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(54) METHOD FOR CALIBRATING AN EAR-LEVEL AUDIO PROCESSING DEVICE

(57) The present invention relates to a method for adjusting with aid of an auxiliary device at least one characteristic of an ear-level audio processing device. The ear-level audio processing device comprises at least one output transducer and the auxiliary device comprises at least one input transducer and/or output transducer. The method comprises :
a) selecting a test signal
b) playing the test signal using an output transducer of the ear-level audio processing device or an output transducer of the auxiliary device,
c) recording, by means of at least one input transducer of the ear-level audio processing device or of the auxiliary device, the test signal from the output transducer,
d) collecting test data from signals obtained from the recording,
e) adjusting the at least one characteristic of the ear-level audio processing device based on the collected test data. wherein in steps b) and c) at least once the auxiliary device is used.

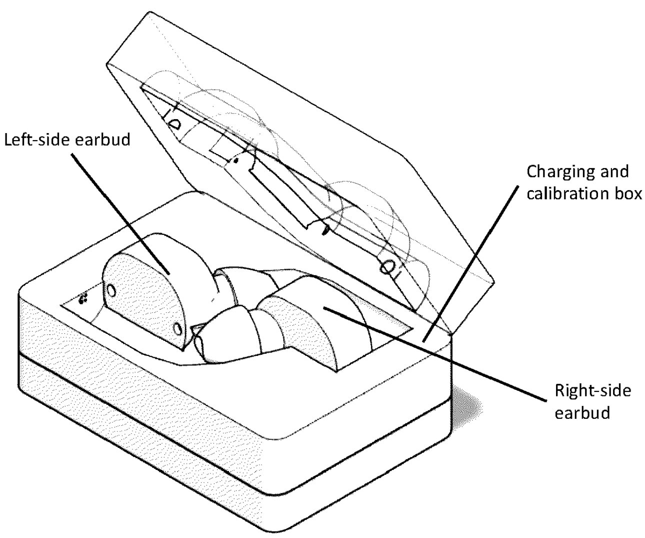

Fig.9

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Description

Field of the invention

[0001] The present invention is generally related to the field of ear-level audio processing devices and methods for adjusting one or more characterizing parameters of such devices.

Background of the invention

[0002] Traditionally, devices providing hearing aid functionality have to undergo periodic device characterization tasks. This is usually done via a hearing instrument test (HIT) box, which performs a series of tests to characterize the device. These tests are described in Hearing Aid standards like ANSI S3.22-2003/ IEC 60118-7 (2005) (pure tone testing), ANSI S3.42 part 1 (1992) / IEC 60118-2 (1996) (noise and speech testing), ANSI S3.42 part 2 (2012) and IEC 60118-15 (2012) (noise and speech testing), ANSI S3.25 (2009) and IEC 60318-4 (2006) (wideband performance) or Audiometer Standards like EN 60645-1:2012 and ANSI S3.6-2010. The tests measure device properties, such as the maximum gain the device can undergo, the frequency response, etc. The mentioned electroacoustic standards do not make a distinction between usage by a trained person and usage by a layperson. Emphasis is put on enforcing that the device be used as intended. For instance, an instruction manual is often required to ensure correct operation of the device. Allowing usage by a layperson may put more constraints on the labelling and instructions to be provided or on the built-in safeguards to be implemented for proper device operation.

[0003] In order to test the performance of a hearing aid device, the latter device is plugged into the test box by using a 2cc coupler, as it is often mandated by standards (e.g. ANSI/ASA S3.55-2014/Part 5 / IEC 60318- 5:2006). These couplers provide a standardized volumetric cavity that resembles the average human ear's acoustical properties.

[0004] After a hearing aid device has been calibrated, its characteristics may degrade during normal use. Common causes of performance degradation include :

- degradation of the sensitivity of the microphones, speaker or other input and output transducers components
- obstruction of the pathway connecting the hearing aid device speaker and the ear canal : a notable issue hearing aid users can face is ear wax accumulation. By continued use of the device, the tips can become clogged, thus severely impairing the ability of the device to perform correctly
- obstruction of the microphones : grease, dust and debris can obstruct the pathway between the environment and the microphone and reduce their ability to measure the environment acoustic pressure. Additionally, feedback microphones located close to the device speaker and the user ear canal may be affected by earwax

[0005] Consumer devices such as smartphones and headsets have taken an important role in the life of most people nowadays. These devices provide sufficient computational power and capability to handle complex audio processing. Recently devices referred to as smart headsets have been hitting the market. Smart headsets are technically advanced, electronic in-the-ear-devices designed for multiple purposes, ranging from wireless transmission to communication objectives, medical monitoring and so on. Smart headsets combine major assets of wearable technology with the basic principle of audio-based information services, conventional rendition of music and wireless telecommunication. In order to be able to handle a variety of complex audio tasks, smart headsets contain tiny but capable processing units.

[0006] Modern headsets are equipped with a system-on-chip (SoC) that includes one or several central processing units (CPU) and digital signal processing units (DSP), random access memory (RAM), flash memory and a wireless connectivity, e.g. Bluetooth connectivity, chipset that can perform very complex tasks. These headsets have reached a sufficient level of processing power and battery life to allow running complex hearing aid algorithms on them on demand. This makes them a suitable alternative for the mild to moderate hearing loss market.

[0007] One example of such a modern headset is a set of True Wireless Stereo (TWS) earbuds. TWS refers to a technology which allows pairing two audio devices via Bluetooth, meaning that the L channel (left) and the R channel (right) can be transmitted separately.

[0008] Such headsets often come in a case that comprises a battery. This allows the headset to provide on-demand charging and also allows for a convenient way of storage with minimal chance of losing the device. Certain devices adapted for performing Active Noise Cancelling (ANC) have a multiple microphone configuration, with at least two microphones per ear side.

[0009] Headsets with Active Noise Cancelling functionality have already been described in the prior art. Just to mention some examples, reference is made to US2020/058287. US2020/058287 discloses active noise cancelling headphones in the form of a part of a headset or as in-ear headphones that reduce acoustic adaptation by providing an electrodynamic speaker in a housing with ventilation openings and an acoustically permeable front panel. These components form a module that can be integrated into ANC headphones. The module reacts to a reduction of the impermeability situation, whereby an impedance change of the speaker takes place below 100 Hz.

[0010] There is a need for improved techniques for adjusting one or more features of a hearing device, which are also suitable for being applied by the hearing device user.

Summary of the invention

[0011] It is an object of embodiments of the present invention to provide for a method for adjusting at least one characteristic of an ear-level audio processing device wherein the availability of an auxiliary device is exploited.

[0012] The above objective is accomplished by the solution according to the present invention.

[0013] In a first aspect the invention relates to a method for adjusting with aid of an auxiliary device at least one characteristic of an ear-level audio processing device. The ear-level audio processing device comprises at least one output transducer and the auxiliary device comprises at least one input transducer and/or output transducer. The method comprises :

a) selecting a test signal
b) playing the test signal using an output transducer of the ear-level audio processing device or an output transducer of the auxiliary device,
c) recording, by means of at least one input transducer of the ear-level audio processing device or of the auxiliary device, the test signal from the output transducer,
d) collecting test data from signals obtained from the recording,
e) adjusting the at least one characteristic of the ear-level audio processing device based on the collected test data.

wherein in steps b) and c) at least once the auxiliary device is used.

[0014] The proposed solution indeed allows for adjusting a characteristic of the ear-level processing device. At least one of the ear-level audio processing device and the auxiliary device is arranged to play the test signal. At least the input transducer of the device not used for playing the test signal captures the latter signal. Test data is then collected from the recorded signals. From the collected data an adjusted value of a characteristic of the ear-level audio processing device can then be determined. It is to be noted that this adjusting of a characteristic in practice comes close to performing calibration, or at least a part thereof, the ear-level processing device. The proposed method lends itself for use in a procedure wherein the ear-level audio processing device is in a possibly automated and possibly periodic way kept up-to-date. For example, the method may be carried out a first time at manufacturing time. Once an end user has purchased the ear-level audio processing device, the method can be repeated at regular or irregular times.

[0015] In preferred embodiments the step of collecting test data comprises determining a noise profile of the output transducer used for playing the test signal and/or of the at least one input transducer used for the recording.

[0016] In one embodiment collecting test data comprises labelling the test data with a time stamp to track an evolution over time. Comparing the noise profile of a given input transducer of the ear-level audio processing device or the auxiliary device.

[0017] Advantageously, the method comprises determining a correlation between two distinct input transducer noise profiles.

[0018] In one embodiment In one embodiment the method comprises anonymizing the collected test data.

[0019] In a preferred embodiment the signals obtained from said recording are stored. The signals obtained from said recording are in some embodiments processed before being stored.

[0020] In preferred embodiments the ear-level audio processing device has audiometer and/or hearing aid functionality.

[0021] In embodiments of the present invention the ear-level audio processing device is an earbud of a pair of earbuds and the auxiliary device is a charging box arranged for charging the pair of earbuds. The charging box may comprise in some embodiments at least one input transducer and at least one output transducer.

[0022] In advantageous embodiments the test signal is also recorded with a feedback input transducer of the device used for playing the test signal.

[0023] In another aspect the invention relates to the use of the method as previously described in a, possibly automated, procedure for obtaining an updated characterization of the ear-level audio processing device or of the auxiliary device. Advantageously said updated characterization is exploited to produce one or more updated digital calibration tables associated with the ear-level audio processing device or of the auxiliary device.

[0024] In another aspect the invention relates to the use of the method as previously described for configuring a sound personalization or hearing loss compensation of a used of said ear-level audio processing device.

[0025] In yet another aspect the invention relates to a hearing assistive system comprising at least one ear-level audio processing device and an auxiliary device. The auxiliary device may in some embodiments be, for example, a charging box or may be implemented rather as a distributed system comprising a charging box and an ear bud of a pair of earbuds, the other one being calibrated.

The hearing assistive system may also comprise a further ear level audio processing device and/or an accessory to an ear level audio processing device, e.g. a remote microphone (which is not carried at ear level). The charging bow could then contain a placeholder for the remote microphone in addition to a placeholder for the ear level audio processing devices. The input transducer of the remote microphone can then be used in the method for calibration as described herein.

[0026] For purposes of summarizing the invention and the advantages achieved over the prior art, certain objects and advantages of the invention have been described herein above. Of course, it is to be understood that not necessarily all such objects or advantages may be achieved in accordance with any particular embodiment of the invention. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

[0027] The above and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

Brief description of the drawings

[0028] The invention will now be described further, by way of example, with reference to the accompanying drawings, wherein like reference numerals refer to like elements in the various figures.

Fig.1 illustrates an outside-facing side of a TWS earbud.
Fig.2 illustrates a head-facing side of a TWS earbud.
Fig.3 illustrates an output pathway view of a TWS headset.
Fig.4 illustrates a TWS headset enclosure and some internal components (excluding speaker canal and ear tip for clarity).
Fig.5 illustrates internal elements of a charging box.
Fig.6 illustrates a possible physical configuration for inter-earbud verification of speaker and microphones.
Fig.7 illustrates an acoustic chamber design for inter-earbud verification of speaker and microphones.
Fig.8 illustrates an acoustic canal design for inter-earbud verification of speaker and microphones enclosed in a charging box.
Fig.9 illustrates a charging and calibration box with left and right-side earbuds installed.

Detailed description of illustrative embodiments

[0029] The present invention will be described with respect to particular embodiments and with reference to certain drawings but the invention is not limited thereto but only by the claims.

[0030] Furthermore, the terms first, second and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

[0031] It is to be noticed that the term "comprising", used in the claims, should not be interpreted as being restricted to the means listed thereafter; it does not exclude other elements or steps. It is thus to be interpreted as specifying the presence of the stated features, integers, steps or components as referred to, but does not preclude the presence or addition of one or more other features, integers, steps or components, or groups thereof. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

[0032] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments.

[0033] Similarly it should be appreciated that in the description of exemplary embodiments of the invention, various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the detailed description are hereby expressly incorporated into this detailed description, with each claim standing on its own as a separate embodiment of this invention.

[0034] Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

[0035] It should be noted that the use of particular terminology when describing certain features or aspects of the invention should not be taken to imply that the terminology is being redefined herein to be restricted to include any specific characteristics of the features or aspects of the invention with which that terminology is associated.

[0036] In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the invention may be practiced without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding of this description.

[0037] First a number of terms are explained which will be used throughout the rest of this document.

Ear-level audio processing device

[0038] In the context of the present invention the term ear level audio processing device is used to refer to any device that resides at ear-level and has at least one audio output and some means for standalone processing (a DSP, a CPU). Throughout this description the terms 'ear level audio processing device' and 'hearing device' are used as synonyms.

Input and output transducers

[0039] Hearing devices typically include a set of input and output transducers, for instance microphones and speakers. Input acoustic transducers convert variations of the sound pressure level (SPL) into electrical signals which are then sampled by an analog-to-digital converter (ADC) and converted in the digital domain. Other transducers such as microelectromechanical systems (MEMS) can convert SPL variation into a digital signal without the need for an external ADC. In a similar fashion, acoustic output transducers coupled with a digital-to-analog converter, can convert a digital signal into variation of the SPL.

[0040] In this description input and output transducers are specifically defined as follows:

- an output transducer converts a digital signal into an acoustic signal, either via vibration of material or via air conduction. Examples of output transducers are a DAC coupled with a speaker and a DAC coupled with a piezoelectric actuator.
- an input transducer converts an acoustic signal into a digital signal. Examples of input transducers include a MEMS microphone, an electret microphone coupled with an ADC, a piezoelectric sensor coupled with an ADC.

Digital calibration tables for input and output transducers

[0041] Each input or output transducer is associated with one or more digital calibration tables containing correction factors to input or output gains to be applied to the frequency response of the associated transducer. Such correction factors are stored in a digital format. A given transducer may be associated with several digital calibration tables for various reasons, for example :

- to store the digital calibration table of a transducer at several points in time, for instance during manufacturing, on the first use of the device after it has been purchased, one year after the first use etc.
- to store the digital calibration table of an acoustic transducer for generating or recording stimuli at distinct input or output levels, for SPL in the case of an acoustic transducer. While it is often possible to model a transducer as behaving linearly, the presence of non-linear effects may require the availability of several digital calibration tables to correct the acoustic transducer behaviour when generating or recording acoustic signals at distinct SPLs.

[0042] Calibration tables constitute a set of adjustment factors to be applied to a digital signal so that:

- the output digital signal represents the measured physical quantity (for instance SPL in a certain frequency range) with acceptable tolerance in the case of an input transducer.
- the resulting SPL generated by an output transducer matches the expected frequency response with acceptable tolerance, given the input digital signal.

Digital Calibration

[0043] A digital calibration is defined as the action of adjusting one or more correction factors contained in one or more digital calibration tables corresponding to one or more input or output transducers in order to represent the relationship between digital control signal and generated vibration or sound pressure (output transducer case) or to represent the relationship between measured vibration or sound pressure level and the output digital representation of this measurement (input transducer). A digital calibration may be, but is not necessarily, linked to a given standard. The calibration can be performed by an end user or by a professional.

Self-testing

[0044] Self-testing is an automated procedure involving the electro-acoustic interaction between a hearing device (be it made of a single physical object as in an over-the-ear headphones form factor, or of several physical objects as in a pair of TWS earbuds, whereby the self-testing is performed first on one of the earbuds and next on the other) and its user and enabling the assessment of the user hearing profile and/or hearing loss and/or audiogram, that can be used to configure a sound personalization and/or hearing loss compensation device or system.

Self-assessment

[0045] Self-assessment is an automated procedure involving one or more hearing devices and/or associated devices producing an updated characterization of the behaviour of the considered hearing devices and/or associated devices, represented in a digital format.

Self-calibration

[0046] Self-calibration is an automated procedure involving one or more hearing devices and/or associated devices, which uses the output of one or more previous self-assessment procedures as well as other information available to the set of devices to produce updated digital calibration tables associated with the set of devices input and/or output transducers.

Auxiliary Device

[0047] With an 'auxiliary device' is meant a single device (e.g. another hearing device or a charging box) used for assisting in a self-assessment or a self-calibration procedure as associated device. In some embodiments the auxiliary device can be part of a distributed system. Other components of the distributed system can be active (i.e. they can generate signals via output transducers, record signal via input transducers, and/or perform computation), but they can also be passive, for instance, in the case of a storage box with no active electronics.

[0048] The present invention aims to provide a method for adjusting a characteristic of an ear-level audio processing device (i.e. a hearing device) with the aid of an auxiliary device via which the ear-level audio processing device can be adjusted, for example be calibrated. Once calibrated the ear-level audio processing device is capable of detecting various types of malfunction, as will be detailed later in this description. The ear-level audio processing device in some embodiments offers audiometer and/or hearing aid functionality. Preferably both hearing aid and audiometer functionality are then provided in the ear-level audio processing device. In other embodiments the ear-level audio processing device is a consumer headset which does not have hearing aid functionality or audiometer functionality.

[0049] A first embodiment of the approach according to the invention is now described. The ear-level audio processing device is in this embodiment implemented as a pair of TWS earbuds, which is one example of what hereafter is also referred to as a headset. Note that a pair of earbuds is here to be considered as a pair of hearing devices, i.e. each earbud is seen as a hearing device on its own. Fig.1 to Fig.4 provide a schematic representation of a modern TWS earbud enhanced with a hearing aid and/or audiometer functionality. The earbuds of the pictured headset each comprise, by way of example, two external microphones (see Fig.1) to capture signals from the acoustic environment and one feedback microphone (see Fig.3) to record variations of acoustic pressure in a speaker pathway and ear canal. Note that the presence and placement of the external and feedback microphones in the device shown in the figures are merely given as an example. The invention is in no way limited hereto. The TWS earbud charging connectors as shown in Fig.2 make contact with the charging connectors of the charging box when the earbuds are inserted into it.

[0050] Further components of a TWS earbud comprise a System-on-Chip comprising amongst other things input/output ports, a CPU and storage and offering wireless connectivity (including but not limited to Bluetooth), and a battery. The TWS earbud internal components are shown in Fig.4. Additionally, the ear-level audio processing device may optionally include sensors such as biometric sensors, contact conduction sensors, capacitive touch sensors, accelerometers, gyroscopes and buttons.

[0051] When it is needed, the pair of TWS earbuds can be inserted in its charging box. The receiving enclosure of the charging box includes charging connectors that make contact with the TWS earbuds when they are placed into the box enclosure. Existing charging boxes include a connector to an external power supply (typically, but not necessarily, USB), a microcontroller arranged to handle the charging process, and charging connectors which allow making contact with the each of the TWS earbud connectors when they are placed in the box enclosure.

[0052] In some embodiments hearing aid functionality can be provided in the headset, i.e. in each of the earbuds, in the form of a pure software solution that runs on the headset, e.g. on the CPU comprised in the headset. The particular hearing characteristics of the user can then be compensated for by adjusting parameters that affect that audio processing. These adjustments as a function of frequency, called fitting, can range from a small amplification to very high levels of amplification. Sometimes, for a given user having substantially different levels (e.g. 60 dB HL) of hearing loss at different frequencies, a large range of required amplification levels can be found. Such solutions obviously need to be acoustically calibrated. On the other hand, audiometer functionality, if present, allows measuring user hearing thresholds based on the presentation of auditory stimuli at a controlled sound pressure level and frequency. As such, solutions allowing audiometer functionality need to be acoustically calibrated as well.

[0053] Headsets that allow for self-testing (for example, resulting in an audiogram) and adjustment of built-in hearing aid functionality have already been proposed in the prior art. For instance, headsets featuring Active Noise Cancellation (ANC) may allow adjusting individual earbud characteristics. The left or right-side earbud generates a test signal using its speaker and records the signal entering the feedback microphone located close to the loudspeaker acoustic pathway while also recording the signal entering the external microphones which are less sensitive to the acoustic pressure variations originating from the loudspeaker because of their position. The processing means can analyse the recorded signals and adjust the relative relationship between loudspeaker and microphones gains and digital filters to allow for a fine-tuning of the ANC.

[0054] A hearing assistive system according to the present invention comprises apart from an ear-level audio processing device, possibly with hearing aid and/or audiometer functionality, also an auxiliary tool which is used in the calibration process. In case a pair of earbuds is used, each earbud being an audio processing device on its own, the charging box takes in an advantageous embodiment the role of auxiliary device employed for calibration purposes. In other embodiments one of the earbuds is the audio processing device of which a characteristic is to be adjusted and the other earbud acts as auxiliary device. The charging box is then part of a distributed system that further comprises the other bud.

[0055] Various embodiments of the approach of this invention implement calibration and self-adjusting and self-diagnostic scenarios by means of the charging box. One option is to provide in the charging box a volumetric cavity (similar to a 2cc coupler) and a central DSP using a configuration with one or more microphones and transducers for converting between electrical and acoustic signals. This set-up allows for a self-testing of one or both of the two TWS earbuds when they are placed into the charging box, either with the purpose of charging or not. In this case the charging box may produce test signals through its output transducer and record the response to these signals using its input transducers.

[0056] A charging box manufacturer may want the manufactured charging box to perform electroacoustic measurements that meet the maximum allowed uncertainties of a standard to be covered. The example is taken of compliance with ANSI S3.22-2003/ IEC 60118-7 (2005), which - among other requirements - specifies the uncertainties allowed for a testing device sound source. Firstly the sound source (pure tone), in combination with a pressure-calibrated controlling microphone, must be capable of producing at the test point the requisite sound pressure levels between 50 dB and 90 dB, with a minimum step size of 5 dB, within a tolerance of $\pm$ 1,5 dB over the frequency range 200 Hz to 2000 Hz and within $\pm$2,5 dB over the range 2000 Hz to 5000 Hz. Requirements for the pressure-calibrated controlling microphone measuring the hearing device output must also be met. The equipment for measuring the coupler sound pressure level produced by the hearing device must fulfil the following requirements :

a) the sound pressure level measurement system is accurate within $\pm$1.0 dB at the frequency of calibration;

b) the indication of the sound pressure level in the acoustic coupler relative to the indication at the frequency of calibration is measured with an expanded uncertainty of no more than $\pm$1.0 dB in the frequency range 200 Hz to 5000 Hz.

Verifying that a hearing device with self-testing capabilities meets the requirements mandated by a given standard requires the use of laboratory equipment and methodologies also mandated by standards. For instance, the reference microphone used to verify the sound output characteristics of self-testing device transducer must be calibrated using a sound calibrator that complies with standard IEC 60942, with validated calibration procedure.

[0057] In summary, if the charging box manufacturer aims at certifying that the manufactured device meets a given standard from the list already mentioned in the background section, it can be demonstrated the criteria of methodology, maximum allowed uncertainties, and measurements traceability are met, and the manufacturer may ask a third-party entity to audit the manufacturing and calibration process to certify the charging box. In addition to certifying the manufactured device characteristics, the manufacturer must make sure that the charging box is used in the intended way (either by a layperson or a trained specialist), for instance by providing complete instructions of use adapted to the targeted user. For the sake of brevity, a manufactured device meeting the requirements given above is labelled as "standard-compliant".

[0058] The charging box may be certified as standard-compliant for a given electroacoustic audiometer or hearing aid standard. A periodic maintenance performed by the charging box manufacturer or a certified technician may be required. The method of the present invention can advantageously applied as another step towards compliance with a standard. Given that the charging box itself is standard compliant, it can be used to perform the self-assessment and self-calibration of the ear-level audio processing device for this standard, provided that the self-assessment or self-calibration is performed in an environment that is compatible with the intended use of the device. The self-assessment and self-calibration performed are then comparable to a laboratory testing instrument such as a Hearing Instrument Testing device. Doing so provides several advantages :

- only the charging box needs manual calibration, maintenance and certification from time to time, the earbuds are calibrated in an automatic way by the charging box
- the charging box is not worn in-ear by the user, hence, it is less prone to obstruction issues by ear wax or debris
- less need for miniaturization of ear-level device components that need calibration, so allowing for a broader selection of components in the ear-level device and reduction of cost

[0059] The above-sketched scenario requires the application of several clauses in the ANSI S3.22 (2014) and IEC 60118-7 (2005) quality control-related standards specify acceptable tolerances for test equipment accuracy. The charging box operates in some embodiments of the invention as a calibration tool that calibrates the earbuds when they are placed in the charging box. The calibrated earbuds so allow measuring sound pressure levels in the ear. Hence, in this scenario the auxiliary device, i.e. the charging box, fulfils an active role in the calibration of the earbuds.

[0060] The proposed set-up allows for offering hearing aid characterization of the ear-level audio processing device in accordance to the list of standards already given in the background section.

[0061] In a variant embodiment the auxiliary device, e.g. the charging box, itself may not be certified as standard-compliant by the manufacturer, for instance to reduce the regulatory and manufacturing costs associated with the compliance with a standard usually applied to laboratory test equipment. In this case the charging box still allows for self-assessment of the enclosed earbuds, the presence of one or more input or output transducers or both input and output transducers enabling the detection of anomalies in the hearing devices components (input and output transducers) and their associated acoustic pathways, and allowing cross-device measurements to be made. Also additional redundancy is provided. This approach may provide enough robustness to be a useful alternative to a standard-compliant solution. Also in this scenario the auxiliary device fulfils an active an active role in the calibration of the earbuds.

[0062] Another scenario is now considered, wherein the auxiliary device is rather part of a distributed system. This system comprises a charging box so designed that, when the earbuds are placed into the charging box, either with the purpose of charging or not, the two earbuds face each other's back end. This allows one earbud to act as the sound generating device, while the other earbud acts as sound recording device. Hence, the charging box and one of the earbuds form the distributed auxiliary system used to characterize the other earbud of the pair, which is the device to be tested. The charging box provides a coupling between the two earbuds and/or allows locating the earbuds with respect to one another, i.e. when placed in the charging box the exact position of the two hearing devices relative to each other is known. Both hearing devices' feedforward and, if present, feedback microphones can be used as control means to identify possible malfunction of the earbud being tested. Self-testing of the ear-level audio processing device is so possible, while keeping the cost reduced (no additional transducers or microphones need to be included in the charging box in this case). Whereas in the embodiments discussed above the charging box was an active component in the calibration process, the charging box is now rather used as a tool to enable the self-assessment and self-calibration. It is in this scenario that the other earbud plays an active part in the self-assessment and self-calibration.

[0063] Now some possible designs for a charging box suitable for use in the above-described approaches are presented. Fig.5 illustrates the main internal components of a TWS earbud charging box, including a SoC, battery and a power supply connector. To accommodate for scenarios wherein the charging box is actually used as an active part in the self-calibration process, the charging box also includes one or more output transducers able to generate sound or vibration and input transducers such as measurement microphones, as shown in Fig.8. Note that these features are not strictly necessary in case a calibration process is adopted wherein the charging box is not actively used.

[0064] Fig.6 shows how TWS earbuds can be spatially arranged so that a device speaker acoustic pathway faces the other earbud's external microphones acoustic pathway. By placing the earbuds in a suitably designed charging box, this spatial arrangement may readily be obtained. An acoustic signal generated via an output transducer of one earbud can be detected and recorded by the other earbud input transducers, such as the external microphones. This allows for inter-device acoustic measurements in the scenario wherein the charging box as such is not actively used.

[0065] Fig.7 shows the design of an acoustic chamber (in the enclosing box) that allows the placement of TWS earbuds as shown in Fig.6. For each earbud side, an acoustic canal connecting one device speaker acoustic pathway to the other device (earbud) is provided. Furthermore, for each TWS earbud, the designed acoustic canal includes at least an opening for connecting it to an external reference microphone (note only one of the two openings is depicted in Fig.7).

[0066] Fig.8 shows a charging box design in which the acoustic chamber depicted in Fig.7 can be implemented, using the box main structure and closing lid when the lid is closed. To allow for scenarios wherein the charging box actively takes part in the calibration procedure, the charging box includes at least two reference microphones, at least one of each being located at the end of each of the two speaker canals. The acoustic canal chamber bottom half also includes charging connectors for each of the two TWS earbuds. A physical constraint with respect to the location of the charging connectors of the TWS earbuds needs to be applied for the connectors to be able to contact the box main structure in the proposed physical configuration.

[0067] Fig.9 shows the charging box depicted in Fig.8 with the left and right earbuds installed.

[0068] An algorithm for adjusting one or more features of an ear-level audio processing device with use of embodiments of the auxiliary device as described above is now presented in a number of variants.

[0069] Possible test signals may come from the set of test signals mentioned in one or more of the various standards listed in the background section of this document. The test signals may include a warble tone, a pure tone, random noise, pseudo-random noise, band limited white noise, chirp, ICRA noise, Real Speech.

[0070] In the present invention the ear-level audio processing device comprises at least one output transducer. In advantageous embodiments the ear-level audio processing device also comprises at least one input transducer. The auxiliary device comprises at least one input transducer or output transducer. In some embodiments the auxiliary device comprises at least one input transducer and at least one output transducer. In some embodiments the auxiliary device comprises at least one transducer which is the opposite of a transducer available in the ear-level audio processing device, e.g. if the ear-level audio processing device contains an output transducer then the auxiliary device has an input transducer. If the ear-level audio processing device comprises both an input transducer and an output transducer, the auxiliary device contains an input transducer or an output transducer or one or more of both.

[0071] In one embodiment the test signal can be played back by a speaker of the auxiliary device (i.e. belonging to either the charging box or a hearing device not being tested, if e.g. a set-up with a headset is considered) and the response to the acoustic pressure derived from playback is recorded via one or more microphones of the hearing device to be tested, assessed or calibrated. Two options are available for storing the microphone recorded signal. In the first option the raw digital signal coming from the microphone is stored. In the second option post-processing of the raw digital signal is applied so that statistics describing the recorded signal are computed by either the auxiliary device (e.g. the charging box) or the hearing device, and only those statistics are stored. An example of statistics that can be computed are the energies in a third-octave frequency filter bank (those energies having been computed in either the temporal or spectral domain), which have been used in the past to implement sound level metering devices. In the remainder of this document statistics computed on the recorded audio signal are referred to as a "noise profile".

[0072] In case the procedure to collect test data uses a speaker of the hearing device to be tested to play the generated test signals, the resulting variations of the sound pressure level can be measured by at least one of, the external microphone(s) of the other hearing device (e.g. in case a pair of earbuds is used) and the same-side reference microphone of the charging box if it is included in the design. Further the sound pressure level may also be measured by a feedback microphone of the sound generating device, if present. In case a speaker of the other hearing device (not being tested) is used, the external microphone(s) or the feedback microphone of the hearing device being tested are used for measuring the sound pressure level or an input transducer of the charging box.

[0073] In case the test data collection procedure uses test signals generated via a transducer of the charging box, the resulting variations of the sound pressure level can be measured by the hearing devices input transducers (in an implementation with a pair of earbuds, both earbuds can be tested simultaneously or sequentially in this use case), and possibly also by the charging box input transducers. In this latter case a reference recording can so be obtained with which the recordings of the tested devices input transducers can be compared.

[0074] Depending on the implemented scenario, the test data collection procedures described above may further involve the synchronization of the devices involved (for example, the charging box and each of the two TWS earbuds). Playback on one device must be synchronized with the recording on the other device(s). Data communication between the devices enables the exchange of synchronization messages. Data communication can be implemented using for example data transfer over the charging connectors or wireless Bluetooth Low Energy connectivity or any other wireless connectivity protocol.

[0075] The data collection steps described above can be performed at several points in time to extract statistics that allow understanding the evolution over time of transducers (including speaker and microphones) response, and the current obstruction state of their acoustic pathways.

[0076] In an advantageous embodiment the data collection sequence is first performed at manufacturing time, where the device characteristics and state of the pathways are as close as possible to the nominal values given the tolerances of the manufacturing process. Characterization before use can also be verified using additional measurement material, as described above. The data collected at this time is stored for the tested device and can be labelled as "factory data".

[0077] After the device has been purchased and taken in use, a data collection sequence can be scheduled (either manually by the user or in an automated, possibly periodic way), and this data collection sequence will be executed for example the next time the hearing device is placed into the charging box. The parameters related to the sound generation part of the test sequence are the same as the ones used for generating the factory data.

[0078] A general method is provided for data collection of test sequences to be used for self-assessment and/or self-calibration using one or more hearing devices coupled with an associated auxiliary device, which in some embodiments can be implemented as a charging box. In other embodiments one of the earbuds of a pair serves as associated auxiliary device. The general method encompasses the use cases described above.

[0079] The devices' output transducer labelling is given as follows. Each hearing device output transducer S_s^t is labelled with an index s ranging from 0 to S-1, where S is the number of hearing devices, and another index t ranging from 0 to T-1, where T is the number of output transducers per hearing device or per accessory to a hearing device. In a minimum set-up T may be 0, provided that the auxiliary device comprises an output transducer. It is assumed for simplicity that each hearing device comprises one output transducer (e.g., T = 1). Note however that this is not strictly needed and hearing devices may in certain embodiments also have more than one output transducer (e.g., T > 1). For simplicity of explanation however hereinafter embodiments of the proposed method are considered with one output transducer per hearing device. Each charging box output transducer b is labelled with an index ranging from 0 to B-1, where B is the number of output transducers in the charging box. For instance, considering the use case with hearing device (e.g. earbud) speaker-generated test signals, whereby a speaker of either the hearing device to be tested or the other hearing device generates the test signal, S equals 2, T equals 1, and a possible index labelling would be :

- s_0^0: left earbud speaker, which, considering that T=1, will be denoted s_0 hereafter
- s_1^0: right earbud speaker, which, considering that T=1, will be denoted s_1 hereafter

In the use case with test signals generated via a charging box output transducer, and assuming only one speaker is included in the charging box, then B equals 1 and the index labelling is:

- b_0: charging box speaker

This approach can readily be extended to handle a case in which the charging box is equipped with more than one output transducer, in which case the sound sources attached to it would be labelled $b_0, b_1, \ldots, b_{B-1}$, with B the number of transducers included in the charging box.
In the case a solution is considered encompassing both use cases (i.e. with hearing device speaker-generated test signals and with test signals generated via a charging box transducer), S equals 2 and B1 and a possible labelling is:

- s_0: left earbud speaker
- s_1: right earbud speaker
- b_0: charging box speaker

[0080] The input transducer labelling in this example is given as follows. Each microphone m is labelled with an index ranging from 0 to M-1, where M is the number of microphones of each device mh_i being used during data collection. If a use case with hearing device speaker-generated test signals is taken and assuming each hearing device is equipped with three microphones (e.g. two external microphones and one feedback microphone), then, for each hearing device, M equals 3 and a possible labelling of the microphones would be :

- mh_0^0, mh_0^1, mh_0^2 denoting the feedback microphone, front-facing external microphone and back-facing external microphone of left hearing device, respectively, with associated sound source labelled s_0.
- mh_1^0, mh_1^1, mh_1^2 denoting the feedback microphone, front-facing external microphone and back-facing external microphone of right hearing device, respectively, with associated sound source labelled s_1.

Furthermore, if a use case with test signals generated via a charging box output transducer is considered, each hearing device charging box acoustic chamber mb_i is equipped with N microphones, and the corresponding charging box acoustic chamber microphones may be labelled as follows :

- $mb_0^0, \ldots, mb_0^{N-1}$: denoting the charging box microphones located in the acoustic chamber connected to the left hearing device
- $mb_1^0, \ldots, mb_1^{N-1}$: denoting the charging box microphones located in the acoustic chamber connected to the right hearing device

Note that this use case can be implemented for $N \geq 1$.

[0081] Below a general account is given of the data collection procedure that is applicable to either the use case with hearing device speaker-generated test signals (hence, where a hearing device is used as auxiliary device) or the use case with test signals generated via a charging box output transducer (hence, where the charging box is used as auxiliary device) or any combination of these use cases. For a test sequence initiated at a given timestamp t, the response to a test signal generated by sound source s_i or b_j can be recorded by microphones mh_0^k, mh_1^k, mb_0^l, mb_1^l, for $0 \leq i < S$, $0 \leq j < B$, $0 \leq k < M$, and $0 \leq l < N$. The microphone signals can be recorded simultaneously or sequentially, given that the generated signal is constant during the recording sequence. The recorded signal is analysed either during recording or after recording (as explained previously), and allows generating any of the following noise profiles :

$N(mh_0^k,t)$: noise profile of left hearing device microphone at index k ($0 \leq k < M$), for a test procedure initiated at time t.
$N(mh_1^k,t)$: noise profile of right hearing device microphone at index k ($0 \leq k < M$), for a test procedure initiated at time t.
$N(mb_0^l,t)$: noise profile of charging box microphones at index l ($0 \leq l < N$) located in the acoustic chamber connected to the left hearing device.
$N(mb_1^l,t)$: noise profile of charging box microphones at index l ($0 \leq l < N$) located in the acoustic chamber connected to the right hearing device.

[0082] At any given time t that a test sequence is initiated, the following procedure is initiated:

- Selecting characteristics of the test signal to generate (including but not limited to: waveform type, start and end amplitude, start and end frequency), labelling this configuration G and storing it.
- Selecting one sound source used to play the test signal, among s_i ($0 \leq i < S$) or b_j($0 \leq j < B$)
- Selecting one or more recording microphones among on the entirety or a subset of the available microphones mh_0^k, mh_1^k, mb_0^l, mb_1^l, for $0 \leq k < M$, and $0 \leq l < N$
- Starting generation of the test signal using the se-

lected sound source

- During playback of the sound source, storing the samples recorded using the selected microphones or computing the noise profiles $N(mh_0^k,t)$, $N(mh_1^k,t)$, $N(mb_0^l,t)$, $N(mb_1^l,t)$ corresponding to the received signals from the one or more selected microphones and storing them.
- If it is necessary to compute statistics (such as average and standard deviation) over time, during playback, performing subsequent computations of the noise profiles $N(mh_0^k, t+a*Dt)$, $N(mh_1^k,t+a*Dt)$, $N(mb_0^l, t+a*Dt)$, $N(mb_1^l, t+a*Dt)$ corresponding to the one or more selected microphones at subsequent time intervals and store them. *Dt* and *a* hereby denote a small time interval so chosen that a higher temporal resolution is achieved and a counting index, respectively.
- Waiting for completion of playback of the signal at the selected source.
- Stopping recording signal on the selected microphones.
- Collecting the stored information for this test sequence, and timestamping the resulting data collection corresponding to time t. Parts of the stored test signal characteristics, stored audio samples or stored noise profiles may have been stored on different devices (be it the left hearing device, the right hearing device or the charging box). The stored data can be copied from one device to another so that all the data corresponding to the collection created for this experiment is available on one device storage. The stored data collection for a given test sequence is labelled *Test_sequence(G, t).*

[0083] The hearing devices and charging box can be connected to a device with increased storage and computational power and possibly with internet connectivity. This is, for instance, the case for existing hearing aids or wireless headsets or earbuds connected to a smartphone and arranged to exchange information with an authorized application installed on the user smartphone.

[0084] The timestamped data obtained after data collection can be analysed to track the evolution over time of the noise profiles obtained after recording a test sequence. To perform this assessment, for a given generator configuration G wherein the test signals are generated, it is possible to compare several test sequences that were performed for the same generator configuration G, taken at different timestamps. The resulting list of data collections is noted [*Test_sequence*(G, t_0), ..., *Test_sequence*(G, t_{T-1})], where T is the number test sequences corresponding to a particular generator configuration, and $t_0, ..., t_{T-1}$ are the timestamps at which these test sequences where produced.

[0085] Given the list of collections [*Test_sequence*(G, t_0), ..., *Test_sequence*(G, t_{T-1})], a first method of self-assessment is to compare the noise profile of a given input transducer of a hearing device and/or auxiliary device at different timestamps, allowing for detecting a change in the transducer characteristics. Several similarity metrics can be used to measure the similarities between noise profiles, including, but not limited to, Root Mean Square error (RMS), Earth-Moving Distance (EMD), Manhattan Distance (MD).

[0086] A second method of self-assessment is to compute the correlation of distinct input transducers noise profiles in a test sequence performed at time t, and also to compute this correlation between successive test sequences produced at time $t_0, ..., t_{T-1}$. Several metrics can be used to measure the correlations between noise profiles, including, but not limited to, cross-correlation, Mutual Information, KL-Divergence.

[0087] The computation of similarity and correlation metrics between noise profiles allows detecting outliers, highlighting a faulty input transducer or its associated pathway. Likewise, if the noise profiles of several input transducers are correlated but present some modification between successive timestamps, this may indicate a defect in the output transducer involved. Detecting outliers can be performed in various ways. Some examples are the following :

- comparing the noise profiles recorded by several input transducers for a signal played back by a given output transducer at a given timestamp to,
- comparing the noise profiles recorded by a given input transducer for a signal played back by several output transducer at successive timestamps within a self-assessment session (i.e. $t = t_0+a*Dt$, and Dt does not exceed a few seconds),
- comparing the noise profiles recorded by a given input transducer for a signal played back by a given output transducer at successive timestamps belonging to successive self-assessment sessions (e.g. t_0+a*Dt, and Dt is superior to a day),
- cross reference the data given in above items. For instance, to compare the noise profiles recorded by two input transducers to the signal generated by four output transducers during a self-assessment session, and between successive measurement sessions performed every week. In another example, measurements can be grouped between all output and input transducer pairs to represent pathway measurements.

In all cases, various statistical outlier detection techniques can be used and their results compared. Unsupervised and clustering techniques allow isolating measurements that do not belong to a group of measurements. In addition, predictive modelling techniques coupled with cross-validation can build a predictive model based on a subset of the measurements (called training set) while the measurements corresponding to a given transducer or acoustic pathway (called validation set) are left apart for validation. The error of the validation data to the model derived from the training set can be computed. Cross-

validation is repeated for all transducers and/or pathways to be tested, resulting in an error score to the predictive model. Transducer or pathways with an error score above a certain threshold can be considered as outliers.
If an input transducer is identified as an outlier, the deviation of its noise profile with respect to the predictive model based on all other measurements can be computed, resulting in correction factors to be applied to it.
If an output transducer is identified as an outlier, the deviation with respect to the predictive model based on all other measurements can be computed, resulting in correction factors to be applied to it.
If a pathway is identified as an outlier, the deviation of the input transducer noise profile with respect to the predictive model based on all other measurements can be applied to it only for measurements originating from the pathway output transducer. Alternatively, correction factors can be applied to the pathway output transducer and applied to it only for measurements performed by the input transducer belonging to said pathway.
The information provided by the noise profiles can then be used to determine e.g. frequency response correction factors. Hearing thresholds provided to the user can be controlled by setting appropriate parameter values wherein the information obtained from the method as described above is taken into account.

[0088] The timestamped data obtained after collection from each user's device(s) can be anonymized and forwarded to a companion application installed on a user smartphone, which can apply further processing on it and upload it to a remote server operated by the device manufacturer or distributor. As a consequence, timestamped data related to self-testing and calibration for all devices manufactured will be available for further processing. Privacy issues can be addressed provided the collected data does not contain personal information and solely reflects the state of calibration of the device. For instance, such processing may allow answering questions like, for example,

- which components are prone to variability of specifications (between devices, and over time), or
- which pathways are prone to obstruction (between devices, and over time)

[0089] Performing such crowd-based verification can bring along the following improvements:

- Computation of corrective calibration constants for each microphone or speaker to be applied to the entirety of devices
- Identification of components with change of characterization during lifetime, hinting at their possible replacement in the next generation of devices
- Identification of acoustic pathways that get obstructed during lifetime, hinting at possible improvements of the mechanical design in the next generation of devices

[0090] In another embodiment the headset is a classical headset, i.e. a set of headphones joined by a band (e.g. placed over the head). The headphones have at least one microphone attached per ear side, and optionally any number of external or feedback microphones per ear side. When the two earcups of the headphones are brought close enough into each other's neighbourhood in a way that the acoustic pathways between one earcup output transducer and the other earcup microphones can be controlled in a reproducible way, the methods as described above can readily be applied. The two earcups can be brought into each other's neigbourhood by using, for instance, a folding mechanical design in which, when the over-the-ear headphone is folded, the two earcups are in vicinity of each other or face each other.

[0091] In yet another embodiment the ear-level audio processing device is a hearing aid. The hearing aid device includes at least one microphone per ear side and can further also include any number of external or feedback microphones per ear side. The hearing aid is further provided with a processing means, for example a digital signal processor or a CPU. The hearing aid is capable of exchanging data, synchronizing playback and recording with an auxiliary tool, for example a charging box or the hearing aid at the other side, using a wireless communication protocol, for example Bluetooth, WiFi or Near-Field Magnetic Induction (NFMI), or using a wired communication protocol via the charging connector.

[0092] In yet another embodiment the ear-level audio processing device is a hearing aid that uses replaceable batteries, as this is the case in several hearing aid models currently distributed on the market. In the methods according to the present invention the enclosing box is then not meant for charging but has the purpose of storage, self-assessment and self-calibration of the hearing aids.

[0093] In yet another embodiment the ear-level audio processing device includes at least a feedback microphone per ear side in addition to other transducers. The role of the feedback microphone, in addition to estimating the output level of the speaker and participating in the self-assessment and self-calibration process described above, is also to provide an estimation of the filtering taking place in the user ear canal due to the user ear canal specific shape, thus yielding an estimate of a Real Ear Measurement (REM). The self-assessment and self-calibration method presented here can be focused at preserving a good approximation of a REM using the feedback microphones included in the hearing devices.

[0094] In yet another embodiment the ear-level audio processing device includes at least a speaker per ear side in addition to other transducers. The speakers included in each side come from a matched pair, which means they have been manufactured and adjusted to have similar characteristics. The self-assessment and self-calibration method presented above can be focused at preserving the matching between the matched speakers.

[0095] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive. The foregoing description details certain embodiments of the invention. It will be appreciated, however, that no matter how detailed the foregoing appears in text, the invention may be practiced in many ways. The invention is not limited to the disclosed embodiments.

[0096] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. Method for adjusting with aid of an auxiliary device at least one characteristic of an ear-level audio processing device, said ear-level audio processing device comprising at least one output transducer and said auxiliary device comprising at least one input transducer and/or output transducer, the method comprising :

    a) selecting a test signal
    b) playing said test signal using an output transducer of said ear-level audio processing device or an output transducer of said auxiliary device,
    c) recording by means of at least one input transducer of said ear-level audio processing device or of said auxiliary device said test signal from said output transducer,
    d) collecting test data from signals obtained from said recording,
    e) adjusting said at least one characteristic of said ear-level audio processing device based on the collected test data.

    wherein in said steps b) and c) at least once said auxiliary device is used.

2. Method as in claim 1, wherein said collecting test data comprises determining a noise profile of said output transducer used for playing said test signal and/or of said at least one input transducer used for said recording.

3. Method as in any of the previous claims, wherein said collecting test data comprises labelling said test data with a time stamp to track an evolution over time.

4. Method as in claim 3, comprising comparing said noise profile of a given input transducer of said ear-level audio processing device or said auxiliary device.

5. Method as in any of claims 2 to 4, comprising determining a correlation between two distinct input transducer noise profiles.

6. Method as in any of claims 3 to 5, comprising anonymizing the collected test data.

7. Method as in any of the previous claims, wherein said signals obtained from said recording are stored.

8. Method as in any of the previous claims, wherein said signals obtained from said recording are processed before being stored.

9. Method as in any of the previous claims, wherein said ear-level audio processing device has audiometer and/or hearing aid functionality.

10. Method as in any of the previous claims, wherein said ear-level audio processing device is an earbud of a pair of earbuds and said auxiliary device is a charging box arranged for charging said pair of earbuds.

11. Method as in claim 10, wherein said charging box comprises at least one input transducer and at least one output transducer.

12. Method as in any of the previous claims, wherein said test signal is also recorded with a feedback input transducer of the device used for playing said test signal.

13. Use of the method as in any of the previous claims in a procedure for obtaining an updated characterization of said ear-level audio processing device or of said auxiliary device.

14. Use of the method as in claim 13, wherein said updated characterization is exploited to produce one or more updated digital calibration tables associated with said ear-level audio processing device or of said auxiliary device.

15. Use of the method as in any of the previous claims

for configuring a sound personalization or hearing loss compensation of a user of said ear-level audio processing device.

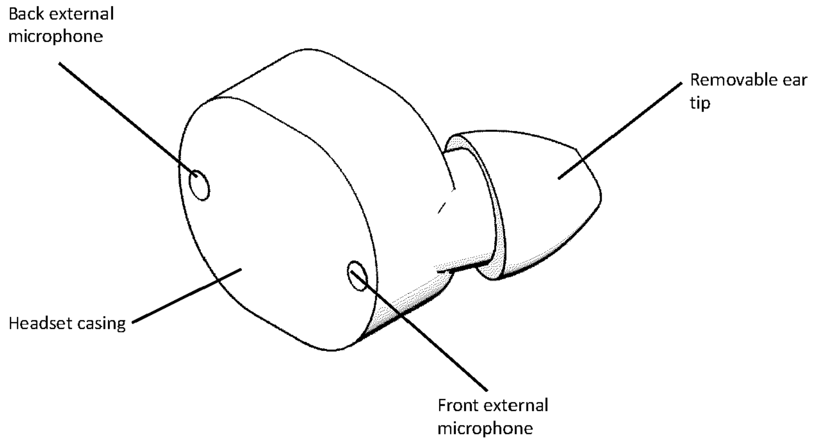
Back external microphone
Removable ear tip
Headset casing
Front external microphone

Fig.1

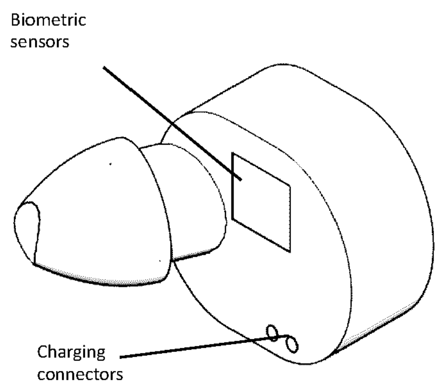
Biometric sensors
Charging connectors

Fig.2

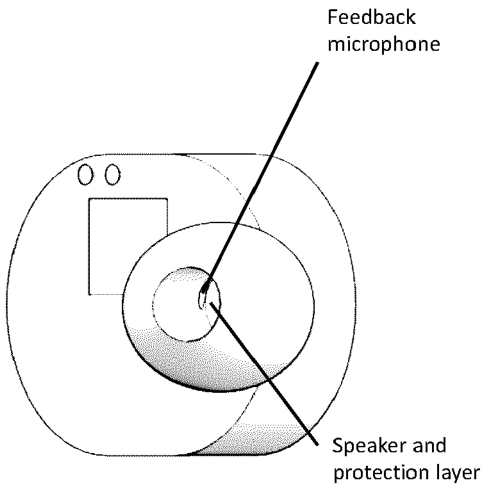
Feedback
microphone
Speaker and
protection layer

Fig.3

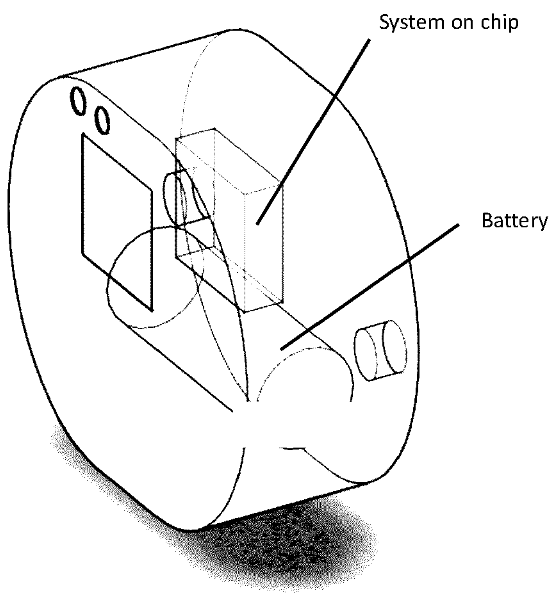
System on chip
Battery

Fig.4

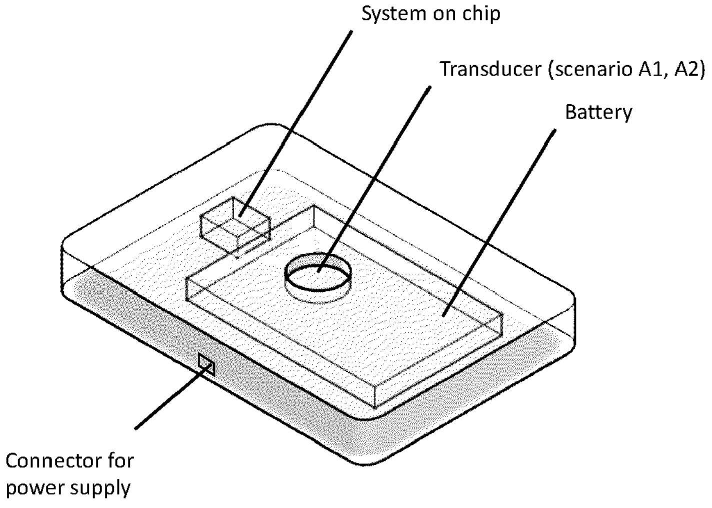
System on chip
Transducer (scenario A1, A2)
Battery
Connector for
power supply

Fig.5

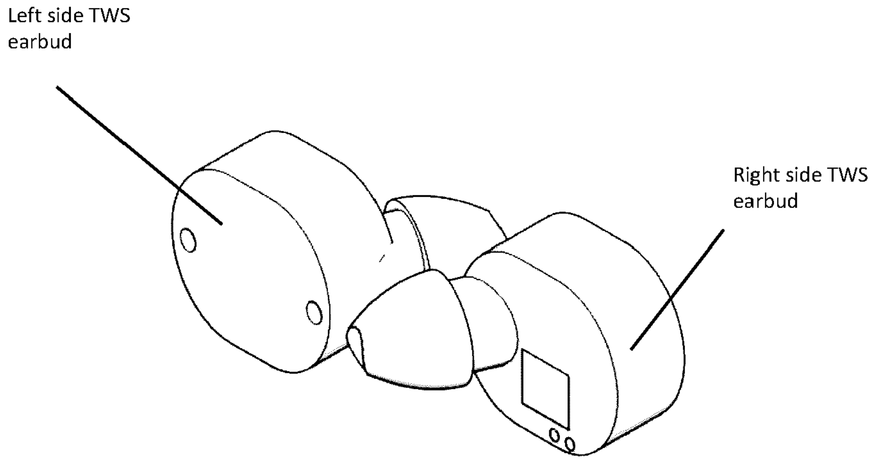
Left side TWS
earbud
Right side TWS
earbud

Fig.6

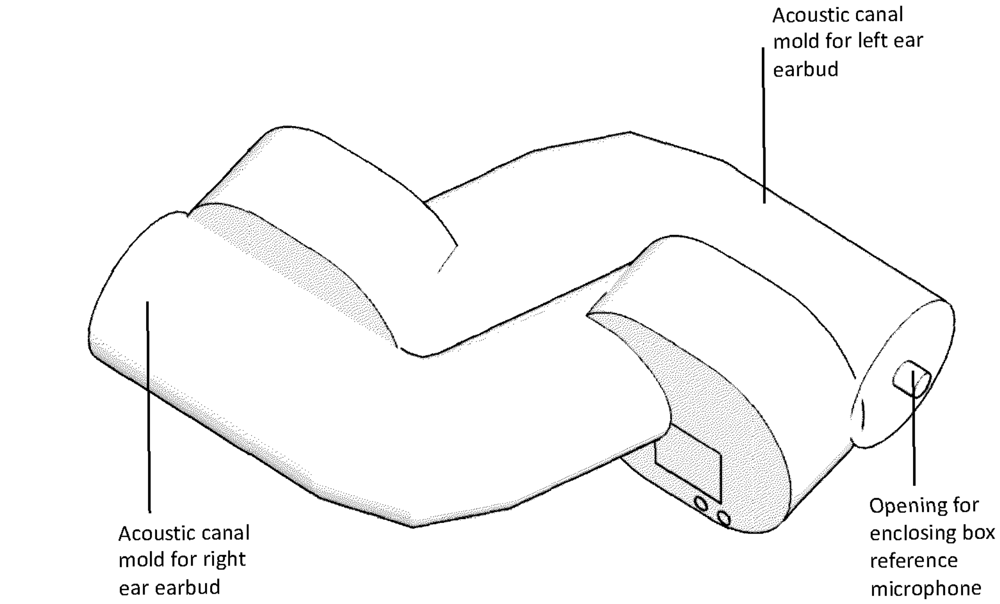
Acoustic canal
mold for left ear
earbud
Acoustic canal
mold for right
ear earbud
Opening for
enclosing box
reference
microphone

Fig.7

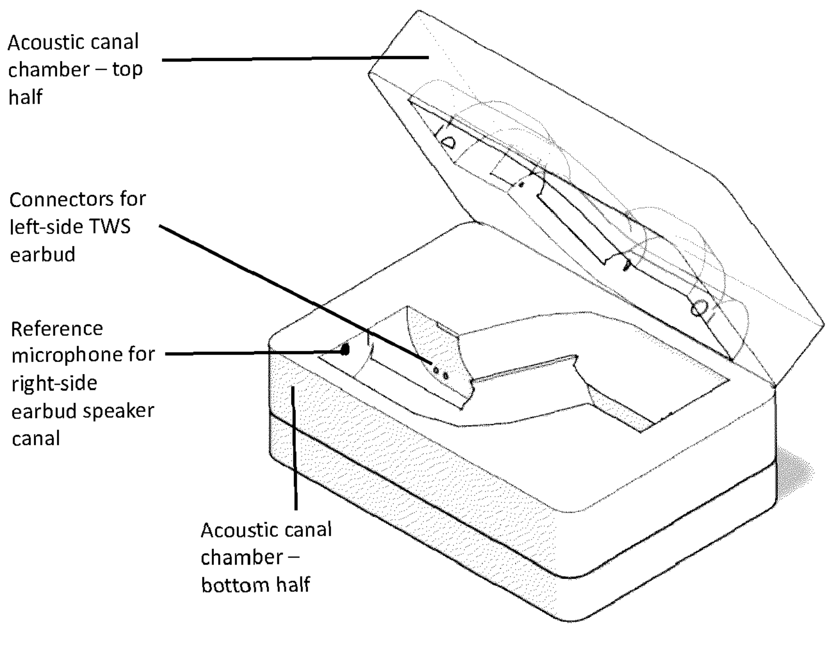
Acoustic canal
chamber – top
half
Connectors for
left-side TWS
earbud
Reference
microphone for
right-side
earbud speaker
canal
Acoustic canal
chamber –
bottom half

Fig.8

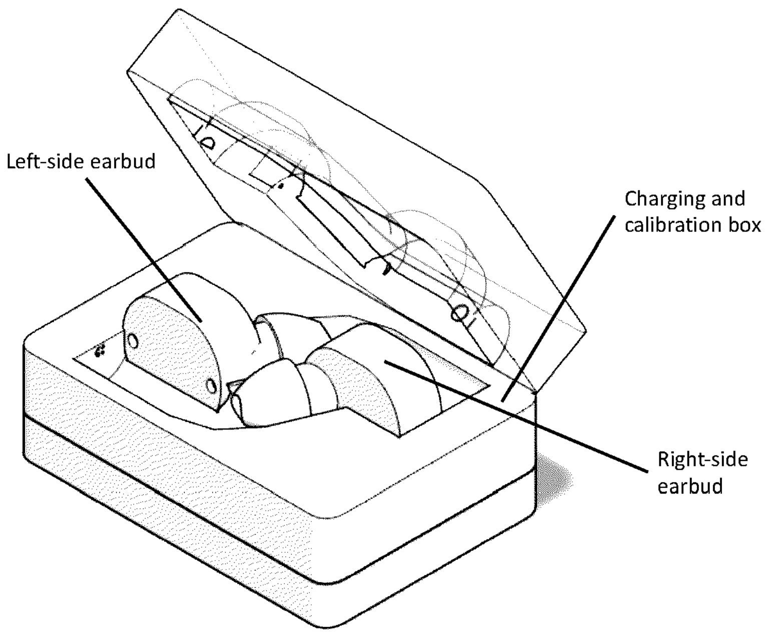
Left-side earbud
Charging and
calibration box
Right-side
earbud

Fig.9

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 20 20 3622

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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X : particularly relevant if taken alone
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