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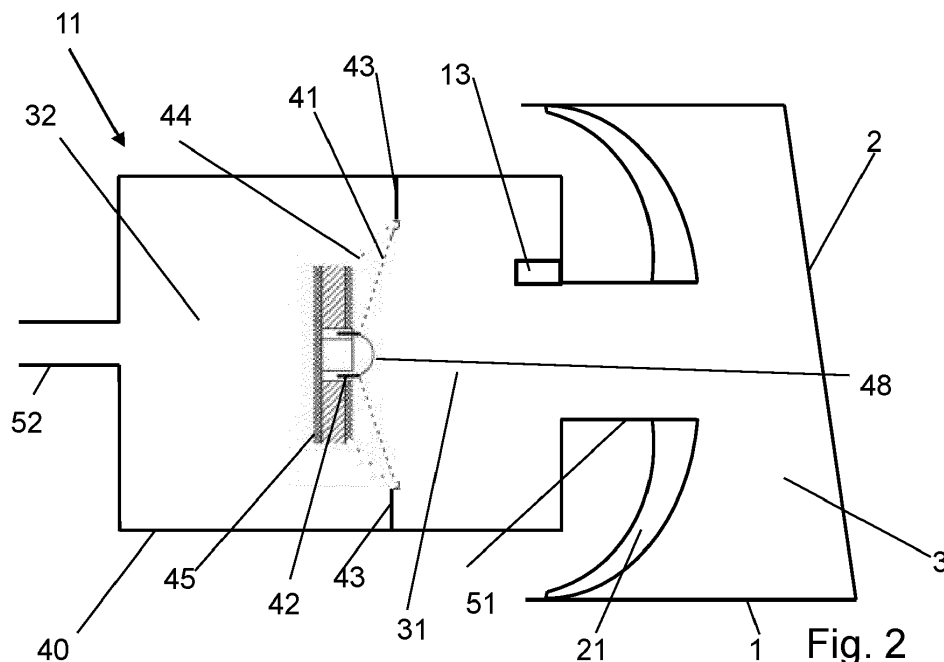
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(54) **HEARING DEVICE WITH ACTIVE NOISE CONTROL**

(57) According to the invention, a hearing device (earphone, 'hearable', earbud, earplug, hearing aid, etc.) with a moving coil speaker and with an active noise control circuit has at least one hole in the speaker membrane (41) and/or, if present, in another element of the partition between the speaker front side and the speaker back

side to which the membrane (41) belongs. Such other element of the partition may for example be a membrane frame (43) surrounding the membrane and connecting it to a housing (40) of the hearing device. The speaker back side is coupled to ambience, for example via at least one rear port (52).



Description

[0001] The invention is in the field hearing devices with active noise control.

[0002] Active noise control is the principle of reducing or suppressing unwanted sound by addition of a sound signal cancelling the unwanted sound.

[0003] Hearing devices with active noise control include devices that receive an electronic sound signal communicated wirelessly or by wire to the hearing device, especially so-called earphones or earbuds that for example couple to mobile phones or other audio devices. Sometimes, the term 'hearables' is used to designate smart earphones or earbuds. Hearing devices with active noise control also include so-called active earplugs, the primary purpose of which is to suppress noise in loud environments. Further, also hearing instruments, especially hearing aids, may include active noise control. For example, a beamformer of a hearing instrument may benefit from suppression of direct noise. Hearing aids are medical devices that help someone hard of hearing to better hear ambient sound by capturing ambient sound, processing the thus obtained signal in a frequency dependent manner, and emitting a processed and often amplified sound signal into the ear canal.

[0004] Active noise control (ANC) necessitates a good predictability and control of the sound in the ear canal. To this end, the hearing device usually has an earpiece having an acoustic sealing function and being shaped to be inserted at least partially into the ear canal to fit tightly to the ear canal ('sealed fit'). Such earpieces include both, earpieces of a standardized shape and having elasticity as well as earpieces of customized shape adapted to an ear canal of an individual user.

[0005] However, a sealed fit to the user's ear canal leads to a high occlusion and entails the risk that the membrane of the speaker of the hearing device may become biased. In hearing aids, to meet this challenge so-called 'vents' are proposed, which are basically thin tubes connecting the volume of the ear canal with the ambience. Such vents are, however, acoustic leakage paths adversely influencing the frequency response for an ANC application.

[0006] Among the common electroacoustic transducers ('speakers' or 'loudspeakers'; also called 'receivers', especially if used in hearing aids) for hearing devices having an earpiece, there are moving coil speakers and balanced armature speakers, in addition to MEMS speakers. While balanced armature speakers are popular for hearing aids for having some specific advantages, moving coil speakers feature the advantage of providing a better sound quality at least for low frequencies. Moreover, they are less costly and more robust. Also, moving coil speakers tendentially act as pressure sources and not as volume velocity sources

[0007] Moving coil speakers have the property of having a membrane that, when arranged in a housing, can be arranged to divide a volume of the housing into a front

volume, from which the sound is emitted, and a back volume. If the back volume is closed, the efficiency of the acoustic transducer is reduced, especially at low frequencies, because the membrane has to vibrate against the closed volume. Also, the low frequency sensitivity depends on the acoustic load. It therefore has already been proposed to provide the back volume with an acoustic port so that it is open to ambience. This is beneficial in view of the low-frequency efficiency and sensitivity of the transducer. However, the acoustic resonance properties of the speaker then depend strongly on the acoustic load which in turn depends on individual parameters such as the quality of the sealing between the earpiece and the ear canal as well as the ear volume of the user. Hence, both options yield an only limited predictability and invariance of the acoustic properties. For Active Noise Control, however, the predictability and invariance of the acoustic property is important.

[0008] In EP 3 849 206 it has been proposed to provide a hearing device having an acoustic transducer, for example of the moving coil type, with a resistive member between the front and back volumes, parallel to the membrane. A second resistive member is placed between the back volume and the ambience. This reduces acoustic side effects arising from acoustic resonances and hence adds to the invariance of the acoustic properties. However, the resistive members are additional elements that add to the complexity of the manufacturing process.

[0009] It is an object of the present invention to provide a hearing device overcoming drawbacks of prior art hearing devices. It is especially an object to provide an improved hearing device having an acoustic transducer being a moving coil speaker and having a microphone as well as an active noise control circuit that is configured to generate an active noise control signal, so that the electrical signal (speaker input signal) that causes the membrane to vibrate does not only depend on any received electronic sound signal but also on the signal picked up by the microphone, with the aim to suppress undesired sound waves. It is specifically an object of the present invention to provide such a hearing device in a manner that it has a low complexity paired with a high predictability of the acoustic properties. According to the invention, the hearing device (earphone, 'hearable', earbud, earplug, hearing aid, etc.) of the above-mentioned kind with a moving coil speaker and with an active noise control feedback circuit has at least one hole in the speaker membrane and/or, if present, in another element of the partition between the speaker front side and the speaker back side to which the membrane belongs. Such other element of the partition may for example be a membrane frame surrounding the membrane and connecting it to a housing of the speaker.

[0010] In addition to the hole in the partition, the speaker has the property of the back side being coupled to ambience, for example via at least one rear port.

[0011] By this approach, two problems are solved. Firstly, the path through the hole(s), due to the back side

being coupled to environment, allow for an equalization of the pressure between the front side and the back side. Thus, there cannot be any situation in which the membrane is subject to a bias due to a pressure difference. Secondly, the hole(s) ensure that the leakage path from the ear canal volume to the ambience is well-defined and predictable.

[0012] Also, small holes in a thin element (such as the membrane or a membrane frame) have an acoustical impedance having the characteristic of a resistor if they are small enough, with diameters of 0.5 mm or smaller, especially 0.4 mm or smaller. for example between 0.1 mm and 0.3 mm. An acoustic resistance leads to an acoustic damping, allowing for a mitigation of the resonance peak of the acoustic port, which resonance peak when pronounced can lead to undesired side effects in active noise control. Also, the size, number and arrangement of the hole(s) allows to engineer the acoustical impedance of the leakage path without adding substantial distortion.

[0013] Further, the approach according to the invention allows to add the controlled leakage path without there being a necessity for further elements such as dedicated resistive members.

[0014] In addition, in embodiments that do not have an additional front acoustic port (which optionally can be present in addition), the approach according to the invention provides the controlled leakage path without there having to be an additional opening in the housing of the speaker, especially without any additional opening in the region facing the inner part of the ear canal. Hence the risk of obstruction due to pollution, for example by earwax, is reduced. A front acoustic port is an acoustic port that connects the front volume to ambience.

[0015] The microphone may be an inner microphone acoustically coupled to the front volume and thereby configured to pick up sound from the ear canal volume. The active noise control circuit then will be an active noise control feedback circuit.

[0016] Alternatively, the microphone may be an outer microphone coupled to ambience and be configured to pick up ambient sound to be suppressed.

[0017] It is also possible that the hearing device comprises both, at least one outer microphone and at least one inner microphone, wherein both, the signal by the inner microphone and the signal picked up by the outer microphone may be used for noise control.

[0018] In many embodiments, the hole(s) is/are in the membrane itself. This approach features the advantage that the membrane can be dimensioned to use any available space in the speaker housing because no space is needed for an acoustic connection between the volumes in the front and in the back of the membrane. The size of the membrane has an influence on the sound quality and speaker efficiency.

[0019] In embodiments, there is not only one hole but a plurality of holes, for example at least 4 holes, at least 8 holes or at least 12 holes.

[0020] The hearing device may comprise a housing encompassing a speaker volume that is divided by the partition - i.e., the membrane and possibly a membrane frame surrounding the membrane - into a speaker front volume and a speaker back volume. The housing may comprise a rear acoustic port - or more than one rear acoustic ports that connect(s) the back volume to ambience.

[0021] There may optionally also be a connection between the front volume and the ambience, for example via a front acoustic port. However, such front acoustic port is not a requirement, due to the approach according to the invention, the front volume is anyway connected to the ambience via the perforation and the rear acoustic port.

[0022] In many embodiments, the hearing device will consist of the earpiece, i.e. all elements of the hearing device may be physically integrated in the one part (earpiece) that in use is partially or fully inserted in the ear. However, it is also possible that the hearing device in addition to the earpiece comprises a further physical element separate therefrom and for example connected by a cable or tube to the earpiece. For example, the electronic control or parts thereof may belong to such separate physical element, whereas the speaker will be integrated in the earpiece.

[0023] Especially if the hearing device consists of the earpiece by not comprising any other parts than the earpiece and if the interface (if any) is a wireless interface, the hearing device may further comprise a battery (especially a rechargeable battery) or a battery compartment. Such battery or battery compartment is optional if the earpiece is connected to another part of the hearing device, such as a behind-the-ear piece, or an external device (such as a mobile phone), via a cable.

[0024] The earpiece, to which the housing may belong, may comprise a flexible member tightly fitting to the ear canal. The flexible member then may carry the housing. It for example accommodates a spout that serves as the sound outlet and that belongs to the housing and forms a housing extension towards the ear canal volume.

[0025] The flexible member may be generic (for example by being provided in one shape and size or in a choice of shapes and/or sizes) or may be custom made. Instead of comprising a flexible member, or in addition thereto, the earpiece may have a custom shaped housing adapted to the anatomy of the person wearing it.

[0026] The hearing device may especially be an earphone or earbud and may to this end be configured to generate the electrical signal (that is converted into the sound signal by the speaker, by the membrane being set into vibration by the electric signal) depending on a received electronic sound signal. The electronic sound signal in this, in embodiments, may be an electronic representation of the sound the user is supposed to hear, whereas the feedback obtained from the inner microphone is used to deduct therefrom any undesired sound portions by adding, to the electronic sound signal when

the electrical signal is calculated by the electronic control, a signal portion that causes the membrane to produce a corresponding sound portion that negatively interferes with the undesired sound portions.

[0027] In this, the electronic sound signal may, as is known in the art, be received wirelessly or via a wired connection. The electronic control may thus comprise an according interface.

[0028] An interface for receiving an electronic sound signal from an external source may optionally be present also if the hearing device is an earplug having the primary purpose of cancelling sound, for example for persons working in a loud environment.

[0029] In addition to such interface, or as an alternative thereto, the hearing device may comprise an outer microphone equipped to pick up an ambient sound signal.

[0030] In addition to concerning a hearing device, the present invention also concerns a method of producing sound in an ear using a hearing device as described in this text by coupling the hearing device to the ear in a manner that the earpiece seals off an ear canal volume from ambience (with, of course, a path between the ear canal volume and ambience remaining through the opening(s)), emitting the sound by causing the membrane to vibrate in that an electrical signal is fed to a coil of the moving coil speaker, the coil being coupled to a central portion of the membrane and being in a magnetic field, and using a signal picked up by the microphone to influence the electrical signal so that undesired sound portions in the ear are cancelled.

[0031] The undesired sound portions correspond to noise picked up by the microphone. If the microphone is an inner microphone, there exists the option that the undesired sound portions may be, as is known per se in active noise control, sound portions picked up by the inner microphone, which sound portions do not belong to an electronic sound signal representing the wanted sound. Signal processing in a manner that sound measured in the ear canal or a difference between measured sound and wanted sound in the ear canal is minimized in a feedback control circuit is known in the art and not described in any more detail here.

[0032] In addition or as an alternative to active noise control by a feedback control circuit, the hearing device may optionally also apply feed-forward noise cancelling, for example by using an outer microphone.

[0033] Hereinafter, basic principles as well as embodiments of the invention are described referring to drawings. The drawings show:

Fig. 1 A scheme of an ear canal with a hearing device;

Fig. 2 A hearing device inserted in an ear canal;

Figs. 3-6 alternative hearing devices in an ear canal; and

Fig. 7 a pattern of openings in a speaker membrane.

[0034] Figure 1 illustrates an ear canal 1 that on one side is terminated by the tympanic membrane (eardrum) 2. An ear canal volume 3 is terminated by the eardrum 2 on one side and by a closed-fitting earpiece 10 on the other side. The closed-fitting earpiece 10 comprises a speaker 11 (electroacoustic transducer). A sound processing unit 12 feeds an (electrical) transducer input signal to the speaker 11. The sound processing unit in the depicted embodiment receives an audio signal from a remote device via a wireless interface 14 and could additionally, or alternatively, receive an audio signal from an optional outer microphone 15 picking up ambient sound, especially for example if the hearing device is a hearing aid.

[0035] The speaker 11 has a sound outlet communicating with the ear canal volume 3. An inner microphone 13 is also acoustically coupled to the ear canal volume 3 to pick up the sound in the ear canal volume, and to provide a feedback signal for an active noise control (ANC) loop to the sound processing unit.

[0036] Figure 2 shows the earpiece of the hearing device with the speaker 11 and the inner microphone 13. The speaker 11 is a moving coil speaker that is housed in a housing 40. It has a membrane 41 dividing the housing between a front volume 31 and a back volume 32. The front volume 31 connects to the ear canal volume 3 via a spout 51. the back volume connects to the ambience via a rear acoustic port 52. The rear acoustic port 52 may for example be a hole in the rear housing, optionally provided with a mechanical protection element, and/or may comprise a rear spout or other access to the rear volume.

[0037] The earpiece comprises a flexible member 21 that fits tightly to the ear canal and carries the housing 40 by accommodating the spout 51 in an interior passage. The flexible member is of the acoustically untransparent 'closed fitting' kind, i.e. it substantially closes off any passage between the ear canal volume and ambience except possibly via the spout 51 and the speaker as described in more detail hereinafter.

[0038] In the depicted embodiment, the inner microphone 13 is illustrated to be arranged within the speaker's front volume 31. This, however, is not a requirement. Rather the inner microphone 13 could also be arranged elsewhere in communication with the ear canal volume 3, for example via a separate access port in the flexible member 21 or in the spout 51 (c.f. Fig. 6) or in the inner part of the housing 40.

[0039] The speaker has a moving coil driver 45 - comprising a magnet - held by a support structure, also called basket 44. The basket 44 is open in that it comprises a plurality of through openings, as is known for many moving coil speakers, i.e. acoustic waves generated on the backside of the membrane can get through the basket in to the remaining part of the rear volume. The membrane 41 - and for example also the basket 44 - is/are held by

a membrane frame 43 that in the depicted embodiment serves as a part of the partition and divides the volume inside the housing into the front volume and the rear volume together with the membrane (to be very precise, in addition to the membrane frame 43 and the membrane 41, also any protective cover (dust cap) of the speaker, if present, belongs to the partition. In the depicted embodiments, the membrane has a vaulted central part 48; however, in alternative embodiments the membrane may have a central hole, sealed off by a protective cover).

[0040] The membrane 41 has a plurality of holes between the speaker front side and the speaker back side, i.e. the front side volume and the back side volume are connected by the holes in the membrane. The holes are comparably small piercing holes.

[0041] In the variants of **Figures 3 and 4**, the holes are provided in the membrane frame 43 instead of in the membrane, and in both, the membrane 41 and the membrane frame 43, respectively. In the embodiment of Fig. 3 with the holes being only in the membrane frame, the basket 44 can optionally be closed.

[0042] The embodiment of **Figure 5** comprises a plurality of the rear acoustic ports 52.

[0043] The embodiment of **Figure 6** comprises in addition to the rear acoustic port 52 also an optional front acoustic port 55. Thereby, the hearing device has, in addition to the controlled acoustic leakage path via the holes in the membrane and/or the membrane frame, a further controlled acoustic leakage path from the ear canal volume 3 to ambience via the front acoustic port 55. While such front acoustic port may, depending on its placement, have the disadvantage of being exposed to possible staining in the ear canal, it may nevertheless in embodiments be desired, for example to influence the frequency dependence of the overall leakage, to avoid undesired resonances, etc.

[0044] **Figure 7** shows, for embodiments having the holes 45 in the membrane 41, a possible distribution of the holes. As can be seen in Fig. 7, the holes 45 can for example be essentially uniformly distributed across the surface of the membrane, for example by being arranged in approximately equal distances on concentric circles. Alternative arrangements, for example grid-like or similar, are also possible.

[0045] In any case, in embodiments it may be advantageous if the number of holes is greater than one, for example at least 4, at least 8 or even at least 12.

[0046] The holes may in embodiments be manufactured by laser cutting/laser punching or by laser piercing.

Claims

1. A hearing device, comprising

- an earpiece configured to be at least partially inserted into an ear canal (1);
- a moving coil speaker (11) accommodated by

the earpiece, the moving coil speaker having a speaker front side and a speaker back side divided by a partition that comprises a membrane (41);

- an electronic control (12) configured to generate an electrical signal that causes the membrane (41) to be subject to a vibration;
- wherein a front volume (31) on the speaker front side connects to a sound outlet (51) of the earpiece,
 - whereby the hearing device is configured to release sound generated by the vibration of the membrane (41) into an ear canal volume (3) via the sound outlet;
- at least one microphone (13);
- wherein the electronic control (12) comprises an active noise control circuit connected to the at least one microphone (13) and configured to generate the electrical signal dependent on a signal obtained from the at least one microphone (13);

characterized in that the partition has at least one hole (45) connecting the speaker front side with the speaker back side, and **in that** the speaker back side is coupled to ambience.

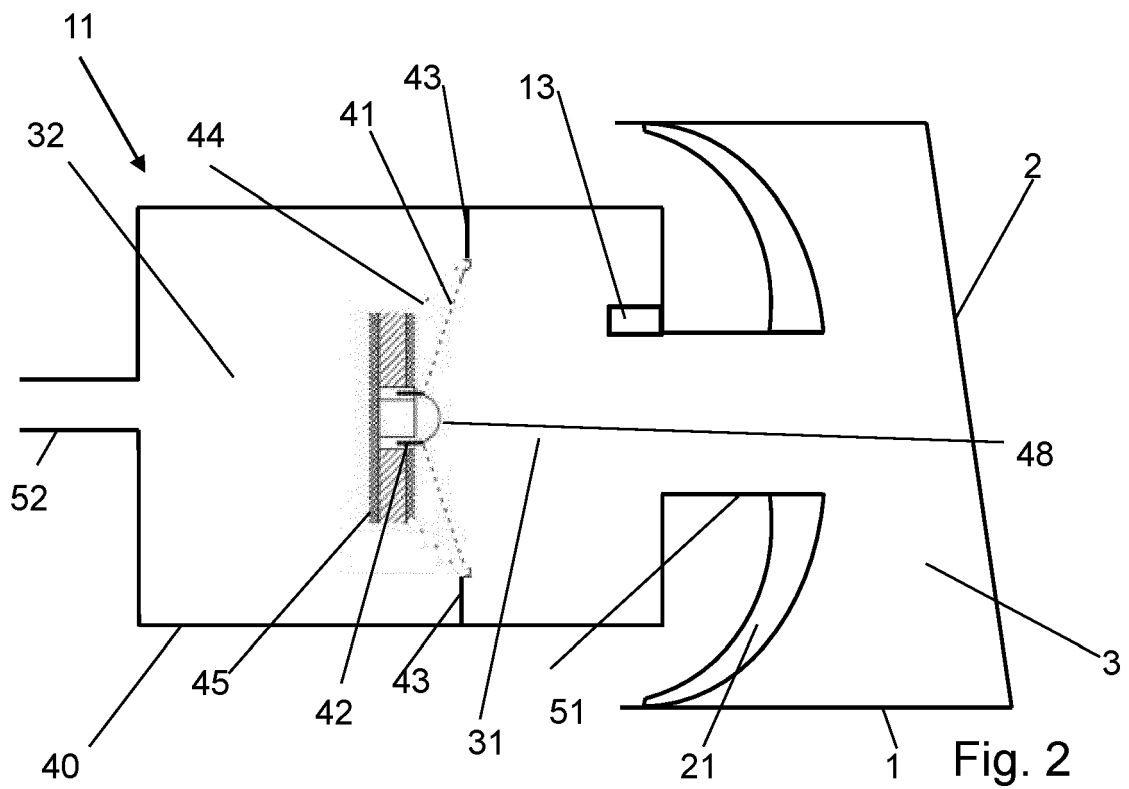
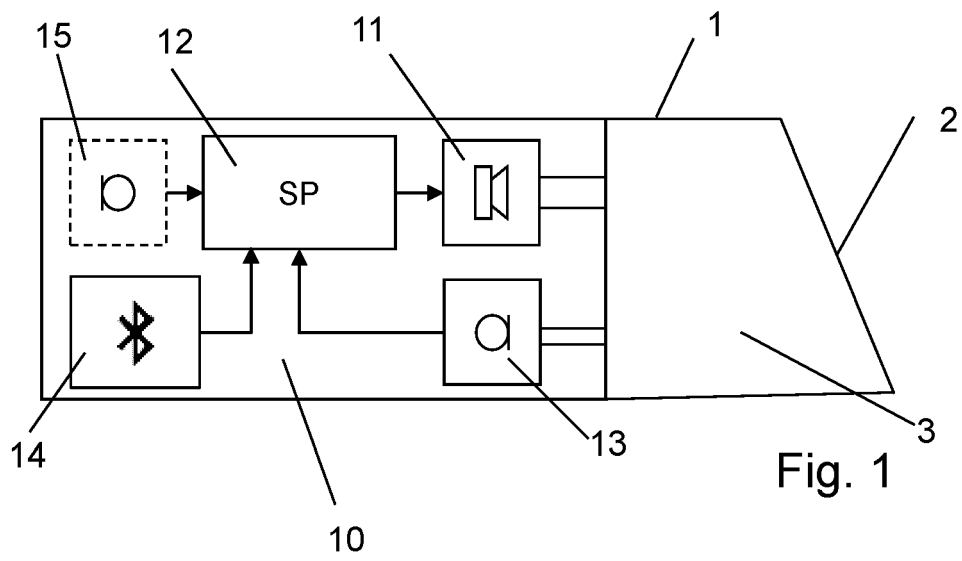
2. The hearing device according to claim 1, wherein the membrane (41) has a plurality of the holes (45).
3. The hearing device according to claim 1 or 2, wherein the partition comprises a membrane frame (43) surrounding the membrane, and where at least one of the holes is in the membrane frame.
4. The hearing device according to claim any one of the previous claims, wherein the number of the holes (45) is at least 4.
5. The hearing device according to any one of the previous claims, wherein the at least one microphone comprises an inner microphone (13) acoustically coupled to the front volume (31), and wherein the active noise control circuit comprises an active noise control feedback circuit.
6. The hearing device according to any one of the previous claims, wherein the at least one microphone comprises an outer microphone acoustically coupled to ambience.
7. The hearing device according to any one of the previous claims, wherein the hearing device has a housing (40) encompassing a speaker volume, wherein the speaker volume is divided by the partition into the front volume (31) and a back volume (32), wherein the back volume connects to ambience via at least one a rear acoustic port.

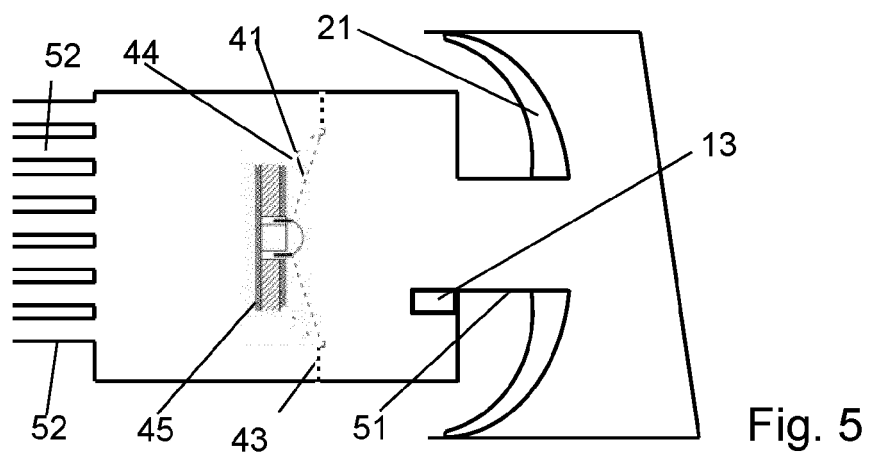
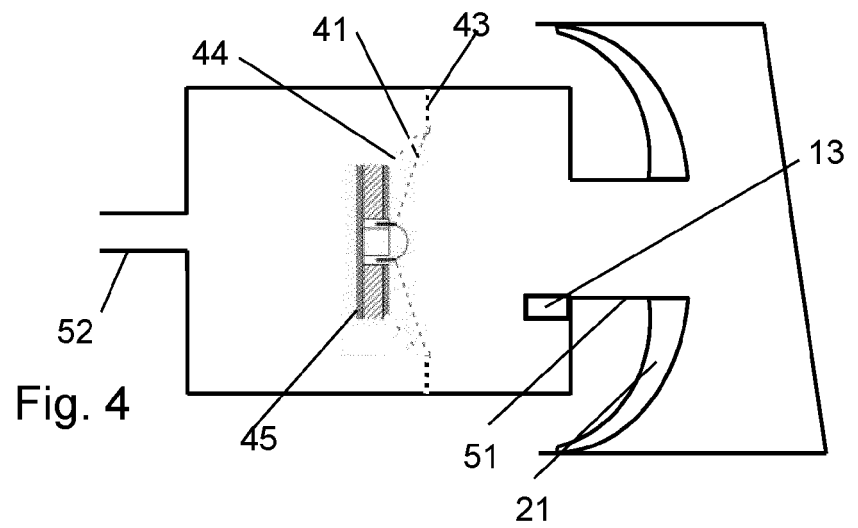
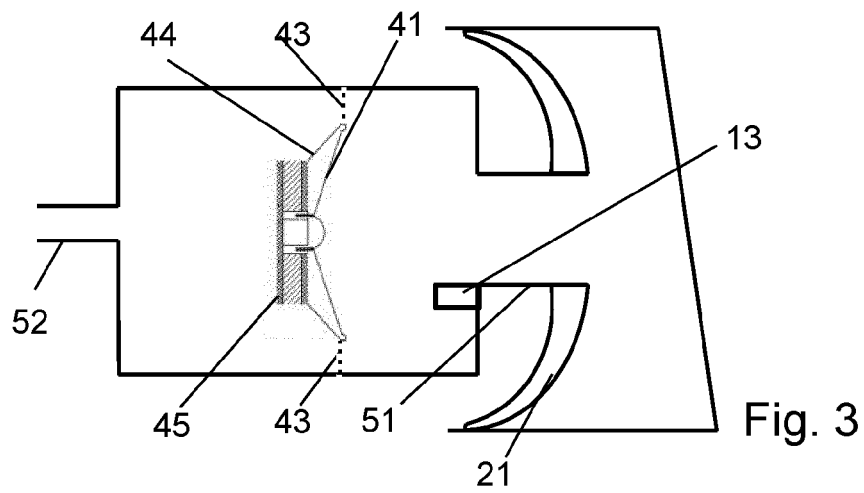
8. The hearing device according to any one of the previous claims, further comprising a front acoustic port (55) connecting the speaker front volume (31) with the ambience. 5
9. The hearing device according to any one of the previous claims, wherein the earpiece comprises a flexible member (21) configured to fit tightly to the ear canal (1), the flexible member carrying the speaker and having a central passage through which the sound outlet (51) extends. 10
10. The hearing device according to any one of the previous claims, wherein the electronic control comprises an interface (14) for receiving an electronic sound signal, wherein the electronic control is configured to generate the electrical signal from the electronic sound signal and from the feedback. 15
11. The hearing device according to any one of the previous claims, wherein the at least one hole is a hole manufactured by piercing. 20
12. The hearing device according to claim 11, wherein the hole is a hole made by laser piercing. 25
13. The hearing device according to any one of the previous claims being an earphone.
14. A method of producing sound in an ear using a hearing device as claimed in any one of the previous claims, the method comprising the steps of providing the hearing device, coupling the hearing device to the hear in a manner that the earpiece seals off an ear canal volume (3) from ambience, emitting the sound by causing the membrane (41) to vibrate in that the electrical signal is fed to a coil of the moving coil speaker, the coil being coupled to a central portion of the membrane (41) and being in a magnetic field, and using the signal picked up by the microphone (13) to influence the electrical signal so that undesired sound portions in the ear are cancelled. 30 35 40

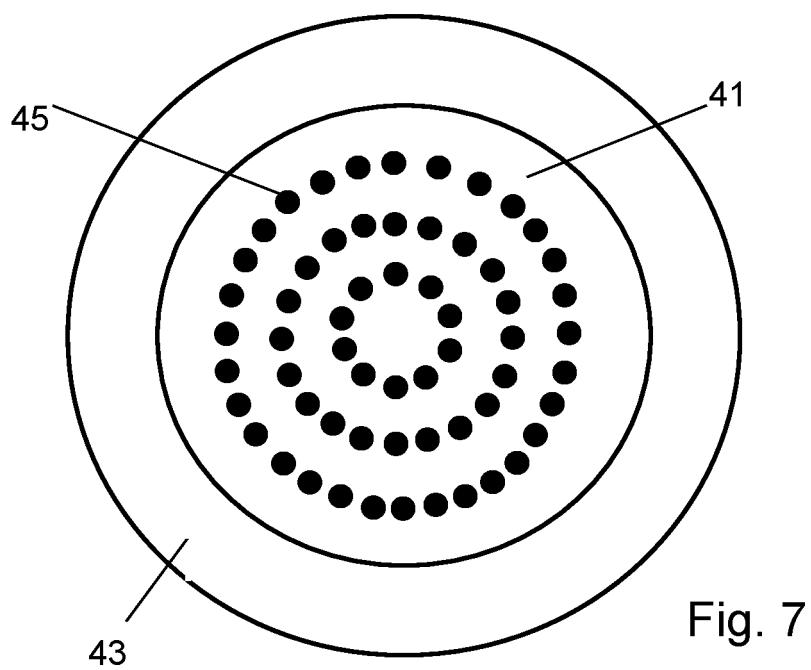
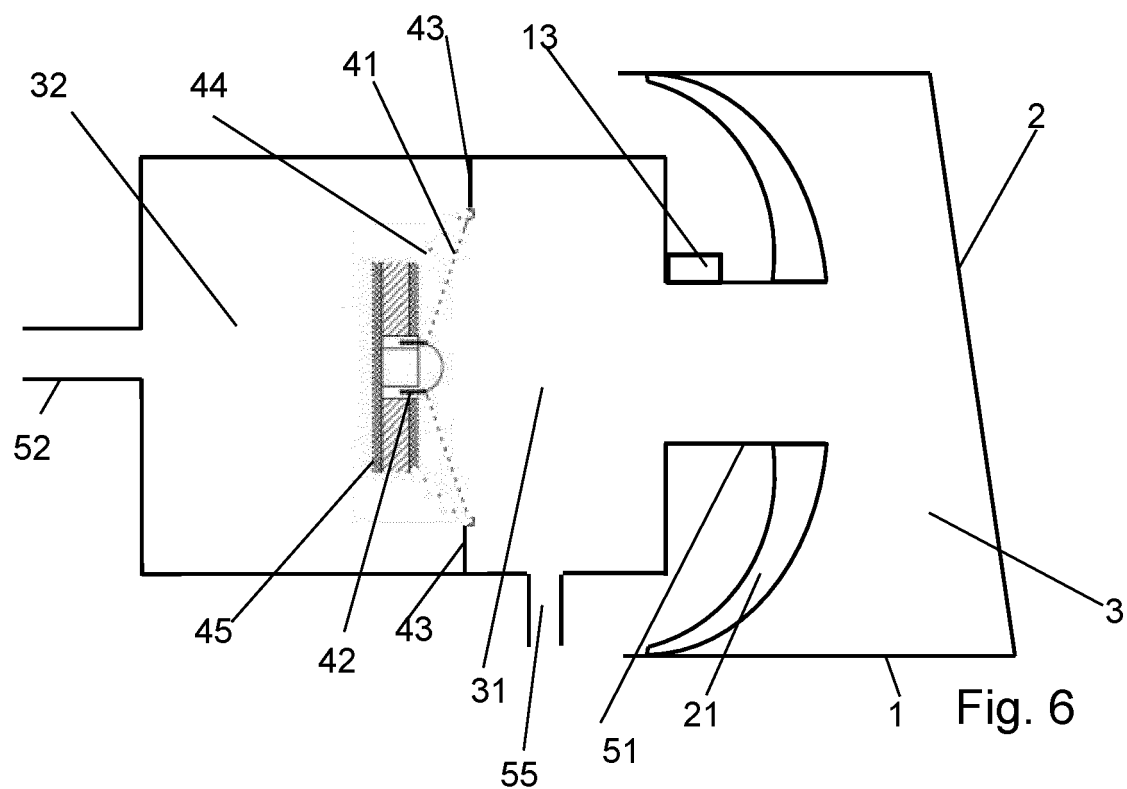
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EUROPEAN SEARCH REPORT

Application Number

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EPO FORM 1503 03.82 (P04C01)

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, D	EP 3 849 206 A1 (SONOVA AG [CH]) 14 July 2021 (2021-07-14)	1, 3-14	INV. H04R1/10
Y	* figures 7-10 * * paragraph [0020] * * paragraphs [0030], [0031], [0034] * * paragraph [0037] * * paragraph [0043] * * paragraph [0070] * * paragraph [0084] *	2	H04R1/28
Y	WO 2019/018549 A1 (SHURE ACQUISITION HOLDINGS INC [US]) 24 January 2019 (2019-01-24)	2	
A	* figure 6 * * paragraph [0039] *	1, 3-14	
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			H04R
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 27 July 2022	Examiner Moscu, Viorel
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 22 15 7257

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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REFERENCES CITED IN THE DESCRIPTION

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