



(51) International Patent Classification:

A61N 1/372 (2006.01) A61N 1/05 (2006.01)
A61N 1/08 (2006.01) A61N 1/375 (2006.01)
A61N 1/36 (2006.01)

(21) International Application Number:

PCT/US2015/066862

(22) International Filing Date:

18 December 2015 (18.12.2015)

(25) Filing Language:

English

(26) Publication Language:

English

(71) Applicant: **ADVANCED BIONICS AG** [CH/CH]; Laub-
isruetistrasse 28, 8712 Staefa (CH).

(72) Inventors; and

(71) Applicants (for US only): **LEE, Sung, Jin** [KR/US];
26111 McBean Parkway, #74, Valencia, CA 91355 (US).
WALTER, Jeryle, L. [US/US]; 27493 Bridgewater Drive,
Valencia, CA 91354 (US). **SMITH, James George, El-
coate** [AU/US]; 24015 Copper Hill Drive, #6207, Valen-
cia, CA 91354 (US). **GOMMEL, Uli** [DE/US]; 23703
Ashwood Place, Valencia, CA 91354 (US). **REED,
Stephanie, M.** [US/US]; 11648 Mayfield Avenue, #302,
Los Angeles, CA 90049 (US).

(74) Agent: **SLAVIN, Craig, A.**; Henricks, Slavin & Holmes
LLP, 840 Apollo Street Suite 200, El Segundo, CA 90245
(US).

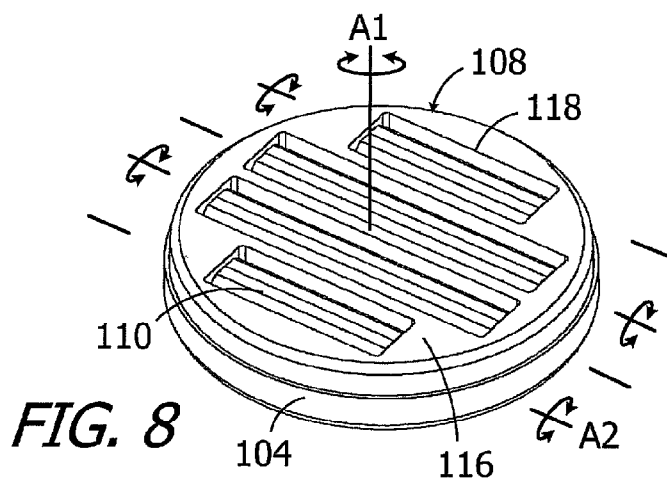
(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
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, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, 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).

Published:

— with international search report (Art. 21(3))

(54) Title: COCHLEAR IMPLANTS HAVING MRI-COMPATIBLE MAGNET APPARATUS



(57) Abstract: A cochlear implant including a cochlear lead, an antenna, a stimulation processor, and a magnet apparatus, associated with the antenna, including a case defining a central axis, a magnet frame within the case and rotatable about the central axis of the case, and a plurality of elongate diametrically magnetized magnets that are located in the magnet frame, the magnets defining a longitudinal axis and a N-S direction and being freely rotatable about the longitudinal axis relative to the magnet frame.

COCHLEAR IMPLANTS HAVING MRI-COMPATIBLE MAGNET APPARATUS

BACKGROUND

1. Field

The present disclosure relates generally to the implantable portion of implantable cochlear stimulation (or “ICS”) systems.

5 2. Description of the Related Art

ICS systems are used to help the profoundly deaf perceive a sensation of sound by directly exciting the intact auditory nerve with controlled impulses of electrical current. Ambient sound pressure waves are picked up by an externally worn microphone and converted to electrical signals. The electrical signals, in turn, are processed by a sound processor, converted to a pulse sequence having varying pulse widths and/or amplitudes, and transmitted to an implanted receiver circuit of the ICS system. The implanted receiver circuit is connected to an implantable electrode array that has been inserted into the cochlea of the inner ear, and electrical stimulation current is applied to varying electrode combinations to create a perception of sound. The electrode array may, alternatively, be directly inserted into the cochlear nerve without residing in the cochlea. A representative ICS system is disclosed in U.S. Patent No. 5,824,022, which is entitled “Cochlear Stimulation System Employing Behind-The-Ear Sound processor With Remote Control” and incorporated herein by reference in its entirety. Examples of commercially available ICS sound processors include, but are not limited to, the Advanced Bionics Harmony™ BTE sound processor, the Advanced Bionics Naída CI Q Series BTE sound processors and the Advanced Bionics Neptune™ body worn sound processor.

As alluded to above, some ICS systems include an implantable cochlear stimulator (or “cochlear implant”), a sound processor unit (e.g., a body worn processor or behind-the-ear processor), and a microphone that is part of, or is in communication with, the sound processor unit. The cochlear implant communicates with the sound processor unit and, some ICS systems include a headpiece that is in communication with both the sound processor unit and the cochlear implant. The headpiece communicates with the cochlear

implant by way of a transmitter (e.g., an antenna) on the headpiece and a receiver (e.g., an antenna) on the implant. Optimum communication is achieved when the transmitter and the receiver are aligned with one another. To that end, the headpiece and the cochlear implant may include respective
5 positioning magnets that are attracted to one another, and that maintain the position of the headpiece transmitter over the implant receiver. The implant magnet may, for example, be located within a pocket in the cochlear implant housing.

The present inventors have determined that conventional cochlear
10 implants are susceptible to improvement. For example, the magnets in many conventional cochlear implants are disk-shaped and have north and south magnetic dipoles that are aligned in the axial direction of the disk. Such magnets are not compatible with magnetic resonance imaging ("MRI") systems. In particular, the cochlear implant 10 illustrated in FIG. 1 includes,
15 among other things, a housing 12 and a disk-shaped solid block magnet 14. The implant magnet produces a magnetic field M in a direction that is perpendicular to the patient's skin and parallel to the axis A , and this magnetic field direction is not aligned with, and may be perpendicular to (as shown), the direction of the MRI magnetic field B . The misalignment of the interacting
20 magnetic fields M and B is problematic for a number of reasons. The dominant MRI magnetic field B (typically 1.5 Tesla or more) may demagnetize the implant magnet 14 or generate a significant amount of torque T on the implant magnet 14. The torque T may dislodge the implant magnet 14 from the pocket within the housing 12, reverse the magnet 14 and/or dislocate the
25 cochlear implant 10, all of which may also induce tissue damage. One proposed solution involves surgically removing the implant magnet 14 prior to the MRI procedure and then surgically replacing the implant magnet thereafter.

One proposed solution involves the use of freely rotatable ball magnets
30 that create a magnetic field which can rotate, from the aforementioned direction that is perpendicular to the patient's skin, to a direction that is aligned with the direction of the MRI magnetic field B . To that end, and referring to FIG. 2, one proposed implantable magnet apparatus 20 includes a

plurality of freely rotatable ball magnets 22 within a case 24. When the magnet apparatus 20 is in very close proximity to an external magnet 26, the ball magnets 22 will align with the external magnet 26 in the manner shown, with the N-S direction of the ball magnets being the same as that of the external magnet. When the external magnet 26 is removed (FIG. 3), the ball magnets 22 will align with one another. The ball magnets 22 will then rotate as necessary in response to the application of the MRI magnetic field, thereby minimizing the torque T, because the MRI magnetic field is far stronger than the attraction between the ball magnets. Turning to FIG. 4, the present inventors have determined that the use of freely rotatable ball magnets 22 is less than optimal because the distance between implanted ball magnets (located within a cochlear implant 28) and the external magnet 26 (located within an external headpiece 30) is so great that the magnetic attraction between the ball magnets is greater than the magnetic attraction between the ball magnets and the external magnet. The N-S direction of the ball magnets 22 is perpendicular to the N-S direction of the external magnet 26. The increased distance, as compared to the distance illustrated in FIG. 3, is a product of, for example, the presence of the implant and headpiece housings and the thickness of the skin flap. The weak magnetic attraction resulting from the misalignment of the magnetic fields prevents the headpiece from properly mounting to the patient's head. One possible solution is to simply increase the size of the external magnet, thereby increasing the strength of the associated magnetic field to the point at which the ball magnets 22 in a cochlear implant will rotate into the orientation illustrated in FIG. 2. The present inventors have determined, however, that the associated increase in the size and weight of the headpiece is undesirable.

Another proposed solution is illustrated in FIG. 5. Here, the cochlear implant 32 includes a diametrically magnetized disk-shaped magnet 34 that is rotatable about an axis A, and that has a N-S orientation which is perpendicular to the axis A. The external headpiece 36 includes a diametrically magnetized disk-shaped magnet 38. The implanted magnet 34 is able to rotate about the axis A into alignment with the external magnet 38, and is also able to rotate about the axis A into alignment with an MRI magnetic that is perpendicular to the

axis A. Turning to FIG. 6, the present inventors have determined that the use of the diametrically magnetized disk-shaped magnet 34 is less than optimal because a dominant magnetic field (e.g., the MRI magnetic field B) that is misaligned by 30° or more may demagnetize the magnet or generate an amount of torque T on the magnet that is sufficient to dislodge or reverse the magnet and/or dislocate the associated cochlear implant.

SUMMARY

A cochlear implant in accordance with one of the present inventions may include a cochlear lead, an antenna, a stimulation processor, an implant magnet apparatus, associated with the antenna, including a case defining a central axis, a magnet frame within the case and rotatable about the central axis of the case, and a plurality of elongate diametrically magnetized magnets that are located in the magnet frame, the magnets defining a longitudinal axis and a N-S direction and being freely rotatable about the longitudinal axis relative to the magnet frame. A system in accordance with one of the present inventions includes such a cochlear implant and an external device. The external device may include an antenna and an external magnet.

There are a number of advantages associated with such apparatus and methods. For example, a strong magnetic field, such as an MRI magnetic field, will not demagnetize the magnet apparatus. Nor will it generate a significant amount of torque on the magnet apparatus and associated cochlear implant. As a result, surgical removal of the cochlear implant magnet prior to an MRI procedure, and then surgically replacement thereafter, is not required. Moreover, in the absence of the strong magnetic field, the magnetic attraction between rotatable magnets in the magnet apparatus will not cause the magnets to rotate into an undesirable N-S orientation.

The above described and many other features of the present inventions will become apparent as the inventions become better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Detailed descriptions of the exemplary embodiments will be made with reference to the accompanying drawings.

5 FIG. 1 is a plan view showing a conventional cochlear implant in an MRI magnetic field.

FIG. 2 is a partial section view of a conventional implant magnet apparatus and external magnet.

FIG. 3 is a partial section view of a conventional implant magnet apparatus.

10 FIG. 4 is a partial section view of a headpiece and an implanted cochlear implant with a conventional implant magnet apparatus.

FIG. 5 is a partial section view of a headpiece and an implanted cochlear implant with a conventional implant magnet apparatus.

15 FIG. 6 is a partial section view of the implanted cochlear implant with a conventional implant magnet apparatus illustrated in FIG. 5 in an MRI magnetic field.

FIG. 7 is a perspective view of an implant magnet apparatus in accordance with one embodiment of a present invention.

20 FIG. 8 is a perspective view of a portion of the implant magnet apparatus illustrated in FIG. 7.

FIG. 9 is a diagrammatic view of a system including the magnet apparatus illustrated in FIG. 7.

FIG. 10 is an exploded view of the implant magnet apparatus illustrated in FIG. 7.

25 FIG. 11 is an end view of a portion of the implant magnet apparatus illustrated in FIG. 7.

FIG. 12 is a perspective view of a portion of the implant magnet apparatus illustrated in FIG. 7.

30 FIG. 13 is a plan view of a portion of the implant magnet apparatus illustrated in FIG. 7.

FIG. 14 is a section view taken along line 14-14 in FIG. 7.

FIG. 14A is a section view showing a portion of the implant magnet apparatus illustrated in FIG. 14 in a different orientation.

FIG. 15 is a section view similar to FIG. 14 with the implant magnet apparatus in an MRI magnetic field.

FIG. 16 is a perspective view of an implant magnet apparatus in accordance with one embodiment of a present invention.

5 FIG. 17 is a section view taken along line 17-17 in FIG. 16.

FIG. 18 is an exploded view of the implant magnet apparatus illustrated in FIG. 16.

FIG. 19 is a perspective view of a portion of an implant magnet apparatus.

10 FIG. 20 is an end view of the portion of an implant magnet apparatus illustrated in FIG. 19.

FIG. 21 is a plan view of a cochlear implant in accordance with one embodiment of a present invention.

15 FIG. 22 is a block diagram of a cochlear implant system in accordance with one embodiment of a present invention.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

20 The following is a detailed description of the best presently known modes of carrying out the inventions. This description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the inventions.

As illustrated for example in FIGS. 7 and 8, an exemplary magnet apparatus 100 includes a case 102, with base 104 and a cover 106, a magnet frame 108, and a plurality of elongate diametrically magnetized magnets 110 within the frame that define a N-S direction. The magnet apparatus 100 may, in some instances, be employed a system 50 (FIG. 9) that includes a cochlear implant 200 (described below with reference to FIG. 21) with the magnet apparatus 100 and an external device such as a headpiece 400 (described below with reference to FIG. 22). The headpiece 400 includes, among other things, a housing 402 and a diametrically magnetized disk-shaped positioning magnet 410.

30

The exemplary case 102 is disk-shaped and defines a central axis A1, which is also the central axis of the magnet frame 108. The magnet frame 108 is

freely rotatable relative to the case 102 about the central axis A1 over 360°. The magnets 110 rotate with the magnet frame 108 about the central axis A1. Each magnet 110 is also freely rotatable relative to the magnet frame 108 about its own longitudinal axis A2 over 360°. As used herein, the phrase “freely rotatable about an axis” refers to an object that can rotate about an axis relative to an adjacent object, albeit with some friction between the two object, without mechanical limitation of the rotation (e.g., with a stop or biasing device that opposes the rotation). In the illustrated implementation, the longitudinal axes A2 are parallel to one another and are perpendicular to the central axis A1.

Given the ability of each magnet 110 to freely rotate about its longitudinal axis A2, the magnets 110 align with one another in the N-S direction in the absence of a relatively strong external magnetic field (e.g., the MRI magnetic field discussed above), and the at rest N-S orientation of the magnets 110 will be perpendicular to the central axis A1, as is illustrated in FIGS. 9 and 14. So oriented, the magnetic fields of the diametrically magnetized magnets 110 are aligned with the magnetic field of the diametrically magnetized disk-shaped positioning magnet 410.

The exemplary case 102 is not limited to any particular configuration, size or shape. In the illustrated implementation, the case 102 is a two-part structure that includes the base 104 and the cover 106 which are secured to one another in such a manner that a hermetic seal is formed between the cover and the base. Suitable techniques for securing the cover 106 to the base 104 include, for example, seam welding with a laser welder. With respect to materials, the case 102 may be formed from biocompatible paramagnetic metals, such as titanium or titanium alloys, and/or biocompatible non-magnetic plastics such as polyether ether ketone (PEEK), low-density polyethylene (LDPE), high-density polyethylene (HDPE), ultra-high-molecular-weight polyethylene (UHMWPE), polytetrafluoroethylene (PTFE) and polyamide. In particular, exemplary metals include commercially pure titanium (e.g., Grade 2) and the titanium alloy Ti-6Al-4V (Grade 5), while exemplary metal thicknesses may range from 0.20 mm to 0.25 mm. With respect to size and shape, the case 102 may have an overall size and shape similar to that of conventional cochlear implant magnets so that the magnet apparatus 100 can be substituted for a conventional magnet in an

otherwise conventional cochlear implant. In some implementations, the diameter that may range from 9 mm to 16 mm and the thickness may range from 1.5 mm to 3.0 mm. The diameter of the case 102 is 12.9 mm, and the thickness is 2.4 mm, in the illustrated embodiment.

5 Although the present inventions are not limited to any particular number, there are four elongate diametrically magnetized magnets 110 in the exemplary magnet apparatus 100. Two of the otherwise identical magnets 110 are relatively long and two are relatively short in order to efficiently utilize the available volume within the case 102, as is best shown in FIG. 8. Turning to
10 FIGS. 10-12, the exemplary magnets 110 are non-circular in a cross-section that is perpendicular to the longitudinal axis A2 and, in the illustrated implementation, include curved surfaces 112 and flat surfaces 114. The magnet width W_M , which extends in the N-S direction, is greater than the magnet thickness T_M , which extends in a direction perpendicular to the N-S direction. The use of elongate
15 diametrically magnetized magnets that are larger in the N-S direction than in the direction perpendicular thereto reduces the likelihood of magnet damage, as is discussed in greater detail below with reference to FIG. 14. Nevertheless, in other implementations, the cross-sectional shape may be circular. The magnet lengths L_M of the relatively long and short magnets 110, i.e. the length in the
20 direction of axis A2, are greater than the magnet width W_M and magnet thickness T_M . Suitable materials for the magnets 110 include, but are not limited to, neodymium-boron-iron and samarium-cobalt.

As illustrated in FIGS 10 and 13, the exemplary magnet frame 108 includes disk 116 and a plurality of magnet receptacles 118 that extend
25 completely through the disk. Two of the otherwise identical magnet receptacles 118 are relatively long and two are relatively short. The magnet receptacles 118, which are rectangular in shape, have receptacle lengths L_R that are substantially equal to (i.e., about 50-100 μm greater than) the magnet lengths L_M , and receptacle widths W_R that are substantially equal to (i.e., about 25-50 μm
30 greater than) the magnet widths W_M . The receptacle thicknesses T_R , one the other hand, are substantially greater than (i.e., about 100-200 μm greater than) the magnet thicknesses T_M . The use of a magnet receptacle that is thicker than the magnet reduces the likelihood of magnet damage, as is discussed in greater

detail below with reference to FIG. 14. In those instances where the apparatus includes magnets with circular cross-sections, similar magnet protection functionality can be achieved by employing a frame that is thicker than the magnet diameter. Suitable materials for the frame 108, which may be formed by machining or injection molding, include paramagnetic metals, polymers and plastics such as those discussed above in the context of the case 102.

As illustrated for example in FIG. 14, absent a dominant MRI magnetic field B, the magnets 110 will remain aligned with one another in the N-S direction and the N-S orientation of the magnets will be perpendicular to the central axis A1 of the case 102. So oriented, the flat surfaces 114 of the magnets 110 will be aligned with one another, will be perpendicular to the central axis A1 and will face the inner surface 120 of the case 102. The N-S orientation of the magnets 110 remains the same, i.e. perpendicular to the central axis A1, both when the external diametrically magnetized disk-shaped positioning magnet 410 is present (FIG. 9) and when it is not (FIG. 14).

A gap G, resulting from the difference in receptacle thicknesses T_R and magnet thicknesses T_M , is located between one of the flat surfaces 114 of each magnet and the inner surface 120 of the case 102 that the flat surface faces. The gap G protects the magnets 110, especially those formed from somewhat brittle ceramic materials, from impacts to the exterior surface of case 102. For example, when the magnet apparatus 100 is oriented in the manner illustrated in FIG. 14 and is impacted by a force F1, the deflection of the case 102 (if any) into the magnet receptacle 118 will not be large enough for the inner surface 120 to impact the adjacent magnet surface 114. If, on the other hand, a force F2 causes deflection of a portion of the case 102 into the magnet receptacle 118, the magnet 110 will slide into the gap G. In both instances, impact on the magnets 100 is minimized. Turning to FIG. 14A, it should be noted that the magnets 110 need not be posited such that one of the flat surfaces 114 is in contact with an inner surface 120 of case 102 to benefit from the gap G. Here, due to the position of the magnet 110, both of the flat surfaces 114 are located adjacent to a portion of the now-split gap G shown in FIG. 14. Accordingly, in those instances where deflection of the case 102 due to force F3 is sufficient to cause the inner surface 120 to come into contact with the adjacent flat surface

114, the magnet 110 can move into the portion of the gap adjacent to the opposite flat surface 114 to prevent magnet damage.

Turning to FIG. 15, when exposed to a dominant MRI magnetic field B, the torque T on the magnets 110 will rotate the magnets about their axis A2 (FIG. 8), thereby aligning the magnetic fields of the magnets 110 with the MRI magnetic field B. The magnet frame 108 will also rotate about axis A1 as necessary to align the magnetic fields of the magnets 110 with the MRI magnetic field B. When the magnet apparatus 100 is removed from the MRI magnetic field B, the magnetic attraction between the magnets 110 will cause the magnets to rotate about axis A2 back to the orientation illustrated in FIG. 14, where they are aligned with one another in the N-S direction and the N-S orientation of the magnets is perpendicular to the central axis A1 of the case 102.

To facilitate rotation of the magnet frame 108 and/or the magnets 110, lubricious friction reducing material may be provided between the case 102 and the magnet frame 108 and/or between the magnets 110 and the case 102 and magnet frame 108. For example, the magnet apparatus 100a illustrated in FIG. 16-18 is substantially similar to the magnet apparatus 100 and similar elements are represented by similar reference numerals. Here, however, a pair of lubricious disks 122 and a lubricious ring 124 formed from PTFE or other suitable materials are positioned between the case 102 and the magnet frame 108. In other implementations, a lubricious layer may be added to the inner surface of the case 102. The lubricious layer may be in the form of a specific finish of the inner surface that reduces friction, as compared to an unfinished surface, or may be a coating of a lubricious material such as PTFE, polyethylene glycol (PEG), Parylene, fluorinated ethylene propylene (FEP) and electroless nickel sold under the tradenames Nedox® and Nedox PF™. In those instances where the base 104 and a cover 106 are formed by stamping, the finishing process may occur prior to stamping. Micro-balls, biocompatible oils and lubricating powders may also be added to the interior of the case 102 to reduce friction.

Alternatively, or in addition, the magnets 110 may be located within a tube 124 formed from low friction material, as is illustrated in FIGS. 19 and 20.

Suitable materials for the tube 124 include silicone, plastics and paramagnet metals. The magnets 110 may be secured to the tubes 124 such that the each tube rotates with the associated magnet about its axis A2, or the magnets may be free to rotate relative to the tubes. The magnet/tube combination is also more mechanically robust than a magnet alone. The magnets 110 may, in place of the tube 124, be coated with the lubricious materials discussed above.

One example of a cochlear implant (or “implantable cochlear stimulator”) including the present magnet apparatus 100 (or 100a) is the cochlear implant 200 illustrated in FIG. 21. The cochlear implant 200 includes a flexible housing 202 formed from a silicone elastomer or other suitable material, a processor assembly 204, a cochlear lead 206, and an antenna 208 that may be used to receive data and power by way of an external antenna that is associated with, for example, a sound processor unit. The cochlear lead 206 may include a flexible body 210, an electrode array 212 at one end of the flexible body, and a plurality of wires (not shown) that extend through the flexible body from the electrodes 212a (e.g., platinum electrodes) in the array 212 to the other end of the flexible body. The magnet apparatus 100 is located within a region encircled by the antenna 208 (e.g., within an internal pocket 202a defined by the housing 202) and insures that an external antenna (discussed below) will be properly positioned relative to the antenna 208. The exemplary processor assembly 204, which is connected to the electrode array 212 and antenna 208, includes a printed circuit board 214 with a stimulation processor 214a that is located within a hermetically sealed case 216. The stimulation processor 214a converts the stimulation data into stimulation signals that stimulate the electrodes 212a of the electrode array 212.

Turning to FIG. 22, the exemplary cochlear implant system 60 includes the cochlear implant 200, a sound processor, such as the illustrated body worn sound processor 300 or a behind-the-ear sound processor, and a headpiece 400.

The exemplary body worn sound processor 300 in the exemplary ICS system 60 includes a housing 302 in which and/or on which various components are supported. Such components may include, but are not limited to, sound processor circuitry 304, a headpiece port 306, an auxiliary device port 308 for an

auxiliary device such as a mobile phone or a music player, a control panel 310, one or more microphones 312, and a power supply receptacle 314 for a removable battery or other removable power supply 316 (e.g., rechargeable and disposable batteries or other electrochemical cells). The sound processor circuitry 304 converts electrical signals from the microphone 312 into stimulation data. The exemplary headpiece 400 includes a housing 402 and various components, e.g., a RF connector 404, a microphone 406, an antenna (or other transmitter) 408 and a diametrically magnetized disk-shaped positioning magnet 410, that are carried by the housing. The headpiece 400 may be connected to the sound processor headpiece port 306 by a cable 412. The positioning magnet 410 is attracted to the magnet apparatus 100 of the cochlear stimulator 200, thereby aligning the antenna 408 with the antenna 208. The stimulation data and, in many instances power, is supplied to the headpiece 400. The headpiece 400 transcutaneously transmits the stimulation data, and in many instances power, to the cochlear implant 200 by way of a wireless link between the antennae. The stimulation processor 214a converts the stimulation data into stimulation signals that stimulate the electrodes 212a of the electrode array 212.

In at least some implementations, the cable 412 will be configured for forward telemetry and power signals at 49 MHz and back telemetry signals at 10.7 MHz. It should be noted that, in other implementations, communication between a sound processor and a headpiece and/or auxiliary device may be accomplished through wireless communication techniques. Additionally, given the presence of the microphone(s) 312 on the sound processor 300, the microphone 406 may be also be omitted in some instances. The functionality of the sound processor 300 and headpiece 400 may also be combined into a single head wearable sound processor. Examples of head wearable sound processors are illustrated and described in U.S. Patent Nos. 8,811,643 and 8,983,102, which are incorporated herein by reference in their entirety.

Although the inventions disclosed herein have been described in terms of the preferred embodiments above, numerous modifications and/or additions to the above-described preferred embodiments would be readily apparent to one skilled in the art. The inventions include any combination of

the elements from the various species and embodiments disclosed in the specification that are not already described. It is intended that the scope of the present inventions extend to all such modifications and/or additions and that the scope of the present inventions is limited solely by the claims set forth

5 below.

We claim:

1 1. A cochlear implant, comprising:
2 a cochlear lead including a plurality of electrodes;
3 an antenna;
4 a stimulation processor operably connected to the antenna and
5 to the cochlear lead; and
6 a magnet apparatus, associated with the antenna, including a
7 case defining a central axis, a magnet frame within the case and rotatable
8 about the central axis of the case, and a plurality of elongate diametrically
9 magnetized magnets that are located in the magnet frame, the magnets defining
10 a longitudinal axis and a N-S direction and being freely rotatable about the
11 longitudinal axis relative to the magnet frame.

1 2. A cochlear implant as claimed in claim 1, wherein
2 the magnets each define a N-S rotational orientation; and
3 the magnets are magnetically attracted to one another in such
4 manner that, absent the presence of a dominant magnetic field, the N-S
5 rotational orientation of the magnets is perpendicular to the central axis of the
6 case.

1 3. A cochlear implant as claimed in claim 1, wherein
2 the magnets each define a length in the direction of the
3 longitudinal axis, a thickness, and a width; and
4 the length is greater than the width and the thickness.

1 4. A cochlear implant as claimed in claim 3, wherein
2 the width is greater than the thickness.

1 5. A cochlear implant as claimed in claim 4, wherein
2 the width extends in the N-S direction.

1 6. A cochlear implant as claimed in claim 3, wherein

2 the magnets each define a cross-section, including first and
3 second curved surfaces that are connected to one another by first and second
4 flat surfaces, in a plane perpendicular to the longitudinal axis;

5 the curved surfaces are separated from one another in the N-S
6 direction; and

7 the flat surfaces are separated from one another in a direction
8 perpendicular to the N-S direction.

1 7. A cochlear implant as claimed in claim 3, wherein
2 the magnet frame defines a thickness; and
3 the thickness of the magnets is less than the thickness of the
4 magnet frame.

1 8. A cochlear implant as claimed in claim 7, wherein
2 the magnet frame includes a plurality of magnet recesses,
3 defining recess lengths and recess widths, in which the plurality of magnets
4 are located;
5 the magnet recess lengths are substantially equal to the magnet
6 lengths; and
7 the magnet recess widths are substantially equal to the magnet
8 widths.

1 9. A cochlear implant as claimed in claim 3, wherein
2 at least one of the magnets is longer than an adjacent magnet.

1 10. A cochlear implant as claimed in claim 1, wherein
2 the magnets each define a non-circular cross-section in a plane
3 perpendicular to the longitudinal axis.

1 11. A cochlear implant as claimed in claim 1, wherein
2 the longitudinal axes of the magnets are parallel to one another.

1 12. A cochlear implant as claimed in claim 1, further comprising:
2 lubricious material between the case and the magnet frame.

1 13. A cochlear implant as claimed in claim 1, further comprising:
2 lubricious material between the magnets and the magnet frame.

1 14. A cochlear implant as claimed in claim 1, wherein
2 the magnets are located within respective tubes formed from
3 lubricious material.

1 15. A cochlear implant as claimed in claim 1, wherein
2 the antenna, the stimulation processor and the magnet
3 apparatus are located within a flexible housing.

1 16. A system, comprising
2 a cochlear implant as claimed in any one of claims 1-15; and
3 an external device including a diametrically magnetized disk-
4 shaped positioning magnet.

1 17. A system, comprising
2 a cochlear implant as claimed in any one of claims 1-15; and
3 a headpiece including
4 an antenna, and
5 a diametrically magnetized disk-shaped positioning magnet
6 associated with the antenna.

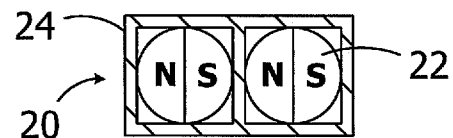
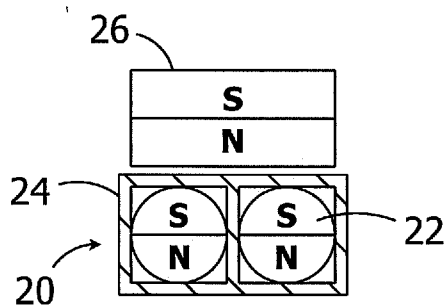
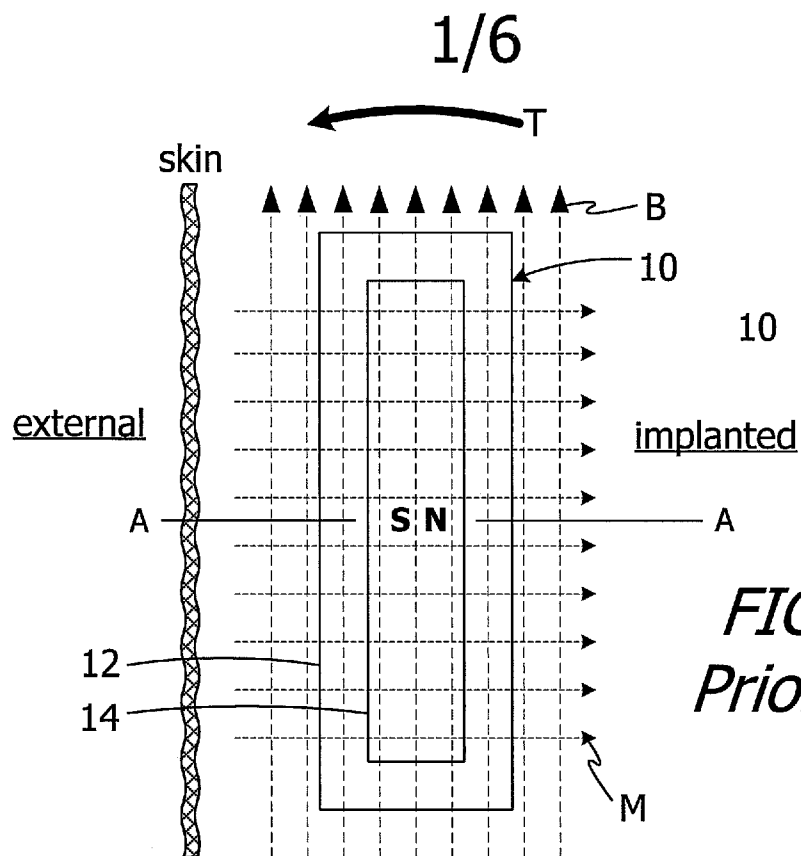
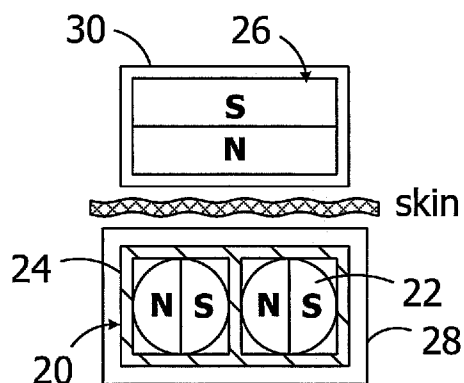


FIG. 4
Prior Art



2/6

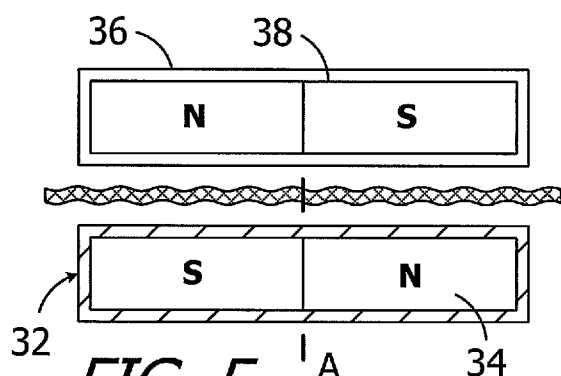


FIG. 5
Prior Art

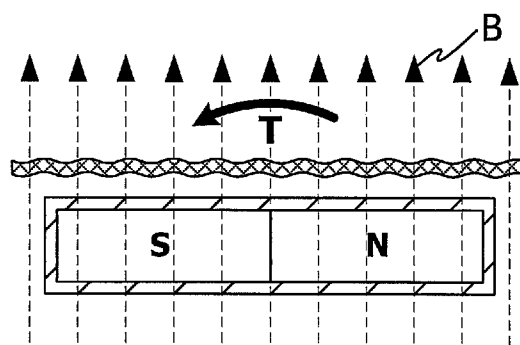


FIG. 6
Prior Art

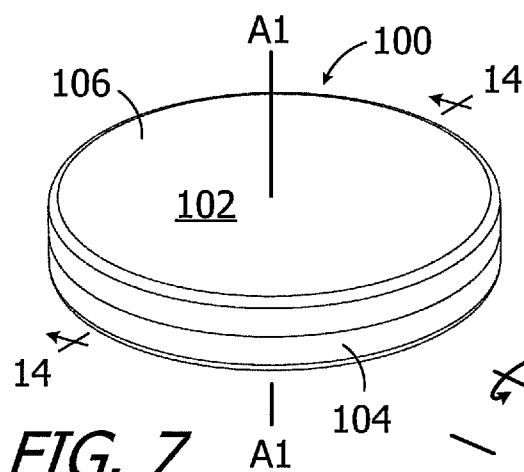


FIG. 7

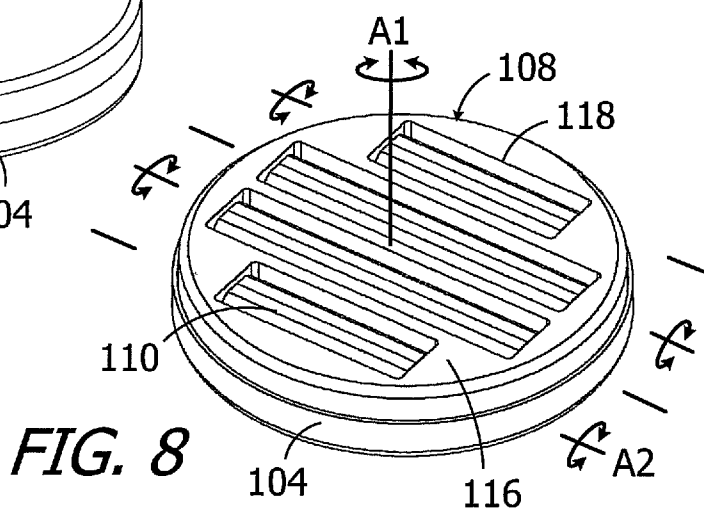


FIG. 8

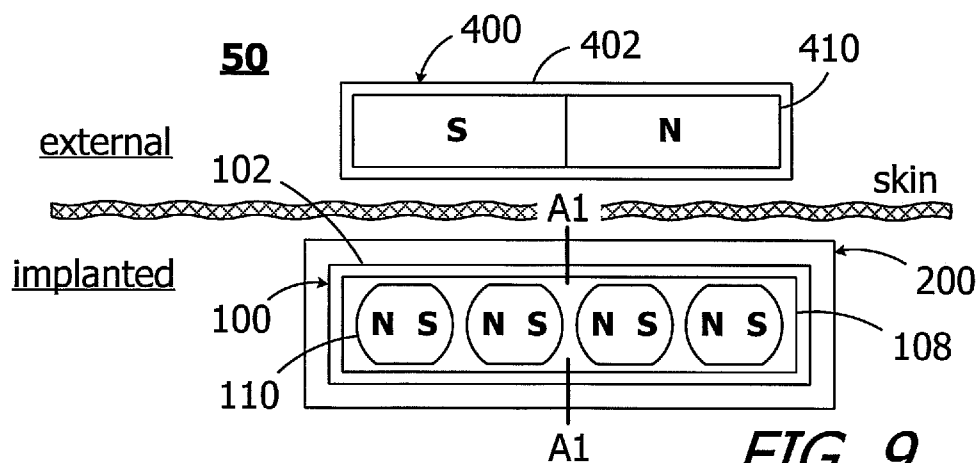
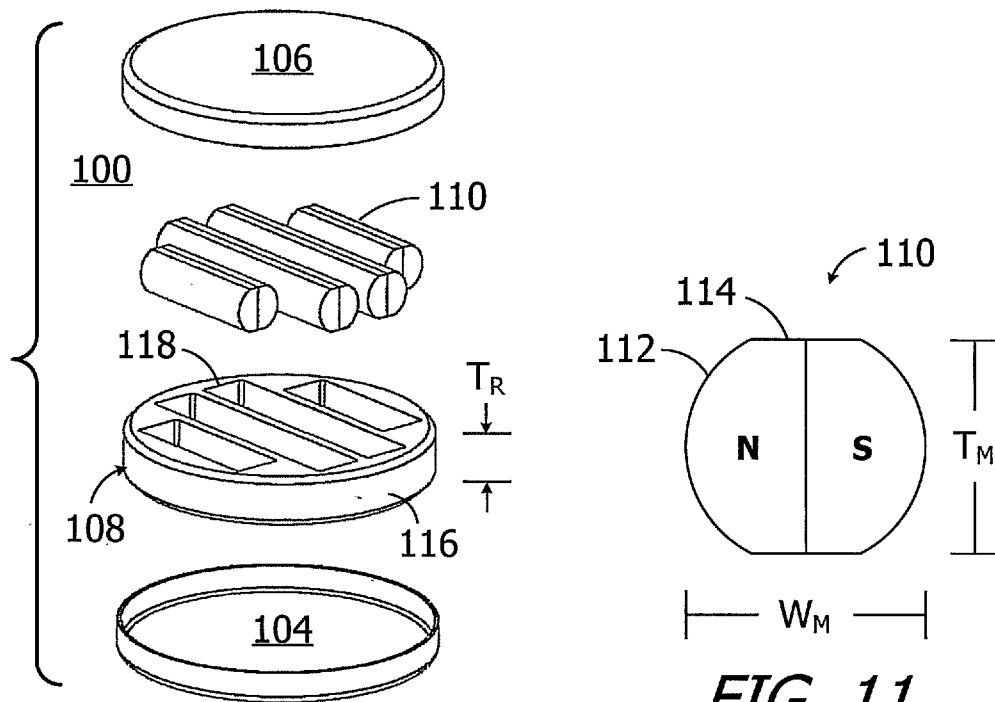
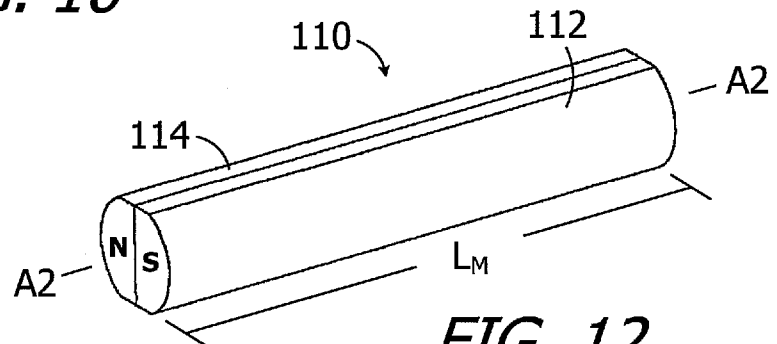
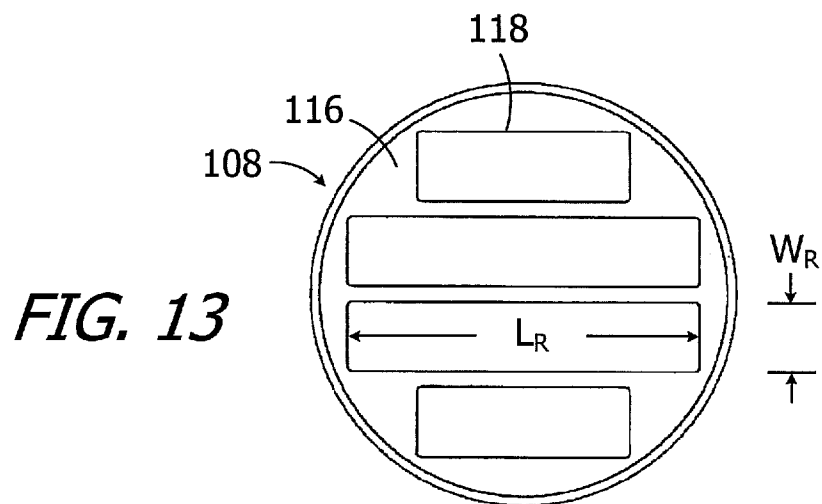
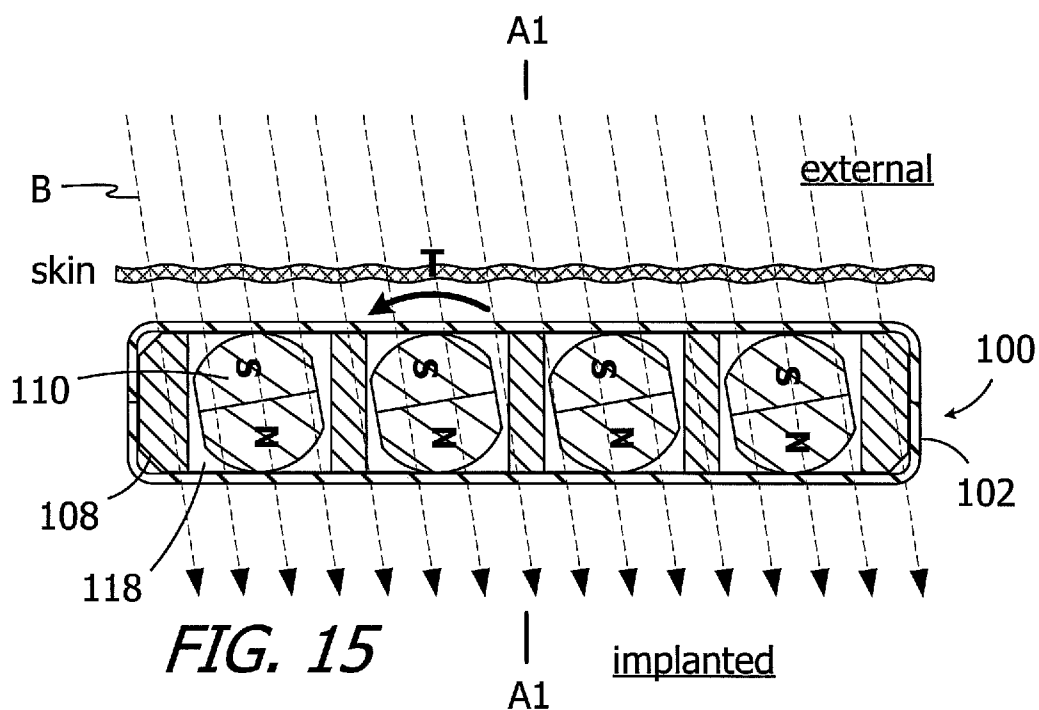
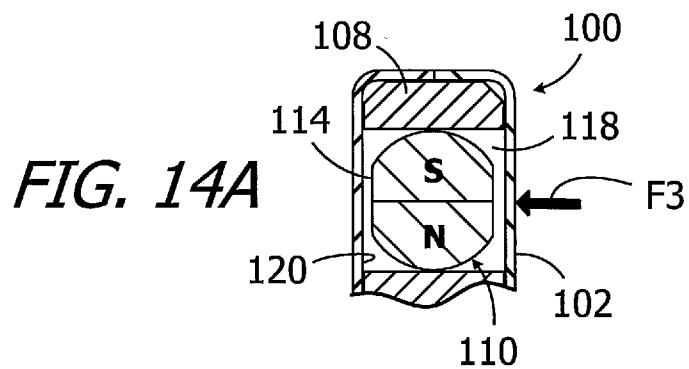
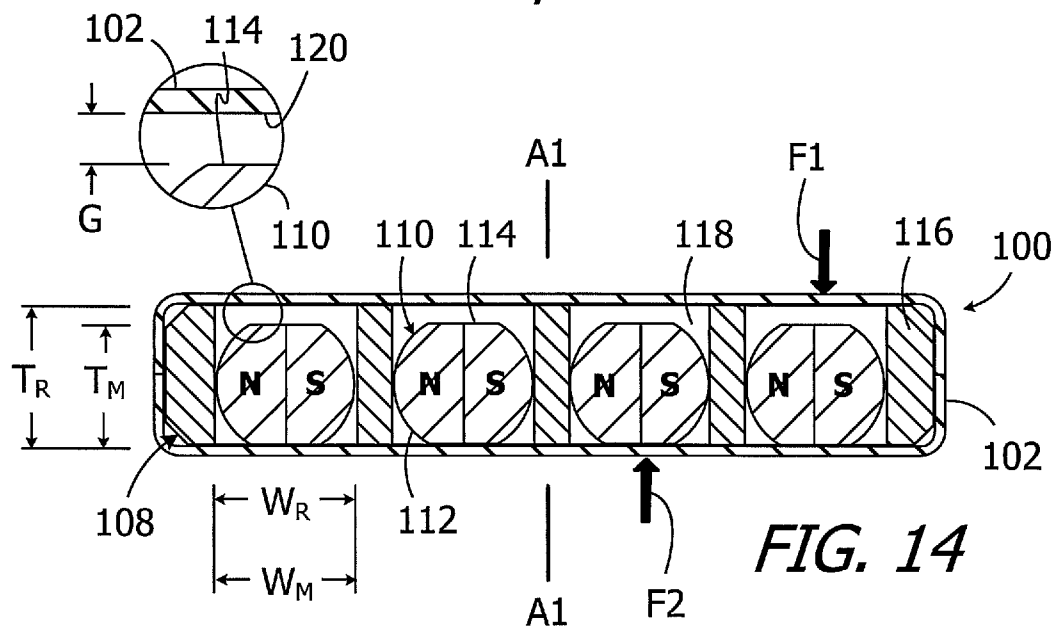


FIG. 9

3/6

**FIG. 10****FIG. 11****FIG. 12****FIG. 13**

4/6



5/6

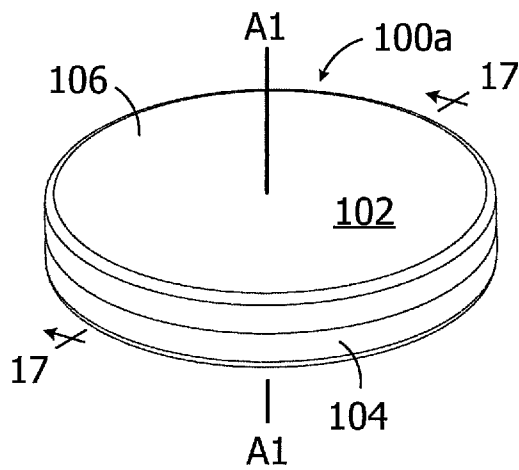


FIG. 16

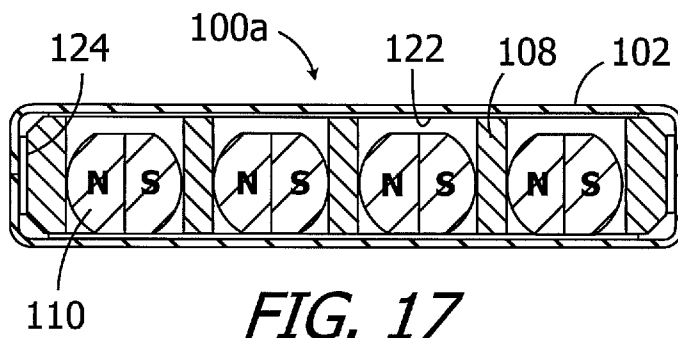


FIG. 17

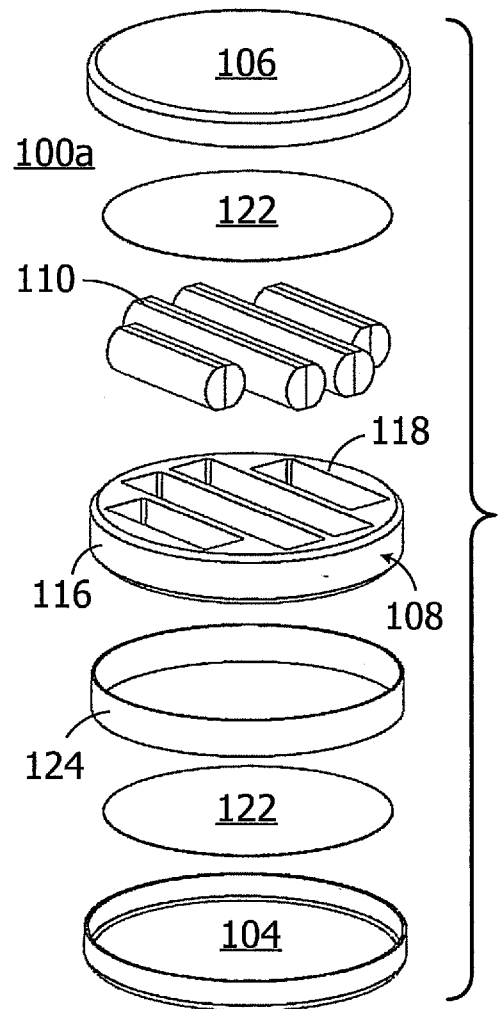


FIG. 18

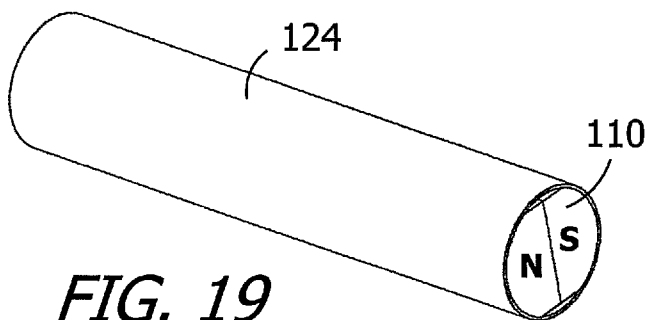


FIG. 19

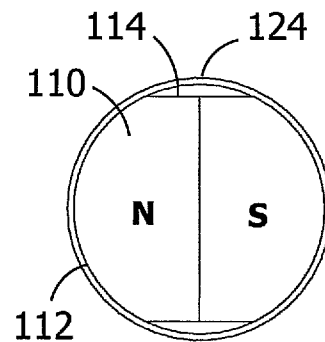
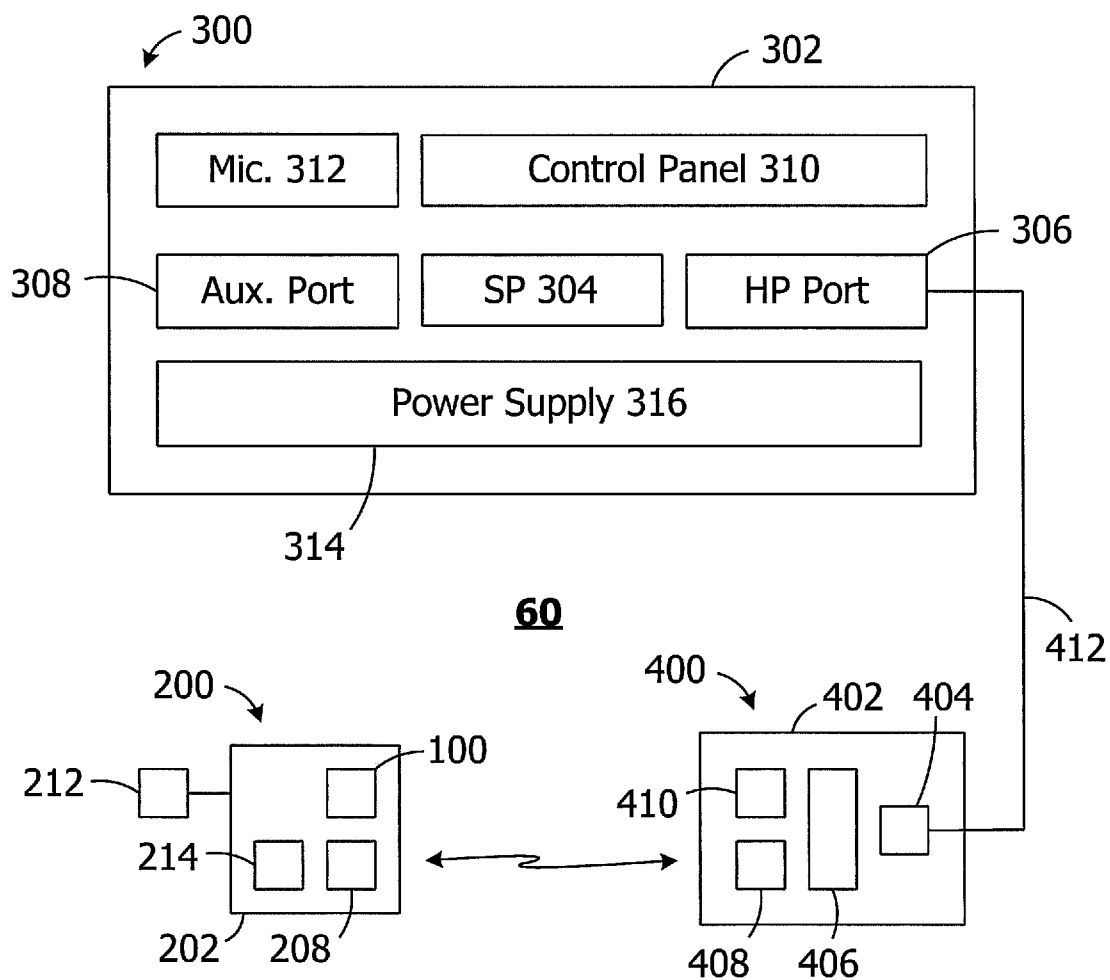
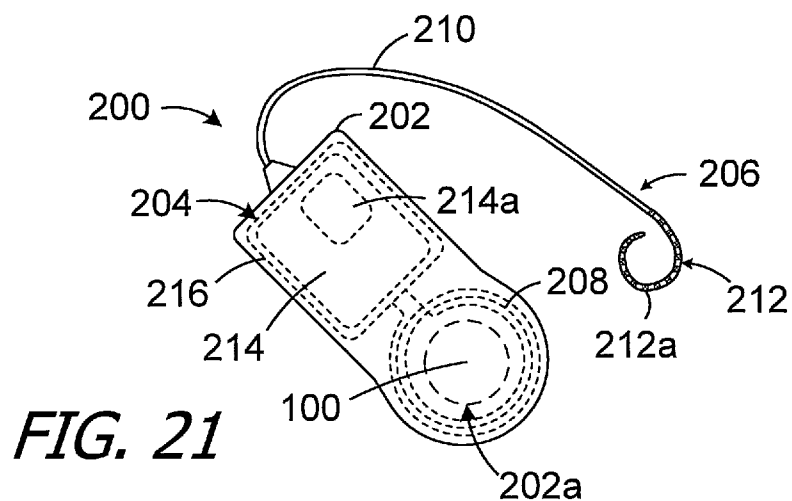


FIG. 20

6/6



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/066862

A. CLASSIFICATION OF SUBJECT MATTER INV. A61N1/372 A61N1/08 A61N1/36 A61N1/05 A61N1/375 ADD.		
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) A61N		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) 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.
Y	WO 2014/164023 A1 (ADVANCED BIONICS AG [CH]; HAZARD STEVE [US]; CLABEAUX SARAH ELIZABETH) 9 October 2014 (2014-10-09) abstract; figure 1 page 1, line 19 - page 2, line 2 page 6, lines 3-20	1-17
Y	US 2011/224756 A1 (ZIMMERLING MARTIN [AT] ET AL) 15 September 2011 (2011-09-15) abstract; figures 4a, 4b, 9 paragraphs [0004], [0009], [0011], [0012], [0049], [0050]	1-17
Y	US 2009/134721 A1 (ZIMMERLING MARTIN [AT]) 28 May 2009 (2009-05-28) abstract; figures 4, 6a, 13 paragraphs [0007] - [0011], [0019], [0057] - [0059], [0073]	1-17
	-/--	
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "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 3 March 2016		Date of mailing of the international search report 14/03/2016
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Pereda Cubián, David

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/066862

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015/065442 A1 (ADVANCED BIONICS AG [CH]; HEERLEIN MARKUS [US]; CRAWFORD SCOTT [US]; N) 7 May 2015 (2015-05-07) the whole document -----	1-17
A	EP 2 853 287 A1 (OTICON MEDICAL AS [DK]) 1 April 2015 (2015-04-01) the whole document -----	1-17
A	US 2015/025613 A1 (NYBERG II DAVID ANDRE [US] ET AL) 22 January 2015 (2015-01-22) the whole document -----	1-17
A	US 2014/343626 A1 (THENUWARA CHULADATTA [US] ET AL) 20 November 2014 (2014-11-20) the whole document -----	1-17
A	US 2014/012349 A1 (ZIMMERLING MARTIN [AT]) 9 January 2014 (2014-01-09) the whole document -----	1-17
A	US 2013/343588 A1 (KARUNASIRI RANKIRI TISSA [US]) 26 December 2013 (2013-12-26) the whole document -----	1-17
A	US 2011/264172 A1 (ZIMMERLING MARTIN [AT] ET AL) 27 October 2011 (2011-10-27) the whole document -----	1-17
A	US 2010/046778 A1 (CRAWFORD SCOTT A [US] ET AL) 25 February 2010 (2010-02-25) cited in the application the whole document -----	1-17
A	US 2010/046779 A1 (CRAWFORD SCOTT A [US] ET AL) 25 February 2010 (2010-02-25) cited in the application the whole document -----	1-17
A	US 2005/004629 A1 (GIBSON PETER [AU] ET AL) 6 January 2005 (2005-01-06) the whole document -----	1-17
A	US 5 824 022 A (ZILBERMAN YITZHAK [FR] ET AL) 20 October 1998 (1998-10-20) cited in the application the whole document -----	1-17

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/066862

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014164023 A1	09-10-2014	CN 105188839 A EP 2968954 A1 US 2015374989 A1 WO 2014164023 A1	23-12-2015 20-01-2016 31-12-2015 09-10-2014
US 2011224756 A1	15-09-2011	AU 2003233025 A1 AU 2008203243 A1 CA 2478324 A1 EP 1490148 A2 US RE45701 E1 US 2004012470 A1 US 2005062567 A1 US 2006244560 A1 US 2010004716 A1 US 2011224756 A1 WO 03081976 A2	13-10-2003 07-08-2008 09-10-2003 29-12-2004 29-09-2015 22-01-2004 24-03-2005 02-11-2006 07-01-2010 15-09-2011 09-10-2003
US 2009134721 A1	28-05-2009	NONE	
WO 2015065442 A1	07-05-2015	NONE	
EP 2853287 A1	01-04-2015	AU 2014233578 A1 CN 104511094 A EP 2853287 A1 US 2015087892 A1	09-04-2015 15-04-2015 01-04-2015 26-03-2015
US 2015025613 A1	22-01-2015	EP 2830706 A1 US 2015025613 A1 WO 2013147799 A1	04-02-2015 22-01-2015 03-10-2013
US 2014343626 A1	20-11-2014	EP 2758125 A1 US 2014343626 A1 WO 2013043176 A1	30-07-2014 20-11-2014 28-03-2013
US 2014012349 A1	09-01-2014	AU 2013286953 A1 CN 104540543 A EP 2869890 A1 US 2014012349 A1 WO 2014008169 A1	22-01-2015 22-04-2015 13-05-2015 09-01-2014 09-01-2014
US 2013343588 A1	26-12-2013	EP 2663362 A1 US 2013343588 A1 WO 2012096848 A1	20-11-2013 26-12-2013 19-07-2012
US 2011264172 A1	27-10-2011	AU 2011242708 A1 CN 102905756 A EP 2560730 A1 KR 20130052574 A US 2011264172 A1 WO 2011133747 A1	25-10-2012 30-01-2013 27-02-2013 22-05-2013 27-10-2011 27-10-2011
US 2010046778 A1	25-02-2010	US 2010046778 A1 US 2015012058 A1	25-02-2010 08-01-2015
US 2010046779 A1	25-02-2010	US 2010046779 A1 US 2012330378 A1 US 2013116747 A1 US 2015181354 A1	25-02-2010 27-12-2012 09-05-2013 25-06-2015

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/066862

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005004629	A1	06-01-2005	US 2005004629 A1 06-01-2005
			US 2008009920 A1 10-01-2008
			US 2013046360 A1 21-02-2013
			US 2016008596 A1 14-01-2016
US 5824022	A	20-10-1998	NONE