**

[30] **Foreign Application Priority Data**

Oct. 16, 1987 [GB] United Kingdom 8724299

[51] **Int. Cl.**[5] **G10K 13/00;** H04R 7/00

[52] **U.S. Cl.** **381/156;** 381/158; 181/159; 181/185

[58] **Field of Search** 381/156, 158; 181/159, 181/185, 186, 152, 177, 156

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,962,374	9/1929	Woolf et al.	181/31
2,183,528	12/1939	Blackburn	181/159
2,942,071	6/1960	Witchey	179/115.5
4,031,337	6/1977	Okamura et al.	381/156
4,050,541	9/1977	Henricksen	181/159
4,152,552	1/1978	Meyer	179/115.5
4,157,741	6/1979	Goldwater	181/156
4,525,604	6/1985	Frye	381/1
4,628,155	12/1986	Robineau et al.	381/156

FOREIGN PATENT DOCUMENTS

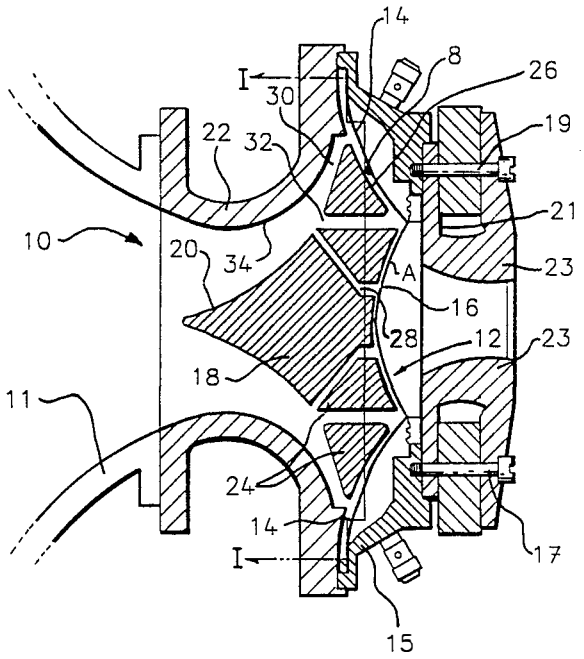
1063062	10/1962	United Kingdom .

Primary Examiner—Jin F. Ng
Assistant Examiner—M. Nelson McGeary, III
Attorney, Agent, or Firm—Sim & McBurney

[57] **ABSTRACT**

A loudspeaker including a diaphragm for generating sound waves, the diaphragm being comprised of a peripheral conical portion adjacent to and surrounding a central domed portion, a flared horn adjacent to the diaphragm for receiving and projecting the sound waves into an acoustical space, a phasing plug intermediate the diaphragm and the horn defining sound pathways for impedance matching of the diaphragm and the horn. A plurality of sound channels extend through the phasing plug from the peripheral conical portion and the central domed portion of the diaphragm to the horn. The plurality of sound channels provide time compensated paths of equal length for the sound waves generated at both the peripheral conical portion and the central domed portion of the diaphragm. The present invention is also directed to a method of forming diaphragms for use in loudspeakers using a mold comprised of a hard die surface on one side and an opposing flexible die surface on the other side for applying uniform pressure to resin-impregnated multiple fabric layers, each layer being oriented with an angular offset of weave angle relative to adjacent layers, resulting in formation of a uniform mold of the multiple fabric layers.

3 Claims, 2 Drawing Sheets



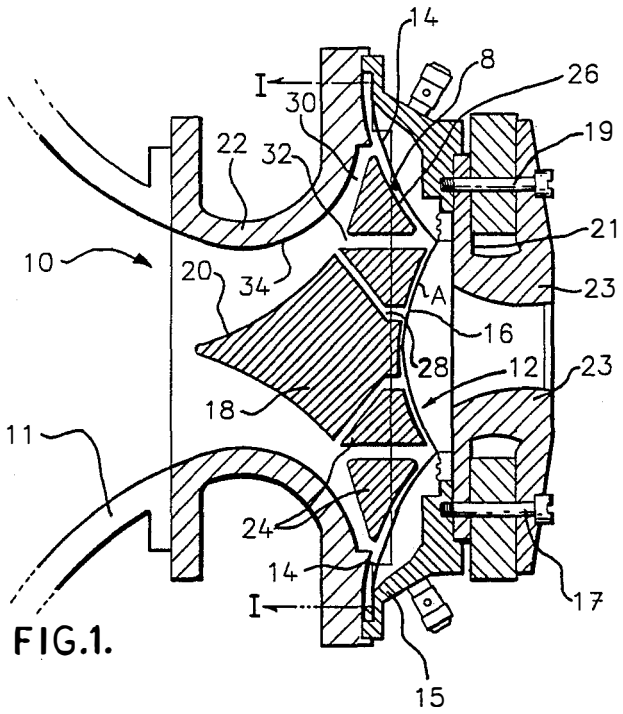

14
8
26
I
30
19
22
32
21
10
20
34
A
23
16
28
12
23
18
11
24
14
17
I
15

FIG.1.

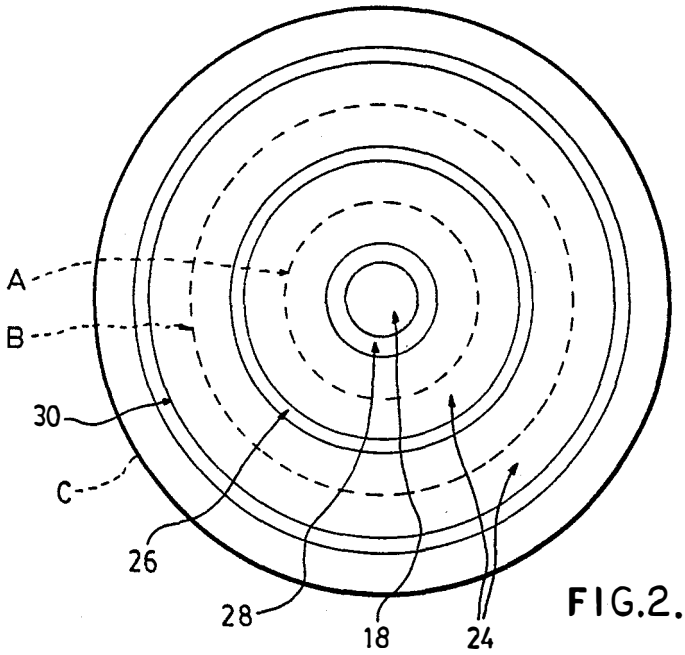

A
B
30
C
26
28
18
24

FIG.2.

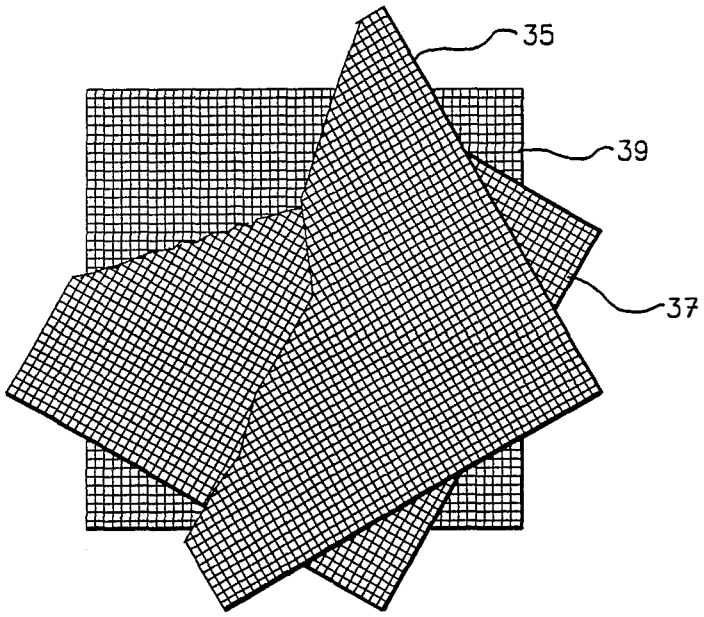


FIG. 3A.

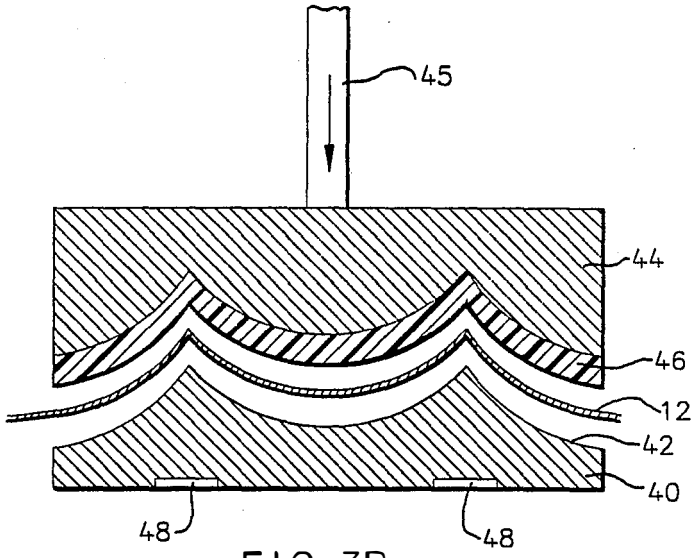


FIG. 3B.

LOUDSPEAKER DESIGN

The present invention relates in general to a horn-type loudspeaker design, and more particularly to a compression driver having equal length time compensated sound paths and to a method of forming diaphragms for loudspeakers.

Phasing plugs are well known in present day loudspeakers for impedance matching the output of a speaker diaphragm to the throat of a flared horn. The phasing plug is typically in the form of a conically nested body and centred within the throat of the horn adjacent to the diaphragm.

For example, U.S. Pat. Nos. 4,152,552 (Meyer), 2,942,071 (Witchey) and 1,962,374 (Roolf et al) each disclose a horn-type loudspeaker employing a phasing plug arrangement adjacent a spherical segment diaphragm. Each of the phasing plugs also includes one or more air channels extending from the diaphragm to the throat of the horn. The converging air channels act to prevent the audio pressure waves generated by the diaphragm from cancelling as the waves converge at the throat of the horn.

U.S. Pat. No. 4,050,541 (Henricksen) discloses a loudspeaker with a spherical diaphragm and a phasing plug having evenly-spaced radial slots or channels formed therein. According to Henricksen, the walls of the slots are tapered exponentially from their inlet ends at the speaker diaphragm towards a flat plane outlet at the throat of the horn in order to provide optimum impedance matching between the output of the diaphragm and the input of the horn.

In a similar vein, U.S. Pat. No. 4,525,604 (Frye) discloses a horn loudspeaker with convex diaphragm and phasing plug having a plurality of linear channels of equal length extending from different portions of the convex dome of the diaphragm to a circular groove joining the phasing plug to the throat of the horn, such that sound entering the horn at the throat from different portions of the diaphragm is in phase, and interference is avoided.

The above-mentioned prior art systems are limited to use with standard spherical shell (i.e. convex or concave) domed diaphragms.

While spherical shell diaphragms are suitable for use in high frequency loudspeakers, it has been found that such diaphragms are typically inappropriate for use with mid-range frequency loudspeakers. For example, a typical mid-range driver requires a 50 to 70 square inch diaphragm surface in order to generate appropriate frequency signals. Since spherical shell diaphragms are vibrated by means of voice coils around the perimeter thereof, a mid-range driver incorporating such a spherical shell diaphragm would require an inordinately large voice coil. The cost and weight of a magnet structure (i.e. motor) driving the voice coil is generally deemed to be prohibitive.

Accordingly, present day mid-range drivers are currently being designed with either a small diameter (e.g. 6-inch) diaphragm as in the above-discussed prior art, or with an inner spherical domed portion and outer conical portion surrounding the central domed portion. The combined dome and conical diaphragm is driven by a voice coil at the joinder of the central domed portion and conical outside portion. The voice coil is not required to extend around the diaphragm perimeter and therefore the voice coil and motor can be dimensioned

to a reasonable size. An example of such a combined spherical and conical diaphragm is shown in U.S. Pat. No. 4,628,155 entitled ELECTRO-ACOUSTIC MOTOR FOR HORNS, issued to Robineau et al on Dec. 9, 1986. The Robineau et al patent also discloses a phasing plug with a plurality of channels extending from the conical portion of the diaphragm to the throat of an external horn.

The device of Robineau et al suffers from the disadvantage that sound waves generated from different parts of the diaphragm (i.e. the domed central portion and conical outside portion) do not reach the throat of the horn at the same time, resulting in phase cancellation which results in lost acoustical energy, loss of smoothness in frequency response, and non-uniform wavefronts which give rise to degraded directional performance.

Furthermore, the throat of the horn in the Robineau et al speaker is shown as being linear. This results in a discontinuity where the throat joins the external horn, thereby contributing to additional phase cancellation due to reflection of sound from the discontinuity to the diaphragm, resulting in reduced sound transmission efficiency.

According to the present invention, a phasing plug is provided for use with a combined spherical and conical diaphragm, including a plurality of equal length channels extending from predetermined locations on the diaphragm to the throat of the horn. The spacing and location of the time compensated paths through the phasing plug are optimized for use with a combined spherical and conical diaphragm in a mid-range driver. Also, a predetermined throat geometry is provided conforming to a rate of change of cross-sectional area which is optimized for uniform acoustic loading of the diaphragm independent of frequency.

As a result, the amplitude and phase response of the speaker in accordance with the present invention is very smooth and linear while the total harmonic distortion is low (e.g. typically 1.2% THD at 120 dB worst case).

According to another aspect of the present invention, a method of forming diaphragms for loudspeakers is provided using a composite material which is molded and cured to the desired shape.

One prior art acoustic diaphragm and the method of construction is shown in U.S. Pat. No. 2,873,813 (Haerther et al) wherein a porous flexible material is impregnated with a thermo-setting resin, the material being mounted and cured in such a manner that the diaphragm has an impervious central portion and porous peripheral portion.

U.S. Pat. Nos. 2,873,813; 4,076,098; 4,128,138 and 4,518,642 each disclose fabric diaphragm structures and procedures for forming the same which are well known in the art.

However, according to the present invention, the fabric weave of individual layers of a multiple-layer resin impregnated fabric (i.e. pre-preg cloth) are angularly arranged with respect to each other according to a predetermined offset orientation, and then cured using a mold cavity with one hard die surface and a second die having a surface of silicone rubber or other flexible release material. This die arrangement allows uniform pressure to be applied to the fabric layers during curing of the resin and permits the formation of an increased uniform-strength diaphragm.

By using a non-uniform diaphragm surface and regular offset spacing of the weaves, thick and thin portions of the diaphragm develop as the weaves bunch up or lie flat relative to one another. This results in irregular cloth thickness. As mentioned above, the flexible die surface applies uniform pressure to the cloth for evening out the non-uniform thickness of cloth. The flexible die surface compensates for heat expansion of the hard die, and squeezes excess resin from the cloth.

In general, according to the present invention, there is provided a loudspeaker comprised of a diaphragm for generating sound waves, including a peripheral conical portion adjacent and surrounding a central domed portion, a flared horn adjacent the diaphragm for receiving and projecting the sound waves into an acoustical space and providing acoustic loading, a phasing plug intermediate the diaphragm and horn defining sound pathways for impedance matching of the diaphragm and horn, and a plurality of sound channels extending through the phasing plug from the peripheral conical portion and the central domed portion of the diaphragm to the horn, whereby the plurality of sound channels provide equal time compensated paths for the sound waves generated at both the peripheral conical portion and the central domed portion of the diaphragm.

According to another aspect of the present invention, there is provided a method of molding multiple layers of resin impregnated fabric comprising the steps of arranging the multiple layers of fabric with angular orientation of weave with respect to successive adjacent ones of the layers, placing the layers of fabric between opposing surfaces of a mold comprised of hard die surface and an opposing flexible die surface, heating the hard die surface for curing the resin, and squeezing the fabric layer between the opposing surfaces of the mold, whereby the flexible die surface applies uniform pressure to the fabric layers during curing of the resin notwithstanding any non-uniform thickness of the multiple layers of fabric, resulting in formation of a uniform mold of the multiple fabric layer.

A better understanding of the present invention will be obtained with reference to the detailed description below in conjunction with the following drawings, in which:

FIG. **1** is a cross-sectional close-up view of a loudspeaker constructed in accordance with one embodiment of the present invention;

FIG. **2** is a cross-sectional view along the line I—I in FIG. **1**;

FIG. **3A** is a partially broken plan view of multiple fabric layers for fabricating a diaphragm in accordance with a further aspect of the present invention; and

FIG. **3B** is a close-up cross-sectional view of a multiple layer fabric being molded in accordance with a further aspect of the present invention.

Turning to FIG. **1**, a loudspeaker **10** is shown for connection to an external horn assembly partially shown and designated as **11**. The loudspeaker **10** is comprised of a diaphragm **12** which includes a peripheral conical portion **14** and a central domed portion **16** integral with the conical portion. The diaphragm may be constructed of any convenient material but is preferably fabricated from a plurality of cloth layers bonded together, as described in greater detail below with reference to FIG. **2**.

The diaphragm is mounted to a rigid cast alloy frame **15** to which a magnet **23** is secured via a pair of bolts **17** and **19**. A high temperature epoxy, flat wire voice coil **21** is connected to the diaphragm **12** where the domed portion **16** meets the conical portion **14**. The permanent magnet **23** has undercut pole pieces producing a symmetrical field in the vicinity of the voice coil **21**. The rigid cast alloy frame establishes a fixed distance separation between magnet **23** and diaphragm **12**.

A phasing plug/throat assembly **18** is shown comprised of a central portion **20**, an outer or throat portion **22** and an insert portion **24** which is located adjacent the joinder portion of diaphragm **12** where the conical portion **14** meets the domed portion **16**. The insert portion **24** may be of one-piece or two-piece construction cemented together.

The insert portion **24** has a slot **26** formed therein defining a sound-transmitting pathway and is positioned adjacent the central portion **20** and the outer or throat portion **22** to define additional pathways **28** and **30**, respectively. The phasing plug assembly **18** is constructed such that the slot **26** and the pathways **28** and **30** are of the same length, so that the path length for sound from the beginning of each slot to the location **32** is the same. Furthermore, the slots or pathways **26**, **28** and **30** are evenly spaced across the surface of diaphragm **12**, resulting in uniform velocity and displacement of air at the beginning of each slot. Moreover, the pathways **26**, **28** and **30** are proportionally dimensioned to provide equal volumetric displacement and velocity of air therewithin. As a result, a uniform load is applied to all portions of the diaphragm **12** resulting in a balance of pressure across the entire diaphragm surface.

With reference to FIGS. **1** and **2** together, the lines A and B define portions of diaphragm **12** which are midway between the sound pathways **28** and **26**; and pathways **26** and **30**, respectively. The ratio of the cross-sectional area of pathway **26** to the toroidal area bounded by lines A and B is equal to the ratio of the cross-sectional area of pathway **28** to the area of the circle circumscribed by the line A, and to the ratio of the cross-sectional area of pathway **30** to the toroidal area bounded by the outer perimeter of diaphragm **12** (i.e. the line C) to the line B. For the embodiment shown, the ratio is approximately 6:1. Also, the slot **30** is positioned mid-way between lines B and C; the slot **26** is positioned mid-way between lines B and A; and the slot **28** is positioned mid-way between the line A and the centre of the plug assembly **18**. Thus, the net movement of air along lines C, B, A and at the centre is zero, and there is a uniform distance for air displaced by the diaphragm **12** to travel to the closest adjacent one of the pathways **26**, **28** and **30**. The dimensions of pathways **26** and **28** are such that pressure changes in the vicinity of region A create equal velocity displacement of air in pathways **26** and **28**. Likewise, pressure changes in the vicinity of B result in equal velocity displacement of air in pathways **26** and **30** since the ratios of cross-sectional areas of the slots or pathways to the adjacent areas bounded by the lines A, B and C, are the same.

As discussed above, sound pressure generated by vibration of the diaphragm results in transmission of sound via the time compensated pathways **26**, **28** and **30** to the location **32** without phase cancellation.

The location **32** defines the throat of a horn and the contour of the inner wall **34** of the outer portion **22** provides the first portion of the flare of the horn which is then continued by horn assembly **11** mounted to the loudspeaker **10**. The throat geometry provided by inner wall **34** in combination with central portion **20** of the phase plug assembly provides a constant directivity

waveguide for the combined sound waves appearing at location **32**. The specific curvature of the throat geometry provides a constant acoustic load independent of frequency. Furthermore, low frequency loading in a mid-range driver typically requires a long horn. Since there is no discontinuity between the throat **34** and external horn assembly **11**, the horn effectively starts at the location **32**, in contrast with prior art systems in which the horn starts at the end of the phase plug assembly.

The horn assembly **11** does not form part of the present invention.

The loudspeaker assembly of FIG. **1** is particularly useful as a mid-range driver operating in a range of approximately 200 to 2,000 Hz, but the principles thereof are applicable to speakers of any range and to diaphragms of differing shape.

The diaphragm **10** is preferably formed from multiple fabric layers as shown in FIG. **3**A. Three such layers **35**, **37** and **39** are shown arranged with the weave at 120 degrees to the next adjacent layer. Multiple fabric layers are preferable because of the high internal losses which result thereby. A uniformly strong product can be obtained using multiple layers with angularly arranged weaves since variations in stretch in the weave are evened out by the relative positioning of the layers.

The layers of fabric, with their weave angularly arranged with respect to each other, are pre-impregnated with a suitable resin, and are placed in a mold cavity shaped to conform to the desired shape of the diaphragm. As shown in FIG. **3**B, the mold cavity comprises a hard die surface **40**, typically of aluminum with a coating **42** of Teflon TM, Frecote TM or other release material, and a second die **44** connected to a pressure ram **45** and having a surface **46** of silicone rubber or other flexible release material on a hard aluminum backing plate. The hard die surface **40** also includes one or more heating elements **48** embedded therewith.

The pre-impregnated fabric is conventionally known in the art as "pre-preg".

In operation, the multiple layers of fabric **12** are placed on the heated die surface **40** and the second die surface **44** is pressed against the fabric layers **12** for curing the fabric layers and squeezing out excess resin. The flexible release material **46** allows the application of uniform pressure to be applied to the fabric layers **12** and permits the formation of a uniform diaphragm product.

This novel procedure may be used to form loudspeaker diaphragms having a variety of shapes, and could also be used to manufacture other thin laminates for industrial applications, such as skin surfaces for dirigibles, etc. In this regard, the shape or profile of the die surface may be modified to suit a particular application.

In summary, the loudspeaker of the present invention provides a uniform path length for sound from the diaphragm to commencement of the horn throat as well as uniform loading of the diaphragm due to optimized dimensions of the sound pathways. The loudspeaker of the present invention has been found to be particularly useful when applied to acoustic waveguide speakers of the variety developed by Dr. E. R. Geddes of the Audio Engineering Society.

The loudspeaker design of the present invention results in substantial advantages over prior art systems, as discussed above. The loudspeaker is characterized by extremely uniform frequency and phase response, low harmonic distortion due to the time compensated pathways, and enhanced efficiency due to uniform loading on the diaphragm.

Also, the phase plug assembly of the present invention is very easy to manufacture as compared with prior art phase plugs since the insert **24** may be manufactured separately from the central portion **20**, without the requirement for sophisticated molds and injections to form the time compensation sound pathways.

A person understanding the present invention may conceive of other embodiments or variations therein. All such modifications and variations are believed to be within the sphere and scope of the present invention as defined by the claims appended hereto.

I claim:

1. A loudspeaker, comprised of:

(a) diaphragm means for generating sound waves, including a peripheral conical portion adjacent to and surrounding a central domed portion,

(b) a flared horn adjacent said diaphragm means for receiving and projecting said sound waves into an acoustical space,

(c) phasing plug means intermediate said diaphragm means and said horn defining sound pathways for impedance matching of said diaphragm means and said horn, and

(d) a plurality of sound pathways extending through said phasing plug means from the peripheral conical portion and the central domed portion of said diaphragm means to said horn, providing equal time compensated paths for said sound waves generated by both said peripheral conical portion and said central domed portion of said diaphragm means, wherein said phasing plug means is further comprised of a central conical member, centred adjacent said central domed portion of said diaphragm means, and an annular insert member surrounding said central conical member and positioned adjacent the join of said peripheral conical portion and said central domed portion of said diaphragm means, wherein at least one of said plurality of sound pathways is defined by an air gap separation between said central conical member and said annular insert member, and another one of said plurality of sound pathways is defined by a slot forming a sound transmitting channel through said annular insert member, wherein said air gap and said slot are of equal length and extend to an identical location of said horn, and further comprising an additional sound pathway defined by a further air gap separation between said annular insert member and said horn, said additional sound pathway being of equal length to said air gap and said slot, and extending from a distal region of said annular insert portion to said identical location of said horn.

2. A loudspeaker as defined in claim **1**, wherein said flared horn and phasing plug means each conform to a uniform curvature forming a constant directivity waveguide therebetween, such that said impedance matching is independent of the frequency of said sound waves.

3. A loudspeaker, comprised of:

(a) diaphragm means for generating sound waves, including a peripheral conical portion adjacent to and surrounding a central domed portion,

(b) a flared horn adjacent said diaphragm means for receiving and projecting said sound waves into an acoustical space,

(c) phasing plug means intermediate said diaphragm means and said horn defining sound pathways for impedance matching of said diaphragm means and said horn, and

(d) a plurality of sound pathways extending through said phasing plug means from the peripheral conical portion and the central domed portion of said diaphragm means to said horn, providing equal time compensated paths for said sound waves generated by both said peripheral conical portion and said central domed portion of said diaphragm means,

wherein at least one of said plurality of sound pathways extends through said phasing plug means from the join of said peripheral conical portion and said central domed portion to said horn.

* * * * *

US005117462A

United States Patent [19]

Bie

[11] Patent Number: 5,117,462

[45] Date of Patent: May 26, 1992

[54] PHASING PLUG FOR COMPRESSION DRIVER

[75] Inventor: David D. Bie, Sepulveda, Calif.

[73] Assignee: JBL Incorporated, Northridge, Calif.

[21] Appl. No.: 672,188

[22] Filed: Mar. 20, 1991

[51] Int. Cl.[5] H04R 25/00

[52] U.S. Cl. 381/156; 381/158; 381/202; 181/159; 181/185

[58] Field of Search 381/156, 157, 158, 199, 381/202, 90; 181/152, 159, 185

[56] References Cited

U.S. PATENT DOCUMENTS

2,037,187	4/1936	Wente	381/156
4,050,541	9/1977	Henricksen	181/159
4,152,552	5/1979	Meyer	381/156
4,157,741	6/1979	Goldwater	181/156
4,164,631	8/1979	Garner et al.	381/156
4,325,456	4/1982	Ureda	181/159
4,975,965	12/1990	Adamson	381/156

FOREIGN PATENT DOCUMENTS

0012070	6/1980	European Pat. Off.	381/156
0048310	4/1977	Japan	381/156
0133123	10/1979	Japan	381/156

Primary Examiner—Jin F. Ng
Assistant Examiner—Huyen D. Le
Attorney, Agent, or Firm—Jones, Day, Reavis & Pogue

[57] ABSTRACT

An improved compression driver has a phasing plug with air passages coupling the compression region of the loudspeaker to the throat of the loudspeaker. An auxiliary air passage combines with a plurality of inner primary passages, which may be of the annular, radial or saltshaker form, to couple variations in pressure from the region around the voice coil to the throat of the speaker.

14 Claims, 3 Drawing Sheets

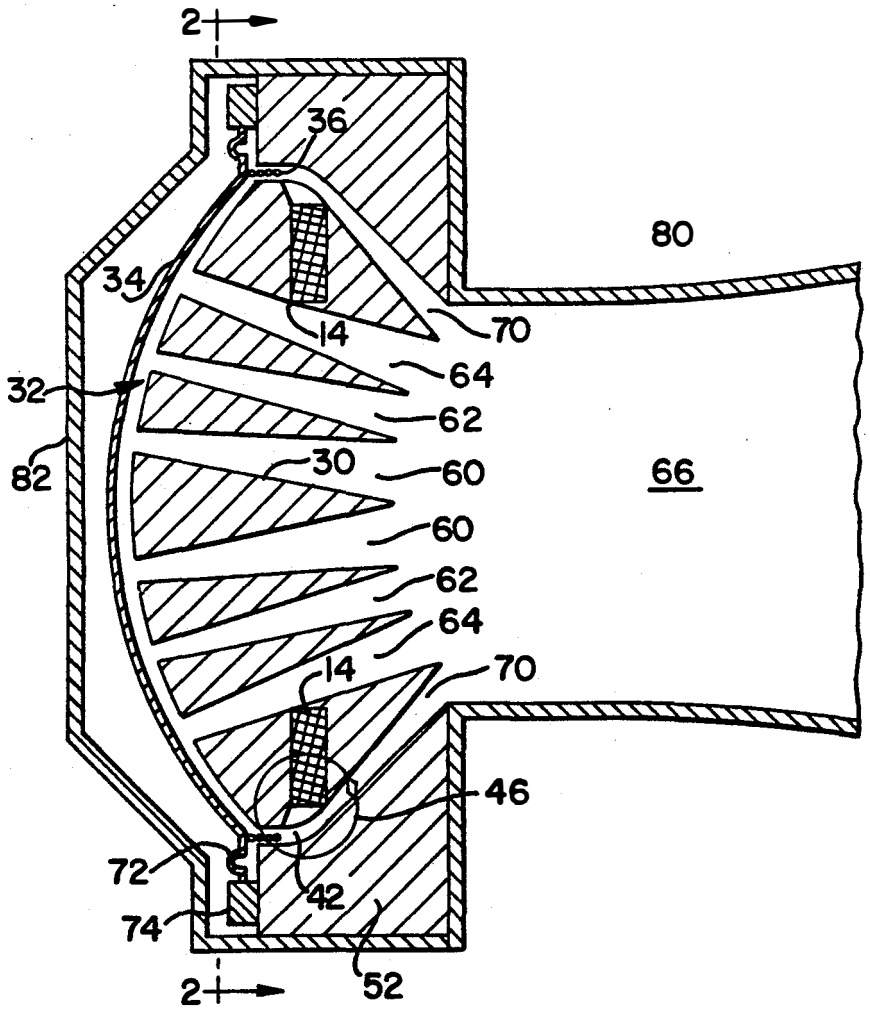


FIG. 1

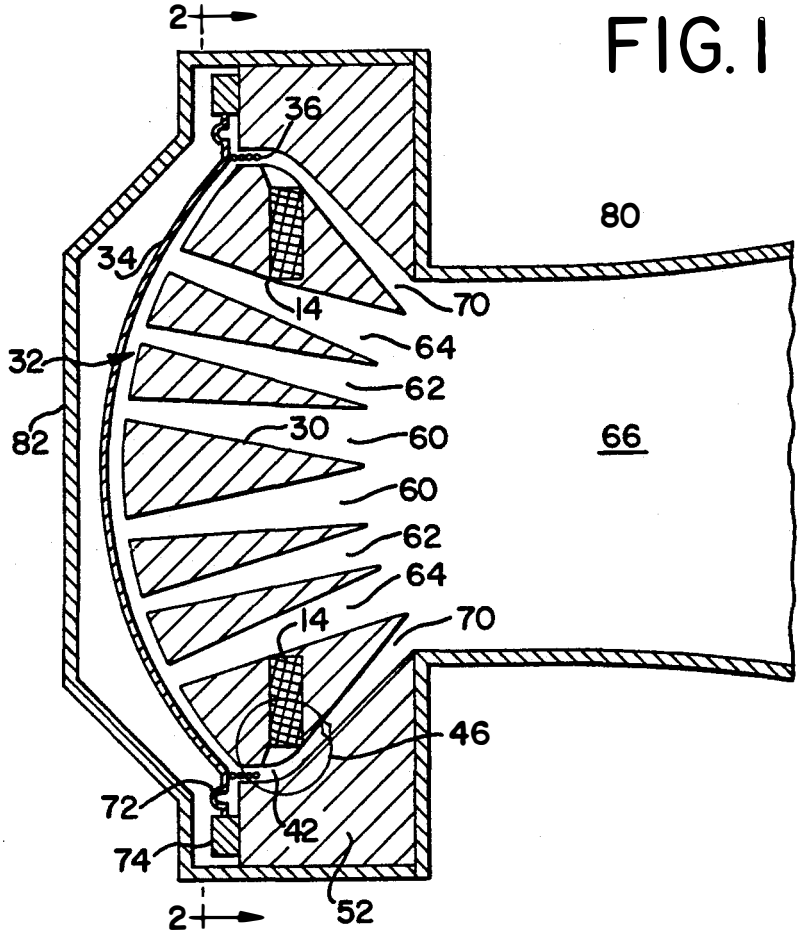

2
36
80
34
14
70
64
32
62
82
30
60
66
60
62
64
14
70
46
72
42
74
52
2

FIG. 2

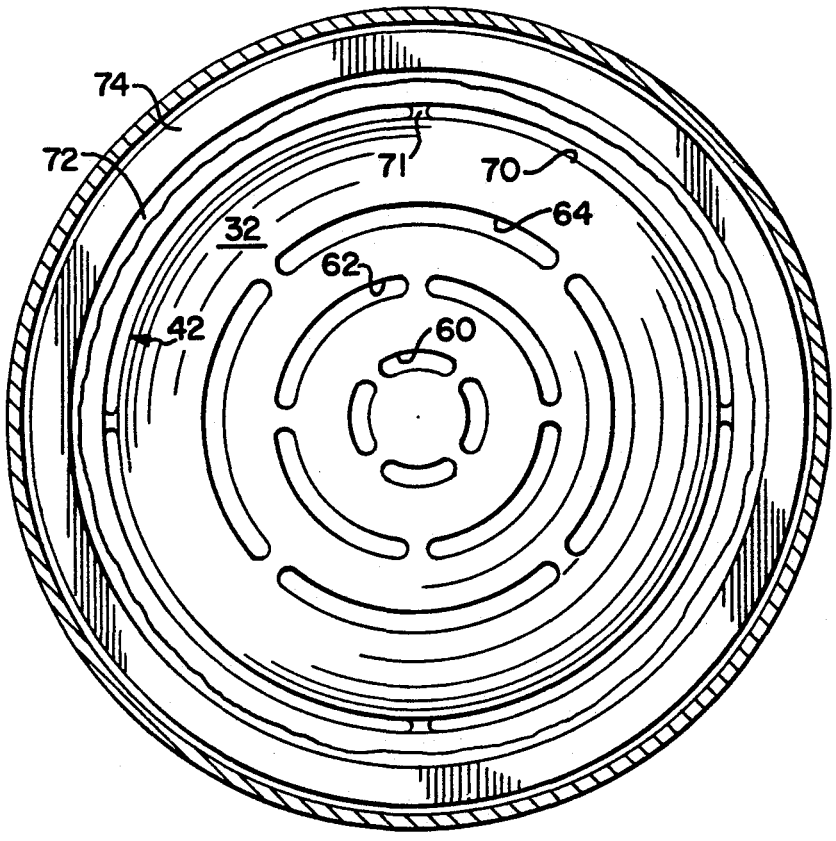

74
72
71
70
64
32
62
42
60

FIG.3

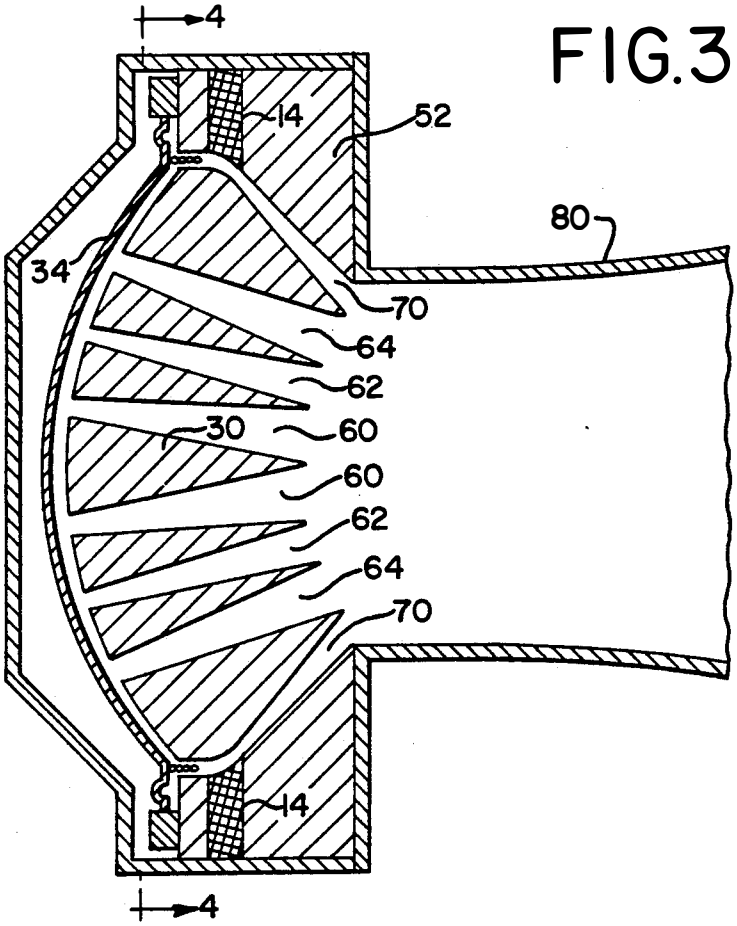
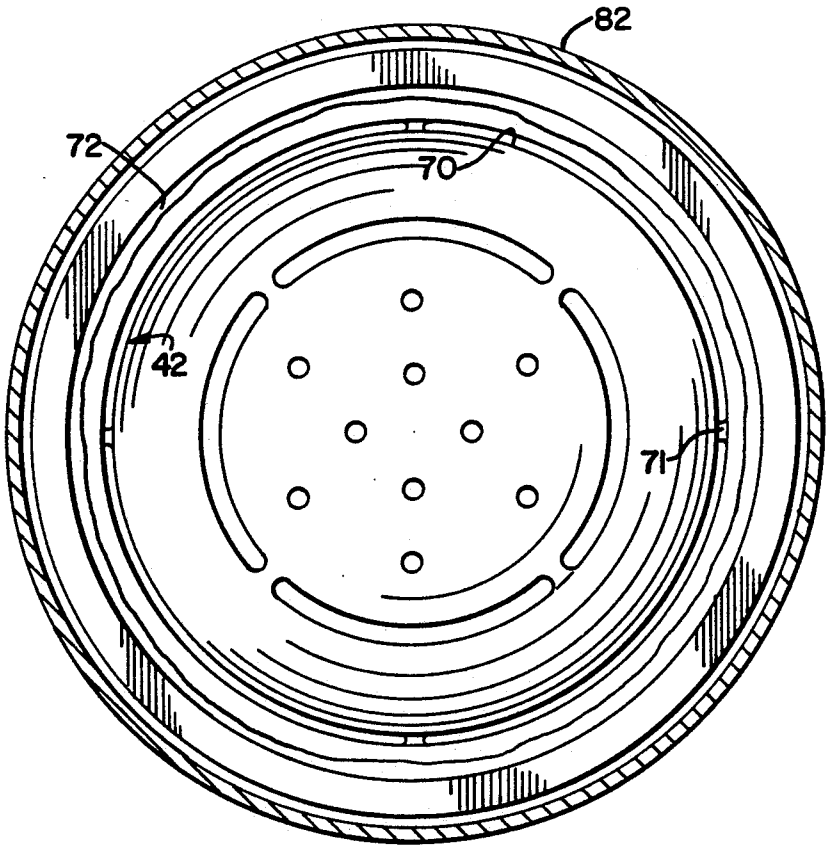


FIG.4



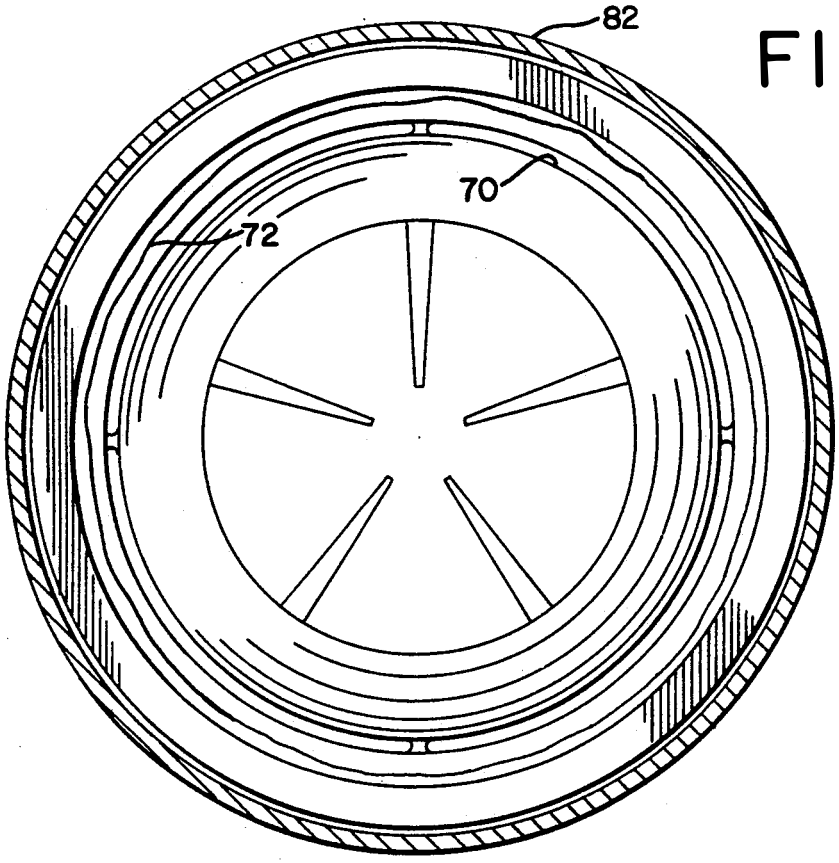


FIG.5

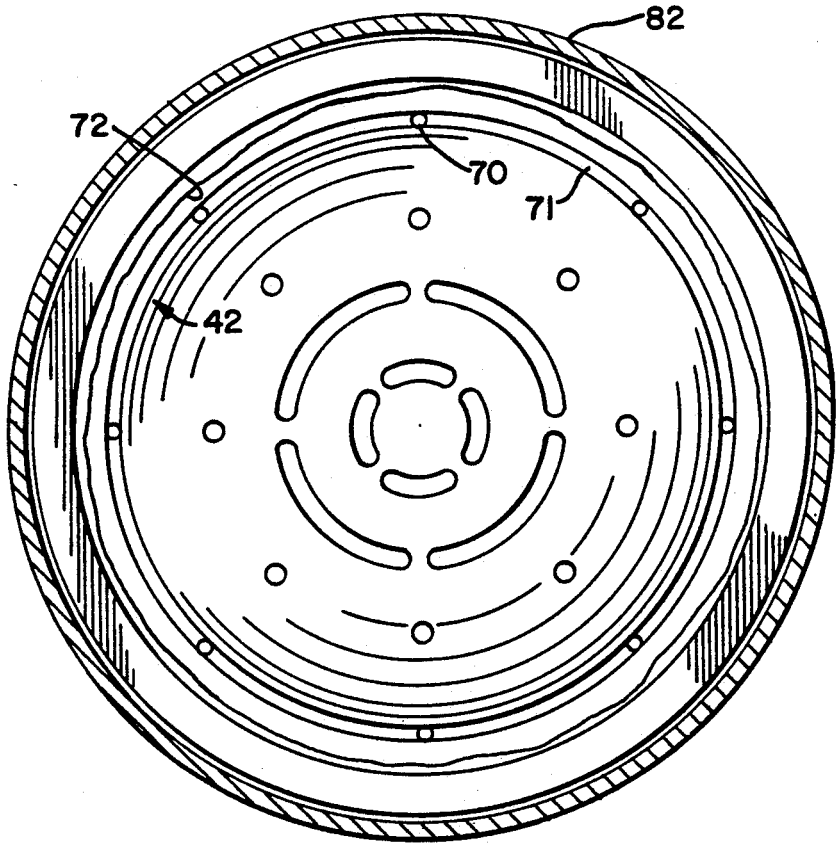


FIG.6

PHASING PLUG FOR COMPRESSION DRIVER

FIELD OF THE INVENTION

This invention relates to eleotrodynamic loudspeakers. In particular, it is an improved phasing plug for those types of loudspeakers known as compression drivers.

BACKGROUND OF THE INVENTION

A compression driver comprises a pole piece made of ferromagnetic material which has a bore therein, the front end or opening of which is adaptable for coupling to the throat of a horn. A diaphragm, usually circular with a central dome-shaped portion, is mounted adjacent the rear opening of the bore so as to be freely vibratable. Attached to the edge of the diaphragm's dome is a cylindrical coil of wire, the voice coil, oriented so that the cylindrical axis of the coil is perpendicular to the diaphragm and coincident with the axis of the pole piece bore. A static magnetic field, usually produced by a permanent magnet, is applied so that an alternating signal current flowing through the voice coil causes it to vibrate along its cylindrical axis. This in turn causes the diaphragm to vibrate along the axis of the bore and generate sound waves corresponding to the signal current. The sound waves are directed through the bore toward its front opening. The front opening of the bore is usually coupled to the throat of a horn which then radiates the sound waves into the air. In the description that follows, the term "throat" is used to mean either the front or downstream end of the pole piece bore or the actual throat of a horn. Interposed between the diaphragm and the pole piece bore is a perforated structure known as a phasing plug for impedance matching the output of the diaphragm to the horn. Within the phasing plug are one or more air passages or channels for transmission of the sound waves. The surface of the phasing plug opposite the diaphragm is of corresponding sphericity and positioned fairly close to the diaphragm while still leaving an air gap, or compression region, in which the diaphragm can vibrate freely.

The phasing plug effects two basic functions. First, because the cross-sectional area of the air channel inlets are smaller than the area of the diaphragm, the air between the diaphragm and the phasing plug (i.e., the compression region) can be compressed to relatively high pressures by motion of the diaphragm. This is what allows a compression driver to output sound at greater pressure levels than can conventional loudspeakers where the diaphragm radiates directly into the air. The efficiency of the loudspeaker is thus increased by virtue of the phasing plug being placed in close opposition to the diaphragm to minimize the volume of air between the diaphragm and the phasing plug Secondly, as the name "phasing plug" implies, the path lengths of the air channels within the phasing plug may be equalized so as to bring all portions of the transmitted sound wave into phase coherence when they reach the throat. Without such path length equalization, sound waves emanating from different air channels would constructively or destructively interfere with one another at certain frequencies so as to distort the overall frequency response.

Phasing plugs have been made with many designs. Perhaps the most frequently used type is one having annular cross-sections that usually increase in area as the principal radius of each annulus decreases in moving

toward the throat of a speaker. This is shown, for example, in U.S. Pat. No. 2,037,187, entitled "Sound Translating Device," issued to Wente in 1936 and hereby incorporated by reference. Another type is the saltshaker design, so called because holes at the spherical outer surface of the plug that extend through to the throat of the speaker resemble the holes of a saltshaker. Another design that has been used, shown in U.S. Pat. No. 4,050,541, entitled "Acousticla Transformer for Horn-type Loudspeaker" and hereby incorporated by reference, couples the diaphragm region to the throat by radial slots extending from the axis of cylindrical symmetry of the speaker.

In order to provide a low reluctance magnetic pathway for the applied static magnetic field, the permanent magnet and the voice coil are disposed within a surrounding environment of ferromagnetic material. As both the magnet and voice coil are commonly located on the side of the diaphragm facing the pole piece, the magnetic pathway includes both the phasing plug and the surrounding pole piece. In order for the voice coil to be free to vibrate, however, it must be disposed within an annular air gap which will be referred to herein as the coil space. Ideally, the coil space should be made as small as possible since air in the magnetic pathway adds reluctance to the magnetic circuit which lessens the field strength at the voice coil. Nevertheless there is a considerable volume of air in the coil space surrounding the voice coil as well as in the spaces along the inner edge of the surround and outer edge of the diaphragm which are continuous with the coil space. This region, comprising the coil space and the space along the surround and outer edge of the diaphragm, is thus an uncoupled region since it is so far from the inlets of the phasing plug air passages that variations of air pressure in that region are coupled little or not at all to the phasing plug and thence to the throat. Such an unused volume is shown in the Wente patent referred to above. These pressure variations thus result in energy losses which lead to heating of the loudspeaker but do not result in the generation of useful sound output. The uncoupled region also causes cavity resonance effects which distort the overall sound output of the speaker due to anomalies in its frequency response. Such resonances, known as parasitic resonances, present a significant design problem for the speaker designer. (See, e.g., "The Influence of Parasitic Resonances on Compression Driver Loudspeaker Performance" by Kinoshita, et al. presented at the 61st Convention of the Audio Engineering Society in 1978 and available as preprint no. 1422 (M-2).)

It would be useful to couple the pressure variations in the uncoupled region around the voice coil to the throat of the horn, in addition to the pressure variations produced by the diaphragm, to improve the efficiency and sound quality of the loudspeaker. Use of the additional pressure variations could be expected to reduce heating in the region around the voice coil as a result of repeated compression and rarefaction of the same air in that region, to produce an increase in the efficiency of the loudspeaker, and to reduce parasitic resonances.

SUMMARY OF THE INVENTION

The present invention is a compression driver with an annular auxiliary air passage for providing an acoustic pathway between the uncoupled region outside of the voice coil and the throat. Sound waves generated by the

vibration of the voice coil and surround are then output from the loudspeaker which thereby reduces heating, increases the efficiency of the loudspeaker, and reduces cavity resonance effects.

Further advantage may be obtained in accordance with the present invention if the auxiliary air passage is made thin so that the added magnetic reluctance is minimized. In order to achieve a compromise between minimizing added reluctance and providing an optimum air passage for soundwaves, part of the auxiliary air passage may be filled with ferromagnetic material.

It is an object of the present invention to provide a compression driver with increased efficiency, and which reduces cavity resonance effects. It is a further object of the present invention to provide a means for accomplishing the above objective in a manner that minimizes any added magnetic reluctance.

Other objects, features, and advantages of the invention will become evident in light of the following detailed description considered in conjunction with the referenced drawings of a preferred exemplary embodiment according to the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional side view of a compression driver in accordance with the present invention, taken along an axis of cylindrical symmetry.

FIG. **2** is a cutaway rear view of the phasing plug of the compression driver of FIG. **1**, taken along section lines **2—2** of FIG. **1**.

FIG. **3** is a sectional side view of an alternate embodiment of a compression driver in accordance with the present invention.

FIG. **4** is a cutaway rear view of a compression driver as shown in FIG. **1**, taken along section lines **2—2** of FIG. **1**, but with a combination of annular and salt-shaker type air passages in the phasing plug.

FIG. **5** is a cutaway rear view of a compression driver as shown in FIG. **1**, taken along section lines **2—2** of FIG. **1**, but with a radial slot type of phasing plug.

FIG. **6** is a cutaway rear view of a compression driver where the auxiliary air passage has been partially filled with ferromagnetic material so as to leave a plurality of salt-shaker type passages.

DETAILED DESCRIPTION OF THE INVENTION

Shown in FIG. **1** is an exemplary embodiment of a compression driver according to the present invention. All of the components in FIG. **1** which are to be described have cylindrical symmetry about a longitudinal axis. A diaphragm **34** is suspended from a mounting plate **74** attached to the back of annular pole piece **52** by means of a resilient surround **72** so that the diaphragm **34** is freely vibratable along the longitudinal axis. A cover housing **82** fits over the pole piece **52** so as to cover the diaphragm and extends over the pole piece's sides to its front surface. Mounted at the front of the pole piece **52** is a horn **80**. The pole piece **52** has within it a bore through which sounds waves generated by the diaphragm at the bore's rear opening are transmitted to the horn. The pole piece bore's front opening is continuous with the throat of the horn and both are designated **66** in the figure. Within the bore of the pole piece **52** is phasing plug **30**. FIG. **2** is a rear sectional view of the driver where the surround **72** has been partially cut away and the diaphragm **34** removed. As can be seen from FIGS. **1** and **2**, coursing through the phasing plug **32** are annular air passages **60**, **62**, and **64** which are referred to herein at main air passages. Each of the main air passages **60**, **62**, and **64** serves as an acoustic pathway through the bore of the pole piece **52**, as does a surrounding annular auxiliary air passage **70** to be described more fully below. As shown in FIG. **2**, each of the air passages **60**, **62**, **64**, and **70** are segmented rings being separated by longitudinal ribs **71** which connect concentric portions of the phasing plug **30** a well as connect the phasing plug **30** to the pole piece **52**. The ribs **71** of air passage **70** do not extend completely to the rear face of the phasing plug so as to leave an annular recess **42** in which the voice coil is free to vibrate.

The diaphragm **34** is mounted adjacent the rear surface of the phasing plug **30** being separated by a thin space or compression region **32** in which the diaphragm is free to vibrate in a direction along the longitudinal axis. The diaphragm **34** is shown as having a central dome-shaped portion with the rear surface of phasing plug **30** being of corresponding sphericity. Attached to the diaphragm **34** around the circumference of its central dome-shaped portion, is a cylindrical voice coil **36** to which the signal voltage is applied. The coil **36** is wrapped perpendicular to the longitudinal axis usually around a longitudinally extending rim or form (not shown) of the diaphragm **34**. In this embodiment, and in most compression drivers, the diaphragm **34** is mounted with its concave surface adjacent the phasing plug **30** in order for the mean path length through the annular air channels of the phasing plug from any point on the diaphragm to the throat **66** to be substantially uniform.

The voice coil **36** must be subjected to a static magnetic field in order to experience oscillation forces corresponding to the oscillatory signal current flowing through it. This is accomplished in all electrodynamic loudspeakers by disposing the voice coil within an air gap which is part of a magnetic circuit, the coil being free to vibrate with in the air gap. The magnetic circuit usually comprises a permanent magnet embedded within ferromagnetic material with the air gap being within the ferromagnetic material. The air gap, which will be referred to herein as the coil space, is made as short as possible in order to maximize the magnetic field intensity impinging on the coil for a given size magnet. For reasons of design simplicity and efficient use of material, it is desirable to place the magnetic circuit on the concave side of the diaphragm (i.e, the compression side) and construct the phasing plug and surrounding pole piece from ferromagnetic material. (Actually, only the outer portion of the phasing plug need be made of ferromagnetic material since no magnetic field lines which impinge on the voice coil pass through the inner portion.) This means that the voice coil and coil space must necessarily also be located on the concave side of the diaphragm. (It is possible, however, to design otherwise so that the voice coil is mounted on the convex side of the diaphragm. See, for example, U.S. Pat. No. 2,832,844, issued to Matsuoka. The present invention is not applicable to those designs where the phasing plug and voice coil are located on opposite sides of the diaphragm).

The embodiment in FIG. **1** thus shows the voice coil **36** being disposed within an annular coil space **42** in which it is free to vibrate in a direction along the longitudinal axis and cause corresponding vibration of diaphragm **34**. An annular permanent magnet **14** is embedded within the outer concentric portion of the phasing plug **30** so as to produce a magnetic field having field

lines such as that designated **46** in FIG. **1**. In accordance with the present invention, the coil space **42** is continuous with annular auxiliary air passage **70** which serves as an acoustic pathway for soundwaves generated by the vibrating voice coil **36** (as well as vibrations of the surround **72** and outer edge of the diaphragm) to reach the throat **66**. Without the auxiliary air passage, the sound energy generated by the voice coil **36**, surround **72**, and outer edge of the diaphragm, in addition to causing cavity resonance effects, would be wasted. Thus the present invention increases the efficiency of the loudspeaker, serves as a means for heat dissipation, and reduces parasitic resonances.

It should be noted, however, that the sound output from the vibrating voice coil **36** and surround **72** only adds to that from the vibrating dome of the diaphragm when the entire structure vibrates in phase in the diaphragm's fundamental mode. When the driving frequency (i.e., the frequency of the signal voltage) equals the second resonance frequency of the surround of the diaphragm, the dome and surround **72** vibrate in opposite phase causing their sound outputs to subtract from one another. Thus, only below the second resonance frequency does the auxiliary air passage **70** actually increase the efficiency of the loudspeaker. The reduction in cavity resonance effects is accomplished, however, at all driving frequencies.

Also in accordance with the present invention, the auxiliary air passage **70** may be designed so that its cross-sectional area increases in going from the coil space **42** to the throat **66**. Adding an auxiliary air passage in the proximity of the magnet necessarily attenuates the magnetic field impinging on the voice coil because the air passage adds reluctance to the magnetic circuit. To minimize this added reluctance, the auxiliary air passage should take up no more volume than necessary. In order to compromise between this objective and providing an optimum path for soundwaves, the auxiliary air passage may be constructed so that its cross-sectional area is small in the proximity of the coil space and increases toward the throat **66**. Additionally, the auxiliary air passage may be partially filled with ferromagnetic material so as to leave a plurality of narrow air passages (e.g., of the salt-shaker type) for transmitting sound from the coil space to the throat.

FIG. **3** shows another embodiment of the present invention in which the magnet **14** is located within the pole piece **52** instead of the phasing plug **30**. The operation of this embodiment is exactly as described above with reference to the first embodiment. Also, the main air passages of the phasing plug **30** do not have to be annular but can be either of the salt-shaker or radial slot design as shown in the rear sectional views of **FIGS. 4** and **5**, respectively.

FIG. **6** shows a rear cutaway view of another embodiment of the present invention in which the auxiliary air passage **70** is partially filled with ferromagnetic material so as to reduce the reluctance added to the magnetic circuit. In this embodiment, the ribs **71** (made of ferromagnetic material) form a segmented annulus separated by round air passages **70** which are shown to be essentially of the salt-shaker type. The round air passages **70** extend all the way to the throat **66** and the ribs **71** may also so extend. As in the previous embodiments, however, the annular ribs **71** do not extend all the way to the rear of the phasing plug so as to leave an annular recess **42** (i.e., coil space) in which the coil is free to vibrate.

Although the invention has been described in conjunction with the foregoing specific embodiment, many alternatives, variations, and modifications will be apparent to those of ordinary skill in the art. Those alternatives, variations, and modifications are intended to fall within the scope of the following appended claims.

What is claimed is:

1. A compression driver, comprising: a pole along an axis piece having a bore therein with upstream and downstream ends, the downstream end of the bore being adapted for coupling to the throat of a horn;

a diaphragm mounted adjacent the upstream end of the bore so as to be vibratable and wherein vibration of the diaphragm produces sound waves directed through the bore toward its front end;

a cylindrical voice coil connected to the diaphragm and disposed within a coil space on the side of the diaphragm facing the pole piece so as to be vibratable within the coil space in a direction parallel to the axis of the pole piece bore;

means for generating a static magnetic field so that oscillatory current flowing through the voice coil causes vibratory motion of the voice coil and thereby vibration of the diaphragm;

a phasing plug disposed between the diaphragm and the upstream end of the bore and having one or more primary air passages for transmitting sound waves from the diaphragm to the downstream end of the bore; and,

wherein an auxiliary air passage is provided for transmitting sound waves from the coil space to the front end of the bore.

2. The compression driver as set forth in claim **1** wherein the diaphragm is dome-shaped with its concave surface positioned adjacent a correspondingly shaped surface of the phasing plug in axial alignment with the bore, the diaphragm and phasing plug being separated by a space in which the diaphragm is free to vibrate.

3. The compression driver as set forth in claim **2** wherein the voice coil is mounted circumferentially around the diaphragm so as to extend into an annular coil space on the concave side of the diaphragm.

4. The compression driver as set forth in claim **3** wherein the auxiliary air passage is an annular slot from the coil space to the front end of the bore.

5. The compression driver as set forth in claim **4** wherein the cross-sectional area of the auxiliary air passage increases from the coil space to the front end of the bore as to minimize the added reluctance to the magnetic circuit which drives the voice coil.

6. The compression driver as set forth in claim **4** wherein the diaphragm is mounted by suspending it by means of a resilient surround connecting the circumference of the diaphragm to the rear of the pole piece.

7. The compression driver as set forth in claim **4** wherein the magnetic field generating means is an annular permanent magnet located within the phasing plug.

8. The compression driver as set forth in claim **4** wherein each primary air passage is an annular slot through the phasing plug which thereby provides an acoustic pathway from the diaphragm to the front end of the bore.

9. The compression driver as set forth in claim **4** wherein each primary air passage is a radial slot through the phasing plug which thereby provides an acoustic pathway from the diaphragm to the front end of the bore.

10. The compression driver as set forth in claim 4 wherein each primary air passage is a borehole extending through the phasing plug which thereby provides an acoustic pathway from the diaphragm to the front end of the bore.

11. The compression driver as set forth in claim 4 wherein the auxiliary air passage is divided into segments by longitudinal ribs which connect the pole piece and phasing plug.

12. The compression driver as set forth in claim 4 wherein the magnetic field generating means is an annular permanent magnet located in the pole piece.

13. The compression driver as set forth in claim 4 wherein the magnetic field generating means is an annular permanent magnet and further wherein the annular slot is thin in the proximity of the permanent magnet and increases in cross-sectional area going toward the front end of the pole piece bore.

14. The compression driver as set forth in claim 3 wherein the auxiliary air passage is a plurality of air passages continuous with the coil space and separated by ribs made of ferromagnetic material.

* * * * *

US006064745A

United States Patent [19]

Avera

[11] Patent Number: 6,064,745

[45] Date of Patent: May 16, 2000

[54] **COMPRESSION DRIVER PHASE PLUG**

[75] Inventor: **Donald Keith Avera**, Toomsuba, Miss.

[73] Assignee: **Peavey Electronics Corporation**, Meridian, Mich.

[21] Appl. No.: **09/089,938**

[22] Filed: **Jun. 4, 1998**

Related U.S. Application Data

[60] Provisional application No. 60/060,180, Sep. 26, 1997.

[51] **Int. Cl.**[7] **H04R 25/00**

[52] **U.S. Cl.** **381/343**; 381/340; 181/159; 181/152

[58] **Field of Search** ..... 381/343, 340, 381/339, FOR 143; 181/159, 152

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,037,187	4/1936	Wente .	
2,183,528	12/1939	Blackburn .	
3,254,484	6/1966	Kopper .	
4,143,738	3/1979	Nakazono et al. .	
5,117,462	5/1992	Bie .	
5,351,220	9/1994	Noselli .	

FOREIGN PATENT DOCUMENTS

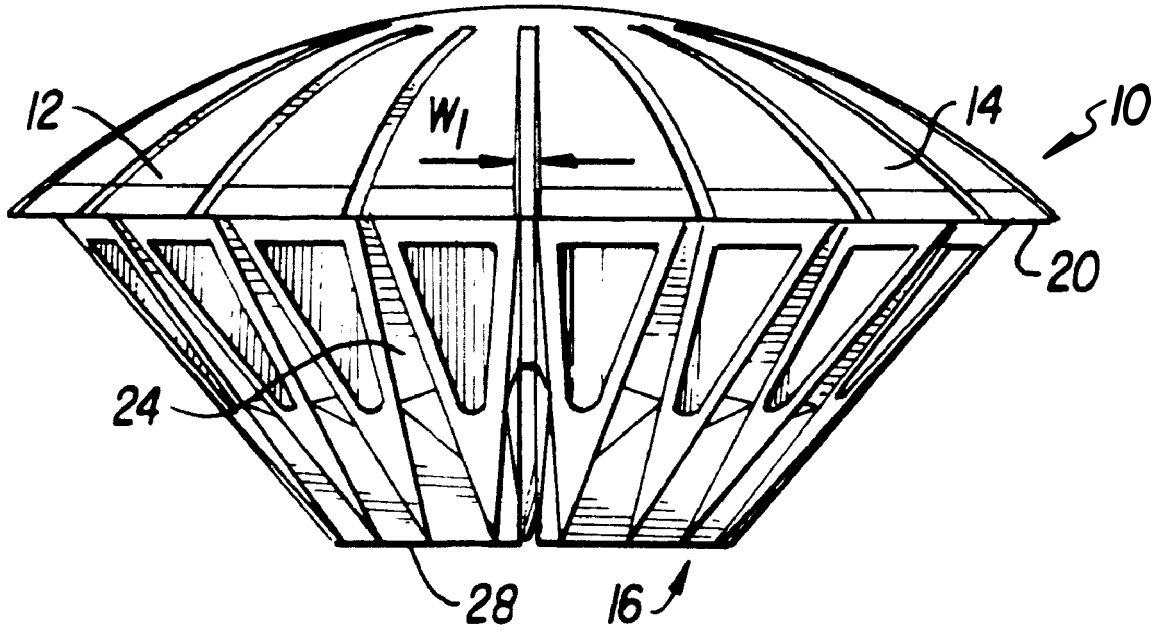
55-166396	12/1980	Japan	381/FOR 143
2-47998	2/1990	Japan	381/FOR 143
1514007	9/1976	United Kingdom .	
8904581	5/1989	WIPO .	

Primary Examiner—Curtis A. Kuntz
Assistant Examiner—Dionne N. Harvey
Attorney, Agent, or Firm—Watson Cole Grindle Watson, P.L.L.C.

[57] **ABSTRACT**

A phase plug for a horn loaded speaker has a frustro-conical body with a spherical entrance end and a planer outlet end. The plug is formed with radial channels. The entrance of the phase plug and the speaker diaphragm are conformal and the channels have generally equal aperture area from the entrance to the outlet, or slightly increasing aperture areas so as to minimize diffraction The truncation surface is defined by the intersection of the sidewalls of the conical body and the cone angle of the horn.

10 Claims, 3 Drawing Sheets



COMPRESSION DRIVER PHASE PLUG

RELATED APPLICATION

This application is related to U.S. Provisional Application Ser. No. 60/060,180 filed Sep. 26, 1997, the teachings of which are interpreted here by reference.

BACKGROUND OF THE INVENTION

The invention pertains to a compression driver or phase plug, and particularly to a compression driver having substantially equal input and output aperture areas and substantially straight acoustical paths there between.

Compression drivers, on horn loaded loud speaker systems are known. The function of a phase plug within a compression driver is to provide an acoustic path which reduces out of phase acoustic signals and destructive cancellation or interference. However, efficient and satisfactory operation of such loud speaker systems is difficult to achieve.

In order to understand this, it is necessary to look at the acoustic principles involved. A compression driver is designed to increase the efficiency of a loud speaker by compressing the acoustical energy and transferring it through a channel to the throat of a horn. Many iterations of compression and channeling have been performed in the past. For instance, there are compression drivers with annular rings (circumferential slit), radial slits (tangerine-like sections) and hole array phase plugs. The purpose of the phase plug is to compress the audio and to equalize the acoustic path lengths to thereby minimize high frequency cancellations caused by phase differences. These prior arrangements have not resulted in a completely satisfactory transformation of the acoustic signal and in particular have not resulted in transformations without high frequency interference.

SUMMARY OF THE INVENTION

The invention relates to an acoustic transformer or phase plug having radial slits. In particular, the invention is directed to an improved phasing plug for a compression driver for a horn loaded loud speaker. The invention is based upon the discovery that such a transformer or phase plug is in the form of a frustro-conical body having an entrance surface in the form of a section of a sphere or spherical entrance surface converging towards a truncation or outlet surface along an acoustic axis. Conical walls of the body have outer wall portions which are perpendicular to the spherical surface, and the radial slits define an aperture area at the truncation or outlet surface which is greater than or equal to the aperture area of the radial slits at the spherical or entrance surface.

In a particular embodiment, the phase plug is employed in a speaker having a diaphragm in the form of a section of a sphere or spherical diaphragm which matches or is conformal with the shape of the spherical entrance surface. In the exemplary embodiment, the speaker is loaded with a horn having a horn angle, and the truncation surface is defined by an intersection of the walls of the cone and a cone formed at the horn angle.

In an exemplary embodiment, the slits generally have an equal aperture area anywhere between the spherical surface and the truncation surface and define generally equal acoustic path lengths. The area of the slits may increase from the spherical surface to the truncation surface. In the exemplary arrangement, the slits diverge outwardly towards the cone wall and the truncation surface.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front perspective view of the compression driver or phase plug according to an exemplary embodiment of the invention;

FIG. **2** is a rear perspective of the phase plug illustrated in FIG. **1**;

FIG. **3** is a side elevation of the phase plug illustrated in FIG. **1**;

FIG. **4** is a front elevation of the phase plug illustrated in FIG. **1**;

FIG. **5** is a rear elevation of the phase plug illustrated in FIG. **1**;

FIG. **6** is a cross section taken along line **6**—**6** of FIG. **4**;

FIG. **6A** is a side elevation of a mold segment defining a slit;

FIG. **7** is a fragmentary schematic sectional drawing illustrating a phase plug of the present invention incorporated into a horn loaded loud speaker with a spherical diaphragm; and

FIG. **7A** is a fragmentary enlargement of a portion of the loud speaker shown in FIG. **7**.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. **1**–**6A** illustrate a compression driver or phase plug **10** in accordance with an embodiment of the invention. The phase plug **10** is generally in the form of a molded body **12** having a frustro-conical shape. The body **12** has a spherical input or entrance surface **14**, a planar output or truncation surface **16** and an intermediate conical side wall **18**. The side walls lie at an angle with respect to the central or acoustic axis AO defining the cone angle θc (FIG. **6**). The side wall **18** is perpendicular to the spherical entrance surface and provides an acoustic path which is generally equal for all frequences, thereby reducing destructive interference.

The spherical surface **14** has a flange portion **20** for positioning of the plug **10** in a horn loaded speaker as hereinafter described. The side wall **18** of the body **12** may be formed with molding recesses **22** to reduce weight. The acoustic axis A extends from the entrance surface **14** to the outlet **16**.

The body **12** is formed with a plurality of radial slits which are in the form of tangerine-like sections forming channels **24** between the input entrance surface **14** and the outer surface **16**. At the input surface **14** the channels **24** have a generally uniform width W1 and form rectangular openings or slits **26**. In the entrance surface, the slits **26** define an aperture area which is roughly 1/10 the total area of the spherical entrance surface **14**.

The channels **26** generally retain the width W1 from the entrance surface **14** to outlet surface **16** along the inner margin. However, the channels **24** diverge outwardly to a width W2 near the truncation surface **16**, as shown, forming triangular openings **28** or apertures thereat. The triangular openings **28** at the truncation surface **16** occupy a much larger percentage of the area thereof and have a total aperture area greater than or equal to the aperture area of the slits **26** in the entrance surface **14**. The aperture area represented by the channels **24** at any cross-section between the entrance **14** and the outlet **16** is normally no less than the aperture area of the slits **26** in the entrance surface. As a result, channels **24** are formed which allow acoustic energy to pass through the plug **10** without interference.

The channels are formed by a number of surfaces. In the embodiment illustrated, the body **12** is formed by a molding

process. Accordingly, the mold is formed with surface portions for producing the channel geometry. In the embodiment illustrated in FIG. **6**, the channels are formed in the body **12** by a first radial slice **30** having a radius R. A second radial slice **32** having the same radius R is formed in the body **10**, as shown. A third radial slice **36** is formed in body **12** likewise having a radius R. A straight fourth cut along line **38** is formed as shown. The first cut **30** is generally of uniform width W1. Cuts **32** and **36** diverge outwardly as does cut **38**. The various defining lines **32**, **36**, and **38** are softened in the final mold to provide a smooth transition through the channel **24**. A profile of the cuts is shown in FIG. **6**A as a portion of the mold segment.

As illustrated in FIGS. **2** and **6**, the truncation surface resembles a plurality of radial fins **40** emanating from a conical tip **42** and having an annular opening **44** as shown. The apertures **22** formed in the conical wall **18**, as shown in FIG. **6**, reduces weight and mold cooling time.

FIG. **7** illustrates an embodiment of the invention in which horn loaded loud speaker **60** is equipped with the phase plug **10** of the invention and a horn **70**. The loud speaker **60** includes a magnet structure **62** and a diaphragm **64** mounted therein. In the exemplary embodiments, the diaphragm **64** has a spherical shape and the entrance surface **14** of the phase plug **10** is conformal therewith, as shown.

The magnetic structure **62** has an inner pole piece **66**, a magnet **68**, and front and back plates **70** and **72**. The inner pole piece **66** has a conical sidewall **76** for receiving the phase plug **10** therein as shown. The sidewall **76** and the phase plug sidewall **18** are generally the same shape so that the phase plug is conformal within the inner pole piece **66** as shown. The inner pole piece **66** has an abutting surface **78** and the flange portion **20** of the phase plug **10** rests against said abutting surface **78** in the magnet **62** as shown. The phase plug **10** and the side wall **78**, the inner pole piece **66** share the same cone angle θc.

In the exemplary embodiment, the inner pole piece **66** and the front plate **70** form an annular air gap **80**. The diaphragm **64** has an radially extending ring **82** captured between inner and outer suspension rings in a recess **88** formed in the front plate and secured by a mounting ring and screws (not shown). Annular voice coil **92** is suspended by the diaphragm in the air gap **80**.

As noted above, the sidewall **18** of the conical body **12** is perpendicular to the entrance surface **14** and is likewise, perpendicular to the diaphragm **64**. In accordance with the invention, both the diaphragm **64** and the phase plug **10** share a common focal point F. Indeed, all points on the diaphragm and all points on the input surface **14** of the plug **10** share the same focal point F.

The loud speaker **60** has a horn **100** mounted to the back plate **72** of the magnet **62**. The horn **100** has a horn angle ϕ_h defining a cone. Back plate **72** has a opening **102** which is a shaped extension of an interior surface **106** of the horn **100** at the proximal or inlet end **108**.

In the exemplary embodiment, the geometry of the horn **100** and that of the phase plug **10** are related. The location of the truncation surface **16** is defined by the intersection of conical sidewall **18** and the extension of the inner surface **106** of the horn **100** disposed and a cone formed by the horn angle ϕ_h. Thus, it can be seen that the open or aperture area of the outlet surface **16** corresponds to the open area of the proximal or inlet end **108** of the horn **100**. The intersection of the two surfaces occurs along a plane P and the output or truncation surface of the body **12** lies in the same plane P as shown.

The compression driver or phase plug **10** of the invention increases the high frequency output. This is achieved by geometrically focusing the acoustic energy towards a central point where all the path lengths are substantially equal. The open aperture area of the channels **24** is such as to keep the open aperture area of the outlet openings **28** of the phase plug **10** equal to or greater than the open aperture area of the slits **26** at the input or entrance **14**. In the exemplary embodiment, the channel area may increase slightly towards the outlet **16**.

In accordance with the invention, the length of the truncated cone of the body **12** is determined by first drawing a tangent line from the outer limits of the diaphragm radius straight to the focal point F creating cone angle θc. The throat or horn angle ϕ_h of the horn **70** is then extended until it defines a cone intersecting the phase plug cone angle θc. This intersection between the two cones defines a plane P where truncation is applied to the phase plug. The exit area or outlet **16** of the phase plug **10** has the sharply defined cone shaped center **42** with the annular area **44** around the cone opened to the acoustic fins **45**. This affects the acoustic energy with a minimum of internal diffraction. Thus, the invention converts a spherical wave created by the diaphragm to a plane wave at the entrance of the horn while increasing the high frequency response of the compression driver. Accordingly, an important aspect of the invention is that it employs a dual focus system wherein the diaphragm and phase plug have the same focal point.

The invention also provides for minimum diffraction by focusing acoustic energy centrally through the channels **24**. The phase plug of the invention having the general shape of a dome on one side and the truncated cone on the other may be described as being focused or centered on the geometric center of a sphere, with the outside limits of the cone wall **18** being perpendicular to the spherical surface **14** at the entrance and also perpendicular to the spherical diaphragm **64**.

The invention concentrates all the acoustic energy to a central point and truncation of the cone is defined by the entrance to the horn throat. In other words, truncation is applied at the point in space where the consolidated area of the channels within the phase plug is equivalent to a throat cross sectional area of the horn.

Further, in accordance with the invention it can be seen that the entrance **14** of the phase plug **10** is broken down into multiple segments **26** creating a relatively high compression ratio of about 10 to 1, that is, the area of the spherical surface **14** and the area of the slits **26** is approximately in the ratio of 10 to 1. The outlet **16** of the phase plug **10** has been optimized to keep the open area equal to or greater than the open area of the entrance. This exit area is likewise equal to the entrance to the horn. The internal open air volume channels **24** within the phase plug has been shaped to create the focusing effect of the acoustic wave as it propagates through the plug. The reason for this is to convert a spherical wave to a plane wave prior to the acoustic energy arriving at the throat of the horn and without generating an acoustical reflection within the plug. This, in turn, prevents an impedance mismatch as well as focuses the acoustic energy throughout the frequency range and particularly the high frequency range. The truncated cone is focused on the center of the sphere represented by the diaphragm with the length of the cone determined by the intersection of the horn entrance and the cone angle on the acoustic axis. The surfaces of the mold forming the channels are smoothed along the boundaries to prevent acoustic interference. The cone may be molded, for example, from polyester or other suitable material.

While there have been described what are at present considered to be the preferred embodiments of the present invention, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is intended in the appended claims to cover such changes and modifications as fall within the spirit and scope of the invention.

What is claimed:

1. A sound translating device for a horn loaded speaker with a spherical diaphragm comprising, a body having a longitudinal axis and a plurality of slots formed therein, said body having an entrance surface defining a portion of a spherical surface, said body having a planar outlet surface disposed substantially perpendicular to said axis, said body also having a frusto-conical surface of a cone extending between said entrance surface and said outlet surface, the center of said spherical surface and the apex of said cone coinciding with one another, every line lying in said frusto-conical surface and coplanar with said axis being perpendicular to a plane tangent to the spherical surface at the point of intersection of the line and the spherical surface, each of said slots having opposite ends which open at said entrance surface and said outlet surface to define open aperture areas at said entrance surface and said outlet surface, said outlet surface having an open aperture area greater than or equal to the open aperture area of said entrance surface.

2. The device of claim **1** wherein said slots have an equal aperture area taken in a plane normal to the longitudinal axis anywhere between the entrance surface and the outlet surface.

3. The device of claim **1** wherein said slots have an aperture area taken in a plane normal to the longitudinal axis increasing from the entrance to the outlet.

4. A sound translating device for a horn loaded speaker with a spherical diaphragm comprising, a body having a longitudinal axis and a plurality of slots formed therein, said body having an entrance surface defining a portion of a spherical surface, said body having a planar outlet surface disposed substantially perpendicular to said axis, said body also having a frusto-conical surface of a cone extending between said entrance surface and said outlet surface, the center of said spherical surface and the apex of said cone coinciding with one another, each of said slots having opposite ends which open at said entrance surface and said outlet surface to define open aperture areas at said entrance surface and said outlet surface, the outlet surface having an open aperture area greater than or equal to the open aperture area of said entrance surface, each of said slots being formed between a pair of spaced opposing walls, each pair of opposing walls being symmetrically disposed about a plane containing said axis, each wall having an inner edge adjacent to and spaced from said axis, said inner edge having a curved portion adjacent to said entrance surface and a linear portion adjacent to said outlet surface.

5. The device of claim **4** wherein said slots have an equal aperture area taken in a plane normal to the longitudinal axis anywhere between the entrance surface and the outlet surface.

6. The device of claim **4** wherein said slots have an aperture area taken in a plane normal to the longitudinal axis increasing from the entrance surface to the outlet surface.

7. The device of claim **4** wherein the spaced opposing walls of each slot diverge from each other toward the frusto-conical surface and diverge from each other toward the planar outlet surface.

8. The device of claim **3** wherein the linear portions of each said inner edge, taken together, define a cylinder having an axis co-linear with the longitudinal axis.

9. The device of claim **8** further comprising an inner cone coaxial with and within said cylinder.

10. A sound translating device for a horn loaded speaker with a spherical diaphragm comprising, a body having a longitudinal axis and a plurality of slots formed therein, said body having an entrance surface defining a portion of a spherical surface, said body having a planar outlet surface disposed substantially perpendicular to said axis, said body also having a frusto-conical surface of a cone extending between said entrance surface and said outlet surface, the center of said spherical surface and the apex of said cone coinciding with one another, every line lying in said frusto-conical surface and coplanar with said axis being normal to the spherical surface, each of said slots having opposite ends which open at said entrance surface and said outlet surface to define open aperture areas at said entrance surface and said outlet surface, said outlet surface having an open aperture area greater than or equal to the open aperture area of said entrance surface.

* * * * *

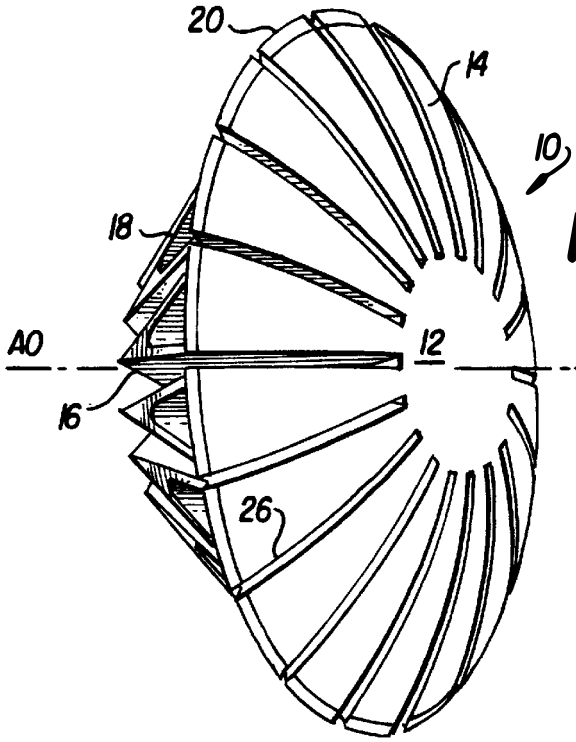


FIG. 1

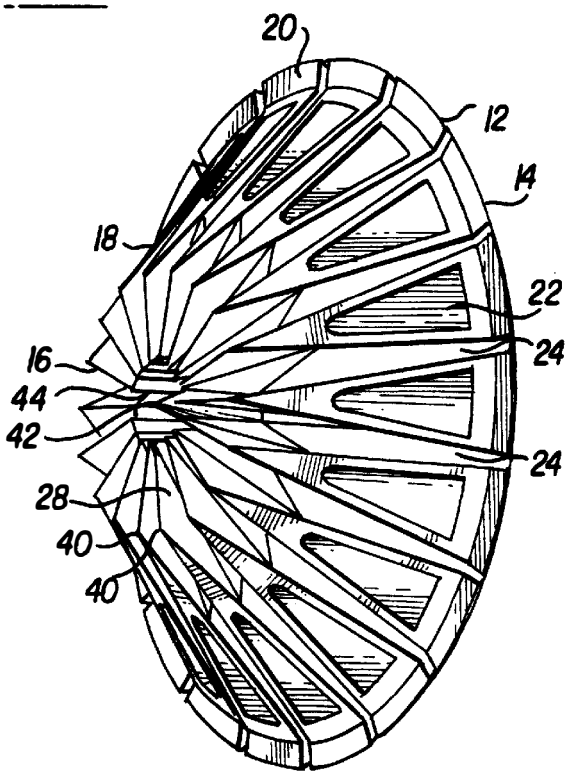


FIG. 2

FIG. 6A

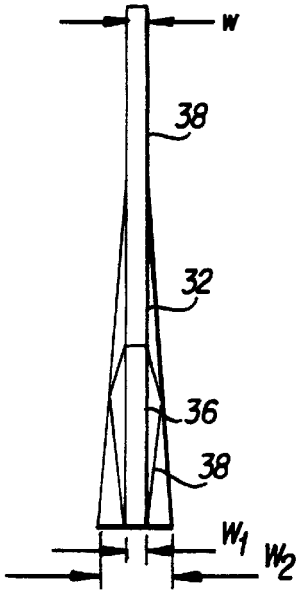
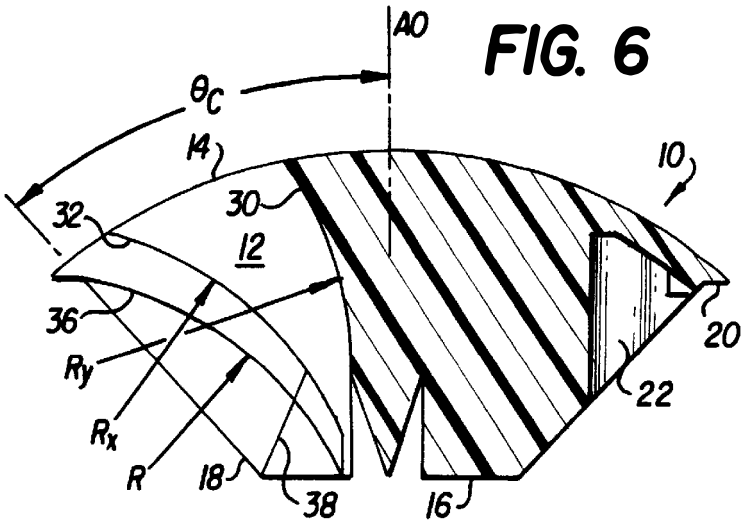


FIG. 6



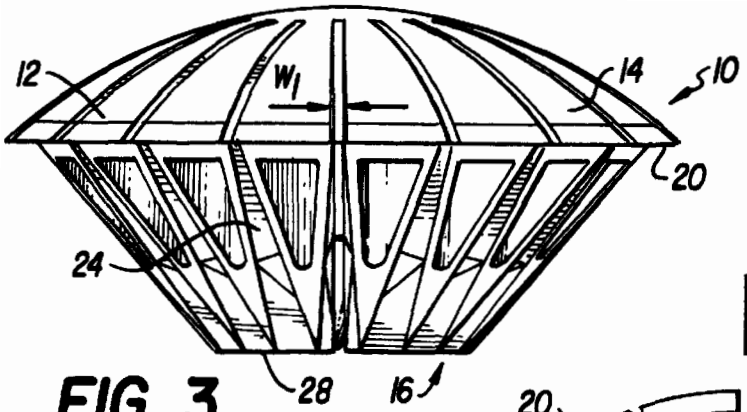


FIG. 3

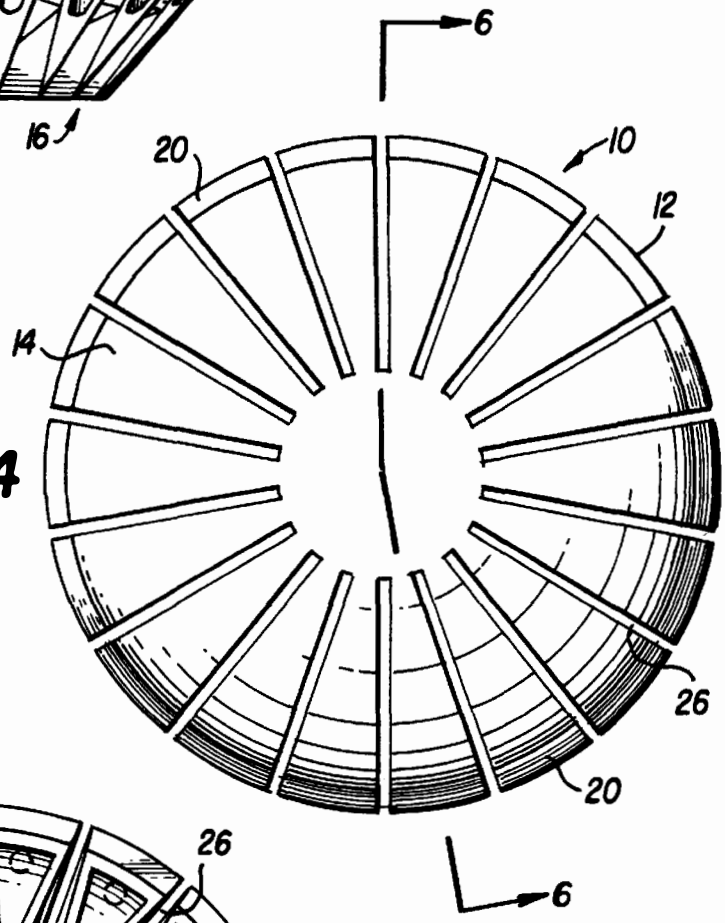


FIG. 4

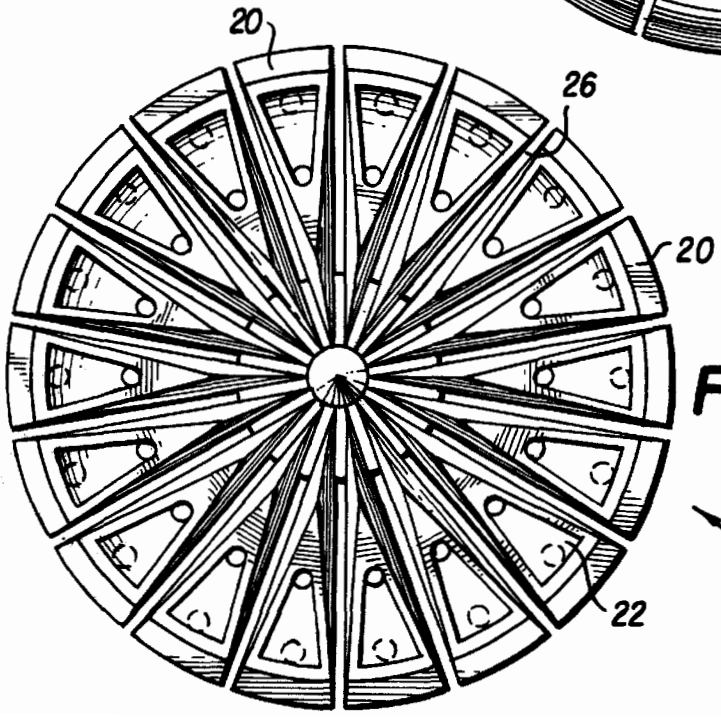


FIG. 5

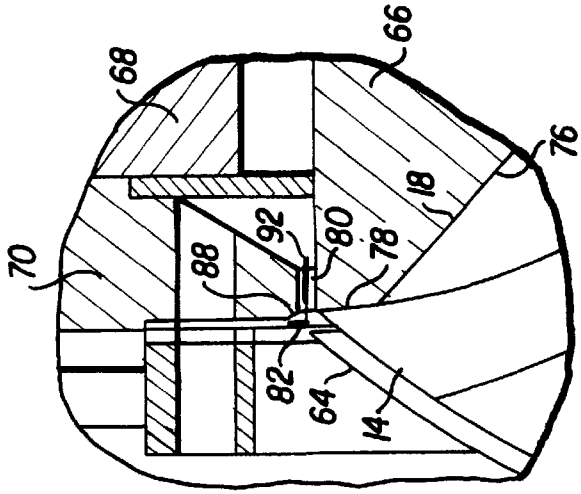

66
68
76
18
70
88
92
80
78
82
64
14

FIG. 7A

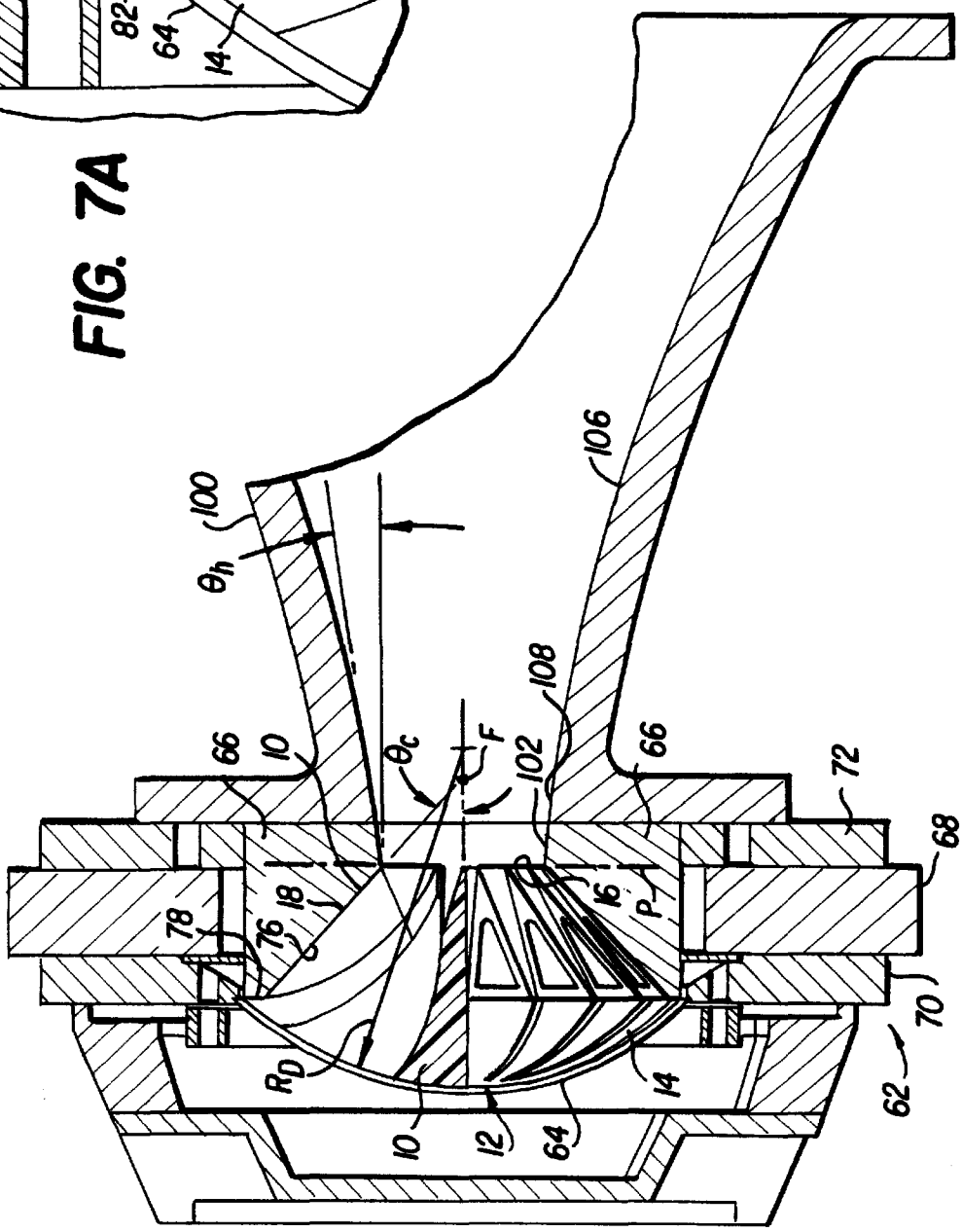

106
100
θ_h
108
66
10
θ_c
F
102
66
72
68
78
18
76
16
P
70
R_D
14
62
10
12
64

FIG. 7

US 20070102232A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2007/0102232 A1**

Geddes (43) **Pub. Date: May 10, 2007**

(54) **WAVEGUIDE PHASE PLUG**

(76) Inventor: **Earl Russell Geddes**, Northville, MI (US)

Correspondence Address:
Earl Geddes
43516 Scenic Lane
Northville, MI 48167 (US)

(21) Appl. No.: **11/272,398**

(22) Filed: **Nov. 10, 2005**

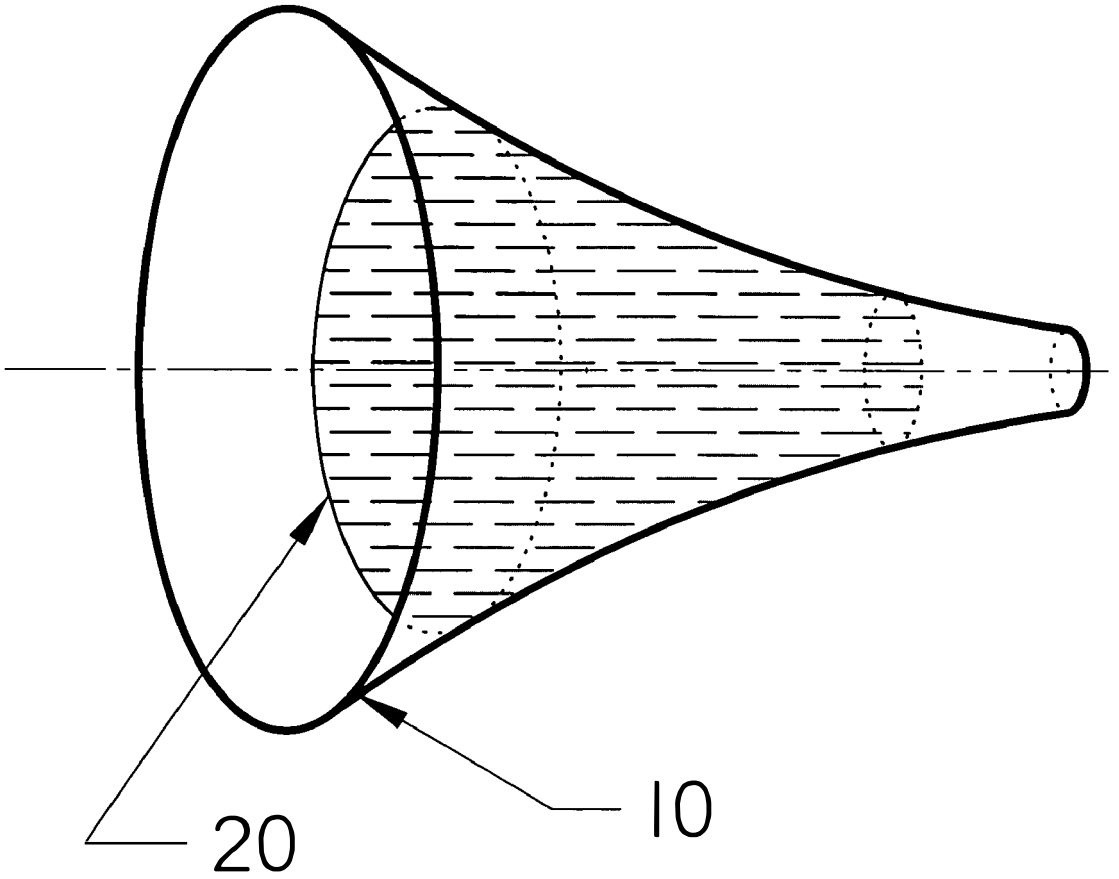
Publication Classification

(51) **Int. Cl.**
G10K 11/00 (2006.01)

(52) **U.S. Cl.** **181/185**

(57) **ABSTRACT**

An improved horn for a compression driver which has an interior foam plug for reducing the amplitude of unwanted non-fundamental wave propagation and better control over the sound radiation pattern of the device.



WAVEGUIDE PHASE PLUG

FIELD OF THE INVENTION

[0001] The present invention pertains to the improvement in sound quality of a horn or waveguide used for acoustic loading and sound radiation control on an electro-acoustic transducer in an audio loudspeaker system.

BACKGROUND OF THE INVENTION

[0002] In the area of audio loudspeakers it is common to use compression drivers for mid to upper frequencies. There are two main reasons for this. First, the compression driver, when coupled to a waveguide (in this application the terms waveguide and horn are synonymous), provides for much higher electro-acoustical efficiency than a direct radiating loudspeaker can achieve. Second, the waveguide provides for better control over the directional characteristics of the sound radiation than can be achieved with a direct radiator loudspeaker. In order to effectively control the sound radiation, the waveguide must be capable of manipulating the sound wavefronts.

[0003] The traditional way of manipulating the wavefront is with diffraction. A small gap is placed within the horn which diffracts the wavefront into a very wide angular coverage spherical wave. This wave is then controlled to a specific angle with by the walls of an additional horn section extending out from the diffraction point.

[0004] The traditional approach has two major disadvantages. The first is that the diffraction slot causes a large amount of the wavefront to be reflected back down the horn creating a standing wave and an acoustic resonance, which is highly audible as sound coloration. The second disadvantage is that the new diverging wavefront is not composed of a single wave propagation mode, but contains many propagation modes which are created by the diffraction slot.

[0005] These "Higher Order Modes" or HOM are highly undesirable because they cause a loss of coherent wavefront propagation resulting in poor sound quality-mostly in terms of the so-called imaging of the sound system. The HOM propagate by reflecting off of the horn walls as they propagate down the device. This is in contrast with the coherent wavefront propagation which does not reflect off of any internal surfaces as it propagates down the device. It is possible for the coherent wavefront energy to be converted into HOM as the wave front propagates. HOM are also created at any slope or area discontinuities within the waveguide.

[0006] Not until Geddes showed the presence of the HOM through his work on waveguides (see Chapter 6 of *Audio Transducers,* GedLee Publishing, 2002 ISBN 0-9722085-0-X) was the importance of the HOM within the waveguide recognized. Geddes showed that HOM exist in all waveguides and that they play a signifcant role in wave propagation in a waveguide at the higher frequencies. In order to control the high frequency polar response one has to control the excitation and propagation of the higher order modes. Clearly the wavefront at the exit aperture of the phase plug, which becomes the horns throat input wavefront should be free from the presence of HOM and this has been addressed by Geddes in his recent patent application Ser. No. 10/919,145. This significant point is missing from the entire body of prior art designs for phase plugs.

[0007] Other inventors, most notably Tamura and Sato in U.S. Pat. No. 4,893,695 have recognized the importance of a smooth reflection free transmission characteristic from a waveguide. In their patent the inventors disclose the use of an absorbing member as defining "the acoustic path". Their invention utilizes absorbing material as the actual boundary of the waveguide thereby creating an absorption of the energy bouncing off of the walls. This method does work, but has the disadvantage of requiring a much larger device to accommodate the absorbing boundary. In order to work effectively, the absorbing member must be fairly thick, which causes a large increase in the volume required for the waveguide device.

[0008] It is the purpose of this invention to disclose a device which is placed within the boundaries of a waveguide to absorb the HOM as well as any standing waves which may exist within the device that result from reflections from the mouth, etc. The net effect of the use of this device is a substantially improved sound quality for the resulting system.

[0009] It has been seen in the marketplace that foam is often placed down the throat of a horn during shipping, presumably to prevent foreign material from entering the device. There is no evidence that this material serves any intended acoustical function and is normally removed prior to usage of the device. There are no teachings that such usage of foam in the throat has any beneficial acoustic effect.

SUMMARY OF THE INVENTION

[0010] When one considers the problem of HOMs the first idea would seem to be to make the walls of the waveguide absorptive as in Tamura and Sato (U.S. Pat. No. 4,893,695). This, however, is problematic and less than completely effective. First the walls would have to be made of a soft absorptive material which would have to be fairly thick, thus dramatically increasing the size of the device. Further, absorptive walls would not effectively attenuate the reflected waves that do not intersect the walls. All in all, this idea is found to be impractical and not totally effective.

[0011] Given the impracticability of an absorptive wall, the only other feasible concept would appear to be a waveguide with a medium within its boundaries that is something other than air. A medium that has a wave speed other than air is often called refractive, just as glass is a refractive medium for light. This patent application revolves around the idea of using a refractive medium within the boundaries of a waveguide.

[0012] Sound absorbing material has often been used at the edges of waveguides (UREI Studio Monitors circa 1980's, models 809-815), or on the front baffle, to affect a variety of sound problems. But none of them placed the material directly in the path of the sound wave, wherein the sound wave was forced to pass through the material, except, as noted above, during shipping for protection.

[0013] The use of open cell polyurethane foam placed around a microphone to act as wind screen is well know in the art, and this foam comes in an extremely wide variety of shapes and densities.

[0014] By cutting and placing a piece (or pieces) of open cell polyurethane foam within the body of the waveguide, two features of the device can be affected. The first is to

attenuation the HOM and the internal standing waves as a result of the high internal damping that the foam presents to the wavefront. The second is that the exit shape of the foam can be tailored to affect the frequency response and the directivity of the waveguide. In this later situation it is the change in the wave speed within the material that affects this wavefront control, much in the same way that the index of refraction of glass affects an optical wavefront in a lens.

[0015] In practice it was found that foams in the density of 20 pores per inch (ppi) to 50 ppi resulted in the most desirable characteristics. It was also found that the exit shape should be convex in the preferred embodiment as this gave the smoothest frequency response. The sound level loss that results from the use of a 30 ppi plug in a waveguide designed to operate from 1000 Hz upwards was found to be 2-3 dB, a not insignificant loss, although it can be compensated for in the system design. The loss associated with the HOM and standing waves is expected to be much higher than the loss to the fundamental mode of wave propagation.

[0016] The reason that the attenuation of the HOM is greater than the attenuation of the principle mode (the one that does not reflect from the walls) is because the reflected HOM waves travel a greater path length within the lossy material. This is also why these modes are so audible, because they are dispersive, i.e. they travel at a net slower wave velocity down the axis of the device than the principle mode and hence arrive at the listener delayed in time—they are thus incoherent sound.

[0017] The same thing is true for the reflections from the mouth, etc. which cause internal standing waves. These waves travel back and forth through the lossy material and are thus readily absorbed.

[0018] The foam plug acts to reduce all undesirable sound propagation to a far greater extent than the desired sound, thus creating a considerable increase in the perceived sound quality of devices which incorporate this technology.

DRAWING FIGURES

[0019] FIG. **1** shows a drawing of the prior art in horn design.

[0020] FIG. **2** shows the preferred embodiment of the addition of the refractive material.

Drawing Numerals			
10	Horn or waveguide	20	Foam plug

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0021] It is the purpose of this invention to disclose an improved horn/waveguide for sound radiation.

[0022] In the preferred embodiment a piece of open cell polyurethane foam is fabricated so that it fits neatly into the interior of a horn. Shown in FIG.(**1**), prior art, a horn (**10**) is filled with air, or said to be unfilled. Shown in FIG.(**2**) is a preferred embodiment, wherein a portion of the horn (**10**) is filled with an open cell polyurethane foam (**20**) such that sound passes through the foam, but is attenuated and delayed by the forced passage through the various channels within the foam.

[0023] It is found in practice that a foam density of between 20 to 30 pores per inch (ppi) had the desired amount of attenuation. The greater the number of ppi, the smaller the holes and the greater the attenuation. Too high a value of ppi results in too much attenuation while too low a value of ppi results in almost no effect at all.

[0024] FIG.(**3**) shows several implementations of foam plugs (**20**) showing how the inlet and outlet of these plugs can be of a variety of shapes. It is also possible that the foam extend outside of the physical bounds of the horn. A feature of this invention is that the foam takes up the majority of the air space within the horn. This is in contrast to the usage of the foam for protection purposes since in this later case the foam takes up only a fractional portion of the total air space within the device. While it is conceivable that small foam plug of a higher density may also work effectively, it is desirable to utilize the lowest possible ppi foam so as to not have a substantial reflection off of the foam.

[0025] Other modifications to this approach are possible and will be apparent to those proficient in the art.

I claim:

1) A horn having:

an inlet and an outlet, wherein the outlet area is greater than the inlet area, and the volume of space enclosed by the horn walls and its inlet and outlet contains a plug composed of open cell foam.

2) The horn of claim 1 wherein;

the plug is made of open cell polyurethane foam.

3) The horn of claim 1 wherein;

the plug is composed of foam with a ppi value in the range of 20 ppi to 40 ppi.

4) The horn of claim 1 wherein;

the plug is made of open cell polyurethane foam in the range of 20 ppi to 40 ppi.

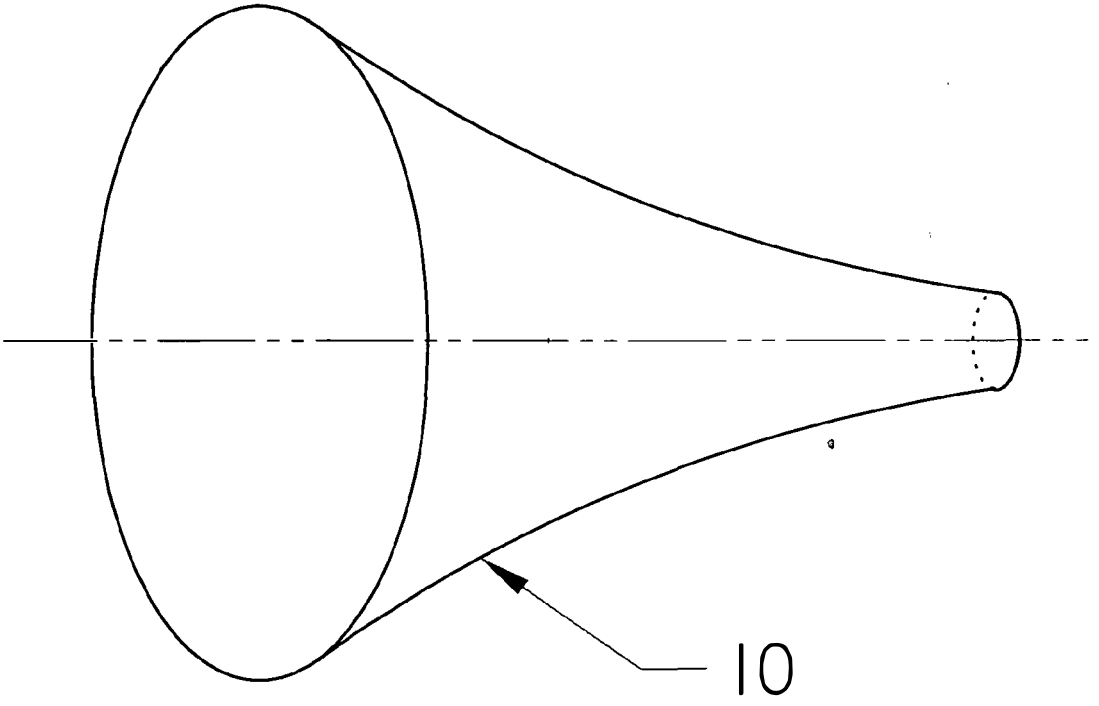
5) The horn of claim 1 wherein;

the plug fills more than 80% of the interior of the horn.

6) The horn of claim 1 wherein;

the plug fills less than 80% of the interior of the horn, but more than 20%.

* * * * *



Prior Art

Fig. 1

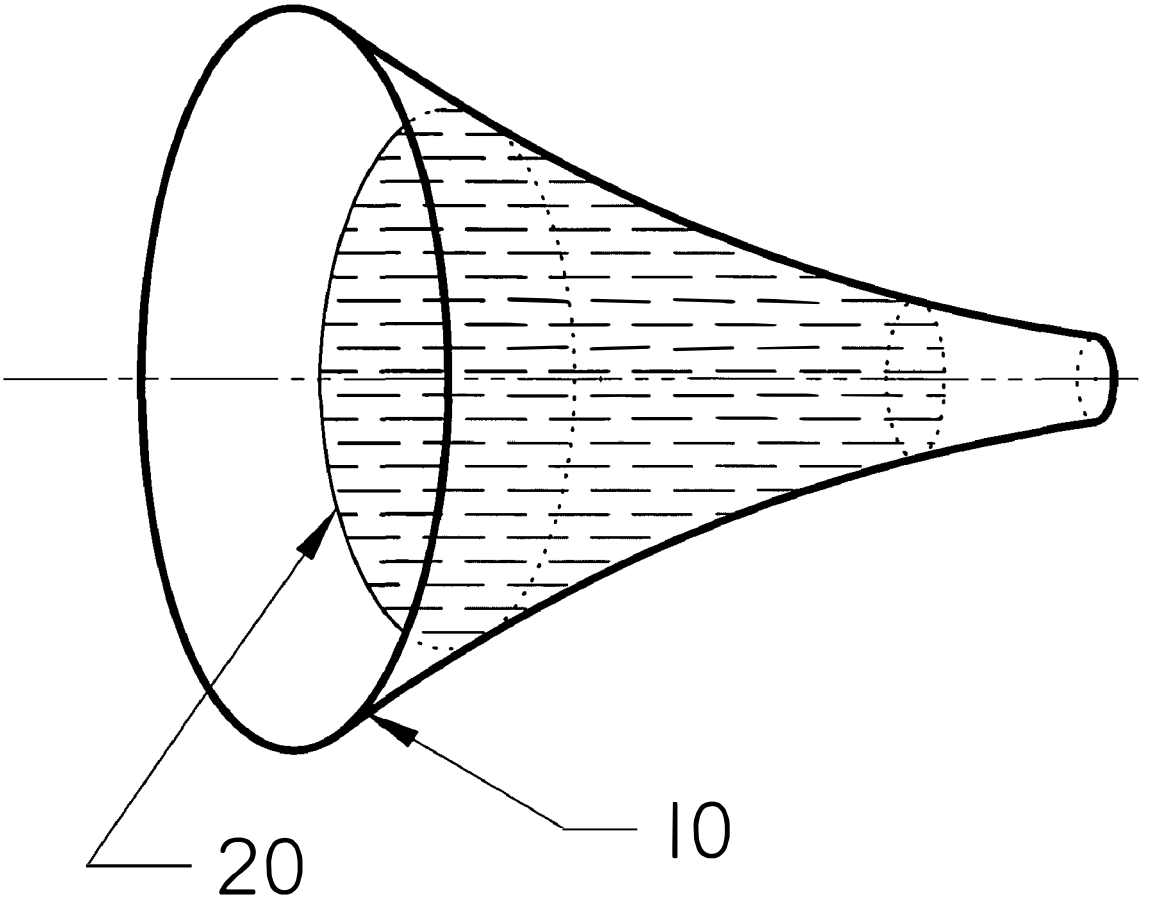


Fig. 2

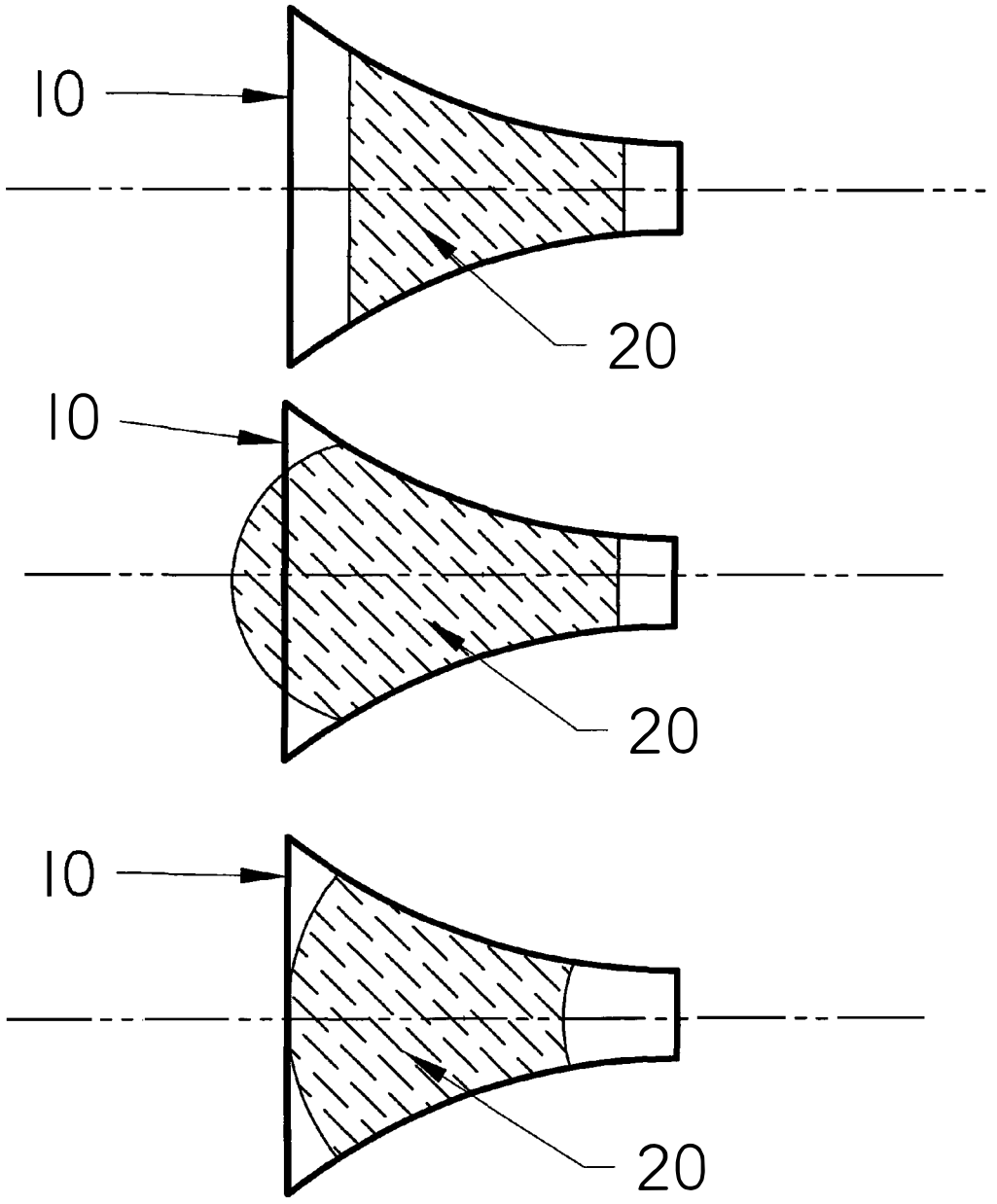


Fig. 3

United States Patent [19]

Tamura et al.

[11] **Patent Number: 4,893,695**

[45] **Date of Patent: Jan. 16, 1990**

[54] **SPEAKER SYSTEM**

[75] Inventors: **Tadashi Tamura**, Kadoma; **Shuji Saiki**, Hirakata; **Kazue Sato**, Neyagawa, all of Japan

[73] Assignee: **Matsushita Electric Industrial Co., Ltd.**, Osaka, Japan

[21] Appl. No.: **206,377**

[22] Filed: **Jun. 14, 1988**

[30] **Foreign Application Priority Data**

Jun. 16, 1987	[JP]	Japan	62-149646
Nov. 20, 1987	[JP]	Japan	62-294419
Apr. 28, 1988	[JP]	Japan	63-106355
May 2, 1988	[JP]	Japan	63-109343

[51] **Int. Cl.**[4] **H05K 5/00**

[52] **U.S. Cl.** **181/151;** 181/146; 181/152; 181/153; 181/159; 181/180; 181/184; 181/187; 181/196; 181/199; 381/156; 381/158

[58] **Field of Search** 181/151, 152, 159, 180, 181/184, 185, 189, 190, 196, 198, 146, 199, 153; 381/156, 158

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,876,035	4/1975	Eckel	181/198
3,982,607	9/1976	Evans	181/152
4,027,117	5/1977	Nakamura	381/158
4,369,857	1/1983	Frazer et al.	181/159
4,381,831	5/1983	Putnam	181/152

FOREIGN PATENT DOCUMENTS

0037139	10/1981	European Pat. Off. .
0129320	12/1984	European Pat. Off. .
49-134312	12/1974	Japan .

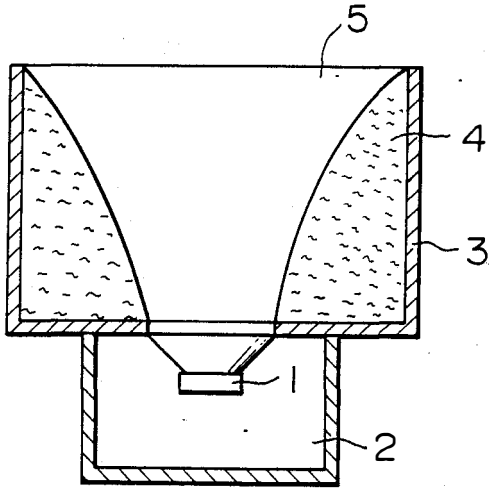
Primary Examiner—B. R. Fuller

Attorney, Agent, or Firm—Stevens, Davis, Miller & Mosher

[57] **ABSTRACT**

A speaker system which has a speaker unit with a diaphragm and an acoustic path provided on the front side of the diaphragm so as to guide sound waves emitted from the diaphragm. The acoustic path is defined by a sound absorbing member. The space in the acoustic path and the sound absorbing member is separated by a partition member which is disposed in such a manner that at least a portion of the sound absorbing member is exposed to the space in the acoustic path, except that the portion of the sound absorbing member just adjacent the diaphragm is not exposed to the acoustic path. This arrangement eliminates peaks and troughs of resonance determined by the length of the acoustic path, so that flat sound pressure frequency characteristics can be obtained over a wide range up to high-pitch tone region.

13 Claims, 7 Drawing Sheets



SPEAKER SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a speaker system having a horn or an acoustic pipe provided in front of the speaker diaphragm and adapted for guiding sonic waves therefrom.

2. Description of the Prior Art

A speaker system is known in which a sound wave generated by a diaphragm is introduced to the second outlet opening of the speaker through a horn or an acoustic pipe provided on the front side of the diaphragm. This type of speaker systems is finding increasingly wide use because it provides a higher level of the output sound pressure and superior directivity as compared with ordinary speaker systems which do not have such a horn or acoustic pipe.

A description will be given hereinunder, with reference to the drawings, as to a known speaker system of the type having a horn or an acoustic pipe.

Referring to FIG. **9** which is a sectional view of a known speaker system of the type mentioned above, a back cavity **2** is provided on the rear side of a speaker unit **1** for the purpose of preventing radiation of reflected sound from the speaker diaphragm. A horn **9** is provided in front of the speaker diaphragm and extends towards the sound outlet opening of the speaker system. The cross-sectional area of the horn **9** is progressively increased from the end adjacent to the speaker diaphragm towards the end adjacent to the sound outlet opening of the speaker system. The horn **9** thus constitutes an acoustic path which introduces the sound wave output from the speaker. The change in the acoustic impedance at the sound outlet opening of the speaker system is made extremely small provided that the horn **9** has a length which is sufficiently greater than the length of the wavelengths of sound wave of the reproduction band. In such a case, a very good matching is obtained at the sound outlet opening of the speaker system so that a flat reproduction sound pressure frequency characteristic is obtained thus realizing an ideal speaker system. Actually, however, in case of incorporation of the speaker system in an acoustic apparatus in sever, it is not practically possible to design horn **9** having a length so large that it is sufficiently greater than the wavelengths of sound waves in the reproduction band. Therefore, the speaker system employing such horns usually exhibit reproduction sound pressure frequency characteristics which contain many peaks and troughs as shown in FIGS. **2** (graph B) and **8** (graph B).

This is attributable to the fact that reflection waves are generated at the sound outlet opening of the speaker due to a drastic change in the acoustic impedance. In consequence, resonances are caused in the acoustic path. The same problem is encountered also with a speaker system which makes use of an acoustic pipe in place of the horn **9**. Thus, the speaker systems which employ acoustic pipes as the acoustic paths exhibit reproduction sound pressure frequency characteristics which contain many peaks and troughs. This is attributed to the fact that, as shown in FIG. **10**, a resonance takes place at a frequency f which is represented by the following formula:

$$f=(2n-1)C/4L(n=1, 2, 3, \ldots,)$$

where, L represents the length of the acoustic pipe, while C represents the velocity of the sonic wave.

FIG. **10** illustrates the sound pressure distribution and velocity distribution as obtained when the number n is 2 (n=2).

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a speaker system which provides a flat sound pressure frequency characteristics free from resonance peaks and troughs without requiring the length of the horn or the acoustic pipe to be increased.

To this end, according to the present invention, there is provided a speaker system comprising: an acoustic path provided on the front side of a speaker diaphragm and adapted for introducing a sound wave, the acoustic path being defined by a sound absorbing member; and a partition member which is disposed in the acoustic path in such a manner that at least a portion of the sound absorbing material is exposed to the interior of the acoustic path, except a part just before the diaphragm.

With this arrangement, the sound wave components reflected due to a drastic change in the acoustic impedance at the sound outlet opening are effectively absorbed by the sound absorbing member constituting the sound path, thereby providing flat sound pressure frequency characteristics with reduced peaks and troughs.

In addition, the components of the sound wave other than those which cause the peaks and troughs are introduced along the surface of the partition member to the sound outlet opening of the speaker system, without being absorbed by the sound absorbing member, whereby the reproduction band can be broadened.

Japanese Patent Unexamined Publication No. 49-134312 discloses a speaker system in which a horn for guiding the sound wave from a diaphragm is made from a material which exhibits a small tendency of generation of reflected waves (noise), i.e., a material which absorbs the noise well. This, however, is irrelevant to the invention of this application which is intended for absorbing reflected waves attributable to a drastic change in the acoustic impedance at the sound outlet opening of the speaker system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of a first embodiment of a speaker system in accordance with the present invention;

FIG. **2** depicts a graph A illustrating the sound pressure frequency characteristics of a first embodiment and the sound pressure frequency characteristics of a known speaker system of the invention and a graph B which illustrates the sound pressure frequency characteristics of a known speaker system.

FIGS. **3**(*a*) to **3**(*c*) are perspective views of different examples of the first embodiment;

FIG. **4** is a sectional view of a second embodiment of the speaker system in accordance with the present invention;

FIG. **5** is a sectional view of a third embodiment of the speaker system in accordance with the present invention;

FIGS. **6**(*a*) and **6**(*b*) are a sectional view and a front elevational view of an essential part of a fourth embodiment of the speaker system of the present invention;

FIG. 7 is a sectional view of a fifth embodiment of the speaker system of the present invention;

FIG. 8 illustrates a graph A showing the sound pressure frequency characteristics of a fifth embodiment and the sound pressure frequency characteristics of a known speaker system of the invention and a graph B illustrating the sound pressure frequency characteristics of a known speaker system;

FIG. 9 is a sectional view of a known speaker system; and

FIG. 10 is an illustration of particle velocity distribution and sound pressure distribution in a longitudinal section of the acoustic pipe.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described hereinunder with reference to the accompanying drawings.

FIG. 1 shows a first embodiment of the speaker system of the present invention and FIG. 4 shows a second embodiment which includes a speaker unit 1, a back cavity 2 on the rear side thereof, an acoustic pipe 3 for guiding and introducing sound waves generated on the front side of the diaphragm of the speaker unit 1 and a partition plate 6 disposed in the acoustic pipe 3 and defining, in part, an acoustic path 5 and a sound absorbing member 4 changed in the space between partition plate 6 and acoustic pipe 3 so as to define therein the acoustic path in cooperation with partition plate 6.

The operation of the above-described speaker system is explained below. The sound emitted from the rear side of the speaker unit 1 is confined in the back cavity 2 so that it is not transmitted to the outside of the speaker system. On the other hand, the sound emitted from the front side of the diaphragm is introduced through the acoustic pipe 3 to the sound outlet opening of the speaker system so as to be radiated therefrom. However, a part of the sound wave introduced to the sound outlet opening is reflected due to a drastic change in the acoustic impedance add at the opening, tending to propagate backward to the diaphragm surface. According to the invention, the reflected sound wave is conveniently absorbed by the sound absorbing material 4 disposed in the acoustic pipe 3, thus eliminating the existance of a standing wave in the acoustic pipe.

As will be seen from FIG. 1, the shorter the distance to the front surface of the diaphragm, the greater the thickness of sound-absorbing member 4 becomes at its portion closest to the diaphragm, and accordingly, the impedance of sound-absorbing member 4 as viewed from the reflected sound wave varies continuously from the diaphragm to the sound outlet opening, whereby the reflected sound wave entering from the sound outlet opening into acoustic path 5 is effectively absorbed by sound absorbing member 4 without any unnecessary reflection.

Namely, the amount of material of the sound absorbing member 4 increases towards the front side of the diaphragm so that the impedance exhibited by the sound absorbing member 4 to the reflected sound wave changes linearly, whereby the reflected sound wave from the sound outlet opening is effectively absorbed by the sound absorbing member without any unnecessary reflection.

The linear and progressive change in the impedance provided by the sound absorbing member may be controlled in various ways. For instance, it is possible to control the manner of change in the impedance by suitably varying the amount of the material of the sound absorbing member 4 along the length thereof, or by changing the material or density of the sound absorbing member 4 so as to adjust the flow resistance per unit area.

Further, partition plate 6 constitutes a wall extending from the diaphragm up to a height which is one-third of the height of acoustic pipe 3 so as to lead the sound wave to the opening end without hindering the high frequency band sound waves liable to be absorbed. It is noted that the velocity of particles of the sound transmitting medium increases in the range above the height of one-third of the acoustic pipe 3 which is measured from the diaphragm, to the opening end. Therefore, it is possible to suppress a sound pressure peak at a frequency at which a standing wave is produced. Further, sound waves at the other frequencies can be led to the opening without being hindered by the sound absorbing material 4 by forming the sound absorbing member 4 in a horn shape.

Needless to say, the sound wave produced by the diaphragm can be introduced to the sound outlet opening thrugh the acoustic path defined by the sound absorbing member 4 without being impeded by the sound absorbing member 4.

FIG. 2 illustrates the reproduction sound pressure frequency characteristics exhibited by a speaker system with the horn or acoustic pipe in accordance with the first embodiment, in comparison with the characteristics exhibited by the conventional arrangement. From this Figure, it will be understood that the conventional speaker system exhibits characteristics B which includes peaks and troughs due to existence of a standing wave, while the speaker system of the first embodiment exhibits flat reproduction sound pressure frequency characteristics A up to a high frequency sound region of the tone.

In the first embodiment as described above, the cross-sectional area of the acoustic path is increased from the end adjacent to the surface of the diaphragm towards the sound outlet opening. Such an acoustic path 5 may be defined partition plate 6 and sound absorbing member 4 in a cylindrical acoustic pipe 3 as shown in FIG. 3(*a*) or, alternatively, in a rectangular parallelopiped acoustic pipe 3, as shown in FIG. 3(*b*). The same advantages can be obtained in either the FIG. 3(*a*) or the FIG. 3(*b*) arrangement.

The advantages brought about by this embodiment can be enjoyed also when the acoustic path 5 has a tubular form of a constant cross-sectional area. The same advantages are derived also from an arrangement of FIG. 3(*c*) in which the sound absorbing member 4 has a horn-like form, while the acoustic pipe 3 is constructed to decrease its cross-sectional area towards the sound outlet opening, thus providing a constant cross-sectional area of the acoustic path 5, as shown in FIG. 3(*c*).

FIG. 5 shows a third embodiment of the speaker system of the present invention. The third embodiment has a speaker unit 1, a back cavity 2, an acoustic pipe 3 for guiding sound wave generated on the front side of the diaphragm in the speaker unit 1, a partition member 6 disposed in the acoustic pipe 3 so as to define an acoustic path 5 and having slits one of which is located near the sound outlet opening of the acoustic pipe 3 while the other is in the region which is about ⅓ of the full length of the acoustic pipe 3 as measured from the surface of

the speaker diaphragm, and a sound absorbing material received in the space between the acoustic pipe **3** and the partition member **6**.

The operation of the speaker system in accordance with the third embodiment is as follows. The sound wave emitted from the rear side of the speaker unit **1** is confined in the back cavity **2** so that it does not radiate outside. On the other hand, the sound from the front side of the diaphragm in the speaker unit **1** is guided by the acoustic pipe **3** to reach the sound outlet opening so as to be radiated therefrom. A portion of the sound wave reaching the sound outlet opening, however, is reflected because the acoustic impedance is drastically changed at the sound outlet opening. The reflected wave tends to propagate backward towards the surface of the diaphragm. The reflected wave, however, is effectively absorbed by the sound absorbing member **4** in the acoustic pipe **3** so that no standing wave is generated in the acoustic pipe.

As explained before, the partition member **6** has slits in the region near the sound outlet opening and in the region which is ¼ of the full length of the acoustic pipe **3** as measured from the surface of the speaker diaphragm, i.e., in the regions where the particle velocity is high. It is therefore possible to selectively absorb the sound wave components of frequency regions having peaks of sound pressure. Other components of the sound wave can be guided to the sound outlet opening without being impeded by the sound absorbing member **4**.

Thus, the third embodiment also provides flat sound pressure frequency characteristics, by suppressing the peaks of sound pressure which are inevitably high in the known horn or acoustic pipe due to the presence of a standing wave.

Obviously, the same advantages are brought about when the acoustic path **5** of the third embodiment is modified as shown in FIGS. **3**(*a*) to **3**(*c*).

FIGS. **6**(*a*) and **6**(*b*) show a fourth embodiment of the speaker system in accordance with the present invention. As will be seen from FIG. **6**(*a*), the fourth embodiment has a speaker unit **1**, a back cavity **2**, an acoustic pipe **3** which guides the sound wave generated on the front side of the diaphragm of the speaker unit **1**, a partition member **6** disposed in the acoustic pipe **3** so as to define an acoustic path **5** and having a plurality of apertures, and a sound absorbing member **4** filling the space between the wall of the acoustic pipe **3** and the partition member **6**.

As will be seen from FIG. **6**(*b*), the apertures **10** formed in the partition member **6** have a diameter of 8 mm and are arranged at a pitch of 30 mm.

The operation of the fourth embodiment of the speaker system will be described hereinunder. The sound emitted from the rear side of the diaphragm of the speaker unit **1** is confined in the back cavity **2** so that it does not radiate to the outside. On the other hand, the sound wave emitted from the front side of the diaphragm is guided to the sound outlet opening through the acoustic pipe **3** so as to be radiated therefrom. A portion of the sound wave reaching the sound outlet opening of the acoustic pipe **3**, however, is reflected to propagate backward so as to reach the front surface of the diaphragm, because a drastic change in the acoustic impedance takes place at the sound outlet opening. The reflected sound wave, however, is absorbed by the sound absorbing member **4** which continuously extends over the entire area of the inner surface of the acoustic pipe **3** so that establishment of standing wave in the acoustic pipe **3** is prevented.

In this embodiment, the partition member **6** has apertures **10** of 8 mm diameter arranged at a pitch of 30 mm. The reflected sound wave causes a resonation with the air in the apertures so that a large sound absorption rate is obtained in the region near 1 KHz, thus enabling absorption of the second peak of the sound pressure in the acoustic pipe **3** which has a length of 40 cm. Other peaks are directly absorbed by the sound absorbing member **4** rather than be resonance with the air in the apertures. The diameter and the pitch of the apertures **10** can be varied as desired to enable absorption of a peak at an arbitrary resonant frequency. Obviously, the configuration of the acoustic path **5** may be varied as illustrated in FIGS. **3**(*a*) to **3**(*c*), without imparing the advantages.

FIG. **7** shows a fifth embodiment of the speaker system in accordance with the present invention. This embodiment has a high frequency sound speaker unit **7**, a low frequency sound speaker **8**, a back cavity **2**, an acoustic pipe **3** for guiding the sound waves generated on the front surfaces of both speaker units **7** and **8**, a partition member **6** disposed in the acoustic pipe **3** so as to define an acoustic path **5** and having slits one of which is located near the sound outlet opening of the acoustic pipe **3** while the other is in a region which is about ¼ of the full length of the acoustic pipe as measured from the end surface of the diaphragm in the speaker unit, and a sound absorbing member **4** disposed in the space defined between the wall of the acoustic pipe **3** and the partition member **6**.

The operation of the speaker system in accordance with the fifth embodiment is as follows. The sound waves emitted from the rear side of the high and frequency sound speaker units **7** and **8** are confined in the back cavity **2** so that it does not radiate outside. On the other hand, the sound waves from the front side of the diaphragm in the speaker units **7** and **8** are guided by the acoustic pipe **3** to reach the sound outlet opening so as to be radiated therefrom. A portion of the sound waves reaching the sound outlet opening is, however, reflected because the acoustic impedance is drastically changed at the sound outlet opening. The reflected wave tends to propagate backward towards the surface of the diaphragm. The reflected wave, however, is effectively absorbed by the sound absorbing member **4** in the acoustic pipe **3** so that no standing wave is generated in the acoustic pipe.

As explained before, the partition member **6** has slits in the region near the sound outlet opening and in the region which is ¼ of the full length of the acoustic pipe **3** as measured from the surface of the speaker diaphragm, i.e., in the regions where the particle velocity is high. It is therefore possible to selectively suppress only the sound waves at frequencies at which standing waves are produced. The sound waves that are liable to be absorbed by sound absorbing material **4** can be guided to the sound outlet opening without being impeded by the sound absorbing member **4**.

FIG. **8** illustrates the reproduction sound pressure frequency characteristics exhibited by a speaker system with the horn or acoustic pipe in accordance with the fifth embodiment, in comparison with the characteristics exhibited by the conventional arrangement. From this figure, it will be understood that the conventional speaker system exhibits characteristics B which includes peaks and troughs due to existence of a standing

wave, while the speaker system of the fifth embodiment exhibits flat reproduction sound pressure frequency characteristics A up to high pitch region of the tone.

Thus, the fifth embodiment also provides relatively flat sound pressure frequency characteristics, by suppressing the peaks of sound pressure which are inevitably high in the known horn or acoustic pipe due to the presence of a standing wave.

Obviously, the advantages offered by the fifth embodiment can equally be enjoyed even when the acoustic path **5** is modified as illustrated in FIGS. **3**(*a*) to **3**(*c*).

What is claimed is:

1. A speaker system, comprising at least one diaphragm having front and rear surfaces; an acoustic path for guiding sound waves generated on said front surface of said diaphram; a sound absorbing member having an inner surface defining said acoustic path; and a partition member disposed on said inner surface of said sound absorbing member to surround a portion of said acoustic path, whereby said partition member is disposed such that said sound absorbing member is exposed to said acoustic path at at least one part of said sound absorbing member, said at least one part being located at any position of said sound absorbing member except at a region thereof just adjacent said diaphragm.

2. A speaker system according to claim **1**, wherein said partition member extends from the front surface of said diaphragm to a position which is spaced from said front surface of said diaphragm by about $\frac{1}{3}$ of the full length of said acoustic path.

3. A speaker system according to claim **1**, wherein the position where said sound absorbing member is exposed is in a region where a standing wave has a high particle velocity distribution.

4. A speaker system according to claim **3** wherein said sound absorbing member is exposed in a region which is spaced from the front surface of said diaphram by about $\frac{1}{3}$ of the full length of said acoustic path and a region which is near the sound outlet opening of said acoustic path.

5. A speaker system according to claim **1**, wherein the cross-sectional area of said acoustic path is progressively increased from one end near said diaphragm towards another end near said sound outlet opening.

6. A speaker system according to claim **5**, further including an acoustic pipe having a wall surrounding said sound absorbing member, wherein said acoustic path is defined by said sound absorbing member and the wall of said acoustic pipe.

7. A speaker system according to claim **1**, wherein said acoustic path has a constant cross-sectional area over the entire length thereof.

8. A speaker system according to claim **7**, wherein said acoustic path is defined by the wall of said sound absorbing member and the wall of an acoustic pipe.

9. A speaker system according to claim **7**, further including an acoustic pipe having a wall surrounding said sound absorbing member, whereby said acoustic path is defined by said sound absorbing member and said wall of said acoustic pipe.

10. A speaker system according to claim **1**, further comprising a plurality of diaphragms having front and rear surfaces, said plurality of diaphragms including said at least one diaphragm, and wherein said acoustic path is provided commonly on the front side of said plurality of diaphragms.

11. A speaker system according to claim **1**, wherein said sound absorbing member is provided in an acoustic pipe.

12. A speaker system according to claim **1**, wherein the amount of the material of said sound absorbing member is progressively decreased from one end near said diaphram towards another end near said sound outlet opening.

13. A speaker system according to claim **1**, wherein the flow resistance per unit area of said sound absorbing member is progressively decresed from one end near said diaphragm towards another end near said sound outlet opening.

* * * * *

FIG. 1

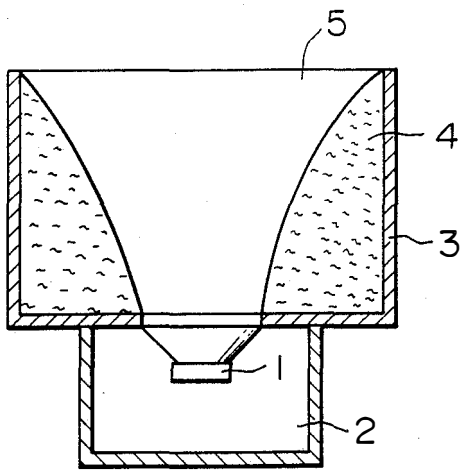

5
4
3
1
2

FIG. 2

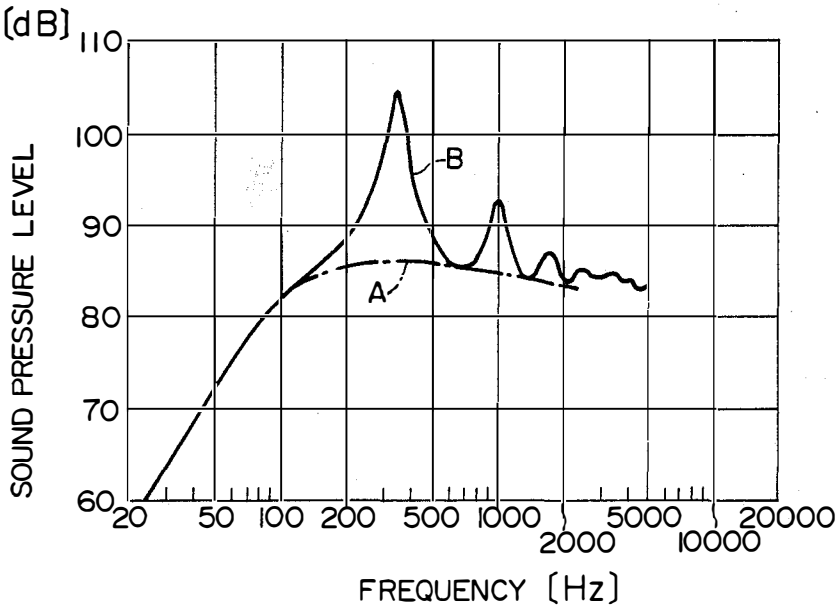

[dB]
110
100
90
80
70
60
SOUND PRESSURE LEVEL
B
A
20
50
100
200
500
1000
2000
5000
10000
20000
FREQUENCY [Hz]

FIG. 3(a)

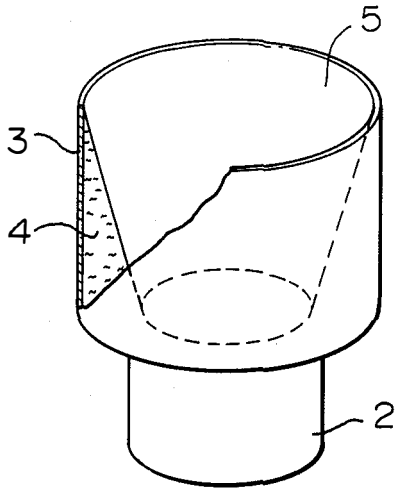


FIG. 3(b)

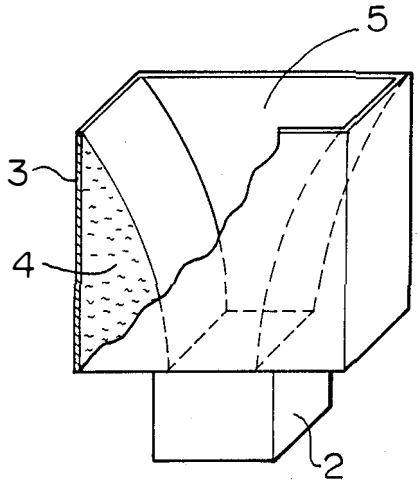


FIG. 3(c)

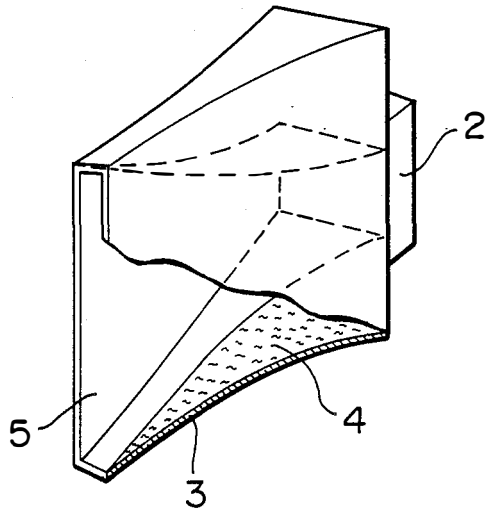


FIG. 4

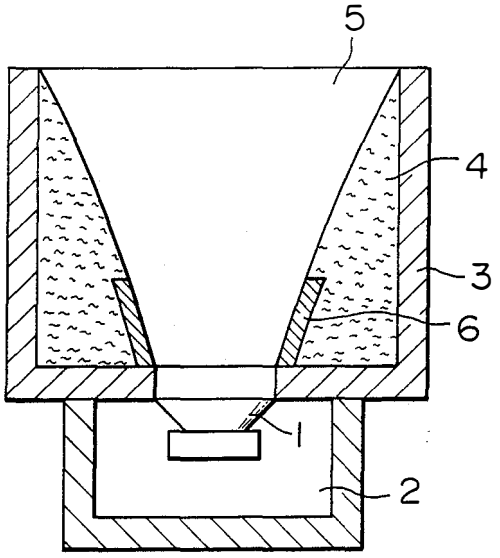


FIG. 5

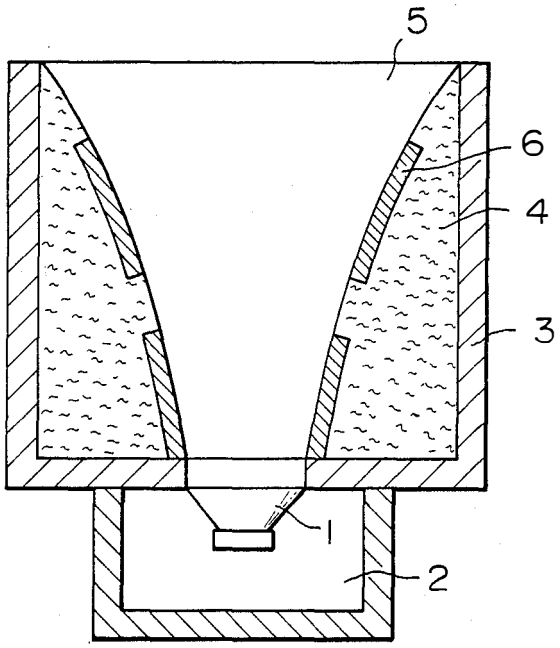


FIG. 6(a)

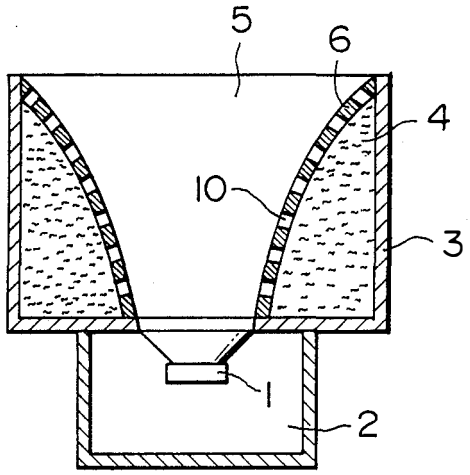


FIG. 6(b)

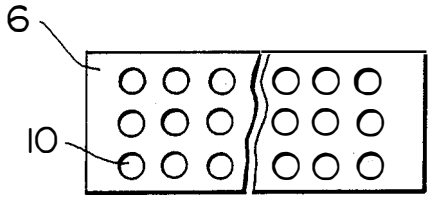


FIG. 7

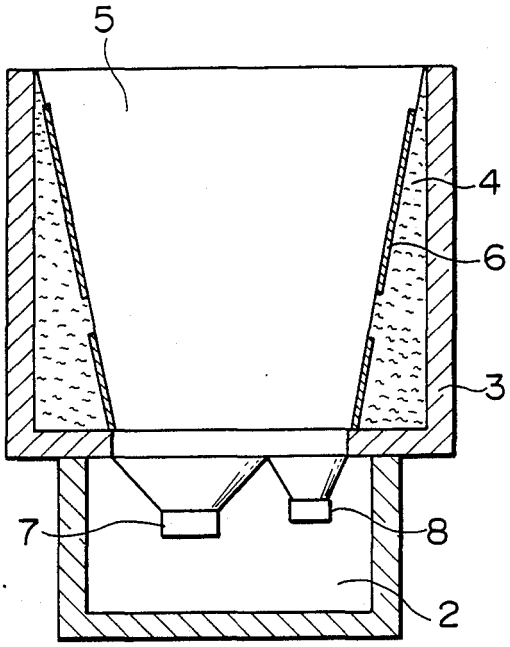

5
4
6
3
7
8
2

FIG. 8

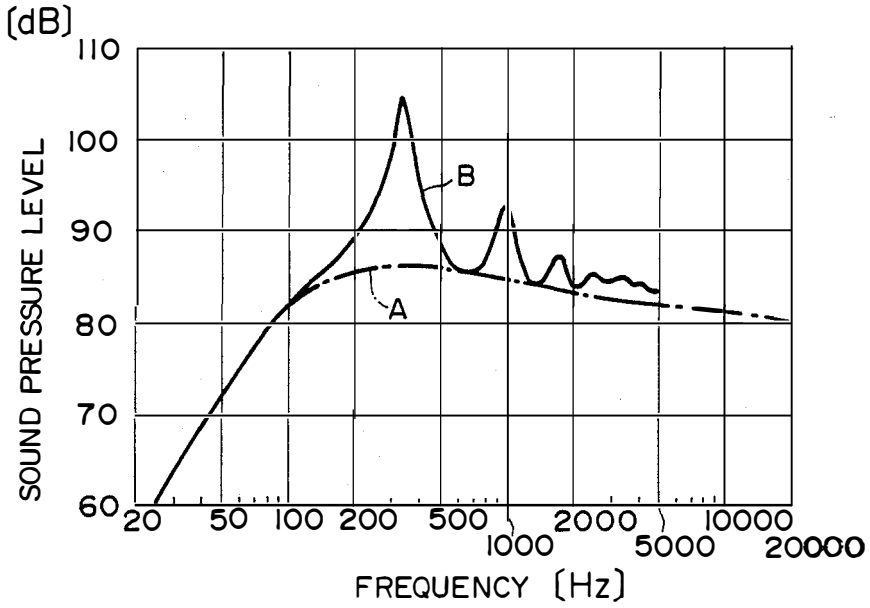

[dB]
110
100
90
80
70
60
SOUND PRESSURE LEVEL
B
A
20
50
100
200
500
1000
2000
5000
10000
20000
FREQUENCY [Hz]

FIG. 9 (PRIOR ART)

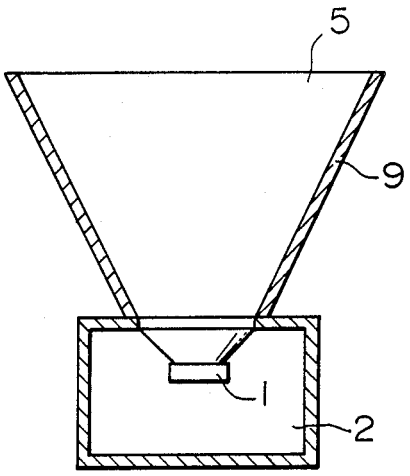


FIG. 10

