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3,378,098

SYSTEM FOR IMPROVED REPRODUCTION OF SOUND

Filed March 22, 1966

2 Sheets-Sheet 1

FIG. 1

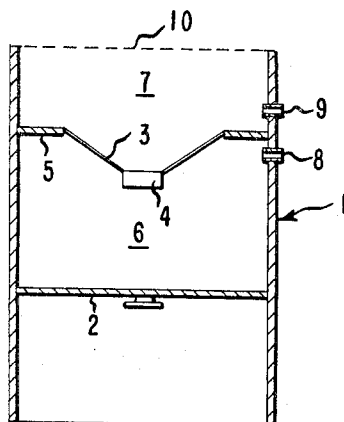
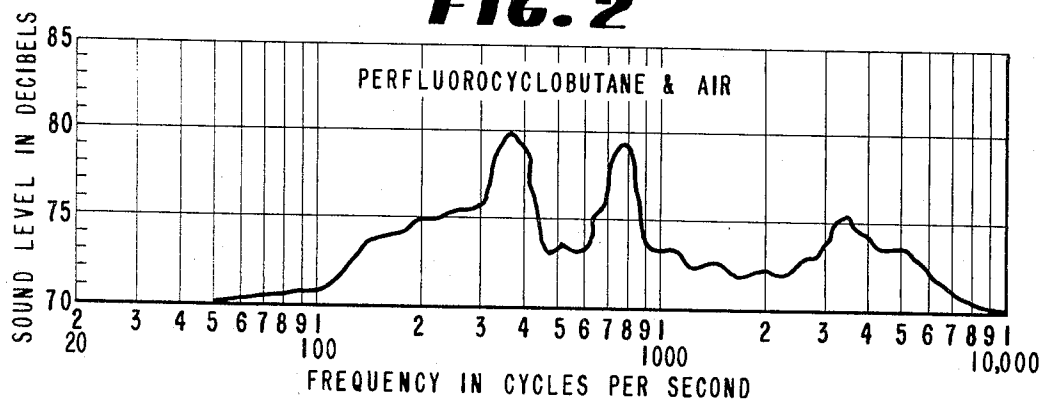


FIG. 2



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FIG. 3

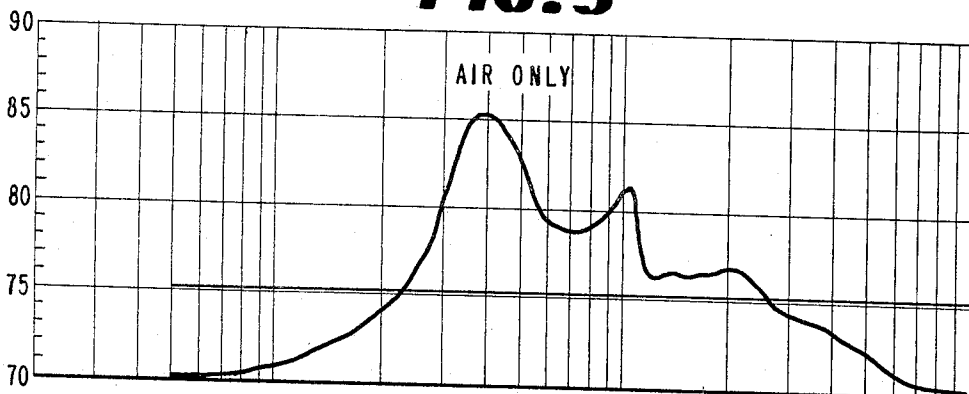


FIG. 4

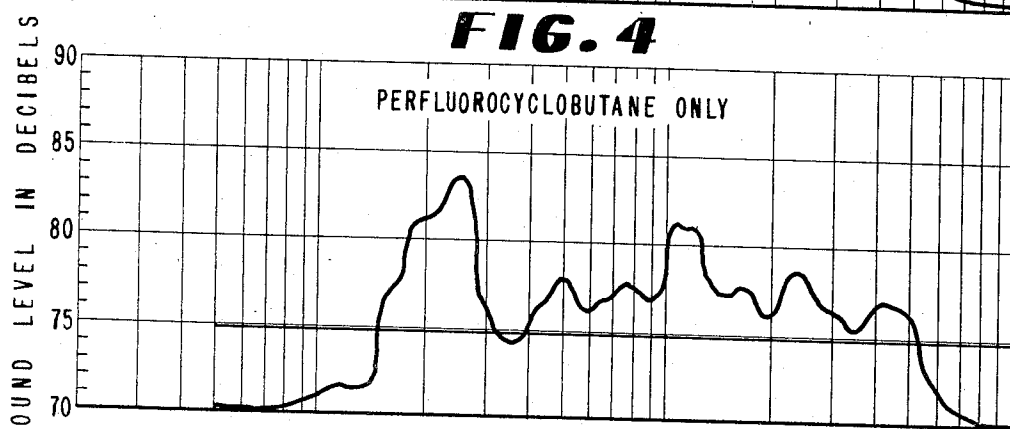
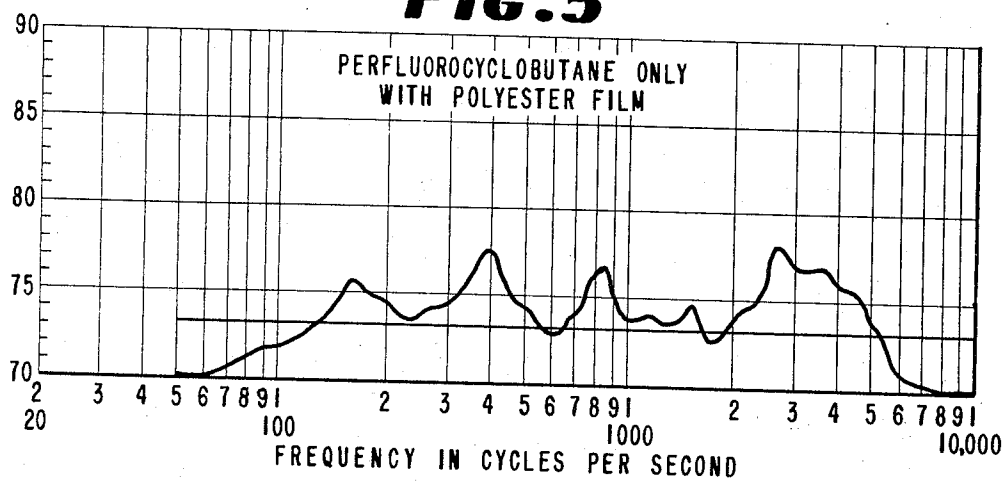


FIG. 5



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SYSTEM FOR IMPROVED REPRODUCTION OF SOUND

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This invention relates to an improved loudspeaker system for the reproduction of sound and, more particularly, to a loudspeaker system in which the speaker diaphragm is in contact with a polyfluorinated compound.

In trying to reproduce instrumental, vocal and other sound via radio and recordings, deficiencies are encountered in the ability to reproduce faithfully the original sound. In the better reproduction systems, the most perceptible deviations from the original sound can generally be attributed to deficiencies in the ability of the loudspeaker system to respond accurately to the impulses being supplied to it. These deficiencies are most often due to a non-uniformity in the intensity of response at different frequencies.

As a general rule, most speakers do not respond to impulses at different frequencies with equal intensity. Most good speakers respond with fairly uniform intensity to the middle frequencies of about 300 to 3,000 cycles per second, but substantial reductions in intensity are encountered with impulses of higher and lower frequencies.

Losses in intensity at the lower frequencies of about 50-300 cycles per second can be compensated for to some extent by carefully selecting the enclosure used with the speaker. Since a peak of sound intensity generally occurs at the resonant frequency of the enclosure, these intensity losses can be reduced to some extent by using an enclosure having a resonant frequency in the range of the intensity losses. The resonant frequency of the enclosure is shifted to these lower frequencies by increasing its size. In order to provide a resonant frequency in the range of 50 to 300 cycles per second, an enclosure size of the order of about 5 cubic feet or more is required. However, since the emphasis today is in the direction of reducing the size of speaker enclosures to render them more desirable for use in home high-fidelity systems, such large enclosures are not practical in many instances.

Another method of improving the response of a speaker system at low frequencies is to use a high compliance speaker, that is, one having a diaphragm support which is relatively non-rigid, resulting in a lower speaker resonance. Although such speakers do have improved bass response, they are more expensive and require a considerably greater amount of power, of the order of several times the amount ordinarily used, to drive them. Moreover, high compliance speakers also introduce distortions of their own, due to their non-rigid construction. Thus there is no simple and economical method of improving the bass response of an ordinary speaker.

It is even more difficult to overcome speaker deficiencies in intensity of response to the higher frequencies of about 3,000 to 10,000 cycles per second and above. These deficiencies can be corrected only by combining the speaker with one or more additional speakers which emphasize these higher frequencies.

Another factor which contributes to the quality of reproduction of sound is the clarity and definition of the sound. All speaker systems have at least minor deficiencies in this regard. Apparently this factor is determined to some extent by the damping characteristics of the speaker diaphragm, although very little is known about its control.

It is an object of this invention to improve the quality

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of sound reproduced by speakers. Another object is to broaden the frequency response of speakers to include higher and lower frequencies than usual. A further object is to provide a simple means by which a speaker can be made to respond with more uniform intensity at different frequencies. A still further object is to improve the clarity and definition of sound emitted by a speaker. These and other objects will become apparent from the following description of this invention.

It has now been discovered that the quality of sound reproduced by speaker systems can be dramatically improved by providing a loudspeaker system comprising a loudspeaker containing a sound producing diaphragm in which at least one surface of the diaphragm is in contact with a gaseous atmosphere of a non-flammable polyfluorinated aliphatic or alicyclic compound characterized in that

$$MW \left(\frac{C_p}{C_v} - 1 \right)^2$$

is less than 1.2 wherein MW is the molecular weight of the compound, C_p is its specific heat at constant pressure and C_v is its specific heat at constant volume.

FIGURE 1 illustrates a typical loudspeaker system used in accordance with this invention. FIGURE 2 is the frequency response curve for a speaker system in which the front surface of the speaker diaphragm is in contact with air and the back surface is in contact with perfluorocyclobutane. FIGURE 3 is the frequency response curve for a speaker system in which both surfaces of the speaker diaphragm are in contact with air. FIGURE 4 is the frequency response curve for a speaker system in which both surfaces of the speaker diaphragm are in contact with perfluorocyclobutane. FIGURE 5 is the frequency response curve for a speaker system in which both surfaces of the speaker diaphragm are in contact with perfluorocyclobutane and a thin polyester film separates the perfluorocyclobutane in front of the diaphragm from the atmosphere.

Quite surprisingly, the polyfluorinated gases defined above have been found to possess an acoustic property which greatly improves the quality of sound emitted from speaker diaphragms in contact with them. When using these gases in accordance with this invention, the frequency range over which the speaker system responds fairly uniformly is broadened to include both higher and lower frequencies than normal. Moreover, the speaker response is more uniform over this broader range than over the narrower range for air. Furthermore, the sound emitted from the speaker has improved clarity and definition. The practical result of these acoustic effects is an improved quality of reproduction of sound with significant enhancement of the listener's pleasure.

Although it is intended that this invention not be restricted to any particular theory, it is considered a possibility that the improvement in frequency response observed in accordance with this invention is due to the defined gases having an unusual elasticity to sound waves whereby there is only relatively slow absorption and degradation of sound energy to heat. It is believed that the improved clarity and definition of sound emitted from speaker systems of this invention may be due in part to improved damping of the speaker diaphragm by the defined gases, perhaps resulting to some extent from their being heavier than air. Thus, the unusual acoustic properties of these gases appear to be due to a unique combination of properties with respect to sound waves.

The polyfluorinated compounds used in accordance with this invention should be non-flammable, non-corro-

sive and non-toxic compounds which are capable of existing as a gaseous atmosphere and for which

$$MW \left(\frac{C_p}{C_v} - 1 \right)^2$$

is less than 1.2. A decrease in the effect would be expected as the value of

$$MW \left(\frac{C_p}{C_v} - 1 \right)^2$$

increases as a function of an increase in the heat capacity ratio

$$\left(\frac{C_p}{C_v} \right)$$

In view of this graduated effect, it is preferred that the

$$MW \left(\frac{C_p}{C_v} - 1 \right)^2$$

value be less than 1.0. By "polyfluorinated compounds" is meant compounds containing three or more fluorine atoms per molecule. By "non-flammable" is meant non-flammable in air at room temperature. Polyfluorinated aliphatic and alicyclic compounds which have been found to possess the requisite characteristics include aliphatic polyfluorohydrocarbons such as hexafluoroethane, 1,1,1,2,2,3,3-heptafluoropropane, octafluoropropane and decafluorobutane; alicyclic polyfluorohydrocarbons such as 1,3-bis(trifluoromethyl)hexafluorocyclobutane and octafluorocyclobutane; aliphatic chloropolyfluorohydrocarbons such as chloropentafluoroethane, 1,2-dichlorotetrafluoroethane, 2-chloroheptafluoropropane, and 1,2-dichlorohexafluoropropane; and aliphatic polyfluoroethers such as 1,1,1,2-tetrafluoroethyl heptafluoropropyl ether.

The beneficial acoustic effect derived from using gases of this invention is about proportional to the molar concentration of the invention gas. That is, if the invention gas is diluted with another gas or gases not within the scope of this invention and the total pressure is held constant, the desirable effect is about proportional to the mole fraction of the invention gas. Similarly, if the partial pressure of the invention gas is held constant and another gas is added to increase the total pressure, no adverse effect is observed. As little as about 10% by volume of invention gas is advantageous in admixture with other gases.

The acoustic effect of gases of this invention also varies in proportion to the partial pressure of the gas. When the concentration of the invention gas is increased by increasing its pressure, a corresponding increase in its effectiveness is obtained. However, if the saturation pressure is approached or reached, whether or not condensation of liquid actually takes place, the beneficial effect of the gas is essentially lost. The gas, therefore, should not be used at or near its saturation pressure. When a single gas is used in a speaker operating at room temperature and atmospheric pressure, it should have a normal boiling point significantly below room temperature. Higher boiling invention gases may be used in mixtures provided the partial pressure of each component gas is significantly below its saturation pressure.

The loudspeakers which are useful in accordance with this invention are electromagnetic transducers having a sound producing diaphragm. Suitable speaker systems include direct-radiator, bass reflex, infinite baffle and horn types.

In accordance with this invention, at least one surface of the speaker diaphragm is in contact with the invention gas. The gas may be in contact with the front side, the back side, or both sides of the speaker diaphragm. The enclosure retaining the invention gas may be composed of metal, wood, plastic or the like. In one embodiment, the gas is retained in the speaker enclosure by the speaker diaphragm which may be made of or coated with a material impervious to the gas thus completing the enclosure of the gas. In another design, a continuation

of the speaker diaphragm may be used to serve as a bag-like enclosure around the back of the speaker, the front of the speaker, or both. The best improvement in quality of sound is obtained when both the front and back surfaces of the speaker diaphragm are in contact with the invention gas. For this purpose, a thin gas-impervious film is stretched across the front of the otherwise airtight speaker enclosure to retain the gas and to transmit sound to the outside air. A film especially suitable for this purpose is a polyester or metallized polyester film. Films made of polyethylene terephthalate have been found to be particularly suitable. Attenuation of sound intensity by the thin film is readily offset by slightly increasing the power input to the speaker.

In retaining the gas of this invention, if a film is used which allows air to diffuse in and mix with the invention gas, there will be a resultant rise of pressure within the enclosure. As diffusion takes place, the tension on the film increases which is desirable so long as no rupture of the film or of the enclosure occurs. Diffusion of air into the enclosure will not interfere with the proper functioning of the invention gas so long as the partial pressure of the invention gas is unchanged. This inward flow of air may be prevented, of course, by employing a film which is impervious to both air and the invention gas.

The improved sound quality described above was obtained using speakers which were designed for use in air. Accordingly, it is contemplated that still further improvements might be achieved with speakers specifically designed for use in accordance with this invention.

The following examples, illustrating the novel speaker systems of this invention, are given without any intention that the invention be limited thereto.

EXAMPLE 1

The acoustic property of the gases of this invention is most readily observed by placing a portable radio in a box-type enclosure which is substantially larger than the radio and is closed on all sides except the top. With the radio tuned to suitable sound such as voice or preferably music, the air in the box is displaced by passing in the heavier invention gas from a compressed gas cylinder. Immediately there is a dramatic improvement in the quality of sound from the radio. The improvement in bass response is particularly noteworthy even to an untrained ear.

The following table contains pertinent data for various gases within the scope of this invention. The specific heats, C_p and C_v , were determined at 1 atmosphere absolute and 21° C.

TABLE

Invention Gas	Boiling Pt., ° C.	MW	C_p/C_v	$MW \left(\frac{C_p}{C_v} - 1 \right)^2$
1,3-bis(trifluoromethyl)hexafluorocyclobutane.....	44	300	-----	<1.20
2-chloroheptafluoropropane.....	-2	204.5	1.05	0.51
Chloropentafluoroethane.....	-39	154.5	1.079	0.96
Decafluorobutane.....	1	238	1.04	0.38
1,2-dichlorohexafluoropropane.....	34	221	1.05	0.55
1,2-dichlorotetrafluoroethane.....	4	171	1.078	1.04
1,1,1,2,2,3,3-heptafluoropropane.....	-17	170	1.058	0.57
Hexafluoroethane.....	-78	138	1.078	0.84
Octafluorocyclobutane.....	-6	200	1.06	0.72
Octafluoropropane.....	-38	188	1.053	0.53
1,1,1,2-tetrafluoroethylheptafluoropropyl ether.....	39	237	1.035	0.29

When the above gases are individually used to displace air in the box described above, significant improvements in the quality of sound are observed in all cases.

EXAMPLE 2

A radio was turned on its back so that the conical speaker diaphragm faced upward and the diaphragm was filled with 1,2-dichlorotetrafluoroethane from a compressed gas cylinder. A thin polyethylene terephthalate film was stretched over the face of the diaphragm thereby enclosing the polyfluorinated gas in contact with the front

surface of the diaphragm. When the radio was tuned to suitable sound, an improvement in quality of sound was observed, particularly in the bass response.

EXAMPLE 3

The following experiments were carried out to determine more precisely the nature of the effect of polyfluorinated gas on speaker performance.

A speaker system similar to that illustrated in FIGURE 1 was employed. The speaker enclosure 1, which was 12 in. x 12 in. x 24 in., was made of ½ in. plywood, glued and screwed together, and was open at each end. The enclosure had an adjustable partition 2 which could be moved to regulate the effective volume of the speaker cavity. The enclosure also contained a speaker having a 5 in. diaphragm 3 and a 6.8 oz. magnet 4. The speaker diaphragm was peripherally mounted on a partition 5 which was 6 in. from the top of the speaker enclosure and which separated the area designated 6 behind the diaphragm from the area designated 7 in front of the diaphragm. The enclosure also had a gas inlet 8 for introducing gas into area 6, and a gas inlet 9 for introducing gas into area 7. In some cases, a 0.3 mil polyethylene terephthalate polyester film 10 was drawn tightly over the top of the speaker enclosure to separate the gas in area 7 from the outside atmosphere.

Signals from a sine-wave generator capable of generating impulses of constant energy over a wide range of frequencies were amplified and sent to the speaker described above. To measure the voltage of the sine-wave generator and verify its constancy, an alternating current vacuum tube voltmeter was used to monitor the generator. An audio analyzer was used to monitor the voltage and power level of the signal passing from the amplifier to the speaker. A sound level meter was placed 4 in. above the top of enclosure 1 to measure the intensity of sound coming from the speaker system and a sound level recorder was connected to the meter to record permanently the results in the form of a frequency response curve.

Tests were made in a room about 10 ft. x 14 ft. which was semi-soundproofed with thick rugs on all surfaces except the ceiling. The partition in the speaker enclosure was adjusted to provide a cavity of about 1.4 cubic feet below the speaker diaphragm. The speaker was activated by signals from the sine-wave generator at frequencies varying from 50 to 10,000 cycles per second and an energy input to the speaker maintained at about 0.5 watt.

FIGURE 3 illustrates the frequency response curve obtained when areas 6 and 7 were filled with air and no polyester film was used. FIGURE 4 is the frequency response curve obtained when areas 6 and 7 were filled with perfluorocyclobutane and no polyester film was used. FIGURE 5 is the frequency response curve obtained when areas 6 and 7 were filled with perfluorocyclobutane and a polyester film was stretched over the top of the speaker enclosure.

The improved results obtained in accordance with this invention can be observed by comparing the relative uniformity or flatness of the above frequency response curves. The flatness of these curves has been determined by computing the standard deviation of each curve from the average decibel value for the curve. In FIGURES 3, 4 and 5 the average decibel value for each curve is shown as a horizontal line extending from 50 to 10,000 cycles per second. In FIGURE 3, the standard deviation from the average decibel value is 4.50 decibels. In FIGURE 4, the standard deviation is 3.67 decibels, while in FIGURE 5 it is 2.18 decibels. In other words, the standard deviation for air is more than 1.2 times the standard deviation for perfluorocyclobutane in FIGURE 4 and more than 2 times the standard deviation for perfluorocyclobutane in FIGURE 5. This represents a substantial improvement in accordance with this invention.

The relative flatness of these frequency response curves can also be determined by measuring the extent of the

frequency range over which each of the curves has no more than a 10 decibel variation. Using a variation of no more than 10 decibels as an indication of fairly flat response, the response curve for air in FIGURE 3 is fairly flat over a range of about 2,000 cycles per second. In the presence of perfluorocyclobutane, the response curve in FIGURE 4 is fairly flat over a range of about 5,000 cycles per second, while in FIGURE 5, the response curve is fairly flat over the entire range of about 10,000 cycles per second. Thus it can be seen that a significant improvement is obtained in accordance with this invention as represented by FIGURES 4 and 5.

In each of the above tests, a record player was connected to the amplifier and musical selections were played through the speaker. The quality of sound obtained when the speaker diaphragm was in contact with perfluorocyclobutane was unmistakably more pleasing than that obtained when it was in contact with air. Particularly, the bass and treble response and the clarity of sound were improved.

EXAMPLE 4

Using the procedure and equipment described in Example 3, the nature of the effect of having only the back surface of the speaker diaphragm in contact with the gas of this invention was determined as follows:

The speaker system illustrated in FIGURE 1 was adjusted by means of partition 2 to give a speaker cavity of 0.4 cubic foot. Perfluorocyclobutane was introduced through inlet 8 into area 6. Area 7 was filled with air and opened to the atmosphere. The frequency response curve obtained is shown as FIGURE 2.

When musical selections were played on the record player through this speaker system, the quality of sound obtained was a significant improvement over that obtained when the speaker diaphragm was in contact with air on both sides.

Although the invention has been described and exemplified by the use of particular polyfluorinated compounds and specific speaker system designs, it is to be understood that it is not limited thereto. As will be apparent to those skilled in the art, numerous modifications and variations of these embodiments may be made without departing from the spirit of the invention or the scope of the following claims.

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

1. A loudspeaker system comprising a loudspeaker containing a sound producing diaphragm in which at least one surface of the diaphragm is in contact with a gaseous atmosphere of a non-flammable polyfluorinated aliphatic or alicyclic compounds characterized in that

$$MW \left(\frac{C_p}{C_v} - 1 \right)^2$$

is less than 1.0, wherein MW is the molecular weight of the compound, C_p is its specific heat at constant pressure and C_v is its specific heat at constant volume.

2. The loudspeaker system of claim 1 in which the gaseous atmosphere contains at least 10% by volume of the polyfluorinated compound.

3. The loudspeaker system of claim 2 in which the polyfluorinated compound is octafluorocyclobutane.

4. The loudspeaker system of claim 2 in which the polyfluorinated compound is decafluorobutane.

5. The loudspeaker system of claim 2 in which the polyfluorinated compound is chloropentafluoroethane.

6. The loudspeaker system of claim 2 in which the polyfluorinated compound is hexafluoroethane.

7. The loudspeaker system of claim 2 in which the back surface of the diaphragm is in contact with the polyfluorinated compound.

8. The loudspeaker system of claim 2 in which the

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front surface of the diaphragm is in contact with the polyfluorinated compound.

9. The loudspeaker system of claim 8 in which the polyfluorinated compound is separated from the outside atmosphere by a tightly stretched, thin film which is im-
pervious to the polyfluorinated compound.

10. The loudspeaker system of claim 9 in which both surfaces of the diaphragm are in contact with the poly-
fluorinated compound.

11. The loudspeaker system of claim 10 in which the thin film is composed of polyethylene terephthalate poly-
ester.

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