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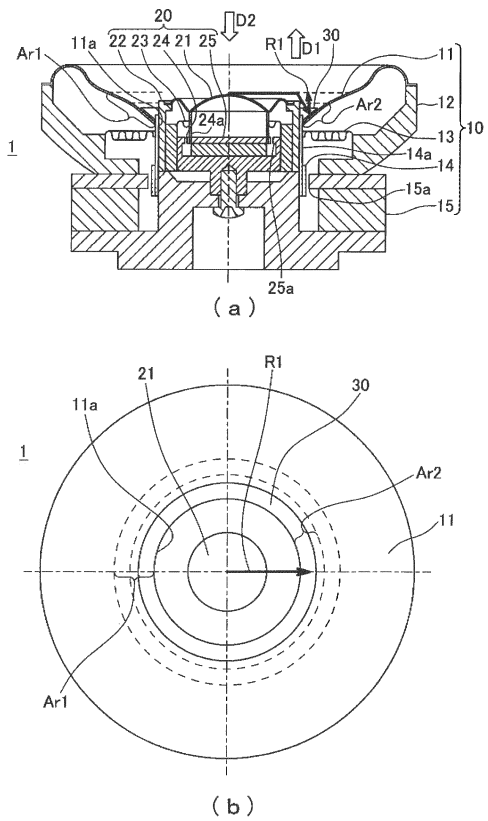
(54) COMPOSITE SPEAKER DEVICE

(57) A composite speaker device capable of restraining a disturbance in sound radiation characteristics caused by propagation of a sound from a tweeter unit to a woofer unit is provided. A composite speaker device (1) includes a first speaker unit (10,16) having a first diaphragm (11,16a), a second speaker unit (20,26) which is installed in a sound radiation direction (D1) of the first diaphragm (11,16a) and has a second diaphragm (20,26a) with a diameter smaller than that of the first diaphragm (11,16a), and a sound absorbing material (30,35,36,51,61) attached to the surface of the first diaphragm (11,16a) in the sound radiation direction (D1) so as to surround the second diaphragm (21,26a).

FIG.1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a composite speaker device.

BACKGROUND ART

[0002] Heretofore, a composite speaker device including a woofer unit (low-frequency speaker unit) having a large-diameter diaphragm and a tweeter unit (high-frequency speaker unit) having a small-diameter diaphragm installed in a sound radiation direction of the large-diameter diaphragm has been known (see, for example, Patent Literature 1). In the composite speaker device disclosed in Patent Literature 1, a holding structure of the tweeter unit is a thin metal rod made of a non-magnetic body so as to reduce blocking objects located in the sound radiation direction of the woofer unit. Accordingly, a disturbance in sound radiation characteristics of the composite speaker device due to reflection and diffraction of a sound from the woofer unit caused by such blocking objects is restrained.

CITATION LIST

PATENT LITERATURE(S)

[0003] Patent Literature 1: JP-A-2008-263257

SUMMARY OF THE INVENTION

PROBLEM(S) TO BE SOLVED BY THE INVENTION

[0004] A part of the sound from the tweeter unit may be occasionally propagated to the woofer unit located in a direction opposite to the sound radiation direction of the tweeter unit due to diffraction of the sound or the like. The propagation of the sound from the tweeter unit to the woofer unit may occasionally cause a disturbance in sound radiation characteristics of the composite speaker device. The composite speaker device disclosed in Patent Literature 1 does not provide any effective countermeasures against such a disturbance in sound radiation characteristics caused by the propagation of the sound.

[0005] In view of the above, a problem to be solved by the invention is to provide a composite speaker device capable of restraining a disturbance in the sound radiation characteristics caused by propagation of sound from a tweeter unit to a woofer unit.

MEANS FOR SOLVING THE PROBLEM(S)

[0006] In order to the solve the above problem, an invention according to a first aspect of the invention relates to a composite speaker device including: a first speaker unit having a first diaphragm; a second speaker unit installed in a sound radiation direction of the first diaphragm, the second speaker unit including a second diaphragm having a diameter smaller than a diameter of the first diaphragm; and a sound absorbing material attached to a surface of the first diaphragm in the sound radiation direction so as to surround the second diaphragm.

BRIEF DESCRIPTION OF DRAWING(S)

[0007]

Fig. 1 illustrates a composite speaker device according to an exemplary embodiment of the invention.

Fig. 2 illustrates measurement of a sound propagated from a tweeter unit (i.e., a second speaker unit) to a woofer unit (i.e., a first speaker unit) illustrated in Fig. 1 and reflected by the woofer unit, and a sound radiated from the tweeter unit.

Fig. 3 illustrates a state that a disturbance in sound radiation characteristics of the composite speaker device illustrated in Fig. 1 is restrained by a sound absorbing material.

Fig. 4 schematically illustrates a woofer unit and a tweeter unit as the first speaker unit and the second speaker unit according to a modification of the exemplary embodiment of the invention.

Fig. 5 schematically illustrates a sound absorbing material according to another modification of the exemplary embodiment.

Fig. 6 illustrates a phenomenon occurring when two sounds at the same frequency overlap with phases thereof being shifted from each other.

Fig. 7 illustrates a composite speaker device according to another exemplary embodiment in which the sound absorbing material is attached to a position away from an opening of a low-frequency diaphragm.

Fig. 8 illustrates a composite speaker device according to a still another exemplary embodiment in which the sound absorbing material is attached to a position away from an opening of the low-frequency diaphragm.

DESCRIPTION OF EMBODIMENT(S)

[0008] A composite speaker device according to an exemplary embodiment of the invention is described hereinbelow. A composite speaker device according to an exemplary embodiment of the invention includes a first speaker unit having a first diaphragm; a second speaker unit installed in a sound radiation direction of the first diaphragm, the second speaker including a second diaphragm having a diameter smaller than a diameter of the first diaphragm; and a sound absorbing material attached to a surface of the first diaphragm in the sound radiation direction so as to surround the second diaphragm. In the composite speaker device, the first speaker unit functions as the woofer unit, and the second speaker unit functions as the tweeter unit. In the composite speaker device, the sound absorbing material is attached to a surface of the first diaphragm in the sound radiation direction so as to surround the second diaphragm. Accordingly, even when a sound from the second speaker unit as the tweeter unit is propagated to the first speaker unit as the woofer unit, the sound is absorbed by the sound absorbing material. In the composite speaker device, a disturbance in sound radiation characteristics caused by propagation of the sound from the tweeter unit to the woofer unit can be restrained by sound absorption using the sound absorbing material. Further, in the composite speaker device, the disturbance in sound radiation characteristics can be restrained with the structure requiring relatively low material cost and production cost, in which the sound absorbing material is attached to the surface of the first diaphragm in the sound radiation direction. Furthermore, in the composite speaker device, the sound absorbing material is attached to the surface of the first diaphragm in the sound radiation direction, and no objects exist in the space in the sound radiation direction of the first diaphragm. Therefore, the outer appearance of the composite speaker device is favorable.

[0009] In the composite speaker device according to the exemplary embodiment of the invention, it is preferable that an axis of the first speaker unit is coincident with an axis of the second speaker unit. In the composite speaker device, since a high-frequency sound and a low-frequency sound are heard from approximately the same position, thereby obtaining a favorable sound image.

[0010] In the preferred composite speaker device, it is further preferable that the sound absorbing material has an annular shape. In the composite speaker device, the sound absorbing material having an annular shape can absorb the sound propagated from the second speaker unit to the first speaker unit evenly around the axis of the second speaker unit, thereby further restraining the disturbance in sound radiation characteristics.

[0011] In the above-described preferable composite speaker device in which the axes of the two speaker units are coincident with each other, it is further preferable that an opening is formed at the center of the first diaphragm and a diameter of the second diaphragm is smaller than a diameter of the opening. In the composite speaker device, it is possible to prevent the second diaphragm from becoming a blocking object in the sound radiation direction of the first diaphragm.

[0012] In the above-described preferable composite speaker device in which the opening is formed at the center of the first diaphragm and the diameter of the second diaphragm is smaller than the diameter of the opening, it is further preferable that the sound absorbing material is attached around the opening. In the composite speaker device, since the sound absorbing material is attached around the opening, which is relatively inconspicuous as seen from the sound radiation direction, it is possible to further improve the outer appearance of the composite speaker device.

[0013] Further, in the composite speaker device according to the exemplary embodiment of the invention, the sound absorbing material is preferably attached to at least one spot within an installation range including a spot at which a length of a propagation path difference between a propagation path of a sound propagated from a surface of the second diaphragm in the sound radiation direction to the surface of the first diaphragm in the sound radiation direction and reflected by the surface of the first diaphragm and a propagation path of a sound radiated from the surface of the second diaphragm in the sound radiation direction is $(2n+1)\times\lambda(1/2\pm1/16)$, where λ represents a wavelength corresponding to an overlapping frequency that is a frequency of a sound radiated from the first speaker unit and a sound radiated from the second speaker unit at the same frequency waves, and n represents a natural number. Within the above installation range, the sound at the overlapping frequency from the second speaker unit overlaps the sound at the overlapping frequency propagated from the surface of the second diaphragm to the surface of the first diaphragm in the sound radiation direction and reflected by the surface of the first diaphragm with phases thereof being shifted from each other by 1/2 wavelengths. This state means that a phase shift is close to 180 degrees. In this state, two sounds interfere to be cancelled with each other and the sound pressure is easily decreased. In the above favorable composite speaker device, since the attachment spot of the sound absorbing material is limited to such a position in which the sound pressure is easily decreased, it is possible to restrain the decrease in the sound pressure and the disturbance in sound radiation characteristics while reducing the amount of the sound absorbing materials to be used and the load applied to the first diaphragm.

[0014] In the preferable composite speaker device, it is further preferable that the absorbing material is attached to at least one spot within an installation range in which a length of the propagation path difference is $(2n+1)\times\lambda(1/2-1/16)$ to $(2n+1)\times\lambda(1/2+1/16)$ on the surface of the first diaphragm in the sound radiation direction. In the composite speaker device, since the attachment spot of the sound absorbing material is limited to the area in which the phase shift in the sounds at the overlapping frequency interfering with each other becomes closer to 180 degrees, it is possible to restrain the disturbance in sound radiation characteristics while further reducing the amount of the sound absorbing materials to be used.

[0015] In the further preferable composite speaker device, it is further preferable that the absorbing material is attached to at least one spot in the vicinity of a spot at which a length of the propagation path difference is $(2n+1)\times\lambda(1/2)$ on the surface of the first diaphragm in the sound radiation direction. In the composite speaker device, since the attachment spot of the sound absorbing material is limited to a position in which the phase shift in the sounds at the overlapping frequency interfering with each other becomes approximately 180 degrees, it is possible to restrain the disturbance in sound radiation characteristics while further reducing the amount of the sound absorbing materials to be used.

[0016] In the above-described preferable composite speaker device in which the absorbing material is attached to at least one spot in the vicinity of the spot at which the length of the propagation path difference is $(2n+1)\times\lambda(1/2)$, it is further preferable that the natural number n is zero. In the composite speaker device, even when there are a plurality of spots in each of which the length of the propagation path difference is $(2n+1) \times \lambda (1/2)$, the sound absorbing material is attached in the vicinity of a spot which is the closest to the second diaphragm among the plurality of spots. Accordingly, even in a relatively small composite speaker device, it is possible to attach the sound absorbing material to a suitable position.

Example(s)

[0017] A composite speaker device 1 according to an exemplary embodiment of the invention is described with reference to Figs. 1 to 3. Fig. 1 illustrates the composite speaker device 1 according to the exemplary embodiment of the invention. Fig. 1(a) is a cross-sectional view of the composite speaker device 1 along a sound radiation direction. Fig. 1(b) schematically illustrates two diaphragms described later of the composite speaker device 1 as seen in a direction indicated by an arrow D2 in Fig. 1(a).

[0018] The composite speaker device 1 includes a woofer unit (low-frequency speaker unit) 10 and a tweeter unit (high-frequency speaker unit) 20. The woofer unit 10 corresponds to one example of a first speaker unit of the invention, and the tweeter unit 20 corresponds to one example of a second speaker unit of the invention.

[0019] The woofer unit 10 includes a low-frequency diaphragm 11, a low-frequency frame 12, a low-frequency damper 13, a low-frequency voice coil 14, and a low-frequency magnetic circuit 15. The low-frequency diaphragm 11 is a cone-shaped member. An opening 11a is formed at the center of the low-frequency diaphragm 11. An outer peripheral edge of the low-frequency diaphragm 11 is connected to the low-frequency frame 12 having a cylindrical shape, and an inner peripheral edge of the opening 11a of the low-frequency diaphragm 11 is connected to a voice coil bobbin 14a having a cylindrical shape. The low-frequency damper 13 is a flexible member having an annular shape. An outer peripheral edge of the low-frequency damper 13 is connected to the low-frequency frame 12, an inner peripheral edge of the low-frequency damper 13 is connected to an outer circumferential surface of the voice coil bobbin 14a. The low-frequency voice coil 14 is formed on the outer circumferential surface of the voice coil bobbin 14a and disposed in a magnetic gap 15a of the low-frequency magnetic circuit 15. The low-frequency diaphragm 11 corresponds to one example of the first diaphragm of this invention.

[0020] The tweeter unit 20 is disposed inside the voice coil bobbin 14a in the woofer unit 10. The tweeter unit 20 includes a high-frequency diaphragm 21, a high-frequency frame 22, a high-frequency damper 23, a high-frequency voice coil 24 and a high-frequency magnetic circuit 25. The high-frequency diaphragm 21 is a domed member having a diameter smaller than that of the low-frequency diaphragm 11, and installed in a sound radiation direction D1 of the low-frequency diaphragm 11. Further, an outer diameter of the high-frequency diaphragm 21 is smaller than an inner diameter of the voice coil bobbin 14a in the woofer unit 10, that is, an inner diameter of the opening 11a in the low-frequency diaphragm 11. The outer peripheral edge of the high-frequency diaphragm 21 is connected to the cylindrical high-frequency frame 22. Furthermore, a surface of the high-frequency diaphragm 21 opposite to the sound radiation direction D1 is connected to an upper periphery of a voice coil bobbin 24a having a cylindrical shape. The high-frequency damper 23 is a flexible member having an annular shape. An outer peripheral edge of the high-frequency damper 23 is connected to the high-frequency frame 22, and an inner peripheral edge of the high-frequency damper 23 is connected to an outer circumferential surface of the voice coil bobbin 24a. The high-frequency voice coil 24 is formed on an outer circumferential surface of the voice coil bobbin 24a and disposed in a magnetic gap 25a of the high-frequency magnetic circuit 25. The high-frequency diaphragm 21 corresponds to one example of the second diaphragm of the invention.

[0021] A low-frequency component of a sound signal supplied to the composite speaker device 1 is supplied to the low-frequency voice coil 14 in the woofer unit 10, and a high-frequency component of the sound signal supplied to the composite speaker device 1 is supplied to the high-frequency voice coil 24 in the tweeter unit 20. As a result, each voice coil vibrates by the Lorentz force applied from each magnetic circuit to each voice coil, and the vibration of each voice coil is transmitted to each diaphragm. Accordingly, the low-frequency diaphragm 11 in the woofer unit 10 radiates a low-frequency sound in the sound radiation direction D1, and the high-frequency diaphragm 21 in the tweeter unit 20 radiates a high-frequency sound in the sound radiation direction D1. In the composite speaker device 1, the low-frequency sound and the high-frequency sound are assigned to two speakers as described above, thereby widening a range.

[0022] Herein, due to diffraction or the like, a part of the sound radiated from the high-frequency diaphragm 21 of the tweeter unit 20 in the sound radiation direction D1 passes over the upper periphery of the high-frequency frame 22 and is propagated to the surface of the low-frequency diaphragm 11 of the woofer unit 10.

[0023] Further, in the composite speaker device 1, a high-frequency range of the sound radiated from the woofer unit 10 and a low-frequency range of the sound radiated from the tweeter unit 20 partially overlap each other. In such a range, a sound at the same frequency waves is radiated from both of the woofer unit 10 and the tweeter unit 20. The range of the frequency, in which the frequencies of the sounds radiated from both of the speaker units overlap each other, is herein referred to as an overlapping frequency. A certain frequency within the range of the overlapping frequency is a crossover frequency.

[0024] At such an overlapping frequency, the sound propagated from the surface of the high-frequency diaphragm 21 in the sound radiation direction D1 to the surface of the low-frequency diaphragm 11 in the sound radiation direction D1 is reflected by the surface of the low-frequency diaphragm 11. When the sound at the overlapping frequency is propagated to the low-frequency diaphragm 11, the low-frequency diaphragm 11 vibrates at the same frequency by a part of energy of a sound wave. Accordingly, the low-frequency diaphragm 11 can be considered as a free end. The above reflection is related to the free end of the sound at the overlapping frequency. Therefore, the sound at the overlapping frequency from the high-frequency diaphragm 21 has no phase shift caused by reflection by the surface of the low-frequency diaphragm 11. Consequently, it is sufficient to take into consideration of only the phase shift caused by a propagation path difference described later.

[0025] The reflected wave interferes the sound radiated from the high-frequency diaphragm 21. Depending on the phase shift between the two sounds, the two sounds interfere to be cancelled with each other, and the sound pressure is decreased. Consequently, the disturbance in sound radiation characteristics of the composite speaker device 1 may occur. In the composite speaker device 1 according to the exemplary embodiment, in order to restrain such a disturbance in sound radiation characteristics, a sound absorbing material 30 having an annular shape is attached to one spot on the surface of the low-frequency diaphragm 11 in the sound radiation direction D1 so as to surround the high-frequency diaphragm 21 by one circle. Even when the sound is propagated from the tweeter unit 20 to the woofer unit 10, the sound is absorbed by the sound absorbing material 30. In the composite speaker device 1, the disturbance in sound radiation characteristics caused by the propagation of the sound from the tweeter unit 20 to the woofer unit 10 can be restrained by the sound absorption using the sound absorbing material 30. The sound absorbing material 30 corresponds to one example of the sound absorbing material of the invention.

[0026] Fig. 2 illustrates measurement of the characteristics of the sound propagated from the high-frequency diaphragm 21 to the low-frequency diaphragm 11 (shown in Fig. 1) and reflected from the low-frequency diaphragm 11 and the characteristics of the sound radiated from the high-frequency diaphragm 21. A propagation path difference R is a difference between a propagation path of the reflected sound wave and a propagation path of the sound wave from the high-frequency diaphragm 21. The propagation path difference R illustrated in Fig. 2 is a sum of a propagation path Ra from the high-frequency diaphragm 21 to the surface of the low-frequency diaphragm 11 and a propagation path Rb from the surface of the low-frequency diaphragm 11 to the height of the high-frequency diaphragm 21.

[0027] Incidentally, the measurement of the characteristics of the speaker device is generally performed using a microphone 70 located 1 m away from the high-frequency diaphragm 21 on an axis of the speaker device. According to the exemplary embodiment, since the diameter of the low-frequency diaphragm 11 is sufficiently smaller than 1 m, Rb is approximately defined as a propagation path located at the same height as that of the high-frequency diaphragm 21 as described above. Otherwise, the propagation path Rb is defined as a distance from the surface of the low-frequency diaphragm 11 to the circumference of a 1-meter radius circle around the microphone 70.

[0028] Fig. 3 illustrates a state that the disturbance in the sound radiation characteristics of the composite speaker device illustrated in Fig. 1 is restrained by the sound absorbing material. Fig. 3 shows a graph G3 representing one example of the sound radiation characteristics in the composite speaker device 1. In the graph G3, an abscissa axis represents a frequency of a sound (Hz) and an ordinate axis represents a sound pressure (dB). One example of the sound radiation characteristics in the composite speaker device 1 illustrated in Fig. 1 is shown by a thick line L1, and one example of the sound radiation characteristics without the provision of the sound absorbing material 30 for comparison is shown by a thin line L2. The sound radiation characteristics shown by the thin line L2 are measured by a measurement method illustrated in Fig. 2, and the sound radiation characteristics shown by the thick line L1 of the composite speaker device 1 illustrated in Fig. 1 are measured by a measurement method similar to that illustrated in Fig. 2.

[0029] In the exemplary embodiment illustrated in Fig. 3, a frequency around 4 kHz is defined as the overlapping frequency. When the sound absorbing material 30 is not provided, as shown in thin line L2, the sound pressure rapidly decreases at the overlapping frequency. This is because of the following reason. In a high-sound pressure area HI in a sound pressure distribution G1 shown in Fig. 2(a), the sound at the overlapping frequency propagated from the tweeter unit 20 and the sound at the same frequency reflected by the low-frequency diaphragm 11 of the woofer unit 10 interfere to be cancelled with each other.

[0030] In contrast, in the composite speaker device 1 of the exemplary embodiment provided with the sound absorbing material 30, the sound at the overlapping frequency from the tweeter unit 20 is absorbed by the sound absorbing material 30 on the low-frequency diaphragm

11 of the woofer unit 10. As a result, as shown by the thick line L1, a decrease in the sound pressure at the overlapping frequency is restrained. As described above, in the composite speaker device 1 according to the exemplary embodiment, the disturbance in the sound radiation characteristics caused by the propagation of the sound from the tweeter unit 20 to the low-frequency diaphragm 11 of the woofer unit 10 can be restrained by the sound absorption using the sound absorbing material 30. Further, in the composite speaker device 1, the disturbance in sound radiation characteristics can be restrained with the structure requiring relatively low material cost and production cost, in which the sound absorbing material 30 is attached to the surface of the low-frequency diaphragm 11 in the sound radiation direction D1. Furthermore, in the composite speaker device 1, the sound absorbing material 30 is attached to the surface of the low-frequency diaphragm 11 in the sound radiation direction D1, and no objects exist in the space in the sound radiation direction D1 of low-frequency diaphragm 11. Therefore, the outer appearance of the composite speaker device 1 is favorable.

[0031] The sound from the tweeter unit 20 reaches the surface of the low-frequency diaphragm 11 of the woofer unit 10 and interferes the sound radiated from the woofer unit 10, and accordingly the disturbance in sound radiation characteristics of the speaker device may occur. In the composite speaker device 1 according to the exemplary embodiment, since such an interference can be restrained by the sound absorption using the sound absorbing material 30, the disturbance in the sound radiation characteristics of the speaker device also can be restrained.

[0032] In the composite speaker device 1 according to the exemplary embodiment, as illustrated in Fig. 1(a), an axis of the woofer unit 10 is coincident with an axis of the tweeter unit 20. In the composite speaker device 1, since a high-frequency sound and a low-frequency sound are heard from approximately the same position, a favorable sound image can be obtained.

[0033] In the composite speaker device 1 according to the exemplary embodiment, as illustrated in Fig. 1(b), the sound absorbing material 30 has an annular shape surrounding the high-frequency diaphragm 21. In the composite speaker device 1, the sound absorbing material 30 having an annular shape can absorb the sound propagated from the tweeter unit 20 to the woofer unit 10 evenly around the axis of the tweeter unit 20. Accordingly, the disturbance in the sound radiation characteristics can be further restrained.

[0034] According to the exemplary embodiment, as one example of the first speaker unit and the second speaker unit of the invention, the woofer unit 10 and the tweeter unit 20 having the axes coincident with each other are exemplified. However, each of the first speaker unit and the second speaker unit of the invention is not limited thereto, and the following modifications are possible.

[0035] Fig. 4 schematically illustrates a woofer unit and a tweeter unit as the first speaker unit and the second speaker unit according to a modification of the invention. Fig. 4 is a schematic plan view of a woofer unit 16 and a tweeter unit 26 according to the modification in which the low-frequency diaphragm 16a and the high-frequency diaphragm 26a are viewed from the sound radiation side in the same manner as Fig. 1(b). Incidentally, in Fig. 4, components other than each diaphragm are not shown.

[0036] The axis of the woofer unit 16 shifts from the axis of the tweeter unit 26 according to the modification. A sound absorbing material 35 having an annular shape is attached to a surface of the low-frequency diaphragm 16a so as to surround the tweeter unit 26 having an axis shifted with respect to the woofer unit 11. According to the modification, since a high-frequency sound and a low-frequency sound are heard from positions slightly shifted from each other, the sound image is inferior a little to the sound image of the composite speaker device 1 according to the exemplary embodiment illustrated in Fig. 1. However, the width of a reproduction range is similar to that of the composite speaker device 1 according to the exemplary embodiment. Also in the another exemplary embodiment, the sound absorbing material 35 can absorb the sound propagated from the tweeter unit 20, thereby restraining the disturbance in the sound radiation characteristics. The sound absorbing material 35 according to another exemplary embodiment also corresponds to one example of the sound absorbing material of the invention.

[0037] According to the exemplary embodiment, the sound absorbing material 30 having an annular shape is exemplified as one example of the sound absorbing material of the invention. However, the sound absorbing material according to the invention is not limited thereto. For example, the following modifications may be adopted as the sound absorbing material of the invention.

[0038] Fig. 5 schematically illustrates a sound absorbing material according to another modification. Fig. 5 is a schematic plan view illustrating a sound absorbing material 36 of another modification as viewed from the sound radiation side in the similar manner as Fig. 1(b). The sound absorbing material 36 according to another modification intermittently surrounds the high-frequency diaphragm 21. Although being inferior a little to the sound absorbing material 30 according to the exemplary embodiment illustrated in Fig. 1, the sound absorbing material 36 of another modification also can absorb the sound propagated from the tweeter unit 20 and restrain the disturbance in sound radiation characteristics. The sound absorbing material 36 according to another exemplary embodiment also corresponds to one example of the sound absorbing material of the invention.

[0039] In the composite speaker device 1 according to the exemplary embodiment illustrated in Fig. 1, the opening 11a is formed at the center of the low-frequency diaphragm 11, and the diameter of the high-frequency diaphragm 21 is smaller than that of the opening 11a. In the composite speaker device 1, it is possible to avoid a situation in which the high-frequency diaphragm 21 becomes a blocking object in the sound radiation direction D1 of the low-frequency diaphragm 11.

[0040] In the composite speaker device 1 according to the exemplary embodiment, the sound absorbing material 30 is attached around the opening 11a of the low-frequency diaphragm 11. More specifically, the sound absorbing material 30 is attached along the inner peripheral edge of the opening 11a in the vicinity of the inner peripheral edge of the opening 11a. In the composite speaker device 1, since the sound absorbing material 30 is attached to a position relatively inconspicuous as seen from the sound radiation direction D1, the outer appearance of the composite speaker device 1 is improved.

[0041] Herein, the decrease in the sound pressure at the overlapping frequency (around 4kHz), which is described by referring to the thin line L2 representing the sound radiation characteristics without the provision of the sound absorbing material 30 shown in a graph G3 of Fig. 3, tends to easily occur in the following cases. Specifically, when the difference in the path of sound between the propagation path of the sound propagated from the tweeter unit 20 and reflected by the surface of the low-frequency diaphragm 11 of the woofer unit 10 and the propagation path of the sound radiated from the surface of the high-frequency diaphragm 21 in the sound radiation direction at the overlapping frequency are shifted from each other by 1/2 wavelengths, the decrease in the sound pressure at the overlapping frequency tends to easily occur. In this case, when the phase shift between the two sounds is close to 180 degrees and the two sounds interfere to be cancelled with each other, the decrease in the sound pressure tends to easily occur.

[0042] In view of the above, according to the exemplary embodiment, the sound absorbing material 30 is attached to one spot within an installation range Ar1 described below on the surface of the low-frequency diaphragm 11 in the sound radiation direction D1. The installation range Ar1 includes a spot at which a length RL1 of a propagation path difference R1 of the sound propagated from the surface of the high-frequency diaphragm 21 in the sound radiation direction D1 to the surface of the low-frequency diaphragm 11 in the sound radiation direction D1 is represented by the following formula.

$$RL1=(2n+1)\times \lambda (1/2\pm 1/16)\ldots(1)$$

"λ" in the formula (1) represents a wavelength corresponding to the overlapping frequency, and "n" is a natural number.

[0043] More specifically, the sound absorbing material 30 is attached in a range Ar2 in which the length RL1 of the propagation path difference R1 is $(2n+1)\times\lambda(1/2-1/16)$ to $(2n+1)\times\lambda(1/2+1/16)$ within the above-described installation range Ar1.

[0044] The position at which the length RL1 of the propagation path difference R1 is $(2n+1) \times \lambda (1/2)$ corresponds to a position at which the sound at the overlapping frequency from the tweeter unit 20 and the sound at the overlapping frequency radiated from the woofer unit 10 overlap with phases thereof being shifted from each other by just 1/2 wavelengths.

[0045] Fig. 6 illustrates a phenomenon occurring when two sounds having the same frequency overlap with phases thereof being shifted from each other. Fig. 6(a) shows a graph G4 representing a phenomenon which occurs when two sounds overlap with phases thereof being shifted from each other by 1/2 wavelengths, and Fig. 6(b) shows a graph G5 representing a phenomenon which occurs when two sounds overlap with phases thereof being shifted from each other by (1/2-1/16) wavelengths. Additionally, Fig. 6(c) shows a graph G6 representing a phenomenon which occurs when two sounds overlap with phases thereof being shifted from each other by (1/2-1/8) wavelengths. In each graph, an abscissa axis represents time and an ordinate axis represents a normalized amplitude.

[0046] In the graph G4 in Fig. 6(a), the first sound is represented by a dotted line L2, the second sound which overlaps the first sound with phases thereof being shifted from each other by 1/2 wavelengths is represented by a chain line L3, and the synthetic sound of the first and second sounds is represented by a solid line L4. Further, herein, it is supposed that the amplitude of the first sound is equal to that of the second sound. When the two sounds overlap with phases thereof being shifted from each other by 1/2 wavelengths, the phase shift of the two sounds becomes 180 degrees and the two sounds cancel with each other to the maximum extent. As a result, the amplitude of the synthetic sound becomes approximately zero.

[0047] In the graph G5 in Fig. 6(b), the second sound which overlaps the first sound represented by the dotted line L2 with phases thereof being shifted from each other by (1/2-1/16) wavelengths is represented by a chain line L5, and the synthetic sound of the first and second sounds is represented by a solid line L6. It is also considered that the amplitude of the first sound is equal to that of the second sound in the graph G5. Even in such a state, the phase shift between the two sounds is close to 180 degrees and the two sounds continue to cancel with each other until the amplitude of the synthetic sound becomes approximately 1/2 or less.

[0048] In the graph G6 in Fig. 6(c), the second sound which overlaps the first sound represented by the dotted line L2 with phases thereof being shifted from each other by (1/2-1/8) wavelengths is represented by a chain line L7, and the synthetic sound of the first and second sounds is represented by a solid line L8. It is also considered that the amplitude of the first sound is equal to that of the second sound. In this state, the phase shift between the two sounds is far from 180 degrees, and the amplitude of the synthetic sound does not attenuate so much.

[0049] The above formula (1) means that the length RL1 of the propagation path difference R1 has such a length that the phase shift between the two sounds becomes close to 180 degrees at least to the extent shown in Fig. 6(b). In the exemplary embodiment, the sound absorbing material 30 is attached in the above-described range Ar2 in which the length RL1 of the propagation path difference R1 becomes such a value. Specifically, in the range Ar2 in which the phase shift between the sound at the overlapping frequency from the tweeter unit 20 and the sound reflected by the surface of the low-frequency diaphragm 11 of the woofer unit 10 becomes close to 180 degrees, the sound absorbing material 30 configured to absorb the former sound is attached. More specifically, the absorbing material 30 is disposed in the vicinity of the spot at which the length RL1 of the propagation path difference R1 is $(2n+1) \times \lambda$ (1/2) when a natural number n is equal to zero, that is, the spot at which the length RL1 of the propagation path difference R1 is λ (1/2).

[0050] As specific numerical examples, when the overlapping frequency is set to 4kHz and a sound speed is set to 340 m/sec, the wavelength λ corresponding to the overlapping frequency becomes 85 mm. When n = 0, the length RL1 of the propagation path difference R1 represented by the formula (1) becomes 42.5 ± 5.3 mm. In the exemplary embodiment, the overlapping frequency is set to 4 kHz. As shown in Fig. 1(a), the propagation path difference R1 is defined as a sum of the path extending approximately horizontally from the top of the domed high-frequency diaphragm 21, folded toward the opening 11a of the low-frequency diaphragm 11 in the vicinity of the upper periphery of the high-frequency frame 22 and led to the surface of the low-frequency diaphragm 11, and the path reflected by the surface of the high-frequency diaphragm 21 and led to the same height as that of the first diaphragm. The sound absorbing material 30 is attached to a position in which the length RL1 of the propagation path difference R1 becomes 41.8 mm. The position corresponds to the vicinity of the spot at which the length RL1 of the propagation path difference R1 is $\lambda(1/2)=42.5$ mm. The propagation path difference R1 corresponds to one example of the propagation path difference of the invention.

[0051] Incidentally, in the exemplary embodiment, the sound absorbing material 30 is attached to a position in which the length RL1 of the propagation path difference R1 becomes 41.8 mm in the vicinity of the inner peripheral edge of the opening 11a of the low-frequency diaphragm 11 along the inner peripheral edge of the opening 11a, for the purpose of improving the outer appearance. However, although being slightly inferior in terms of the outer appearance, a sound absorbing material may be attached at a position away from the opening 11a of the low-frequency diaphragm 11 satisfying the above-described conditions of the propagation path difference.

[0052] Fig. 7 illustrates a composite speaker device according to another exemplary embodiment in which the sound absorbing material is attached at a position away from the opening of the low-frequency diaphragm. Fig. 7 is a cross-sectional view of the composite speaker device 5 according to another exemplary embodiment in the similar manner as the cross-sectional view of Fig. 1(a). It should be noted that, only a right half of the composite speaker device 5 is illustrated in Fig. 7. The composite speaker device 5 according to another exemplary embodiment is the same as the composite speaker device 1 illustrated in Fig. 1 except the attachment spot of the sound absorbing material 51. In Fig. 7, components equivalent to those in Fig. 1 are assigned with the same reference numerals used in Fig. 1, and the explanation of the components will be omitted.

[0053] In the composite speaker device 5 according to another exemplary embodiment, the propagation path R2 of the sound from the high-frequency diaphragm 21 of the tweeter unit 20 extends approximately horizontally from the top of the domed high-frequency diaphragm 21, passes over the vicinity of the upper periphery of the high-frequency frame 22, to be led to the surface of the low-frequency diaphragm 11. Unlike the propagation path difference R1 illustrated in Fig. 1(a), the propagation path R2 is led to a spot away from the opening 11a of the low-frequency diaphragm 11. In the exemplary embodiment, the propagation path R2 corresponds to the propagation path difference.

[0054] A sound absorbing material 51 having an annular shape is attached to one spot in the vicinity of the spot at which the length RL2 of the propagation path difference R2 is $\lambda(1/2)=42.5$ mm (e.g., RL2 = 41.8 mm). The sound absorbing material 51 attached to such a position also can absorb the sound which is propagated from the tweeter unit 20 and has a phase shift with the sound at the overlapping frequency from the woofer unit 10 of approximately 180 degrees. Accordingly, the composite speaker device 5 according to another exemplary embodiment also can restrain the disturbance in the sound radiation characteristics. The sound absorbing material 51 according to another exemplary embodiment also corresponds to one example of the sound absorbing material of the invention. The propagation path difference R2 according to another exemplary embodiment also corresponds to one example of the propagation path difference of the invention.

[0055] Fig. 8 illustrates a composite speaker device according to still another exemplary embodiment in which the sound absorbing material is attached to a position away from an opening of the low-frequency diaphragm. Fig. 8 is a cross-sectional view of a composite speaker device 6 according to still another exemplary embodiment in the similar manner as the cross-sectional view of Fig. 1(a). It should be noted that, only a right half of the composite speaker device 6 is illustrated in Fig. 8 in the similar manner as Fig. 7. The composite speaker device 6 according to still another exemplary embodiment is the same as the composite speaker device 1 illustrated in Fig. 1 except the attachment spot of the sound absorbing material 61. In Fig. 8, components equivalent to those in Fig. 1 are assigned with the same reference numerals used in Fig. 1, and the explanation of the components will be omitted.

[0056] In the composite speaker device 6 according to still another exemplary embodiment, the tweeter unit 20 is protruded in the sound radiation direction D1 as compared with the tweeter unit 20 illustrated in Figs. 1 and 7. As a result, the propagation path difference R3 of the sound from the tweeter unit 20 is slightly longer than the propagation path difference R1 illustrated in Fig. 1 and the propagation path difference R2 illustrated in Fig. 7. The propagation path difference R3 illustrated in Fig. 8 extends approximately horizontally from the top of the domed high-frequency diaphragm 21, folded toward the opening 11a of the low-frequency diaphragm 11 in the vicinity of the upper periphery of the high-frequency frame 22, and led to the surface of the low-frequency diaphragm 11. Unlike the propagation path difference R1 illustrated in Fig. 1(a), the propagation path difference R3 is also led to a spot away from the opening 11a of the low-frequency diaphragm 11. A sound absorbing material 61 having an annular shape is attached to one spot in the vicinity of the spot at which the length RL3 of the propagation path difference R3 is $\lambda(1/2)$=42.5 mm (e.g., RL3 = 45.5 mm). The sound absorbing material 61 attached to such a position also can absorb the sound which is propagated from the tweeter unit 20 and has a phase shift with the sound at the overlapping frequency from the woofer unit 10 of approximately 180 degrees. Accordingly, the composite speaker device 6 according to the still another exemplary embodiment also can restrain the disturbance in the sound radiation characteristics. The sound absorbing material 61 according to the still another exemplary embodiment also corresponds to one example of the sound absorbing material of the invention. The propagation path difference R3 according to the still another exemplary embodiment also corresponds to one example of the propagation path difference of the invention.

[0057] As described above, in the composite speaker device 1 in the exemplary embodiment, the sound absorbing material 30 is attached within the installation range Ar1 in which the phase shift between the two sounds at the overlapping frequency is approximately 180 degrees and the decrease in the sound pressure tends to easily occur. Since the attachment site of the sound absorbing material 30 is limited to such a position, it is possible to restrain the disturbance in the sound radiation characteristics while reducing the amount of the sound absorbing materials 30 to be used, the load applied to the low-frequency diaphragm 11 and the decrease in the sound pressure.

[0058] Further, the sound absorbing material 30 is attached within a range Ar2 in which the length RL1 of the propagation path difference R1 is $(2n+1) \times \lambda$ (1/2-1/16) to $(2n+1) \times \lambda$ (1/2+1/16) in the above-described installation range Ar1 in the composite speaker device 1 according to the exemplary embodiment. In the composite speaker device 1, since the attachment spot of the sound absorbing material 30 is limited to the position in which the phase shift of the sounds at the overlapping frequency interfering with each other becomes further closer to 180 degrees, it is possible to restrain the disturbance in sound radiation characteristics while further restraining the amount of the sound absorbing materials 30 to be used.

[0059] Further, in the composite speaker device 1 according to the exemplary embodiment, the sound absorbing material 30 is attached in the vicinity of the spot at which the length RL1 of the propagation path difference R1 is $(2n+1) \times \lambda$ (1/2). According to the composite speaker device 1, since the attachment spot of the sound absorbing material 30 is limited to the position in which the phase shift of the sounds at the overlapping frequency interfering with each other becomes approximately 180 degrees, it is possible to restrain disturbance in sound radiation characteristics while further restraining the amount of the sound absorbing materials 30 to be used.

[0060] In the composite speaker device 1 according to the exemplary embodiment, the sound absorbing material 30 is attached in the vicinity of the spot at which the above-described natural number n becomes zero, that is, in the vicinity of the spot at which the length RL1 of the propagation path difference R1 is λ (1/2). Specifically, the sound absorbing material 30 is attached in the vicinity of the spot nearest the high-frequency diaphragm 21 among the spots at each of which the length RL1 of the propagation path difference R1 is $(2n+1) \times \lambda(1/2)$. Although the specific size of the composite speaker device 1 is not limited in the exemplary embodiment, since the attachment spot of the sound absorbing material 30 is near the high-frequency diaphragm 21 as described above, even when the composite speaker device 1 is small to some extent, it is possible to attach the sound absorbing material 30 at a suitable position.

[0061] It should be noted that, the above-described exemplary embodiments are only typical ones of the invention, and the scope of the invention is not limited to the exemplary embodiments. Specifically, those skilled in the art may modify the invention in various ways according to conventional knowledge without departing from the scope of the invention. As long as the modification includes a configuration of the composite speaker device of the invention, as a matter of course, the modification is included in the scope of the invention.

[0062] For instance, in the above-described exemplary embodiments, the sound absorbing materials 30, 35, 36, 51 and 61 each attached to one spot so as to surround the high-frequency diaphragm 21 by one circle are described as examples of the sound absorbing material of the invention. However, the sound absorbing material according to the invention is not limited thereto. The sound absorbing material may be attached to a plurality of spots so as to surround the high-frequency diaphragm (i.e., second diaphragm) by two or more circles.

[0063] Additionally, in the above-described exemplary embodiments, the cone-shaped diaphragm (i.e., low-frequency diaphragm 11) is described as one example of the first diaphragm of the invention, and the dome-shaped diaphragm (i.e., high-frequency diaphragm 21) is described as one example of the second diaphragm of the invention. However, each of the first diaphragm and the second diaphragm of the invention is not limited to the diaphragm of the above-described types, but may be a diaphragm of any type including the cone-shaped diaphragm and the dome-shaped diaphragm.

EXPLANATION OF CODE(S)

[0064]

1,5,6	composite speaker device
10,16	woofer unit
11,16a	low-frequency diaphragm
11a	opening
12	low-frequency frame
13	low-frequency damper
14	low-frequency voice coil
15	low-frequency magnetic circuit
20,26	tweeter unit
21,26a	high-frequency diaphragm
22	high-frequency frame
23	high-frequency damper
24	high-frequency voice coil
25	high-frequency magnetic circuit
30,35,36,51,61	sound absorbing material

Claims

1. A composite speaker device comprising:

   a first speaker unit having a first diaphragm;
   a second speaker unit installed in a sound radiation direction of the first diaphragm, the second speaker unit comprising a second diaphragm having a diameter smaller than a diameter of the first diaphragm; and
   a sound absorbing material attached to a surface of the first diaphragm in the sound radiation direction so as to surround the second diaphragm.

2. The composite speaker device according to claim 1, wherein an axis of the first speaker unit is coincident with an axis of the second speaker unit.

3. The composite speaker device according to claim 2, wherein the sound absorbing material has an annular shape.

4. The composite speaker device according to claim 2, wherein
   an opening is formed at a center of the first diaphragm, and
   a diameter of the second diaphragm is smaller than a diameter of the opening.

5. The composite speaker device according to claim 4, wherein the sound absorbing material is attached around the opening.

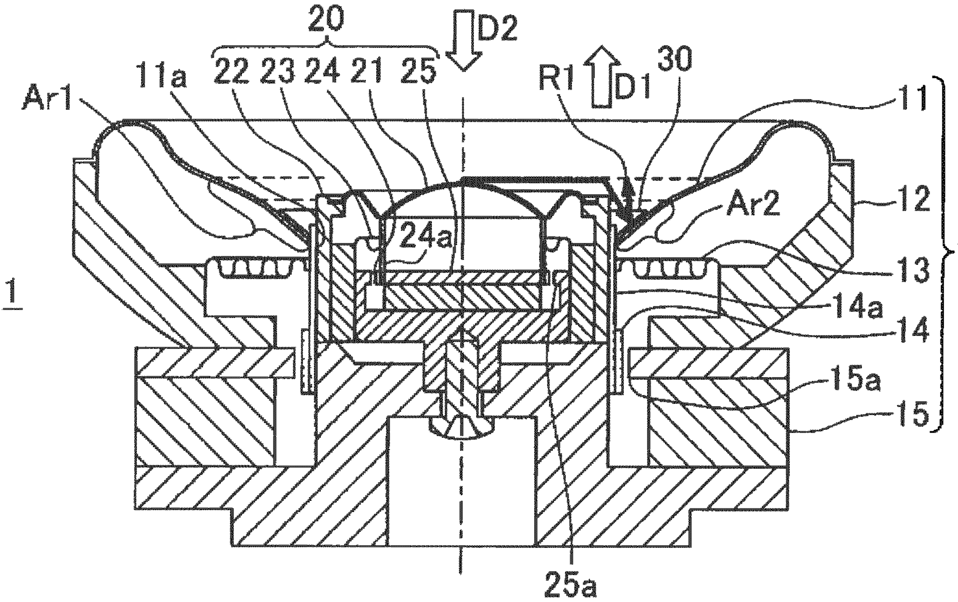
6. The composite speaker device according to claim 1, wherein
   the sound absorbing material is attached to at least one spot within an installation range including a spot at which a length of a propagation path difference between a propagation path of a sound propagated from a surface of the second diaphragm in the sound radiation direction to the surface of the first diaphragm in the sound radiation direction and reflected by the surface of the first diaphragm and a propagation path of a sound radiated from the surface of the second diaphragm in the sound radiation direction is $(2n+1) \times \lambda (1/2 \pm 1/16)$ on the surface of the first diaphragm in the sound radiation direction, where
   λ represents a wavelength corresponding to an overlapping frequency that is a frequency of a sound radiated from the first speaker unit and a sound radiated from the second speaker unit at the same frequency waves, and n represents a natural number.

7. The composite speaker device according to claim 6, wherein
   the sound absorbing material is attached to at least one spot within an installation range in which a length of the propagation path difference is $(2n+1) \times \lambda(1/2-1/16)$ to $(2n+1) \times \lambda (1/2+1/16)$ on the surface of the first diaphragm in the sound radiation direction.

8. The composite speaker device according to claim 7, wherein
   the sound absorbing material is attached to at least one spot in the vicinity of a spot at which a length of the propagation path difference is $(2n+1) \times \lambda (1/2)$ on the surface of the first diaphragm in the sound radiation direction.

9. The composite speaker device according to claim 8, wherein the natural number n is zero.

FIG.1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D2
22 23 24 21 25
11a
Ar1
R1
D1
30
11
12
Ar2
24a
13
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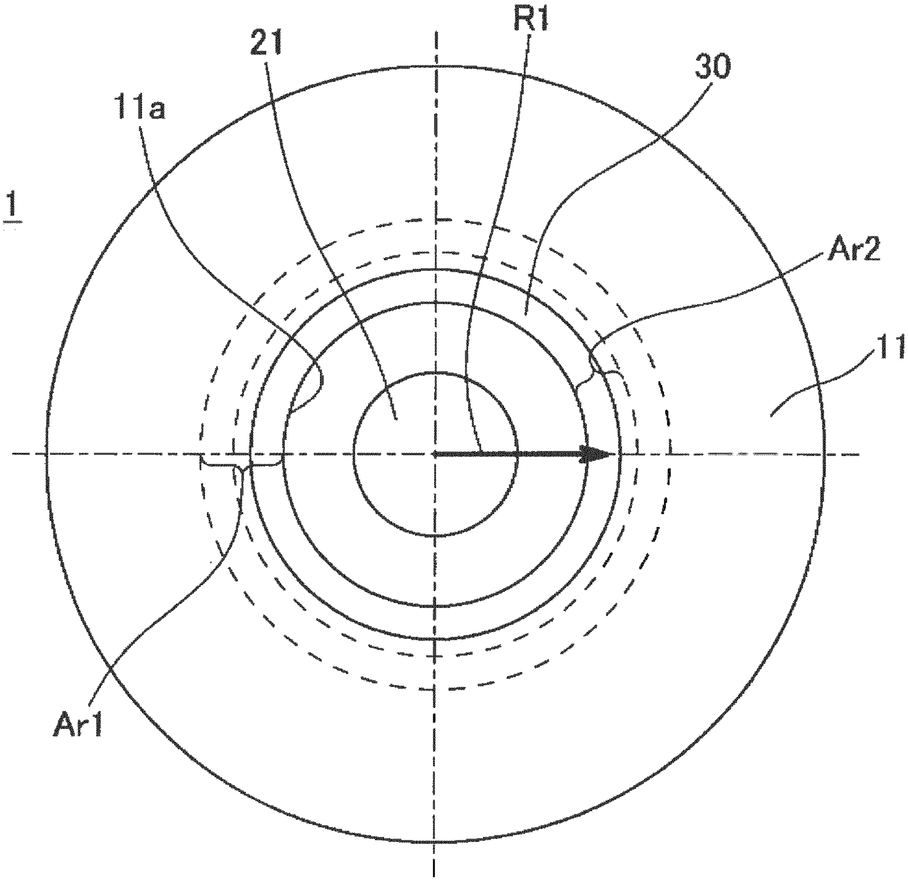
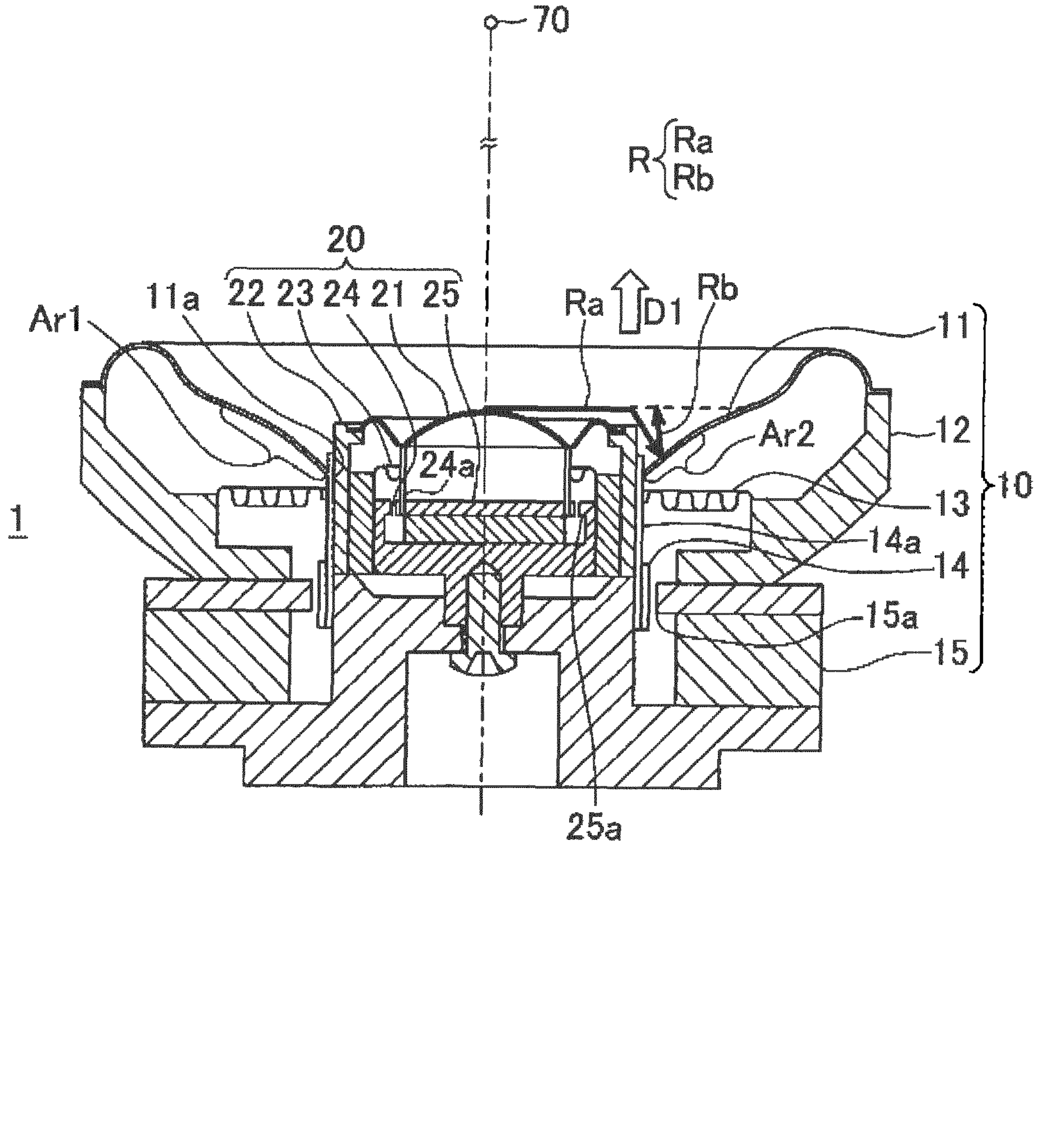
15a
15
25a

(a)


R1
21
30
11a
1
Ar2
11
Ar1

(b)

FIG. 2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Rb
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15a
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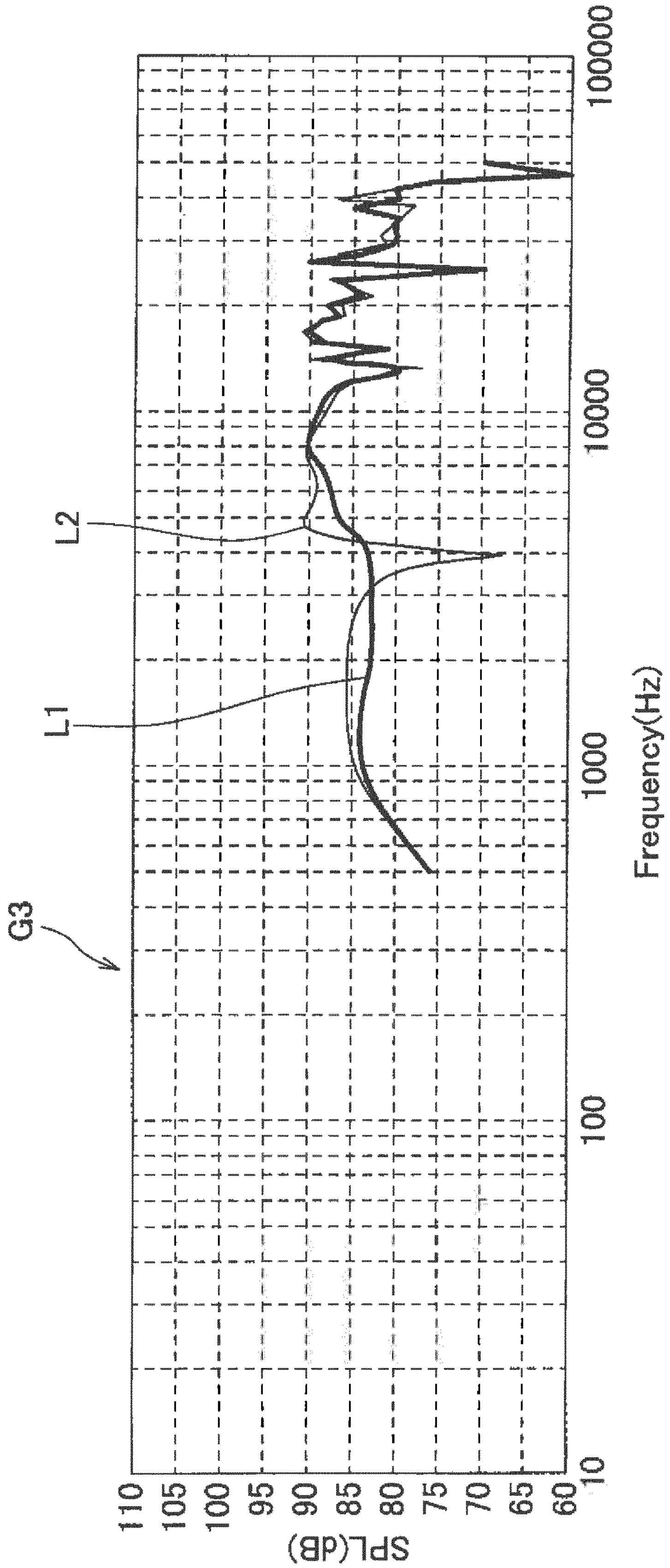
25a

FIG.3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L2
SPL(dB)
110
105
100
95
90
85
80
75
70
65
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Frequency(Hz)
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100
1000
10000
100000

FIG.4

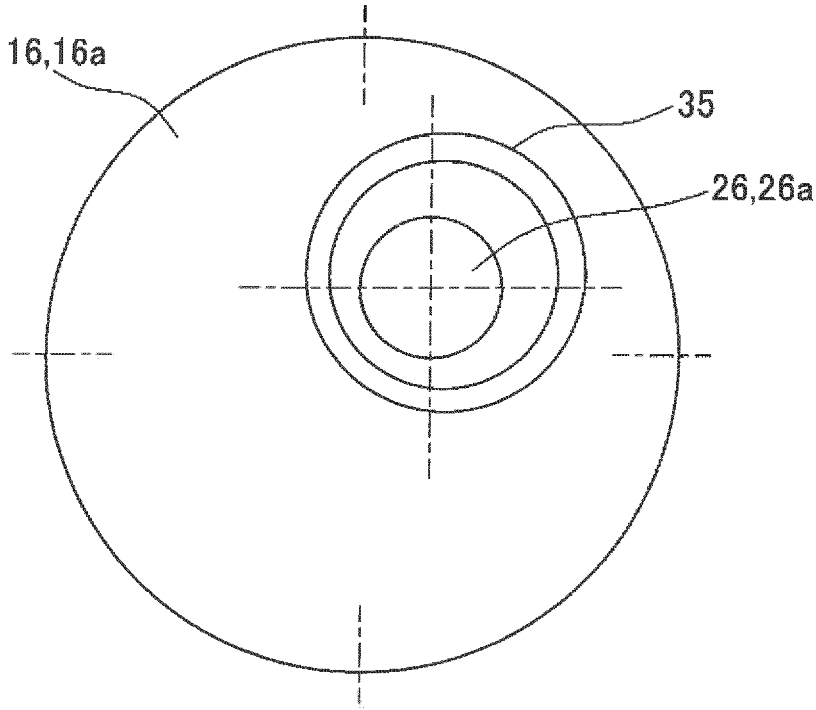


FIG.5

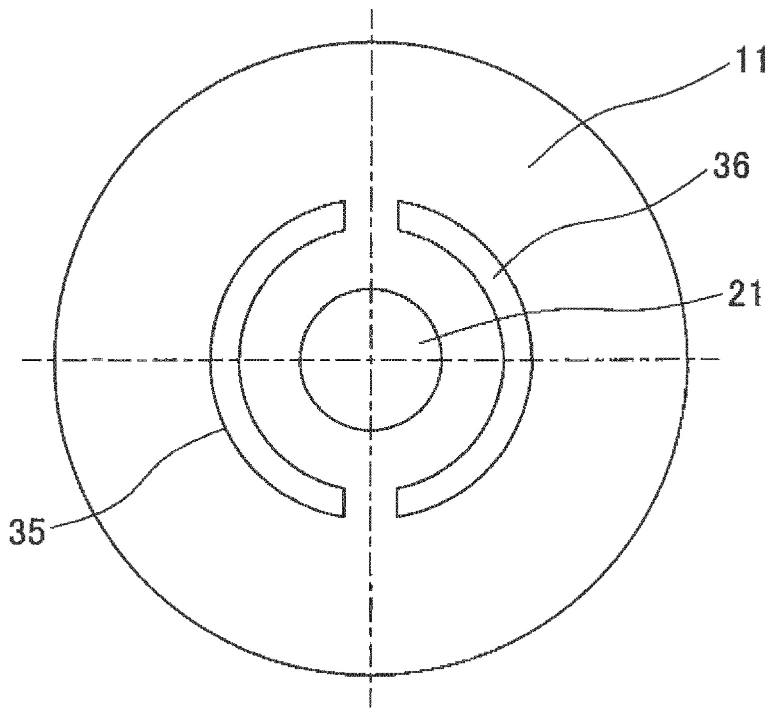
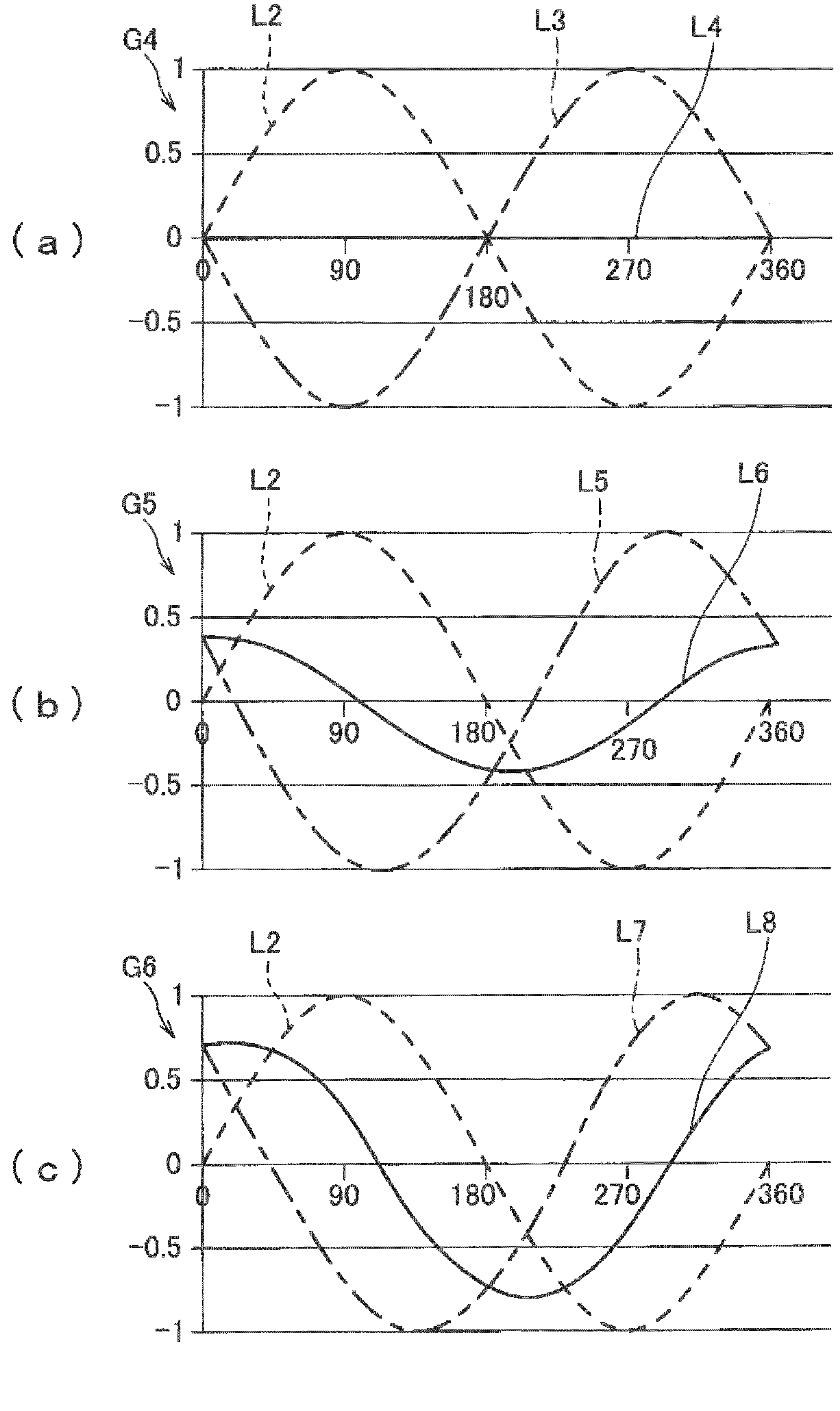


FIG.6


G4
L2
L3
L4
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0.5
0
-0.5
-1
0
90
180
270
360
G5
L2
L5
L6
(b)
1
0.5
0
-0.5
-1
0
90
180
270
360
G6
L2
L7
L8
(c)
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0
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-1
0
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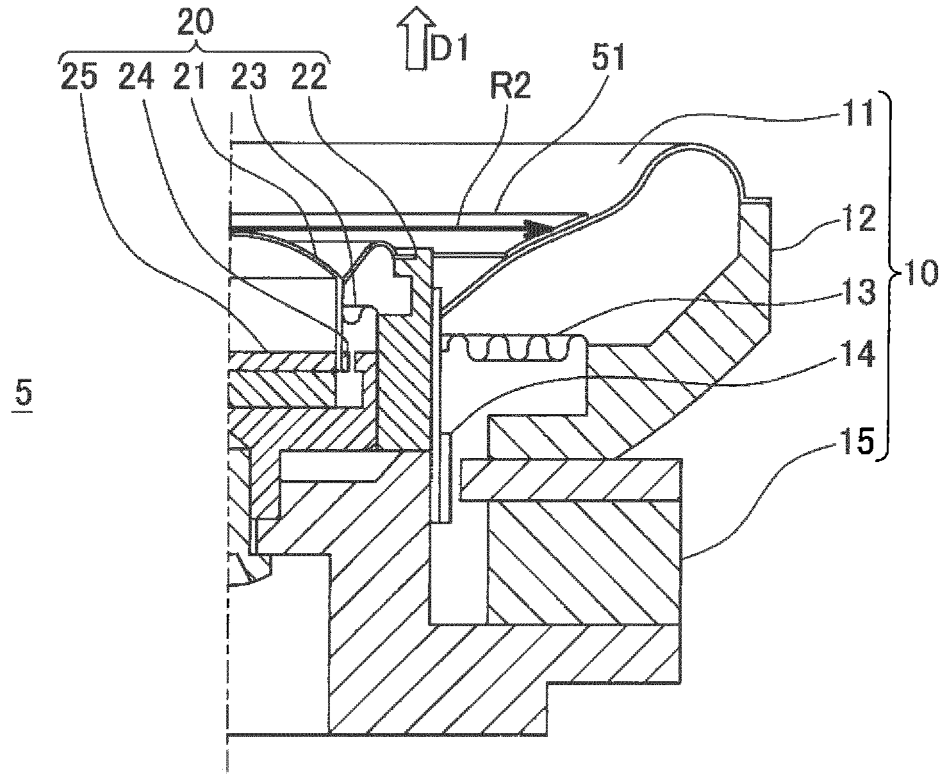
360

FIG.7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D1
R2
51
11
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13
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14
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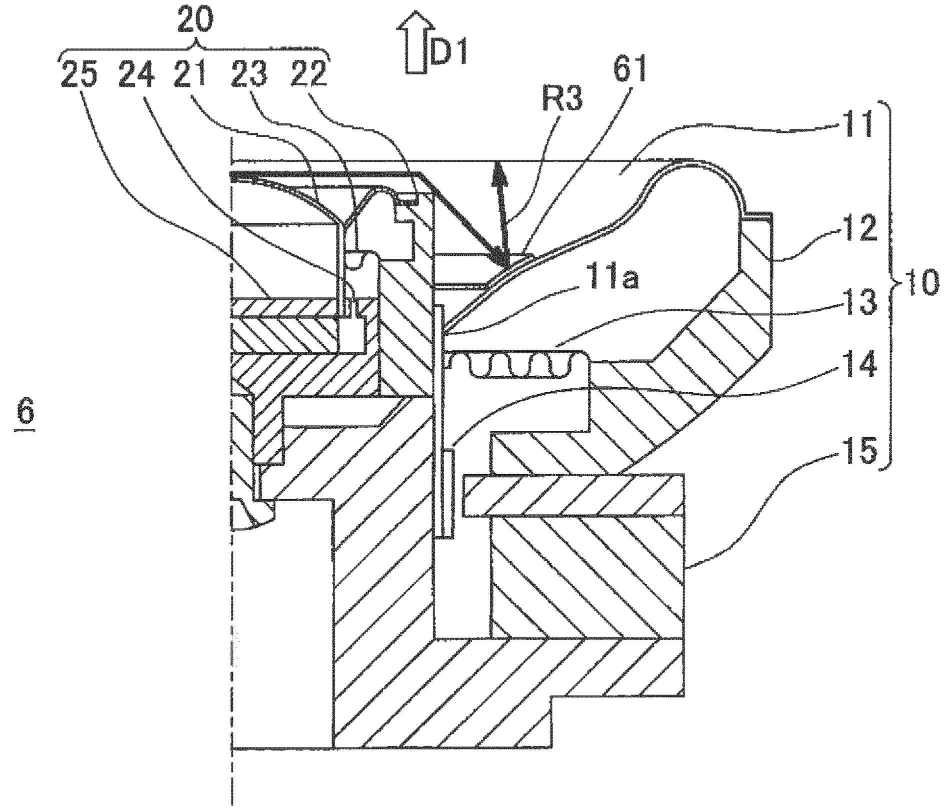
5

FIG.8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22
D1
R3
61
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11a
13
10
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15
6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/069754

A. CLASSIFICATION OF SUBJECT MATTER
H04R1/24(2006.01)i, *H04R7/12*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04R1/24, H04R7/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2014
Kokai Jitsuyo Shinan Koho	1971-2014	Toroku Jitsuyo Shinan Koho	1994-2014

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 4497981 A (Harman International Industries Inc.), 05 February 1985 (05.02.1985), column 2, line 36 to column 3, line 45; fig. 1 & DK 244983 A0 & DK 244983 A & EP 95876 A2 & AU 1495783 A & JP 59-41999 A & CA 1204498 A & AU 559440 B & DE 3378559 D & MX 159045 A	1-3 4,5 6-9
Y A	US 5295194 A (Eugene J. Christensen), 15 March 1994 (15.03.1994), fig. 1A & US 5062139 A & WO 1990/015513 A1	4,5 6-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 October, 2014 (21.10.14)	04 November, 2014 (04.11.14)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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Patent documents cited in the description

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