



(51) International Patent Classification:

H04R 1/10 (2006.01) *A61F 11/14* (2006.01)
H01Q 1/36 (2006.01) *H01Q 1/27* (2006.01)
H01Q 9/16 (2006.01) *H01Q 11/08* (2006.01)
H04R 5/033 (2006.01)

(21) International Application Number:

PCT/IB2021/052587

(22) International Filing Date:

29 March 2021 (29.03.2021)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/008,120 10 April 2020 (10.04.2020) US

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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,

(54) Title: ANTENNA FOR PROTECTIVE PERSONAL EQUIPMENT

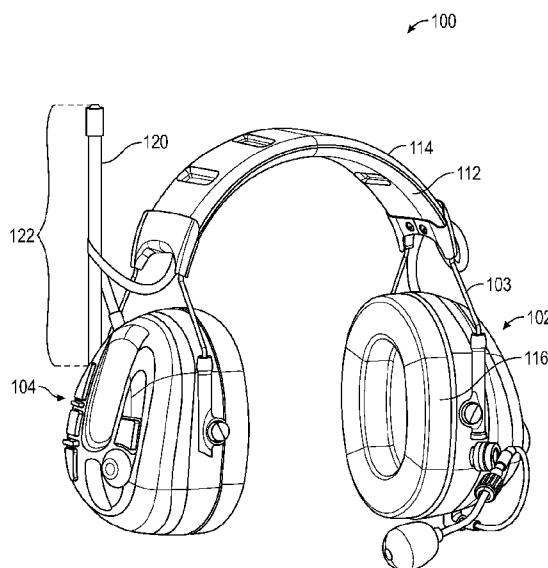


FIG. 2

(57) Abstract: A hearing protection device is provided. The hearing protection device includes a first earmuff connected to a second earmuff by a connector. Each of the first and second earmuffs are configured to receive an ambient sound and provide a dampened ambient sound to a wearer. The hearing protection device also includes an antenna, located within a housing of the first earmuff. The antenna comprises an external portion and an internal portion. The external portion is substantially outside the housing. The internal portion is located substantially within the housing. The internal portion connects to the external portion at a feed point. The hearing protection device also comprises a printed circuit board located within the housing. The printed circuit board comprises a ground plane. The antenna is configured to receive a radio signal in the 87.5-280 MHz range.



DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *with international search report (Art. 21(3))*
- *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

ANTENNA FOR PROTECTIVE PERSONAL EQUIPMENT

BACKGROUND

[0001] The use of hearing devices are well known. Many hearing devices involve an antenna configured to receive radio frequencies (RF) which is then demodulated to produce (possibly with other information) a sound signal that can be provided to a user through a speaker. Hearing devices often come in the form of in-ear plugs or over-the-ear headsets. Sound quality and consistency have been issues facing construction of new hearing devices.

SUMMARY

[0002] A hearing protection device is provided. The hearing protection device includes a first earmuff connected to a second earmuff by a connector. Each of the first and second earmuffs are configured to receive an ambient sound and provide a dampened ambient sound to a wearer. The hearing protection device also includes an antenna, located within a housing of the first earmuff. The antenna comprises an external portion and an internal portion. The external portion is substantially outside the housing. The internal portion is located substantially within the housing. The internal portion connects to the external portion at a feed point. The hearing protection device also comprises a printed circuit board located within the housing. The printed circuit board comprises a ground plane. The antenna is configured to receive a radio signal in the 87.5-280 MHz range.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

[0004] FIG. 1 illustrates an environment in which embodiments of the present invention may be useful.

[0005] FIG. 2 illustrates an example hearing protection device in accordance with an embodiment of the present invention.

[0006] FIG. 3 illustrates a schematic of an example hearing protection device in accordance with an embodiment of the present invention.

[0007] FIGS. 4A-E illustrate an example embodiment of the present invention.

- [0008] FIGS. 5A-E illustrate another example embodiment of the present invention.
- [0009] FIGS. 6A and 6B illustrate impedance of the embodiment of FIGS. 5A-4E.
- [0010] FIGS. 7A and 7B illustrate additional example embodiments of the present invention.
- [0011] FIG. 8 illustrates a method of using a headset antenna in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0012] Reference will now be made in detail to certain embodiments of the disclosed subject matter, examples of which are illustrated in part in the accompanying drawings. While the disclosed subject matter will be described in conjunction with the enumerated claims, it will be understood that the exemplified subject matter is not intended to limit the claims to the disclosed subject matter.

[0013] In the methods described herein, the acts can be carried out in any order without departing from the principles of the disclosure, except when a temporal or operational sequence is explicitly recited. Furthermore, specified acts can be carried out concurrently unless explicit claim language recites that they be carried out separately. For example, a claimed act of doing X and a claimed act of doing Y can be conducted simultaneously within a single operation, and the resulting process will fall within the literal scope of the claimed process.

[0014] The term “about” as used herein can allow for a degree of variability in a value or range, for example, within 10%, within 5%, or within 1% of a stated value or of a stated limit of a range, and includes the exact stated value or range.

[0015] The term “substantially” as used herein refers to a majority of, or mostly, as in at least about 50%, 60%, 70%, 80%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9%, 99.99%, or at least about 99.999% or more, or 100%.

[0016] Many different audio frequencies exist for transmitting sound from a source to a receiver. While AM and FM frequencies are both well known, Digital Audio Broadcasting (DAB) is a digital radio standard that is becoming more common. When compared to analog FM, for example, DAB is more efficient with respect to its spectrum use, allowing for more radio services for a given bandwidth. DAB can also be more robust with regard to noise and multipath fading. However, while FM operates around the 100 MHz range, DAB

operates around 174-280 MHz. DAB receiving chips typically have an antenna and matching system different from those used in conventional RF interfaces. Some DAB chips have a high impedance input with a tunable varactor. Therefore, a matching circuit should resonant the capacitive behavior of the antenna with a fixed inductor. Resonance can then be tuned by tuning the internal varactor. The capacitive behavior of the antenna is key for addressing tuning the modified behavior director within the matching circuit. Resonance occurs when the voltage is high, and tuning is required to get the maximum voltage output. Without this behavior, then resonance is not possible, and the voltage output will not maximize. Higher voltage, the better signal quality of received signals.

[0017] An antenna for a DAB receiving personal protective equipment (PPE) system, therefore, needs to have different behavior than traditional antennas which are often tuned to 50 Ohms and have a zero imaginary part of the impedance. In contrast, an antenna for a DAB receiving system must have a high negative imaginary part and a low real part of the impedance. Additionally, the antenna should be mechanically robust.

[0018] FIG. 1 illustrates an environment in which embodiments of the present invention may be useful. An individual 10, wearing personal protective equipment 20, can receive signals in the DAB 40 or FM 50 wavelength ranges. While not drawn to scale, FIG. 1 does illustrate that FM signal wavelengths 52 are longer than DAB signal wavelengths 42, often many times longer than a desired length of an antenna 30.

[0019] Personal Protective Equipment (PPE) often includes a headset with a set of over-the-ear hearing protection devices, often referred to as ear muffs. However, while a headset is illustrated and described, it is explicitly contemplated that other configurations may be possible. For example, FIG. 1 illustrates a headset with a headband connecting two earmuffs, 22R and 22L. However, while an over-the-head connection is illustrated, two earmuffs could also be connected using a neckband, or other suitable connection mechanisms. Each ear muff 22L, R is configured to dampen ambient environmental sounds, but also includes electronic circuitry configured to pick up ambient sounds and reproduce them, through internal speakers, at a sound level safe for a user. However, it is important that received containing at least sound information received and transmitted through electronic means be reproduced as close to nature as possible. In order to do this, an antenna for a hearing protection device needs to have an omnidirectional radiation pattern with little gain deviation. This allows the hearing protection device to be part of a Natural Interaction

Behavior (NIB) communication system. Omnidirectional behavior is also important for a DAB antenna which is omnireceiving, and needs to be well-received in any direction the user's head is pointing.

[0020] An NIB communication system uses the receiving signal strength to determine the distance between users wearing different headsets. Using the determined distance, a volume level may be derived, so that users moving apart will perceive the sound level being attenuated with increasing distance.

[0021] In one preferred embodiment, the antenna is integrated into one of the headset's cups only. This can reduce the cost of manufacturing the headset, but increases the difficulty of providing natural-sounding reproduced sound as the antenna needs to receive signals in a 360° range around a user's head. This requires the antenna to work properly with a human head blocking a portion of the range. While a single antenna is contemplated in many embodiments described herein, in other embodiments it is contemplated that a second antenna is present in a second earmuff.

[0022] FIG. 2 illustrates an example hearing protection device in accordance with an embodiment of the present invention. Headset 100 includes two over-the-ear hearing protection devices 102 and 104 connected by a headband 114. Hearing protector devices 102, 104 are mechanically connected by headband 114, which may also include padding 112 for user comfort. The mechanical connection may include one or more metallic spring wires 103 to keep hearing protection devices 102 in place by applying a certain pressure to the human head. The spring wires can be supported by a sheet of metal or plastic encased in a soft material which also acts like a cushion to enhance comfort for the user while wearing headset 100.

[0023] Each hearing protector device 102 includes a microphone (not shown), which in a preferred embodiment may be configured such that wind noise is reduced. Additionally, each hearing protector device 102 may in a preferred embodiment also include cushioning 116 which may be configured to both increase user comfort and dampen ambient sounds.

[0024] FIG. 3 illustrates a schematic of an example hearing protection device in accordance with an embodiment of the present invention. Hearing protection device 300 may in a preferred embodiment be similar to hearing protection device 100 of FIG. 2. Device 300 may also include control circuitry such as storage and processing circuitry. Storage and processing circuitry may include storage such as nonvolatile memory (e.g., flash memory

or other electrically-programmable-read-only memory configured to form a solid-state drive), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry in storage and processing circuitry may be used to control the operation of device 300. This processing circuitry may be based on one or more microprocessors, microcontrollers, digital signal processors, baseband processor integrated circuits, application specific integrated circuits, or other such devices as known to those practiced in the art.

[0025] Storage and processing circuitry may be used to run software on device 300. The software may handle communications, may process sensor signals and take appropriate action based on the processed sensor signals (e.g., to turn on or off functions in device 300, to start or stop audio playback, etc.), and may handle other device operations. To support interactions with other PPE equipment, storage and processing circuitry 16 may be used in implementing communications protocols. Communications protocols that may be implemented using storage and processing circuitry include wireless local area network protocols (e.g., IEEE 802.11 protocols—sometimes referred to as WiFi® and WiGig), protocols for other short-range wireless communications links such as the Bluetooth® protocol, cellular telephone protocols, as well as others known to those practiced in the art. For example, the protocol described in WO 2016/200950, published on December 15, 2016, which is incorporated herein by reference, may be used in some embodiments.

[0026] Device 300 includes a pair of ear muffs 310 connected by an ear muff connector 318. Device 300 also has an antenna 340 configured to receive wireless radio signals, such as DAB or FM signals. In addition to antenna 340, device 300 also has a PCB board 370. Power to components of device 300 is provided by power source 320.

[0027] Device 300 may include microphones, speakers, tone generators, and other audio components (see, e.g., one or more speakers 314). Microphones 330 may gather voice signals and/or ambient noise signals. Speakers may play back sound for a user either at ambient levels or after being processed by control circuitry.

[0028] Device 300 may include also include a power source 320, such as a battery, for example, to provide power to the circuitry of device 300. A battery 320 may be a rechargeable battery, chargeable either in a wired or wireless configuration. In another embodiment, battery 320 is not be a rechargeable battery.

[0029] Personal protective device 300 may also include an antenna 340. In one embodiment, antenna 340 can be considered as two antenna components, an external component 350 and an internal component 342. Each of external and internal portions has a length, 362 and 344, respectively.

[0030] Device 300 includes an FM receiver 352 configured to receive wireless signals in the FM bandwidth. Additionally, device 300 includes a DAB receiver 354, configured to receive wireless signals in the DAB bandwidth. Receiver 352, 354 may be located externally or internally within antenna 340. Antenna 340 may also include a top-loading feature 356, in some embodiments. External antenna portion may also include other features 358.

[0031] Antenna 340, as described in greater detail below, can be described as having a length 362, and, in some embodiments, a turn-by-turn distance 364. Because the wavelength of a DAB signal is longer than an end-to-end length of antenna 340 (e.g. a length 122 of antenna 120 illustrated in FIG. 2), it is desired to increase an overall material length 362 of antenna 340. This can be done, as illustrated in FIGS. 4A and 4B, for example, by winding the antenna such that it has a turn-by-turn distance 364. As described in greater detail below, the turn-by-turn radius 364 may be consistent for antenna portion 350, or it may vary along the length of external portion 350.

[0032] Internal portion 342 of antenna 340 can also be characterized as having a length 344. Internal portion 342 is, in one embodiment, housed within a housing of earmuff 310. Internal portion 342 can also be characterized as having other features.

[0033] Antenna 340 has an impedance 380 that can be characterized as having a real portion 384 and an imaginary portion 382. Antenna 340 has a large, negative imaginary portion and a reduced real portion when compared to a standard FM-receiving antenna. It is important that the imaginary portion be at least -50 to have good signal reception. In some embodiments, the imaginary portion is in a range of -50 to -1400.

[0034] Hearing protection device 300 also includes a printed circuit board (PCB) 370 which has a ground plane 372 and a reference plane 374 which are separate from the internal portion 342 of antenna 340. However, in some embodiments, internal portion 342 is connected to PCB 370. In some embodiments, PCB 370 also includes a conducting trace 376. PCB 370 may also have other features or functionality 378. In one embodiment, PCB

is a rigid material configured to be fixed in place within an earmuff housing. The rigid PCB material may be fire-retardant, such as an FR-4 grade glass fiber and resin laminate.

[0035] In some embodiments, an antenna may have a feed that includes a positive antenna feed terminal and a ground antenna feed terminal. The transmission line may be used to couple radio-frequency transceiver circuitry to the antenna. The transmission line may have a positive signal path such as a line and a ground signal path. The transmission lines may include coaxial cable paths, microstrip transmission lines, stripline transmission lines, edge-coupled microstrip transmission lines, edge-coupled stripline transmission lines, transmission lines formed from combinations of transmission lines of these types, etc. Filter circuitry, switching circuitry, impedance matching circuitry, and other circuitry may be interposed within the transmission lines, if desired. The connections to the antenna or to a plurality of antennas may use an unbalanced transmission line for each antenna the transmission line may include filter circuitry, switching circuitry, impedance matching networks and other items known to those practiced in the art.

[0036] FIGS. 4A and 4B illustrate an antenna in accordance with an embodiment of the present invention. Antenna 400 has an external portion 410 and an internal portion 420. Housings for external and internal portions 410, 420 have been removed for ease in understanding.

[0037] External portion 410 is a helical monopole antenna, with a length 410. External portion includes conducting spring wire, in one embodiment, wound tightly. A material length of the conducting spring wire, in one embodiment, is longer than length 410. In one embodiment, the material length is at least twice, or at least three times as long as length 410.

[0038] An internal portion 420 includes a conducting structure 422 configured to substantially fit within an earmuff housing. In one embodiment, conducting structure 422 is a metallic sheet. In another embodiment, the conducting structure is a metallic tape. As illustrated in FIG. 4A, in one embodiment the conducting structure 422 is substantially flat. In one embodiment, external portion 410 and internal portion 420 can be viewed as a dipole-like structure consisting of helical wound conductor on the one side and the conducting sheet on the other side. The external portion 410, in one embodiment, feeds into the internal portion at point 430. Feed point 430, in one embodiment, is substantially at an end of internal portion 420 and substantially at an end of external portion 410. Internal portion, in

one embodiment, is made from a conductive material such as copper or aluminum. However, other conductive materials may also be suitable, including silver, gold, a gold-plated material, steel or a steel sheet, or iron. Internal portion 420 may also include zinc.

[0039] Similarly, external portion 410 should also be formed from a conductive element, but must also be mechanically stable. In one embodiment, external portion comprises steel, such as a heat treated.

[0040] FIG. 4B illustrates a view of internal portion 420, with conducting structure 422 fit within a housing 424, in one embodiment. However, while FIG. 4B illustrates internal portion 420 as a metal sheet wound around an interior of a housing, other configurations are expressly possible. For example, internal portion 420 could also be embedded within the housing. Further, internal portion 420 could be a coating on the interior or exterior of the housing. Additionally, in some embodiments, the internal portion is built into the PCB board.

[0041] The internal portion 420 must have a certain length to be suitable, as if it is too small, it becomes inductive and does not work. The length should be at least half the length of the height of the antenna, in one embodiment. The width of the internal portion should be half an inch minimum.

[0042] The embodiment illustrated in FIGS. 4A and 4B result in an enlarged negative imaginary part and the reduced real part of the antenna impedance, as illustrated in FIGs 4C and 4D. This design also avoids a zero imaginary part, which would result in self resonance, in the frequency bands of interest. These effects are mainly influenced by the number of windings and the distance between each winding. Self resonances are problematic for the intended matching circuit as it voids the chance of generating a variable LC-resonance in combination with the matching circuit and the varactor inside the receiver IC.

[0043] Instead, device 400 has an imaginary part that is negative. The imaginary part can be further increased by choosing a winding and distance ratio which generates a nearly linear imaginary part. Additionally, the overall active area of the antenna can be enlarged, which reduces the real part. The active area is enlarged mainly with the addition of internal portion 420. Electromagnetic fields can now build up and extend more easily between the helix and the plane. Because of reciprocity, the same is also true for the receiving direction.

[0044] FIG. 4E illustrates a plot of the antenna impedance over frequency. The imaginary part $Z(\text{im})$ is designed to be below zero in the frequency bands of interest which are between 87,5MHz and 108MHz for FM and 174,160MHz and 239,968MHz for DAB. The antenna shall work at both frequency bands. The real part $Z(\text{re})$ was designed to be as low as possible. The picture shows good performance in the FM Band and very good performance in the more DAB band.

[0045] FIGS. 5A and 5B illustrate an antenna in another embodiment of the present invention. Device 500 includes two antenna portions, an external portion 510 and an internal portion 530. Housing for the external portion and the internal portion have been removed for ease of understanding. External portion is a helical wound conducting trace 514. Conducting trace 514 has a material length that is longer than a length 512 of external portion 510.

[0046] Conducting trace 530, in one embodiment, is fixed to PCB 540, for example using solder or another fixing mechanism such as an adhesive. Conducting trace 530, in one embodiment, is substantially planar. In one embodiment, conducting trace 530 has a consistent cross section 536 and a length that is longer than a length 532 of PCB board 540. Conducting trace 530 also has a height 534 with respect to the has at least one corner and at least roughly follows an outline of PCB 540. In one embodiment, conducting trace 530 includes two or more corners, such as three corners or four corners, for example, in order to follow an outline of PCB 540. As illustrated in FIGS. 5A and 5B, conducting trace 530 has three bend points 538.

[0047] Conducting trace 530 and PCB board 540 are configured to fit substantially within a housing of a hearing protector cup (not shown). Conducting trace 530, along with external portion 510, can be seen as a dipole-like structure consisting of helical wound conductor 514 on the one side and conducting trace 530 on the PCB on the other side. The active area of antenna 500 is, therefore, enlarged by conductive trace 530 on the lower end of antenna 500 inside the cup. E-Fields can now build up and extend more easily between conductor 514 and trace 530. Because of reciprocity, the same is also true for the receiving direction.

[0048] A feed point 520 connects external portion 510 and conducting trace 530. As illustrated in FIG. 5B, conductive trace 530 is designed to fit on PCB 540. Care has to be taken with regard to the layout of the remaining PCB structures such as placement of a

microcontroller, power converters and other PCB ground planes to keep influence on the antenna structure as small as possible. In one embodiment, conductive trace 530 is made of any suitable conductive materials copper with preferably a gold coating.

[0049] FIGS. 5C and 5D illustrate dimensions for one embodiment of a device 500. FIG. 5E illustrates dimensions for the helical portion of an antenna, such as the antenna illustrated in FIGS. 4A-4B or 5A-5D, for example. As illustrated in FIG. 5E, the helical portion can be characterized as a series of windings, each of which has a height 550 and a diameter 560. The windings are illustrated as circular, however other shapes are also expressly contemplated for other embodiments, including but not limited to an oval, a square, or a triangle.

[0050] The benefit of design 500 is that an existing PCB 540 can be used to contain the second arm (or ground plane) of antenna 500. This makes fabrication easier, but may have some affect on performance. It also allows for the use of state-of-the art FM and DAB receivers. However, while existing PCB boards may be used, it has been found that adding an internal portion may allow for better receiving quality.

[0051] FIGS. 6A and 6B illustrate plots of antenna impedance over frequency for the device illustrated in FIGS. 5A and 5B. The next pictures show a plot of the antenna impedance over frequency. The imaginary part $Z(im)$ is designed to be below zero in the frequency bands of interest which are between 87,5MHz and 108MHz for FM and 174,16MHz and 239,968MHz for DAB. The antenna was shown to work at both frequency bands. The real part $Z(re)$ is designed to be as low as possible.

[0052] FIGS. 7A and 7B illustrate additional embodiments of the present invention. The illustrated features of FIGS. 7A and 7B may be practiced alone, or in combination with features described above with respect to devices 400 and 500.

[0053] FIG. 7A illustrates an external portion 700 of an antenna with a variable turn-to-turn distance over the whole length 710 of external portion 700. One turn of wire 720 itself can be considered as a combination of an inductive part (wire 720) and a capacitive part (coupling between neighboring turns). The inductive part can be influenced by the length (the circumference, measured as π multiplied by diameter 722) and the thickness 724 of wire 720. The capacitive part is influenced by the distance of one turn to another, e.g. distances 712, 714 716, or 718, as well as thickness 724 and turn-length of the wire. The

whole antenna acts as multiple LC circuits in serial configuration, generating the overall impedance.

[0054] Usually, helix antennas have a constant turn diameter and a constant distance between each turn. FIG. 7A illustrates a helix monopole stub working in normal mode where all these parameters are modified over length 710 of the antenna.

[0055] The turn-to-turn distance is varied along length 710, as illustrated in the difference between distances 712, 714, 716 and 718, starting with low distance on the bottom and large distance on the top. This can also be the other way around, as illustrated in FIG. 7B.

[0056] Varying a turn-to-turn distance can increase mechanical stability for the antenna, for example by having a smaller turn-by-turn distance positioned at the base of the antenna. It can also generate denser electrical fields where the turn-by-turn distance is smaller, for example near reference number 718, which can raise overall capacitance of the antenna impedance.

[0057] Using the approach of FIG. 7A, the impedance of the antenna can be very precisely modified without changing length 710 or diameter 722 of the helix. While FIG. 7A illustrates a gradual increase in turn-by-turn distance, it is also expressly contemplated that turn-by-turn distance could increase in a stepwise fashion, e.g. a first turn-by-turn distance for ten turns and then a second turn-by-turn distance for another ten turns. In another embodiment, more than two turn-by-turn distances are present, for example three, four, five or more distinct turn distances are present along length 710. In another embodiment, the turn-by-turn distances are varied for different numbers of turns, for example a first turn-by-turn distance for four turns, a second turn-by-turn distance for an additional six turns, and a third turn-by-turn distance for another ten turns.

[0058] Additionally, while FIG. 7A illustrates an embodiment where diameter 722 remains substantially constant and turn-by-turn length changes, it is also expressly contemplated that diameter 722 could vary along distance 710 instead of, or in addition to, turn-by-turn length. For example, external portion 720 could have a big helix diameter (e.g. 8mm) on the bottom and a small diameter (e.g. 4.73mm) on the top. Alternatively, external portion 720 could have a small diameter on the bottom and a larger diameter on the top. In addition to turn-by-turn length and diameter, it is also envisioned that the thickness of conductor 720 could vary along distance 710.

[0059] Changing the turn distance, the helix diameter and thickness of the conductor can also be combined to gain maximal flexibility for impedance and mechanical constraints. The change of the turn distance and/or the change in helix diameter and/or the change in thickness of the conductor can follow a certain mathematical function or can be freely defined. Possible mathematical functions can be a linear function or any other function like e.g. hyperbolic, rectangular or e-function or a combination of those. Any of the methods of changing turn distance, turn diameter or conductor thickness may be used alone or in conjunction with either internal portion 420 or conducting trace 530.

[0060] In the embodiment illustrated in FIG. 7A, the diameter of the helix conductor is fixed at 1mm and the helix turn-diameter is 4.73mm (mid to mid of the conductor). The helix starts on the bottom with a turn-to-turn distance of 2mm. On the top of the antenna the turn-to-turn distance is 5mm. The transition of the turn-to-turn distance between bottom and top is linear.

[0061] FIG. 7B illustrates a further modification, which can be used with any of devices 400, 500 or alone. As discussed above, the new FM/DAB Receiver chip needs the antennas impedance to be as capacitive as possible. This is due to the fact that the input impedance of the chip is relatively high (around 1.5k). In this constellation, the antenna and the matching circuit can create a series resonance circuit which boosts the voltage across the inductor at a certain frequency. The chip also includes a tuning varactor with which its resonance frequency can be tuned to the actual receiving frequency.

[0062] Because of the high-impedance chip input impedance, the antenna acts like a collector mainly for electric fields. At a transmitting antenna, electric fields excitation can be improved by adding additional conducting areas on both ends of a dipole antenna, referred to as top-loading the antenna. As the antenna is reciprocal, this is also true for the receiving path.

[0063] To add top-loading to the previously described antenna solution, one possibility is to add a conducting cylindric solid or shell 770 to the top of antenna 750. This can also be a conducting solid cylinder, which is placed inside upper part of the existing helix, which will shorting the upper windings, illustrated by turn-by-turn length 762. All these methods will enlarge the conducting area on top of the antenna. By selecting the right wirelength and length of the helix, the antenna can be designed such that the E-field on the helix-conductor generate a maximum intensity on the top-loading.

[0064] As illustrated in FIG. 7B, in one embodiment the diameter of the helix conductor is fixed at 1mm along the length. The helix turn-diameter is about 4.73mm around the middle of the conductor, but varies along length 760, as illustrated by turn-diameters 762, 764, 766, and 768. (mid to mid of the conductor). The overall length 760 is about 160mm. The helix starts on the bottom with a turn-to-turn distance of 2mm. On the top of the antenna the turn-to-turn distance is 5mm. The transition of the turn-to-turn distance between bottom and top is linear.

[0065] Top-loading has been added by placing a solid cylinder 770 with the diameter of the helix on the top 30mm of the helix. FIG. 7B illustrates a top-loaded antenna 770 in combination with an internal portion 780 that includes conducting trace 784 on PCB 782. However, it is also contemplated that a top-loaded antenna could be used with internal portion 420, or another suitable internal portion of an antenna.

[0066] With top-loading the imaginary part is more negative as before, also preventing the resonance to occur. Top-loading also improves the ohmic losses in the antenna at higher frequencies as can be observed in the real part. Reduced ohmic losses and higher negative imaginary part of the impedance result in better performance of the antenna.

[0067] FIG. 8 illustrates a method of using a headset antenna in accordance with an embodiment of the present invention. Method 800 may be useful for a headset antenna within a hearing protection device. A hearing protection device is designed to dampen ambient sound for a user. Microphones are configured to receive ambient sound, and the hearing protection device is configured to process the ambient sound to a safe level for a user. An antenna, such as the antennae described with respect to FIGS. 2-5, is used for receiving Radio frequency (RF) signals, such as those in the FM or DAB wavelength spectrums and processing them to reproduce sound for a user such that the sound accurately reflects a distance between the wearer of the hearing protection device and the transceiver antenna at source of the sound. This requires an antenna that allows the hearing protection device to operate within an NIB environment. Such an antenna may need to function omnidirectionally.

[0068] In block 810, ambient sound is received. Ambient sound may be received by a microphone, in one embodiment. A microphone may be located in one earpiece, as indicated in block 802, or in both earpieces of a headset, as indicated in block 804. Sounds from the user are also captured by microphone 805. Sound from another user of a similar

hearing protection device may be demodulated by a transceiver after being picked up by an antenna.

[0069] In block 820, reproduced sound is provided to a user. Sound may be reproduced in only one earmuff, as indicated in block 812, or in both earmuffs, as indicated in block 814. If a suitable antenna is present that is capable of allowing a headset to detect distance and direction of a sound, reproduced sound may also be provided such that it sounds omnidirectional, instead of from only two speakers. Other features may also be present, in other embodiments.

[0070] The reproduced sound may be provided such that it is not altered, as indicated in block 822. In another embodiment, the sound is processed, as indicated in block 824, for example to reduce the sound to a safe level for a user to hear. The reproduced sound may also have other features.

[0071] A hearing protection device is presented. The hearing protection device includes a first earmuff connected to a second earmuff by a connector. Each of the first and second earmuffs are configured to receive an ambient sound and provide a dampened ambient sound to a wearer. The hearing protection device also includes an antenna, on the first earmuff. The antenna includes an external portion that is substantially outside the housing and an internal portion, associated with the housing. The internal portion connects to the external portion at a feed point. The antenna also includes a printed circuit board located within the housing. The printed circuit board includes a ground plane. The antenna is configured to receive a radio signal in the 87.5-280 MHz range.

[0072] The hearing protection device may be implemented such that the external portion includes a conducting element. The conducting element is wound helically within an external portion housing.

[0073] The hearing protection device may be implemented such that a length of the conducting element is longer than a length of the external portion housing.

[0074] The hearing protection device may be implemented such that the length of the conducting element is at least twice the length of the external portion housing.

[0075] The hearing protection device may be implemented such that the internal portion includes a conducting element.

[0076] The hearing protection device may be implemented such that the conducting element has a planar surface.

[0077] The hearing protection device may be implemented such that the planar surface is substantially parallel to the printed circuit board.

[0078] The hearing protection device may be implemented such that the planar surface is substantially perpendicular to the printed circuit board.

[0079] The hearing protection device may be implemented such that the conducting element is curved within the earmuff housing.

[0080] The hearing protection device may be implemented such that the conducting element includes copper.

[0081] The hearing protection device may be implemented such that the conducting element includes a gold coating.

[0082] The hearing protection device may be implemented such that the helical structure includes a plurality of turns. Each of the plurality of turns have substantially the same diameter.

[0083] The hearing protection device may be implemented such that the helical structure includes at least a first turn and a second turn. A first diameter of the first turn differs from a second diameter of the second turn.

[0084] The hearing protection device may be implemented such that the helical structure includes a plurality of turns, each turn having a diameter. The diameter of each turn increases from a first end of the helical structure to a second end of the helical structure.

[0085] The hearing protection device may be implemented such that the first end of the helical structure is a connection point with the earmuff housing.

[0086] The hearing protection device may be implemented such that the second end of the helical structure is a connection point with the earmuff housing.

[0087] The hearing protection device may be implemented such that the helical structure includes a plurality of turns, and a plurality of turn-by-turn radii corresponding to a distance between corresponding turns. The plurality of turn-by-turn radii are substantially the same.

[0088] The hearing protection device may be implemented such that the helical structure includes a plurality of turns, and a plurality of turn-by-turn radii corresponding to a distance between corresponding turns. The plurality of turn-by-turn radii increase from a first end to a second end of the helical structure.

[0089] The hearing protection device may be implemented such that the external portion includes a top-loading feature.

[0090] The hearing protection device may be implemented such that it includes a top-loading feature that fits within the helical structure.

[0091] The hearing protection device may be implemented such that the top-loading feature includes a cylindrical feature.

[0092] The hearing protection device may be implemented such that the hearing protection device includes a microphone configured to receive the ambient sound, and a speaker within the earmuff to provide the dampened ambient sound.

[0093] The hearing protection device may be implemented such that the internal portion is inside the housing.

[0094] The hearing protection device may be implemented such that the internal portion is an integral part of the housing.

[0095] The hearing protection device may be implemented such that the internal portion is wrapped around an exterior of the housing.

[0096] An antenna for a personal protection device is presented that includes a first portion comprising a first conducting element wound in a helical structure. The first portion has a first portion length, and the conducting element has a conducting element length. The conducting element length is greater than the first portion length. The antenna also includes a second portion comprising a second conducting element with a substantially planar surface. The antenna also includes a printed circuit board is configured to facilitate the antenna receiving radio wave signals in the 174-280 MHz range.

[0097] The antenna may be implemented such that the antenna is also configured to receive radio wave signals around 87.5-100 MHz.

[0098] The antenna may be implemented such that the antenna has an impedance with a real portion and an imaginary portion. The imaginary portion is negative. The magnitude of the imaginary portion is greater than a magnitude of the real portion.

[0099] The antenna may be implemented such that the first conducting element length is at least twice as long as the first portion length.

[00100] The antenna may be implemented such that the first and second portions operate as a dipole antenna.

[00101] The antenna may be implemented such that the helical structure has a plurality of windings. Each winding has a height and a diameter. One of the height and the diameter varies along the first portion length.

[00102] The antenna may be implemented such that the height or the diameter vary in a step-wise manner, a linear manner, an exponential manner, a hyperbolic manner, a rectangular manner, an e-function manner, or a combination thereof.

[00103] The antenna may be implemented such that the first portion has a first end and a second end. One of the height or diameter vary such that one of the height or diameter is greatest at the first end. The first end connects to the second portion.

[00104] The antenna may be implemented such that the first portion has a first end and a second end. One of the height or diameter vary such that one of the height or diameter is least at the first end. The first end connects to the second portion.

[00105] The antenna may be implemented such that the planar surface of the second conducting element is substantially parallel to the printed circuit board.

[00106] The antenna may be implemented such that a portion of the planar surface of the second conducting element is substantially perpendicular to the printed circuit board.

[00107] The antenna may be implemented such that the second conducting element is fixed to the printed circuit board.

[00108] The antenna may be implemented such that the first portion also includes a top-loading element.

[00109] The antenna may be implemented such that the top-loading element includes a cylinder.

[00110] The antenna may be implemented such that the cylinder is configured to fit within a diameter of the helical structure.

[00111] The antenna may be implemented such that the second portion and the printed circuit board are configured to fit within a housing of an earmuff.

[00112] The antenna may be implemented such that the second portion is inside the housing.

[00113] The antenna may be implemented such that the second portion is an integral part of the housing.

[00114] The antenna may be implemented such that the second portion is wrapped around an exterior of the housing.

WHAT IS CLAIMED IS:

1. A hearing protection device comprising:
 - a first earmuff connected to a second earmuff by a connector, wherein each of the first and second earmuffs are configured to receive an ambient sound and provide a dampened ambient sound to a wearer; and
 - an antenna, on the first earmuff, wherein the antenna comprises:
 - an external portion, wherein the external portion is substantially outside the housing;
 - an internal portion, associated with the housing, and wherein the internal portion connects to the external portion at a feed point;
 - a printed circuit board located within the housing, wherein the printed circuit board comprises a ground plane; and
 - wherein the antenna is configured to receive a radio signal in the 87.5-280 MHz range.
2. The hearing protection device of claim 1, wherein the external portion comprises a conducting element, wherein the conducting element is wound helically within an external portion housing.
3. The hearing protection device of claim 2, wherein a length of the conducting element is longer than a length of the external portion housing.
4. The hearing protection device of claim 3, wherein the length of the conducting element is at least twice the length of the external portion housing.
5. The hearing protection device of any of claims 1-4, wherein the internal portion comprises a conducting element.
6. The hearing protection device of claim 5, wherein the conducting element has a planar surface.
7. The hearing protection device of claim 6, wherein the planar surface is substantially parallel to the printed circuit board.
8. The hearing protection device of claim 6, wherein the planar surface is substantially perpendicular to the printed circuit board.
9. The hearing protection device of claim 5, wherein the conducting element is curved within the earmuff housing.

10. The hearing protection device of claim 5, wherein the conducting element comprises copper.
11. The hearing protection device of claim 10, wherein the conducting element comprises a gold coating.
12. The hearing protection device of any of claims 2-11, wherein the helical structure comprises a plurality of turns, and wherein each of the plurality of turns have substantially the same diameter.
13. The hearing protection device of any of claims 2-12, wherein the helical structure comprises at least a first turn and a second turn, and wherein a first diameter of the first turn differs from a second diameter of the second turn.
14. The hearing protection device of any of claims 2-13, wherein the helical structure comprises a plurality of turns, each turn having a diameter, and wherein the diameter of each turn increases from a first end of the helical structure to a second end of the helical structure.
15. The hearing protection device of claim 14, wherein the first end of the helical structure is a connection point with the earmuff housing.
16. The hearing protection device of claim 14, wherein the second end of the helical structure is a connection point with the earmuff housing.
17. The hearing protection device of any of claims 2-16, wherein the helical structure comprises a plurality of turns, and a plurality of turn-by-turn radii corresponding to a distance between corresponding turns, and wherein the plurality of turn-by-turn radii are substantially the same.
18. The hearing protection device of any of claims 2-17, wherein the helical structure comprises a plurality of turns, and a plurality of turn-by-turn radii corresponding to a distance between corresponding turns, and wherein the plurality of turn-by-turn radii increase from a first end to a second end of the helical structure.
19. The hearing protection device of any of claims 1-18, wherein the external portion includes a top-loading feature.
20. The hearing protection device of any of claims 2-19, and further comprising a top-loading feature that fits within the helical structure.
21. The hearing protection device of claim 20, wherein the top-loading feature comprises a cylindrical feature.

22. The hearing protection device of any of claims 1-21, wherein the hearing protection device comprises a microphone configured to receive the ambient sound, and a speaker within the earmuff to provide the dampened ambient sound.
23. The hearing protection device of any of claims 1-22, wherein the internal portion is inside the housing.
24. The hearing protection device of any of claims 1-23, wherein the internal portion is an integral part of the housing.
25. The hearing protection device of any of claims 1-24, wherein the internal portion is wrapped around an exterior of the housing.
26. An antenna for a personal protection device, the antenna comprising:
 - a first portion comprising a first conducting element wound in a helical structure, wherein the first portion has a first portion length, and the conducting element has a conducting element length, and wherein the conducting element length is greater than the first portion length;
 - a second portion comprising a second conducting element with a substantially planar surface; and
 - a printed circuit board, wherein the printed circuit board is configured to facilitate the antenna receiving radio wave signals in the 174-280 MHz range.
27. The antenna of claim 26, wherein the antenna is also configured to receive radio wave signals around 87.5-100 MHz.
28. The antenna of claim 26 or 27, wherein the antenna has an impedance with a real portion and an imaginary portion, and wherein the imaginary portion is negative, and wherein the magnitude of the imaginary portion is greater than a magnitude of the real portion.
29. The antenna of any of claims 26-28, wherein the first conducting element length is at least twice as long as the first portion length.
30. The antenna of any of claims 26-29, wherein the first and second portions operate as a dipole antenna.
31. The antenna of any of claims 26-30, wherein the helical structure has a plurality of windings, wherein each winding has a height and a diameter, and wherein one of the height and the diameter varies along the first portion length.

32. The antenna of claim 31, wherein the height or the diameter vary in a step-wise manner, a linear manner, an exponential manner, a hyperbolic manner, a rectangular manner, an e-function manner, or a combination thereof.
33. The antenna of claim 31, wherein the first portion has a first end and a second end, and wherein one of the height or diameter vary such that one of the height or diameter is greatest at the first end, wherein the first end connects to the second portion.
34. The antenna of claim 31, wherein the first portion has a first end and a second end, and wherein one of the height or diameter vary such that one of the height or diameter is least at the first end, wherein the first end connects to the second portion.
35. The antenna of any of claims 26-34, wherein the planar surface of the second conducting element is substantially parallel to the printed circuit board.
36. The antenna of any of claims 26-35, wherein a portion of the planar surface of the second conducting element is substantially perpendicular to the printed circuit board.
37. The antenna of any of claims 26-36, wherein the second conducting element is fixed to the printed circuit board.
38. The antenna of any of claims 26-37, wherein the first portion also comprises a top-loading element.
39. The antenna of claim 38, wherein the top-loading element comprises a cylinder.
40. The antenna of claim 39, wherein the cylinder is configured to fit within a diameter of the helical structure.
41. The antenna of any of claims 26-40, wherein the second portion and the printed circuit board are configured to fit within a housing of an earmuff.
42. The antenna of any of claims 26-41, wherein the second portion is inside the housing.
43. The antenna of any of claims 26-42, wherein the second portion is an integral part of the housing.
44. The antenna of any of claims 26-43, wherein the second portion is wrapped around an exterior of the housing.

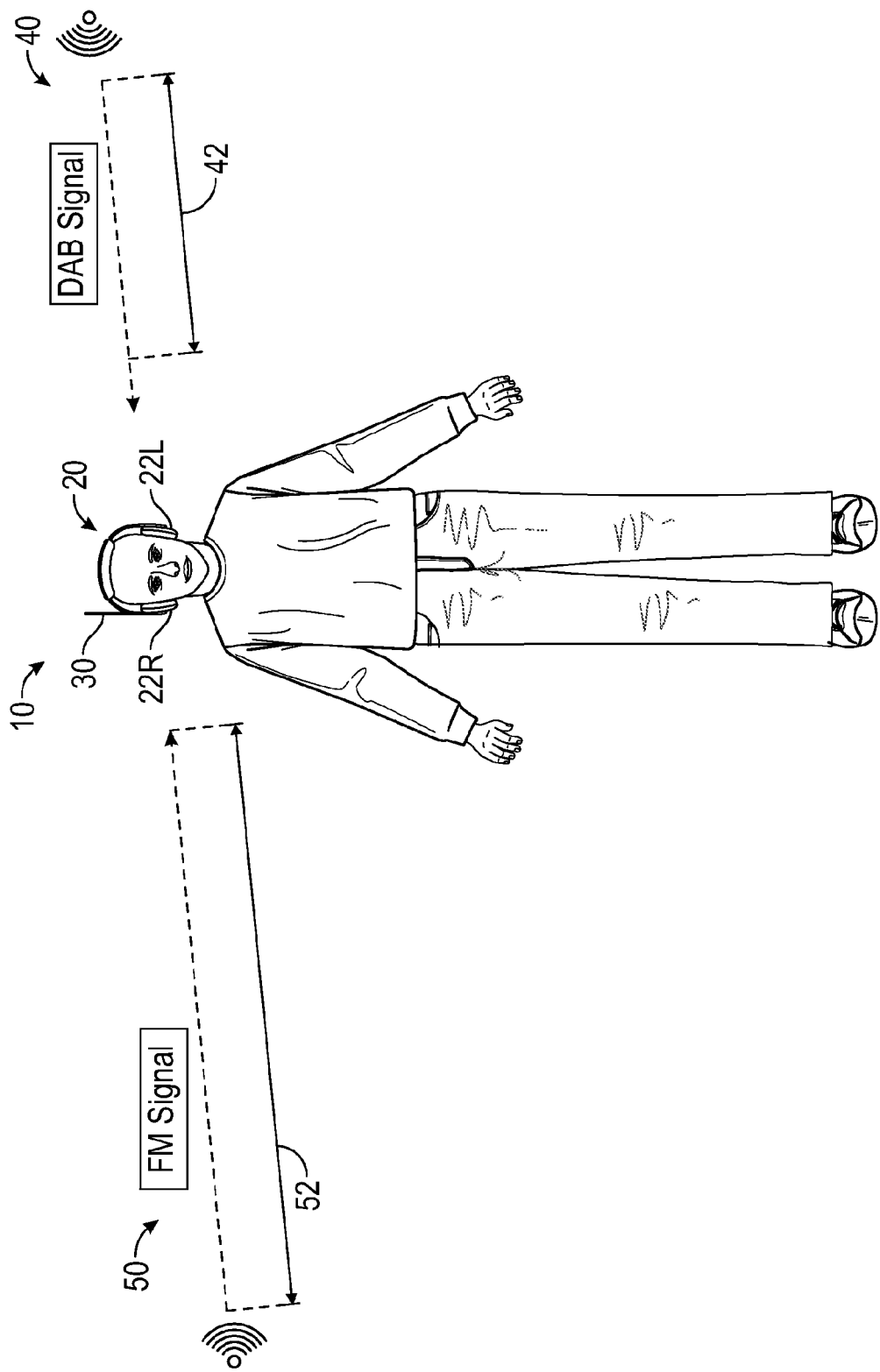


FIG. 1

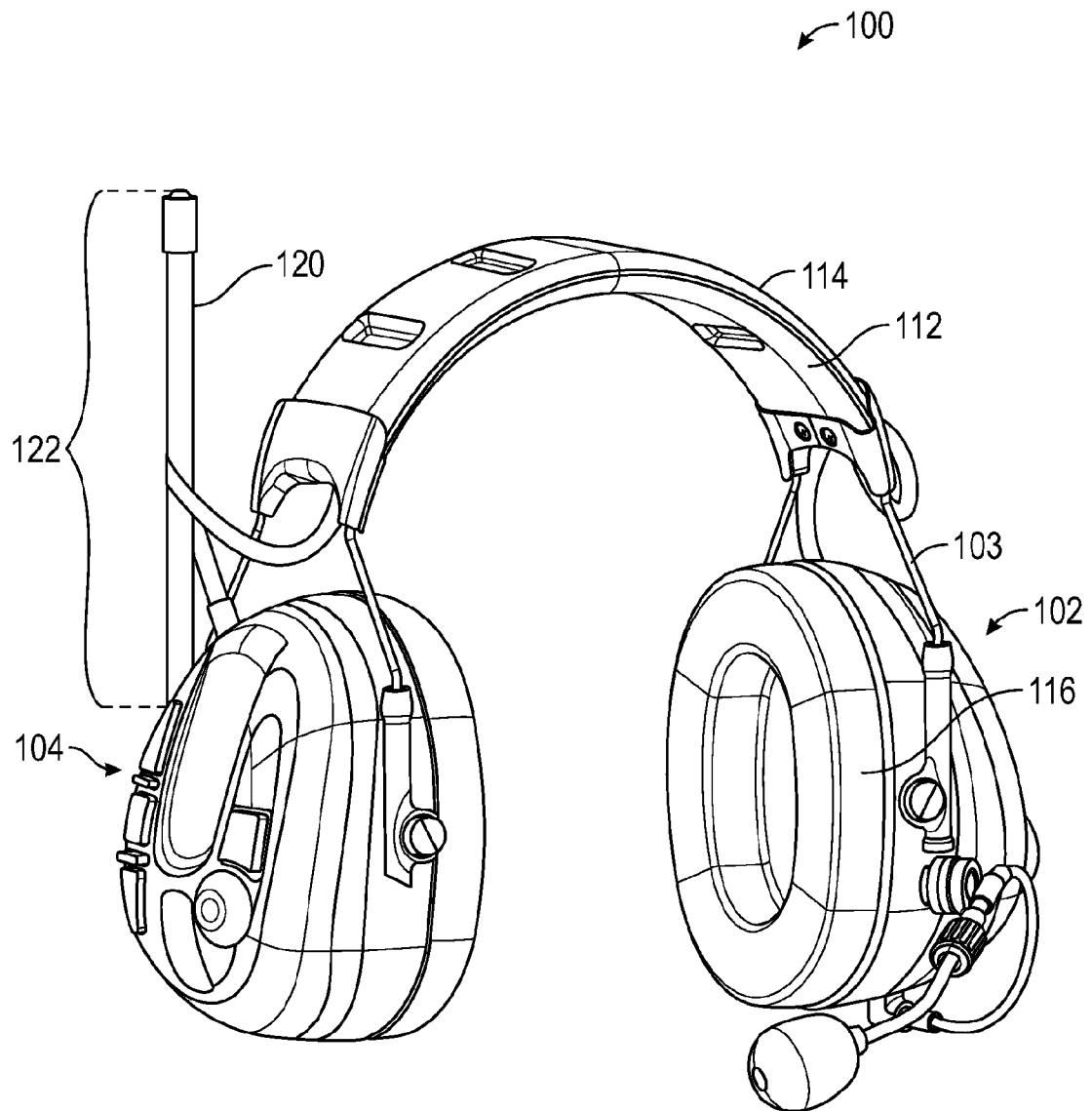


FIG. 2

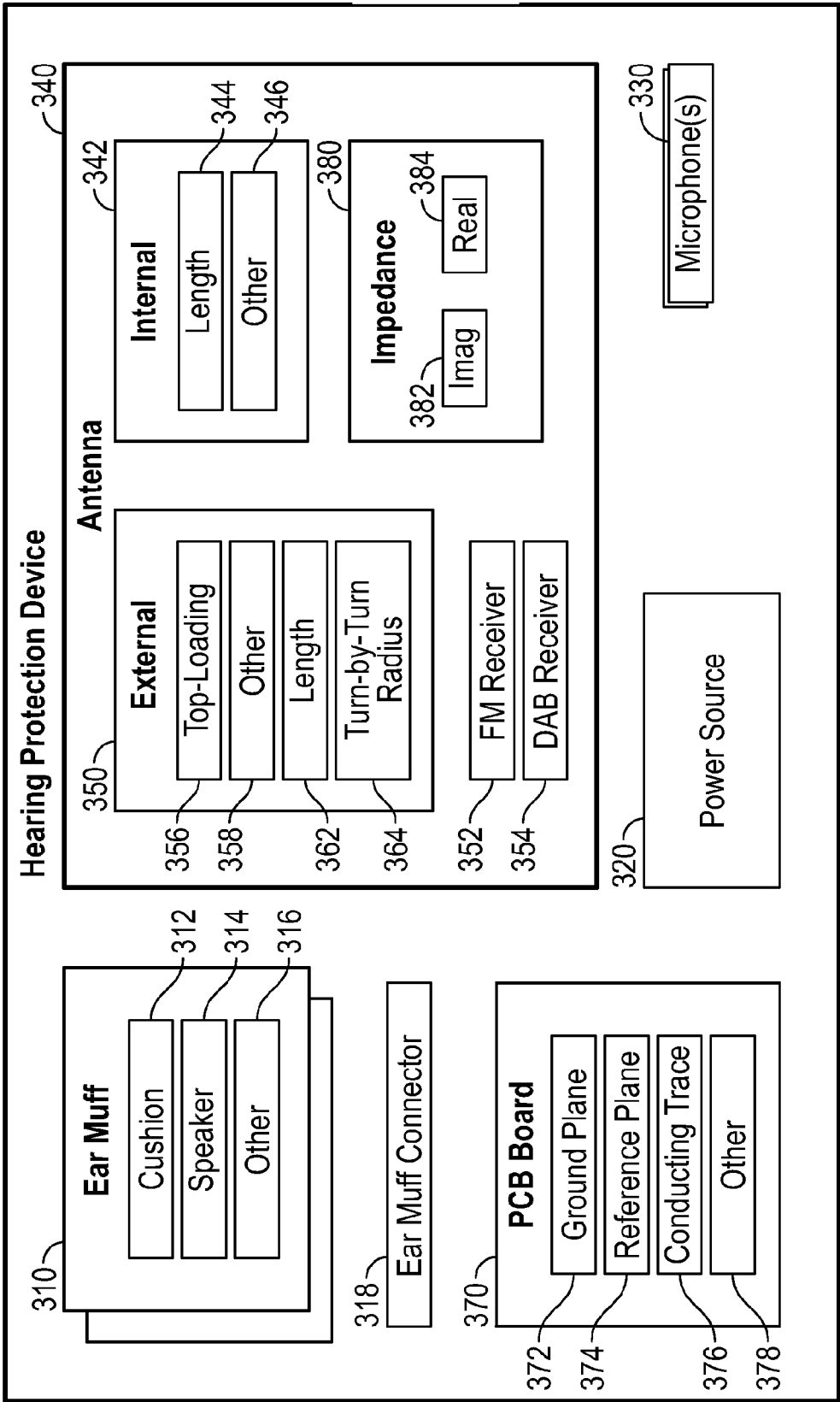


FIG. 3

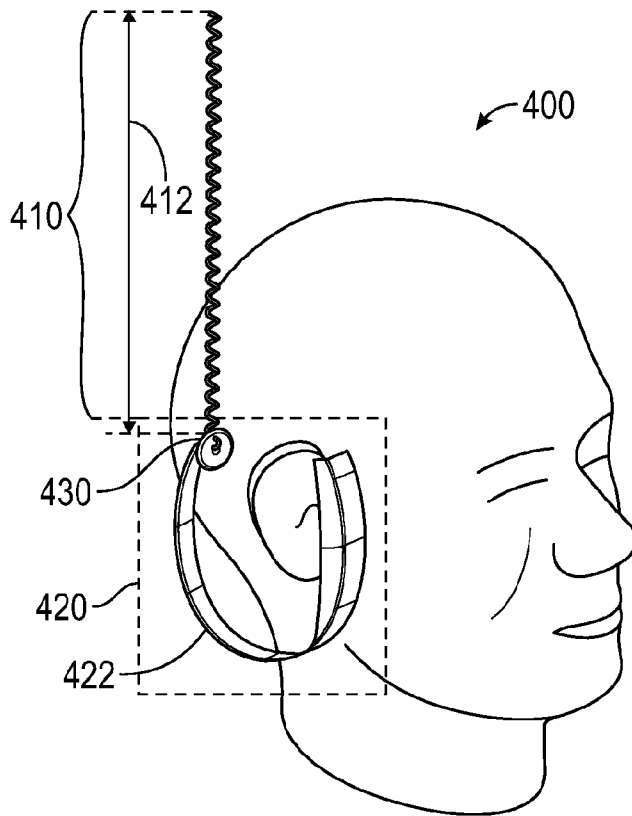


FIG. 4A

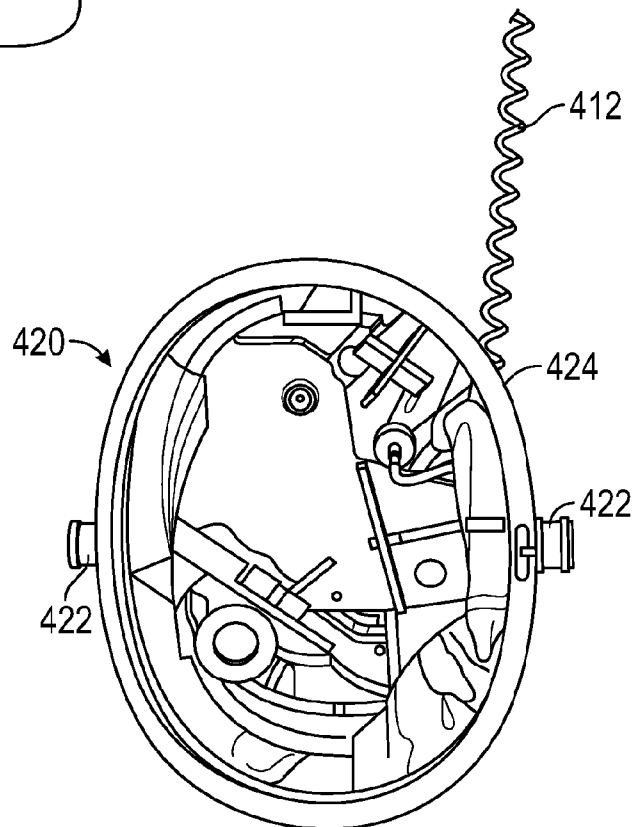


FIG. 4B

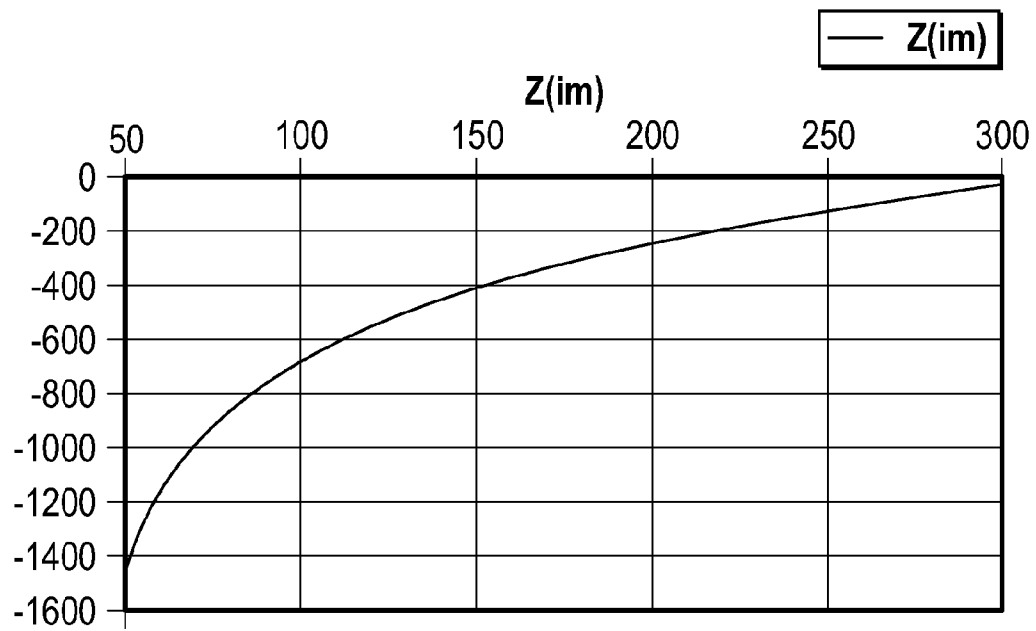


FIG. 4C

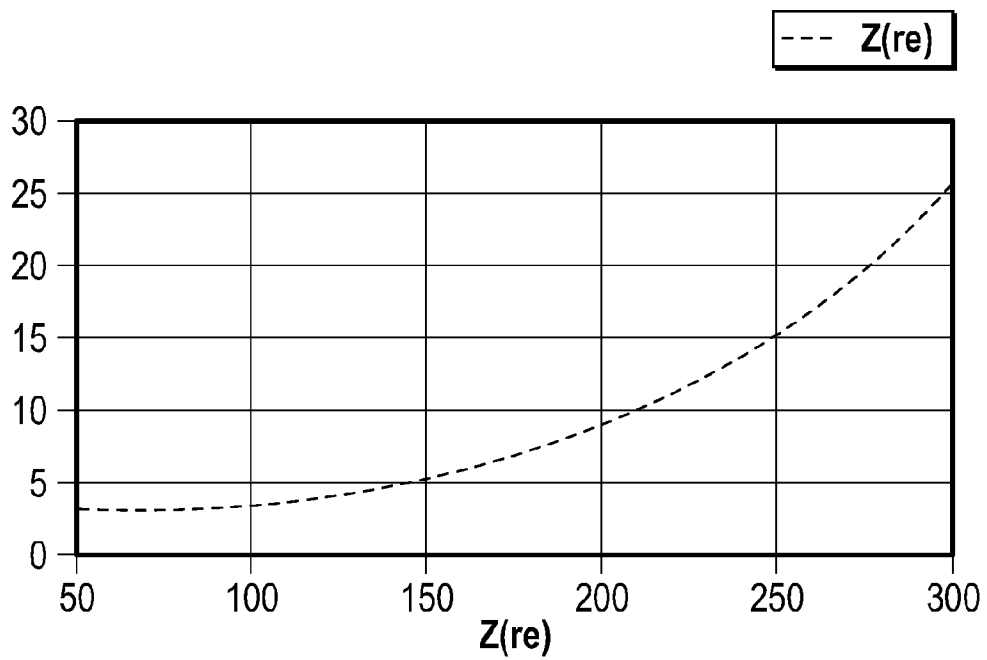


FIG. 4D

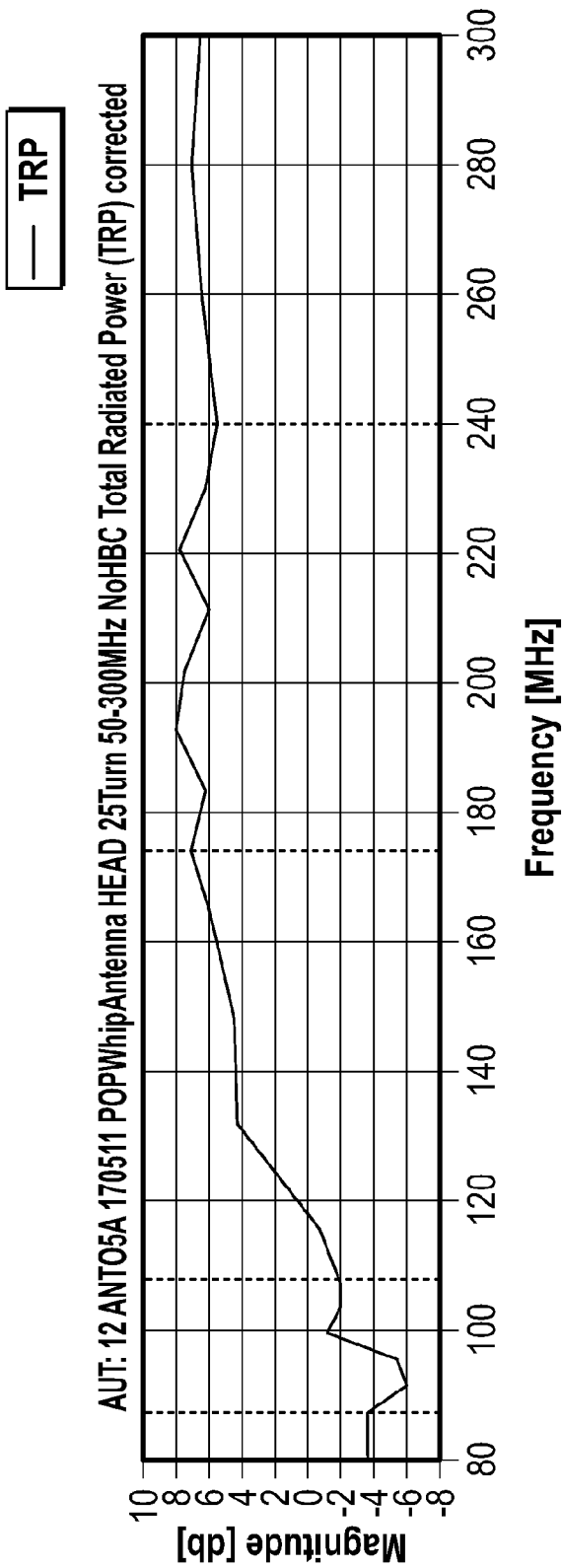


FIG. 4E

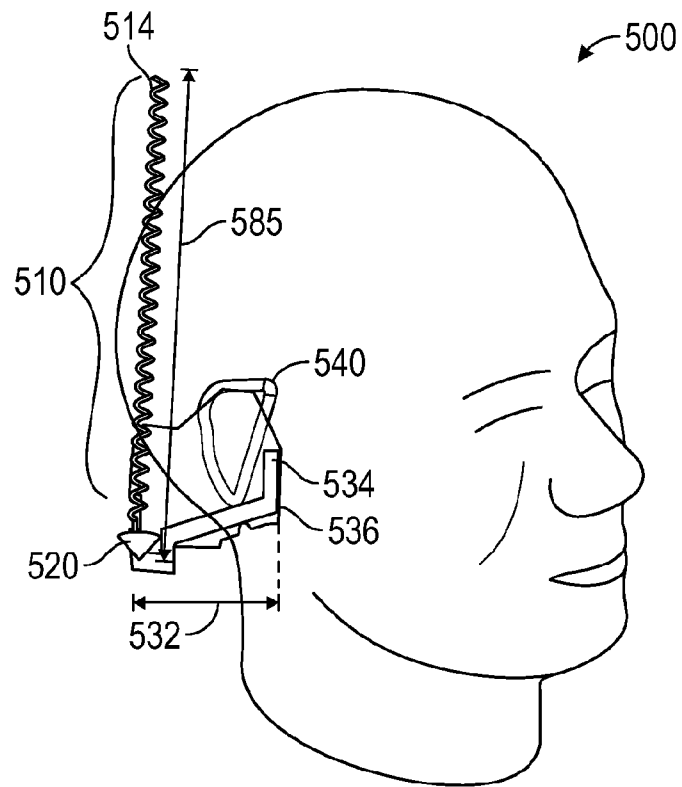


FIG. 5A

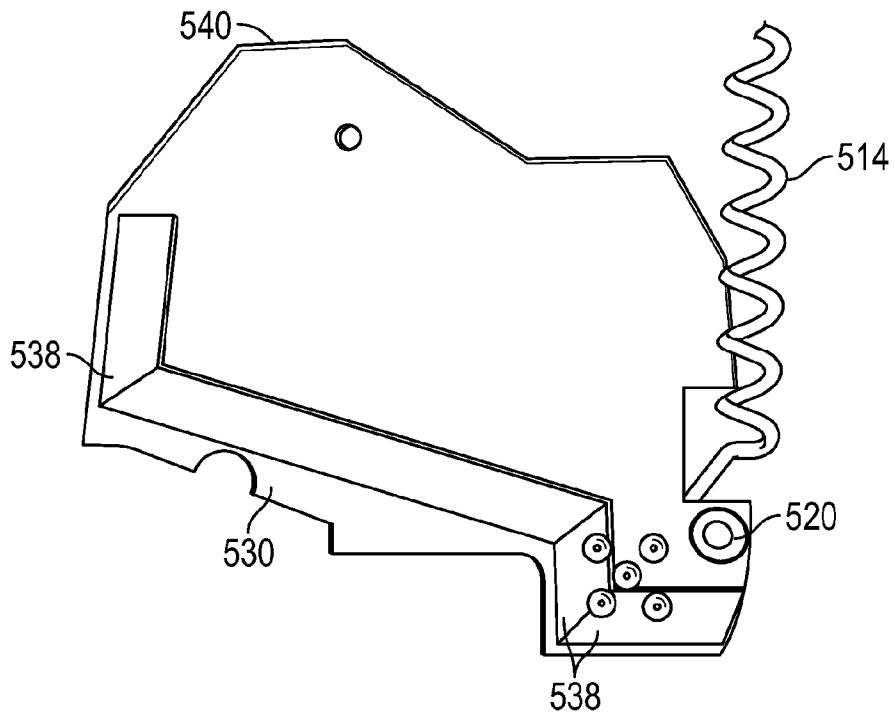


FIG. 5B

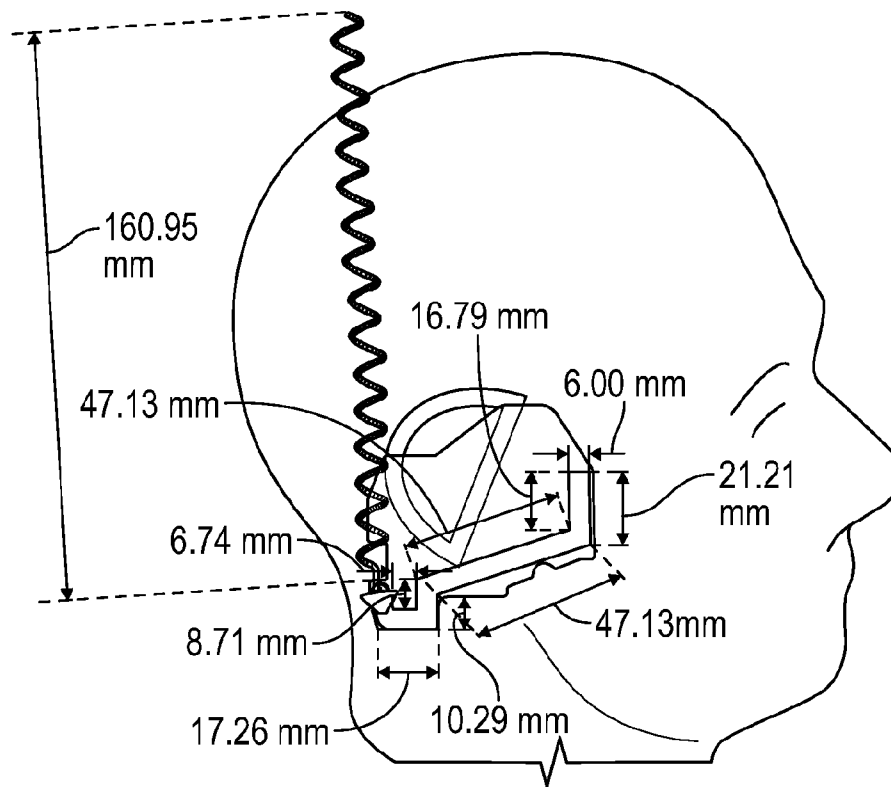


FIG. 5C

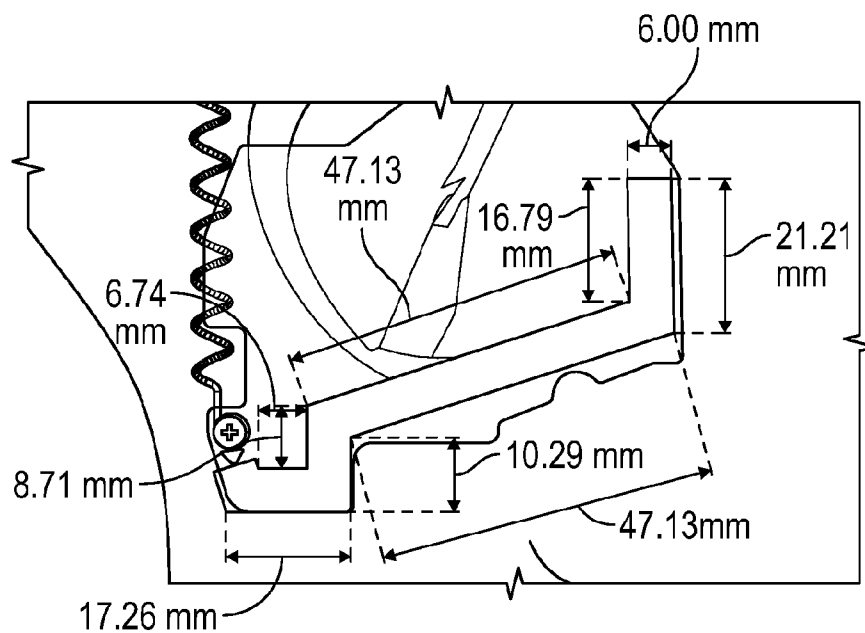


FIG. 5D

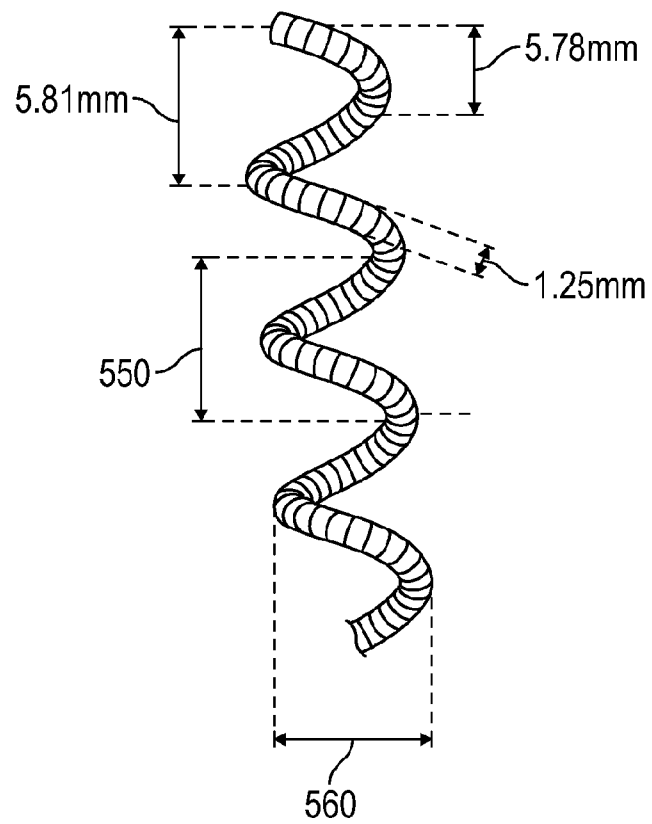


FIG. 5E

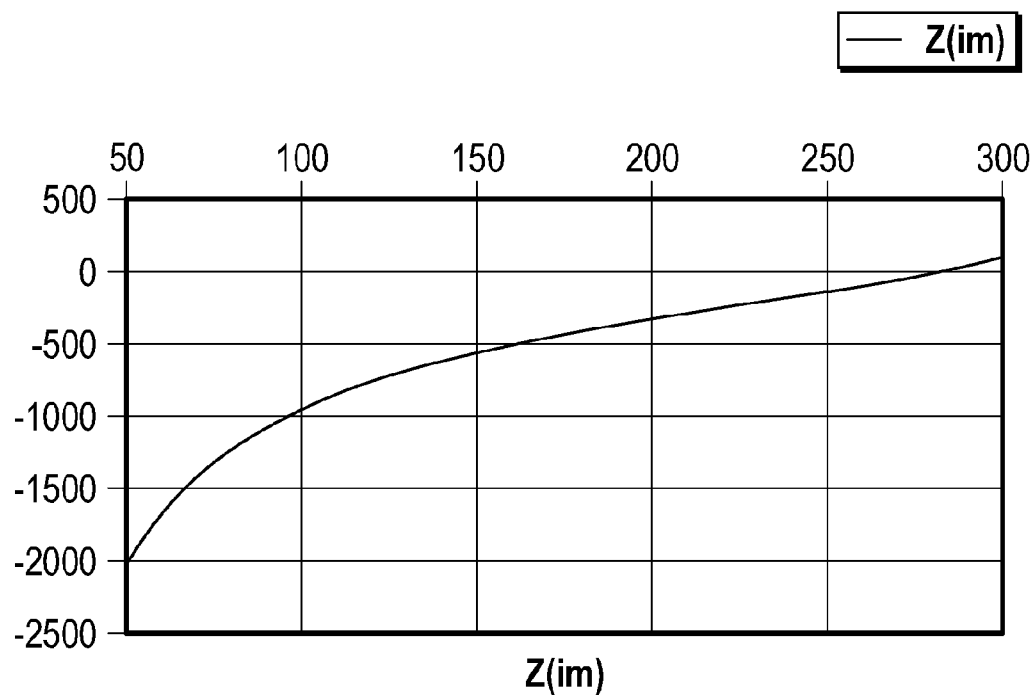


FIG. 6A

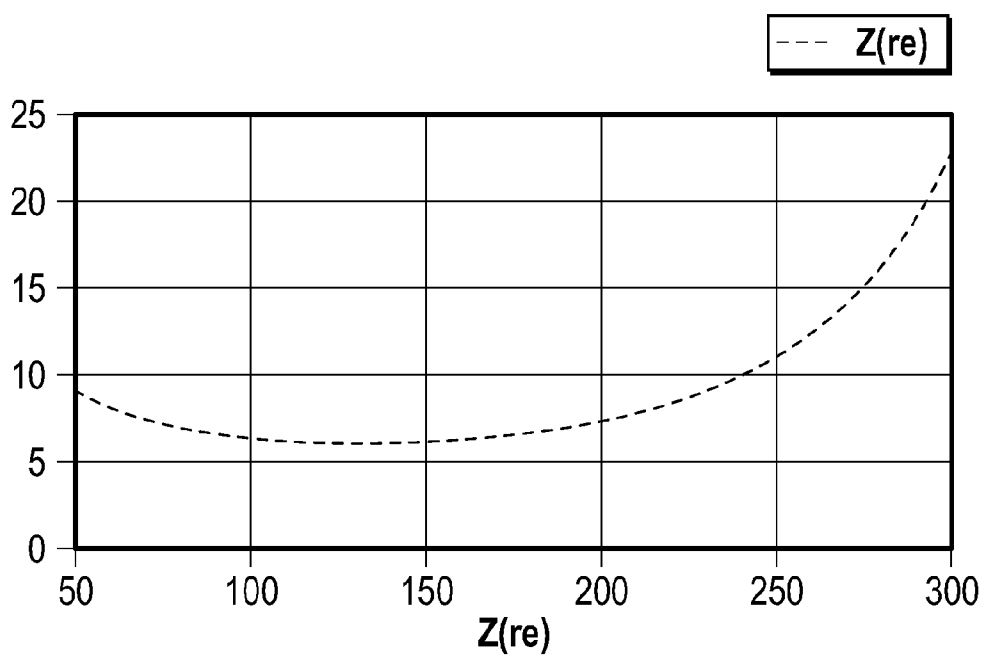


FIG. 6B

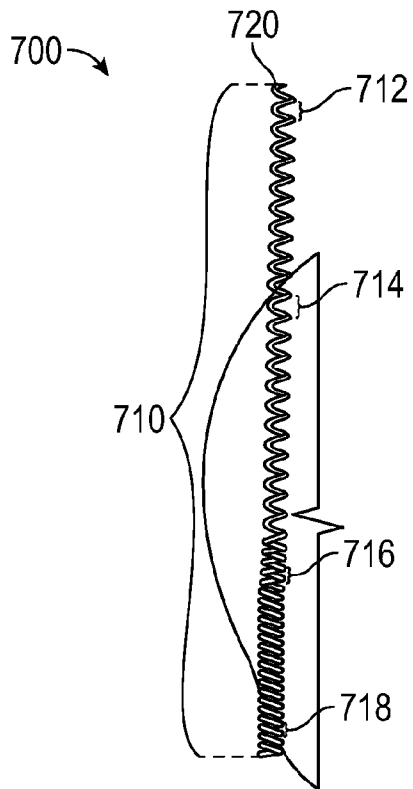


FIG. 7A

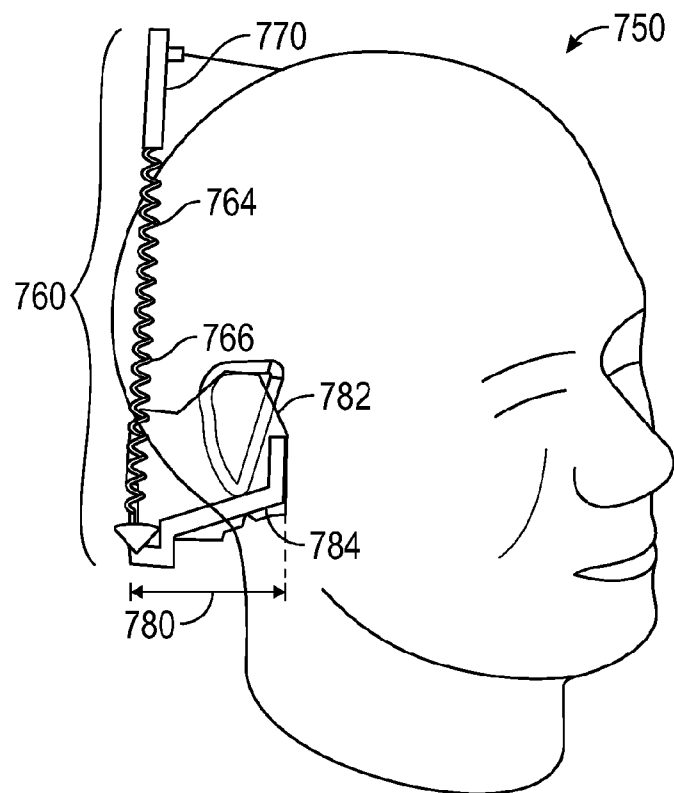


FIG. 7B

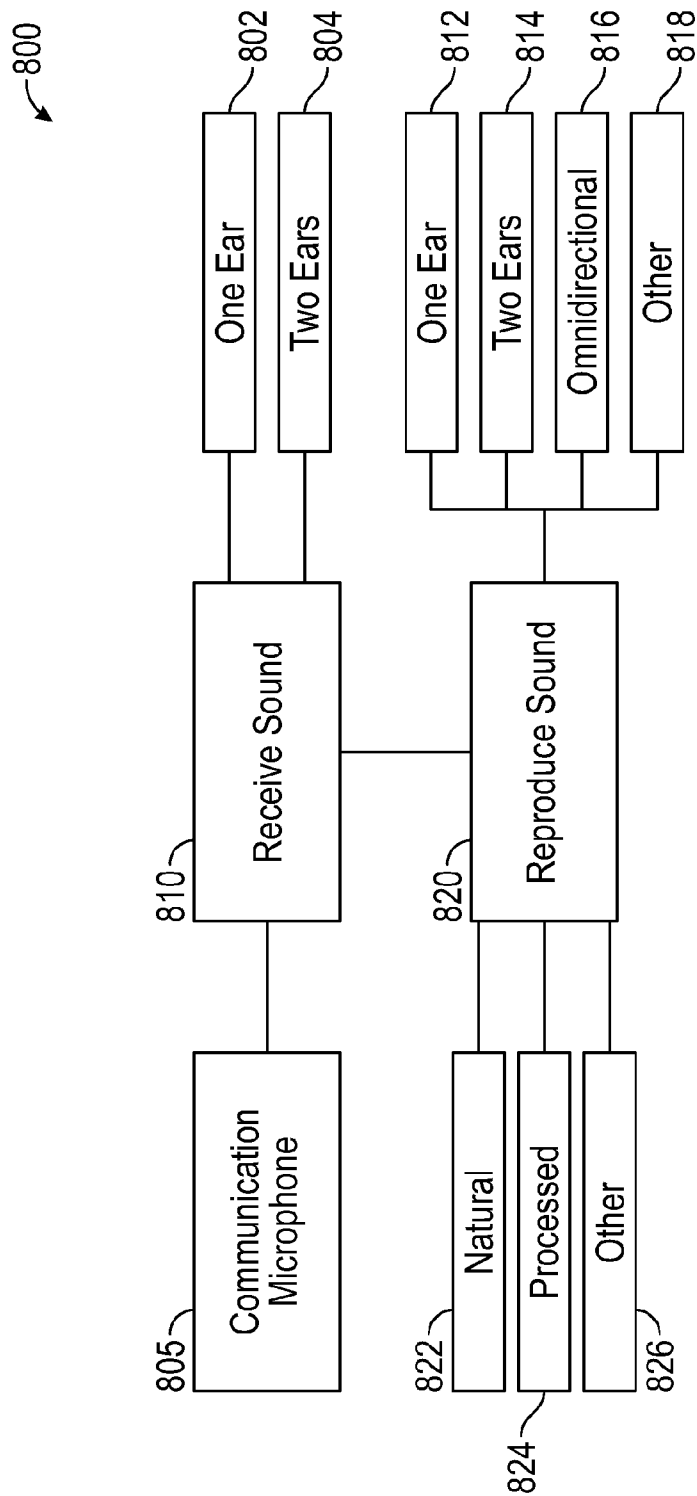


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2021/052587

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04R1/10 H01Q1/36 H01Q9/16
ADD. H04R5/033 A61F11/14 H01Q1/27 H01Q11/08

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 A61F H01Q

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)

EPO-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.
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Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"&" document member of the same patent family

Date of the actual completion of the international search

2 June 2021

Date of mailing of the international search report

11/06/2021

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
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Fax: (+31-70) 340-3016

Authorized officer

Streckfuss, Martin

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2021/052587

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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