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Wright

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[45] **Dec. 11, 1973**

[54] **ELECTROSTATIC LOUDSPEAKER HAVING ACOUSTIC WAVEFRONT MODIFYING DEVICE**

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[73] Assignee: **Dayton Wright Associates Limited,** Toronto, Ontario, Canada

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[52] **U.S. Cl.** ..... **179/111 R,** 181/31 B

[51] **Int. Cl.** **H04r 19/02**

[58] **Field of Search** ..... 179/111; 340/8 L; 181/27, 31 A, 31 B; 179/1 E

[56] **References Cited**

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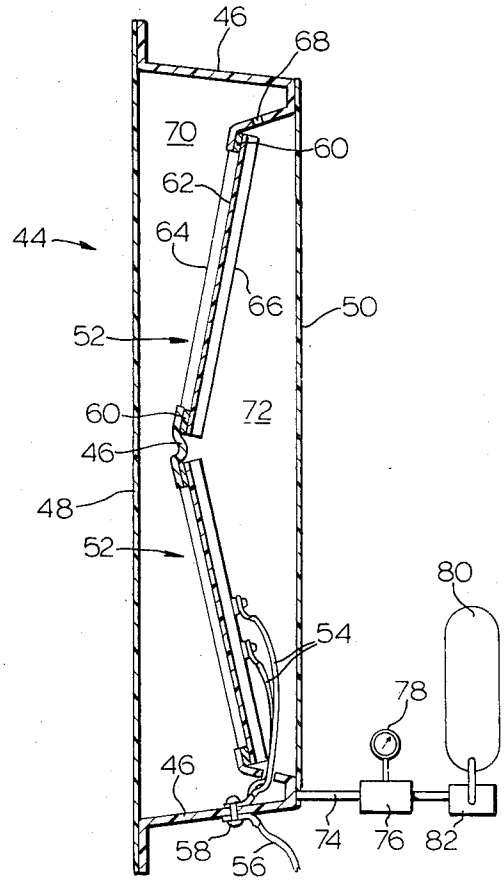
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Primary Examiner—Kathleen H. Claffy
Assistant Examiner—Thomas L. Kundert
Attorney—Douglas S. Johnson

[57] **ABSTRACT**

An Acoustic Wavefront Modifying Device can be used with acoustic waves having audio frequencies within the range of human hearing as a lens or prism. The device comprises an enclosure having at least a portion of its surface space acoustically transparent and having therein a gas in which the speed of sound differs from the speed of sound in the ambient gas. The device is most particularly embodied in an electrostatic loudspeaker having one or a plurality of electrostatic transducer units within a gas enclosure and having acoustically transparent front and back surfaces. The gas is usually sulphurhexafluoride or perfluoropropane or a mixture of them or either of them with air.

12 Claims, 10 Drawing Figures



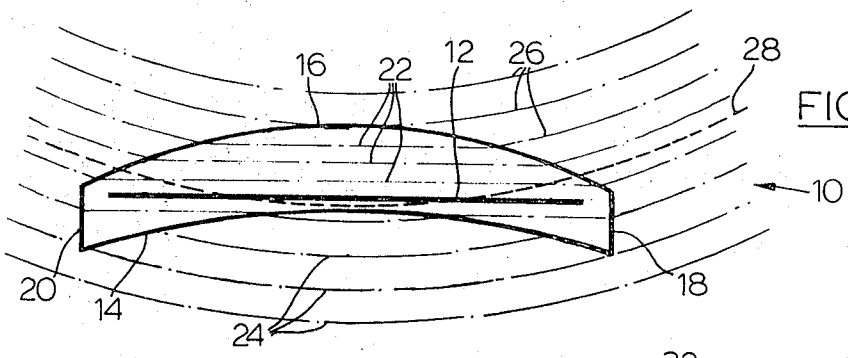


FIG. 1

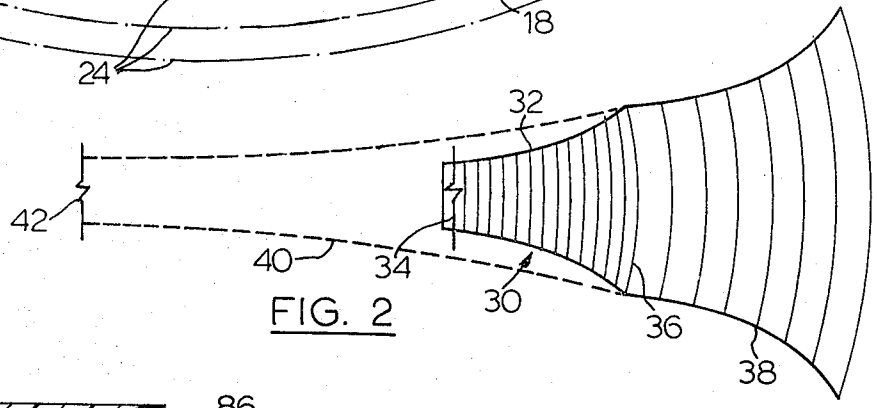


FIG. 2

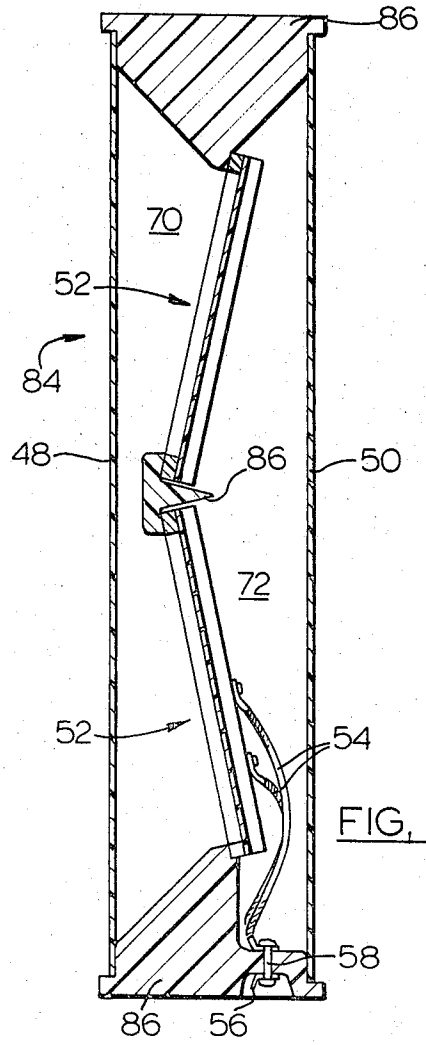


FIG. 4

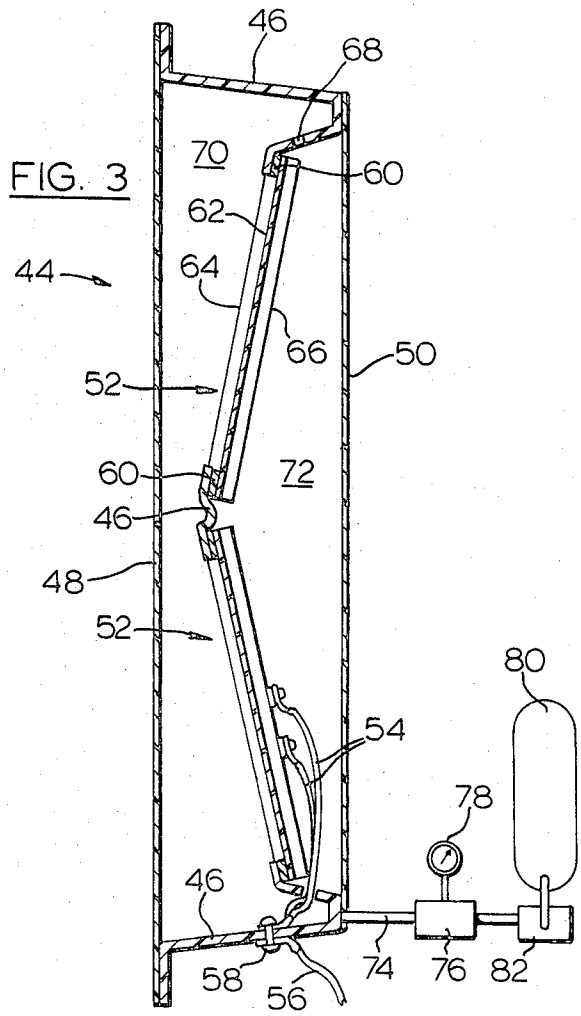


FIG. 3

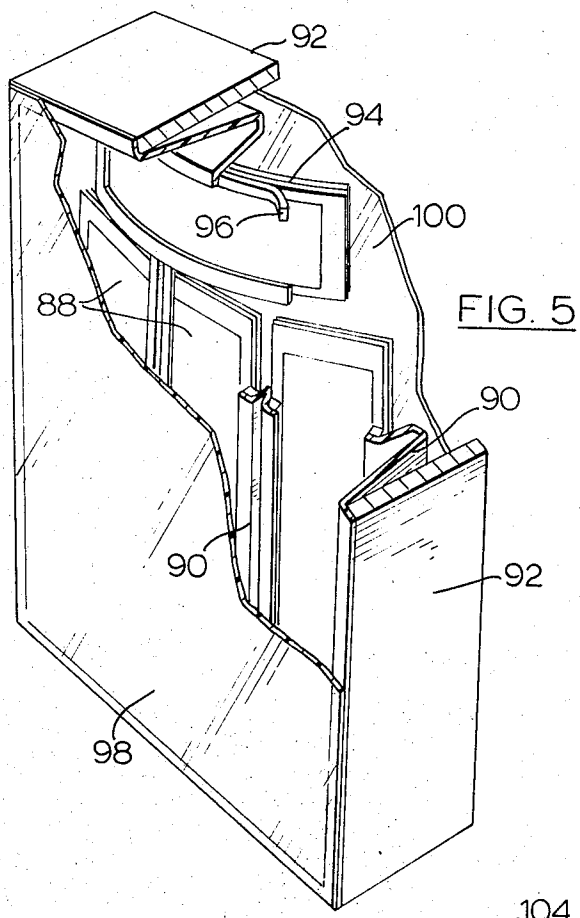


FIG. 5

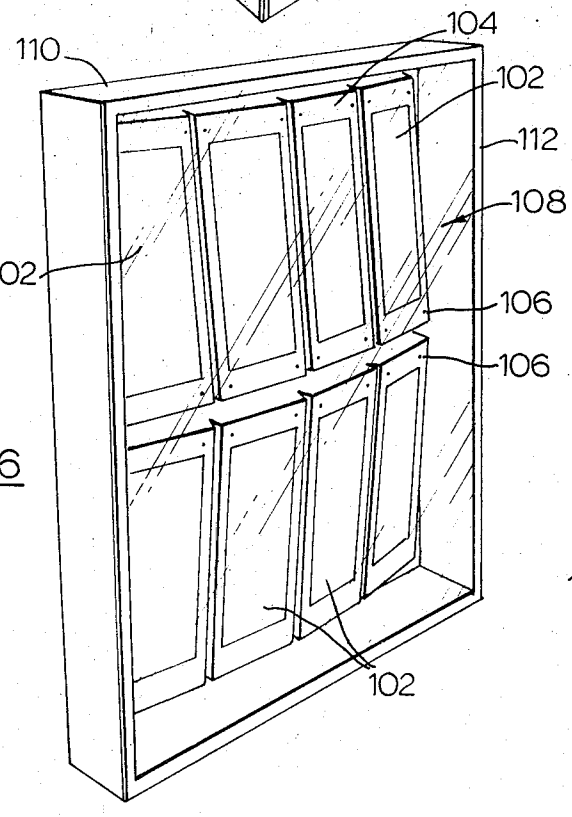
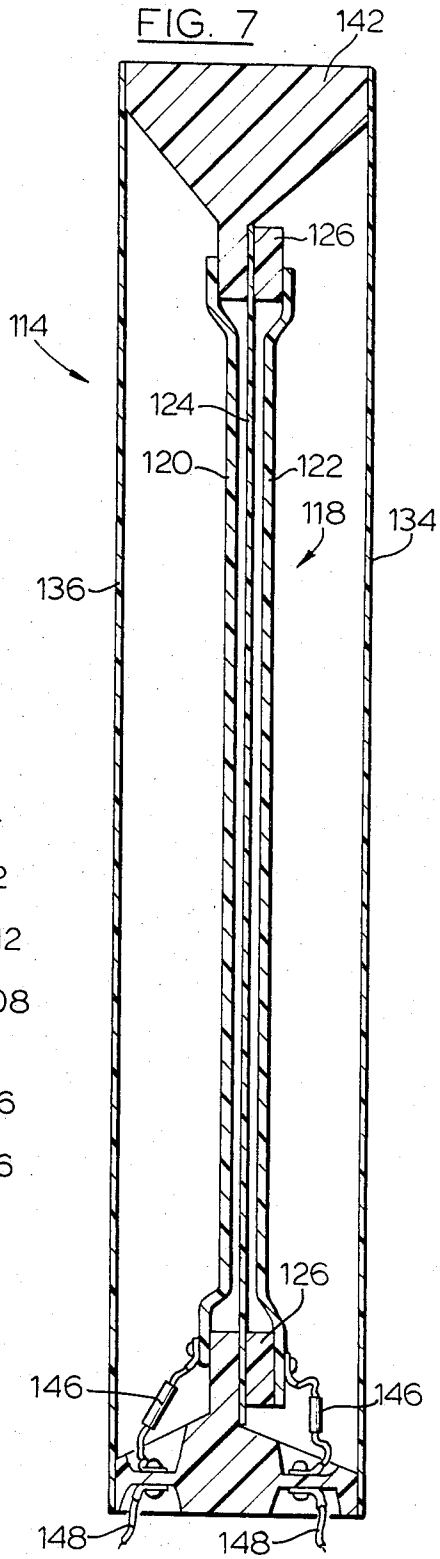


FIG. 6

FIG. 7



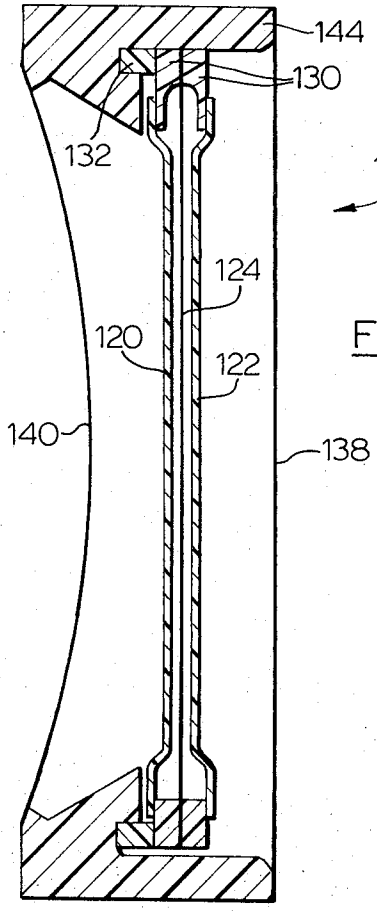


FIG. 8

FIG. 9

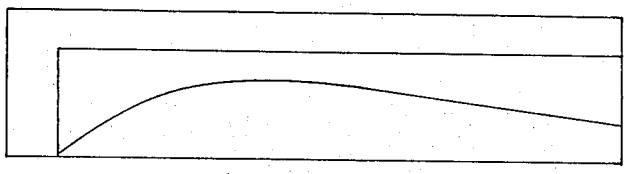
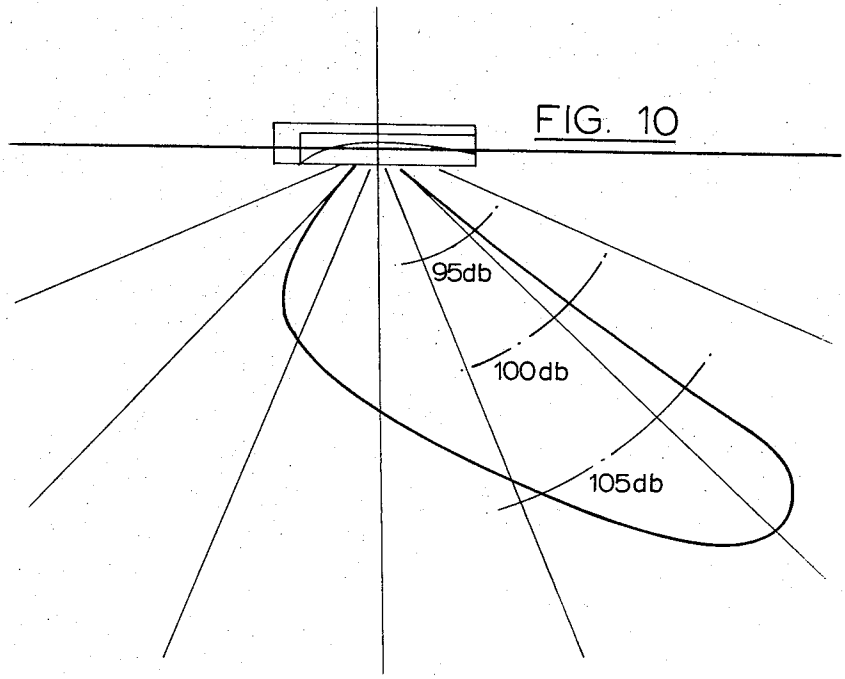


FIG. 10



ELECTROSTATIC LOUDSPEAKER HAVING ACOUSTIC WAVEFRONT MODIFYING DEVICE

FIELD OF THE INVENTION

This invention relates to the field of acoustics, and provides an acoustic wavefront modulation or modifying device. More particularly, the invention provides an acoustic lens device, and especially one in which an electrostatic transducer may be mounted. The present invention thereby provides an electrostatic loudspeaker system having improved power handling capabilities; and one which can be tuned insofar as its polar radiating pattern is concerned. Therefore, for practical and commercial purposes, this invention provides a means whereby large, high power speakers may be provided in any particular circumstance, whose polar radiating patterns may be predetermined or predicted, and whereby stereo fusion from a plurality of such speakers over a large area may be assured. Such loudspeaker devices are particularly intended for installation in such large halls as theatres, concert halls, etc.

BACKGROUND OF THE INVENTION

An early design for an electrostatic transducer unit is taught in Wright U.S. Pat. No. 3,135,838 dated June 2, 1964; and a more advanced electrostatic transducer of the push-pull variety and driveable from a constant voltage source is taught in Wright Canadian Pat. No. 866,963 dated Mar. 23, 1971. A brief consideration is made in the latter patent of enclosing the acoustic diaphragm of an electrostatic speaker within a gas enclosure; but no consideration was given of the effect of the gas enclosure having a gas therein in which the speed of sound is different than the speed of sound in air. Thus, refraction effects are possible at the interface between two gases having different propogation rates for acoustic wavefronts, and this invention provides means whereby prism or lens effects are possible with acoustic waves in the audio range, and which may be realized for practical and commercial purposes.

E. J. Jordan, writing in Wireless World, November, 1970, at pages 533 to 537 remarks, at the conclusion of that paper, that full-range electrostatic loudspeakers do not have any large power handling capacity, particularly at low audio frequencies - say, in the range of 30 Hz. He concludes that further loudspeaker development should be such as to achieve the definition standard set by full-range electrostatic loudspeakers coupled to the wide-power bandwidth of cone speakers. Thus, it has not been known to provide a full-range, extended gradient electrostatic loudspeaker having high power handling capabilities.

Further, in such installations as cinemas and theatres, concert halls, etc., it is very often desirable to provide a plurality of channels on which audio information can be played, so as to provide a sense of directionality of the source of the sound to a listener sitting in the auditorium of such a hall. It is therefore desirable to provide a system whereby the polar radiating pattern of each loudspeaker may be designed and predicted for any particular installation so as to provide stereo fusion from a plurality of speakers over a very large area of the auditorium. In such an installation, it is possible to reduce the number of channels on which sound information is to be provided. This is a major consideration in terms of the number of channels of sound information which can be printed on film, or carried on magnetic tape played in synchronism with film.

Still further, it is very often desirable to provide high power, low frequency response in as small an enclosure as may be physically possible. Thus, it is desirable to reduce the physical length of a horn, if possible; or it is desirable to reduce the physical size of a bass frequency cabinet of any of the known designs; or especially with respect to this invention, it is desirable to provide an electrostatic speaker having very high power handling capacity at bass frequencies. H. W. Sullivan, in U.S. Pat. No. 2,797,766, dated July 2, 1957, provides a loudspeaker in which a relatively heavy gas is used to increase or extend the low frequency response. However, Sullivan completely overlooks all possibilities of the use of an enclosure having a gas therein in which the speed of sound is less than that in air for refraction effects with respect to sound waves generated within that enclosure, or on the other side of the enclosure as in a prism. Neither, of course, does Sullivan in any way consider the use of an electrostatic transducer or loudspeaker element.

It has been discovered that the use of the diaphragm of an electrostatic unit, within an enclosure which is filled with a gas in which the speed of sound is different than that in air, can provide a loudspeaker in which the apparent source of sound can be shifted with respect to the precise geometry of the loudspeaker enclosure.

An electrostatic transducer of the push-pull type, in its simplest and most common embodiment, requires two electrodes which are rigid, and between which there is suspended a taut membrane or diaphragm having a high resistive coating over a major portion of its surface. Such an electrostatic transducer is taught in the aforementioned Wright Canadian patent. Certain parameters effect the operation of such a transducer, and limit the operation in certain ways. For example, the breakdown voltage of the gaseous medium in which the DC field operates will, of course, determine the limitations of the DC gradient of that field and of the imposed voltage for any given electrode spacing. Further, the breakdown voltage of the gaseous medium may also determine the upper limitations of signal voltage which may be applied to the transducer, and the limitations to which diaphragm excursion may extend at high power without clipping or other induced or apparent distortion to the audio signal occuring and being heard from that transducer. Also, the elasticity of the gas in which the transducer diaphragm moves, the throttling effect of the holes in the electrodes through which the gas passes as it is driven by the diaphragm, and the radiation resistance of the gas, all have an effect on the operation of the electrostatic transducer, and therefore, upon the electrical characteristics of the transducer at any frequency. For example, at high frequencies, an electrostatic transducer may operate effectively as a shunt on the output of an amplifier because it is essentially a capacitor which tends to have an electrical shorting effect at higher frequencies; unless the amplifier has a very high damping factor and/or negative feedback around its output stage so that it operates essentially as a voltage source. In any event, with electrostatic transducers of the sort contemplated in this invention and taught in the previous Wright Canadian patent, the diaphragm moves essentially as a piston above its resonant frequency, which is very low and may be in the subsonic region; and the diaphragm moves as a

catenary below its resonant frequency. Thus, the wavefronts coming from the diaphragm in either direction - it being recalled that an electrostatic transducer of the push-pull variety is a dipole - are essentially planar in nature because of the piston-like motion of the diaphragm. If the diaphragm is at an angle to another membrane which acts as a gas interface between two gases having differing speeds of sound, refractive effects will occur across the interface, as the planar waves arrive at it. The material of the interface, of course, is an essentially acoustically transparent material having very light weight and therefore essentially no sound or energy absorption. If the gas used is one in which the speed of sound is only one third that of the speed of sound in air, and in which the voltage breakdown is three times higher than that of air, then: the size of an enclosure can be minimized, or the apparent horn length of a horn made to be considerably longer than the actual physical horn length; or the power handling capacity of an electrostatic speaker operating in such gas can be increased by up to 81 times the power handling capacity of an identical speaker operating in air. This is because the bias voltage can be increased by a factor of three, and therefore, the power by a factor of nine; and also, the drive voltage can be increased by a factor of three, which also allows a power increase by a factor of nine; and therefore, the allowable audio power output at dielectric breakdown of the electrostatic transducer operating in the gas may be up to 81 times greater. Of course, larger power supplies having higher output voltages by a factor of three, and larger audio transformers having higher output power ratings are required to utilize and effectively exploit the much higher power handling capacity of an electrostatic transducer operating in such a gas as spoken of above. Such gases include sulphurhexafluoride, and perfluoropropane mixtures of the two, and mixtures of either or both of the two gases with up to about 25 percent air, as well as carbon dioxide, Freon gases, and mixtures of them. Thus, electrostatic loudspeakers having eight cells, mounted in a gas enclosure having overall dimensions of 40 inches by 48 inches by 8 inches, have been provided having continuous input power handling capacity of at least 250 watts at 60 Hz.

By using curved gas diaphragms at the gas interface of an acoustic lens according to this invention, convergent or divergent wavefront dispersion patterns may be produced from the curved diaphragm depending on the nature and amount of curvature and on the refractive index between the gases at the interface represented by such a diaphragm. Similarly, by arranging one or a plurality of substantially planar diaphragms on the apparent surface of a sphere within a gas enclosure each at an angle to a substantially planar outer diaphragm defining one surface of the gas enclosure, it is also possible to produce convergent or divergent wave patterns from the loudspeaker so embodied. In this case, a loudspeaker is usually a dipole, and the convergent and divergent wave patterns are found on opposite sides thereof.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an acoustic wavefront modifying device with a gas enclosure having therein a gas in which the speed of sound differs from the speed of sound in air, and having at least one acoustically transparent portion of the surface of that enclosure.

A further object of this invention is to provide an acoustic wavefront modifying device having a gas enclosure with at least a portion of its surface comprising an acoustically transparent material, which enclosure has a wavefront refractive effect on audio wavefronts of frequencies in the range of human hearing.

Yet another object of this invention is to provide an electrostatic loudspeaker unit having a gas enclosure in which at least one electrostatic transducer unit adapted to propogate essentially planar wavefronts of audio frequency is mounted.

A further object of this invention is to provide an electrostatic loudspeaker unit whose polar radiating pattern can be predetermined.

A still further object of this invention is to provide a gas enclosure for a gas in which the speed of sound differs from the speed of sound in air, and which may be adapted as a lens element or a prism with respect to acoustic wavefronts of audio frequency. Another object of this invention is to provide an electrostatic loudspeaker unit having high power handling capacity at low audio frequencies, and which may be easily assembled.

Still another object of this invention is to provide means whereby an electrostatic loudspeaker may be mass produced at relatively low cost with respect to the cost per watt of audio power output of the loudspeaker.

Yet another object of this invention is to provide an electrostatic loudspeaker having a relatively high conversion efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features and advantages of the present invention are discussed in greater detail hereafter in association with the drawings in which:

FIG. **1** is a plan diagram of an acoustic lens;

FIG. **2** is a diagram showing real and apparent horn lengths of a device in accordance with this invention;

FIG. **3** is a section view of a device in accordance with this invention;

FIG. **4** is a section view of an alternate embodiment of a device similar to that of FIG. **3**;

FIG. **5** is a perspective, partially broken, view of an electrostatic speaker unit in accordance with this invention;

FIG. **6** is a perspective view of an electrostatic speaker unit of the sort shown in FIGS. **3** and **4**;

FIG. **7** is a section view of yet another elecrostatic speaker unit according to this invention;

FIG. **8** is a section view of a still further embodiment of an electrostatic speaker unit of the sort shown in FIG. **7**;

FIG. **9** is the apparent diagramatic plan view of an assymetric accoustic lens; and

FIG. **10** is a typical polar pattern taken for the assymetric lens of FIG. **9**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As indicated above, the purposes of this invention are obtained by providing a gas enclosure in which there is enclosed a gas having a differing speed of sound than the speed of sound in the gas external of the enclosure, which is usually air. That is to say, an enclosure is provided in which sound travels at a different speed than

it travels in air, or whatever other gas surrounds the enclosure and is external of it; and for purposes of this invention, the gas usually used in such enclosures is such that the speed of sound is lower in that gas than in air. In addition, as noted, certain of the gases which can be used may also have the added advantage, especially useful with electrostatic transducers, of much higher breakdown voltages, thereby providing higher power handling capabilities for such units. Also, as noted, the invention is particularly adapted for use where at least one of the diaphragms of an electrostatic transducer element or the diaphragm of the gas interface with the environment in which the speaker is operating, is planar; or, in the case where both diaphragms are planar, the diaphragms are tilted, one withrespect to the other.

Turning to FIG. **1**, a device is shown at **10** having installed therein a diaphragm **12** which is essentially planar, and with a front diaphragm or membrane **14** and a rear diaphragm or membrane **16.** Sides **18** and **20** are provided, whereby the device can be entirely hermetically sealed so as to form a gas enclosure. A plurality of wave fronts **22** are shown in the enclosure **10,** and because the diaphragm **12** is planar, so also are the wave fronts **22.** It is assumed that the speed of sound in the gas within the enclosure **10** is approximately one-third of the speed of sound in the environment outside the enclosure **10,** which would usually be air. A plurality of wave fronts **24** is shown outside the enclosure **10** at the front thereof (front being conveiently chosen for purposes of this discussion) and a further plurality of wavefronts **26** is shown at the rear of the enclosure **10.** The distance that the wave fronts **24** or **26** are apart from one another is, of course, three times greater than the distance that wave fronts **22** are apart from one another because of the difference in the velocities or speeds of sound in air and in the gas within the enclosure **10.** It is thus seen that, because of the well known refractive effects at the membranes or diaphragms **14** and **16** which comprise gas interfaces between the gas within the enclosure **10** and the air external of the enclosure **10,** wavefronts **24** and **26** assume the curvilinear shape which is shown in FIG. **1.** The apparent shape of the diaphragm **12** is shown at **28.** No further consideration is given for the purpose of the present discussion to the nature of the sound producing or propogating agent which is the diaphragm **12.** The device or enclosure **10** illustrated in FIG. **1** is, therefore, essentially an acoustic lens; but, in this case, the wavefronts which the lens refracts are generated and propogated within the lens itself. As noted, the lens effect comes because of the refractive index which occurs because of the differing speeds of sound of wave transmission in the gas within the enclosure **10** and the gas external of the enclosure **10,** and the refraction occurs at the gas interfaces defined by the external diaphragms **14** and **16.**

If a sound source were to be placed at the front or rear of the enclosure **10,** and the effect of wavefronts moving from that sound source were to be observed on the other side of the enclosure, the enclosure would operate substantially as a prism. Also, it should be noted that because of the apparent shape of the diaphragm as indicated at **28,** a point source of sound can be postulated or inferred to be at the centre of the apparent curvature of the diaphragm, which may be some considerable distance behind the enclosure **10.**

FIG. **2** shows the effect of the use of a gas in which the speed of sound is about one third that of the speed of sound of air, to physically shorten a horn and to provide a horn having a much longer apparent horn length. In this case, a horn **30** is provided with a driver diaphragm **34** of the type well known in the art relating to acoustic horns, and is suitably connected to an audio source, not shown. The flare of the inner portion of the horn - i.e., the shortened portion - is shown at **32,** and it is terminated by a diaphragm **36** which functions as a gas isolation or gas interface diaphragm. In this case, therefore, the diaphragm **36** is a substantially acoustically transparent diaphragm in a portion of the enclosure **30** at the end thereof opposite the driver diaphragm **34.** Ideally, the diaphragm **36** is arranged so as to coincide with the surface of each wavefront which comes to it; and the surface of the wave front is, of course, curved because of the flare of the horn **32.** The horn is extended beyond the diaphragm **36** with a differing flare, as indicated at **38.** The flare rate differences are based on a scaling factor which is derived from the relative wavelengths between wavefronts moving in the gas within the enclosure **30** and in air outside the enclosure **30,** beyond the diaphragm **36.** The real length of the gas filled horn portion **30** is between the diaphragm **36** and driver diaphragm **34;** but the apparent length of the horn is indicated by dotted lines **40** and terminates at **42.** Once again, it can be assumed that the gas within the enclosure **30** between the driver diaphragm **34** and the gas interface diaphragm **36** is sulphurhexafluoride or perfluoropropane, each of which is about three times as dense as air, and in each of which the speed of sound is approximately one third the speed of sound in air.

As will be discussed in greater detail hereafter, when gases such as SF_6 or perfluoropropane are used, such gases exhibit more linear compressive characteristics than air. In other words, such gases are more ideal gases, and have better damping or spring characteristics than air, especially at low frequencies. Thus, reflections in the horn portion **38** due to the discontinuity at diaphragm **36** are less likely to occur, because the throat pressure distortion in the gas within the horn **30** will be less than it would be in air.

There is illustrated in FIG. **3** an electrostatic speaker unit **44,** comprising a "bin" **46,** front diaphragm **48,** rear diaphragm **50,** and electrostatic transducer units **52.** The transducer units may be electrically connected using wires **54;** and because the enclosure of the speaker **44** is hermetically sealed, suitable electric connections may be made to wires **56** external of the bin **46** by conducting rivets **58** which are hermetically installed in the wall of the bin **46.** As noted hereafter in association with FIG. **5** or **6,** the bin may be vacuum formed from a suitable material such as styrene or acrylonitrile butadiene styrene.

Each of the electrostatic transducer units **52** may suitably be such as those illustrated in the Wright Canadian patent noted above, and each is suitably mounted to the bin using a flexible foam tape **60** having adhesive on both sides thereof, and which may be formed of foamed polyethylene or other plastic material. Each of the electrostatic transducer units **52** comprises a diaphragm **62,** a front electrode **64,** and a rear electrode **66.** A vent **68** may be formed in the bin between the front partial gas enclosure **70** and the rear partial gas enclosure **72.** The diaphragms **48** and **50** may be attached to the bin **46** by suitable adhesive means, such as a urethane based adhesive. The diaphragms are

acoustically transparent, having extremely low mass, and therefore, no substantial energy absorption characteristics, even at high frequencies - and may suitably be formed of such material as Mylar (especially heat-shrinkable Mylar), nylon, Saran, acetate, etc. The enclosure **44**, including partial gas enclosure **70** and **72**, is hermetically sealed and may be filled with a gas such as sulphurhexafluoride (SF_6), perfluoropropane, or a mixture of them, or either of them, with air. As discussed hereafter, the enclosure **44** may be connected through suitable conduit means **74** to pressure regulating means **76** with pressure indicating means **78**, and thence to a further reservoir or enclosure **80** having suitable header and manifold means **82**. The gas within the enclosure **80** is, of course, the same as is within the enclosure **44**; and it may be at a higher pressure so as to require the pressure regulating means **76**, or it may be at atmospheric pressure in which case regulating means **76** may not be required except for valving purposes as discussed hereafter.

An enclosure **84** which is, in many ways, substantially similar to enclosure **44**, is shown in FIG. **4**. Front and rear diaphragms **48** and **50** are included in the enclosure **84**; as are electrostatic transducer units **52**, wiring **54** and **56**, rivets **58**, and foam tape **60**. However, the bin **86** is substantially more massive than the bin **46**, and is intended to be moulded of a suitable material such as rigid, self-skinning polyurethane foam. Otherwise, the enclosure **84** includes the partial gas enclosures **70** and **72**, and is hermetically sealed as discussed above with respect to the enclosure **44**.

Turning to FIG. **5**, there is shown an electrostatic speaker having three electrostatic transducer units or cells indicated at **88** which are arranged in an arc and mounted in a vacuum formed bin **90**. The bin **90** is, in turn, held within a frame **92** which may be wood, or wood veneered for purposes of appearance. A curved electrostatic transducer unit **94** is also secured within the bin **90**; and all of the electrostatic transducer units **88** and **94** may be secured to the bin **90** by using double-sided adhesive foam tape **96**. A front diaphragm **98** and a rear diaphragm **100** are also secured to the bin **90**, in the manner discussed above; and a gas such as SF_6 or perfluoropropane is sealed within the speaker.

In FIG. **6**, there is illustrated yet another embodiment of an electrostatic speaker which has eight cells **102** mounted in a vaccum formed bin **104**. In this case, the electrostatic transducer units or cells **102** may be secured within the bin **104** using a double-sided adhesive foam tape (not shown), and may also be secured by such fastening means as screws **106**. A front diaphragm **108** is secured to the front of the bin **104**, and the similar diaphragm is secured to the rear of the bin **104**. The bin is mounted in a frame **110**, and a cover frame **112** is secured to the frame **110** to protect the edges of the bin **104** and to provide additional rigidity to the frame **110** and bin **104**. All of the cells **102** are mounted in the bin **104** so as to be substantially on the surface of a sphere. It will be noted that each of the cells **102** is substantially planar - in that the diaphragm of each electrostatic transducer unit is planar - and each is mounted so as to be at an angle with respect to the front diaphragm **108** and the rear diaphragm.

The distinction is now drawn that an electrostatic speaker is one which comprises one or a plurality of electrostatic transducer units or cells, each of which may be electrically connected to a high voltage DC source and to a source of audio frequency voltage - and each of the cells may have impressed upon it a full-range audio signal and voltage or a limited range signal, such as a high audio frequency or low audio frequency signal. The electrostatic speaker thereby includes the gas enclosure having installed within it the electrostatic transducer units or cells, and including at least a front diaphragm of an acoustically transparent material. No baffles, ports, or ducts are required as in the usual sense with conventional, cone-type speakers.

In the case of an electrostatic speaker such as that illustrated in FIG. **6**, and when the hermetically sealed enclosure of that speaker is filled with a gas such as sulphurhexafluoride or perfluoropropane, and when substantially the full frequency range of the audio signal applied to the speaker is applied to each of the electrostatic transducer units **102**, somewhat different manners of operation occur at high, middle and low audio frequencies, as follows. High frequency audio signals transmitted from each of the electrostatic transducer units **102** tend to be propagated in the gas substantially straightforwardly from each of the cells **102**. However, at low frequencies, a mutual coupling occurs within the gas between the various cells **102**, and the actual radiating area of the electrostatic speaker is apparently increased. Because the gas within the enclosure is quite linear - more than air - good coupling between each of the diaphragms of each of the cells **102** and the outer diaphragms occurs; and if the resonant frequency of a front or rear diaphragm such as diaphragm **108** is essentially subsonic (below the range of human hearing) and is damped, the front or rear diaphragms will move substantially as a piston at low frequencies. A speaker such as that illustrated in FIG. **6** is an acoustic dipole, and since the effective acoustic resistance on a large moving piston which is unbaffled is proportional to the area whereas the effective acoustic resistance of a baffle of equivalent area having up to 20 percent of its area as a moving piston - such as in conventional cone speakers - is proportional to the square root of the area, the coupling to the listening environment of the large moving piston is obviously much better. Therefore, the outer diaphragms of an electrostatic speaker such as that illustrated in FIGS. **5** or **6** moves as a piston at low audio frequencies and which is the effective radiating area of the speaker which is coupled to the listening room. When the speaker is installed in a room which is otherwise filled with air, the nonlinearity of the air over a very wide area is much less troublesome than over a narrow throat area where throat distortion may occur as the mean pressure changes involved are very much smaller in the former case. Also, because the gas within the speaker enclosure is essentially linear it tends to move in a block as the diaphragms are moving at low frequencies, the holes which are formed in the rigid electrodes of each of the electrostatic transducer units **102** can be used and chosen so as to provide throttling or flow break-up of the gas, and thereby to control the Q-factor of the resonant system which comprises the entire electrostatic speaker. Also, the mass of the effective moving system at very low frequencies includes the mass of each of the diaphragms of the electrostatic transducer units, plus the mass of the front and back diaphragms of the speaker, plus the mass of the gas within the enclosure.

At higher frequencies, the mutual coupling between the cells becomes less, and by about 1,000 Hz., the cells each are beginning to act as individual radiators. There is, therefore, a gradual change in the radiation impedance of the speaker system from low to high frequencies. Of course, proper choice of the volume of the gas within the enclosure - and therefore its mass for any given density - together with proper spacing of the individual cells, the radius of curvature of the spherical surface on which the cells are apparently mounted, and the size of holes in the rigid electrodes in each of the electrostatic transducer units, can achieve an even or desired response over the entire frequency range in which the electrostatic speaker is intended to operate.

Turning now to FIGS. **7** and **8,** two electrostatic speakers **114** and **116** are shown, each in cross-section. Each of the electrostatic speakers **114** and **116** includes a single electrostatic transducer unit **118,** which has front and back rigid electrodes **120** and **122** respectively, and a taut diaphragm **124** suspended between them. Differing mounting arrangements for the electrodes **120** and **122** are shown, including the use of a foam tape **126** in FIG. **7** and spacers **130** and foam tape **132** in FIG. **8.** The speaker **114** includes a rear diaphragm **134** and a front diaphragm **136;** and the speaker **116** includes a rear diaphragm **138** and a curved front diaphragm **140.** The bin **142** of speaker **114** or **144** of speaker **116** is, in each case, suitably moulded of such material as rigid, self-skinning polyurethane foam. The electrostatic transducer unit **118,** in each case, is conveniently electrically connected to a source of audio frequency voltage as well as to a high voltage DC source by such means as wiring **146** and conductive rivets **148.** In their physical size, each of the electrostatic speakers **114** and **116** may be reasonably small - say in the order of 20 inches by 8 inches by 4 or 6 inches - and while each of the electrostatic speakers may have the entire audio frequency output impressed on the electrostatic transducer unit, each of the speakers **114** and **116** is essentially operative only in higher audio frequencies as a mid-range or tweeter unit.

In the case of the electrostatic speaker **114,** the front and rear diaphragms **136** and **134** may be tilted with respect to the electrostatic transducer unit diaphragm **124.** In the case of the electrostatic speaker **116,** at least the front diaphragm **140** is curved. Thus, each of the electrostatic speakers **114** and **116** functions as an acoustic wavefront modulating device insofaras its effect on audio wavefronts propagated within either speaker enclosure from the electrostatic transducer unit diaphragms **124.**

In FIG. **9** there is illustrated a diagramatic plan view of an assymetric lens. The manner in which the lens may be formed using the acoustic wavefront modulating device of the present invention can be by curvature of an outer diaphragm of a gas enclosure, curvature or placing or both of one or a plurality of diaphragms of electrostatic transducer units within the enclosure, or a combination of any of them. In any event, what is shown in FIG. **9** is a diagramatic plan view of the apparent plan of one of a specially designed pair of speakers for a stereophonic installation - in this case, the left hand speaker. FIG. **10** shows a polar radiating pattern - in polar co-ordinates - of a speaker having an assymetric lens such as that shown in FIG. **9.** The lens produced polar radiating pattern shown in FIG. **10** is typical of one taken from such a speaker at a hypothetical distance of six feet. It should be stressed that the polar radiating pattern of FIG. **10** is in polar co-ordinates, and is not an isobaric diagram showing a constant pressure line. It should also be remarked that the polar radiating pattern of the speaker is essentially a modified cosecant^2 pattern. Such polar radiating patterns can be predetermined for a given design of speaker including an assymetric acoustic lens having an acoustic wavefront modifying device according to this invention - especially when electrostatic transducer units having essentially planar moving diaphragms are mounted within the speaker units thus produced. Also, as noted above, when it is required that a specific polar radiating pattern be produced in a given listening environment, a suitable acoustic lens can be designed using electrostatic transducer units together with gas enclosures to produce the desired polar radiating pattern therefrom.

There has been described a wavefront modulating device for acoustic wavefronts, particularly in the audio range - which is to say, the range of human hearing. The acoustic wavefront modulating device of the present invention has been shown in several embodiments, particularly those including an electrostatic transducer unit suitably electrically connected to an audio frequency voltage source, and to a high voltage DC source. This is because, as mentioned, the essentially planar diaphragm of the electrostatic transducer unit is easily produced, and the lens effect within a wavefront modulating device according to this invention can be easily predicted knowing the angle of tilt or of curvature of the enclosure diaphragm with respect to the electrostatic transducer unit diaphragm. There has also been discussed the fact that mutual coupling between a plurality of electrostatic transducer units or cells, each operating at low audio frequency can increase the low frequency output of the electrostatic speaker unit, and improve the coupling of that unit to the surrounding ambient. Still further, there has been discussed the fact that an electrostatic speaker can be provided having greatly increased power handling capabilities. It should also be noted, of course, that the conversion efficiency of such an electrostatic speaker can be greatly increased, especially when the dielectric strength or breakdown of the gas within the enclosure in which the electrostatic transducer units operate is higher than that of air; thereby permitting higher DC field gradients and higher signal voltages, as well as taking greater advantage of the linearity of the gas within the enclosure as opposed to the non-linearity of air.

Finally, it should be noted that it may be desirable in certain circumstances - such as voice reconstruction - to fill a gas enclosure with gases other than those discussed above, including such gases as helium having a higher sound transmission rate than air; and in any event, an acoustic wavefront modulation device according to this invention may operate either as a lens or a prism depending particularly upon relative curvatures or apparent curvatures and whether or not the acoustic wavefront propagating means is within a gas enclosure or one side of it. The refractive effects at the interface between a gas enclosure and its ambient - usually air- have been discussed, and when the interface is an acoustically transparent material having very low mass, no effect can be noted with respect to the sound being transmitted or radiated through or from the interface material, except as to the apparent source of

sound or the radiating pattern away from the device, as desired.

The embodiments of the invention where an exclusive privilege or property is claimed, are defined as follows:

1. An acoustic wavefront modifying device comprising:

an enclosure having at least one substantially planar and acoustically transparent portion of the surface thereof;

electrostatic acoustic transducer means within said enclosure and adapted to propagate acoustic waves and to transmit them to one side of said planar and acoustically transparent portion of said enclosure;

said electrostatic acoustic transducer means having at least two substantially planar working areas arranged in said enclosure each at an angle to said substantially planar and acoustically transparent surface portion of said enclosure and at an angle to each other;

said enclosure having a gas therein in which the speed of sound differs from the speed of sound in the gas external to said enclosure; so that said acoustic waves transmitted to the one side of said planar and acoustically transparent portion of said enclosure and past the substantially acoustically transparent material thereof, are subject to wavefront refraction in accordance with the refractive index determined by the ratio of speeds of sound in said gases within and external to said enclosure.

2. The acoustic wavefront modifying device of claim 1, wherein said enclosure is hermetically sealed, and the gas external of said enclosure is air; and where the gas within said enclosure has a lower speed of sound than that of air, is more dense than air, and has a higher electrical breakdown voltage than that of air.

3. The acoustic wavefront modifying device of claim 1, wherein said enclosure is hermetically sealed and is connected for gas flow with a further enclosure having said gas therein.

4. The acoustic wavefront modifying device of claim 3, further including pressure and gas flow regulating means between said enclosure and said further enclosure.

5. The acoustic wavefront modifying device of Claim 2, where said at least one substantially planar and acoustically transparent portion of the surface of said enclosure comprises a membrane of plastic material.

6. The acoustic wavefront modifying device of claim 2, comprising two opposed substantially acoustically transparent portions of the surface of said enclosure, each said portion comprising a membrane of plastic material.

7. The acoustic wavefront modifying device of claim 6, where one of said membranes of plastic material is curved so as to give a lens effect with respect to the acoustic waves being transmitted thereto and past said material.

8. The acoustic wavefront modifying device of claim 1 where said gas is chosen from the group consisting of sulphur hexafluoride, perfluoropropane, perfluoropropane/sulphur hexafluoride mixture, air/sulphur hexafluoride mixture, air/perfluoropropane mixture and air/perfluoropropane/sulphur hexafluoride mixture.

9. An electrostatic loudspeaker comprising at least two push-pull electrostatic acoustic transducer units and an hermetically sealed, gas filled enclosure, wherein:

each of said at least two push-pull electrostatic acoustic transducer units comprises a substantially planar diaphragm having a high-resistivity coating over at least a major portion thereof, situated between a pair of substantially rigid, electrically conductive electrodes, each said electrostatic transducer unit being electrically connected to a direct current high voltage source and to an audio frequency voltage source;

said enclosure having at least one substantially planar and acoustically transparent diaphragm means in a portion of the surface thereof, and being filled with a gas having a speed of sound transmission characteristic, at least in the audio range, different than that of air; said substantially planar diaphragms of said at least two push-pull electrostatic acoustic transducers are arranged each at an angle to said substantially planar and acoustically transparent portion of the surface of said enclosure and at an angle to each other.

10. The electrostatic loudspeaker of claim 9 where said enclosure comprises a pair of opposed diaphragms of substantially acoustically transparent plastic material, and said at least two electrostatic transducer units are secured within an hermetically sealed enclosure at least partially defined by said pair of opposed diaphragms; and where the gas within said enclosure has a lower speed of sound than that of air, is more dense than air, and has a higher electrical breakdown voltage than that of air.

11. The electrostatic loudspeaker of claim 9, where not less than one of the at least two electrostatic transducer units are electrically connected to said audio frequency voltage source so as to have impressed thereon the total frequency range of the output of said audio frequency voltage source.

12. The electrostatic loudspeaker of claim 11, where at least one of said electrostatic transducer units is electrically connected to said audio frequency voltage source so as to have impressed thereon a limited frequency range of the output of said audio frequency voltage source.

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