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(54) **METHOD AND DEVICE FOR PROVIDING STIMULATION TO OBSTRUCTED COCHLEA**

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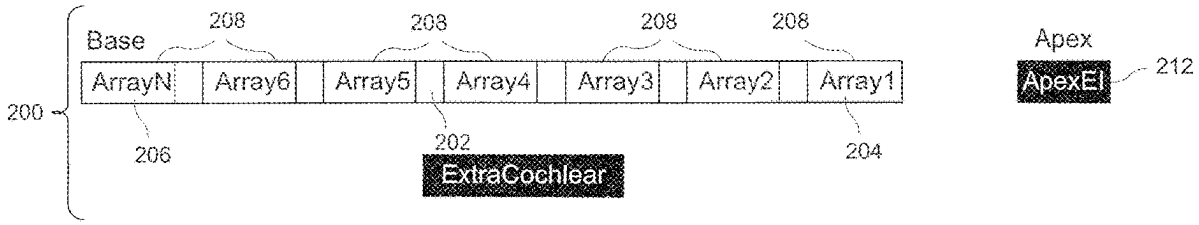
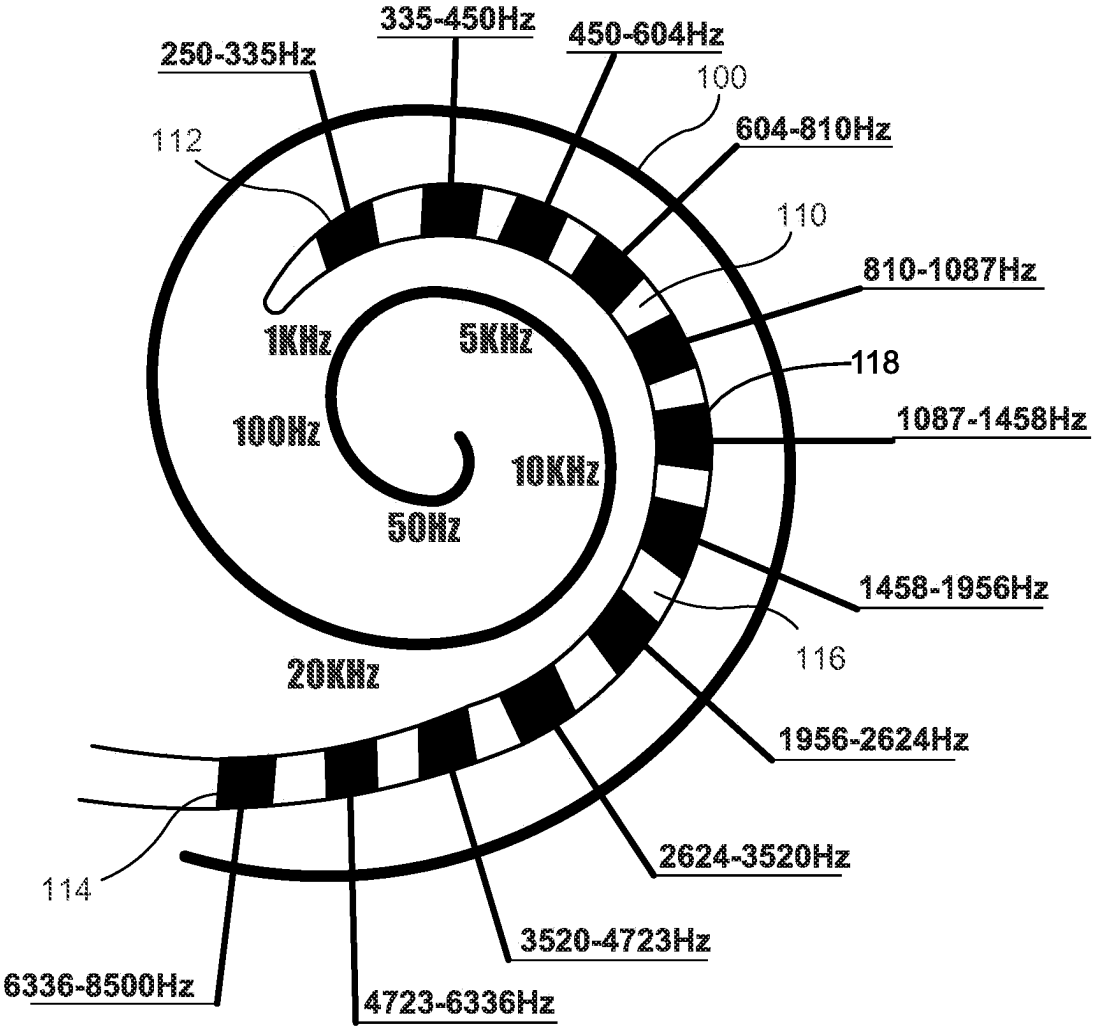
(57) **ABSTRACT**

A cochlear implant includes first and second ground electrodes, a flexible electrode array, a flexible electrode array, and a processing arrangement. The first electrode is positioned external to a cochlea of a patient. The second electrode is positioned within the cochlea on an apical side of an obstruction within the cochlea. The array has distal and proximal ends defining a length therebetween. The array includes electrode contacts arranged along at least a portion of the length. The array is inserted into the cochlea such that the distal end advances from a base of the cochlea towards an apex of the cochlea to a point located basally of the obstruction. The arrangement maps a first one of the contacts to the first electrode for providing a first electrical stimulation from the first contact to the first electrode to stimulate hearing of the patient at a first location in the cochlea, and a second mapping providing a second electrical stimulation from the first contact to the second electrode to stimulate hearing of the patient at a second location in the cochlea. The first location is positioned adjacent to the first contact when the implant is inserted into the cochlea in an operating position, and the second location is positioned further towards the apex as compared to the first contact when the implant is in the operating position.




335-450Hz
450-604Hz
250-335Hz
100
604-810Hz
112
110
810-1087Hz
1KHz
5KHz
118
1087-1458Hz
100Hz
10KHz
50Hz
1458-1956Hz
116
20KHz
1956-2624Hz
2624-3520Hz
114
3520-4723Hz
6336-8500Hz
4723-6336Hz

F I G. 1

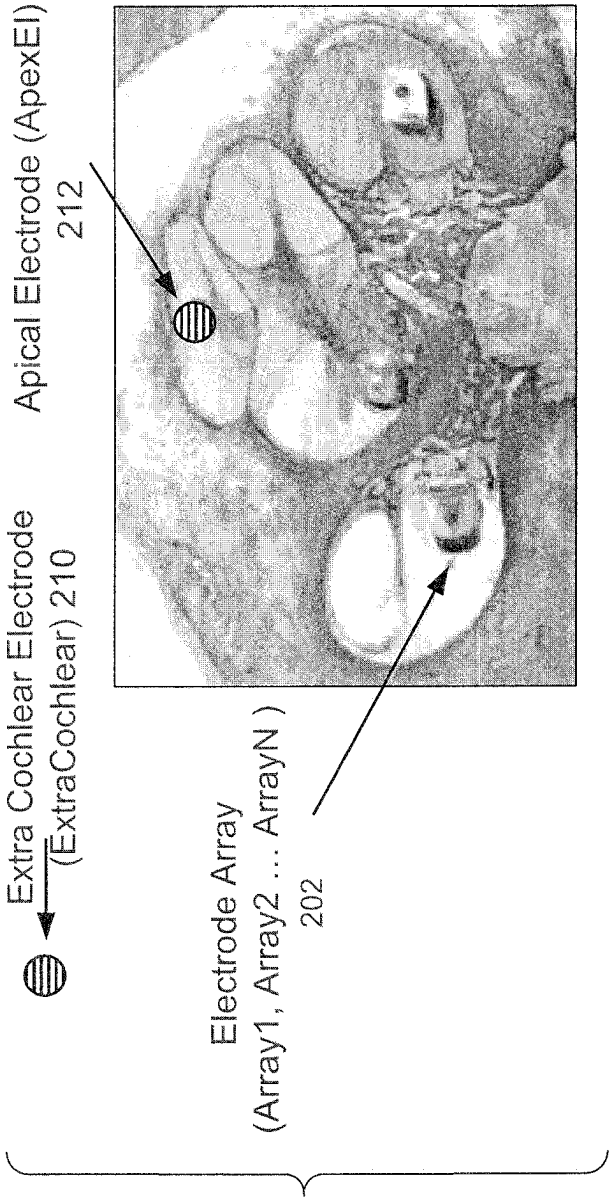

Extra Cochlear Electrode
(ExtraCochlear) 210
Apical Electrode (ApexEI)
212
Electrode Array
(Array1, Array2 ... ArrayN)
202

FIG. 3

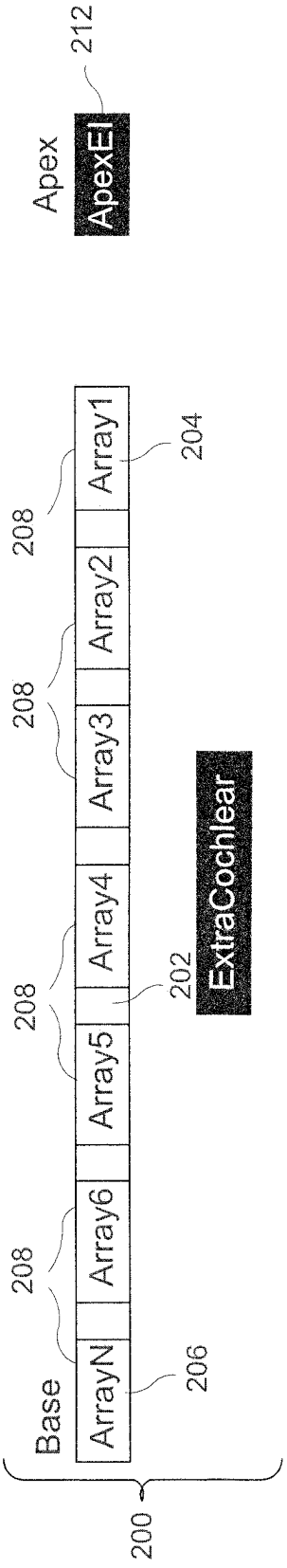

Apex
ApexEI
212
208
Array1
Array2
Array3
Array4
Array5
Array6
ArrayN
204
202
ExtraCochlear
Base
206
200

FIG. 2

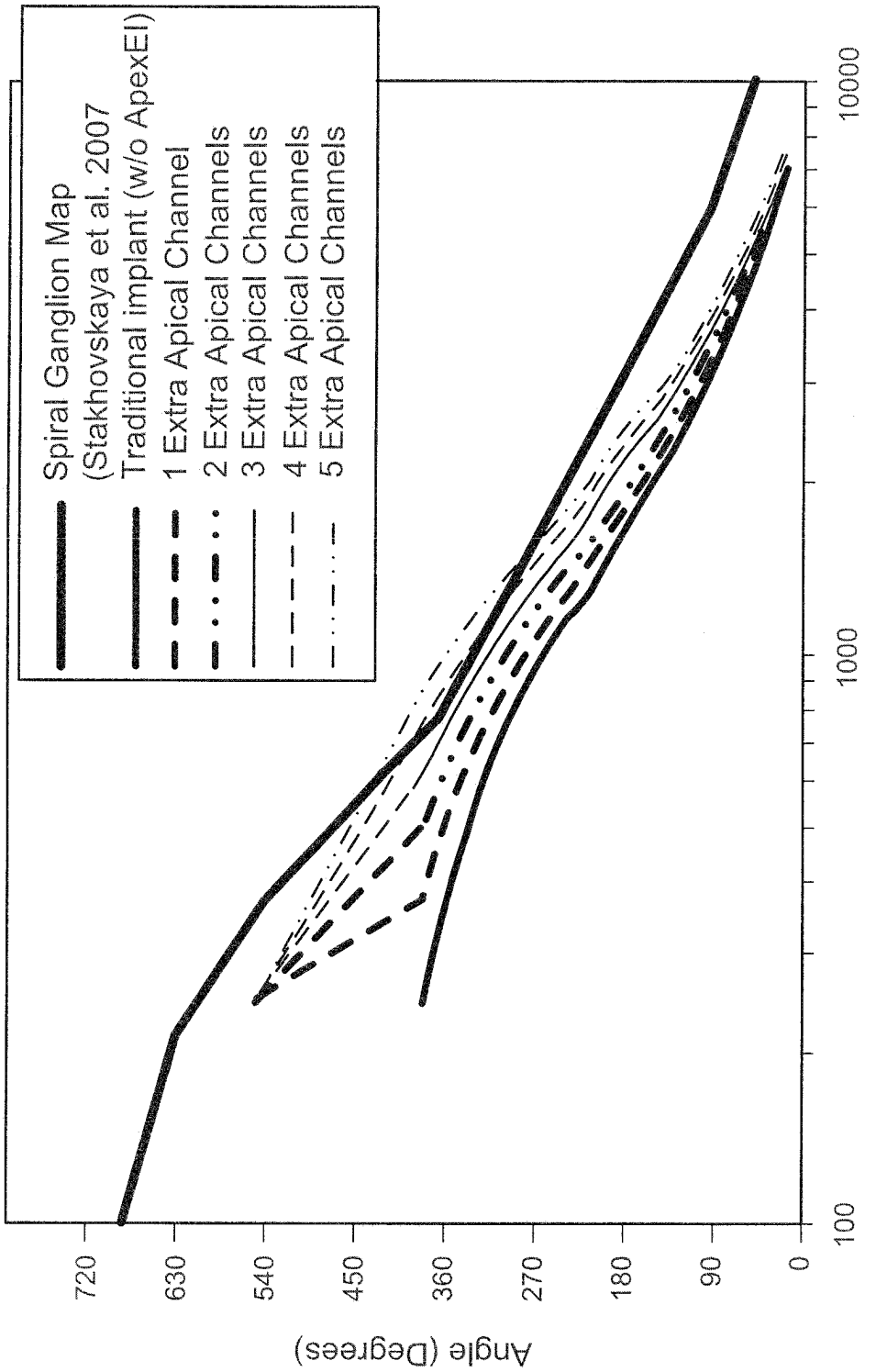

Spiral Ganglion Map
(Stakhovskaya et al. 2007
Traditional implant (w/o ApexEI)
1 Extra Apical Channel
2 Extra Apical Channels
3 Extra Apical Channels
4 Extra Apical Channels
5 Extra Apical Channels
720
630
540
450
360
270
180
90
0
Angle (Degrees)
100
1000
10000
Frequency

FIG. 4

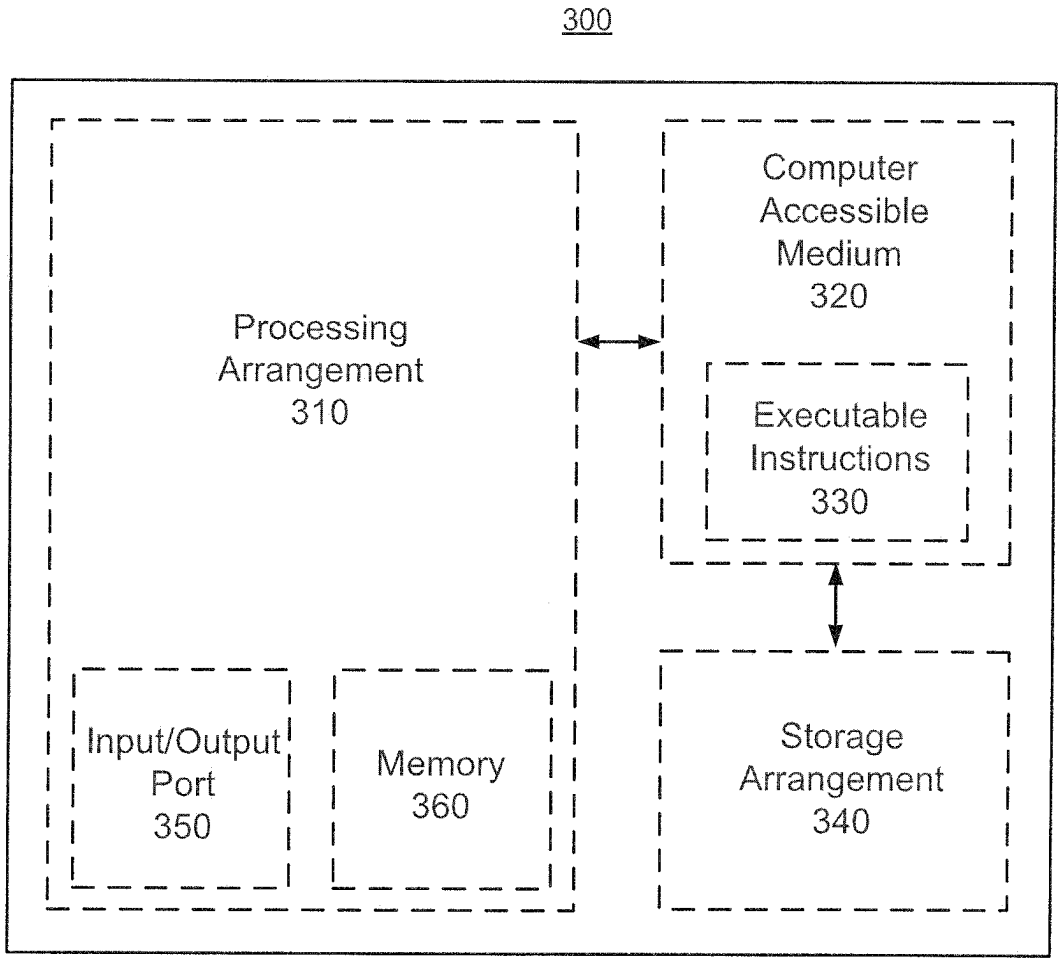

300
Processing Arrangement 310
Computer Accessible Medium 320
Executable Instructions 330
Input/Output Port 350
Memory 360
Storage Arrangement 340

FIG. 5

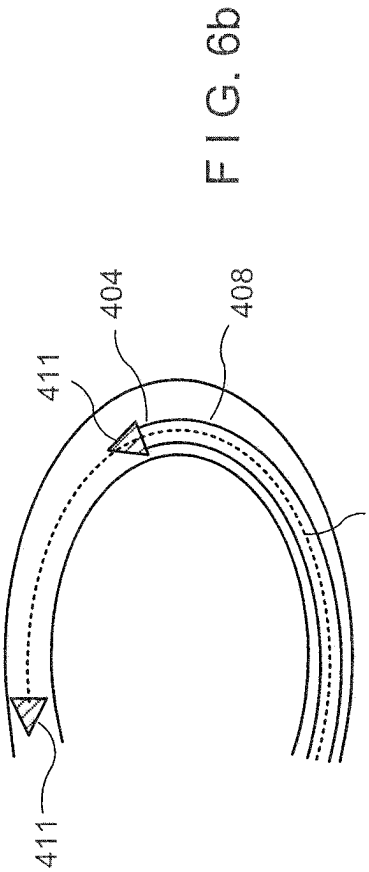


FIG. 6b

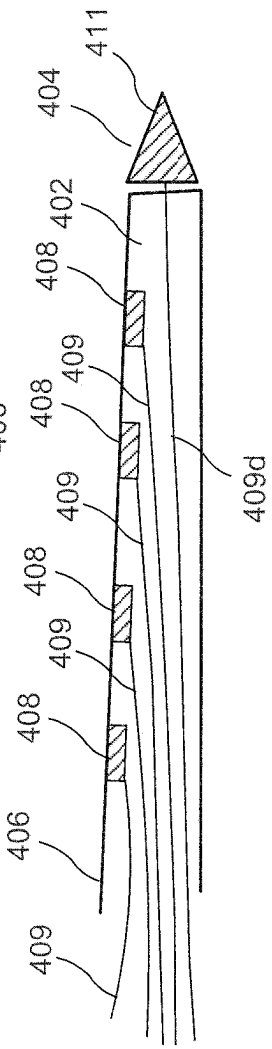


FIG. 6a

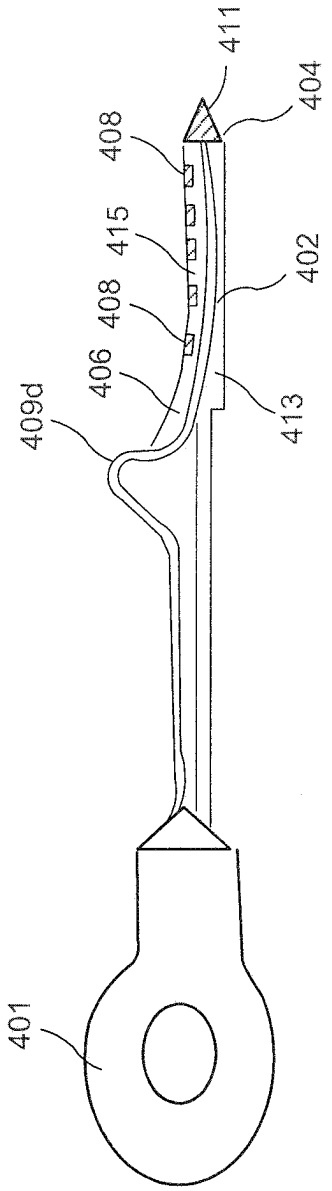


FIG. 6c

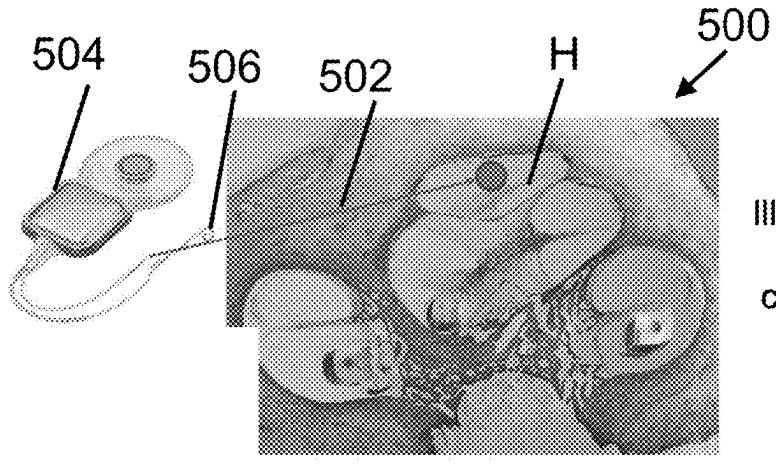


Fig. 7
Illustration of placement of ECE1 electrode in cochlear helicotrema

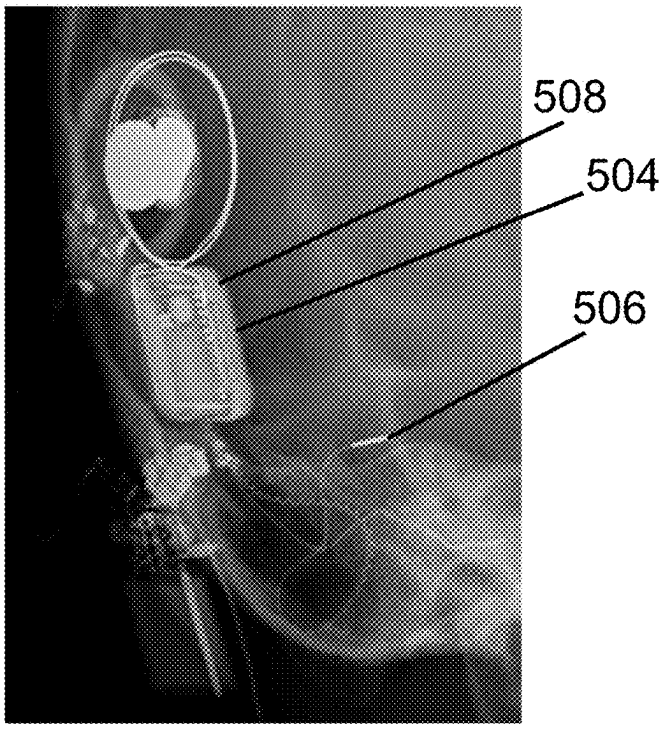


Fig. 8 Partial insertion from original implantation

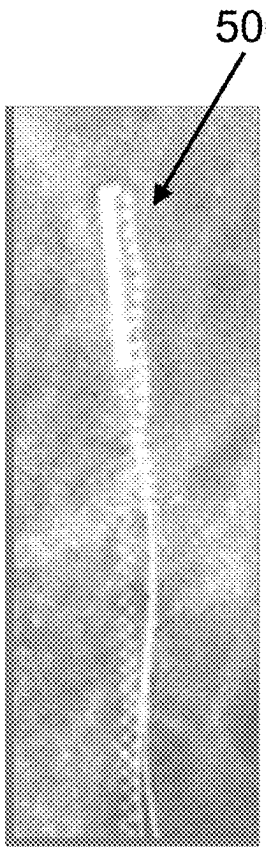


Fig. 9

METHOD AND DEVICE FOR PROVIDING STIMULATION TO OBSTRUCTED COCHLEA

PRIORITY CLAIM

[0001] The present application claims priority to U.S. Provisional Patent Application Ser. No. 63/551,349 entitled "Method and Device for Providing Stimulation to Obstructed Cochlea" filed on Feb. 8, 2024, the entire disclosure of which is incorporated herein by

BACKGROUND

[0002] The cochlea is the anatomical structure which, in the normal hearing human car, transforms physical vibrations into electrical impulses which are transmitted along the auditory nerve. The cochlea is a snail-shaped structure that typically wraps about 2.75 turns from the bottom (base) to the top (apex). The cochlea is arranged tonotopically with the lowest frequencies encoded near the apex and the highest frequencies encoded at the base.

[0003] Cochlear implants provide hearing to profoundly deafened individuals by converting sound information into an electrical code that the brain can understand. This conversion happens after an array of electrode contacts have been correctly placed into the cochlea. Each of the electrode contacts on the array stimulates a different part of the cochlea and therefore, due to the tonotopic organization of the cochlea, provides a different pitch. Typically, the electrode arrays are inserted from the cochlear base (either via the round window or via a cochleostomy) and then extend through and wrap up within the cochlea. Most electrode arrays are inserted only about 1 to 1.25 turns into the cochlea which allows for the stimulation of the cochlear regions that typically represent approximately 700 Hz and higher. Longer electrode arrays (such as the MED-EL Flex28) can reach deeper into the cochlea and can additionally stimulate regions representing lower frequencies. However, longer electrode arrays increase the risk of damaging the structures of the cochlea during insertion make the insertion of the array more difficult.

[0004] However, certain conditions such as ossification of the cochlea may prevent an electrode array from being inserted into the cochlea to a desired degree limiting the ability of cochlear implants to restore hearing to these individuals.

SUMMARY

[0005] The present disclosure relates to a cochlear implant. The implant includes a first ground electrode configured to be positioned external to a cochlea of a patient; a second ground electrode configured to be positioned within the cochlea on an apical side of an obstruction within the cochlea; a flexible electrode array having a distal end and a proximal end defining a length therebetween, the electrode array comprising a plurality of electrode contacts arranged along at least a portion of the length of the electrode array, wherein the electrode array is configured to be inserted into the cochlea such that the distal end of the electrode array advances from a base of the cochlea towards an apex of the cochlea to a point located basally of the obstruction; and a processing arrangement configured to map a first one of the electrode contacts to the first ground electrode for providing a first electrical stimulation from the first electrode contact to the first ground electrode to stimulate hearing of the patient at a first location in the cochlea, and a second mapping for providing a second electrical stimulation from the first electrode contact to the second ground electrode to stimulate hearing of the patient at a second location in the cochlea.

[0006] The first location in the cochlea is positioned adjacent to the first electrode contact when the implant is inserted into the cochlea in an operating position, and the second location in the cochlea is positioned further towards the apex of the cochlea as compared to the first electrode contact when the implant is in the operating position.

[0007] In an embodiment, the first electrical stimulation is a monopolar electrical stimulation.

[0008] In an embodiment, the second electrical stimulation is a bipolar electrical stimulation.

[0009] In an embodiment, the second ground electrode includes a ball tip at a distal end thereof configured for insertion into the cochlea.

[0010] In an embodiment, the first ground electrode includes a plate electrode.

[0011] In an embodiment, the first ground electrode is on an implant package configured to be positioned in use external to the cochlea.

[0012] In an embodiment, the electrode array is configured to be inserted into the cochlea along a curve of no more than 540 degrees from the base of the cochlea toward the apex of the cochlea.

[0013] In an embodiment, the electrode array is configured to be inserted into the cochlea along a curve of no more than 450 degrees from the base of the cochlea toward the apex of the cochlea.

[0014] In an embodiment, the electrode array is configured to be inserted into the cochlea along a curve of no more than 360 degrees into the cochlea from the base of the cochlea towards the apex of the cochlea.

[0015] In an embodiment, an extended length of the electrode array **202** is less than 31 mm.

[0016] In an embodiment, the extended length of the electrode array is less than 28 mm.

[0017] In an embodiment, the extended length of the electrode array is less than 25 mm.

[0018] In an embodiment, the extended length of the electrode array is less than 20 mm.

[0019] In an embodiment, the extended length of the electrode array is less than 16 mm.

[0020] In an embodiment, a number of electrode contacts in the electrode array is no less than 10 and no more than 30.

[0021] In an embodiment, the number of electrode contacts in the electrode array is 22.

[0022] In an embodiment, the implant further comprises a transmitter and a receiver configured to transmit data to an external processing arrangement and to receive instructions from the external processing arrangement.

[0023] In an embodiment, the processing arrangement is configured to map each of the electrode contacts to one or more of the first and second ground electrodes.

[0024] In an embodiment, the electrode contacts are electrically isolated from one another along the electrode array.

[0025] In an embodiment, the implant further includes a distalmost one of the electrode contacts that is movable relative to a proximal portion of the electrode array so that, when the electrode array is positioned as desired within the cochlea, the distalmost electrode contact may be advanced

further apically into the cochlea relative to the proximal portion of the electrode array.

[0026] In an embodiment, the distalmost electrode contact is connected to a wire sufficiently to permit the distalmost electrode contact to be further apically while remaining coupled to the processing arrangement.

[0027] These and other aspects of the present disclosure will become apparent to those skilled in the art after a reading of the following detailed description of the present disclosure, including the figures and appended claims.

BRIEF DESCRIPTION OF THE FIGURES

[0028] FIG. **1** shows a schematic of a cochlea where a cochlear implant having an array of electrode contacts is inserted therein.

[0029] FIG. **2** shows an exemplary embodiment of a cochlear implant comprising an electrode and two ground electrodes.

[0030] FIG. **3** shows an exemplary embodiment of a placement of an apical ground electrode relative to an electrode array and an extra cochlear electrode.

[0031] FIG. **4** shows an exemplary relationship between the frequency expected at a given cochlear angle by the spiral ganglion and the frequency provided at the same angle by the cochlear implant.

[0032] FIG. **5** illustrates an exemplary computer system for performing a method for electrically stimulating a cochlea of a hearing-impaired patient or a method for fitting a cochlear implant.

[0033] FIG. **6***a* shows another exemplary embodiment of an electrode array for a cochlear implant.

[0034] FIG. **6***b* shows an exemplary deployment of an advanceable tip of the electrode array of FIG. **6***a* in an apical direction.

[0035] FIG. **6***c* shows an exemplary embodiment of a cochlear implant having the electrode array of FIG. **6***a* with an advanceable ground electrode.

[0036] FIG. **7** shows an exemplary embodiment of a system for providing apical stimulation.

[0037] FIG. **8** shows an X-Ray of an incomplete electrode insertion from an obstructed cochlea using a conventional approach without an electrode (ECE1) placed into the apex.

[0038] FIG. **9** shows an X-ray of an electrode (ECE1) placed into the apex of the cochlea with an incomplete electrode array insertion shown in FIG. **7**.

DETAILED DESCRIPTION

[0039] Cochlear implants may restore the hearing to a deaf or partially deaf individual by providing to the auditory nerve electrical stimulation corresponding to an audio signal. For example, a cochlear implant may comprise an array of electrodes configured for insertion into the cochlea. As would be understood by those skilled in the art, the electrode array of a cochlear implant may comprise multiple contacts distributed along the array. In addition, the cochlear implant may comprise one or more ground electrodes. Each of the contacts on the array may be paired with a ground electrode and configured to stimulate a different part of the cochlea. Because the cochlea is arranged such that each location represents a different frequency (i.e., tonotopic organization of the cochlea), each pair of an electrode contact and a ground electrode may be perceived as having a different "place pitch" and therefore, may be used to generate signals representing in clinical fittings a specific frequency region.

[0040] The most common cochlear implant array designs are built to be inserted only about 360 to 450 degrees into the cochlea (i.e., to extend within the cochlea through one full turn of the path of the cochlea to 1.25 turns within the cochlea). In the normal hearing car, the region represented by an electrode array inserted in this manner typically encodes frequencies of about 800 Hz and above. However, as such cochlear implants are typically configured to encode a range of about 200-8000 Hz, a mismatch may be created between a frequency that would be expected at a specific location (i.e., a frequency that would be generated at a given cochlear location in a healthy car) in a normal hearing cochlea and the frequency that is received by a cochlear implant at that location.

[0041] FIG. **1** shows a schematic of a cochlea **100** with a cochlear implant **110** having an electrode array **116** of electrode contacts **118** inserted therein. The cochlear implant **110** may further comprise a microphone for receiving input signals, e.g., sounds to be stimulated to the patient, a signal processor for receiving and processing the input signals, and one or more computer processors for analyzing the input data and/or controlling the electrical stimulation that is imparted to the patient via the electrode contacts. In some embodiments, the array **116** of electrode contacts **118** may be operably connected an external component (e.g., implant package) of the cochlear implant **110** configured for location, when in use, external to the cochlea **100**, in particular, external to the car of the patient, such as, for example, reversibly attached to a location behind an car of the patient. The external component may comprise a microphone, a signal processor, and/or one or more computer processors. The microphone may comprise any suitable sensor for detecting an analog audio signal from an external environment. The microphone may be operably connected to a signal processor to transmit signals corresponding to the analog audio signal to the signal processor.

[0042] The signal processor may comprise any suitable component(s) for converting an analog audio signal to a digital signal. The signal processor may also further process the signal to de-noise, amplify certain desired portions, or otherwise modify the incoming signal. The digital signal or modified digital signal may then be transmitted as input data to one or more computer processors. The one or more computer processors may be configured to analyze this input data and/or control electrical stimulation of the cochlea **100** delivered by the cochlear implant **110**. More particularly, the electrical stimulation of the cochlea is delivered to the cochlea via the array **116** of electrode contacts **118**. In particular, the one or more computer processors may analyze the input data and generate instructions to supply to the cochlea stimulating electrical signals via the array **116** of electrode contacts **118** corresponding to the input data such that the patient is stimulated to hear sounds corresponding to the analog audio signals detected by the microphone. The processors may also be configured to perform a portion or the entirety of the methods described in the present application.

[0043] As shown in FIG. **1**, the frequency values identified in the drawing on the interior portion of the snail-like structure of the cochlea **100** correspond to frequencies expected (i.e., generally sensed) at a given location in the normal car (i.e., either the characteristic frequencies along

the Organ of *Corti* or Spiral Ganglion). The frequency ranges shown on the exterior portion of the snail like structure of the cochlea in the drawing correspond to frequencies that may be provided by electrical stimulation via an exemplary embodiment at each of the electrode contacts **118** in the array **116**, as shown in FIG. **1**. As would be understood by those skilled in the art, the more apically inserted electrode contacts **118** correspond to lower frequency ranges, whereas more basally located electrode contacts **118** correspond to higher frequency ranges.

[0044] As shown in the example of FIG. **1**, the most apical electrode contact **112** imparts an electrical signal that stimulates hearing in the patient corresponding to an input signal in the range of 250-335 Hz. In other embodiments, the most apical electrode contact **112** may impart an electrical signal that stimulates hearing in the patient corresponding to an input signal in the range of 250-500 Hz. In contrast, the most basal electrode contact **114** shown in the example of FIG. **5** may impart an electrical signal that stimulates hearing in the patient corresponding to an input signal in the range of 6336-8500 Hz. In another embodiment, the most basal electrode contact **114** may impart an electrical signal that stimulates hearing in the patient corresponding to an input signal in the range of 3800-6800 Hz. As can be seen in FIG. **1**, there may be a mismatch between frequencies expected at any given cochlear location in a normal car as compared to the frequencies stimulated by the electrical signals imparted by each of the electrode contacts **118**. Therefore, if the array **116** is moved more or less apically within the cochlea **100**, or if the length of the array **116** is changed, the relationship between place of stimulation and the frequency provided at that location can be modified/further distorted. Furthermore, after the implantation surgery, the locations of the electrode contacts **118** and the places of stimulation corresponding to the individual electrode contacts **118** are surgically fixed, but the frequency values of the filters used in the cochlear implant **110** may be further modified and may be arbitrarily re-mapped as desired.

[0045] Selecting an appropriate length of an electrode array is a tradeoff. The longer the electrode array, the more chance there is for damage of the cochlea which can lead to either loss of any remaining residual hearing or damage to the structure of the cochlea, which is necessary for good functioning of a cochlear implant. However, it is believed that longer electrode arrays provide better performance than shorter electrode arrays. For example, a cochlear implant having a shorter electrode array may provide poorer speech in noise scores than a different cochlear implant having longer electrode arrays when only electrical stimulation is used. As another example, electrode arrays that are designed to be inserted beyond 450 degrees may provide better performance than similar arrays inserted less than approximately 450 degrees.

[0046] Furthermore, it is believed that stimulation deep into the second cochlear turn is beneficial. In particular, apical stimulation (e.g., beyond 450 degrees) is believed to provide better temporal discrimination than stimulation at a location in the first cochlear turn. It is also believed that low rates of stimulation (i.e., rates useful for temporal quality) provide a poor sound quality in the first cochlear turn, but have a much better sound quality in the apex. Consistently, it is further contemplated that apical stimulation activates a pathway specialized for temporal coding.

[0047] In a cochlear implant, stimulation may be in a "monopolar mode" in which current flows from an intracochlear electrode to a ground electrode, such as, for example, an extra-cochlear ground electrode. However, monopolar and other modes of stimulation are both contemplated by the present disclosure. Although only one ground electrode is needed for monopolar stimulation, exemplary cochlear implants of the present application may have two ground electrodes so that one can be used as a ground electrode for stimulation while another ground electrode can be used for recording. One ground electrode may be positioned external to the cochlea, such as, for example, on an implant package. Another ground electrodes may be positioned at various places in the cochlear implant system, such as, for example, internal to the cochlea when the device is in use. In one embodiment, the cochlear implant may comprise at least two ground electrodes that are configured to be placed at different parts of an car into which the cochlear implant is inserted in an operating configuration. For example, one ground electrode may be positioned outside of a cochlea and another ground electrode may be positioned on, within, or near an apex of the cochlea.

[0048] Furthermore, each of the electrode contacts on the array may be configured to be paired with one or more ground electrodes to provide stimulation at a predetermined frequency or frequency range to the cochlea. In some embodiments, the second ground electrode may be connected to or attached to a wire separate from the electrode array that is inserted into the cochlea. This second ground electrode may be placed under the temporalis muscle. Although most electrodes only stimulate regions representing about 700 Hz and above, lower frequencies may be presented by an exemplary cochlear implant of the present disclosure but at a cochlear location different from which the normal auditory system would expect to hear that frequency. For example, a 240 Hz stimuli may be provided to a contact positioned in an operating configuration at a cochlear location expecting approximately 725 Hz (which is about 3 octaves higher). Similarly, a 1000 Hz stimuli could be presented to a cochlear location expecting approximately 1670 Hz. It is believed that if deeper stimulation could be achieved then sound quality would improve, and subjects would perform better (and quicker reach asymptotic performance) on speech in noise tasks.

[0049] In a further embodiment described below, an extracochlear ground ("ECE1", an independent lead usually placed under the temporalis muscle) is inserted into the cochlear helicotrema via an apical cochleostomy.

[0050] The present application describes a new surgical approach in which a ground electrode affixed on its own lead may be placed near or on the apex of the cochlea via an apical cochleostomy. Once the ground electrode has been placed in the apex, stimulation of an electrode along an electrode array placed within the cochlea can be paired with either a ground electrode on an implant package (e.g., at an extra-cochlear position) or a ground electrode located at or near the cochlear apex. When current flows from the electrode array to the apical ground electrode, it is expected to stimulate neurons located more apically than neurons stimulated by current flowing from the electrode array to an extracochlear ground electrode located on the package (which is the typical path). As a result, when stimulating using an apical ground electrode, parts of the cochlea used to encode lower frequencies should respond by producing a

lower pitch than when stimulated in conjunction with the extra-cochlear ground electrode. This may be used to improve speech in noise performance and sound quality without requiring a new hardware design or a longer electrode array which risks additional damage to cochlear structure damage.

[0051] In one exemplary embodiment, a cochlear implant **200** configured to provide apical stimulation may be provided, such as, for example, that shown in FIG. **2**. FIG. **3** shows an exemplary embodiment of a placement of an apical electrode **212** relative to an electrode array **202** and an extra cochlear electrode **210** within a cochlea of a patient. The cochlear implant **200** may include an electrode array **202** formed from a flexible material (e.g., an elastic material) that that is biased to a coiled shape corresponding to the snail-like shape of the cochlea. For example, the electrode array **202** may comprise a flexible non-conductive substrate on which a plurality of electrode contacts **208** may be attached, such as, a shape-memory material, e.g., thermoplastic elastomers, silicone, etc. The electrode array **202** may be sufficiently flexible such that the electrode array **202** may be extendable to an elongated shape, as shown in FIG. **2**, to facilitate insertion of the electrode array **202** into the cochlea.

[0052] The electrode array **202** may have a distal end **204** and a proximal end **206** defining a length therebetween. In an operating configuration, the distal end **204** of the electrode array **202** may be inserted in a direction towards the apex of the cochlea. The electrode array **202** may have any suitable length for insertion into the cochlea. In particular, the electrode array **202** may have a length configured for insertion into the cochlea by one turn, one and a quarter turns, or one and a half turns from a base the cochlea and into the cochlea, in a direction towards the apex of the cochlea. When the electrode array **202** is inserted into the cochlea, the distal end **204** of the electrode array **202** is advanced from the base through the turn(s) towards the apex. In one exemplary embodiment, the electrode array **202** may have a length configured for insertion into the cochlea by no more than about 540 degrees, 450 degrees, or 360 degrees into the cochlea towards the apex. For example, the electrode array **202** may have an extended length (i.e., when the electrode array **202** is uncoiled and extended lengthwise) less than approximately 31 mm, less than approximately 28 mm, less than approximately 25 mm, less than approximately 20 mm, or less than approximately 16 mm.

[0053] The electrode array **202** of this embodiment comprises a plurality of electrode contacts **208** that are arranged linearly along a length or a portion of a length of the electrode array **202**, such as, for example, that shown in FIG. **2**. The electrode array **202** may comprise any suitable number of contacts. As can be seen in FIG. **2**, the electrode array **202** may comprise N contacts, where N can be any suitable integer from 10 to 30. In some embodiments, the electrode array **202** may comprise at least 10 electrode contacts, at least 15 electrode contacts, or at least 20 electrode contacts. In one particular embodiment, the electrode array **202** may comprise 22 electrode contacts. Each of the electrode contacts **208** may be electrically isolated from the other electrode contacts **208** and may be configured to deliver an electrical stimulation to a designated portion of the cochlea. In an operating configuration, the electrode array **202** may be inserted into the cochlea such that each of the electrode contacts **208** is adjacent to a portion of the cochlea, each portion corresponding to a different range of frequencies and thereby representing a different pitch that may be stimulated to a hearing-impaired patient.

[0054] The exemplary cochlear implant **200** may further comprise of a first ground electrode **210** that is suitable for placement external to the cochlea, and a second ground electrode **212** that may be positioned on, within, or near an apex of the cochlea. The first ground electrode **210** and the second ground electrode **212** may be any suitable type of electrodes as would be understood by those skilled in the art. In one embodiment, the first ground electrode **210** may be a plate electrode. In another embodiment, the second ground electrode **212** may be a ball electrode. The first ground electrode **210** may be placed, for example, on an implant package, which may be placed, in use, external to the cochlea while the second ground electrode **212** may be surgically placed at or near the apex of the cochlea, e.g., via an apical cochleostomy.

[0055] The exemplary embodiment of a cochlear implant of the present disclosure may further include a processing arrangement configured to decompose an audio input signal into a plurality of frequency channels, and to map each of the electrode contacts **208** of the electrode array **202** to provide electrical stimulation (e.g., monopolar or other types of stimulation) to stimulate hearing of the patient in at least one frequency channel. The processing arrangement may comprise one or more computer processors configured to execute one or more sets of instructions configured to map each of the electrode contacts **208** to one or more of the first ground electrode **210** and the second ground electrode **212**, respectively, and/or control delivery of an electrical signal to stimulate hearing in the cochlea within predetermined frequency channels. The processing arrangement may also be operably connected via any suitable communications link (e.g., wired or wireless) to an external input and/or output device for interfacing with an operator. Alternatively, the cochlear implant may comprise a transmitter and a receiver, or a transceiver, configured to transmit data to an external processing arrangement and receive instructions from the external processing arrangement for mapping each of the electrode contacts **208** to one or more of the first ground electrode **210** and the second ground electrode **212**, respectively, and/or to control delivery of an electrical signal to stimulate hearing in the cochlea within predetermined frequency channels.

[0056] The electrode array **202**, along with the first ground electrode **210** and the second ground electrode **212** may be operably connected to the processing arrangement configured to control delivery electrical signal delivered from by a selected one of the electrode contacts **208** on the electrode array **202** to at least one of the first ground electrode and the second ground electrode **212**. Each of the electrode contacts **208** on the electrode array **202** may be mapped with the first ground electrode, the second ground electrode, or with both. For example, each electrode contact **208** on the electrode array **202** may be mapped with the first ground electrode **210** and/or the second ground electrode **212** such that each combination may deliver an electrical signal that stimulates hearing in the cochlea within a different predetermined frequency channel or frequency range.

[0057] In some embodiments, for at least one or more of the electrode contacts **208** on the electrode array **202**, each of the electrode contacts **208** may be mapped to provide electrical stimulation to stimulate hearing of the patient for

two different frequency channels, corresponding to two different frequency ranges. In particular, the two different frequency channels may comprise a first frequency channel that may be stimulated at a location within a first turn from the base of the cochlea, such as for example, at a location where a normal cochlea would expect a frequency at or greater than 800 Hz, and a second frequency channel audio frequency that may be stimulated at a more apical location within the cochlea. The more apical location may be any location that is more apical than the position of the electrode contact **208** that is being mapped. For example, the more apical location may be further towards the apex of the cochlea as compared to the distal end of the electrode array **202**. The more apical location may be, for example, deeper towards the apex beyond the first turn from the base of the cochlea. Typically, the first location may be adjacent to the electrode contact **208** and the second location may be more apical than the location of the electrode contact **208**, thereby providing a virtual extension of the electrode's ability to provide more apical stimulation of the cochlea, with reduced risk to the patient as compared a physical extension to the length of an electrode array **202**. As discussed above, extended length electrode arrays that can be physically inserted deeper towards the apex of the cochlea may increase the risk for structural damage to the cochlea during insertion thereby irreversibly harming the patient's hearing as opposed to improving it.

[0058] In an alternative embodiment, an electrode array **402** having a distal end **404** and a proximal end **406** may comprise a plurality of electrode contacts **408** arranged linearly along a length or a portion of a length of the electrode array as shown in FIG. **6***a*. Each of the electrode contacts **408** may be electrically isolated from each other. Each electrode contact **408** may be connected to a wire **409** that is operably connected to a power source and/or a controller or processing arrangement for controlling delivery of stimulation to the cochlea via the electrode contacts. In certain embodiments, the power source and/or controller or processing arrangement may be incorporated in an implant body **401**.

[0059] The implant body **401**, when in use, may be attached external to the cochlea of the patient and operably connected to an electrode array, an apical ground electrode and, optionally an extracochlear ground electrode, which may, for example, be attached to the implant body **401**. The electrode array **402** may also include a distalmost electrode contact **411** positioned at or near the distal end of the electrode array, in particular, at the distal tip of the electrode array **402**. The distalmost electrode contact **411** may comprise a component that projects distally from the distal end of the electrode array **402** (e.g., a wire stylet extendable from the distal end of the electrode array **402**). The distalmost electrode contact **411**, in particular, the distally projectable component of the distalmost electrode contact **411**, may be connected to a wire **409***d* (e.g., an advanceable ground wire) that is sufficiently long to allow for further apical advance of the distalmost electrode contact **411** while operably connecting the distalmost contact to a power source and/or a controller or processing arrangement for controlling delivery of stimulation to the cochlea via the distalmost electrode contact **411**. Therefore, this alternative embodiment of an electrode array **402** may be inserted into the cochlea and advanced more apically (and therefore into lower frequency regions of the cochlea) than the insertion depth of the electrode array, in particular, by pushing/advancing the distalmost electrode contact **411** (e.g., wire stylet) towards the apex of the cochlea.

[0060] For example, when in use, the electrode array **402** may be first inserted into a cochlea of a patient and the distalmost electrode contact **411** may be advanced further apically after full electrode insertion, as shown in FIG. **6***b*. The electrode array may have any suitable length, for example, the electrode array may have a length from about 20 to about 25 mm. This alternative embodiment may be stimulated in a bipolar mode with other more proximal electrode contacts or singularly in combination with a ground electrode (e.g., an external ground electrode). In a particular exemplary embodiment, a cochlear implant may comprise a 20 to 25 mm electrode array with a tip electrode contact that can be advanced beyond the electrode insertion depth by pushing/advancing a wire stylet connected to the tip contact. This small contact could be advanced deeper (more apically) into the lower frequency regions. This contact may be stimulated in a bipolar mode with other more proximal contacts or singularly to the external ground electrode.

[0061] In a particular embodiment, as shown in FIG. **6***c*, the electrode array **402** may further include a flexible non-conductive substrate **415** on which the plurality of electrode contacts **408** may be attached. The non-conductive substrate **415** may comprise or be formed from a shape-memory material, e.g., thermoplastic elastomers, silicone, etc. In particular, the non-conductive substrate **415** may have an elongated shape having a distal end **404** and a proximal end **406**. The non-conductive substrate **415** may comprise a channel **413** extending therethrough from the distal end **404** to the proximal end **406** defining a lumen therein. The distalmost electrode contact **411** may comprise a distally extendable component connected to the wire **409***d*. The wire **409***d* may extend from the implant body **401** through the channel **413** to the distalmost electrode contact **411**. The wire **409***d* may be sufficiently long to operably connect the distalmost electrode contact **411** to a power source and/or a controller or processing arrangement for controlling delivery of stimulation to the cochlea via the distalmost electrode contact **411**. In particular, the wire **409***d* may be longer than wires **409** connected to the other electrode contacts **408** on the electrode array **402** array so as to accommodate additional advancement of the distalmost electrode contact **411** towards the apex of the patient's cochlea.

[0062] Another aspect of the present application is a new fitting (mapping) technique for cochlear implant users. A typical mapping for a cochlear implant involves mapping a frequency range to each of the electrode contacts in an array. In the new fitting strategy, a frequency range may now be mapped to a combination of an intra-cochlear electrode contact and a ground electrode, whether it be an extracochlear ground electrode or an apical ground electrode. In other words, the lowest frequencies (such as, for example, 75-150 Hz) could be mapped to the most apical electrode on the electrode array with use of the apical ground electrode as the accompanying ground electrode. The next lowest frequencies (such as, for example, 150-300 Hz) could also be mapped to the most apical electrode on the electrode array and with use of an extra-cochlear ground electrode as the accompany ground electrode. Alternatively, 150-300 Hz could be mapped to the second most apical electrode using

the apical ground electrode for a ground. Perceptual experiments may be conducted to determine the optimal mapping configuration.

[0063] In one exemplary embodiment, a method for fitting an exemplary cochlear implant as discussed above may be provided. The fitting process may include repeated hearing tests administered to the patient post-surgery to map and adjust the mapping of each electrode contact to at least one audio frequency range. For example, a first audio signal at a first frequency may be administered and mapped to an electrode contact. Subsequently, a second audio signal at a different frequency may be administered and mapped to the same or a different electrode contact. This may be repeated for as many different frequencies as needed. The fitting process for each electrode contact may also include selection of either the first ground electrode or the second ground electrode to be used to impart an electrical stimulus to the cochlea. The first ground electrode, which is positioned external to the cochlea, may be selected when the frequency of the audio signal is high.

[0064] In contrast, the second ground electrode, which is positioned in or near the apex of the cochlea, may be selected when the frequency of the audio signal is low. The low frequency audio signal may tonotopically correspond to a more apical location within the cochlea as discussed above. Furthermore, the electrode array may be mapped according to a frequency allocation table, where each electrode contact on an array is assigned to at least one different frequency channel or frequency range, in the manner described above. In some embodiments, at least one electrode contact is assigned to two different frequency channels or frequency ranges. The mapping of the frequency allocation table may be performed within a predetermined period of time.

[0065] In one exemplary embodiment, the electrode array may comprise a predetermined number of electrode contacts, and a plurality of frequency channels may be mapped to the electrode contacts of the electrode array, in particular, the number of frequency channels may be greater than the predetermined number of electrode contacts. For example, the electrode array may comprise 22 electrode contacts, which may be mapped to more than 22 frequency channels, such as for example, 44 frequency channels.

[0066] The present application also provides a new method which may be used to provide apical stimulation without increasing the length of the electrode array inserted into the cochlea. Typically, cochlear implants provide stimulation on one intra-cochlear electrode contact and ground the stimulation to an electrode external to the cochlea. A cochlear implant may include two electrodes that are designed to be used as extra cochlear grounds to allow for redundancy or to provide separate extra cochlear electrodes for stimulation and recording when measuring neural responses within the cochlea. One of the electrodes designed to be an extracochlear ground may be implanted inside the apex of the cochlea via an apical cochleostomy (ApexE1) as illustrated in an exemplary embodiment shown in FIGS. **2** and **3**. If so, stimulation may be provided from any electrode contact **208** (e.g., Array1, Array2, ... ArrayN) on the electrode array **202** to either the ground electrode located near the apical electrode **212** (ApexE1) or the remaining extra cochlear electrode **210** (ExtraCochlear) as illustrated in the exemplary embodiments shown in FIGS. **2** and **3**.

[0067] More specifically, FIG. **3** shows placement of the apical electrode **212** (ApexE1) relative to the electrode array **202** and extra cochlear electrode **210**. FIG. **3** shows electrode contacts and labelled as further described below. The electrode contacts **208** placed on an exemplary cochlear implant electrode array **202** as shown in FIGS. **2** and **3** are labeled Array1, Array2 . . . . ArrayN where Array1 **204** is the most apical of the electrode contacts on the intracochlear array **202** and ArrayN **206** is the most basal of the electrode contacts **208** on the intracochlear electrode array **202**. The apical electrode **212** placed in the apex via a cochleostomy is labeled ApexE1. The extra cochlear electrode **210** is positioned away from the electrode array **202** and is labeled ExtraCochlear.

[0068] Stimulation using ExtraCochlear **210** as a ground electrode may provide stimulation to portions of the cochlea to which an electrode contact may be adjacent. However, stimulation from any one of the electrode contacts **208** on the electrode array **202** (ArrayX) to ApexE1 **212** may route the electrical stimulation, e.g., current, towards the apex of the cochlea. It is believed that this will provide more apical stimulation.

[0069] Using this new approach, a cochlear implant **200** sound processing strategy may use stimulation from ArrayN **206** to either ApexE1 **212** or ExtraCochlear **210** as separate channels. Alternatively, ArrayN **206** may provide stimulation to either ApexE1 **212** or ExtraCochlear **210** simultaneously. Both of these options would allow a potential increase in the number of channels provided to the cochlear implant user. Additionally, electrode contacts **208** on the apical end of the electrode array **202** (e.g., Array1 or Array2) that are grounded to ApexE1 **212** may provide stimulation at cochlear locations beyond the most apical electrode contact **208** on the array (Array1), effectively extending the functional length of the electrode array **202** without increasing the physical length of the electrode array **202**.

[0070] One implementation of a speech coding strategy may be to use a standard envelope extracting algorithm. Any suitable envelope extracting methods may be used, for example, advanced combination encoder (ACE) or continuous interleaved sampling (CIS) methodologies, such as those commercially available from Cochlear Corporation. In this case, the lowest frequency channels may be associated with electrode contacts **208** relatively apically located on the electrode array **202** and grounded by the apical electrode **212**. The same electrode contacts **208** on the electrode array **202** may be mapped to either the apical electrode **212** or the extra cochlear electrode **210**.

[0071] An exemplary signal processing method (e.g., utilizing CIS or other suitable envelop extracting methods) with a cochlear implant may include any suitable number of channels and/or electrode contacts. In one exemplary embodiment, the method may utilize 4 channels and 4 corresponding electrode contacts arranged linearly along an electrode array. Although the CIS signal processing method is described herein with respect to 4 channels and 4 corresponding electrode contacts, it is contemplated that any suitable number of channels and/or electrode contacts (e.g., 12, 15, or 22) for a cochlear implant may be used. An initial audio input signal may be received and processed using a bandpass filter, in which the input signal is separated by different ranges of audio frequencies to the 4 different channels. The bandpass filters are such that usually there is one filter for each electrode contact.

[0072] For each channel, the envelope of the bandpass filtered signal, which is within the desired range for each channel, may be extracted and converted to a series of pulses representing the amplitude of the bandpass filtered signal at any given moment of time. The pulses may be presented to each of the corresponding electrode contacts implanted into a cochlea of a patient, where each contact is located at a different position along the spiral shape of the cochlea. Specifically, the filter representing the lowest frequencies yields an output on the most apically implanted electrode contact of the array. The filter representing the second lowest set of frequencies will result in instructions for stimulating the second most apical electrode, etc. In one particular example, the frequencies for a cochlear implant may include 12 channels, each corresponding to a different range of frequencies to which the input signal may be bandpass filtered to correspond to 12 differently placed electrode contacts inserted into the cochlea.

[0073] The new apical channels (produced by stimulating between the apical ground and the electrode array) could be used for encoding lower frequencies using a temporal or fine structure algorithm instead of an envelope extraction.

[0074] In another example, the circuitry in the cochlear implant may be modified to produce stimulation directly from the apical electrode **212** (ApexE1). This may allow stimulation from ApexE1 **212** to ExtraCochlear **210**, providing an additional site of stimulation that could be even more apical than stimulation between the apical electrode **212** and an intra-cochlear electrode or electrode contact **208**.

[0075] In a further example, stimulation may be provided independently on each electrode contact **208**. For example, each electrode contact **208** may be connected to an independent current source. In this situation, the apical electrode **212** (ApexE1) may be used to shape the electrical field. For example, stimulation from Array1 **204** may be routed completely to ApexE1 **212**, or a combination of ApexE1 **212** and ExtraCochlear **210**. The relative weighting of current going to ApexE1 **212** and ExtraCochlear **210** may determine the shape of the spread of excitation with some intermediary shape between the field created by Array1->ApexE1 stimulation and Array1->ExtraCochlear stimulation. Additionally, current steering could be provided between ApexE1 **212** and other combinations of ExtraCochlear **210** and any of the electrode contacts **208** on the electrode array **202** (ArrayX).

[0076] Additional apical channels provided by the new configuration may also be used to provide lower frequencies than are typically encoded by a conventional system. This would leave the mismatch between spiral ganglion place and the corresponding frequency delivered by the implant at that location as is but would provide a greater range of frequencies to the listener.

[0077] As described above, in some exemplary embodiments of a cochlear implant, at least two ground electrodes may be included, one of which may be placed at or near the apex of the cochlea. If the most apical electrode contact **208** in an electrode array **202** (Array1) is stimulated with the apical electrode **212** (ApexE1), the current would flow from Array1 **202** up the cochlea. Therefore, an electrode contact **208** within an electrode array **202** as described herein could be used with either an extra cochlear electrode **210** or an apical electrode **212**, in the alternative, to provide to stimulation at two different possible cochlear locations. Therefore, a single electrode contact within the electrode array **202** may be used to provide electrical stimulation to two different possible locations in the cochlea, depending on which ground electrode is used in combination with the electrode contact **208**. Therefore, additional bandpass filters may also be used to separate input signals to additional frequency channels that may be stimulated at these additional locations.

[0078] For example, if the electrode array includes 22 electrode contacts and all 22 electrode contacts may be used in both modes (e.g., with an apical ground electrode or with an extracochlear ground electrode), a total of 44 frequency channels and therefore **44** bandpass filters may be used. In some embodiments, frequency channels having the lowest frequencies may be stimulated using electrode contacts that are more apically positioned on the electrode array **202** in combination with a ground electrode in the apical electrode **212**, while frequency channels having the highest frequencies would be stimulated using electrode contacts **208** that are more basally positioned on the electrode array in combination with an extra cochlear electrode **210**. Examples of this new relationship are provided in FIG. **4**, as further discussed below. It is contemplated that not all electrode contacts need to operate in both modes. Rather, a portion of the contacts may be able to operate in both modes, while other contacts may be configured to operate with only one of the two ground electrodes.

[0079] FIG. **4** shows a relationship between the frequency expected at a given cochlear angle by the spiral ganglion (top line) and the frequency provided at the same angle by the cochlear implant. For a cochlear implant without ApexE1, the y-axis indicates an example of where each electrode on the array might be placed (in degrees) and the x-axis indicates the center frequency provided at the corresponding electrode. If one additional apical channel is created by stimulating from Array1 to ApexE1 and the most apical channel is now routed to the Apex 1->ApexE1, FIG. **4** shows that the cochlear extent represented by the intracochlear electrodes (Array1 . . . . ArrayN) shifts towards the spiral ganglion (green) line because the frequency range represented by Array1 . . . . ArrayN is missing the lowest frequencies (which have been rerouted to the new Array1->ApexE1 channel. FIG. **4** also shows additional examples where additional apical channels (such as including Array2->ApexE1) may be included such that the range represented by the intracochlear electrodes (Array1 . . . ArrayN) and the range represented by stimulation incorporating ApexE1 moves further towards the top line as additional apical stimulation channels are added.

[0080] The same frequency range typically used by a cochlear implant may be used with the new configuration. However, with the addition of new apical channels, the fixed frequency range may be spread over a greater portion of the cochlea (FIG. **4**). Some of the advantages may include: Apical stimulation might result in better sound quality and performance; Deviations from spiral ganglion may be smaller—this may make it easier for the auditory system to process resulting in a) shorter times for the subject to reach asymptotic performance and b) better asymptotic results; and as the cochlear region represented by a fixed frequency range may be increased, the spacing between two fixed frequencies along the cochlea may increase in angle along the cochlea. The result is believed to be that it will be easier for the listener to discriminate the two frequencies and will provide better spectral resolution. In another example, a

method for electrically stimulating a cochlea of a hearing-impaired patient may be provided.

[0081] The method may be performed by any suitable processing arrangement for directing stimulation of a cochlea by a cochlear implant. For example, a receiving arrangement or the cochlear implant may receive an input audio signal that is to be processed to generate corresponding electrical stimulations to the cochlea of the patient. The input audio signal may be any form of audio that is to be heard by the patient, such as, for example, speech. The input audio signal may be decomposed into a plurality of frequency channels, each frequency channel corresponding to a different range of audio frequencies. Each frequency channel may be mapped to an electrode contact and a ground electrode. Therefore, for stimulation in a desired frequency channel a stimulation (e.g., monopolar or other types of stimulation) may be provided from an electrode contact on the electrode array to a ground electrode to stimulate hearing of the patient within the frequency range of the desired frequency channel. The method may select one of the two available ground electrodes depending on the frequency range of the frequency channel. The first ground electrode, which is positioned external to the cochlea, may be selected when the frequency range is high. In contrast, the second ground electrode, which is positioned in or near the apex of the cochlea, may be selected when the frequency range is low. The low frequency audio signal may tonotopically correspond to a more apical location within the cochlea as discussed above.

[0082] Those skilled in the art will understand that the exemplary embodiments described herein may be implemented in any number of manners, including as a separate software module, as a combination of hardware and software, etc. For example, the exemplary analysis methods may be embodiment in one or more programs stored in a non-transitory storage medium and containing lines of code that, when compiled, may be executed by at least one of the plurality of processor cores or a separate processor. In some embodiments, a system comprising a plurality of processor cores and a set of instructions executing on the plurality of processor cores may be provided. The set of instructions may be operable to perform the exemplary methods discussed below. The at least one of the plurality of processor cores or a separate processor may be incorporated in or may communicate with any suitable electronic device, for example, a cochlear implant, a mobile computing device, a smart phone, a computing tablet, a computing device, etc.

[0083] For example, the exemplary methods may be embodied in an exemplary system **300** as shown in FIG. **5**. The exemplary system **300** may be part of an implant body attached external to a cochlea of a patient and operably connected to an electrode array, an apical ground electrode and, optionally an extracochlear ground electrode, which may, for example, be attached to the implant body. Alternatively, all or parts of the system **300** may be incorporated within a cochlear implant that is inserted into the cochlea of a patient with in an operative configuration. An exemplary method described herein may be performed entirely or in part by a processing arrangement **310**. For example, the system **300** may be configured to decompose an audio input signal into a plurality of frequency channels, and to map each of the electrode contacts of the electrode array to provide electrical stimulation (e.g., monopolar or other types of stimulation) to stimulate hearing of the patient in at least one frequency channel. The system **300** may also be operably connected via any suitable communications link (e.g., wired or wireless) to an external input and/or output device for interfacing with an operator. Alternatively, the system **300** may be configured to receive audio input data from a cochlear implant or a microphone, and to transmit instructions to a cochlear implant for mapping each of the electrode contacts to one or more ground electrodes and/or controlling delivery of an electrical signal to stimulate hearing in the cochlea within predetermined frequency channels.

[0084] Such processing/computing arrangement **310** may be, e.g., entirely or a part of, or include, but not limited to, a computer/processor that can include, e.g., one or more microprocessors, and use instructions stored on a computer-accessible medium (e.g., RAM, ROM, hard drive, or other storage device). As shown in FIG. **5**, e.g., a computer-accessible medium **320** (e.g., as described herein, a storage device such as a hard disk, floppy disk, memory stick, CD-ROM, RAM, ROM, etc., or a collection thereof) can be provided (e.g., in communication with the processing arrangement **310**). The computer-accessible medium **320** may be a non-transitory computer-accessible medium. The computer-accessible medium **320** can contain executable instructions **330** thereon. In addition or alternatively, a storage arrangement **340** can be provided separately from the computer-accessible medium **320**, which can provide the instructions to the processing arrangement **310** so as to configure the processing arrangement to execute certain exemplary procedures, processes and methods, as described herein, for example.

[0085] The system **300** may also include a receiving arrangement (now shown) for receiving an input audio signal, e.g., an audio receiver or a microphone. The receiving arrangement may be part of a larger device, e.g., a cochlear implant. The system **300** may further transmit instructions for administering electrical stimulus to a cochlear implant, in particular, a cochlear implant having a plurality of electrode contacts on an electrode array along with an apical ground electrode and/or an extracochlear ground electrode. The cochlear implant may include a microphone, a signal processor, one or more electrode contacts, and/or one or more computer processors for performing a portion or the entirety of the methods described above.

[0086] FIG. **7** shows an exemplary embodiment of a system **500** configured to provide apical stimulation using, for example, a standard length electrode array that is adapted to treat patients with cochlear ossification or any other condition preventing complete insertion of an electrode array **506** into the cochlea. The system **500** includes an implant **504** which is implanted in the same manner described above except that one ground electrode **502** (e.g., "ECE1", an independent lead usually placed under the temporalis muscle) formed in a manner suitable for use as an extra-cochlear ground electrode is inserted into the cochlear helicotrema H via an apical cochleostomy or any other suitable procedure. FIG. **9** shows an X-ray of the ground electrode **502** (ECE1) placed into the apex of the cochlea with an incomplete electrode array insertion according to FIG. **7**.

[0087] The present disclosure describes outcomes of a case study to illustrate how the placement of an additional apical electrode may provide benefits for patients where complete electrode array insertions are not possible. While

conventional cochlear implants may stimulate the auditory nerve in a "monopolar mode" in which current flows from an intra-cochlear electrode array **506** to a ground electrode, such as (e.g., the ground electrode **502**), the present embodiments allow for multiple stimulation modes to enhance results. Although only one ground electrode **502** may be needed for monopolar stimulation, exemplary cochlear implants of the present disclosure include two or more ground electrodes so that one can be used as a ground electrode for stimulation, while another ground electrode (e.g., the ground electrode **502**) is inserted into the cochlear helicotrema H past the obstruction (e.g., ossification) via, for example, an apical cochleostomy. This may provide enhanced results for patients whose anatomy prevents the full insertion of the electrode array **506** into the cochlea.

[0088] Outcomes with such placement not employing the ground electrode placement within the cochlea as described herein have typically been poor because only the most basal region of the cochlea is stimulated resulting in a highly compressed spectral representation of an auditory signal. In the current embodiments, the ground electrode **502** (i.e., ECE1) is surgically placed into the cochlea past the obstruction, typically in the cochlear helicotrema H (e.g., via a second cochleostomy). One of the surgical advantages to this approach relative to a split/double electrode array is that the decision to place the additional ground electrode **502** into the cochlear apex does not need to be made pre-op and can be made when the surgeon learns that he is unable to achieve a full insertion of the electrode array **506**—even in unanticipated situations. Furthermore, no additional devices are required. The implant **504** does not need to be removed and replaced. No additional cost is involved with opening a second CI package. There is no requirement that a second, specialized cochlear implant device be available during the surgery.

[0089] One typical solution for such patients has been to employ a split/double array design. In this configuration, instead of a single long electrode array, two shorter electrode arrays both connected to the same cochlear implant are inserted. One is placed inside the cochlea from the base (using a standard approach) and the other is placed deeper into the cochlea past the obstruction by way of a second opening in the cochlea at the second turn. If the surgeon was going to perform a cochlear implant in a patient with an obstructed (often ossified) cochlea, there would generally be a split/double array device in the operating theatre. A major issue with this device is that the surgeon would typically try and fail to completely insert a full-length electrode array. Upon failure, the surgeon would have to remove the electrode array and remove the cochlear implant and replace it with another cochlear implant model with a split/double array. This may be problematic for many reasons. First, it may require opening a second implant which is very expensive. Second, it may require having in the clinic a second implant with a split/double array on the shelf, ready to go.

[0090] For example, for the implant **504** including an electrode array with 22 electrodes, a certain patient may show cochlear ossification that permits only 10 out of 22 of these electrodes from being inserted into the cochlea. In such a case, the initial sound quality may be insufficient to enable the patient to understand speech with the standard implantation of the implant **504**. For this type of the cochlear implant, the clinical fitting software provides in a typical configuration, up to 22 channels, with each stimulating a corresponding one of the electrodes in the array. However, as would be understood by those skilled in the art, the clinical system allows each frequency channel to stimulate in reference to either an electrode on an implant case **508** ("MP2") providing monopolar stimulation or with reference to the apically placed ground electrode **502** ("MP1"). Multiple stimulus and frequency allocation configurations may then be applied to determine optimal outcomes.

[0091] According to the present disclosure, the ground electrode **502** is implanted into the cochlear helicotrema H via, for example, an apical cochleostomy while the other ground electrode is positioned external to the cochlea, such as, for example, on the implant case **508** (MP2). As would be understood by those skilled in the art, any other ground electrodes may be positioned at various places in the cochlear implant system, such as, for example, internal to the cochlea when the device is in use. Each of the electrode contacts on the electrode array **506** may be configured to be paired with one or more of the ground electrodes to provide stimulation at a predetermined frequency or frequency range to the cochlea.

[0092] At activation after implantation of the ground electrode **502** in the cochlear helicotrema H, the patient may be provided with two or more different maps. For example, one map may be a conventional map stimulating all intracochlear electrodes on the electrode array **506** in monopolar mode without using the ground electrode **502**. The other map may include an additional channel in which the lowest frequencies are presented on the most apical electrode on the electrode array **506** with reference to the ground electrode **502** in the cochlear helicotrema H. At a second mapping, the patient may be queried as to the results provided by each map. It appears that the map including the cochlear helicotrema H reference of the ground electrode **502** provides superior results.

[0093] As would be understood by those skilled in the art, additional mappings may then be performed to further optimize tonotopic representation. Furthermore, the decision to place the ground electrode **502** in the cochlear apex may be made after trouble is experienced in achieving full insertion of the full-length electrode array **506** into the cochlea without completely replacing the implant **504**.

[0094] This technique is believed to improve the representation of low frequency sounds by providing electric stimulation deeper into the cochlea without requiring the insertion into the cochlea of longer electrode arrays. The is expected, consequently, to improve the understanding of speech amid background noise as well to improve sound and music quality relative to currently used configurations.

[0095] In current configurations of such cochlear implants **504**, the number of potential channels corresponds to a number of electrodes along the electrode array **506** located within the cochlea. With the present embodiments, stimulation of each intracochlear electrode may produce separate channels via selective grounding to the apical electrode or to the extra-cochlear ground, increasing the potential number of channels. Furthermore, stimulation from the apical electrode can be made with reference to the implant case **508**, adding an additional number of channels. This increase in the number of potential channels is especially important in cases where the number of intracochlear electrodes inserted into the cochlea is reduced as with certain populations having cochlear ossification, etc.

[0096] Exemplary stimulation configurations include using only the electrodes along the electrode array **506** with reference to the extra-cochlear ground. This produces the same stimulation patterns as used with a standard approach or, in addition to the standard channels described above, an additional channel can be provided in the apex. This channel can be provided either in AS mode (apical electrode grounded to the extra-cochlear electrode) or in a bipolar configuration spanning from the electrode array to the apical electrode. Additional channels can also be added by changing the choice of grounding electrode.

[0097] In addition to the new surgical technique described above, signal processing techniques as well as optional new designs for cochlear implant electrodes and/or electrode arrays can improve results. A standard signal processing strategy can be used to stimulate all channels included in a program (as shown above). These standard strategies include CIS (Continuous Interleaved Sampling) or ACE (Advanced Combination Encoder). Additional signal processing can be implemented to enhance temporal coding. Data suggests temporal coding is especially important in the cochlear apex. Additional changes can be made to the frequency to electrode/channel assignment to better approximate the "correct" spiral ganglion representation and to provide a broader frequency range to the cochlear apex. This allows for multiple harmonics in a single filter. This allows both a larger range of frequencies to be represented in the apex, but also increases the probability of multiple harmonics to be represented in an apical channel.

[0098] As indicated above, in one embodiment the free ground wire from the Cochlear device (e.g., the ground electrode **502**) is employed as a separate apical electrode implanted in the cochlear helicotrema H via, for example, an apical cochleostomy using unmodified hardware as described in regard to FIGS. **1-6** above. Alternatively, in one embodiment the ground electrode **502** may be modified for more effective use. Specifically, in place of an elongated pin on the implant **504**, an implant according to this further embodiment includes a small ball 0.5 to 1 mm contact for use as the ground electrode **502**. This is a new design that permits the ground electrode **502** to fit entirely within the cochlear lumen. This permits the ground electrode **502** to be implanted within the cochlear lumen, in contact with cochlear fluids which enhances the operation of the implant **504** as opposed to the positioning of this ground electrode **502** on the surface of the cochlea or external to the endosteum of the cochlea. In the embodiments of FIGS. **1-6**, the apically placed electrode often is placed partially in and partially out of the cochlear lumen because the shape of ECE1 (a long pin) in these embodiments often requires that, when the tip of the electrode ECE1 is inserted into the lumen, a significant proportion (often majority) of the electrode array remains outside the lumen.

[0099] In another embodiment, an electrode array, with a wire up the middle attached to the tip configured as a contact, is inserted into the cochlea in the usual fashion and the wire is advanced to push the tip contact deeper into the cochlea. In another embodiment, the electrode array may be partially inserted into the cochlea (e.g., for patients with obstructed cochlea, such as an ossified cochlea). For these patients, an additional electrode is placed apically using a design and approach as described above with the ground electrode **502** being positioned in the in the cochlear helicotrema H as described above.

[0100] The addition of the ground electrode **502** in the cochlear helicotrema H as described allows new stimulation configurations permitting deeper stimulation and more sites of stimulation than a traditional electrode array placement including, for example:

[0101] 1. Monopolar Stimulation (MP). Stimulation from each of the electrodes on the electrode array can be made with reference to an external ground, typically located on the package of the cochlear implant. This provides the same stimulation patterns and locations available with a standard configuration.

[0102] 2. Monopolar Apical Stimulation (AS). The electrode placed in the cochlear apex can be stimulated with reference to the external ground electrode. This produces what is effectively monopolar stimulation, deep into the apex, and providing stimulation deeper than what would be available with a standard configuration.

[0103] 3. Electrode Array to Apical Stimulation (Bipolar; BP). Stimulation can be provided from one of the electrodes along the electrode array with reference to the apical electrode. This provides stimulation deeper into the cochlea than can be achieved in MP stimulation but not as deep as AS. This potentially allows multiple sites of stimulation, between the apical electrode and the electrode array.

[0104] 4. Current Shaping: Using multiple current sources, these stimulation patterns can be combined to produce many sites of stimulation, potentially even at sites that are obstructed by ossification.

[0105] The number of sites of stimulation can be increased using this technique beyond the sites of stimulation provided by an electrode array with a standard site of stimulation. With only one current source, each electrode along the array can be stimulated in MP or BP to Apical stimulation modes, effectively doubling the sites of stimulation available. AS stimulation would then add another additional site of stimulation. Additional sites of stimulation between the apical electrode and the array can be created in one embodiment using virtual channels. As would be understood by those skilled in the art, virtual channel consists of simultaneous stimulation in-phase on multiple electrodes such that the electric fields interact. This allows finer control over the placement of sites of stimulation between the electrode array and the apical electrode. Additional sites of stimulation between the apical and electrode and the array can also be created by stimulating out-of-phase on multiple electrodes.

[0106] Considerable data appears to suggest that the auditory system is more sensitive to temporal coding and less sensitive to place coding in the cochlear apex than in the portion of the cochlea typically stimulated by an electrode array. According to the present disclosure, apical sites of stimulation (such as but not limited to AS stimulation) can be used to specifically encode temporal information. Temporal modulation techniques can involve increasing the modulation depth or changing the rate of stimulation to encode temporal information.

[0107] As would be understood by those skilled in the art, the assignment of frequency to electrodes, channels, or sites of stimulation can be set by software. By extending the frequency allocation to incorporate the apical sites of stimulation, frequency mismatches relative to the spiral ganglion can be reduced. In a standard implant configuration, each frequency is represented basally along the cochlea relative to

location along the spiral ganglion which represents the corresponding characteristic frequency.

[0108] Additionally, it may be desirable that the apical stimulation (e.g., using AS or Apical BP modes) be provided with relatively large frequency bandwidths (e.g., 100-400 Hz) as place specificity is less important in the cochlear apex and therefore frequencies can be provided at the same location. In addition, wider frequency ranges for the apical site of stimulation allow more harmonics to be represented in that channel. As those skilled in the art understand, unresolved harmonics are instrumental for representing temporal information via modulations. Finally, wider frequency ranges for the apical site reduce the frequency/spiral ganglion mismatch relative to a standard frequency allocation configuration.

[0109] Current can flow from an electrode contact in the basal turn (normal location) to the apical contact inside the top of the cochlea. This current will activate neurons deeper in the cochlea including those that code for lower frequencies which the current electrodes in use do not access. In addition, it has been noted that Trans-Impedance Matrix (TIM) measurements can be used to verify appropriate placement and that stimulation in BP-Apical mode provides lower pitch percepts than stimulation in MP mode from the electrode array. Furthermore, stimulation in AS mode has been shown to provide lower pitch percepts than stimulation in BP-Apical mode and stimulation in BP-Apex mode provides lower pitch percepts than stimulation from the electrode array in MP mode.

[0110] The present disclosure describes a new surgical approach in which a ground electrode affixed on its own lead may be placed near or on the apex of the cochlea via an apical cochleostomy. Once the ground electrode has been placed in the apex, stimulation of an electrode along the electrode array **506** placed within the cochlea can be paired with either a ground electrode on the implant case **508** (e.g., at an extra-cochlear position) or a ground electrode located at or near the cochlear apex.

[0111] When current flows from the electrode array to the apical ground electrode, it is expected to stimulate neurons located more apically than neurons stimulated by current flowing from the electrode array to an extracochlear ground electrode located on the package (which is the typical path). As a result, when stimulating using an apical ground electrode, parts of the cochlea used to encode lower frequencies should respond by producing a lower pitch than when stimulated in conjunction with the extra-cochlear ground electrode. This may be used to improve speech in noise performance and sound quality without requiring a new hardware design or a longer electrode array which risks additional damage to cochlear structure damage.

[0112] The present disclosure described and claimed herein is not to be limited in scope by the specific embodiments herein disclosed since these embodiments are intended as illustrations of several aspects of this present disclosure. Any equivalent embodiments are intended to be within the scope of this present disclosure. Indeed, various modifications of the present disclosure in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description. Such modifications are also intended to fall within the scope of the appended claims. All publications cited herein are incorporated by reference in their entirety.

What is claimed is:

1. A cochlear implant, comprising:

a first ground electrode configured to be positioned external to a cochlea of a patient;

a second ground electrode configured to be positioned within the cochlea on an apical side of an obstruction within the cochlea;

a flexible electrode array having a distal end and a proximal end defining a length therebetween, the electrode array comprising a plurality of electrode contacts arranged along at least a portion of the length of the electrode array, wherein the electrode array is configured to be inserted into the cochlea such that the distal end of the electrode array advances from a base of the cochlea towards an apex of the cochlea to a point located basally of the obstruction; and

a processing arrangement configured to map a first one of the electrode contacts to the first ground electrode for providing a first electrical stimulation from the first electrode contact to the first ground electrode to stimulate hearing of the patient at a first location in the cochlea, and a second mapping for providing a second electrical stimulation from the first electrode contact to the second ground electrode to stimulate hearing of the patient at a second location in the cochlea,

wherein the first location in the cochlea is positioned adjacent to the first electrode contact when the implant is inserted into the cochlea in an operating position, and the second location in the cochlea is positioned further towards the apex of the cochlea as compared to the first electrode contact when the implant is in the operating position.

2. The cochlear implant of claim **1**, wherein the first electrical stimulation is a monopolar electrical stimulation.

3. The cochlear implant of claim **1**, wherein the second electrical stimulation is a bipolar electrical stimulation.

4. The cochlear implant of claim **1**, wherein the second ground electrode includes a ball tip at a distal end thereof configured for insertion into the cochlea.

5. The cochlear implant of claim **1**, wherein the first ground electrode includes a plate electrode.

6. The cochlear implant of claim **5**, wherein the first ground electrode is on an implant package configured to be positioned in use external to the cochlea.

7. The cochlear implant of claim **1**, wherein the electrode array is configured to be inserted into the cochlea along a curve of no more than 540 degrees from the base of the cochlea toward the apex of the cochlea.

8. The cochlear implant of claim **7**, wherein the electrode array is configured to be inserted into the cochlea along a curve of no more than 450 degrees from the base of the cochlea toward the apex of the cochlea.

9. The cochlear implant of claim **8**, wherein the electrode array is configured to be inserted into the cochlea along a curve of no more than 360 degrees into the cochlea from the base of the cochlea towards the apex of the cochlea.

10. The cochlear implant of claim **1**, wherein an extended length of the electrode array **202** is less than 31 mm.

11. The cochlear implant of claim **10**, wherein the extended length of the electrode array is less than 28 mm.

12. The cochlear implant of claim **11**, wherein the extended length of the electrode array is less than 25 mm.

13. The cochlear implant of claim **10**, wherein the extended length of the electrode array is less than 20 mm.

14. The cochlear implant of claim **10**, wherein the extended length of the electrode array is less than 16 mm.

15. The cochlear implant of claim **1**, wherein a number of electrode contacts in the electrode array is no less than 10 and no more than 30.

16. The cochlear implant of claim **15**, wherein the number of electrode contacts in the electrode array is 22.

17. The cochlear implant of claim **1**, further comprising a transmitter and a receiver configured to transmit data to an external processing arrangement and to receive instructions from the external processing arrangement.

18. The cochlear implant of claim **17**, wherein the processing arrangement is configured to map each of the electrode contacts to one or more of the first and second ground electrodes.

19. The cochlear implant of claim **17**, wherein the electrode contacts are electrically isolated from one another along the electrode array.

20. The cochlear implant of claim **1**, further comprising a distalmost one of the electrode contacts that is movable relative to a proximal portion of the electrode array so that, when the electrode array is positioned as desired within the cochlea, the distalmost electrode contact may be advanced further apically into the cochlea relative to the proximal portion of the electrode array.

21. The cochlear implant of claim **20**, wherein the distalmost electrode contact is connected to a wire sufficiently to permit the distalmost electrode contact to be further apically while remaining coupled to the processing arrangement.

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