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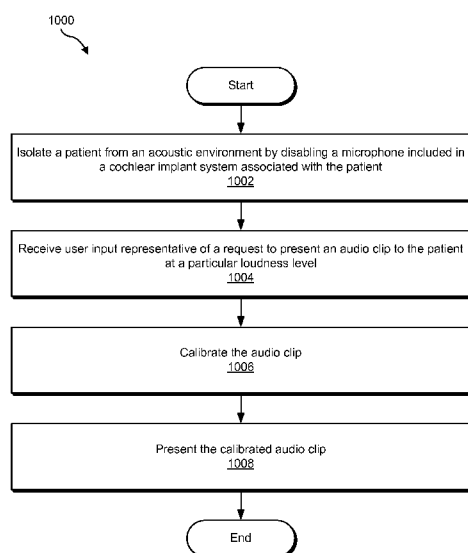


Fig. 10

(57) Abstract: An exemplary programming system 1) isolates a patient from an acoustic environment by disabling a microphone included in a cochlear implant system associated with the patient, 2) receives user input representative of a request to present an audio clip to the patient at a particular loudness level, 3) calibrates the audio clip to ensure that the audio clip has the particular loudness level, and 4) presents the calibrated audio clip to the patient.



SYSTEMS AND METHODS FOR EMULATING A SOUND BOOTH FOR A COCHLEAR IMPLANT PATIENT

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BACKGROUND INFORMATION

[0001] It is often desirable to evaluate how well a cochlear implant system is performing for a particular patient. For example, it may be desirable to present the patient with audio clips (e.g., audio clips that include speech and/or other material of interest) at different loudness levels and determine how well the patient recognizes the content of the audio clips at the different loudness levels. It may also be desirable to assess how the audio clips sound to the patient (e.g., in terms of comfort, clarity, etc.).

[0002] Ideally, such evaluations are performed in a sound booth (e.g., an anechoic chamber). A sound booth may isolate the patient from exterior sources of noise and ensure that audio clips are presented to the patient at accurate loudness levels, thereby facilitating relatively accurate test results. Unfortunately, however, many clinicians who evaluate performance of cochlear implant systems have limited or no access to a sound booth. Moreover, even if a clinician has access to a sound booth, it may be time consuming, cumbersome, and expensive for a patient to be evaluated in the sound booth.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The accompanying drawings illustrate various embodiments and are a part of the specification. The illustrated embodiments are merely examples and do not limit the scope of the disclosure. Throughout the drawings, identical or similar reference numbers designate identical or similar elements.

[0004] FIG. 1 illustrates an exemplary cochlear implant system according to principles described herein.

[0005] FIG. 2 illustrates a schematic structure of the human cochlea according to principles described herein.

[0006] FIG. 3 shows an exemplary configuration in which a programming system is communicatively coupled to a sound processor according to principles described herein.

[0007] FIG. 4 illustrates an exemplary implementation of the programming system shown in FIG. 3 according to principles described herein.

[0008] FIG. 5 illustrates an exemplary programming system according to principles described herein.

[0009] FIG. 6 shows an exemplary graphical user interface according to principles described herein.

5 [0010] FIG. 7 shows an exemplary flowchart that includes various steps that may be performed in order to calibrate an audio clip for a particular loudness level requested by a user according to principles described herein.

[0011] FIG. 8 shows an exemplary presentation of audio clips separated by intervals of silence according to principles described herein.

10 [0012] FIG. 9 shows an exemplary graphical user interface according to principles described herein.

[0013] FIG. 10 illustrates an exemplary method of emulating a sound booth for a cochlear implant patient according to principles described herein.

15 [0014] FIG. 11 illustrates an exemplary computing device according to principles described herein.

DETAILED DESCRIPTION

[0015] Systems and methods for emulating a sound booth for a cochlear implant patient are described herein. As will be described in more detail below, a programming system separate from and communicatively coupled to a sound processor included in a cochlear implant system may isolate a patient from an acoustic environment by disabling a microphone included in the cochlear implant system associated with the patient, receive user input representative of a request to present an audio clip to the patient at a particular loudness level, and calibrate the audio clip. The programming system may calibrate the audio clip by 1) determining, in response to the user input and based on a root mean square ("RMS") value of a system calibration signal having a known loudness level, a target RMS value for the audio clip and that will produce the particular loudness level, 2) determining an initial RMS value of the audio clip, 3) determining, based on the initial RMS value of the audio clip and the target RMS value, a gain factor that, when applied to the audio clip, will result in the audio clip having the target RMS value and the particular loudness level, and 4) applying the gain factor to the audio clip. The programming system may then present the calibrated audio clip to the patient.

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[0016] The systems and methods described herein may provide a “virtual sound booth” and thereby facilitate accurate and effective evaluation of cochlear implant system performance for a patient without requiring the patient to be located in an actual sound booth during the evaluation. Moreover, because the audio clips presented by the programming system are calibrated to have precise loudness levels and then digitally streamed directly to the cochlear implant system, the systems and methods may provide comparable or even better test results during the evaluation of a cochlear implant system for a patient than if the patient were located in an actual sound booth. This is because accurate loudness levels (i.e., loudness levels that are actually what the clinician specifies during the evaluation process) in a sound booth depend on proper and manual sound calibration for the sound booth, which is difficult to achieve or ensure, especially from sound booth to sound booth.

[0017] FIG. 1 illustrates an exemplary cochlear implant system 100. As shown, cochlear implant system 100 may include various components configured to be located external to a user including, but not limited to, a microphone 102, a sound processor 104, and a headpiece 106. Cochlear implant system 100 may further include various components configured to be implanted within the user including, but not limited to, a cochlear implant 108 and a lead 110 (also referred to as an intracochlear electrode array) with a plurality of electrodes 112 disposed thereon. As will be described in more detail below, additional or alternative components may be included within cochlear implant system 100 as may serve a particular implementation. The components shown in FIG. 1 will now be described in more detail.

[0018] Microphone 102 may be configured to detect audio signals presented to the user. Microphone 102 may be implemented in any suitable manner. For example, microphone 102 may include a microphone that is configured to be placed within the concha of the ear near the entrance to the ear canal, such as a T-MIC™ microphone from Advanced Bionics. Such a microphone may be held within the concha of the ear near the entrance of the ear canal by a boom or stalk that is attached to an ear hook configured to be selectively attached to sound processor 104. Additionally or alternatively, microphone 102 may be implemented by one or more microphones disposed within headpiece 106, one or more microphones disposed within sound processor 104, one or more beam-forming microphones, and/or any other suitable microphone as may serve a particular implementation.

[0019] Sound processor 104 (i.e., one or more components included within sound processor 104) may be configured to direct cochlear implant 108 to generate and apply electrical stimulation (also referred to herein as “stimulation current”) representative of one or more audio signals (e.g., one or more audio signals detected by microphone 102, input by way of an auxiliary audio input port, etc.) to one or more stimulation sites associated with an auditory pathway (e.g., the auditory nerve) of the user. Exemplary stimulation sites include, but are not limited to, one or more locations within the cochlea, the cochlear nucleus, the inferior colliculus, and/or any other nuclei in the auditory pathway. To this end, sound processor 104 may process the one or more audio signals in accordance with a selected sound processing strategy or program to generate appropriate stimulation parameters for controlling cochlear implant 108. Sound processor 104 may include or be implemented by a behind-the-ear (“BTE”) unit, a body worn device, and/or any other sound processing unit as may serve a particular implementation. For example, sound processor 104 may be implemented by an electro-acoustic stimulation (“EAS”) sound processor included in an EAS system configured to provide electrical and acoustic stimulation to a user.

[0020] In some examples, sound processor 104 may wirelessly transmit stimulation parameters (e.g., in the form of data words included in a forward telemetry sequence) and/or power signals to cochlear implant 108 by way of a wireless communication link 114 between headpiece 106 and cochlear implant 108. It will be understood that communication link 114 may include a bidirectional communication link and/or one or more dedicated unidirectional communication links. In some examples, sound processor 104 may execute and operate in accordance with a sound processing program that has been loaded into memory contained within sound processor 104.

[0021] Headpiece 106 may be communicatively coupled to sound processor 104 and may include an external antenna (e.g., a coil and/or one or more wireless communication components) configured to facilitate selective wireless coupling of sound processor 104 to cochlear implant 108. Headpiece 106 may additionally or alternatively be used to selectively and wirelessly couple any other external device to cochlear implant 108. To this end, headpiece 106 may be configured to be affixed to the user’s head and positioned such that the external antenna housed within headpiece 106 is communicatively coupled to a corresponding implantable antenna (which may also be implemented by a coil and/or one or more wireless communication components) included within or otherwise associated with cochlear implant 108. In this

manner, stimulation parameters and/or power signals may be wirelessly transmitted between sound processor 104 and cochlear implant 108 via a communication link 114 (which may include a bidirectional communication link and/or one or more dedicated unidirectional communication links as may serve a particular implementation).

5 **[0022]** Cochlear implant 108 may include any type of implantable stimulator that may be used in association with the systems and methods described herein. For example, cochlear implant 108 may be implemented by an implantable cochlear stimulator. In some alternative implementations, cochlear implant 108 may include a brainstem implant and/or any other type of active implant or auditory prosthesis that
10 may be implanted within a user and configured to apply stimulation to one or more stimulation sites located along an auditory pathway of a user.

[0023] In some examples, cochlear implant 108 may be configured to generate electrical stimulation representative of an audio signal processed by sound processor 104 (e.g., an audio signal detected by microphone 102) in accordance with one or more
15 stimulation parameters transmitted thereto by sound processor 104. Cochlear implant 108 may be further configured to apply the electrical stimulation to one or more stimulation sites within the user via one or more electrodes 112 disposed along lead 110 (e.g., by way of one or more stimulation channels formed by electrodes 112). In some examples, cochlear implant 108 may include a plurality of independent current
20 sources each associated with a channel defined by one or more of electrodes 112. In this manner, different stimulation current levels may be applied to multiple stimulation sites simultaneously (also referred to as “concurrently”) by way of multiple electrodes 112.

[0024] FIG. 2 illustrates a schematic structure of the human cochlea 200 into which
25 lead 110 may be inserted. As shown in FIG. 2, the cochlea 200 is in the shape of a spiral beginning at a base 202 and ending at an apex 204. Within the cochlea 200 resides auditory nerve tissue 206, which is denoted by Xs in FIG. 2. The auditory nerve tissue 206 is organized within the cochlea 200 in a tonotopic manner. Relatively low frequencies are encoded at or near the apex 204 of the cochlea 200 (referred to as an
30 “apical region”) while relatively high frequencies are encoded at or near the base 202 (referred to as a “basal region”). Hence, each location along the length of the cochlea 200 corresponds to a different perceived frequency. Cochlear implant system 100 may therefore be configured to apply electrical stimulation to different locations within the

cochlea 200 (e.g., different locations along the auditory nerve tissue 206) to provide a sensation of hearing.

[0025] In some examples, a programming system separate from (i.e., not included within) cochlear implant system 100 may be selectively and communicatively coupled to sound processor 104 in order to perform one or more programming or fitting operations with respect to cochlear implant system 100. For example, the programming system may present audio clips to the patient by way of the cochlear implant system in order to facilitate evaluation of how well the cochlear implant system is performing for the patient.

[0026] To illustrate, FIG. 3 shows an exemplary configuration 300 in which a programming system 302 is communicatively coupled to sound processor 104. Programming system 302 may be implemented by any suitable combination of physical computing and communication devices including, but not limited to, a fitting station or device, a programming device, a personal computer, a laptop computer, a handheld device, a mobile device (e.g., a mobile phone), a clinician's programming interface ("CPI") device, and/or any other suitable component as may serve a particular implementation. In some examples, programming system 302 may provide one or more graphical user interfaces ("GUIs") (e.g., by presenting the one or more GUIs by way of a display screen) with which a clinician or other user may interact.

[0027] FIG. 4 illustrates an exemplary configuration 400 in which programming system 302 is implemented by a computing device 402 and a CPI device 404. As shown, computing device 402 may be selectively and communicatively coupled to CPI device 404 by way of a cable 406. Likewise, CPI device 404 may be selectively and communicatively coupled to sound processor 104 by way of a cable 408. Cables 406 and 408 may each include any suitable type of cable that facilitates transmission of digital data between computing device 402 and sound processor 104. For example, cable 406 may include a universal serial bus ("USB") cable and cable 408 may include any type of cable configured to connect to a programming port included in sound processor 104. In some examples, computing device 402 may present an audio clip to the patient by digitally streaming the audio clip to sound processor 104 by way of cable 406, CPI device 404, and cable 408 without the audio clip ever being converted to an analog signal. In some alternative examples, wireless connections may be used to communicatively couple computing device 402 and CPI device 404, as well as CPI device 404 and sound processor 104.

[0028] Configuration 400 corresponds to a unilateral cochlear implant system (i.e., there is a single sound processor 104 that corresponds to one ear of the patient). It will be recognized that the systems and methods described herein may be applied to a bilateral cochlear implant system in which separate sound processors are associated with each ear of the patient or by a bimodal system in which a sound processor is associated with one of the patient's ears and a hearing aid is associated with the patient's other ear. In these instances, programming system 302 may be implemented by two CPI devices each associated with one of the sound processors.

[0029] FIG. 5 illustrates exemplary components of programming system 302. As shown, programming system 302 may include a sound booth emulation facility 502 ("emulation facility 502") and a storage facility 504, which may be in communication with one another using any suitable communication technologies. Storage facility 504 may maintain emulation data 506 generated and/or used by emulation facility 502 and audio clip data 508 representative of one or more audio clips that may be presented to the patient. As will be described below, audio clip data 508 may be in the form of digital audio files. Storage facility 504 may maintain additional or alternative data as may serve a particular implementation.

[0030] Emulation facility 502 may perform various operations configured to emulate a sound booth for a patient while the patient's cochlear implant system is communicatively coupled to programming system 302 (e.g., while a sound processor included in the cochlear implant system is communicatively coupled to programming system 302).

[0031] For example, emulation facility 502 may isolate the patient from an acoustic environment of the patient. In some examples, emulation facility 502 may isolate the patient from the acoustic environment by disabling each microphone included in the cochlear implant system. Emulation facility 502 may disable a microphone included in the cochlear implant system by transmitting a command to the sound processor included in the cochlear implant system to turn off the microphone and/or in any other suitable manner.

[0032] Emulation facility 502 may also receive user input representative of a request to present an audio clip to the patient at a particular loudness level. The user input may be provided and received in any suitable manner. For example, emulation facility 502 may provide a GUI and receive the user input by way of the GUI.

[0033] FIG. 6 shows an exemplary GUI 600 that may be provided for display by emulation facility 502 and that may be used by a user to provide an input command representative of a request to present an audio clip to the patient at a particular loudness level. As shown, GUI 600 may include a header portion 602 and a main portion 604. Header portion 602 may include various options associated with selecting and presenting audio clips to the patient. Main portion 604 may include various types of content associated with programming and/or evaluating a cochlear implant system. For example, main portion 604 may include an interface that may be used to test how well the patient recognizes words and/or sentences included in an audio clip that is presented to the patient in accordance with the systems and methods described herein.

[0034] As shown, GUI 600 may include a list 606 of available audio clips that may be presented to the patient. A user may select a desired audio clip by positioning a selector object 608 over a title of the desired audio clip. For example, FIG. 6 shows that selector object 608 has been positioned over an audio clip entitled "Track B". An audio clip may otherwise be selected for presentation to the patient in any other manner as may serve a particular implementation.

[0035] In some examples, data representative of each audio clip shown in list 606 may be maintained by programming system 302. For example, programming system 302 may locally store audio files representative of the audio clips (e.g., as audio clip data 508 in storage facility 504). To illustrate, programming system 302 may import (e.g., by copying) a plurality of audio files (e.g., tracks) that each include one or more audio clips from a compact disc ("CD"). Additionally or alternatively, programming system 302 may download or remotely access (e.g., by way of a network, a media player device plugged into programming system 302, etc.) an audio file stored within a different computing device or database.

[0036] Returning to FIG. 6, the user may set the particular loudness level at which the audio clip is to be presented to the patient by interacting with field 610. For example, the user may input (e.g., type) the particular loudness level directly into field 610, incrementally increase or decrease the loudness level by selecting up arrow button 612 or down arrow button 614, and/or set the loudness level in any other suitable manner. As shown in FIG. 6, the user has set the loudness level to be 63 dB HL.

[0037] Once the desired audio clip and loudness level have been selected, the user may select option 616 to direct programming system 302 to begin presenting the audio clip to the patient at the selected loudness level.

[0038] In some examples, emulation facility 502 may calibrate (e.g., in response to a user selection of option 616 to begin presenting the audio clip to the patient) the audio clip to ensure that the audio clip actually has the particular loudness level selected by the user. For example, with respect to the example shown in FIG. 6, emulation facility 502 may calibrate the audio clip entitled "Track B" to ensure that the audio clip actually has a loudness level of 63 dB HL when the audio clip is presented to the patient.

[0039] Calibration of the audio clip may ensure that the audio clip actually has the particular loudness level selected by the user, regardless of the initial loudness level of the audio clip (i.e., the loudness level at which the audio clip is recorded or otherwise created), regardless of the particular programming system 302 (i.e., the particular hardware) used to present the audio clip to the patient, and regardless of the particular components included in the cochlear implant system used by the patient. In this manner, a clinician may use different programming systems 302 (e.g., different computing devices) during different visits by the patient to the clinician's office to present audio clips to the patient and know that the selected loudness levels of the audio clips are accurate and consistent between the different programming systems 302.

[0040] Emulation facility 502 may calibrate the audio clip in any suitable manner. For example, FIG. 7 shows an exemplary flowchart 700 that includes various steps that may be performed by emulation facility 502 in order to calibrate an audio clip for a particular loudness level requested by a user. While FIG. 7 illustrates exemplary steps according to one embodiment, other embodiments may omit, add to, reorder, and/or modify any of the steps shown in FIG. 7.

[0041] As shown, in step 702, calibration of the audio clip may include determining, in response to the user input and based on an RMS value of a system calibration signal having a known loudness level, a target RMS value for the audio clip and that will produce the particular loudness level. The system calibration signal may include any suitable signal having a known (e.g., predetermined) loudness level. For example, the system calibration signal may include a one kilohertz sine wave that has a known loudness level of 60 dB SPL.

[0042] The RMS value of the system calibration signal may be determined (e.g., by emulation facility 502) in any suitable manner. For example, the RMS value of a sine wave may be determined in accordance with $a/\sqrt{2}$, where a is the amplitude of the sine wave and representative of the known loudness level of the system calibration signal.

[0043] In some examples, programming system 302 may store data representative of the RMS value of the system calibration signal together with data representative of the known loudness level of the system calibration signal and that corresponds to the RMS value. Emulation facility 502 may access this data when determining the target
5 RMS value or the calibration signal. Emulation facility 502 may alternatively access the data representative of the RMS value of the system calibration signal from a source other than programming system 302 in any suitable manner.

[0044] Emulation facility 502 may use the RMS value of the system calibration signal to determine the target RMS value for the audio clip in any suitable manner. For
10 example, if the known loudness level of the system calibration signal is a_1 , the RMS value of the system calibration signal is RMS_1 , the particular loudness level requested by the user is a_2 , and the target RMS value of the audio clip that will result in the audio clip having the particular loudness level is RMS_2 , emulation facility 502 may determine the target RMS value by calculating the following equation: $RMS_2 = RMS_1 * a_2 / a_1$.

[0045] In step 704, emulation facility 502 may determine an initial RMS value of the audio clip. As used herein, the "initial RMS value" of the audio clip refers to the original
15 RMS value of the audio clip before it is calibrated. Emulation facility 502 may determine the initial RMS value of the audio clip in any suitable manner. For example, emulation facility 502 may store information representative of the initial RMS value of
20 the audio clip within metadata associated with the audio clip and determine the initial RMS value of the audio clip by accessing the metadata. To illustrate, when an audio clip is initially loaded onto (e.g., copied or downloaded by) programming system 302, emulation facility 502 may measure the RMS value of the audio clip and designate the measured RMS
25 value as the initial RMS value of the audio clip. The measured RMS value may be stored in metadata associated with the audio clip and then accessed as needed by emulation facility 502 in order to determine the initial RMS value of the audio clip.

[0046] As mentioned, an audio file stored or otherwise accessed by emulation
30 facility 502 may include a plurality of audio clips (e.g., a plurality of audio clips separated by periods of silence). In this scenario, emulation facility 502 may determine the initial RMS value of a particular audio clip included in the audio file by measuring an RMS value of an entire audio file and designating the measured RMS value as the initial RMS value of the audio clip. Hence, in this embodiment, each audio clip included in the audio file may be assigned the same initial RMS value. Alternatively, emulation

facility 502 may measure individual RMS values for each audio clip included in an audio file.

[0047] In some alternative examples, a single calibration track may be provided for a set of audio files that each include one or more audio clips. For example, a CD may

5 include a calibration track associated with a remaining number of tracks on the CD.

The calibration track may include an audio clip encoded at the same loudness level of the other tracks on the CD. Hence, when the CD is loaded onto the programming system 302, emulation facility 502 may recognize the presence of the calibration track and measure the RMS value of the calibration track. The measured RMS value may be
10 designated by emulation facility 502 as the initial RMS value of each of the audio clips included in the remaining tracks on the CD. In this manner, programming system 302 may avoid having to measure the RMS values of each of the individual tracks provided on the CD.

[0048] In step 706, emulation facility 502 may determine, based on the initial RMS
15 value of the audio clip and the target RMS value, a gain factor that, when applied to the audio clip, will result in the audio clip having the target RMS value and the particular loudness level. This may be performed in any suitable manner. For example, emulation facility 502 may set the gain factor to be substantially equal to a difference between the target RMS value and the initial RMS value.

[0049] To illustrate, if the target RMS value is higher than the initial RMS value (i.e.,
20 if the particular loudness level requested by the user is higher than the original loudness level of the audio clip), emulation facility 502 may set the gain factor to a value that amplifies the audio clip when the audio clip is presented to the patient. Alternatively, if the target RMS value is lower than the initial RMS value (i.e., if the
25 particular loudness level requested by the user is lower than the original loudness level of the audio clip), emulation facility 502 may set the gain factor to a value that attenuates the audio clip when the audio clip is presented to the patient.

[0050] In step 708, emulation facility 502 may apply the gain factor to the audio clip. This may be performed in any suitable manner. For example, emulation facility 502
30 may apply the gain factor to the audio clip in real time as the audio clip is being streamed by emulation facility 502 to the sound processor of the cochlear implant system. Additionally or alternatively, emulation facility 502 may apply the gain factor to the audio clip before the audio clip is streamed to the sound processor (e.g., by buffering data representative of the gain factor-applied audio clip).

[0051] Once the audio clip has been calibrated (or as the audio clip is being calibrated in real time), emulation facility 502 may present the calibrated audio clip to the patient. This may be performed in any suitable manner. For example, emulation facility 502 may digitally stream the audio clip to the sound processor included in the cochlear implant system. In some examples, the calibrated audio clip may be digitally streamed to the sound processor without the calibrated audio clip ever being converted to an analog signal. This may ensure that the calibrated audio clip is presented at the specified loudness level.

[0052] Emulation facility 502 may perform various other types of operations configured to emulate conditions within a sound booth for a cochlear implant patient. Some of these operations will now be described.

[0053] In some examples, emulation facility 502 may emulate “silence” perceived by a typical patient (i.e., a patient that has a cochlear implant system with an enabled microphone) in a sound booth. The silence may be perceived, for example, by the patient after a particular audio clip is done being presented to the patient. While the patient may not consciously recognize that the silence actually has a loudness level (which may be caused, for example, by a noise floor of the sound booth environment) when he or she hears the silence, the patient may readily recognize the absence of silence (i.e., absolute silence that occurs when the microphone of the cochlear implant system is disabled and no audio clips are being presented to the patient). This may undesirably interfere with testing of the patient’s ability to hear quiet sounds because the contrast between absolute silence and when the quiet sound begins is more pronounced than when the patient can perceive actual silence.

[0054] Emulation facility 502 may emulate silence in any suitable manner. For example, emulation facility 502 may maintain data representative of an audio clip that is representative of silence within the sound booth (such an audio clip may be referred to herein as a “silence clip”). The silence clip may be generated in any suitable manner. For example, the silence clip may be generated by recording an interval of silence within the sound booth. The recording may be performed in any suitable sound booth that has characteristics typical of most sound booths. Alternatively, the silence clip may be generated by generating a silence clip that has a computer generated noise floor similar to that found in a sound booth.

[0055] The silence clip may be presented to the patient during intervals of silence that temporally separate audio clips representative of speech and/or other signals of

interest. For example, FIG. 8 shows an exemplary presentation 800 of audio clips separated by intervals of silence. As shown, emulation facility 502 may present an audio clip labeled “audio clip A” during a time interval defined by times t_0 and t_1 .

Emulation facility 502 may detect a completion of audio clip A, and, in response,

5 present the silence clip (labeled “silence clip” in FIG. 8) until the next audio clip (i.e., the audio clip labeled “audio clip B”) is presented. As shown, the interval of silence is defined by times t_1 and t_2 . As shown, emulation facility 502 may subsequently present audio clip B, then the silence clip, and then an audio clip labeled “audio clip C”. This pattern may continue until all of the desired audio clips are presented to the patient.

10 **[0056]** In some examples, emulation facility 502 may emulate conditions within a sound booth for a patient associated with a cochlear implant system by emulating a noise floor of a sound processor included in the cochlear implant system. It will be recognized that each sound processor has an inherent noise floor caused by the electrical noise of the analog signal path of the sound processor. However, this analog
15 signal path is bypassed in accordance with the systems and methods described herein (because audio clips are digitally streamed to the sound processor). This may create a problem when measuring thresholds or other performance characteristics of the cochlear implant system.

[0057] To emulate the noise floor of the sound processor, emulation facility 502 may
20 maintain or otherwise access data representative of a recording of the noise floor of the sound processor. The recording of the noise floor may then be mixed in to the calibrated audio clip (e.g., in real time as the calibrated audio clip is presented to the patient) so that the calibrated audio clip includes the recording of the noise floor when the calibrated audio clip is presented to the patient. The mixing may be performed in
25 any suitable manner.

[0058] The recording of the noise floor of the sound processor may be generated by programming system 302 or by a system separate from programming system 302. In some examples, the noise floor recording is specific to the actual sound processor being used by the patient. Alternatively, the noise floor recording corresponds to a
30 particular type of sound processor (e.g., a particular model of sound processor provided by a particular manufacturer).

[0059] In some examples, emulation facility 502 may emulate conditions within a sound booth for a patient associated with a cochlear implant system by emulating a spectral signature of the cochlear implant system. The spectral signature may be

influenced by various factors that are bypassed or avoided by digitally streaming audio clips to the patient. Such factors may include, but are not limited to, filtering induced by a microphone included in the cochlear system, mounting characteristics of the microphone, pre-emphasis filtering performed by a sound processor included in the sound processor, etc.

[0060] To emulate the spectral signature of the cochlear implant system, emulation facility 502 may maintain or otherwise access data representative of the spectral signature. Emulation facility 502 may then filter the calibrated audio clip in accordance with the spectral signature as the calibrated audio clip is presented to the patient. In this manner, the calibrated audio clip may be filtered in a manner similar to how it would be filtered if the audio clip were to be presented to the patient in the analog domain.

[0061] The spectral signature may be specific to the actual cochlear implant system being used by the patient. Alternatively, the spectral signature may be associated with a particular type of cochlear implant system (e.g., a particular model of sound processor, microphone, etc.).

[0062] In some examples, emulation facility 502 may emulate conditions within a sound booth for a patient associated with a cochlear implant system by emulating an audiometer associated with the sound booth. For example, an audiometer used in conjunction with a sound booth may display data representative of loudness levels using a first unit of measurement (e.g., dB HL). Hence, the same unit of measurement may be displayed in GUIs presented by emulation facility 502. To illustrate, field 610 in GUI 600 may display the presentation level in dB HL. However, for various reasons, it may be advantageous for emulation facility 502 to use a second unit of measurement (e.g., dB SPL) for the presentation level when performing various operations described herein (e.g., when determining the target RMS value for the audio clip). To facilitate this, emulation facility 502 may convert the first unit of measurement to the second unit of measurement in any suitable manner. For example, emulation facility 502 may perform the conversion by taking into account various characteristics of the audio clip and the way in which it is being presented to the user. To illustrate, different conversion factors may be used for speech versus a tone of one frequency versus a tone of another frequency, etc. Moreover, different conversion factors may be used depending on whether emulation facility 502 is emulating playback via free-field, via supra-aural headphones, or via insert earphones.

[0063] In some examples, emulation facility 502 may facilitate multi-channel mixing of audio clips. A user may specify an exact loudness level for each audio clip. This may facilitate, for example, variable signal-to-noise ratios without having to pre-record signals of interest at the different signal-to-noise ratios.

5 **[0064]** To illustrate, FIG. 9 shows an exemplary GUI 900 that may be provided for display by emulation facility 502 and that may be used to facilitate mixing (i.e., concurrent presentation) of two audio clips. GUI 900 is similar to GUI 600, except that in GUI 900, the user may select two audio clips for concurrent presentation to the user. For example, the user may select a first audio clip from a first list 902-1 and a second
10 audio clip from a second list 902-2. In some examples, the first audio clip includes a signal of interest (e.g., speech) and the second audio clip includes noise (e.g., background noise that the user desires to present together with the signal of interest). In some examples, the second audio clip may be presented in a continuous fashion in the background while different first audio clips are selected and presented.

15 **[0065]** As shown, GUI 900 includes a first field 904-1 with which the user may interact to set a particular loudness level at which the first audio clip is to be presented to the patient. GUI 900 also includes a second field 904-2 with which the user may interact to set a particular loudness level at which the second audio clip is to be presented to the patient. If the second audio clip is representative of noise, the
20 loudness level at which the second audio clip is to be presented to the patient may be referred to herein as a “noise loudness level.” As shown in FIG. 9, the user has set the loudness level of the first audio clip to be 63 dB HL and the loudness level of the second audio clip to be 43 dB HL.

[0066] Once the desired audio clips and their corresponding loudness levels have
25 been selected, the user may select option 906 to direct programming system 302 to begin presenting the audio clip to the patient at the selected loudness level.

[0067] In some examples, emulation facility 502 may facilitate presenting the same audio clip at different loudness levels to the patient and to a clinician. For example, a clinician may listen to what is being presented to the patient by way of an independent
30 monitor path. In this example, a particular audio clip may be presented at a first loudness level to the patient and at a second loudness level to the clinician.

[0068] In some examples, emulation facility 502 may calibrate (e.g., in response to a user selection of option 906 to begin presenting the audio clips to the patient) each audio clip to ensure that the audio clips actually have the particular loudness levels

selected by the user. The calibration may be performed in any of the ways described herein.

[0069] Once the audio clips have been calibrated, emulation facility 502 may concurrently present the first and second audio clips to the patient (e.g., by mixing the first and second audio clips in real-time as they are presented to the patient).

[0070] It will be recognized that as an audio clip is calibrated, multiple gain factors may be generated for application to the audio clip. For example, a first gain factor may be generated based on the loudness level selected by the patient and a second gain factor may be generated in order to emulate one or more conditions in the sound booth.

In some examples, the gain factors may be combined into a single composite gain factor that is applied to the audio clip in a single step. In this manner, repeated manipulation of the audio clip (which could lead to a loss of precision for the audio clip) may be avoided.

[0071] In some examples, emulation facility 502 may emulate conditions within a sound booth for a patient associated with a cochlear implant system by facilitating streaming of continuous audio content to the patient. The continuous audio content may include, for example, live speech provided via a microphone, audio delivered from an external auxiliary device (e.g., an MP3 player, a radio, etc.), and/or any other audio content not pre-recorded and stored as a file within storage facility 504.

[0072] Emulation facility 502 may facilitate streaming of continuous audio content to the patient in any suitable manner. For example, emulation facility 502 may display, within one or more GUIs, one or more source volume unit ("VU") meters that may be used by a user (e.g., a clinician) to monitor the loudness level of the continuous audio content. The user may use the one or more source VU meters to ensure that the loudness level of the continuous audio content is relatively constant.

[0073] For example, the user may play continuous audio content (e.g., from an external auxiliary device plugged into programming system 302). While doing so, the user may view a source VU meter displayed within a GUI. The source VU meter is configured to graphically portray a loudness level of the continuous audio content. The user may adjust the volume on the auxiliary device so that the source VU meter is at 0 dB. One or more offset levels may then be applied by emulation facility 502 (e.g., in response to a user selection of the one or more offset levels) in order to ensure that the loudness level of the continuous audio content as perceived by the patient is calibrated and constant.

[0074] FIG. 10 illustrates an exemplary method 1000 of emulating a sound booth for a cochlear implant patient. While FIG. 10 illustrates exemplary steps according to one embodiment, other embodiments may omit, add to, reorder, and/or modify any of the steps shown in FIG. 10. One or more of the steps shown in FIG. 10 may be performed
5 by programming system 302 and/or any implementation thereof.

[0075] In step 1002, a programming system isolates a patient from an acoustic environment by disabling a microphone included in a cochlear implant system associated with the patient. Step 1002 may be performed in any of the ways described herein.

10 **[0076]** In step 1004, the programming system receives user input representative of a request to present an audio clip to the patient at a particular loudness level. Step 1004 may be performed in any of the ways described herein.

[0077] In step 1006, the programming system calibrates the audio clip. Step 1006 may be performed in any of the ways described herein.

15 **[0078]** In step 1008, the programming system presents the calibrated audio clip. Step 1008 may be performed in any of the ways described herein.

[0079] In certain embodiments, one or more of the processes described herein may be implemented at least in part as instructions embodied in a non-transitory computer-readable medium and executable by one or more computing devices. In general, a
20 processor (e.g., a microprocessor) receives instructions, from a non-transitory computer-readable medium, (e.g., a memory, etc.), and executes those instructions, thereby performing one or more processes, including one or more of the processes described herein. Such instructions may be stored and/or transmitted using any of a variety of known computer-readable media.

25 **[0080]** A computer-readable medium (also referred to as a processor-readable medium) includes any non-transitory medium that participates in providing data (e.g., instructions) that may be read by a computer (e.g., by a processor of a computer). Such a medium may take many forms, including, but not limited to, non-volatile media, and/or volatile media. Non-volatile media may include, for example, optical or magnetic disks and other persistent memory. Volatile media may include, for example, dynamic
30 random access memory ("DRAM"), which typically constitutes a main memory. Common forms of computer-readable media include, for example, a disk, hard disk, magnetic tape, any other magnetic medium, a compact disc read-only memory ("CD-ROM"), a digital video disc ("DVD"), any other optical medium, random access memory

("RAM"), programmable read-only memory ("PROM"), erasable programmable read-only memory ("EPROM"), electrically erasable programmable read-only memory ("EEPROM"), a Flash EEPROM device, any other memory chip or cartridge, or any other tangible medium from which a computer can read.

5 **[0081]** FIG. 11 illustrates an exemplary computing device 1100 that may be specifically configured to perform one or more of the processes described herein. As shown in FIG. 11, computing device 1100 may include a communication interface 1102, a processor 1104, a storage device 1106, and an input/output ("I/O") module 1108 communicatively connected via a communication infrastructure 1110. While an
10 exemplary computing device 1100 is shown in FIG. 11, the components illustrated in FIG. 11 are not intended to be limiting. Additional or alternative components may be used in other embodiments. Components of computing device 1100 shown in FIG. 11 will now be described in additional detail.

[0082] Communication interface 1102 may be configured to communicate with one
15 or more computing devices. Examples of communication interface 1102 include, without limitation, a wired network interface (such as a network interface card), a wireless network interface (such as a wireless network interface card), a modem, an audio/video connection, and any other suitable interface.

[0083] Processor 1104 generally represents any type or form of processing unit
20 capable of processing data or interpreting, executing, and/or directing execution of one or more of the instructions, processes, and/or operations described herein. Processor 1104 may direct execution of operations in accordance with one or more applications 1112 or other computer-executable instructions such as may be stored in storage device 1106 or another computer-readable medium.

25 **[0084]** Storage device 1106 may include one or more data storage media, devices, or configurations and may employ any type, form, and combination of data storage media and/or device. For example, storage device 1106 may include, but is not limited to, a hard drive, network drive, flash drive, magnetic disc, optical disc, RAM, dynamic RAM, other non-volatile and/or volatile data storage units, or a combination or sub-
30 combination thereof. Electronic data, including data described herein, may be temporarily and/or permanently stored in storage device 1106. For example, data representative of one or more executable applications 1112 configured to direct processor 1104 to perform any of the operations described herein may be stored within

storage device 1106. In some examples, data may be arranged in one or more databases residing within storage device 1106.

[0085] I/O module 1108 may be configured to receive user input and provide user output and may include any hardware, firmware, software, or combination thereof

5 supportive of input and output capabilities. For example, I/O module 1108 may include hardware and/or software for capturing user input, including, but not limited to, a keyboard or keypad, a touch screen component (e.g., touch screen display), a receiver (e.g., an RF or infrared receiver), and/or one or more input buttons.

[0086] I/O module 1108 may include one or more devices for presenting output to a
10 user, including, but not limited to, a graphics engine, a display (e.g., a display screen), one or more output drivers (e.g., display drivers), one or more audio speakers, and one or more audio drivers. In certain embodiments, I/O module 1108 is configured to provide graphical data to a display for presentation to a user. The graphical data may be representative of one or more graphical user interfaces and/or any other graphical
15 content as may serve a particular implementation.

[0087] In some examples, any of the facilities described herein may be implemented by or within one or more components of computing device 1100. For example, one or more applications 1112 residing within storage device 1106 may be configured to direct
20 processor 1104 to perform one or more processes or functions associated with emulation facility 502. Likewise, storage facility 504 may be implemented by or within storage device 1106.

[0088] In the preceding description, various exemplary embodiments have been described with reference to the accompanying drawings. It will, however, be evident that various modifications and changes may be made thereto, and additional
25 embodiments may be implemented, without departing from the scope of the invention as set forth in the claims that follow. For example, certain features of one embodiment described herein may be combined with or substituted for features of another embodiment described herein. The description and drawings are accordingly to be regarded in an illustrative rather than a restrictive sense.

30

CLAIMS

What is claimed is:

- 5 1. A system comprising:
 at least one physical computing device that:
 isolates a patient from an acoustic environment by disabling a microphone
 included in a cochlear implant system associated with the patient,
 receives user input representative of a request to present an audio clip to
10 the patient at a particular loudness level,
 calibrates the audio clip by
 determining, in response to the user input and based on a root
 mean square ("RMS") value of a system calibration signal having a known loudness
 level, a target RMS value for the audio clip and that will produce the particular loudness
15 level,
 determining an initial RMS value of the audio clip,
 determining, based on the initial RMS value of the audio clip and
 the target RMS value, a gain factor that, when applied to the audio clip, will result in the
 audio clip having the target RMS value and the particular loudness level, and
20 applying the gain factor to the audio clip; and
 presents the calibrated audio clip to the patient.
2. The system of claim 1, wherein the at least one physical computing
device:
25 presents a graphical user interface; and
 receives the user input by way of the graphical user interface.
3. The system of claim 2, wherein the at least one computing device:
 displays, within the graphical user interface, data representative of the particular
30 loudness level using a first unit of measurement; and
 performs the determination of the target RMS value using a second unit of
 measurement for the particular loudness level.
4. The system of claim 1, wherein the system calibration signal is a one
35 kilohertz sine wave.

5. The system of claim 1, wherein the at least one physical computing device stores data representative of the RMS value of the calibration signal and the known loudness level.

5

6. The system of claim 1, wherein the at least one physical computing device:

stores information representative of the initial RMS value of the audio clip within metadata associated with the audio clip; and

10

determines the initial RMS value of the audio clip by accessing the metadata associated with the audio clip.

7. The system of claim 1, wherein the at least one physical computing device determines the initial RMS value of the audio clip by:

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measuring an RMS value of the audio clip when the audio clip is loaded onto the at least one physical computing device; and

designating the measured RMS value as the initial RMS value of the audio clip.

8. The system of claim 1, wherein the at least one physical computing device determines the initial RMS value of the audio clip by:

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measuring an RMS value of an entire audio file that includes the audio clip and one or more additional audio clips; and

designating the measured RMS value as the initial RMS value of the audio clip.

9. The system of claim 1, wherein the at least one physical computing device determines the initial RMS value of the audio clip by:

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measuring an RMS value of a calibration track associated with the audio clip; and

designating the measured RMS value as the initial RMS value of the audio clip.

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10. The system of claim 1, wherein the at least one physical computing device determines the gain factor by setting the gain factor to be equal to a difference between the target RMS value and the initial RMS value.

11. The system of claim 1, wherein the applying of the gain factor to the audio clip amplifies the audio clip.

12. The system of claim 1, wherein the applying of the gain factor to the audio clip attenuates the audio clip.

13. The system of claim 1, wherein the at least one physical computing device presents the calibrated audio clip to the patient by digitally streaming the audio clip to a sound processor included in the cochlear implant system without converting the calibrated audio clip to an analog signal.

14. The system of claim 1, wherein the at least one physical computing device:
detects a completion of the presentation of the calibrated audio clip to the patient;
presents, in response to detecting the completion of the presentation of the calibrated audio clip to the patient, audio representative of silence within a sound booth;
and
continuing to present the audio representative of the silence within the sound booth until an additional audio clip is presented to the patient.

15. The system of claim 1, wherein the at least one physical computing device:
maintains a recording of a noise floor of a sound processor included in the cochlear implant system; and
mixes the recording of the noise floor of the sound processor into the calibrated audio clip so that the calibrated audio clip includes the recording of the noise floor of the sound processor when the calibrated audio clip is presented to the patient.

16. The system of claim 1, wherein the at least one physical computing device:
maintains data representative of a spectral signature of the cochlear implant system; and

filters the calibrated audio clip in accordance with the spectral signature as the calibrated audio clip is presented to the patient.

17. The system of claim 1, wherein:

5 the audio clip comprises a signal of interest;
the request to present the audio clip to the patient at the particular loudness level comprises a request to present the audio clip together with noise having a particular noise loudness level; and
the at least one physical computing device
10 calibrates an additional audio clip that comprises the noise so that the additional audio clip has the particular noise loudness level, and
presents the calibrated additional audio clip together concurrently with the calibrated audio clip by mixing the calibrated additional audio clip into the calibrated audio clip.

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18. The system of claim 1, wherein the at least one physical computing device further calibrates the audio clip by:

determining one or more additional gain factors that are to be applied to the audio clip; and

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combining the gain factor and the one or more additional gain factors into a single composite gain factor;

wherein the applying of the gain factor to the audio clip comprises applying the single composite gain factor to the audio clip.

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19. The system of claim 1, wherein the at least one physical computing device facilitates streaming, to the patient, of continuous audio content that is not pre-recorded and stored by the at least one physical computing device.

20. A system comprising:

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at least one physical computing device that:
isolates a patient from an acoustic environment by disabling a microphone included in a cochlear implant system associated with the patient,
maintains data representative of
a first audio clip that comprises speech,

a second audio clip that comprises speech different than the speech included in the first audio clip, and

a third audio clip representative of silence within a sound booth;

receives user input representative of a request to present, to the patient,

5 the first audio clip at a particular loudness level followed by an interval of silence followed by the second audio clip at the particular loudness level,

calibrates the first and second audio clips by

determining, in response to the user input and based on a root mean square ("RMS") value of a system calibration signal having a known loudness
10 level, a target RMS value for the first and second audio clips and that will produce the particular loudness level,

determining an initial RMS value of the first audio clip and an initial RMS value of the second audio clip,

determining, based on the initial RMS values of the first and
15 second audio clips and the target RMS value, a first gain factor that, when applied to the first audio clip, will result in the first audio clip having the target RMS value and the particular loudness level, and a second gain factor that, when applied to the second audio clip, will result in the second audio clip having the target RMS value and the particular loudness level, and

20 applying the first gain factor to the first audio clip and the second gain factor to the second audio clip,

presents the calibrated first audio clip to the patient,

detects a completion of the presentation of the calibrated first audio clip to the patient,

25 presents, in response to a completion of the presentation of the calibrated first audio clip to the patient and during the interval of silence, the third audio clip representative of silence within the sound booth, and

presents, in response to a completion of the interval of silence, the calibrated second audio clip to the patient.

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21. A method comprising:

isolating, by a programming system, a patient from an acoustic environment by disabling a microphone included in a cochlear implant system associated with the patient;

receiving, by the programming system, user input representative of a request to present an audio clip to the patient at a particular loudness level;

calibrating, by the programming system, the audio clip by

5 determining, in response to the user input and based on a root mean square ("RMS") value of a system calibration signal having a known loudness level, a target RMS value for the audio clip and that will produce the particular loudness level,

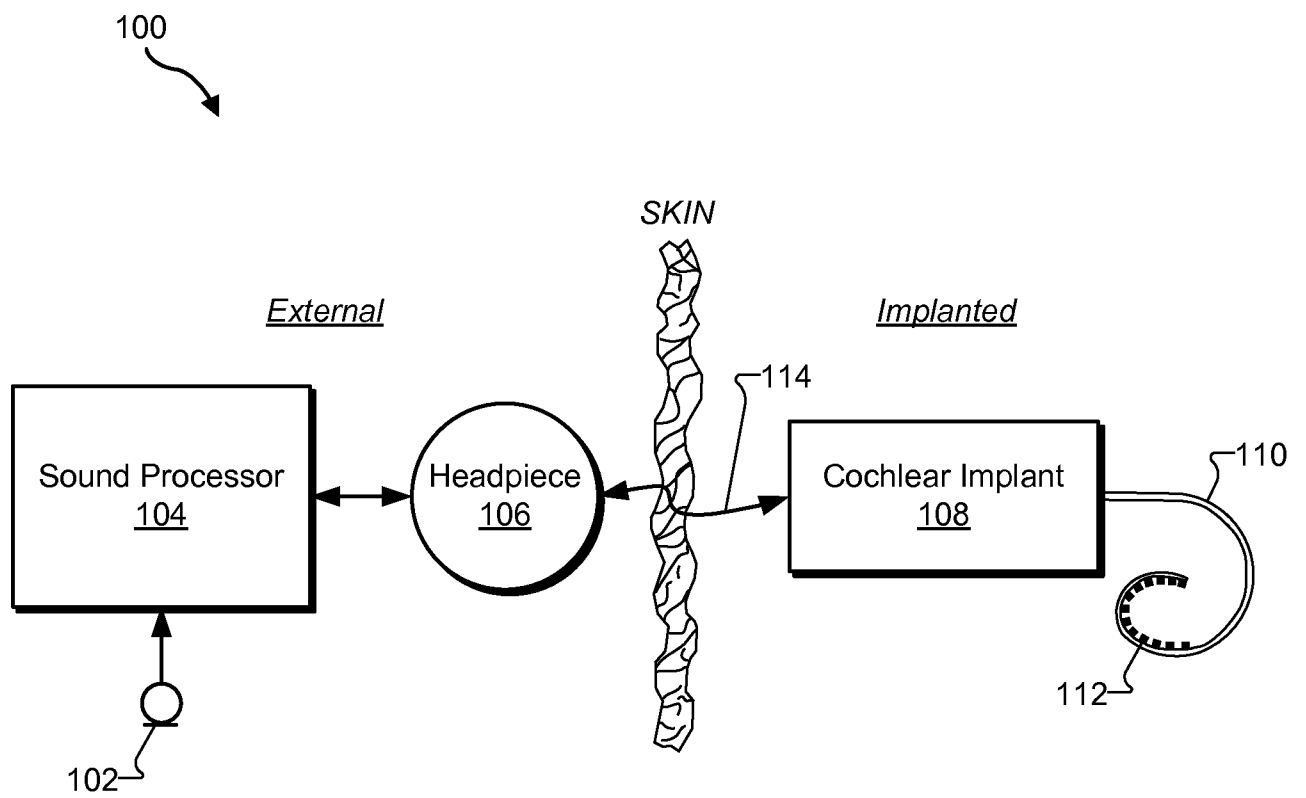
determining an initial RMS value of the audio clip,

determining, based on the initial RMS value of the audio clip and the target RMS value, a gain factor that, when applied to the audio clip, will result in the
10 audio clip having the target RMS value and the particular loudness level, and

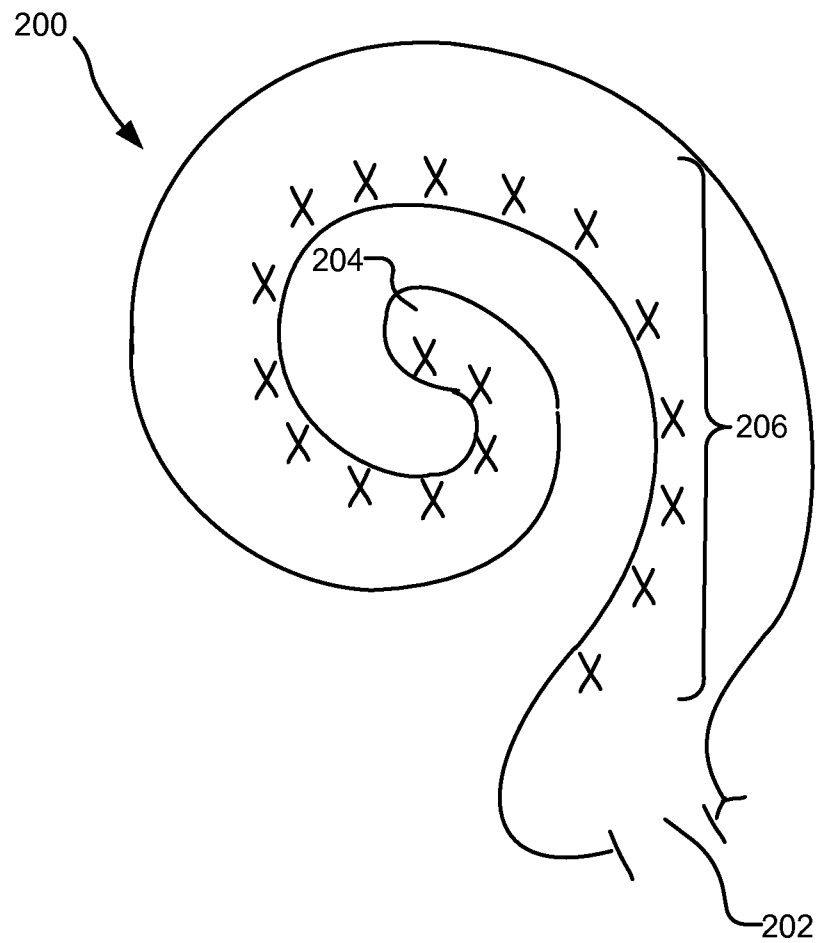
applying the gain factor to the audio clip; and

presenting, by the programming system, the calibrated audio clip to the patient.

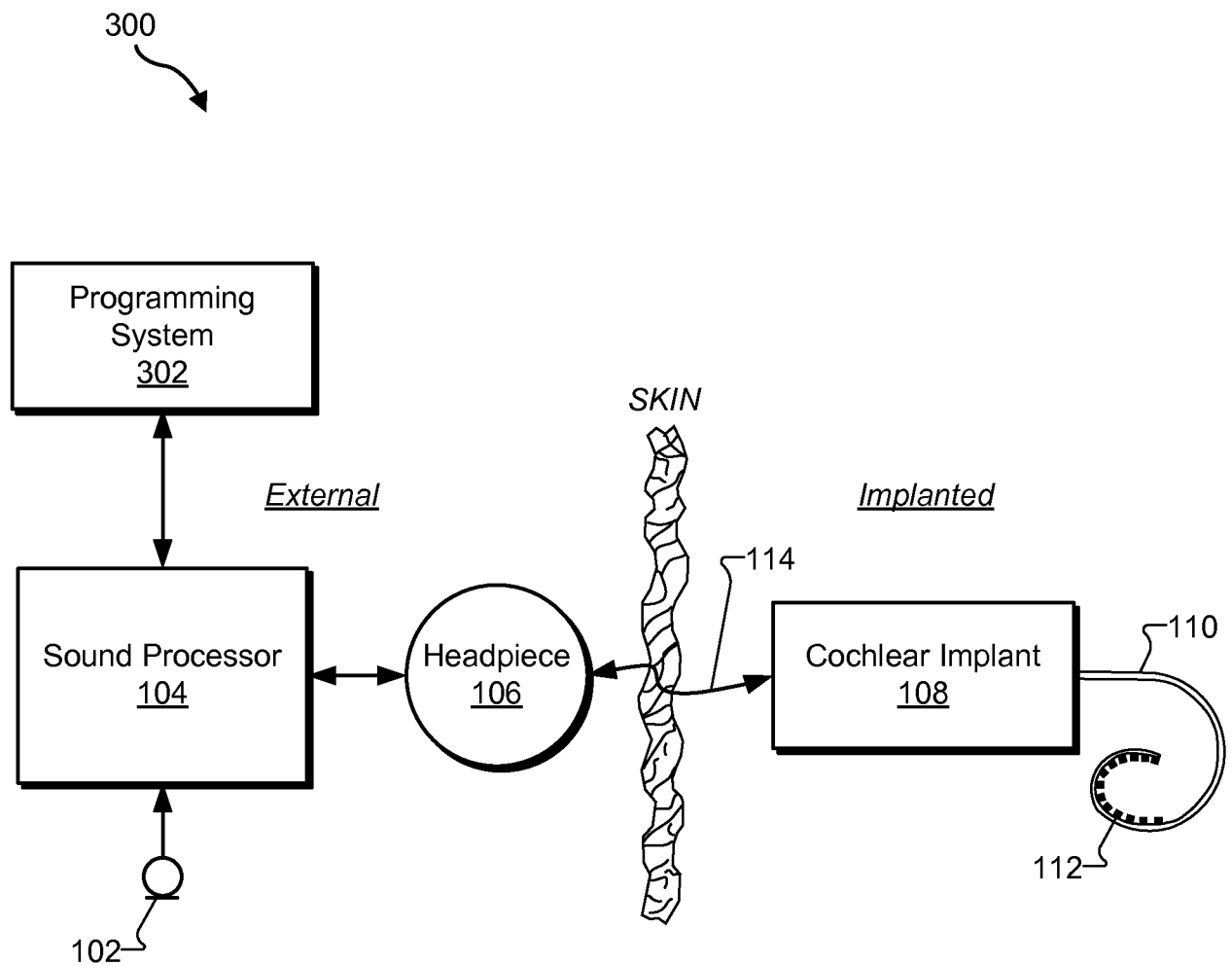
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**Fig. 1**

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**Fig. 2**

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**Fig. 3**

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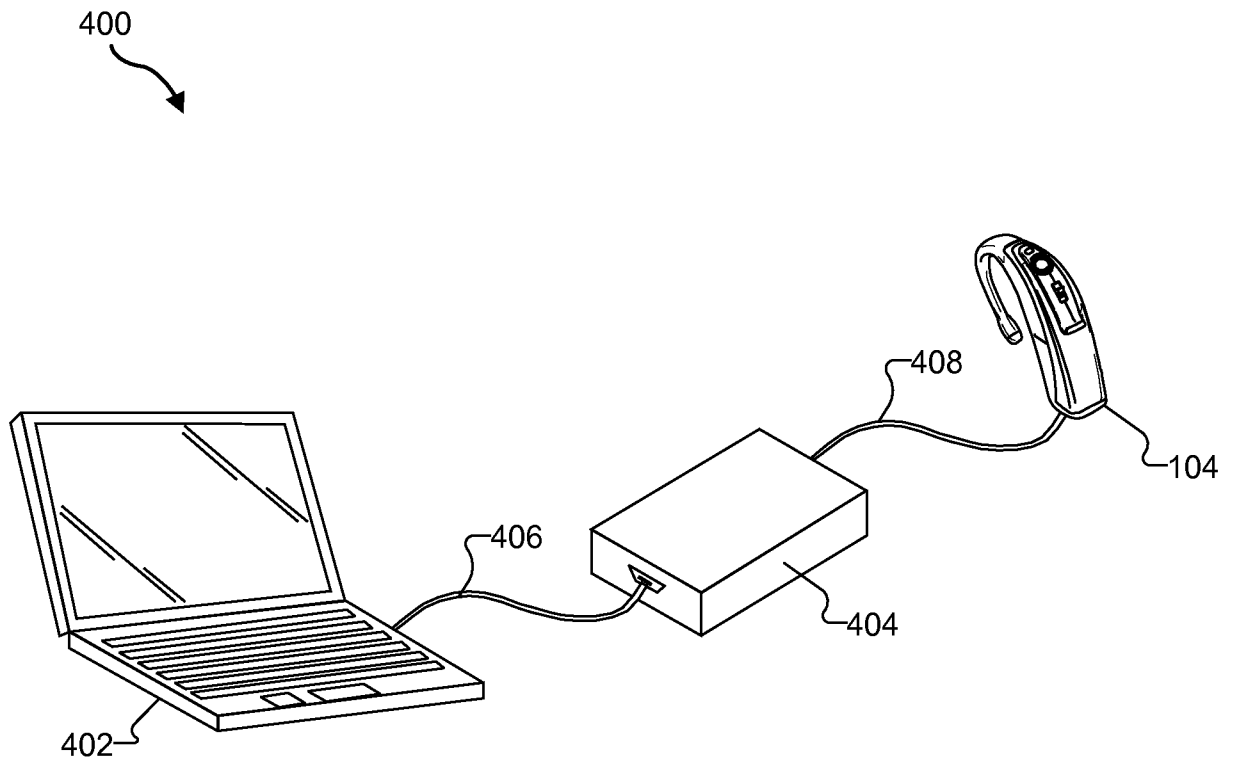


Fig. 4

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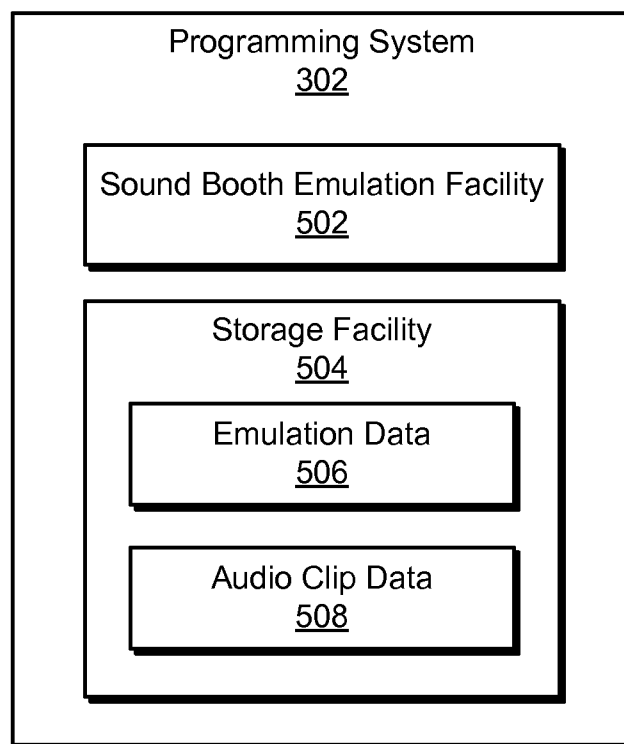


Fig. 5

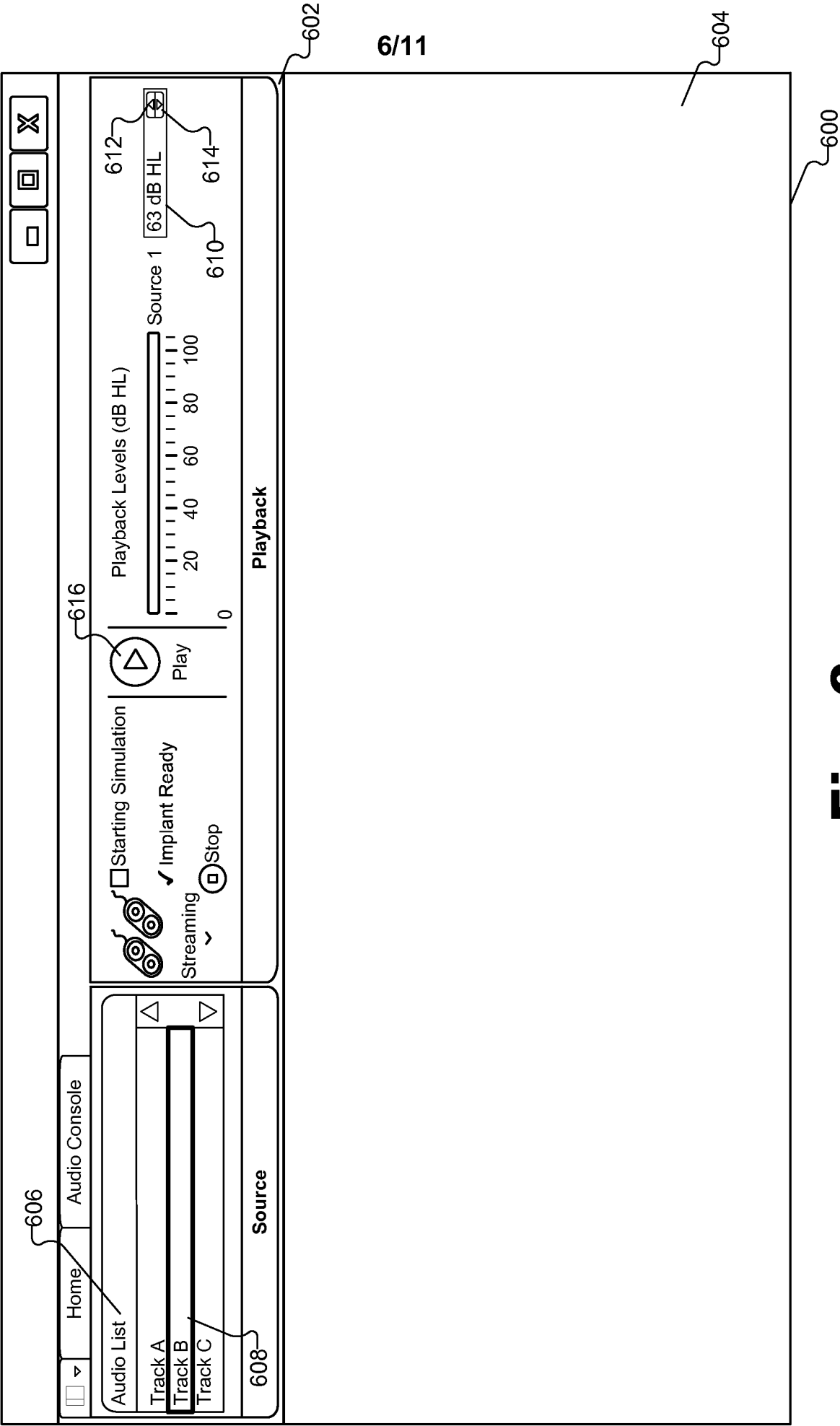
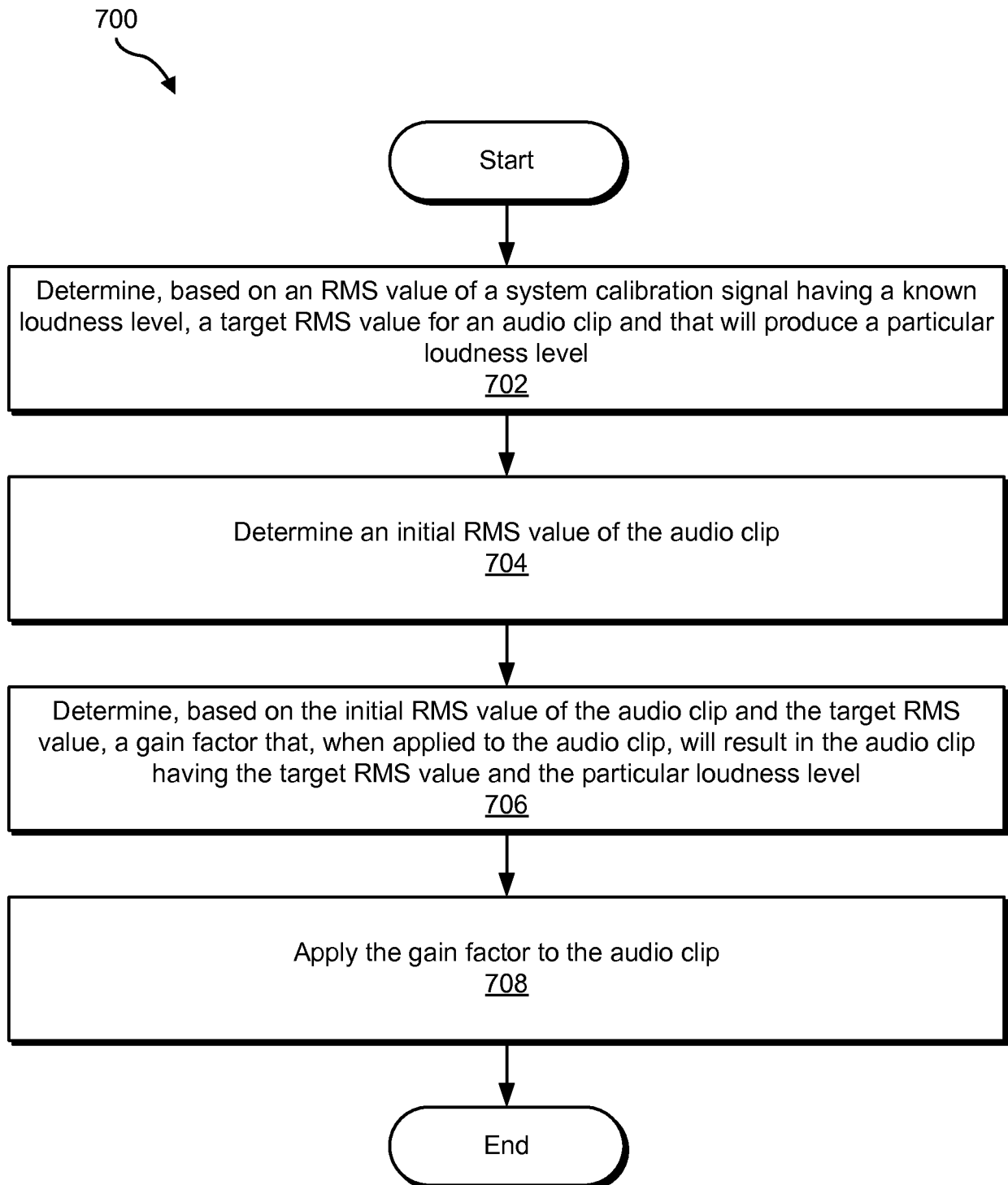


Fig. 6

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**Fig. 7**

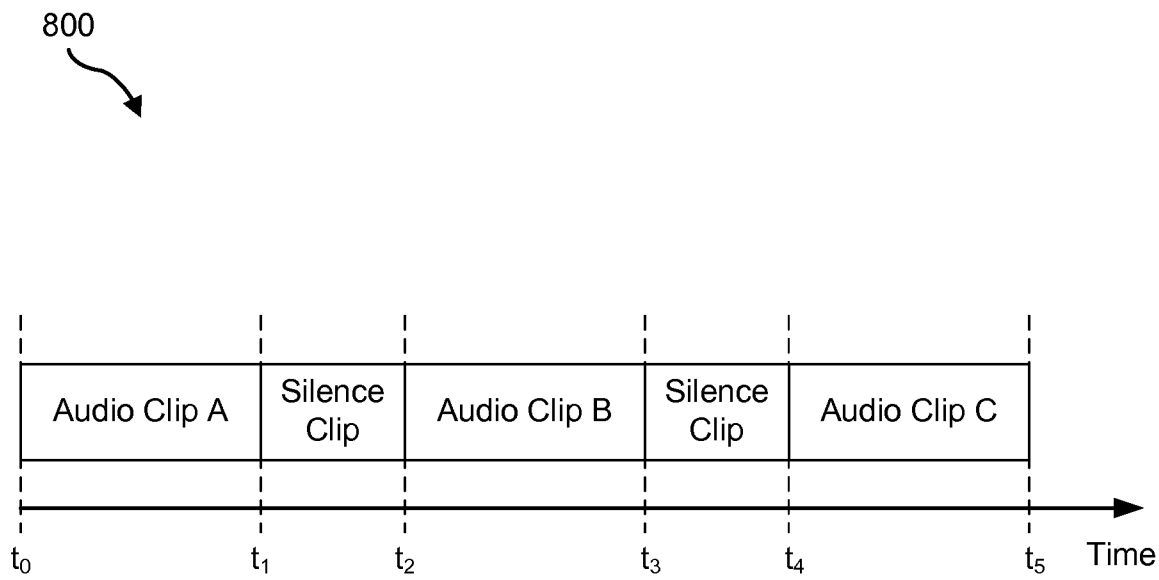


Fig. 8

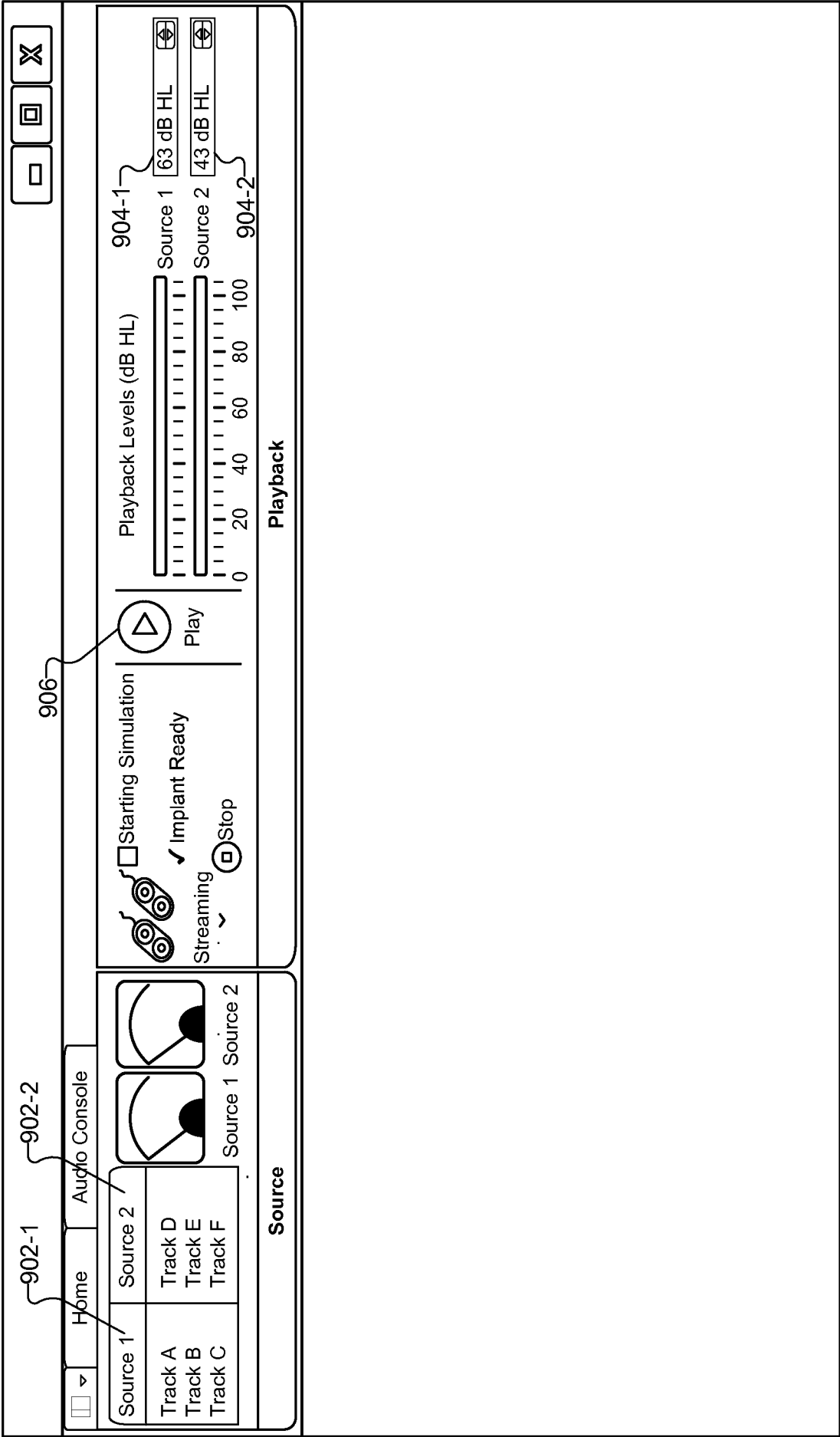
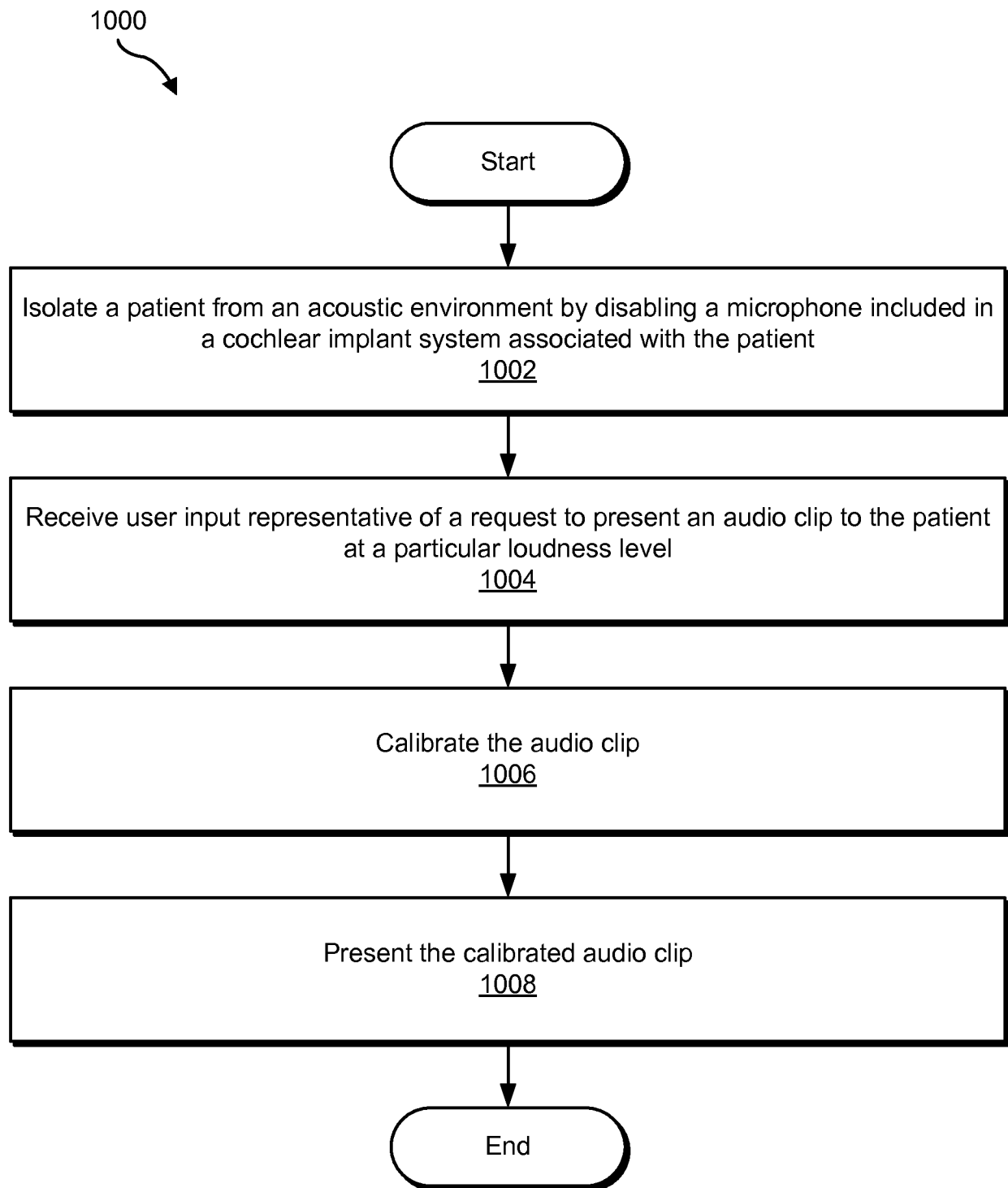
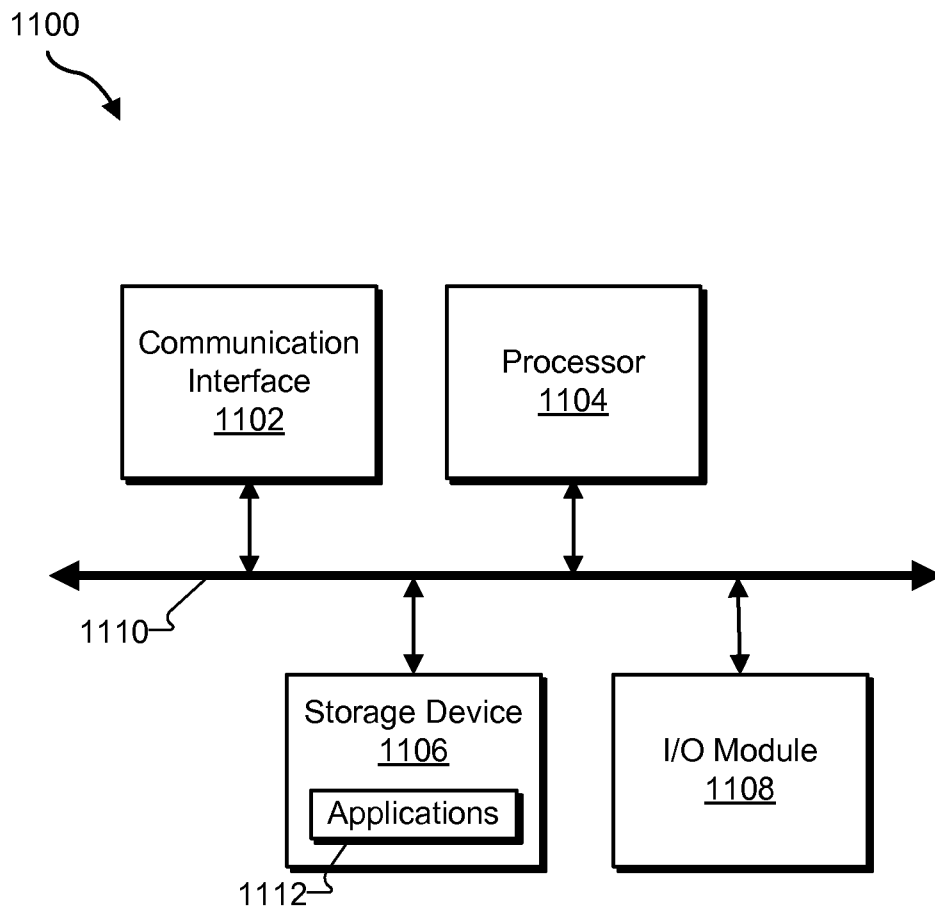


Fig. 9

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**Fig. 10**

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**Fig. 11**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2015/052153

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04R25/00

ADD. A61B5/12

A61N1/05

A61N1/36

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04R A61B A61N

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

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

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009/264963 A1 (FALTYS MICHAEL A [US] ET AL) 22 October 2009 (2009-10-22) paragraph [0014] - paragraph [0017] paragraphs [0030], [0048] paragraph [0064] - paragraph [0065] paragraph [0071] - paragraph [0074] paragraph [0081] - paragraph [0086] figures 2A, 2B, 4A, 7, 8 -----	1-21
Y	US 2013/159852 A1 (CLASSEN HOLGER [DE] ET AL) 20 June 2013 (2013-06-20) paragraph [0005] - paragraph [0007] paragraph [0018] paragraph [0024] - paragraph [0033] figure 2 ----- -/--	1-3,5-21



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

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Date of the actual completion of the international search

20 June 2016

Date of mailing of the international search report

24/06/2016

Name and mailing address of the ISA/

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Valenzuela, Miriam

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2015/052153

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	----- US 2007/043403 A1 (BLAMEY PETER J [AU] ET AL) 22 February 2007 (2007-02-22) paragraph [0037] - paragraph [0049] figure 2 -----	1-21

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Information on patent family members

International application No

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