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(54) **EARPHONE**

(57) An earphone includes a housing having a cup-like shape and comprising a bottom wall and a circumferential sidewall, the bottom wall and the sidewall encompassing an open chamber, the chamber being closed when the earphone is worn over an ear of a user. The earphone further includes a low-frequency loudspeaker mounted to the bottom wall and configured to radiate low-frequency sound into the chamber, and a front array of at least three high frequency loudspeakers mounted to the sidewall and configured to radiate high-frequency sound

into the chamber, the front array being disposed adjacent to the rostral end of the ear when the earphone is worn over the ear of the user. The bottom wall and the sidewall are made from or comprise sound absorbing material adjacent to the chamber. The low-frequency loudspeaker and the high-frequency loudspeakers are configured to receive one electrical signal to be acoustically reproduced. A headphone includes two such earphones, each earphone being supplied with at least one signal to be reproduced.

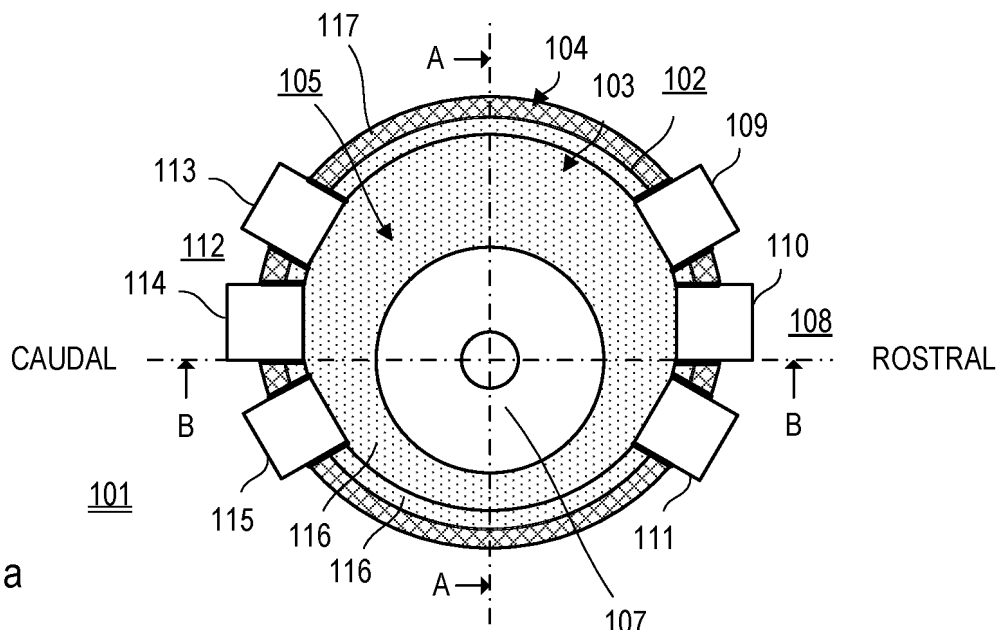


FIG 1a

EP 4 478 735 A1

Description

BACKGROUND

1. Technical Field

[0001] The disclosure relates to an earphone.

2. Related Art

[0002] Conventional headphones use a single, large loudspeaker mounted parallel to a plane defined by the ear's pinna, aiming at acoustically bypassing the pinna. Headphones of this type require diffuse-field equalization or a similarly derived "target function", usually determined by a standard coupler or artificial ear, and exhibit low timbral distortion, but they fail to eliminate in-the-head localization of sound images, and exhibit poor, mostly elevated center images in a stereo panorama. Some designs propose multiple transducers built into or in the proximity of the main baffle. This makes, in particular, rear sound difficult to render because the transducers are located behind the pinna and are therefore obstructed. It is desirable to design headphones that reduce, or even better overcome, the drawbacks outlined above.

SUMMARY

[0003] An earphone includes a housing having a cup-like shape and comprising a bottom wall and a circumferential sidewall, the bottom wall and the sidewall encompassing an open chamber, the chamber being closed when the earphone is worn over an ear of a user. The earphone further includes a low-frequency loudspeaker mounted to the bottom wall and configured to radiate low-frequency sound into the chamber, and a front array of at least three high frequency loudspeakers mounted to the sidewall and configured to radiate high-frequency sound into the chamber, the front array being disposed adjacent to the rostral end of the ear when the earphone is worn over the ear of the user. The bottom wall and the sidewall are made from or comprise sound absorbing material adjacent to the chamber. The low-frequency loudspeaker and the high-frequency loudspeakers are configured to receive an electrical signal to be acoustically reproduced.

[0004] A headphone includes two such earphones, each earphone being supplied with at least one signal to be reproduced.

[0005] Other apparatuses, features and advantages will be, or will become, apparent to one with skill in the art upon examination of the following detailed description and appended figures. It is intended that all such additional apparatuses, features and advantages be included within this description, be within the scope of the invention, and be protected by the following claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The system can be better understood with reference to the following drawings and description. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. Moreover, in the figures, like referenced numerals designate corresponding elements throughout the different views.

Figure 1a is cross-sectional front view of an example earphone having a low-frequency loudspeaker and a rear and front array of high frequency loudspeakers radiating sound into an anechoic chamber.

Figure 1b is cross-sectional side view of the earphone shown in Figure 1a.

Figure 1c is cross-sectional top view of the earphone shown in Figure 1a.

Figure 2 is three-dimensional front-top view of an example shell employed in the earphone shown in Figures 1a-1c.

Figure 3 is a circuit diagram illustrating the electrical connections of a front array and a rear array in the earphone shown in Figures 1a-1c.

Figure 4 is an amplitude vs. frequency diagram illustrating frequency responses of a raw front array with and without chamber damping.

Figure 5 is an amplitude vs. frequency diagram illustrating frequency responses of test loudspeaker for determining a head-related transfer function (HRTF) before and after equalization.

Figure 6 is an amplitude vs. frequency diagram illustrating in-room measured near-field head-related transfer functions and the average thereof at an angle of 45° ipsilateral.

Figure 7 is an amplitude vs. frequency diagram illustrating the average of in-room measured near-field head-related transfer functions at an angle of 135° ipsilateral.

Figure 8 is an amplitude vs. frequency diagram illustrating frequency responses of measured ipsilateral and contralateral head-related transfer functions, the difference thereof and an approximation of a cross-feed function based thereon.

Figure 9 is an amplitude vs. frequency diagram illustrating frequency responses of an example high-frequency loudspeaker with and without equalization, and the frequency response of the equaliza-

tion filter employed for equalization.

Figure 10 is an amplitude vs. frequency diagram illustrating frequency responses representative of the chamber and head diffraction equalization.

Figure 11 is an amplitude vs. frequency diagram illustrating frequency responses of the low-frequency loudspeaker, front array of high-frequency loudspeakers, cross-over filters, equalization filter and a combination thereof before and after equalization in view of a target function.

Figure 12 is an amplitude vs. frequency diagram illustrating combined frequency responses of the low-frequency loudspeaker, rear array of high-frequency loudspeakers, cross-over filters, and equalization filter after equalization in view of the target function.

Figure 13 is an amplitude vs. frequency diagram illustrating room impulse responses at positions front left, front right, rear left and rear right.

Figure 14 is a block diagram illustrating the signal processing structure supplied with the stereo signal to be reproduced and connected upstream of the low-frequency loudspeaker and the array of high-frequency loudspeakers.

DETAILED DESCRIPTION

[0007] Electroacoustic transducers of any kind that convert electrical audio signals into corresponding sound are herein referred to as loudspeakers. Electroacoustic transducers of any kind that convert sound into corresponding electrical audio signals are referred to as microphones. High frequency loudspeakers are loudspeakers that are operated in an upper frequency band of an audio spectrum to be reproduced while low frequency loudspeakers are operated in a lower frequency band of the audio spectrum. The upper and lower frequency bands may overlap or be next to each other with no gap between them. An anechoic (non-reflective) chamber is a room designed to significantly reduce or stop reflections of sound. An earphone is understood to be assigned to one ear and a headphone includes two earphones and, accordingly, is assigned to two ears, possibly with specific left/right adaptations of the earphones. Frequency responses are depicted herein using amplitude A [dB] vs. frequency f [Hz] graphs. Auralization is a procedure designed to model and simulate the experience of acoustic phenomena, rendered as a soundfield in a virtualized space. Auralization is used, for example, to configure the soundscape of architectural structures, concert venues, and public spaces, as well as to make coherent sound environments within virtual immersion systems.

[0008] Disclosed herein is an earphone, in which a low-frequency loudspeaker and a front array of (e.g., miniature) high-frequency loudspeakers are built into the wall of a miniature acoustic anechoic chamber established by an acoustically damped housing and the head around a user's ear. Such an arrangement allows the elimination of undesired reflections, a more accurate, unobstructed inclusion of pinna features at the correct angle of arriving sound, and a better controlled timbre and sound quality. Optionally, a rear array of (e.g., miniature) high-frequency loudspeakers provides surround sound rendering and playback of pre-captured acoustic environments, known as "auralization". The high-frequency portion of the wearers head-related transfer function (HRTF) is, by design, part of the headphone's acoustic transfer function. The remaining HRTF features such as head shadowing, inter-aural time delay, and head diffraction can be easily personalized with simple parametric filters. Instead of a commonly used diffuse-field equalization or a similarly derived target function, a binaural, head-related target function may be optionally applied.

[0009] An exemplary earphone 101 illustrated in Figures 1a (cross-sectional front view), 1b (cross-sectional side view) and 1c (cross-sectional top view) includes a cup-shaped housing 102 that has a circular (or any other appropriate shape) bottom wall 103 and a circumferential sidewall 104. The housing 102 encompass a chamber 105 that is open at a top side 106 opposite to the bottom wall 103. However, the chamber 105 is closed when the earphone 101 is worn over an ear of the user (not shown). Accordingly, the top side 106 of the earphone 101 touches the user's head around the ear.

[0010] The earphone 101 further includes a low-frequency loudspeaker 107 mounted to the bottom wall 103, e.g., fitted into an opening (not shown) in the bottom wall 103 and fixed thereto by adhesive, screws, clamps etc. The low-frequency loudspeaker 107 is configured and positioned to radiate unhindered (e.g., by absorbing material) low-frequency sound into the chamber 105, and, for example, straight into the user's ear canal when the earphone is worn over an ear. The low-frequency loudspeaker 107 may be, for example, a conventional headphone driver having a diameter of 40 to 50 mm.

[0011] A front array 108 of three (or more) high-frequency loudspeakers 109, 110, 111 is mounted to the sidewall 102 adjacent to the rostral end of the ear when the earphone 101 is worn over the ear of the user (not shown in Figures 1a-1c). Further, the front array 108 is configured, e.g., positioned, to radiate unhindered high-frequency sound into the chamber 105 and to the pinna from a rostral direction. The three high-frequency transducers 109, 110, 111 of the front array 108 may each have a diameter of 14 to 18 mm. The high-frequency loudspeakers 109, 110, 111 may each be placed away from the ear at an angle α of between 25° and 35°, e.g., 30° from a horizontal line in a rostral direction starting from the position of the ear canal entrance 119 when the earphone is worn. Such placement of the high-frequency

loudspeakers 109, 110, 111 corresponds to the common position of a loudspeaker of a stereo setting in a listening room.

[0012] Optionally, a rear array 112 of three (or more) high-frequency loudspeakers 113, 114, 115 is mounted to the sidewall 102 adjacent to the caudal end of the ear when the earphone 101 is worn over the ear of the user (not shown). Further, the rear array 112 is configured and positioned to radiate unhindered high-frequency sound into the chamber 105 and to the pinna from a caudal direction. The high-frequency transducers 113, 114, 115 of the rear array 112 may each have a diameter of 14 to 18 mm. Each of the high-frequency loudspeakers 113, 114, 115 may be placed away from the ear at an angle of between 25° and 35°, e.g., 30° from a horizontal line in a caudal direction starting from the position of the ear canal entrance 119, which is in the opposite direction (not shown in Figure 1c) from that described above in connection with loudspeakers 109, 110, 111. Such positioning of the high-frequency loudspeakers 109, 110, 111 corresponds to the common position of the rear loudspeakers of a multi-channel loudspeaker setting in a listening room.

[0013] The bottom wall 103 and the sidewall 102 are made from or comprise sound absorbing material, e.g., comprise a sound-absorbing layer 116 on the inside of the housing adjacent to the chamber 107. The space along the sidewall 102 and bottom wall 103 between the low-frequency loudspeaker 107, high-frequency loudspeakers 109, 110, 111 of the front array 108 and high-frequency loudspeakers 113, 114, 115 of the rear array 112 may be layered or padded with damping material such as, for example, polyester wool, sheep wool or properly tuned meta-material. However, the absorbing material is disposed in manner so as not to damp the direct radiation from a respective loudspeaker to the ear. The resulting compartment can be viewed as a miniature "anechoic" chamber, i.e., acoustically non-reflective room.

[0014] The earphone shown in Figures 1a-1c is adapted to be used on the user's left ear. In an earphone that fits to the right ear, the positions of the front and rear arrays are interchanged (complementary) compared to the left-ear earphone. Otherwise the structure of such earphone is the same as shown in Figures 1a-1c.

[0015] Some or all loudspeakers 107, 109, 110, 111, 113, 114, 115 may be open at their rear sides and may be protected by rigid caps with or without vents. Figures 1b and 1c show only a cap 118 with a vent 119 used in connection with the low-frequency loudspeaker 107, but optional caps for the high-frequency loudspeakers may be similar.

[0016] A three-dimensional illustration of a part of the housing 102, including the bottom wall 103 and the sidewall 104 but without the sound-absorbing layer 116, is shown in Figure 2. The part shown in Figure 2 is the rigid shell 117, which is here a one-piece structure to which sound absorbing material forming a layer (both not

shown in Figure 2) can be adhered on its inner surface. Holes 201-206 in the bottom wall 103 and sidewall 102 allow mounting of the loudspeakers 109, 110, 111, 113, 114, 115. The positions of the high-frequency loudspeaker 109, 110, 111 of the front array 108 are such that, in a horizontal plane 210 that expands away from an ear canal entrance 208, a line 209 between the ear canal entrance 208 and the position of the loudspeaker 114 (represented by hole 206) forms an angle of 30° to a line 207 that extends from the caudal end to the rostral end of the ear and intersects the ear canal entrance 208. The holes 201-204 and 206 representative of the positions of the high-frequency loudspeakers 109, 110, 111, 113, 114 and 115 are disposed correspondingly.

[0017] Referring to Figure 3, the high-frequency loudspeakers 109, 110, 111 of the front array 108 or the high-frequency loudspeakers 113, 114, 115 of the rear array or each of arrays 108 and 112 may be electrically connected in series to form a short (curved) line array to improve the incoming wave shape when the wave shape resembles a plane wave from a far field source.

[0018] A raw frequency response of the front array 108, i.e., a frequency response obtained without using damping material and equalization filters while wearing the earphone, is depicted in graph 401 in Figure 4. The frequency response was measured with an in-ear microphone such as a custom molded, blocked-ear-canal microphone. The identically obtained frequency response using a layer of damping material is depicted in graph 402.

[0019] As already mentioned, conventional headphones with a single, large transducer mounted parallel to the ear require diffuse-field equalization or a similarly derived "target function", usually determined by a standard coupler or artificial ear. Instead of this, the earphone presented herein allows for an out-of-the-head localization of sound images, and creates rich center images in a stereo panorama by applying, e.g., a binaural, head-related target function (target function pair in the case of a headphone). Such a target function (pair) can be determined in a normal listening room or an anechoic chamber with a test (broadband) loudspeaker, which must be small enough to qualify as a point source in the frequency band of interest (up to 10 KHz). The frequency response of an example (broadband) test loudspeaker having an operating frequency band of 50 Hz to 20 kHz and a size of 45 mm by 50 mm is shown in Figure 5 in graph 501. Deviations from a flat response that results from a high-frequency membrane breakup can be equalized by a (digital) filter as depicted in graph 502.

[0020] Initially, the custom molded test microphone is disposed in a manner so as to block the ear canal, and the test loudspeaker is positioned at a sufficiently large distance (0.5 to 1 meter) in the far field, at ear height, and at angles such as, for example, +/-30°... 45°; +/-135°, which correspond to the angles of a stereo loudspeaker pair or rear surround loudspeakers, respectively. The frequency

responses are then measured at the "ipsilateral" ear (facing the speaker), as well as the "contralateral" ear (opposite side). Figure 6 shows ipsilateral responses (multiple fine lines 601) at 45° with multiple repositioning of the test loudspeaker, and their average as bold line 602. The responses were shown to be consistent and reproducible. Figure 7 shows respective responses 701 for the rear angle 135°. The frequency responses 701 are used as target functions for earphone equalization filters.

[0021] Figure 8, at the bottom, shows a graph 801 representing the ipsilateral frontal target from Figure 6, graph 501, together with a graph 802 representing the contralateral response. The contralateral frequency response, which may be implemented as a cross-feed filter, is the difference between the respective logarithmic-magnitude functions and is shown in Figure 8, graph 803. It may be approximated by a second-order shelving filter whose frequency response is depicted in graph 804. The inter-aural delay may be implemented as a frequency-independent pure delay of, e.g., 3...5 milliseconds as shown in the signal processing block diagram shown in Figure 14.

[0022] To approximate the target functions set out in Figures 6 and 7, equalization filters may be employed. The equalization filters may be implemented as a cascade of second order infinite impulse response (IIR) filters (also known as "biquad filters" or short "biquads") that include driver equalization, as shown in Figure 9, and chamber equalization, as can be seen from Figure 10, graph 1003.

[0023] The frequency responses of the high-frequency loudspeakers 109, 110, 111 (and optionally 113, 114, 115) were pre-measured in an open baffle in order to obtain data that form the basis for designing an equalization filter. Figure 9 shows graphs 901, 902, representing the frequency responses of an example high-frequency loudspeaker before (901) and after (902) equalization, using an equalization filter. The employed equalization filter, a biquad filter, exhibits the equalization filter response depicted in graph 903 in Figure 9. The earphone may be operated as a sealed pressure chamber when worn, leading to a significant amplitude increase below 1 KHz, as can be seen from the raw responses of the front array without (graph 401) and with (graph 402) the chamber damping (sound absorbing layer) shown in Figure 4.

[0024] The earphone may be equalized by three low-shelving filters (implemented as biquads) for head diffraction equalization, the frequency responses of which are depicted in Figure 10 in graphs 1001, 1002, 1003. One of filters performs a bass boost as depicted by graph 1001. The combined frequency response of the three low-shelving filters is shown in graph 1004 in Figure 10. To further approximate the target functions set out in Figures 6 and 7, an equalization filter may be employed that provides head diffraction equalization as depicted in Figure 10, graph 1005. Part of every head-related transfer function is a significant amplitude increase around 3 KHz resulting from head diffraction. The equalization

filter may be implemented using a single biquad filter, operated as a peak filter. For personalization, filter parameters may be included in a user interface to be individually adjusted.

[0025] Reference will now be made to Figure 11, which illustrates a summary of the equalization process. In the top diagram of Figure 11, graph 1101 depicts the frequency response of the low frequency loudspeaker and graph 1102 depicts the frequency response of the high-frequency loudspeaker front array. Further, a crossover filter such as, e.g., a 3rd order Chebyshev filter, is employed to split an input signal (signal to be reproduced) into a signal for the low-frequency loudspeaker (see frequency response graph 1103) and a into a signal for the high-frequency loudspeaker array (see frequency response graph 1104), resulting in the combined response shown in the second from top diagram in graph 1105. Graph 1106 depicts in the third diagram the frequency response of the combined equalization, including the above-mentioned three components. The final response is shown in graph 1107 in the bottom diagram, along with the frequency response of the target function depicted in graph 1108.

[0026] The same or a similar course of action is taken to approximate the rear target function which results in the frequency response shown in graph 1201 of Figure 12. The equalization filters may be of low order, both in order to leave the fine details of the frequency response above 5 KHz uncorrupted and to provide a design that is "cue-preserving", which means individual features of the pinna remain part of the acoustic path. The target function is represented by frequency response graph 1202 in Figure 12.

[0027] Accordingly designed headphones can render stereo recordings in front of the head with correctly depicted phantom images as intended by the sound producers. However, most studio recordings use multiple microphones disposed close to the instruments and containing insufficient distance cues, such as early reflections or reverberations, of the recording space. Playback over loudspeakers usually causes sound images which have little depth to appear between the speakers, and accordingly, creates images very close to the head when listening through the 3D headphones. However, there are exceptions to this, such as when certain classical music, or jazz recorded in a natural environment with distant microphones, is played back.

[0028] To fully render a loudspeaker stereo setup via headphones, the acoustic properties of the listening room may be included in the signal processing paths, generally referred to as "auralization". Auralization is used, for example, in architectural acoustics or automotive acoustics, to directly compare different audio scenarios with a reference room. However, the binaural recording device commonly used in connection with auralization to capture listening room acoustics, e.g. a dummy head or an in-ear microphone, fails here because the headphones described above already incorporate bi-

naural features, which would thus appear twice in the acoustic processing path. A good option is a first order Ambisonics microphone, which uses cardioid capsules oriented in four room directions (front left up, front right down, back left down, back right up). Such a device generates an Ambisonics "A-Format" to be converted, using a matrix, into "B-Format", which includes ± 1 coefficients and EQ filters as described, for example, in Franz Zotter, Matthias Frank, "Ambisonics, A practical 3D audio theory". Springer Topics in Signal Processing, Vol. 19, 2019. The B-Format contains four cartesian room signal components (W, X, Y, Z) that can be recombined to a "decoded" signal H with a first order cardioid microphone characteristic that points into a desired room direction. In the horizontal plane, only (W, X, Y) is required: $H = aW + X \cos \varphi + Y \sin \varphi$, wherein "a" is a scaling factor for the omnidirectional component W and may be used to adjust the polar characteristic, and φ is the desired angle. Typical room impulse responses obtained with this method are shown in Figure 13 for the angles $\pm 45^\circ$ (Left/ Right), and $\pm 135^\circ$ (Left Surround Channel/ Right Surround Channel). They may be applied directly at the input of the signal processing chain.

[0029] Illustrated in Figure 14 is an example stereo (left channel, right channel) signal processing chain for a headphone 1427 with two complementary earphones 1425 and 1426, which are designed as shown in Figure 1. Two stereo signals 1401 (Right Channel) and 1402 (Left Channel) are first processed by optional auralization stages 1403, 1404 which provide auralization without binaural effects (see above). The auralization stages 1403, 1404 may be implemented as finite impulse response (FIR) filters with a length of between 1K and 8K. The crossfeed paths from the right channel to the left channel and vice versa each include a crossfeed filter 1405, 1406 and a delay element 1407, 1408. The crossfeed filters 1405, 1406 may be one-stage shelving filters and the delay elements 1407, 1408 may signal delay by between 3 and 5 milliseconds. Summing stages 1409, 1410 each sum up the direct signal from the corresponding auralization stage 1403, 1404 and the crossfeed signal originating from the respective other auralization stage 1404, 1403.

[0030] Signals output by the summing stages 1409, 1410 are fed (in any order) for each channel into a series connection of an optional loudspeaker equalization stage 1411, 1412 in order to compensate acoustic room effects, into an optional chamber equalization stage 1413, 1414 in order to compensate acoustic room effects, and into an optional head diffraction equalization stage 1415, 1416 in order to compensate head-related acoustic effects. The loudspeaker equalization stage 1411, 1412 may be implemented as one-biquad peak filter, the chamber equalization stage 1413, 1414 as three-biquads shelving filter, and the head diffraction equalization stage 1415, 1416 as one-biquad peak filter. The signal provided by the series connection of the loudspeaker equalization stage 1411, 1412, the chamber equalization stage 1413, 1414, and

the head diffraction equalization stage 1415, 1416 are then split for each channel into high-frequency signals 1421 and 1422 and low-frequency signals 1423, 1424 for the high frequency loudspeaker front arrays (not shown in Figure 14) and the low-frequency loudspeakers (not shown in Figure 14) of the earphones 1425 and 1426 of the headphone 1427 using highpass filters 1417, 1418 and lowpass filters 1419, 1420. The highpass filters 1417, 1418 and lowpass filters 1419, 1420 may be third-order filters having a Chebyshev structure and sharing the same cut-off frequency. The signal processing shown in Figure 14 is adapted to earphones that have only front arrays. Optional rear arrays may be controlled in the same manner as the front arrays, based, however, on target functions adapted to the rear positions.

[0031] The signal processing structure described above may be implemented not only by hardware but also by software and/or firmware stored on or in a computer-readable medium, machine-readable medium, propagated-signal medium, and/or signal-bearing medium as instructions for execution by a processor or alternatively or additionally, any type of logic. The media may comprise any device that contains, stores, communicates, propagates, or transports executable instructions for use by or in connection with an instruction executable system, apparatus, or device.

[0032] The description of embodiments has been presented for purposes of illustration and description. Suitable modifications and variations to the embodiments may be performed in light of the above description or may be obtained by practicing the methods. For example, unless otherwise noted, one or more of the described methods may be performed by a suitable device and/or combination of devices. The described methods and associated actions may also be performed in various orders in addition to the order described in this application, or in parallel, and/or simultaneously. The described systems are exemplary in nature, and may include additional elements and/or omit elements.

[0033] As used in this application, an element or step recited in the singular and proceeded with the word "a" or "an" should not be understood as excluding the plural of said elements or steps, unless such exclusion is stated. Furthermore, references to "one embodiment" or "one example" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0034] While various embodiments of the invention have been described, it will be apparent to those of ordinary skilled in the art that many more embodiments and implementations are possible within the scope of the invention. In particular, the skilled person will recognize the interchangeability of various features from different embodiments. Although these techniques and systems have been disclosed in the context of certain embodiments and examples, it will be understood that these techniques and systems may be extended beyond the specifically disclosed embodiments to other embodi-

ments and/or uses and obvious modifications thereof.

Claims

1. An earphone comprising:

a housing having a cup-like shape and comprising a bottom wall and a circumferential sidewall, the bottom wall and the sidewall encompassing an open chamber, the chamber being closed when the earphone is worn over an ear of a user; a low-frequency loudspeaker mounted to the bottom wall and configured to radiate low-frequency sound into the chamber; and a front array of at least three high frequency loudspeakers mounted to the sidewall and configured to radiate high-frequency sound into the chamber, the front array being disposed adjacent to the rostral end of the ear when the earphone is worn over the ear of the user; wherein the bottom wall and the sidewall are made from or comprise sound absorbing material adjacent to the chamber; and the low-frequency loudspeaker and the high-frequency loudspeakers are configured to receive an electrical signal to be acoustically reproduced.

2. The earphone of claim 1, further comprising a rear array of at least three high frequency loudspeakers mounted to the sidewall opposite of the front array and configured to broadcast into the chamber, the rear array being disposed adjacent to the caudal end of the ear when the earphone is worn over the ear of the user.

3. The earphone of claim 1 or 2, wherein the housing comprises a rigid cup-shaped shell that is configured to support all loudspeakers present and comprises a sound absorbing layer adjacent to the chamber, the sound absorbing layer covering the inner side of the shell except for the positions where the loudspeakers are disposed.

4. The earphone of any of the previous claims, wherein the high-frequency loudspeakers of the front array are placed away from the ear at an angle of between 25° and 35° from a horizontal line in a rostral direction starting from the position of the ear canal entrance.

5. The earphone of any of the previous claims, wherein the high-frequency loudspeakers of the front array or the high-frequency loudspeakers of the rear array or the loudspeakers of each array are each electrically connected in series.

6. The earphone of any of the previous claims, further

comprising a splitting filter configured to separate the signal to be reproduced into a high-frequency signal supplied to the front array of high-frequency loudspeakers and into a low-frequency signal supplied to the low-frequency loudspeaker.

7. The earphone of any of the previous claims, further comprising a head diffraction equalization filter having a frequency response configured to compensate for distortions of the signal to be reproduced, caused by the head of the user.

8. The earphone of any of the previous claims, further comprising a chamber equalization filter having a frequency response configured to compensate for distortions of the signal to be reproduced, caused by the chamber.

9. The earphone of any of the previous claims, further comprising a loudspeaker equalization filter having a frequency response configured to compensate for distortions of the signal to be reproduced, caused by at least one of the low-frequency and high-frequency the loudspeakers of the front array.

10. The earphone of any of claims 7-9, wherein the signal to be reproduced is filtered before reproduction so that a binaural, head-related target function is met, the binaural, head-related target function being determined based on the frequency response of the low-frequency loudspeaker measured in a normal listening room or an anechoic chamber.

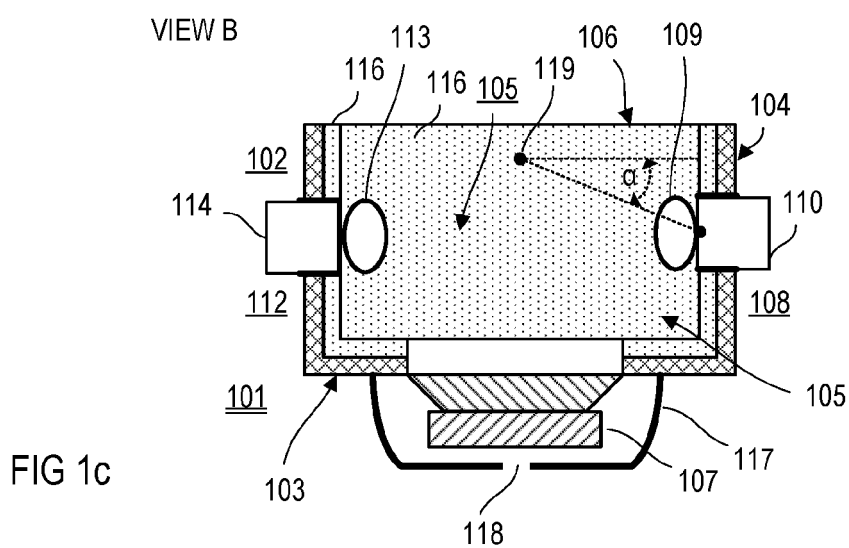
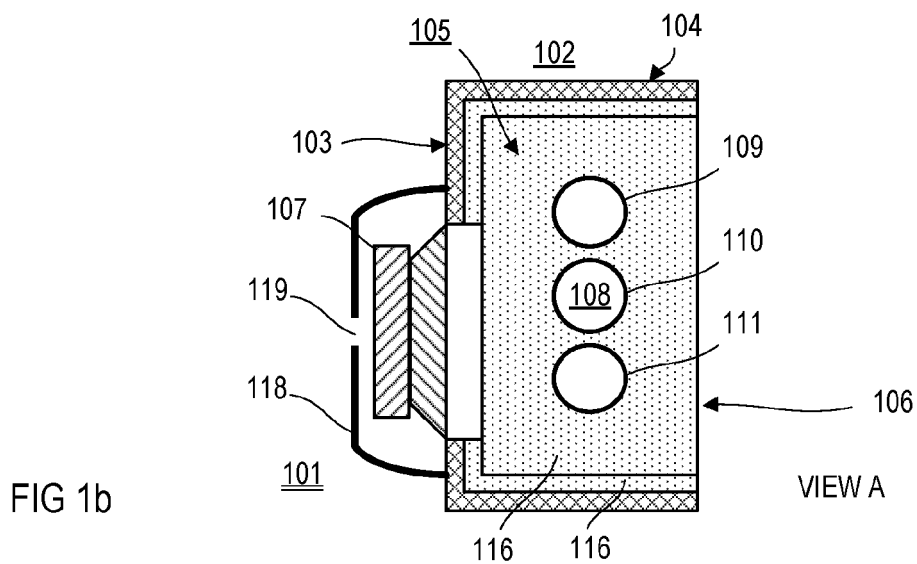
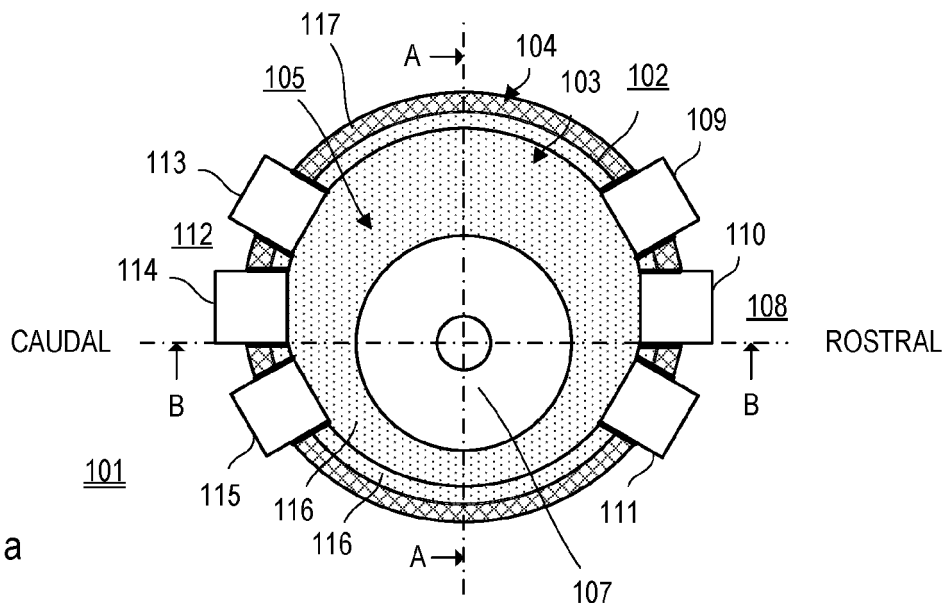
11. A headphone comprising two earphones according to claims 1-10, each earphone being supplied with at least one signal to be reproduced.

12. The headphone of claim 11, further comprising two crossfeed paths configured to transfer one of the two signals to be reproduced to the other one and to add the one, transferred signal to the other, non-transferred signal.

13. The headphone of claim 12, wherein each crossfeed path comprises a crossfeed filter configured to model interaural distortions caused by the head of the user.

14. The headphone of claim 12 or 13, wherein each crossfeed path comprises a delay element configured to delay the one, transferred signal relative to the other, non-transferred signal.

15. The headphone of any of claims 12-14, comprising an auralization filter configured to provide auralization effects without taking into account binaural effects.



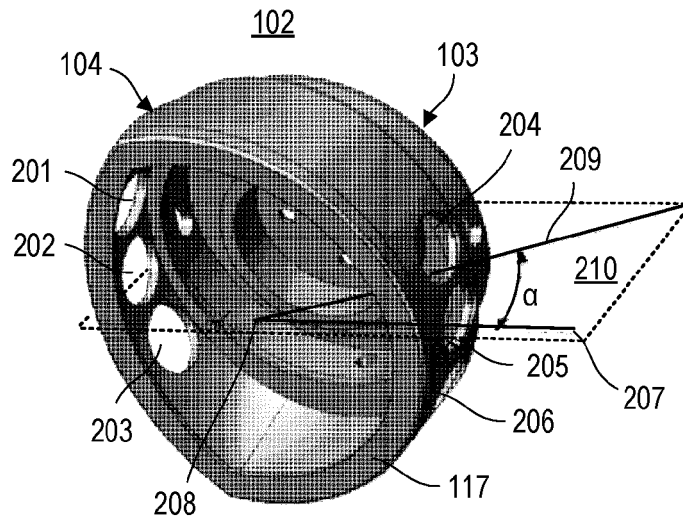


FIG 2

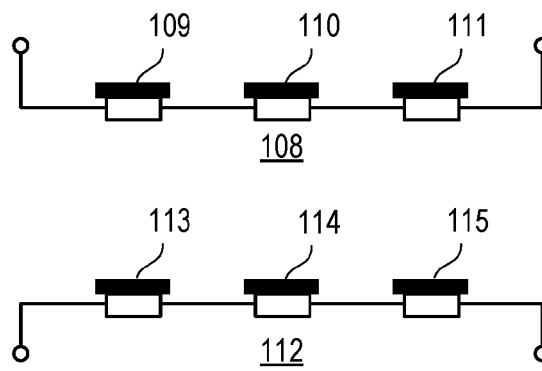


FIG 3

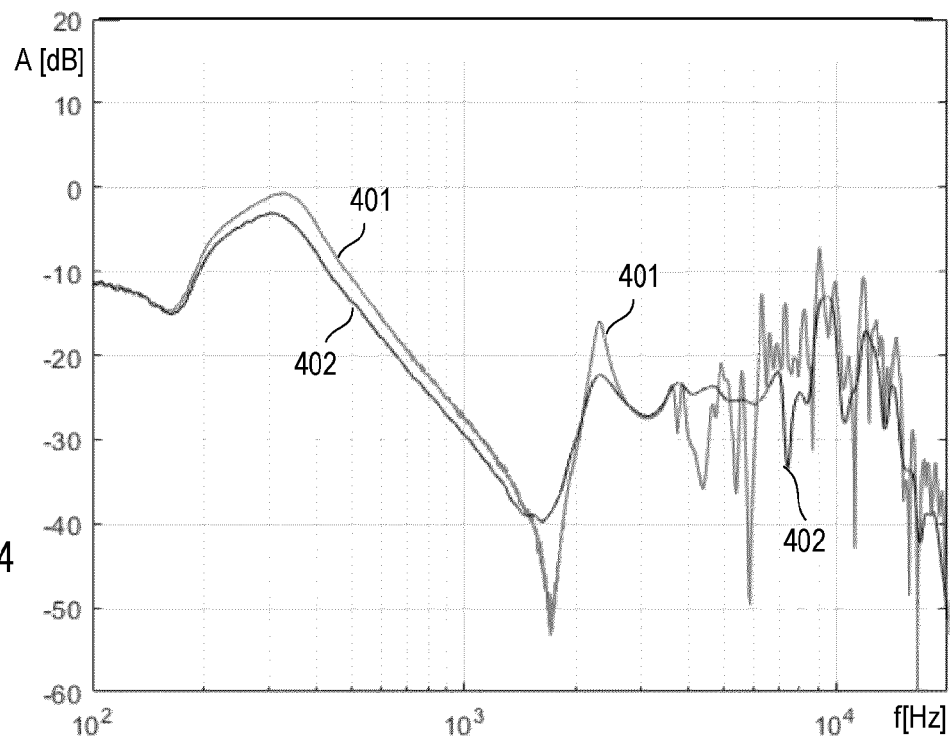


FIG 4

FIG 5

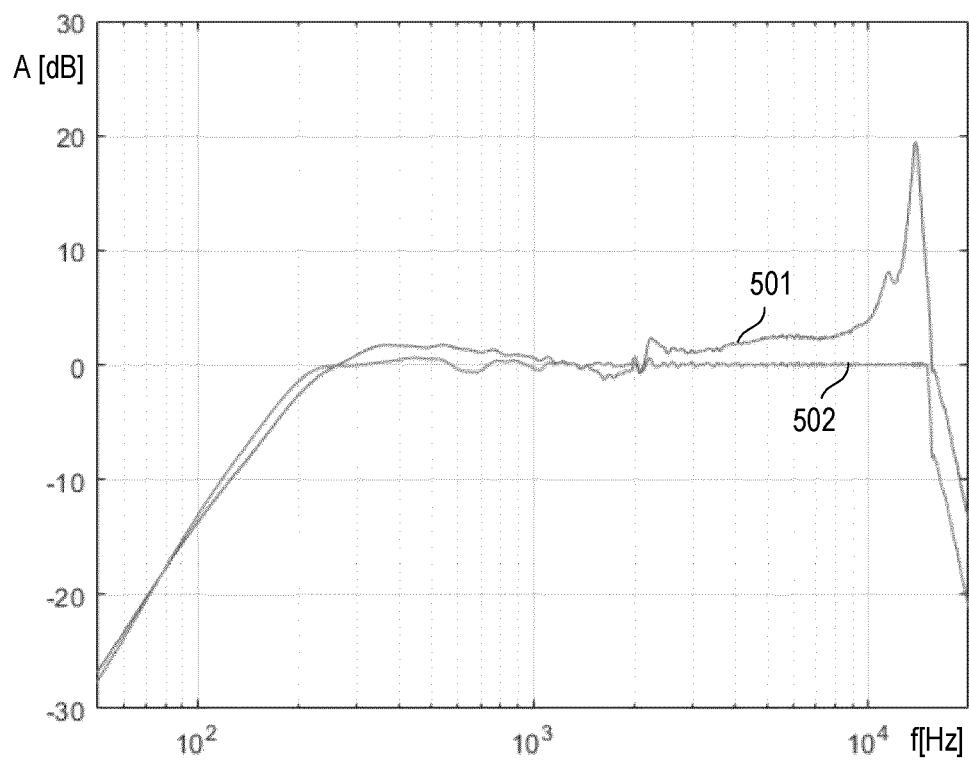


FIG 6

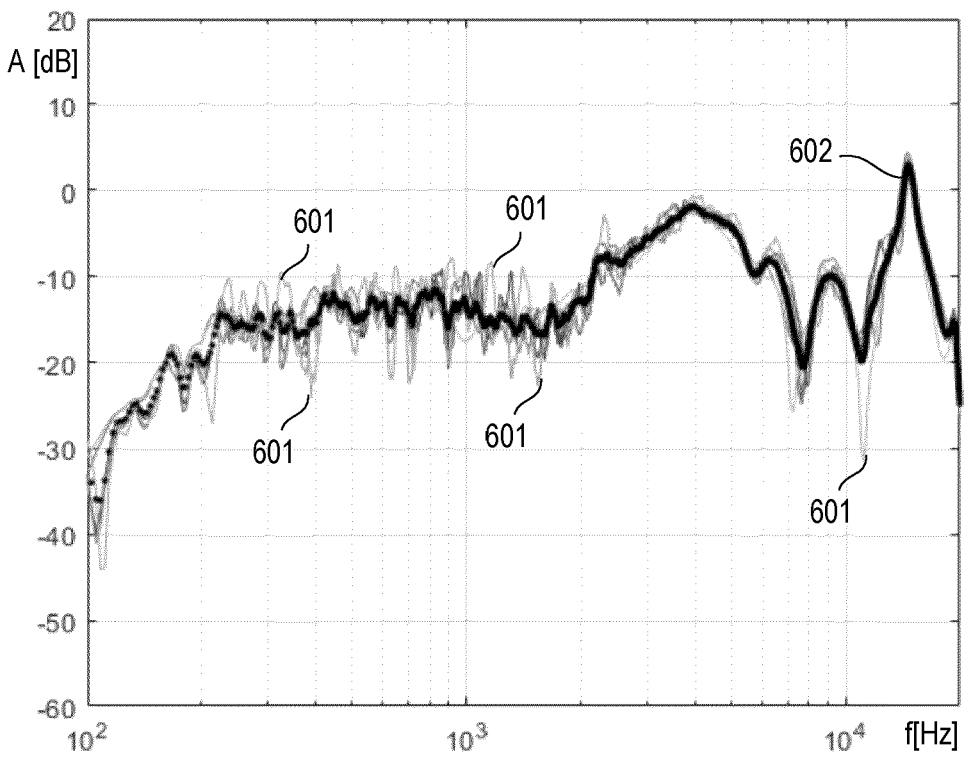


FIG 7

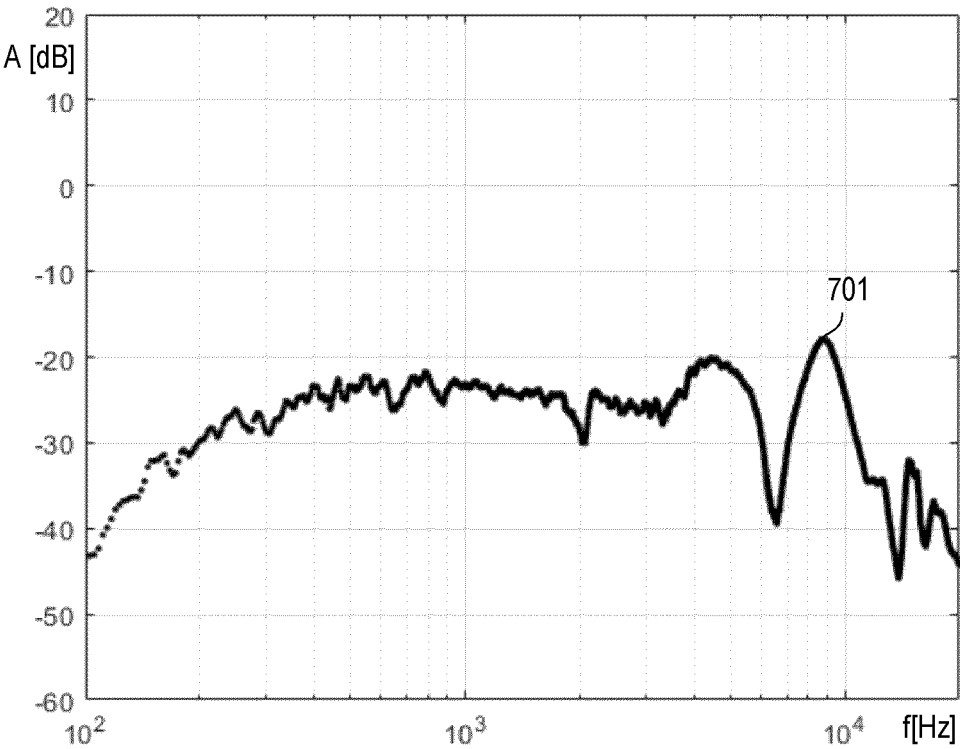


FIG 8

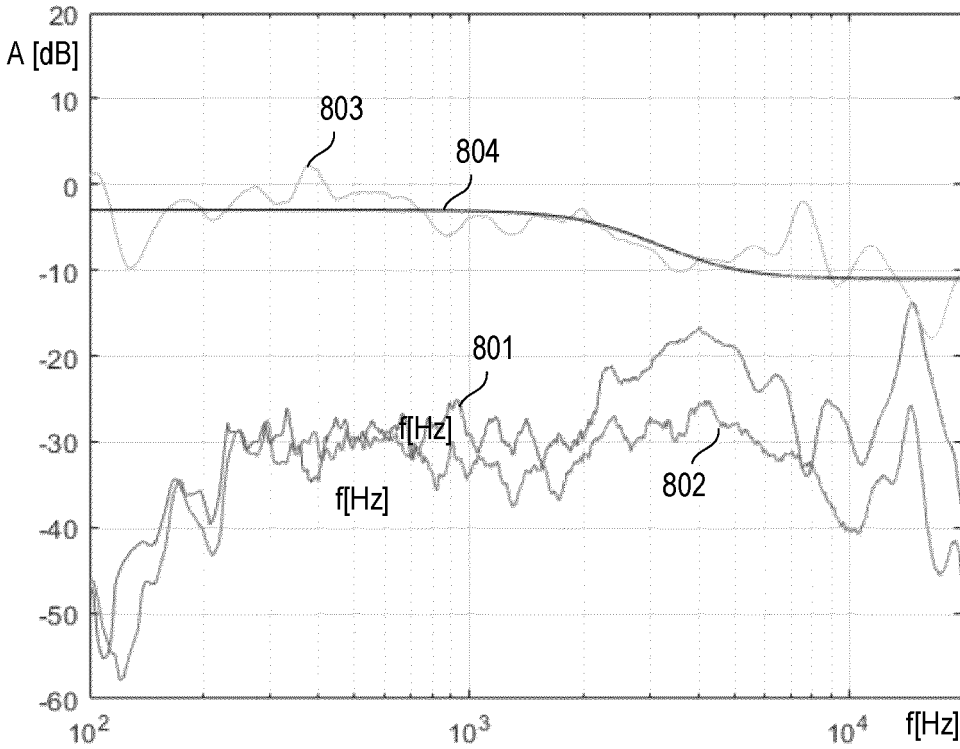


FIG 9

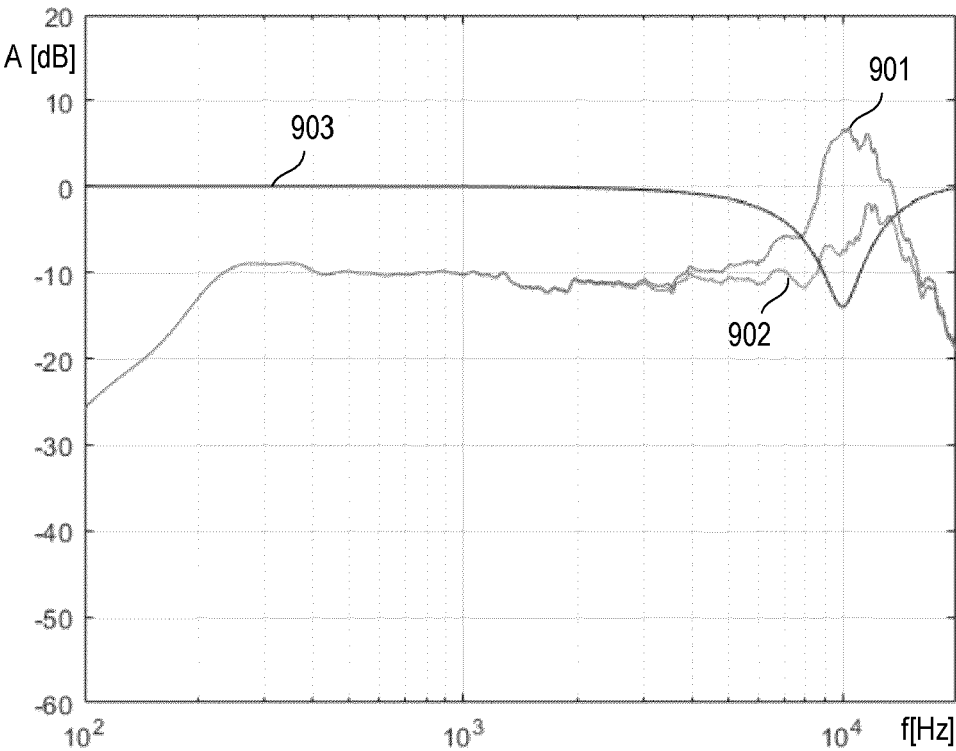
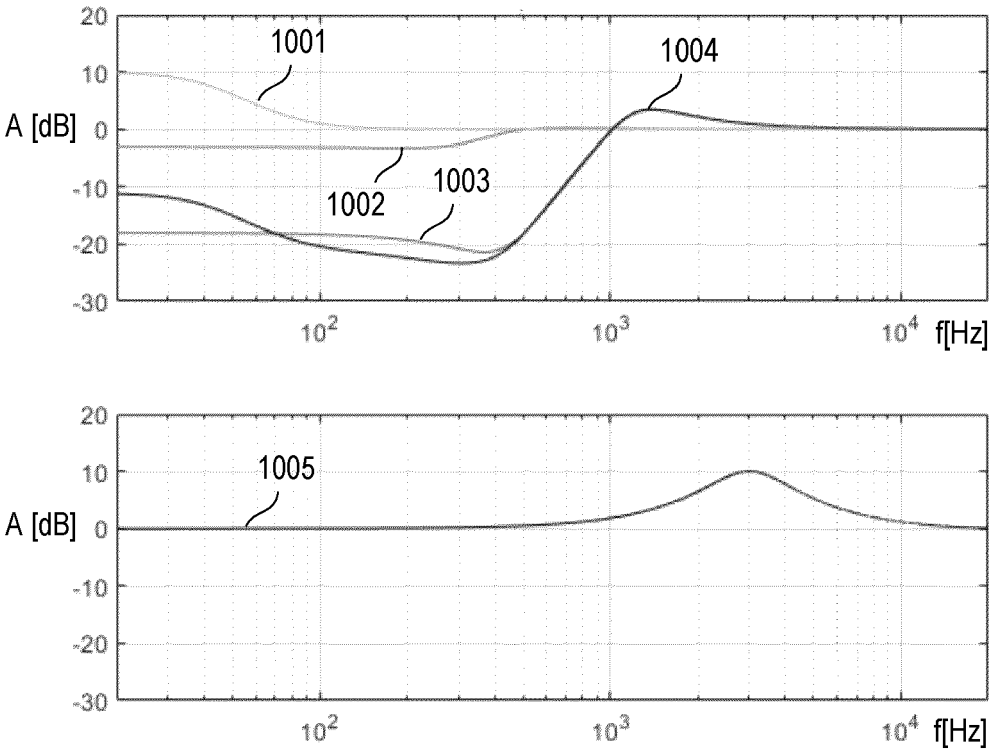


FIG 10



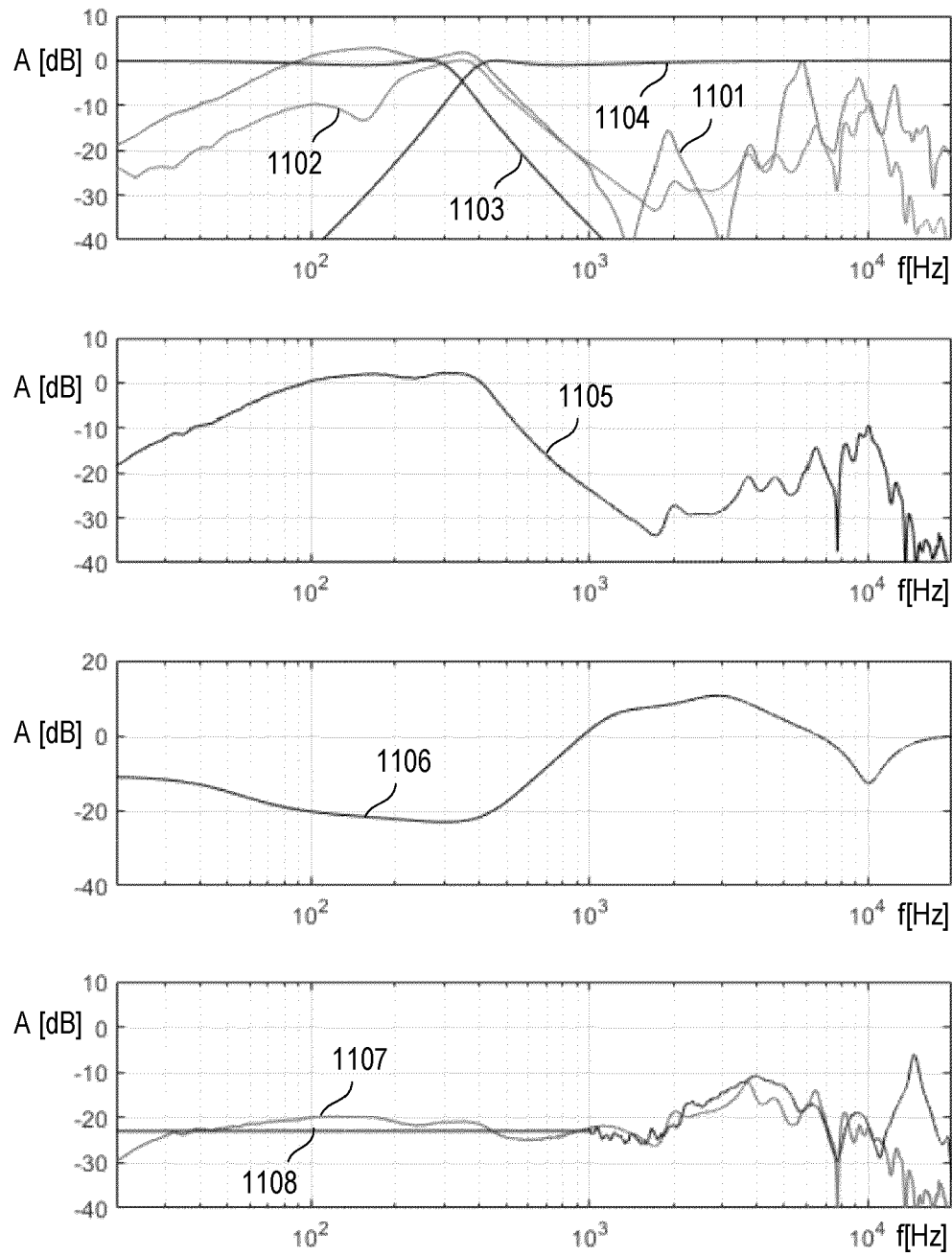
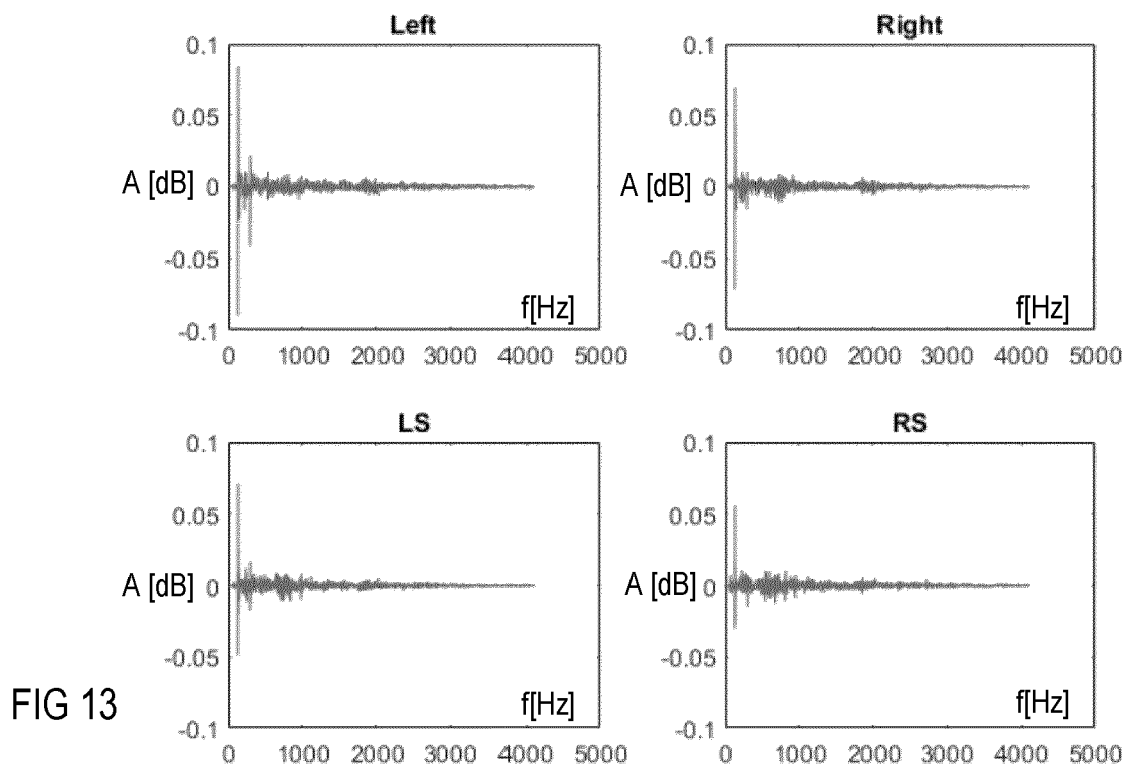
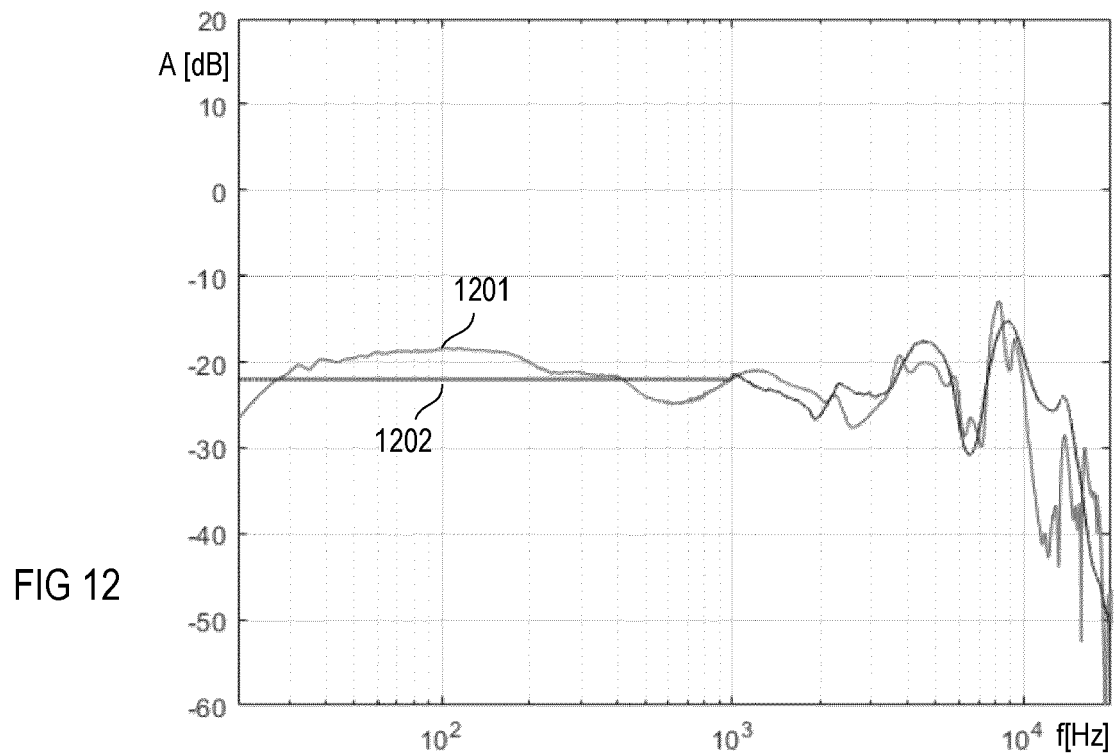


FIG 11



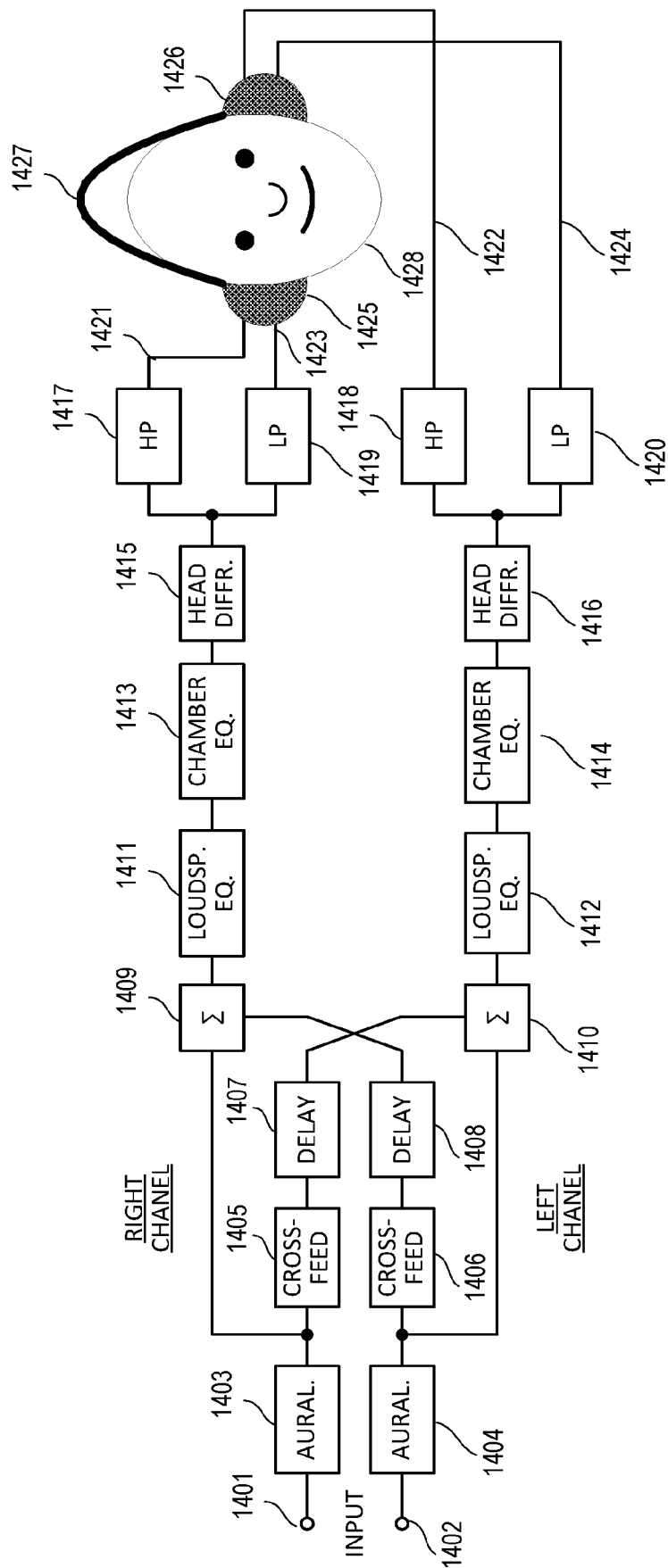


FIG 14



EUROPEAN SEARCH REPORT

Application Number

EP 23 17 9546

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2023/084469 A1 (HEAVYS INC [US]) 19 May 2023 (2023-05-19)	1, 2, 4-6, 11-15	INV. H04R1/10
Y	* paragraph [0034] - paragraph [0038] * * figures 1A-3B *	3, 7-10	H04R1/26 H04R5/033
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Y	* paragraph [0085] - paragraph [0086] * * paragraph [0090] - paragraph [0102] * * figures 2, 4, 7, 10 *	3, 7-10	
Y	US 2018/192227 A1 (WOELFL GENARO [DE]) 5 July 2018 (2018-07-05)	3, 7-10	
A	* paragraph [0031] - paragraph [0033] * * paragraph [0038] * * paragraph [0075] * * paragraph [0080] - paragraph [0081] *	1	
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	* column 8, line 19 - column 9, line 46 *		
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Place of search Munich		Date of completion of the search 1 December 2023	Examiner Meiser, Jürgen
CATEGORY OF CITED DOCUMENTS		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	
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