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(54) Title: ELECTROMAGNETIC BONE CONDUCTION HEARING DEVICE

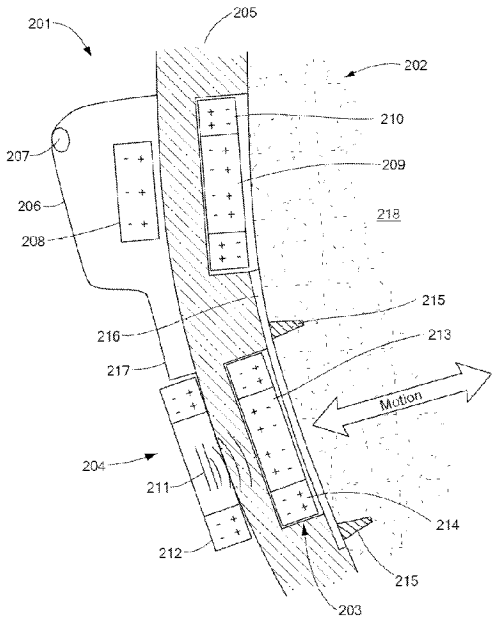

FIG. 2

(57) Abstract: An external component for a hearing implant is described. An external housing contains an attachment magnet configured to magnetically connect with an implant magnet of an implanted signal transducer. A pair of external electromagnetic drive coils within the external housing are adjacent to the attachment magnet for conducting electrical current to develop magnetic drive signals through the skin to the signal transducer to generate responsive vibrations of the signal transducer for perception by the patient as sound. The drive coils are configured such that their respective magnetic drive signals have opposing magnetic directions.

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TITLE

Electromagnetic Bone Conduction Hearing Device

[0001] This application claims priority from U.S. Patent Application 13/604,759, filed September 6, 2012; which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to medical implants, and more specifically to a novel transcutaneous auditory prosthetic implant system.

BACKGROUND ART

[0003] A normal ear transmits sounds as shown in Figure 1 through the outer ear **101** to the tympanic membrane (eardrum) **102**, which moves the ossicles of the middle ear **103** (malleus, incus, and stapes) that vibrate the oval window **106** and round window **107** membranes of the cochlea **104**. The cochlea **104** is a long narrow duct wound spirally about its axis for approximately two and a half turns. It includes an upper channel known as the scala vestibuli and a lower channel known as the scala tympani, which are connected by the cochlear duct. The cochlea **104** forms an upright spiraling cone with a center called the modiolar where the spiral ganglion cells of the cochlear nerve **105** reside. In response to received sounds transmitted by the middle ear **103**, the fluid-filled cochlea **104** functions as a transducer to generate electric pulses which are transmitted to the cochlear nerve **105**, and ultimately to the brain.

[0004] Hearing is impaired when there are problems in the ability to transduce external sounds into meaningful action potentials along the neural substrate of the cochlea **104**. To improve impaired hearing, auditory prostheses have been developed. For example, when the impairment is related to operation of the middle ear **103,** a conventional hearing aid or middle ear implant may be used to provide acoustic-mechanical stimulation to the auditory system in the form of amplified sound. Or when the impairment is associated with the cochlea **104**, a cochlear implant with an implanted stimulation electrode can electrically stimulate auditory nerve tissue with small currents delivered by multiple electrode contacts distributed along the electrode.

[0005] Middle ear implants employ electromagnetic transducers to convert sounds into mechanical vibration of the middle ear **103**. A coil winding is held stationary by attachment to a non-vibrating structure within the middle ear **103** and microphone signal current is delivered to the coil winding to generate an electromagnetic field. A magnet is attached to an ossicle within the middle ear **103** so that the magnetic field of the magnet interacts with the magnetic field of the coil. The magnet vibrates in response to the interaction of the magnetic fields, causing vibration of the bones of the middle ear **103**. *See* U.S. Patent 6,190,305, which is incorporated herein by reference.

[0006] U.S. Patent Publication 20070191673 (incorporated herein by reference) describes another type of implantable hearing prosthesis system which uses bone conduction to deliver an audio signal to the cochlea for sound perception in persons with conductive or mixed conductive/sensorineural hearing loss. An implanted floating mass transducer (FMT) is affixed to the temporal bone. In response to an externally generated electrical audio signal, the FMT couples a mechanical stimulation signal to the temporal bone for delivery by bone conduction to the cochlea for perception as a sound signal. A certain amount of electronic circuitry must also be implanted with the FMT to provide power to the implanted device and at least some signal processing which is needed for converting the external electrical signal into the mechanical stimulation signal and mechanically driving the FMT.

SUMMARY OF THE INVENTION

[0007] Embodiments of the present invention include an external component for an implantable hearing prosthesis of a recipient patient. An external housing contains an attachment magnet configured to magnetically connect with an implant magnet of an implanted signal transducer. A pair of external electromagnetic drive coils within the external housing are adjacent to the attachment magnet for conducting electrical current to develop magnetic drive signals through the skin to the signal transducer to generate responsive vibrations of the signal transducer for perception by the patient as sound. The drive coils are configured such that their respective magnetic drive signals have opposing magnetic directions.

[0008] There also may be a signal processor for generating electrical drive signals for the electromagnetic drive coils. The signal processor may be enclosed within the external housing, or within a signal processor housing separate from and connected to the external housing. There also may be at least one sensing microphone for developing an audio input signal to the signal processor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figure 1 shows anatomical structures of a typical human ear.

[0010] Figure 2 shows a cross-sectional view of an implantable hearing prosthesis arrangement according to an embodiment of the present invention.

[0011] Figure 3 A-B shows top plan views of the outside and internal structures of an external component for an embodiment of the invention.

[0012] Figure 4 shows a top plan view of the implant portion of an embodiment of the invention.

[0013] Figure 5 shows various aspects of an external component according to another embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0014] Various embodiments of the present invention are directed to an implantable hearing prosthesis for a recipient patient. An implant component and an external signal drive component each have two main lobes characterized by a distinctive magnet arrangement and a flexible connector member that maintains a constant distance between the two main lobes. One of the external main lobes contains a sensing microphone, an audio signal processor, and an attachment magnet which magnetically connects with a corresponding implant attachment magnet that forms one of the implant main lobes. The other external main lobe contains a ring drive magnet surrounding an electromagnetic signal drive coil that generates a magnetic drive signal from the signal processor which is

representative of sound detected by the sensing microphone. The other implant main lobe is a ring magnet arrangement that is fixed to the skull bone to magnetically couple the magnetic drive signal to the skull bone which delivers the signal to the cochlea by bone conduction where it is sensed as sound by the patient.

[0015] Figure 2 shows a cross-sectional view of one exemplary embodiment of the present invention including an implantable attachment magnet **202** which is fixable beneath the skin **205** of the patient to underlying skull bone **218**. The implantable attachment magnet **202** magnetically connects with a corresponding external attachment magnet **208** over the skin **205**. An implantable signal transducer **203** magnetically cooperates with corresponding external signal drive coil **204** that provides an externally generated magnetic audio signal to couple a corresponding mechanical stimulation signal to the skull bone **218** for delivery by bone conduction as an audio signal to the cochlea. An implant connector member **216** flexibly connects and positions the attachment magnet **202** a fixed distance from the signal transducer **203**. A corresponding external component **201** includes an external attachment magnet **208** that is fixable on the skin **205** to magnetically connect with the implant attachment magnet **202** beneath the skin **205**. An external signal drive coil **204** provides the magnetic audio signal to the implant signal transducer **203** beneath the skin **205**. An external connector member **217** flexibly connects and positions the external attachment magnet **208** a fixed distance from the signal drive coil **204**.

[0016] In the embodiment shown in Fig. 2, the implant attachment magnet **202** is specifically implemented as an outer ring magnet **210** having a first magnetization direction and inner core magnet **209** having an opposite second magnetization direction. Likewise, the signal transducer **203** also includes an outer ring magnet **214** having a first magnetization direction and inner core magnet **213** having an opposite second magnetization direction. Such ring magnet arrangements minimize problems that can arise from strong external magnetic fields such as with magnetic resonance imaging. This subject is explored more fully in U.S. Provisional Patent Application 61/227,632, filed July 22, 2009; which is incorporated herein by reference. In the embodiment shown in Fig. 2, the external attachment magnet **208** is a typical disk-shaped magnet sized adapted to magnetically connect with the inner core magnet **209** of the implant attachment magnet

202. In other embodiments, the external attachment magnet **208** may be like the implant attachment magnet **202** in having an inner core magnet that is surrounded by an outer ring magnet, both of which are sized and adapted to optimize the magnetic connection with the implant attachment magnet **202.** Similarly, the external signal drive coil **204** shown in the embodiment in Fig. 2 includes an outer ring magnet **212** sized and magnetically adapted to optimize the cooperation with the outer ring magnet **214** of the implanted signal transducer **203**. The inner core **211** of the signal drive coil **204** includes an electromagnetic coil (with or without a core) that produces the magnetic audio signal which is coupled across the skin to the implanted signal transducer **203**.

[0017] Figure 3 A-B shows top plan views providing further detail regarding the outside and internal structures of the external component **201**. The external attachment magnet **208** is contained within a processor housing **301** made of an impact resistant material such as plastic. A battery compartment **302** contains a battery power supply **304** that provides electrical power to the external component **201**. The processor housing **301** also contains openings for one or more sensing microphones **207** that sense the nearby acoustic environment and generate a representative microphone signal output. A signal processor **305** within the processor housing **301** receives the microphone signal and generates a corresponding electrical stimulation signal output. Signal leads **303** in the flexible member **217** couple the electrical stimulation signal from the signal processor **305** to the signal drive coil **204** for output to the implant.

[0018] Figure 4 shows a top plan view providing further detail regarding the implant portion used in Figure 2. The implant signal transducer **203** may be adapted for fixed attachment to the skull bone **218** by one or more bone screws **215** through corresponding flange openings **401** distributed around the outer circumference of the implant signal transducer **203.** Alternatively or in addition, some embodiments may be adapted for fixation of the signal transducer **203** in a prepared recessed transducer well in the skull bone **218**. The lobe of the signal transducer **203** and/or the lobe of the implant attachment magnet **202** may be hermetically enclosed such as with a biocompatible membrane.

[0019] While the specific embodiment depicted in Fig. 2 shows an external component

with a signal drive arrangement based on an electromagnetic drive coil surrounded by a ring permanent magnet, the invention is not necessarily limited to such a specific structure. For example, Figure 5 shows various aspects of an external component **500** according to another embodiment of the present invention. An external housing **501** contains an attachment magnet **502** configured to magnetically connect with one or more implant magnets **505** in an implanted signal transducer **504**. A pair of external electromagnetic drive coils **503** are located within the external housing **501** adjacent to the attachment magnet **502** configured such that their respective magnetic drive signals have opposing magnetic directions. The drive coils **503** conduct electrical current to develop magnetic drive signals through the skin to the implanted signal transducer **504** to generate responsive vibrations of the signal transducer **504** for perception by the patient as sound.

[0020] The external attachment magnet **502** cooperates most strongly with the closest counterpart implant magnet **505** within the implanted signal transducer **504**. In the specific embodiment in Fig. 5, the implanted signal transducer **504** is shown having a stack of three implant magnets **505** with alternating different lateral magnetization directions. This arrangement improves the compatibility of the implanted signal transducer **504** with the far field of MRI imaging systems—the sum of the magnetic moments of the implant magnets **504** with a N/S magnetization direction should be substantially equal to the sum of the magnetic moments of the magnets with S/N magnetization direction. And different embodiments may have different numbers and specific arrangements of the implant magnet **505,** and so instead of three magnets (as shown), there may be one, two, four or more with their own specific magnetic orientation arrangements.

[0021] The external housing **501** can contain other components such as a signal processor for generating electrical drive signals for the electromagnetic drive coils **503**. There also may be a sensing microphone for developing an audio input signal to the signal processor. Alternatively, an embodiment may be arranged more like in Fig. 2 with a separate attached housing that encloses other components such as a signal processor, microphone, power supply, etc.

[0022] One advantage embodiments of the present invention possess which is lacking in

earlier arrangements such as FMT-based systems is that there is no requirement that the implanted components include electronic circuits and associated power circuitry. The prior art has to convert a received electrical signal and therefore must have some necessary functional overhead including electrical power and signal conversion circuitry. But with embodiments of the present invention there is simply no requirement for any subcutaneous electronic circuitry.

[0023] Embodiments of the present invention such as those described above can be easily and directly implemented in existing products with corresponding size and geometry replacement magnets, either for the implanted magnet and/or the external magnet. Embodiments may usefully contain permanent magnetic material and/or ferro-magnetic material as well as other structural materials. These include without limitation magnetic ferrite materials such as Fe_3O_4, $BaFe_{12}O_{19}$ etc., compound materials such as plastic bonded permanent magnetic powder, and/or sintered material such as sintered NdFeB, SmCo, etc. Selection of the proper materials and arrangements may help avoid or reduce undesired eddy currents.

[0024] Although various exemplary embodiments of the invention have been disclosed, it should be apparent to those skilled in the art that various changes and modifications can be made which will achieve some of the advantages of the invention without departing from the true scope of the invention.

CLAIMS

What is claimed is:

1. An external component for a hearing implant, the component comprising:
an external housing containing an attachment magnet configured to magnetically connect with an implant magnet of an implanted signal transducer;
a pair of external electromagnetic drive coils within the external housing adjacent to the attachment magnet configured to conduct electrical current to develop magnetic drive signals through the skin to the signal transducer to generate responsive vibrations of the signal transducer for perception by the patient as sound;
wherein the drive coils are configured such that their respective magnetic drive signals have opposing magnetic directions.

2. An external component according to claim 1, further comprising:
a signal processor for generating electrical drive signals for the electromagnetic drive coils.

3. An external component according to claim 2, wherein the signal processor is enclosed within the external housing.

4. An external component according to claim 2, wherein the signal processor is enclosed within a signal processor housing separate from and connected to the external housing.

5. An external component according to claim 2, further comprising:
at least one sensing microphone for developing an audio input signal to the signal processor.

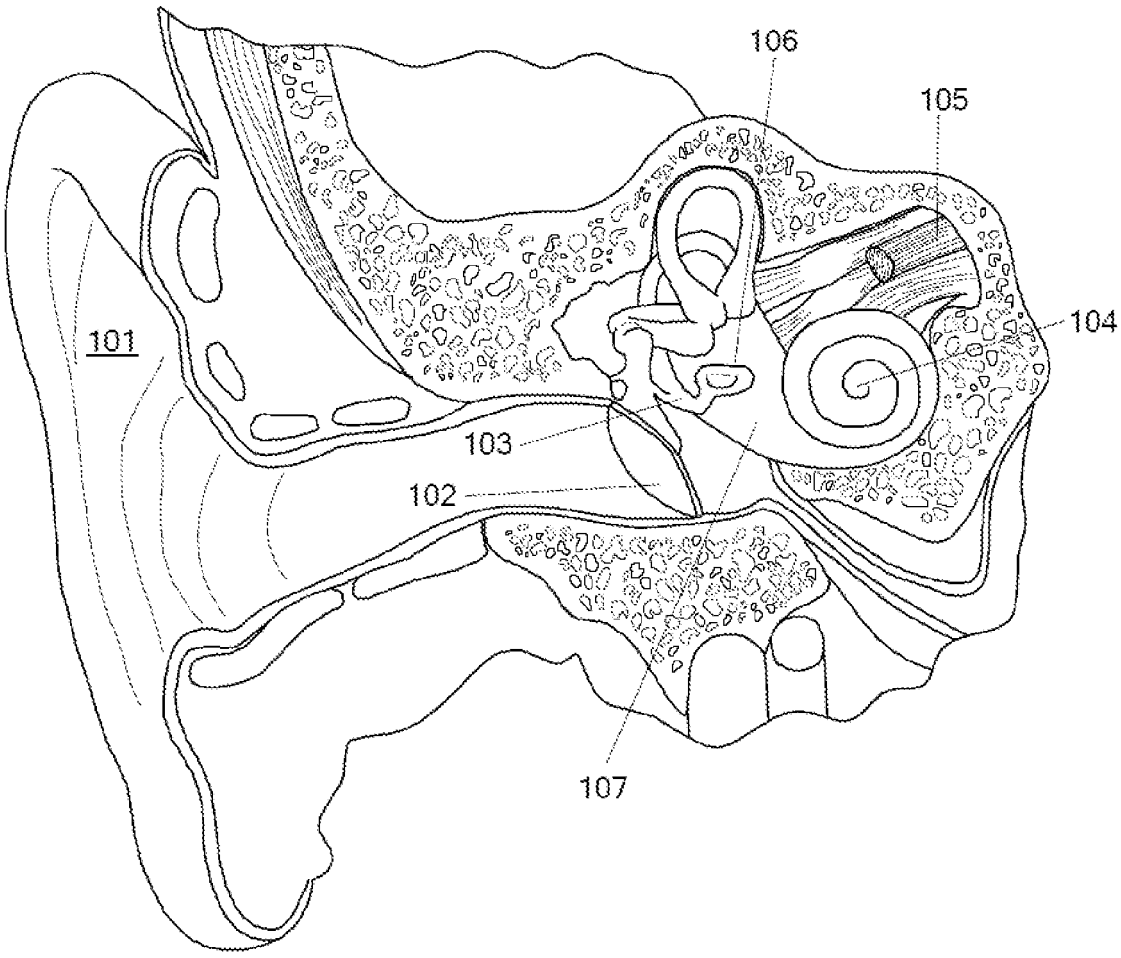
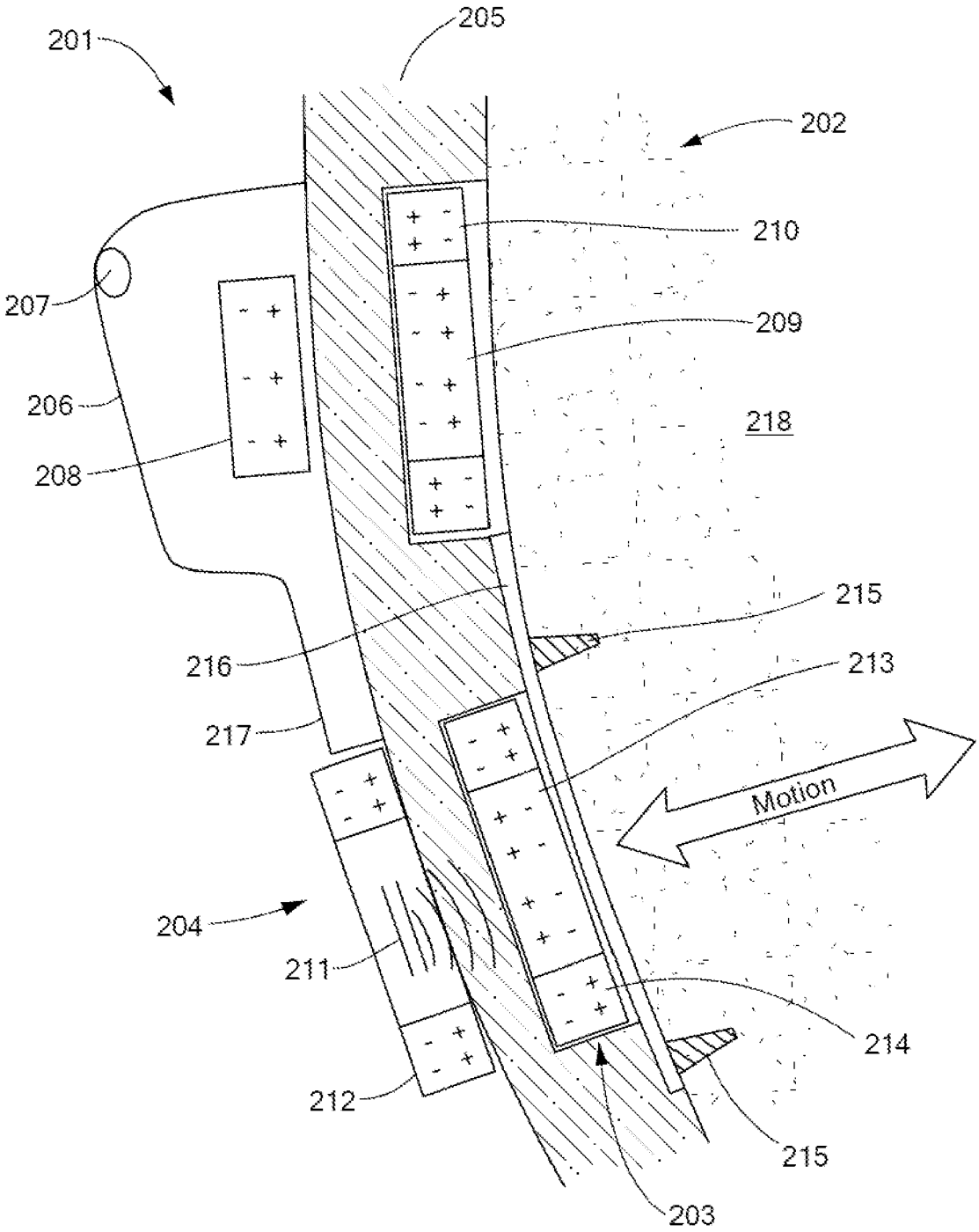


FIG. 1


201
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203

FIG. 2

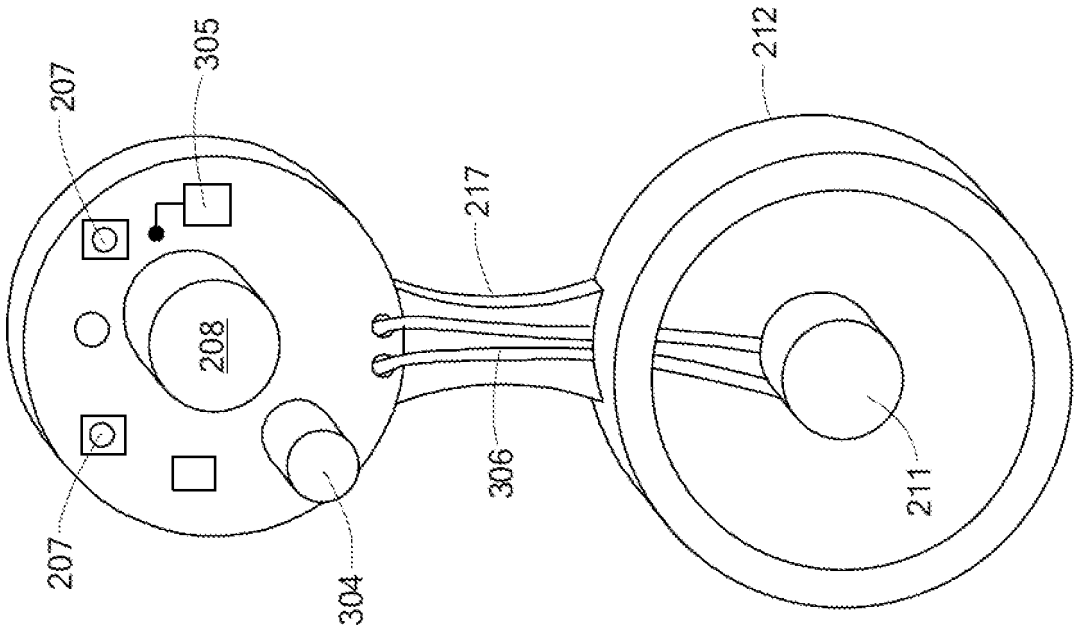

FIG. 3B

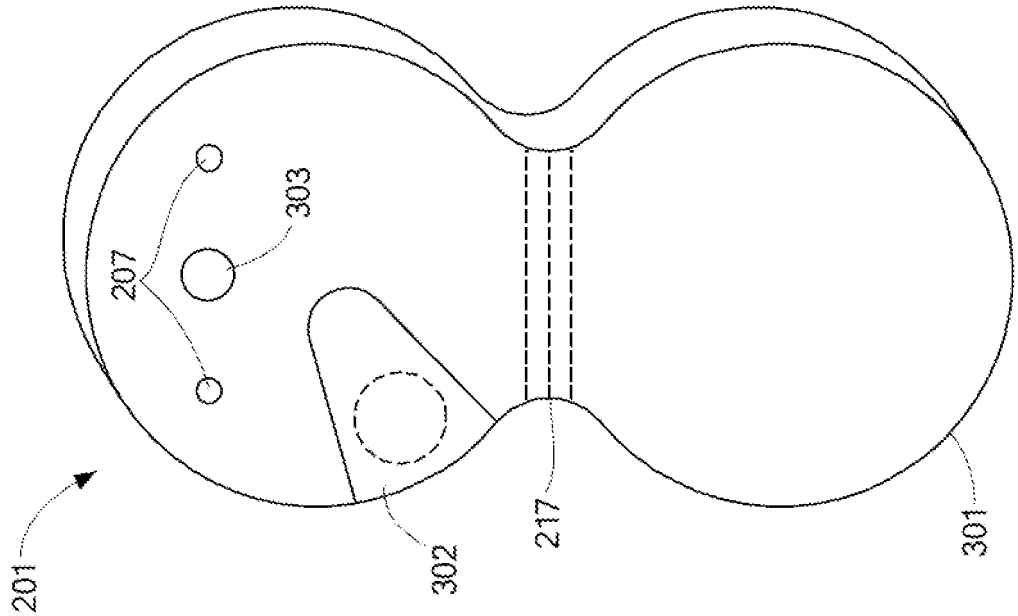

FIG. 3A

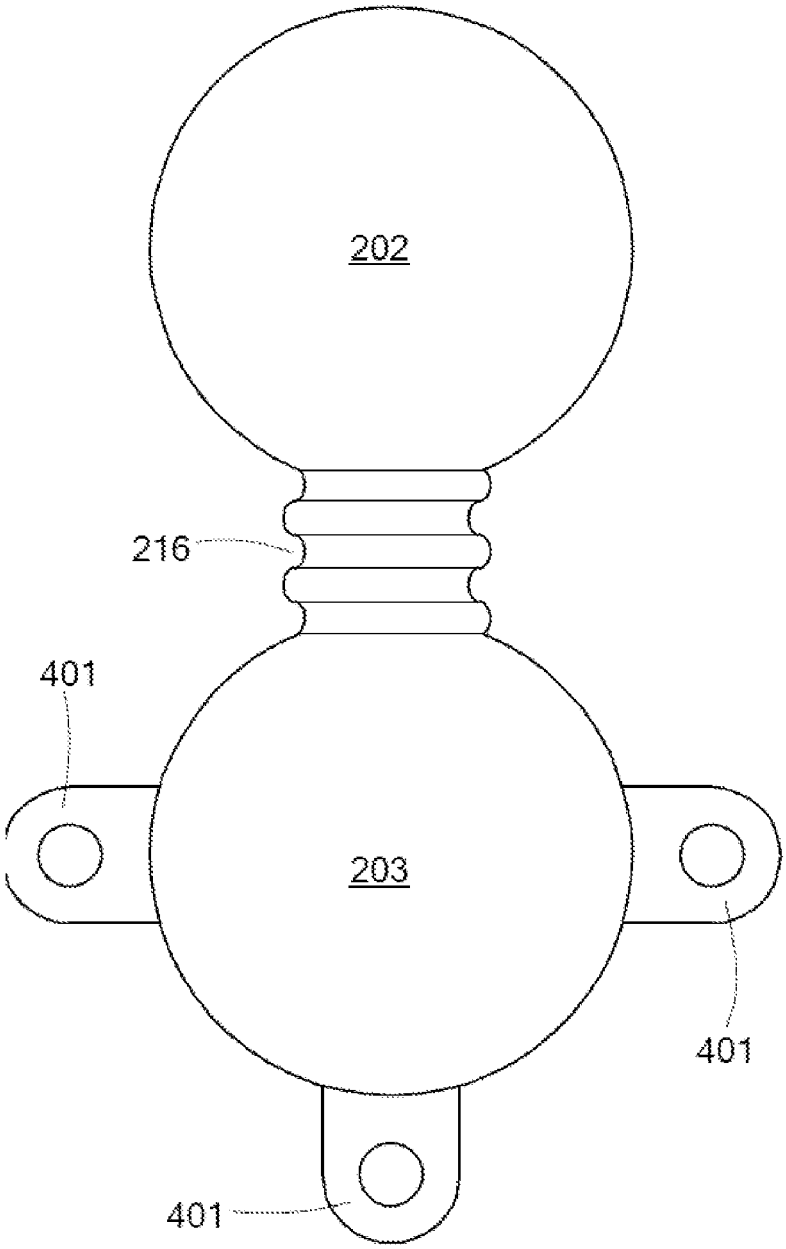

FIG. 4

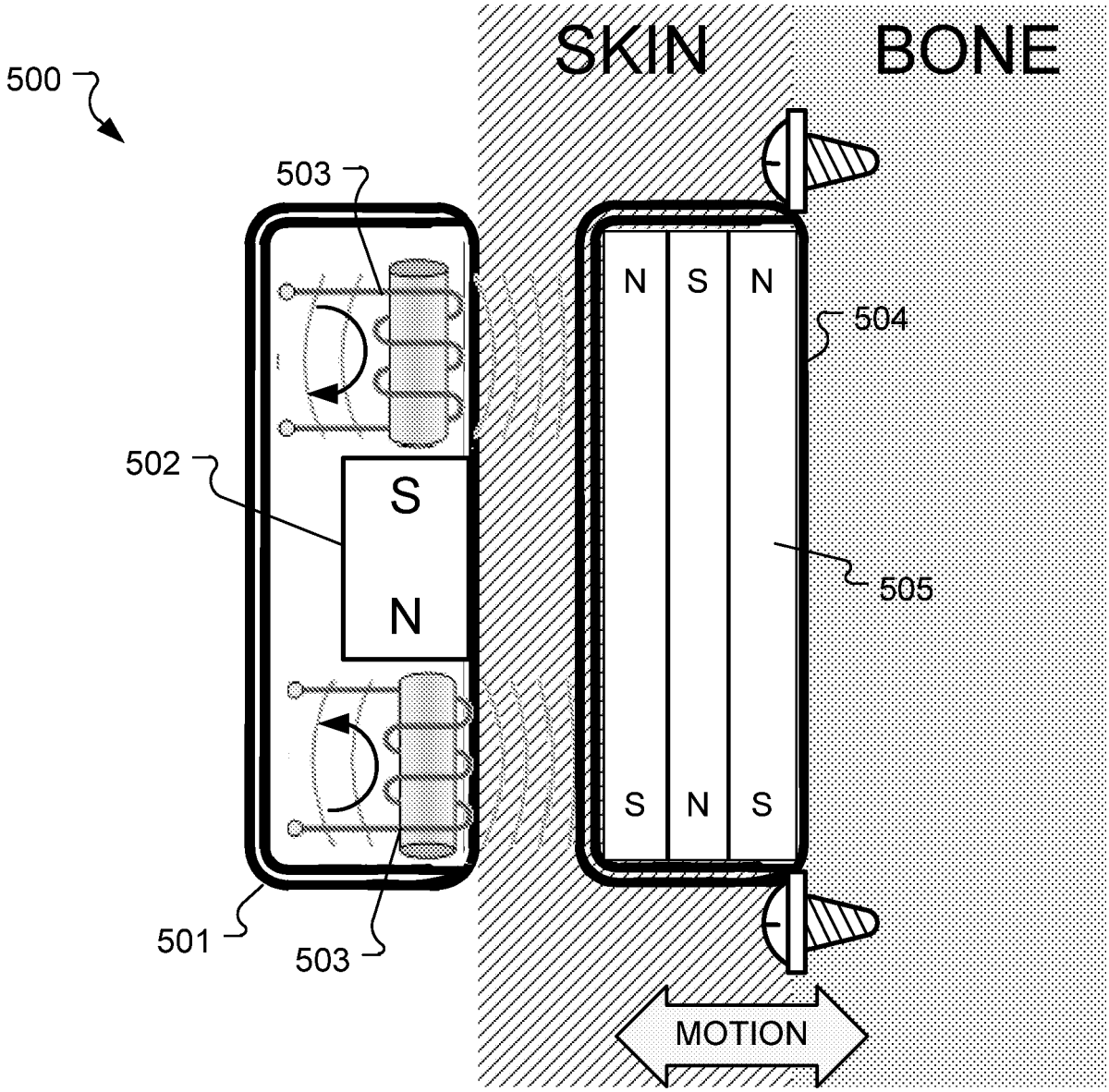

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US13/58375

A. CLASSIFICATION OF SUBJECT MATTER
IPC: **A61N 1/00**(2006.01);**H04R 25/00**(2006.01)

USPC: 607/55-57;600/25;381/312
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)
U.S. : 607/55-57;600/25;381/312

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)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,624,376 A (BALL et al) 29 April 1997 (29.04.1997), see entire document.	1-5
A	US 6,178,353 B1 (GRIFFITH et al) 23 January 2001 (23.01.2001), see entire document.	1-5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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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	Date of mailing of the international search report
19 September 2013 (19.09.2013)	20 SEP 2013
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (571) 273-3201	Authorized officer William Krynski Telephone No. 571-272-1700

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INTERNATIONAL SEARCH REPORT	International application No. PCT/US13/58375

Continuation of B. FIELDS SEARCHED Item 3:
US-PGPUB, USPAT, DERWENT, USOCR: second, third, additional, coil, same, multiple, external, electromagnet, alternate, anticipate, previous, prior, common, usual, known, obvious, embodiment, alternative, component, housing, magnet, attach, drive, signal, electric, current, implant, skin, transcutaneous, transciever, vibrate, vibrational,, sound, bone, conduct, percept, field, opposite, flux, inverse, directional, mirror, opposing, flip, invert, separate, own, dfferent, near, process, secure, mount, microphone, audio.