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Remarks:
Amended claims in accordance with Rule 137(2) EPC.

(54) **DIRECTIONAL LOUDSPEAKER**

(57) Directional midrange frequency loudspeaker comprising an acoustic box (1) with mounted in a cone speaker (2) and openings (4). The openings (4) facing same direction as midrange cone speaker (2) this allows to create a new rear wave source of the same frequencies obtained from back waves (6) of the cone speaker (2) reflected from the walls (7) of the acoustic box (1), which move in the same direction as front waves (5) emitted from cone speaker (2) and has a mutual coupling effect which increase the directivity, also increase the sensitivity of the loudspeaker by up to a factor of two (3db). Mutual coupling effect is obtained in widest frequency range by changing position of inner wall (7) of the acoustic box (1).

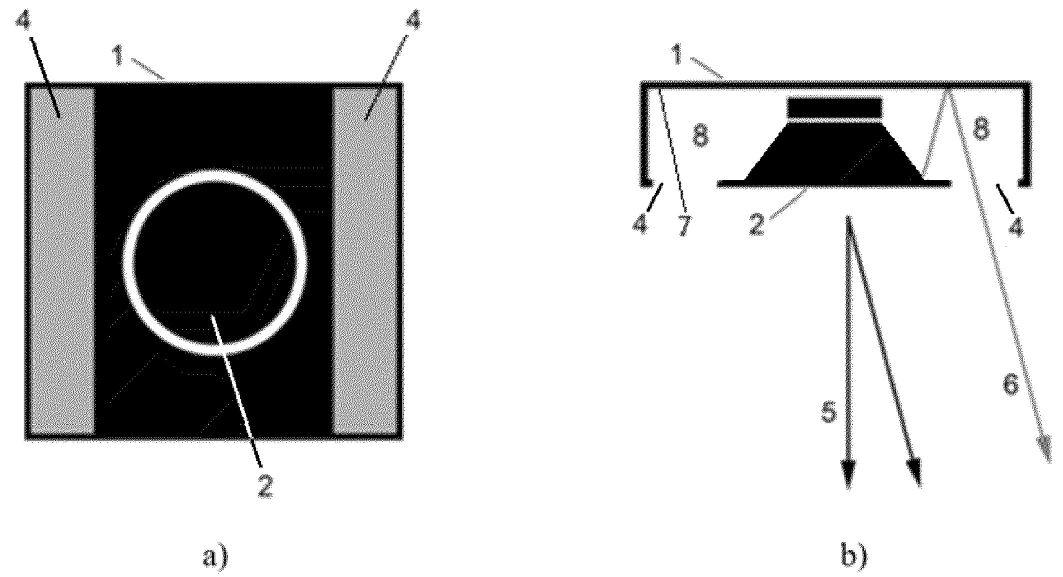

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a directional loudspeaker, and, in particular, to a directional loudspeaker for use in the mid frequency range of the audio spectrum and a directional loudspeaker system comprising one or more of such directional loudspeakers.

BACKGROUND OF THE INVENTION

[0002] It is well known that the interaction between the loudspeakers and the reflecting surfaces of the room has a huge influence on the sound and its quality.

[0003] Quality acoustic treatment of a room often can and usually does exceed the cost of quality speakers.

[0004] Therefore, it makes more sense to enhance sound quality by directing sound waves toward the listener while trying to radiate as few sound waves to reflective surfaces as possible thus decreasing interaction between speakers and the room.

[0005] There are lots of solutions linked to sound waves controlled directivity within different systems used in loudspeakers. Improvements in this area have been made for a long time and very widely.

[0006] Several techniques are known to be used to increase midrange directivity. Like horns, which are bulky and expensive to manufacture, dipole loudspeakers which have back reflections and are therefore demanding for positioning in the room and impairing the localization of the soundstage, and cardioid-type systems, where active arrays of loudspeakers are used or passive solutions.

[0007] The closest prior art EP3018915A1 (published on May 5, 2016) describes a directional loudspeaker designed for use in the mid frequency range of the audio spectrum. It includes a housing with acoustic resistive material, an acoustic transducer mounted to the front panel, and one or more openings in the side panels and back panel. The resistive material, openings, and reflective back panel delay, attenuate, and shape the back waves in the mid frequency range, creating an attenuation at the backside of the loudspeaker of at least 15dB for midrange frequencies. This solution performs directivity correction only at lower mid-range frequencies and does not have the benefits (directivity and sensitivity) of mutual coupling at mid-higher frequencies.

[0008] Mid-frequency range plays a crucial part in recreating a sound stage. Below 1000 Hz it's relatively difficult to control the directivity. Conventional speaker in a wide frequency range is not suitable for this, because its directivity changes as the frequency changes. Waveguides are no longer effective in that range; horns must be relatively huge.

[0009] This invention appertains to passive cardioid. The passive cardioid solutions known to date are used to control the low frequency and lower midrange frequency.

[0010] To address the mid-range frequency (MF) correction of directivity in the MF range, was created acoustic loudspeaker enclosure, which allows to improve the desired properties:

1) Increase the directivity in midrange frequency - decreasing interaction between speakers and the room:

    a) increase of horizontal directivity (less reflections from side and back walls);
    b) increase of vertical directivity (less reflections from ceiling and floor).

2) Up to two times (3db) increase the sensitivity at frequency of ROI (region of interest) (300 - 1700 Hz) of the system.
3) Get less driver distortion (higher SPL (sound pressure level) with the same driver motor movement).
4) With the help of openings on the front of the panel equalize the pressure generated inside enclosure and outside the speaker. This way loudspeakers therefore operate symmetrically with minimal internal pressure loading.
5) Subsequent driver beaming, the ability to use the loudspeaker efficiently over a wider frequency range at higher frequencies.

SUMMARY OF THE INVENTION

[0011] Mentioned problems is solved with proposed invention: directional loudspeaker comprising: an acoustic box; with

at least one cone speaker mounted in front side of the acoustic box, being configured to produce front waves radiating out of the acoustic box and rear waves radiating into inner part of the acoustic box; and

one or more openings in the front side of the acoustic box is configured in such way allowing at least part of said rear waves, reflected from the inner walls in the acoustic box to exit said acoustic box in the same direction and with relative phase difference not exceeded within 120° phase as said front waves, in the midrange frequency between part of said front waves and said rear waves exiting through said openings is obtained a mutual coupling, such that increased directivity and sensitivity of the loudspeaker by up to a factor of two (3db) is achieved.

[0012] Mutual coupling is a wave summation effect achieved when two or more sources reproduce the same signal, and the acoustic centers of the sources are close together and point in the same direction. This invention appertains as a passive cardioid loudspeaker.

[0013] This construction of the loudspeaker with cone speaker which front and rear wave phases coincide over the widest possible frequency range from 200 Hz to 2000 Hz and its frequency ROI is as uniform as possible over this range.

[0014] By usage of this mutual coupling the biggest effect is in frequency ranges from 300 Hz to 1700 Hz.

[0015] Mutual coupling effect in the widest frequency range and the correction of the rear wave phase can be varied in several ways:

- by changing the area of the front holes, openings area - from 10 to 300% of cone speaker cone area, best when openings area is closer or identical to the area of the cone speaker cone;
- by changing the dimensions of the rear chamber;
- by changing the angle of inclination or curvature of the inner wall of the acoustic box; best results were obtained
- by forming inverted split V-shaped wall in the inner part of the chamber and when inside the box is used a Helmholtz resonator tuned to absorb the peak created by an acoustic filter formed in the rear chamber.

[0016] This invention is special because directivity correction is performed by the principle of mutual coupling of waves, thus not only increasing the directivity but also increasing the sensitivity of the system by up to a factor of two (3db).

[0017] Subsequent driver beaming, the ability to use the loudspeaker efficiently over a wider frequency range at higher frequencies.

[0018] This invented directional enclosure can be combined with other frequencies directional modules.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

Fig. 1 shows an acoustic box with openings positioned in one plane of the loudspeaker a) front view, b) top view.

Fig. 2 shows the acoustic boxes with A) opening in the front near the membrane; B) openings in the sides of the box; C) openings at the back of the box; D) closed type.

Fig. 3 graph shows the simulated frequency response of Fig. 2 options.

Fig. 4 shows a graph of the simulated SPL and phase versus frequency.

Fig. 5 is shown simulations of modifications A (Black - line) and D (Grey - line) from Fig. 2, enclosures for horizontal directivity pattern at 600 Hz (left) and 1000 Hz (right).

Fig. 6 shows the vertical directivity index (DI) in decibels in relation to frequencies, vertical plot of the directivity index of the A (Black - line) and D (Grey - line) modifications also shows the influence of the coupling effect.

Fig. 7 shows an acoustic box with retracted split V-shaped walls a) view from front, b) cut view from above.

Fig. 8 shows horizontal directivity diagram of acoustic box (Fig. 7) combined with other frequencies directional modules like low frequency (LF) dipole module and high frequency compact horn, when the acoustic box (Fig. 7) was used at medium frequencies.

DETAILED DESCRIPTION

[0020] In proposed invention Fig. 1, an acoustic box 1 with in front side mounted one (or more) cone speaker 2 with two sound waves of same frequency which behave as two (front and rear) sound sources: a front wave 5 radiating out of the acoustic box 1 and a rear wave 6 produced by cone speaker 2 in inner part 8 of acoustic box and reflected from the inner walls 7 in the acoustic box 1 exiting through the front openings 4 of the acoustic box. The openings 4 in the acoustic box are positioned facing the same side as cone speaker 2, so that both the front wave 5 and the rear wave 6 move in the same direction and have a mutual coupling effect.

[0021] As an example, here are some research results. There was modelled an acoustic box with a 160 mm diameter loudspeaker diaphragm (assumed to be ideal). The dimensions of the box are 39,6 cm wide, 50 cm high and 15,4 cm deep, with a wall thickness of 1,8 cm. And was analyzed variations (Fig. 2) of loudspeakers with different constructions of acoustic boxes like: A) with openings in the front near the membrane; B) with openings in the side of the box; C) with openings at the back of the box; and D) closed type.

[0022] In the simulation model, the area of the openings was identical to the area of the loudspeaker diaphragm. The Fig. 3 graph shows the simulated frequency response of options A, B, C and D (Fig. 2) at 1 meter on the driver axis. Modification A and B have a higher SPL compared to the frequency response of closed box D. Notably, the SPL of modification A is highest over a wide range of frequencies, due to the above mentioned fulfilled conditions of mutual coupling effect.

[0023] For the front and rear waves 5, 6 to be constructive but not destructive, their phases must at least partially coincide.

[0024] To find the summation of the waves depending on the phase difference, there was used the Leonhard Euler formula:

Assuming SPL of the rear and the front pressure side is equal (Pf=Pb=P), so the total pressure is Pt, i is implied unit, and phases of front wave is ϕf and backwave phase ϕb

$$\mathrm{Pt} = \mathrm{P} * (\exp[-\mathrm{i} * \phi f] + \exp[-\mathrm{i} * \phi b])$$

and the module is

$$|Pt| = P * \sqrt{[2 * (2 + 2Cos[\phi f - \phi b])]}$$

[0025] To get higher pressure than Pf the value under the square root must be greater than 1,

$$\sqrt{[2 * (2 + 2Cos[\phi f - \phi b])]} \geq 1$$

from there is got that relative phase difference is ϕf - ϕb should not exceed 120 deg.

[0026] In Fig. 4 is a graph of the simulated SPL and phase versus frequency. The mutual coupling effect changes the overall system directivity by summing up waves moving in the same direction.

[0027] In Fig. 5 is simulations of modifications A and D enclosures for horizontal directivity pattern at 600 Hz (left) and 1000 Hz (right). In (Black - A, Grey - D) show that the acoustic box A radiates more forwards than laterally. This results in more directing soundwaves toward the listener and fewer to reflective side surfaces.

[0028] In Fig. 6 is defined vertical directivity index (DI) in decibels in relation to frequencies (Black - A, Grey - D). The vertical plot of the directivity index of the A and D modifications also shows the influence of the coupling effect. Not only is the directivity increased, but the pattern becomes evenly wider over the frequency range and starts narrowing (speaker beaming starts) at higher frequency, thus achieving the goal of having a higher and more even directivity index in as wide a range of frequency as possible.

[0029] As can be seen from this graph, in the D-box the driver starts to beam from 1,4 kHz, while in the A-box it starts from 1,7 kHz, giving 300 Hz more of an effective uniformly directional bandwidth.

[0030] In Fig. 7 is shown one of the design solutions of an acoustic box 1, with cone speaker 2 which front wave 5 and reflected rear wave 6 coincide over the widest possible frequency range and whose frequency ROI is as uniform as possible over this range. The correction of the rear wave phase can be varied in several ways, by changing the area of the front openings 4 and by changing the dimensions of the rear chamber 8. The best results were obtained by forming inverted split V-shaped inner wall 7 in the inner 8 part of chamber 1. Inside the box is used a Helmholtz resonator tuned to absorb the rear wave peak of cone speaker 2, by an acoustic filter formed in the rear chamber 3. The advantage of this solution is that is obtained a very directive complex system for the whole audible acoustic frequency spectrum.

[0031] This invented directional enclosure can be combined with other frequencies directional modules. For example, if the invented loudspeaker is combined with other low frequency (LF) dipole module and high frequency compact horn, there is obtained very directive complex system for whole audible acoustic frequency spectrum. This combination leads to significantly more detailed soundstage and better sound resolution when compared to traditional systems.

[0032] The horizontal directivity diagram of such a system based on actual measurements can be seen in Fig. 8 graph, when the invented acoustic box is used at medium frequencies.

[0033] Furthermore, the description of the present invention is provided for the purposes of illustration and description but should not be interpreted as being limited to the precise form disclosed. Various modifications and variations can be made by those skilled in the art without departing from the scope of the invention. The embodiment selected and described herein is for illustrative purposes and is best suited to explain the principles of the invention and its practical application, so that those skilled in the art may utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated.

Claims

1. Directional loudspeaker comprising:

    an acoustic box (1);
    at least one cone speaker (2) mounted in front side of said acoustic box (1), being configured to produce front waves (5) radiating out of the acoustic box (1) and rear waves (6) radiating into inner part (8) of the acoustic box (1);
    one or more openings (4) in front part of acoustic box (1) allowing at least part of said rear waves (6), reflected from positioned inner walls (7) in the acoustic box (1) to exit said acoustic box (1) in the same direction and with relative phase difference not exceeded within 120° phase as said front waves (5) for part of said front waves (5) and said rear waves (6) exiting through said openings (4) in the midrange frequency having mutual coupling such that increased directivity and sensitivity of the loudspeaker is achieved.

2. Directional loudspeaker according to claim 1 **characterised in that** said mutual coupling effect in mid frequency range is between 200 Hz and 2000 Hz, preferably 300 Hz and 1700 Hz.

3. Directional loudspeaker according to any of claims 1-2 **characterised in that** said openings (4) area are from 10 % to 300 % of cone speaker (2) cone area, preferably close in size to the area of cone speaker (2) cone.

4. Directional loudspeaker according to any of claims 1-3 **characterised in that** position of the inner walls (7) in the acoustic box (1) are arranged that said mutual coupling effect is in widest frequency range.

5. Directional loudspeaker according to claim 4 **char-**

acterised in that further the inner walls (7) are inclined in such an angle that said mutual coupling effect is in widest frequency range.

6. Directional loudspeaker according to any of claims 4, 5 **characterised in that** further curvature of the inner walls (7) are such that said mutual coupling effect is in widest frequency range.

7. Directional loudspeaker according to any of claims 1-6, **characterised in that** further comprises retracted one or more inner walls (7) in the inner part (8) of the acoustic box (1), forming rear chamber (3) as a Helmholtz resonator for absorbing the rear waves (6) peak of cone speaker (2), by an acoustic filter formed in the rear chamber (3).

8. Directional loudspeaker according to claim 7, **characterised in that** the inner walls (7) are inclined diagonally forming inverted, split V-shape in the inner part (8) of the acoustic box (1) for said mutual coupling effect in wider frequency range.

9. Directional loudspeaker system comprising: directional loudspeaker according to any of claims 1-8, combined with other frequencies directional modules for more directive complex system for whole audible acoustic frequency spectrum.

Amended claims in accordance with Rule 137(2) EPC.

1. Directional loudspeaker comprising:

an acoustic box (1);
at least one cone speaker (2) mounted in front side of said acoustic box (1), being configured to produce front waves (5) radiating out of the acoustic box (1) and rear waves (6) radiating into inner part (8) of the acoustic box (1);
one or more openings (4) in front part of acoustic box (1) allowing at least part of said rear waves (6), reflected from inner walls (7) in the acoustic box (1) to exit said acoustic box (1)
characterised in that
the inner walls (7) are positioned in front of the rear of the cone speaker (2); and
an acoustic centers of the sources - cone speaker (2) and openings (4) are close together and point in the same direction such that some of said rear waves (6) reflected from positioned inner walls (7) exits said acoustic box (1) without interruption in the same direction and with relative phase difference not exceeded within 120° phase, as said front waves (5) for part of said front waves (5) and said rear waves (6) exiting through said openings (4) in the midrange frequency having wave summation such that increased directivity and sensitivity of the loudspeaker is achieved.

2. Directional loudspeaker according to claim 1 **characterised in that** said wave summation in mid frequency range is between 200 Hz and 2000 Hz, preferably 300 Hz and 1700 Hz.

3. Directional loudspeaker according to any of claims 1-2 **characterised in that** said openings (4) area are from 10 % to 300 % of cone speaker (2) cone area, preferably close in size to the area of cone speaker (2) cone.

4. Directional loudspeaker according to any of claims 1-3 **characterised in that** position of the inner walls (7) in the acoustic box (1) are arranged that said wave summation is in widest frequency range.

5. Directional loudspeaker according to claim 4 **characterised in that** further the inner walls (7) are inclined in such an angle that said wave summation is in widest frequency range.

6. Directional loudspeaker according to any of claims 4, 5 **characterised in that** further curvature of the inner walls (7) are such that said wave summation is in widest frequency range.

7. Directional loudspeaker according to any of claims 1-6, **characterised in that** further comprises retracted one or more inner walls (7) in the inner part (8) of the acoustic box (1), forming rear chamber (3) as a Helmholtz resonator for absorbing the rear waves (6) peak of cone speaker (2), by an acoustic filter formed in the rear chamber (3).

8. Directional loudspeaker according to claim 7, **characterised in that** the inner walls (7) are inclined diagonally forming inverted, split V-shape in the inner part (8) of the acoustic box (1) for said mutual coupling effect in wider frequency range.

9. Directional loudspeaker system comprising: directional loudspeaker according to any of claims 1-8, combined with other frequencies directional modules for more directive complex system for whole audible acoustic frequency spectrum.

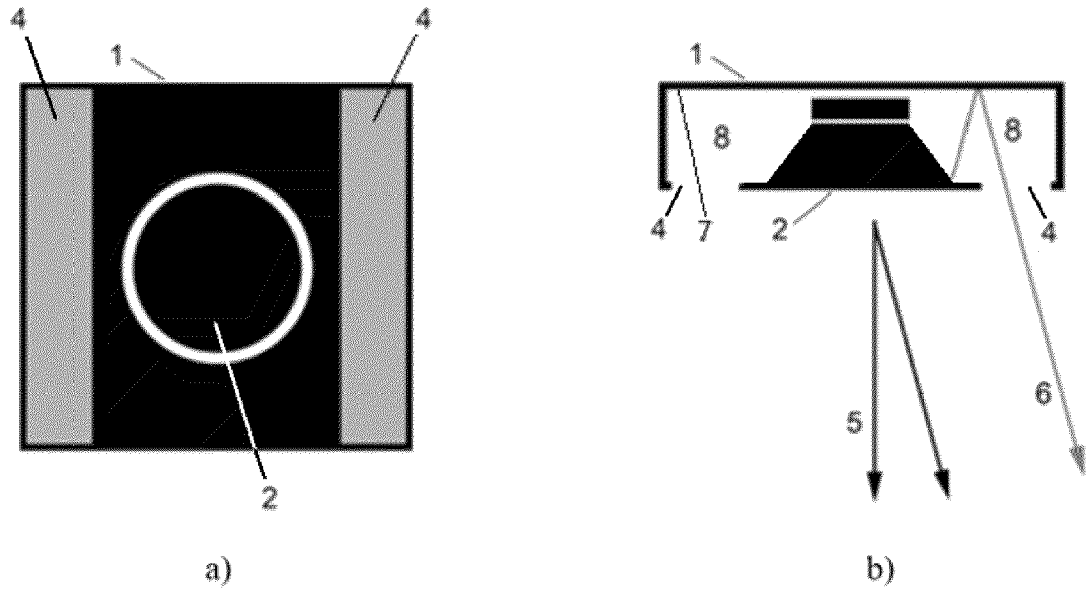

Fig. 1

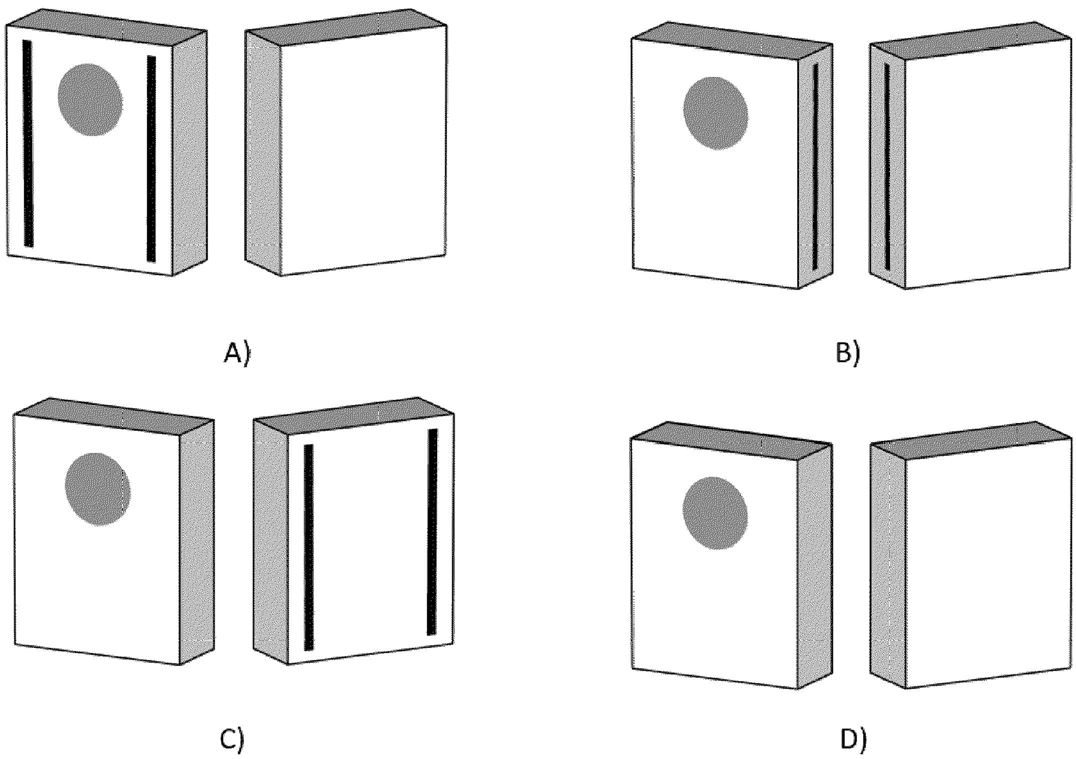

Fig. 2

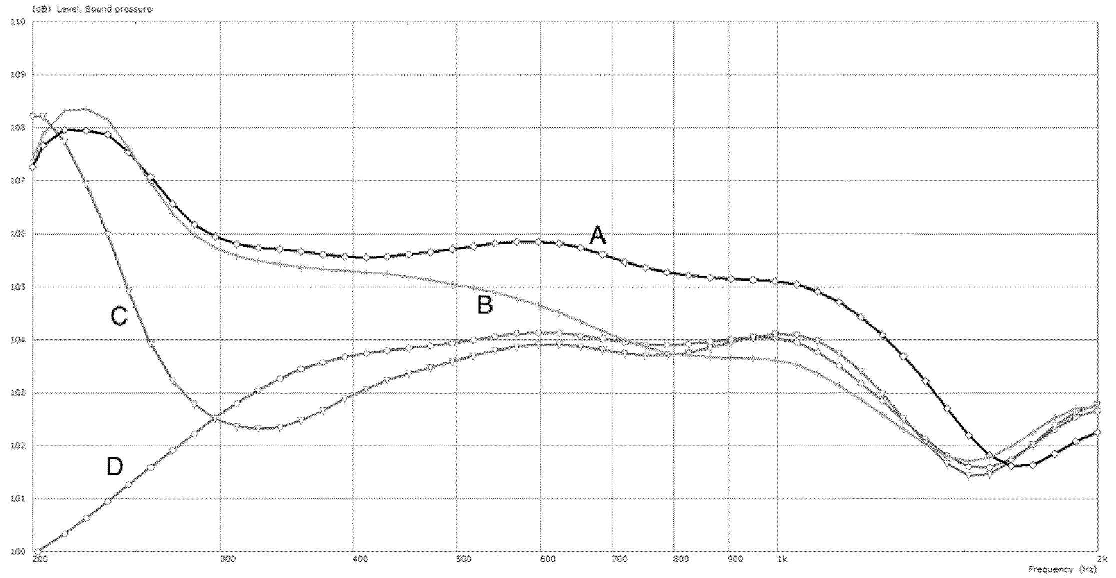
(dB) Level, Sound pressure
A
B
C
D
Frequency (Hz)

Fig. 3

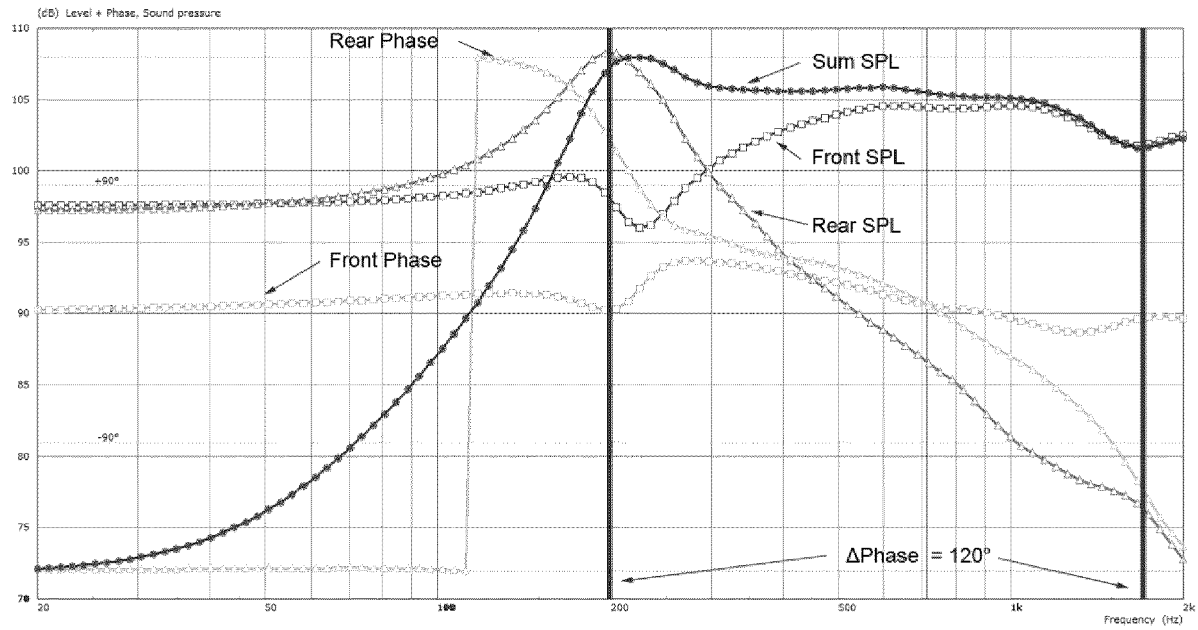
(dB) Level + Phase, Sound pressure
Rear Phase
Sum SPL
Front SPL
Rear SPL
Front Phase
+90°
-90°
ΔPhase = 120°
Frequency (Hz)

Fig. 4

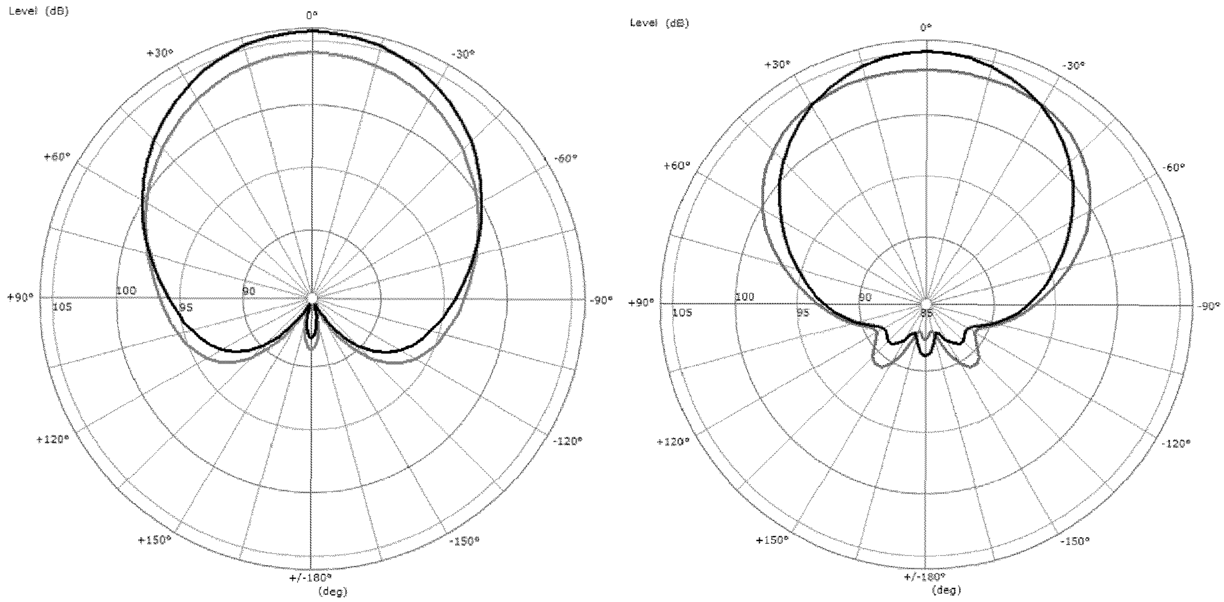
Level (dB)
0°
+30°
-30°
+60°
-60°
+90°
-90°
105
100
95
90
+120°
-120°
+150°
-150°
+/-180°
(deg)
Level (dB)
0°
+30°
-30°
+60°
-60°
+90°
-90°
105
100
95
90
85
+120°
-120°
+150°
-150°
+/-180°
(deg)

Fig. 5

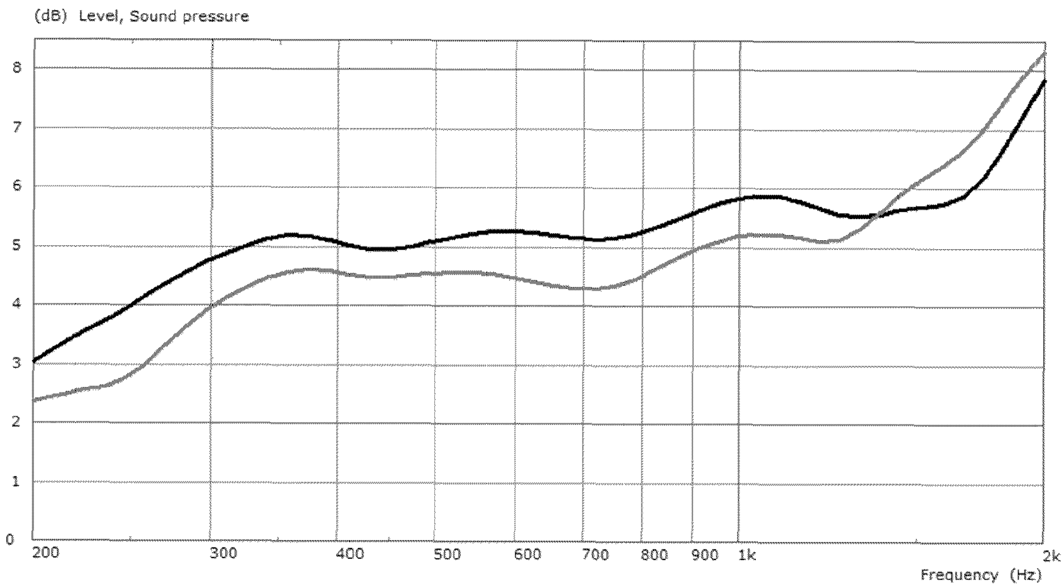
(dB) Level, Sound pressure
8
7
6
5
4
3
2
1
0
200
300
400
500
600
700
800
900
1k
2k
Frequency (Hz)

Fig. 6

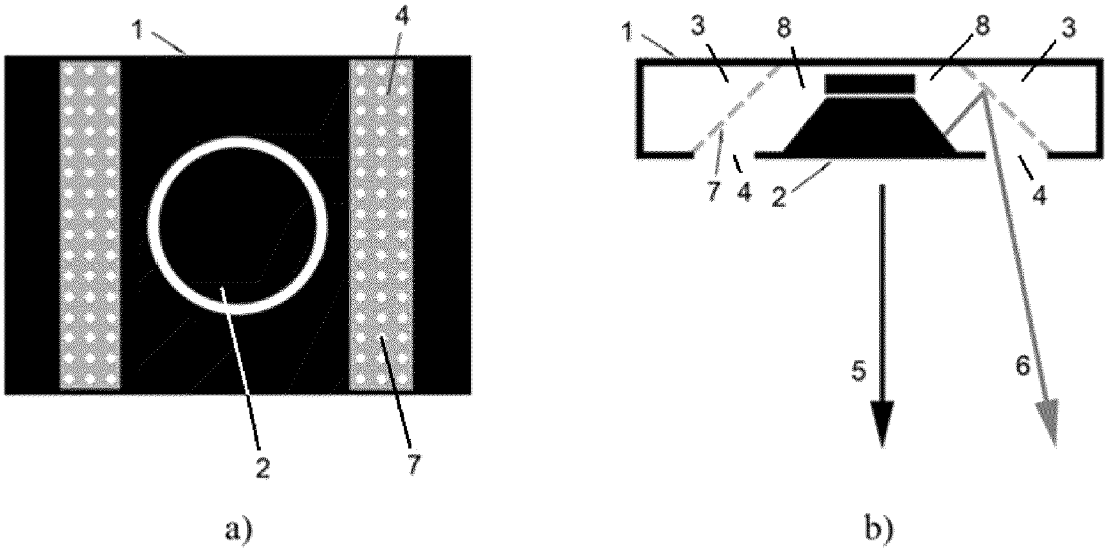
1
4
2
7
a)
1
3
8
8
3
7
4
2
4
5
6
b)

Fig. 7

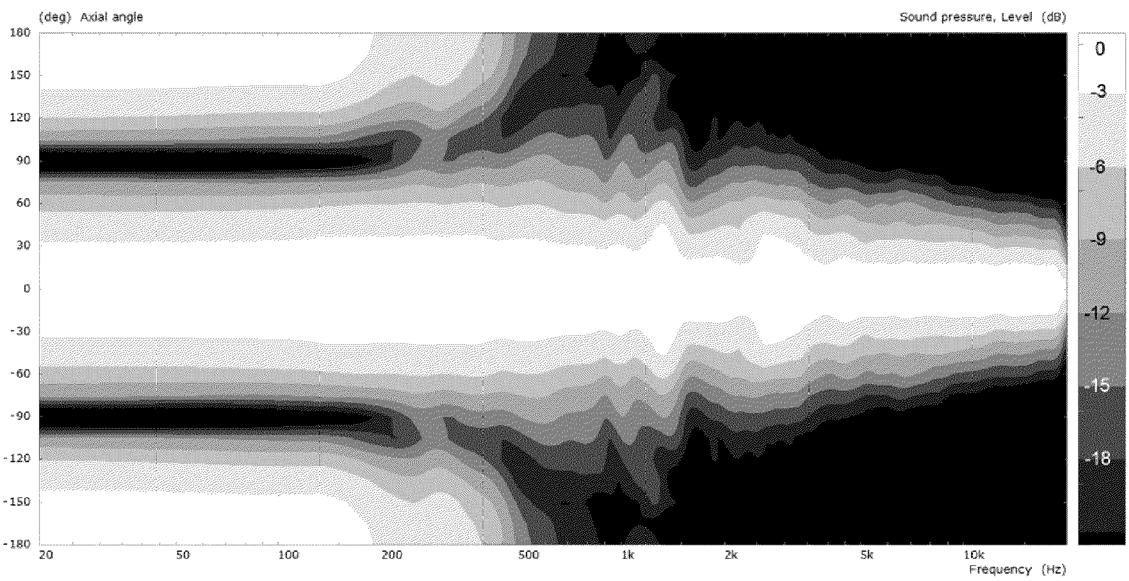
(deg) Axial angle
Sound pressure, Level (dB)
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
20
50
100
200
500
1k
2k
5k
10k
Frequency (Hz)
0
-3
-6
-9
-12
-15
-18

Fig. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 23 17 3508

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 3 696 886 A (ARMSTRONG JAMES C) 10 October 1972 (1972-10-10) * the whole document *	1-4,7,9 1-9	INV. H04R1/34 ADD. H04R1/02 H04R1/40
X	US 5 552 569 A (SAPKOWSKI MECHISLAO [VE]) 3 September 1996 (1996-09-03) * column 2, line 50 - column 5, line 42; figures 7-11 *	1-4,9	
X Y	EP 3 018 915 A1 (DUTCH & DUTCH B V [NL]) 11 May 2016 (2016-05-11) * paragraphs [0022] - [0037]; figures 1-4 *	1-4,9 1-9	
A	US 3 722 616 A (BEAVERS B) 27 March 1973 (1973-03-27) * column 2, line 48 - column 6, line 27; figures 1-8 *	1-9	

TECHNICAL FIELDS SEARCHED (IPC)

H04R

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	27 October 2023	Navarri, Massimo

CATEGORY OF CITED DOCUMENTS

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EP 23 17 3508

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27-10-2023

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 3696886	A	10-10-1972	NONE	
US 5552569	A	03-09-1996	NONE	
EP 3018915	A1	11-05-2016	NONE	
US 3722616	A	27-03-1973	NONE	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

- EP 3018915 A1 **[0007]**