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(54) IMPLANTABLE MULTI-LENGTH RF ANTENNA

IMPLANTIERBARE HF-ANTENNE MEHRERER LÄNGEN

ANTENNE RF À MULTIPLES LONGUEURS IMPLANTABLE

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(73) Proprietor: **Cardiac Pacemakers, Inc.**
St. Paul, MN 55112-5798 (US)

(72) Inventor: **AMERI, Masoud**
Maple Plain, MN 55359 (US)

(74) Representative: **Pfenning, Meinig & Partner GbR**
Patent- und Rechtsanwälte
Joachimstaler Strasse 12
10719 Berlin (DE)

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Description

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Benefit of priority is hereby claimed to U.S. Provisional Patent Application Serial Number 61/033,535, filed on March 4, 2008.

[0002] Benefit of priority is hereby claimed to U.S. Provisional Patent Application Serial Number 61/087,476, filed on August 8, 2008.

BACKGROUND

[0003] Medical devices can be implanted in a body to perform tasks including monitoring, detecting, or sensing physiological information in or otherwise associated with the body, diagnosing a physiological condition or disease, treating or providing a therapy for a physiological condition or disease, or restoring or otherwise altering the function of an organ or a tissue. An examples of an implantable medical device can include a cardiac rhythm management device, such as a pacemaker, a cardiac resynchronization therapy device, a cardioverter or defibrillator, a neurological stimulator, a neuromuscular stimulator, or a drug delivery system. In certain examples, the implantable medical device can include a telemetry circuit and an antenna, coupled to the telemetry circuit, the combination of which can be configured to provide wireless communication between the implantable medical device and an external device, e.g., to send information (such as physiological or other information) from the implantable medical device to the external device, or to receive information (e.g., such as programming instructions) at the implantable medical device from the external device.

[0004] Magnetic coupling can be used to provide short-range (e.g., a few centimeters) communication between an implantable medical device implanted in a body and an external device, or between an implantable medical device outside of the body and an external device. However, magnetic coupling communication largely relies on near-field radiation, where the field distribution communication largely relies on near-field radiation, where the field distribution is highly dependent upon the distance from, and orientation of, the antenna, which grossly limits the effective range of wireless communication between the implantable medical device and the external device.

[0005] As an alternative to magnetic coupling communication, or in addition to magnetic coupling communication, low power radio frequency (RF) communication can be used to provide communication between an implantable medical device and an external device having an extended range over magnetic coupling. However, current RF communication circuits and antennas tuned for radiation from within a body tend to provide poor radiation outside of the body, and vice versa.

[0006] US 2005/203583 A1 shows a system including an implantable telemetry circuit and an implantable multi length antenna connected to the implantable telemetry circuit and configured to wirelessly transfer information electromagnetically at a specified first operating frequency range in a first medium. The antenna has an meandering shape comprising a pitch which is selected to maintain the antenna characteristics of an antenna with the unfolded antenna length.

OVERVIEW

[0007] This document discusses, among other things, a system and method for wirelessly transferring information electromagnetically at a specified first operating frequency range in a first medium and at a specified second operating frequency range in a second medium using an implantable multi-length antenna. The implantable multi-length antenna is configured to appear electrically as a first electrical length in the first medium and as a different second electrical length in the second medium. The first operating frequency range is specified using the first electrical length and the second operating frequency range is specified using the second electrical length.

[0008] The problems are solved by a system or a method according to the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

FIG. 1 illustrates generally an example of a system including an implantable telemetry circuit and an implantable antenna.

FIG. 2 illustrates generally an example a system including an implantable telemetry circuit and an implantable telemetry antenna in communication with one or more external modules.

FIG. 3 illustrates generally an example of a system including an implantable medical device (IMD) in communication with at least one of a patient monitor or a programmer.

FIG. 4 illustrates generally an example of a system including two or more implantable telemetry circuits in communication with each other, or in communication with one or more external modules.

FIGS. 5A-5B illustrate generally examples of at least a portion of an implantable multi-length antenna.

FIGS. 6A-6B illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna when substantially surrounded by two different media.

FIGS. 7A-7D illustrate generally examples of top and section views of at least a portion of an implantable multi-length antenna substantially surrounded by two different media.

FIGS. 8A-8B, 9A-9B, and 10A-10B illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna substantially surrounded by two different media.

FIG. 11 illustrates generally an example of at least a portion of an implantable multi-length antenna having a tapered width.

FIG. 12 illustrates generally an example of at least a portion of an implantable multi-length antenna having a tapered width and one or more arc-shaped switchback segments.

FIGS. 13A-13B illustrate generally examples of at least a portion of an implantable multi-length antenna having at least two switchback segments positioned in different planes.

FIG. 14 illustrates generally an example of at least a portion of an implantable multi-length antenna having at least two different distances between adjacent switchback configurations.

FIGS. 15A-15B illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna having at least two different distances between adjacent switchback configurations.

FIG. 16 illustrates generally an example of a radiation efficiency of an implantable multi-length antenna substantially surrounded by two different media.

FIG. 17 illustrates generally an example of a radiation efficiency of an implantable multi-length antenna having multi-frequency capability substantially surrounded by two different media.

FIG. 18 illustrates generally an example of at least a portion of a system including a telemetry circuit coupled to an implantable multi-length antenna.

FIG. 19 illustrates generally an example of a process including wirelessly transferring information electromagnetically at a first operating frequency range in a first medium and wirelessly transferring information electromagnetically at a second operating frequency range in a second medium.

FIG. 20 illustrates generally a relationship between an effective impedance of an antenna and a relative permittivity of a medium.

DETAILED DESCRIPTION

[0010] In certain examples, it can be desirable to establish a communication link between an implantable medical device and an external device before implanting the implantable medical device in a body, e.g., to test, program, or otherwise send information to or receive information from the implantable medical device, as well as after implanting the implantable medical device in the body, e.g., to program, monitor, or otherwise send information to or receive information from the implantable medical device. In an example, various wireless communication systems can provide communication between an external device and an implantable medical device both inside of and outside of the body. However, many communication systems tuned to radiate efficiently at a given frequency inside of the body do so poorly outside of the body. In other examples, a wireless communication system can include more than one telemetry circuit or antenna, the telemetry circuits or antennas individually tuned to radiate efficiently inside a human or animal body.

[0011] The present inventor has recognized, among other things, that it can be advantageous to use a single telemetry circuit, a single antenna, or a single combination of a telemetry circuit and an antenna to provide a communication link between the implantable medical device and the external device before implant as well as after implant, e.g., to reduce the number of system components, to reduce the overall size of the device, etc.

[0012] The present inventor has recognized, among other things, that one or more antenna characteristics can be used to tune or otherwise configured a single antenna to provide communication in more than one media (e.g., tissue, air, etc.) having one or more different transmission characteristics (e.g., different relative dielectric constants, etc.). In an example, utilizing a difference in relative dielectric constants in different media (e.g., between air and tissue), a single antenna can be configured have different electrical lengths in different media. In an example, in a first media having a first relative dielectric constant, a first portion of an antenna can exhibit little to no capacitive coupling to a second portion of the antenna or other conductor. However, in a second media having a second relative dielectric constant, the first portion of the antenna can exhibit a higher amount of capacitive coupling than in the first media to the second portion of the antenna or other conductor, thus effectively changing the electrical length of the antenna due to the higher capacitive coupling.

[0013] In an example, in free space, or in a medium having a relative dielectric constant of approximately 1, an antenna can be configured to have a desired length approximately equal to one quarter of a specified operating wavelength. In other examples, in free space, or in the medium having the relative dielectric constant of approximately 1, the antenna can be configured to have an acceptable length shorter than the desired length equal to one quarter of the specified operating wavelength. In certain examples, the shorter length can become necessary because otherwise, the quarter wavelength can become too long to work with. Generally, the desired length of the antenna changes roughly inversely proportionately to the square root of the relative dielectric constant of the medium surrounding the antenna. Thus, as the relative dielectric of the medium increases, the desired antenna length decreases.

[0014] The present inventor has recognized, among other things, that because a desired length of an antenna at a first specified operating frequency in free space is longer than a desired length of an antenna at the first specified operating frequency in tissue, and because the relative dielectric constant of tissue is different than the relative dielectric constant of free space, a coupling, such as a capacitive coupling, between one or more portions of an antenna can be utilized to provide a single antenna having a first electrical length equal to the desired length at a first specified operating frequency in free space and having a second electrical length equal to the desired length at the first specified operating frequency in tissue.

[0015] In an example, the antenna can include a first impedance corresponding to the first electrical length in the first medium, and a second impedance corresponding to the second electrical length in the second medium. In an example, the antenna can be tuned, designed, or configured in such a way that the first and second impedance are the same, so that a single matching network can optimize the radiation of the antenna.

[0016] **FIG. 1** illustrates generally an example of a system 100 including an implantable telemetry circuit 115 and an implantable antenna 120. In an example, the system 100 can include an implantable assembly housing 110 configured to house at least a portion of an implantable telemetry circuit 115. In an example, the implantable assembly housing 110 can be made of a conductive biocompatible material, such as titanium. In certain examples, the implantable antenna 120 can be driven by the telemetry circuit 115 via a feed-through 118 through the implantable assembly housing 110. In an example, the feed-through 118 can prevent the implantable assembly housing 110 from attenuating, shorting out, or otherwise altering the radiation of electromagnetic energy 150 by the implantable antenna 120.

[0017] In an example, the implantable antenna 120 can include a switchback 122 and a non-switchback segment 123 configured to radiate electromagnetic energy 150 or to receive radiated electromagnetic energy 150 over one or more specified frequency ranges.

[0018] In an example, the implantable antenna 120 can be configured to radiate electromagnetic energy 150 or to receive radiated electromagnetic energy 150 when substantially surrounded by a first or a second medium. In an example, the first medium can include at least one of free space or air. In other examples, the second medium can include an implant medium 102. In certain examples, the implant medium 102 can include a biological medium, such as bodily fluid, skin tissue, fat tissue, muscle tissue, organ tissue, bone, or other biological medium. In an example, the implant medium 102 can include a portion of a human or a portion of an animal (e.g., an implantable medical device (IMD) can be used as a monitoring device or therapy delivery device for pets, livestock, etc.)

[0019] **FIG. 2** illustrates generally an example a system 200 including an implantable telemetry circuit 215 and an implantable telemetry antenna 220 in communication, such as in RF wireless communication (e.g., using a first RF wireless communication link 250A, a second RF wireless communication link 250B, etc.), with one or more external modules, such as a first external module 230A, a second external module 230B, etc. In an example, the implantable telemetry circuit 215 and the implantable telemetry antenna 220 can be implanted within a patient 202, e.g., subcutaneously, intramuscularly, intrathoracically, or otherwise implanted within the patient 202. In an example, the implantable antenna 220 can be at least partially surrounded by a dielectric compartment 221 comprising a biocompatible dielectric material (e.g., the implantable antenna 220 can be inserted into a cavity within the compartment 221, or the compartment 221 can be formed at least in part by overmolding the antenna 220).

[0020] In an example, the first external module 230A or the second external module 230B can include an external telemetry circuit, e.g., a first external telemetry circuit 225A or a second external telemetry circuit 225B, respectively. In certain examples, the first RF wireless communication link 250A can be accomplished using a first range of RF operating frequencies, and the second RF wireless communication link 250B can be accomplished using a second range of RF operating frequencies different than the first range of operating frequencies. In other examples, the first external telemetry circuit 225A or the second external telemetry circuit 225B can use either a first or second operating range of frequencies, or both, for wireless communication. In certain examples, the first external telemetry circuit 225A or the second external telemetry circuit 225B can be electrically connected to one or more external antennas.

[0021] **FIG. 3** illustrates generally an example of a system 300 including an implantable medical device (IMD) 310 in communication, such as in RF wireless communication (e.g., using a first RF wireless communication link 350A, a second RF wireless communication link 350B, etc.), with at least one of a patient monitor 331 or a programmer 332.

[0022] In the example of FIG. 3, the IMD 310 can include a implantable telemetry circuit 315 electrically connected to an implantable antenna 320. As similarly discussed with respect to FIG 2, in some examples, the first RF wireless communication link 350A or the second RF wireless communication link 350B can use more than one RF operating frequency range. In such examples, a single implantable antenna 320 can be configured to operate at two or more RF wireless operating frequencies to support the first RF wireless communication link 350A or the second RF wireless communication link 350B.

[0023] According to the example of FIG. 3, the implantable antenna 320 can be at least partially surrounded by a connector block 321. In certain examples, the connector block 321 can be at least partially made of a dielectric material. In various examples, the connector block 321 can also provide an electrical or mechanical connection between the IMD 310 and one or more implantable leads, e.g., a first implantable lead 312A or a second implantable lead 312B. In some examples, the first implantable lead 312A or the second implantable lead 312B can be routed within a patient body 302 to various sites, e.g., to provide a physiologic monitoring of an electrical or a mechanical signal, or to provide a therapy, such as an electrostimulus therapy, a targeted drug release, or other therapy. In the example of FIG. 3, the first implantable lead 312A can be routed to a cardiac tissue site 303 (e.g., an endocardial site, an epicardial site, a site within the myocardium, or other cardiac tissue site) to deliver a therapy, such as a cardiac rhythm management therapy, or the second implantable lead 312B can be routed to a neural target 304 (e.g., a vagal nerve or other neural target) to deliver a therapy, such as a neural stimulation therapy.

[0024] In certain examples, the patient monitor 331, the programmer 332, or both the patient monitor 331 and the programmer 332 can be communicatively coupled, e.g., using a first coupling 351A or a second coupling 351B, with a network 352. In an example, the first coupling 351A or the second coupling 351B can include a wired coupling or a wireless coupling. In an example, information can be wirelessly transferred from the IMD 310 to the patient monitor 331 or the programmer 332, and then transferred from the patient monitor 331 or the programmer 332 to the network 352 using the first coupling 351A or using the second coupling 351B.

[0025] **FIG. 4** illustrates generally an example of a system 400 including two or more implantable telemetry circuits, such as a first implantable telemetry circuit 410A, a second implantable telemetry circuit 410B, etc., in communication, such as in RF wireless communication (e.g., using a RF wireless communication link 451), with each other, or in communication, such as in RF wireless communication (e.g., using a first RF wireless communication link 450A, a second RF wireless communication link 450B, etc.), with one or more external modules, such as a first external module 430A, a second external module 430B, etc.

[0026] In an example, the first implantable telemetry circuit 410A or the second implantable telemetry circuit 410B can use the same RF wireless communication scheme for wirelessly coupling to each other (e.g., using the RF wireless communication link 451) as can be used for wirelessly coupling to an external module (e.g., using the first RF wireless communication link 450A or the second RF wireless communication link 450B). In other examples, the first implantable telemetry circuit 410A or the second implantable telemetry circuit 410B can use a first RF wireless operating frequency range for wirelessly coupling to each other,(e.g., using the RF wireless communication link 451), and a second RF wireless operating frequency range for wirelessly coupling to an external module (e.g., using the first RF wireless communication link 450A or the second RF wireless communication link 450B). In certain examples, the RF wireless communication link 451 can include an optical, an acoustic, a magnetic, a body conductive, or other communication link.

[0027] In an example, a single first implantable antenna 420A or a single second implantable antenna 420B can be configured to operate at multiple RF wireless communication frequency ranges.

[0028] **FIGS. 5A-5B** illustrate generally examples of at least a portion of an implantable multi-length antenna 500. In the example of **FIG. 5A**, the implantable multi-length antenna 500 can have a feed segment 524A coupled to a telemetry circuit. A switchback 522A can be coupled to the feed segment 524A, and a non-switchback segment 523A can be coupled to the switchback 522A. In an example, the implantable multi-length antenna 500 can have a physical length and shape as of **FIG. 5A**. In an example, the implantable multi-length antenna 500 can have an electrical length and shape when operated in a first operating frequency range as of **FIG. 5A** when the implantable multi-length antenna 500 is substantially surrounded by a first medium (e.g., free space, air, or other medium having a relative dielectric constant approximately equal to 1).

[0029] In the example of **FIG. 5B**, the implantable multi-length antenna 500 of **FIG. 5A** can be substantially surrounded by a second medium having a higher relative dielectric constant than the first medium. In an example, the implantable multi-length antenna 500 can have a physical length as **of FIG. 5A**, but can have a shorter electrical length (e.g., the electrical path length along the implantable multi-length antenna 500 corresponding to an RF current resulting in radiation can be shorter than the physical length of the implantable multi-length antenna 500, where the physical length corresponds to the sum of all constituent segment and transition lengths). In an example, when the implantable multi-length antenna 500 is operated in the second medium in a second operating frequency range, capacitive coupling between a first physical switchback segment 519A and a second physical switchback segment 519B can result in a reduction of the electrical length of the implantable multi-length antenna 500 compared to the physical length. In an example, the switchback 522A of **FIG. 5A**, when substantially surrounded by a second medium having a higher relative dielectric constant than the first medium, can appear electrically as a coupled segment 522B. In this example, the coupled segment 522B can essentially directly (or substantially directly) couple the feed segment 524A to the non-switchback segment 523A, electrically bypassing the intervening switchback.

[0030] Thus, the present inventor has, among other things, recognized that a single antenna 500 can appear as two different electrical lengths corresponding to operation in a first frequency range in a first medium and to operation in a second frequency range in a second, different, medium. Further, the present inventor has recognized, among other things, that the physical arrangement of the switchback 522A with respect to the feed segment 524A or the non-switchback segment 523A can be used to alter the electrical length of the implantable multi-length antenna 500. In certain examples, the first operating frequency range and the second operating frequency range can overlap, can be substantially the same, or can be the same.

[0031] In certain examples, the feed segment 524A, the switchback 522A, or the non-switchback segment 523A can be etched, stamped, formed, cut, or the like. In some examples, the feed segment 524A, the switchback 522A, or the non-switchback segment 523A can comprise a conductive material, such as platinum, iridium, gold, silver, copper, tin, aluminum, steel, a combination of metals, or other conductive material. In an example, when a portion of the implantable multi-length antenna 500 is configured to be in contact with a biological medium, a bio-compatible conductive alloy can be used, such as platinumiridium.

[0032] In an example, the switchback 522A can include different geometric parameters, such as a switchback cross sectional area, a switchback cross section shape, a spacing between the first switchback segment 519A and the second switchback segment 519B, a shape of a path formed by switchback segment 519A or 519B (e.g., a switchback segment, such as the first switchback segment 519A or the second switchback segment 519B, need not be linear), a length of a transition segment 521, a shape of a path formed by the transition segment 521, a conductor cross sectional area, or other one or more other geometric parameter.

[0033] **FIGS. 6A-6B** illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna 600 when substantially surrounded by two different media.

[0034] **FIG. 6A** illustrates generally an example of an implantable multi-length antenna 600 in a first medium, the implantable multi-length antenna 600 including a feed segment 624A, a switchback segment 622, and a non-switchback segment 623. In an example, the implantable multi-length antenna 600 (having a physical length and shape as of **FIG. 6A**) can be driven at the feed segment 624A at a first range of frequencies when substantially surrounded by a first medium. In an example, the first medium can include free space, air, or other medium having a low relative dielectric constant (e.g., 1 or approximately 1, etc.). In an example, the switchback 622 can have additional segments, such as one or more other switchback segments, etc., the additional segments electrically connected to the feed segment 624A or to the non-switchback segment 623.

[0035] **FIG. 6B** illustrates generally an example of an implantable multi-length antenna 600 in a second medium. In an example, the second medium can include an implant medium, such as tissue, skin, fat, muscle, bodily fluid, or other implant medium having a relative dielectric constant of more than 1. In an example, the implantable multi-length antenna 600 can have a second electrical length when the implantable multi-length antenna 600 can be used in a second range of frequencies when substantially surrounded by a second, different, medium having a higher relative dielectric constant.

[0036] **FIGS. 7A-7D** illustrate generally examples of top and section views of at least a portion of an implantable multi-length antenna 700 substantially surrounded by a first medium 702A versus a second medium 702B. **FIG. 7A** illustrates generally an example of an implantable multi-length antenna 700 in a first medium 702A having a physical length and shape corresponding to a first path 720A, described by a first switchback segment 722A coupled to a first non-switchback segment 723A, and the first non-switchback segment coupled to a second switchback segment 722B.

[0037] In the examples of **FIGS. 7A-7B,** when the implantable multi-length antenna 700 is substantially surrounded by a first medium 702A (e.g., air), the implantable multi-length antenna 700 can have an electrical length corresponding to a first path 720A when the antenna is operated in a first range of frequencies.

[0038] In the examples of **FIGS. 7C-7D,** when the implantable multi-length antenna 700 is substantially surrounded by a second medium 702B (e.g., a biological medium), the implantable multi-length antenna 700 can have an electrical length corresponding to a second path 720B when the antenna is operated in a second range of frequencies. In some examples, a reduction in electrical length associated with path 720B can occur as a result of an increased electrical flux density in the second medium 702B versus the first medium 702A. In certain examples, the increased electrical flux density can be conceptualized as an increased first capacitance 760A or an increased second capacitance 760B between one or more adjacent segments included in switchback 722A.

[0039] **FIGS. 8A-8B** illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna 800 substantially surrounded by two different media. In the example of **FIG. 8A**, the implantable multi-length antenna 800 can have a physical shape and length as formed by a feed segment 824A, a first switchback 822A, a first non-switchback segment 823A, a second switchback 822B, and a second non-switchback 823B. When the implantable multi-length antenna 800 is substantially surrounded by a first medium (e.g., air), the implantable multi-length antenna 800 can have an electrical shape and length corresponding to the physical path of **FIG. 8A.** ,

[0040] In the example of **FIG. 8B,** the implantable multi-length antenna 800 can have a physical shape and length as of **FIG. 8A,** but can have an electrical length and shape formed by a feed segment 824B, a first coupled segment 822C, a first non-switchback segment 823C, a second coupled segment 822D, and a second non-switchback segment 823D. In an example, when the antenna 800 is used in a second range of frequencies substantially surrounded by a second, different, medium having a higher relative dielectric constant, the first switchback 822A can appear electrically as the first coupled segment 822C, and the second switchback 822B can appear electrically as a second coupled segment 822D. The present inventor has recognized, among other things, that having more than one switchback, such as the first switchback 822A and the second switchback 822B, can result in more efficient radiation along the length of the implantable multi-length antenna 800, or can provide a greater range of control over the implantable multi-length antenna 800 input impedance looking into the feed segment 824A.

[0041] **FIGS. 9A-9B** illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna 900 substantially surrounded by two different media. In the example of **FIG. 9A**, a first switchback 922A and a second switchback 922B can deviate in, for example, two directions from a centerline axis formed by a feed segment 924A, a first non-switchback segment 923A, and a non-switchback segment 923B.

[0042] In an example, when the implantable multi-length antenna 900 is operated at a second frequency range and terminated in a second medium, the first switchback 922A can appear as multiple coupled segments, such as a first coupled segment 922C and a second coupled segment 922D. Similarly, the second switchback 922B can appear as a third coupled segment 922E and a fourth coupled segment 922F.

[0043] In other examples, in the second medium, a feed segment 924B can appear as a slightly different electrical length than the corresponding feed segment 924A in the first medium. Similarly, in the second medium, a non-switchback segment 923C and a non-switchback segment 923D can appear as a slightly different electrical length as the corresponding first non-switchback segment 923A and the non-switchback segment 923B in the first medium...

[0044] **FIGS. 10A-10B** illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna 1000 substantially surrounded by two different media. In the example of **FIG. 10A**, a feed segment 1024A can form part of a switchback segment 1022A. In certain examples, the switchback segment 1022A can include one or more segments or transitions, and can be connected to a non-switchback segment 1023B. In an example, when the implantable multi-length antenna 1000 is operated at a second frequency range in a second medium, the switchback segment 1022A can electrically represent multiple capacitive coupled segments extending from a feed segment 1024B, such as shown by a first coupled segment 1022A, a second coupled segment 1022B, a third coupled segment 1022C, a fourth coupled segment 1022D, or a fifth coupled segment 1022E in the example of **FIG. 10B**.

[0045] The present inventor has, among other things, also recognized that at lower frequencies (e.g., below the frequency range where capacitive coupling can dominate), the switchback segment 1022A can have enhanced inductance and can be used to provide a loading effect (e.g., to alter the input impedance of the implantable multi-length antenna 1000 looking into the feed segment 1024A in order to provide an improved impedance match between the implantable multi-length antenna 1000 and a driving or receiving telemetry circuit).

[0046] **FIG. 11** illustrates generally an example of at least a portion of an implantable multi-length antenna 1120 having a tapered width. In an example, the implantable multi-length antenna 1120 can expand in width linearly (e.g., with respect to a centerline axis) as it extends from a feed segment 1124. In other examples, the shape of the taper can be non-linear (e.g., exponential, sinusoidal, in conformance to a shape of a dielectric housing, in conformance to a shape of an IMD housing, biased more on one side of a centerline axis, or other shape or configuration). In some examples, the shape of the taper can be inverted with respect to the previously described examples (e.g., starting wider at the feed segment 1124 and narrowing along the length of the implantable multi-length antenna 1120).

[0047] Generally, a relative dielectric constants of a biological medium can vary significantly. In certain examples, one or more bodily fluids can have a relative dielectric constant over 50, and muscle tissue can have a relative dielectric constant over 20. In an example, the implantable multi-length antenna 1120 can be applied in a variety of different biological mediums, including a bodily fluid (e.g., blood, a digestive juice, a lymph, water, or other bodily fluid), muscle tissue, bone tissue, fat tissue, skin, or other biological medium.

[0048] The present inventor has recognized, among other things, that when an antenna is locally surrounded by a material having a lower relative dielectric constant (e.g., such as by a coating or a surrounding dielectric housing), a tapered shape can help to more gradually match the antenna to a spatial impedance of a higher relative dielectric constant medium, and, in certain examples, can provide more efficient radiation into the higher relative dielectric constant medium.

[0049] The present inventor has recognized, among other things, that a gradual shift in feature size can be made on the implantable multi-length antenna 1120, a usable bandwidth can be increased (e.g., size of an operating frequency range).

[0050] In an illustrative example, TECOTHANE™ polymer material can have a relative dielectric constant of approximately 4.4 over a range of frequencies. Generally, a biological medium can have a relative dielectric constant greater than 5. In certain examples, an IMD connector block can be made from TECOTHANE™, and can surround part or all of the implantable multi-length antenna 1120. In various examples, the implantable multi-length antenna 1120 can be wider in a region where the connector block is thicker, and the implantable multi-length antenna 1120 can be narrower in a region where the connector block is thinner, such as in order to help match the implantable multi-length antenna 1120 to an effective relative dielectric constant comprising a combination of the TECOTHANE™ and the biological medium.

[0051] Generally, the desired antenna length in a given medium can be inversely proportional to the square root of the effective relative dielectric constant as seen by the antenna when surrounded by one or more media. The present inventor has recognized, among other things, that a tradeoff can exist between proximity to an IMD housing and radiation efficiency, when the IMD housing includes a conductor. In an example, as the implantable multi-length antenna 1120 is located more closely to a conductive IMD housing, the degree of impedance stability of the implantable multi-length antenna 1120 can increase (e.g., become less sensitive to the medium surrounding the IMD). In other examples, as the implantable multi-length antenna 1120 is located more closely to the conductive IMD housing, the effective dielectric constant as seen by the antenna can be more stable. However, as the implantable multi-length antenna 1120 is located more closely to a conductive IMD housing, the implantable multi-length antenna 1120 can radiate less efficiently, in certain examples, because the IMD housing can "short out" the antenna radiation, or because the implantable multi-length antenna 1120 can appear electrically longer because the effective relative dielectric constant seen by the implantable multi-length antenna 1120 can be lower.

[0052] **FIG. 12** illustrates generally an example of at least a portion of an implantable multi-length antenna 1220 having a tapered width and one or more arc-shaped switchback segments extending from a feed segment 1224. Similar to the example of **FIG. 11** with respect to tapering, the present inventor has recognized, among other things, that having one or more segments or transitions of the implantable multi-length antenna 1220 arranged at right angles (e.g., perpendicular to one another) can enhance a radiation efficiency of the implantable multi-length antenna 1220 (e.g., can enhance a radiation resistive component of an impedance of the implantable multi-length antenna 1220). In the example of **FIG. 12**, one or more switchback segments can be arc-shaped to allow approximately right angles where the one or more switchback segments are connected to one or more non-switchback segments.

[0053] **FIG. 13A** illustrates generally an example of at least a portion of an implantable multi-length antenna 1300 having at least two switchback segments positioned in different planes. In the example of **FIG. 13A**, the implantable multi-length antenna 1300 can be driven at a feed segment 1324 leading into one or more first switchback segments located in a first plane. In an example, the first plane can be formed by a first axis 1330 located along the implantable multi-length antenna 1300 and a line forming a second axis 1310 perpendicular to the first axis 1330. In an example, a second plane, different than the first plane, can be formed by the first axis 1330 and a third axis 1320. In certain examples, one or more second switchback segments located in the second plane can be connected to the first switchback segments located in the first plane. In an example, the second plane can be normal (perpendicular) to the first plane. In other examples, the second plane can be different than the first plane, but need not be at a right angle.

[0054] The present inventor has recognized, among other things, that the implantable multi-length antenna 1300 can exhibit greater directivity (e.g., less isotropic radiation pattern) when constrained to a single plane than when having switchback segments in different planes.

[0055] In an example, isotropic radiation can be desired to improve a reliability of RF wireless communication between an IMD and another IMD or an external device (e.g., to prevent communication drop-outs due to device orientation, dead spots, etc.

[0056] In certain examples, one or more switchback or non-switchback segments can be located in more than one plane to increase a radiation pattern uniformity (e.g., to provide radiation in all directions more uniformly). Further, in certain examples, the whole implantable multi-length antenna 1300, or at least a portion of the implantable multi-length antenna 1300, can bend along the main axis (e.g., rotate, etc.) to an angle other than a right angle or other than perpendicular to the main axis. In an example, this bending can provide a more distribution radiation directions than just having the switchbacks in two perpendicular planes.

[0057] **FIG. 13B** illustrates generally an example of at least a portion of an implantable multi-length antenna 1300 having at least two switchback segments positioned in different planes. In an example, the first plane can be formed by a first axis 1330 located along the implantable multi-length antenna 1300 and a line forming a second axis 1310 perpendicular to the first axis 1330. In an example, a second plane, different than the first plane, can be formed by the second axis 1310 and a third axis 1320. In certain examples, one or more second switchback segments located in the second plane can be connected to the first switchback segments located in the first plane. In an example, the second plane can be normal (perpendicular) to the first plane. In other examples, the second plane can be different than the first plane, but need not be at a right angle.

[0058] **FIG. 14** illustrates generally an example of at least a portion of an implantable multi-length antenna 1400 having at least two different distances between adjacent switchback configurations. In the example of **FIG. 14,** a first length L_1 1410 defines a distance between a first switchback 1422A and a second switchback 1422B. The first length L_1 1410 can correspond to a resonant frequency associated with a first operating frequency range when the implantable multi-length antenna 1400 is driven at a feed segment 1424. In an example, L_1 can be an integer multiple of approximately a quarter wavelength. Similarly, a second length L_2 1420 can be defined by a distance between the first switchback 1422A and a third switchback 1422C, corresponding to a second, different, operating frequency range, or resonance. In other examples, at least one of the first length L_1 1410 or the second length L_2 1420 can be significantly different than the quarter wavelength.

[0059] **FIGS. 15A-15B** illustrate generally examples of physical and electrical lengths of at least a portion of an implantable multi-length antenna 1500 having at least two different distances between adjacent switchback configurations.

[0060] The present inventor has recognized, among other things, that a multi-length antenna can be configured to operate in at least two different media, and can also be operated in two different frequency ranges in the at least two different media using more than one non-switchback segments of varying length between one or more switchback.

[0061] **FIG. 15A** illustrates generally a first electrical shape and length of an implantable multi-length antenna 1500 having multi-frequency capability in a first medium. Similar to the example of **FIG. 14,** a first length L_1 1510 can define a region corresponding to a first "pitch" between adjacent switchbacks, such as between a first switchback 1522A, a second switchback 1522B, and a third switchback 1522C. Similarly, a second length L_2 1520 can define a region corresponding to a second "pitch" between adjacent switchbacks, such as between the first switchback 1522A, the second switchback 1522B, the third switchback 1522C, a fourth switchback 1522D, and a fifth switchback 1522E. In an example, at least one of the first length L_1 1510 or the second length L_2 1520 can establish a first or a second operating frequency range for the implantable multi-length antenna 1500 in the first medium.

[0062] In the example of **FIG. 15B,** the implantable multi-length antenna 1500 is surrounded in a second medium having a higher relative dielectric constant than the first medium. In an example, the switchback segments from **FIG. 15A** can capacitively couple in the second medium. In certain examples, the effective electrical length of the implantable multi-length antenna 1500 shown in **FIG. 15A** can appear, in the second medium, as the shape and length shown in **FIG. 15B**. In an example, the length of the implantable multi-length antenna 1500 in the first medium and the effective electrical length of the implantable multi-length antenna 1500 in the second medium can be used to provide communication in the first medium and in the second medium.

[0063] **FIG. 16** illustrates generally an example of a first radiation efficiency 1630 of an implantable multi-length antenna substantially surrounded by a first medium, and a second radiation efficiency 1640 of an implantable multi-length antenna substantially surrounded by a second medium. In an example, a radiation efficiency (*e.g.*, "η") can be defined as the ratio of radiated electromagnetic energy versus the energy supplied to an implantable antenna by a connected telemetry circuit.

[0064] On a vertical axis, a radiation efficiency 1610, ("η"), of the implantable multi-length antenna can be plotted versus frequency 1620. In an example, an implantable multi-length antenna can provide a first radiation efficiency peak 1635 or a second radiation efficiency peak 1645 above a specified minimum radiation efficiency 1615, ("η_{MIN}"). In certain examples, a first operating frequency range 1637 can be defined by a region where the first radiation efficiency 1635 is at or above the specified minimum radiation efficiency 1615. In other examples, a mid-band frequency 1650, f_c, can be defined approximately where the first radiation efficiency peak 1635 occurs.

[0065] Similarly, in the example of **FIG. 16**, a second radiation efficiency peak 1645 can occur at or approximately the mid-band frequency 1650. In certain examples, a second operating frequency range 1647 can be defined by a region where the second radiation efficiency 1640 is at or above the specified minimum radiation efficiency 1615.

[0066] In an example, the first radiation efficiency 1630 can correspond to an implantable multi-length antenna surrounded by a first medium, and the second radiation efficiency 1640 can correspond to an implantable multi-length antenna surrounded by a second medium having a greater relative dielectric constant than the first medium (e.g., the first medium can include free space or air, and the second medium can include a biological medium), or vice versa. The present inventor has recognized, among other things, that even if the second radiation efficiency 1640 is generally much lower than the first radiation efficiency 1630, a usable second operating frequency range 1647 above the specified minimum radiation efficiency 1615 can exist using a single physical antenna length. In certain examples, the second operating frequency range 1647, or the second radiation efficiency peak 1645 can be greater, or larger, respectively, than a corresponding single-length antenna omitting a capacitive-coupled switchback segment, where a corresponding single-length antenna substitutes a non-switchback segment for the switchback segment.

[0067] In an example, the second radiation efficiency peak 1645 can occur at a different frequency than the first radiation efficiency peak 1635 (e.g., the multi-length antenna can be physically arranged to provide the first operating frequency range 1637 in air and the second operating frequency range 1647 in a biological medium.)

[0068] In some examples, at least one of the first radiation efficiency peak 1635 or the second radiation efficiency peak 1645 can occur when a multi-length antenna is operated at or near a resonant frequency.

[0069] **FIG.17** illustrates generally a conceptualized example of a first radiation efficiency 1730 of an implantable multi-length antenna having multi-frequency capability substantially surrounded by a first medium, and a second radiation efficiency 1740 of an implantable multi-length antenna having multi-frequency capability substantially surrounded by a second medium.

[0070] In the example of **FIG. 17**, the implantable multi-length antenna can have a first frequency radiation efficiency peak 1735A in the first medium at or near a first mid-band frequency 1750A, and a second frequency radiation efficiency peak 1735B in the first medium at or near a second mid-band frequency 1750B. In an example, a first operating frequency range 1737A in the first medium can be specified by defining a region in which a first radiation efficiency 1730 is greater than or equal to a specified minimum radiation efficiency 1715. Similarly, a second operating frequency range 1737B in the first medium can be specified by defining a region at which the first radiation efficiency 1730 is greater than or equal to a specified minimum radiation efficiency 1715.

[0071] In an example, the implantable multi-length antenna can have a first frequency radiation efficiency peak 1745A in the second medium at or near a first mid-band frequency 1750A, and a second frequency radiation efficiency peak 1745B in the second medium at or near a second mid-band frequency 1750B.

[0072] In an example, a first operating frequency range 1747A in the second medium can be specified by defining a first lower frequency limit, f_{1L}, in the second medium and a first upper frequency limit, f_{1H}, in the second medium at which the first radiation efficiency 1740 is greater than or equal to the specified minimum radiation efficiency 1715. Similarly, a second operating frequency range 1747B in the second medium can be specified by defining a second lower frequency limit, f_{2L}, in the second medium and a second upper frequency limit, f_{2H}, in the second medium at which the first radiation efficiency 1740 is greater than or equal to the specified minimum radiation efficiency 1715.

[0073] In an example, when substantially surrounded by the second medium (*e.g.*, implanted in tissue), the implantable multi-length antenna can be configured to operate over the first operating frequency range 1747A of approximately f_{1L} = 375 MHz. and f_{1H} = 425 MHz, having the first mid-band frequency 1750A of approximately f_1 = 400 MHz. Further, in this example, the implantable multi-length antenna can be configured to operate over the second frequency range 1747B of approximately f_{2L} = 850 MHz. and f_2H = 900 MHz., having the second mid-band frequency 1750B of approximately f_2 = 875 MHz.

[0074] In another example, the implantable multi-length antenna can be configured to operate over the first operating frequency range 1747A of approximately f_{1L} = 900 MHz. and f_{1H} = 950 MHz., having the first mid-band frequency 1750A of approximately f_1 = 925 MHz. Further, in this example, the multi-frequency antenna can be configured to operate over the second frequency range 1747B of approximately f_{2L} = 2.4 GHz. and f_{2H} = 2.5 GHz., having the second mid-band frequency 1750B of approximately f_2 = 2.45 GHz.

[0075] In other examples, the multi-frequency antenna can be substantially surrounded by the first medium or the second medium, and can be configured to operate in at least two of:

(1) a Short Range Device (SRD) band range (*e.g.*, 862-870 MHz.);
(2) a first Industrial-Scientific-Medical (ISM) band range (*e.g.*, 902-928 MHz.);
(3) a second Industrial-Scientific-Medical (ISM) band range (*e.g.*, 2.4-2.5 GHz.);
(4) a Medical Implant Communications Service (MICS) band range (*e.g.*, 402-405 MHz.); or
(5) one or more other frequency band ranges configured for communication between an IMD and one or more other implantable or external devices.

[0076] **FIG. 18** illustrates generally an example of at least a portion of a system 1800 including a telemetry circuit 1815 electrically connected to an implantable multi-length antenna 1820. In an example, the telemetry circuit 1815 can include a telemetry transceiver 1817 coupled to a matching circuit 1816 using a first RF input/output line 1820A. In an example, the telemetry transceiver 1817 can be coupled to the matching circuit 1816 using a first RF input/output line 1820A.

[0077] In an example, the telemetry circuit 1815 can be partially or completely enclosed in an IMD housing 1810. In certain examples, the IMD housing 1810 can be made of a conductive material, such as a metal, a combination of metals, a biocompatible metal, etc. In an example, the telemetry transceiver 1817 can be coupled to the telemetry circuit 1815 using a first connection 1840A. Further, the telemetry circuit 1815 can be electrically connected to the IMD housing 1810 using a second connection 1840B. In an example, an RF current return path can be provided from the telemetry transceiver 1817 to the telemetry circuit 1815 using the first connection 1840A, and from the telemetry circuit 1815 to the IMD housing 1810 using the second connection 1840B.

[0078] In an example, the telemetry circuit 1815 can be coupled to the implantable multi-length antenna 1820 using a second RF input/output line 1820B. In certain examples, the second RF input/output line 1820B can penetrate the IMD housing 1810 to couple the telemetry circuit 1815 and the implantable multi-length antenna 1820. In other examples, at least a portion of the implantable multi-length antenna 1820 or the telemetry circuit 1815 can be contained in the IMD housing 1810, in a dielectric or other compartment coupled to the IMD housing 1810, or outside of the IMD housing 1810.

[0079] In an example, the implantable multi-length antenna can include a first switchback 1823A and a second switchback 1823B. In other examples, one or both of the first switchback 1823A or the second switchback 1823B can be omitted from the implantable multi-length antenna 1820, and a similar length non-switchback segment can be substituted. In this example, the implantable multi-length antenna 1820 can provide a capacitive load to the telemetry circuit 1815 (e.g., at the second RF input/output line 1820B looking into the implantable multi-length antenna 1820 through the feed-through 1818). In certain examples, the matching circuit 1816 (e.g., including an impedance matching element) can be included to compensate for an excess inductance or capacitance of the implantable multi-length antenna 1820. In the example of an omitted first switchback 1822A or second switchback 1822B, the impedance matching element 1816 can include a discrete inductor. In the example of **FIG. 18**, the inclusion of a first switchback 1822A or a second switchback 1822B can reduce the value of or eliminate the need for the impedance matching element 1816 within the telemetry circuit 1815.

[0080] In certain examples, a conjugate impedance match between the first RF input/output line 1820A and the implantable multi-length antenna 1820 can provide or can enhance a power transfer to the implantable multi-length antenna 1820 at a given frequency. In an example, the real portion of the input impedance of the implantable multi-length antenna 1820 can include a real value of 50 Ohms. In this example, when the first switchback 1822A or the second switchback 1822B is omitted from the implantable multi-length antenna 1820 and a similar length non-switchback segment is substituted, the implantable multi-length antenna 1820 can include an imaginary portion of an impedance of approximately -*j*20 Ohms (e.g., the implantable multi-length antenna 1820 can present a capacitive load to the telemetry circuit 1815).

[0081] In certain examples, a conjugate impedance match can be provided or otherwise configured between the telemetry circuit 1815 and the implantable multi-length antenna 1811, using, for example, the phase contribution of the first RF input/output line 1819A and the second RF input/output line 1819B, the impedance matching element 1816 can provide an inductive contribution to the output impedance of the telemetry transceiver 1817 of approximately +*j20* Ohms to approximately cancel out the capacitance of the implantable multi-length antenna 1820.

[0082] In another example, at least one of the first switchback 1822A or the second switchback 1822B can compensate for the capacitance of the implantable multi-length antenna 1820 to provide an approximately real input impedance (e.g., without an imaginary component) looking into the implantable multi-length antenna 1820 at the feed-through 1818. In this example, the impedance matching element 1816 can be omitted, or can be replaced with a purely resistive matching element (e.g., a substantially resistive mismatch can exist between the implantable multi-length antenna 1820 and an output impedance of the telemetry transceiver 1817).

[0083] In an example, when the implantable multi-length antenna 1820 is operated at multiple frequencies, the matching element 1816 can be used to provide an enhanced conjugate match at a first operating frequency range, and the impedance matching contribution from the first switchback 1822A or the second switchback 1822B can be minimal in the first operating frequency range. Similarly, in an example, an impedance matching contribution from the matching element 1816 can be minimal in a second operating frequency range, and the impedance matching contribution from the first switchback 1822A or the second switchback 1822B can be used to provide an enhanced conjugate match (e.g., if the matching element 1816 is operated at its unity-power factor self-resonant frequency, it can appear as a resistive element rather than as a capacitor or an inductor).

[0084] In one example, when the implantable multi-length antenna 1820 is operated at multiple frequencies, the matching element 1816 can be controllably switched out of the transmit and receive path between the first RF input/output line 1819A and the second RF input/output line 1819B. In certain examples, one or more values for the matching element 1816 can be selected to provide an approximate conjugate match at more than one specified range of operating frequencies, or in more than one medium surrounding the implantable multi-length antenna 1820.

[0085] In certain examples, the implantable telemetry circuit 1815 can be configured as a transmitter, a receiver, or both. Generally, the principles described in connection with bi-directional wireless information transfer between an implantable antenna and another wireless device can also apply to uni-directional wireless information transfer. According to a physical principal of reciprocity, antenna behavior can be generally reciprocal (e.g., an antenna physically arranged as a transmitting antenna can also act as a receiving antenna having similar characteristics).

[0086] **FIG. 19** illustrates generally an example of a process 1900 including, at 1905, wirelessly transferring information electromagnetically at a first operating frequency range in a first medium and wirelessly transferring information electromagnetically at a second operating frequency range in a second medium.

[0087] In an example, the first medium (e.g., free space, air, or one or more other mediums having a relative dielectric constant approximately equal to 1) can be different than the second medium (e.g., a biological medium, bodily fluid, skin tissue, fat tissue, muscle tissue, organ tissue, bone, or one or more other biological mediums). In an example, the first operating frequency range can be substantially equal to or the same as the second operating frequency range.

[0088] In other examples, the implantable multi-length antenna can be configured to appear electrically as a first length ("the first electrical length") in the first medium and to appear electrically as a second length ("the second electrical length") in the second medium. In an example, the first electrical length can include a length different than the second electrical length. In certain examples, the first operating frequency range can be dependent at least in part upon (e.g., tuned or otherwise configured using) the first electrical length, and the second operating frequency range can be dependent at least in part upon (e.g., tuned or otherwise configured using) the second electrical length.

[0089] **FIG. 20** illustrates generally an example of a Smith Chart illustrating a relationship between an effective impedance of an antenna and a relative permittivity of a medium. In an example, a first impedance 1901 at a first frequency (F_0) in a first medium having a first relative permittivity (E_{r1}) can be plotted against a second impedance 1902 at the first frequency (F_0) in a second medium having a second relative permittivity (E_{r2}). In certain examples, as long as the impedance of the antenna in the first medium and the second, different, medium has the same impedance, one matching network (or compensation network) can be used to maximize radiation in the first medium and in the second medium, such as at a point of common impedance (e.g., as illustrated in **FIG. 20**).

Claims

1. A system (100) comprising:

an implantable telemetry circuit (115) for implant within a human or animal body;
an implantable multi-length antenna (120) for implant within a human or animal body, the implantable multi-length antenna electrically connected to the implantable telemetry circuit and configured to wirelessly transfer information electromagnetically at a specified first operating frequency range in a first medium and at a specified second operating frequency range in a different second medium wherein the first medium has a first relative dielectric constant and the second medium has a different second relative dielectric constant;, the implantable multi-length antenna including:

a first non-switchback segment (522B);
a first switchback (523A), electrically connected to the first non-switchback segment, the first switchback comprising first and second switchback segments (519A, 519B), wherein the first and second switchback segment are connected using a transition segment (521);
a second non-switchback (823A) segment electrically connected to the first switchback;
wherein the implantable multi-length antenna is configured to appear electrically as a first electrical length in the first medium and as a different second electrical length in the second medium;
wherein the second electrical length in the second medium is less than a physical length of the antenna due at least in part to a capacitive coupling of the first switchback segment and the second switchback segment in the second medium; and
wherein the first operating frequency range is specified by the first electrical length and the second operating frequency range is specified by the second electrical length.

2. The system of claim 1, wherein the first operating frequency range is substantially equal to the second operating frequency range.

3. The system of any of claims 1 through 2, wherein at least one of the first switchback segment or the second switchback segment comprise an arc shaped segment having a constant radius from a specified position.

4. The system of any of claims 1 through 3, wherein the first non-switchback segment is positioned approximately parallel to a first axis;
wherein the first and second switchback segments comprising the first switchback are approximately parallel to a second axis; and
wherein the second non-switchback segment is approximately parallel to the first axis.

5. The system of claim 4, wherein the second axis is substantially perpendicular to the first axis; and
wherein the implantable multi-length antenna includes a second switchback electrically connected to the second non-switchback segment, wherein the first switchback is positioned in a plane defined by the first axis and the second axis, wherein the second switchback is positioned in a plane defined by the first axis and a third axis, and wherein the third axis is substantially perpendicular to the first axis and different than the second axis.

6. The system of any of claims 1 through [[5]] 4, wherein the implantable multi-length antenna includes:

a second switchback electrically connected to the second non-switchback segment, the second switchback located a first distance from the first switchback;
a third non-switchback segment electrically connected to the second switchback, the third non-switchback segment approximately parallel to the first axis; and
a third switchback electrically connected to the third non-switchback segment, the third switchback located a different second distance from the second switchback.

7. The system of claim 6, wherein the implantable multi-length antenna is configured to wirelessly transfer information electromagnetically at a specified third operating frequency range in the first medium and at a specified fourth operating frequency range in the second medium;
wherein the third operating frequency range is different than the first operating frequency range and the fourth operating frequency range is different than the second operating frequency range;
wherein the first operating frequency range and the second operating frequency range are specified using the first distance between the first switchback; and
wherein the third operating frequency range and the

fourth operating frequency range are specified using the second distance between the second switchback and the third switchback.

8. A method comprising:

wirelessly transferring information electromagnetically at a specified first operating frequency range in a first medium and a specified second operating frequency range in a different second medium using an implantable telemetry circuit coupled to an implantable multi-length antenna, wherein the implantable telemetry circuit and the implantable multi-length antenna are for implant within a human or animal body;
wherein the implantable multi-length antenna is configured to appear electrically as a first electrical length in the first medium and as a different second electrical length in the second medium, the implantable multi-length antenna including:

a first non-switchback segment;
a first switchback, electrically connected to the first non-switchback segment, the first switchback comprising first and second switchback segments, wherein the first and second switchback segment are connected using a transition segment;
a second non-switchback segment electrically connected to the first switchback;
wherein the first medium has a first relative dielectric constant and the second medium has a different second relative dielectric constant;
wherein the second electrical length in the second medium is less than a physical length of the antenna due at least in part to a capacitive coupling of the first switchback segment and the second switchback segment in the second medium; and
wherein the first operating frequency range is specified using the first electrical length and the second operating frequency range is specified using the second electrical length.

9. The method of claim 8, wherein the first operating frequency range is substantially equal to the second operating frequency range.

10. The method of any of claims 8 through 9, wherein the first non-switchback segment is positioned approximately parallel to a first axis;
wherein the first and second switchback segments comprising the first switchback are approximately parallel to a second axis; and
wherein the second non-switchback segment is approximately parallel to the first axis.

Patentansprüche

1. System (100), welches aufweist:

eine implantierbare Telemetrieschaltung (115) zur Implantierung innerhalb eines menschlichen oder tierischen Körpers;
eine implantierbare Mehrlängenantenne (120) zur Implantierung innerhalb eines menschlichen oder tierischen Körpers, wobei die implantierbare Mehrlängenantenne elektrisch mit der implantierbaren Telemetrieschaltung verbunden und ausgebildet ist zur elektromagnetischen Funkübertragung in einem bestimmten ersten Operationsfrequenzbereich in einem ersten Medium und in einem bestimmten zweiten Operationsfrequenzbereich in einem unterschiedlichen zweiten Medium, wobei das erste Medium eine erste relative dielektrische Konstante hat und das zweite Medium eine unterschiedliche zweite relative dielektrische Konstante hat; welche implantierbare Mehrlängenantenne enthält:

ein erstes mäanderfreies Segment (522B);
einen ersten Mäanderteil (523A), der elektrisch mit dem ersten mäanderfreien Segment verbunden ist, wobei der erste Mäanderteil ein erstes und ein zweites Mäandersegment (519A, 519B) aufweist und das erste und das zweite Mäandersegment durch Verwendung eines Übergangssegments (521) verbunden sind;
ein zweites mäanderfreies Segment (823A), das elektrisch mit dem ersten Mäanderteil verbunden ist;
wobei die implantierbare Mehrlängenantenne so ausgebildet ist, dass sie elektrisch als eine erste elektrische Länge in dem ersten Medium und als eine unterschiedliche zweite elektrische Länge in dem zweiten Medium erscheint;
wobei die zweite elektrische Länge in dem zweiten Medium kürzer als eine physische Länge der Antenne ist aufgrund zumindest teilweise einer kapazitiven Kopplung des ersten Mäandersegments und des zweiten Mäandersegments in dem zweiten Medium; und
wobei der erste Operationsfrequenzbereich durch die erste elektrische Länge und der zweite Operationsfrequenzbereich durch die zweite elektrische Länge spezifiziert sind.

2. System nach Anspruch 1, bei dem der erste Operationsfrequenzbereich im Wesentlichen gleich dem zweiten Operationsfrequenzbereich ist.

3. System nach einem der Ansprüche 1 oder 2, bei dem zumindest eines von dem ersten Mäandersegment oder dem zweiten Mäandersegment ein bogenförmiges Segment mit einem konstanten Radius von einer bestimmten Position aus aufweist.

4. System nach einem der Ansprüche 1 bis 3, bei dem das erste mäanderfreie Segment angenähert parallel zu einer ersten Achse positioniert ist;
bei dem das erste und das zweite Mäandersegment, die den ersten Mäanderteil aufweisen, angenähert parallel zu einer zweiten Achse sind; und
bei dem das zweite mäanderfreie Segment angenähert parallel zu der ersten Achse ist.

5. System nach Anspruch 4, bei dem die zweite Achse im Wesentlichen senkrecht zu der ersten Achse ist; und
bei dem die implantierbare Mehrlängenantenne einen zweiten Mäanderteil enthält, der elektrisch mit dem zweiten mäanderfreien Segment verbunden ist, wobei der erste Mäanderteil in einer Ebene positioniert ist, die durch die erste Achse und die zweite Achse definiert ist, bei der der zweite Mäanderteil in einer Ebene positioniert ist, die durch die erste Achse und eine dritte Achse definiert ist, und bei der die dritte Achse im Wesentlichen senkrecht zu der ersten Achse und verschieden von der zweiten Achse ist.

6. System nach einem der Ansprüche 1 bis 4, bei dem die implantierbare Mehrlängenantenne enthält:

> einen zweiten Mäanderteil, der elektrisch mit dem zweiten mäanderfreien Segment verbunden ist, wobei sich der zweite Mäanderteil in einem ersten Abstand von dem ersten Mäanderteil befindet;
> ein drittes mäanderfreies Segment, das elektrisch mit dem zweiten Mäanderteil verbunden ist, wobei das dritte mäanderfreie Segment angenähert parallel zu der ersten Achse ist; und
> einen dritten Mäanderteil, der elektrisch mit dem dritten mäanderfreien Segment verbunden ist, wobei sich der dritte Mäanderteil in einem unterschiedlichen zweiten Abstand von dem zweiten Mäanderteil befindet.

7. System nach Anspruch 6, bei dem die implantierbare Mehrlängenantenne ausgebildet ist zur elektromagnetischen Funkübertragung von Informationen in einem bestimmten dritten Operationsfrequenzbereich in dem ersten Medium und in einem bestimmten vierten Operationsfrequenzbereich in dem zweiten Medium;
wobei der dritte Operationsfrequenzbereich verschieden von dem ersten Operationsfrequenzbereich ist und der vierte Operationsfrequenzbereich verschieden von dem zweiten Operationsfrequenzbereich ist;
wobei der erste Operationsfrequenzbereich und der zweite Operationsfrequenzbereich unter Verwendung des ersten Abstands zwischen dem ersten Mäanderteil bestimmt sind; und
bei dem der dritte Operationsfrequenzbereich und der vierte Operationsfrequenzbereich unter Verwendung des zweiten Abstands zwischen dem zweiten Mäanderteil und dem dritten Mäanderteil spezifiziert sind.

8. Verfahren, welches aufweist:

> elektrisches Funkübertragen von Informationen in einem bestimmten ersten Operationsfrequenzbereich in einem ersten Medium und einem bestimmten Operationsfrequenzbereich in einem unterschiedlichen zweiten Medium unter Verwendung einer implantierbaren Telemetrieschaltung, die mit einer implantierbaren Mehrlängenantenne gekoppelt ist, wobei die implantierbare Telemetrieschaltung und die implantierbare Mehrlängenantenne zur Implantierung innerhalb eines menschlichen oder tierischen Körpers dienen;
> wobei die implantierbare Mehrlängenantenne ausgebildet ist, elektrisch als eine erste elektrische Länge in dem ersten Medium und als eine unterschiedliche zweite elektrische Länge in dem zweiten Medium zu erscheinen, welche implantierbare Mehrlängenantenne enthält:
>
>> ein erstes mäanderfreies Segment;
>> einen ersten Mäanderteil, der elektrisch mit dem ersten mäanderfreien Segment verbunden ist, welcher erste Mäanderteil ein erstes und ein zweites Mäandersegment aufweist, wobei das erste und das zweite Mäandersegment unter Verwendung eines Übergangssegments verbunden sind;
>> ein zweites mäanderfreies Segment, das elektrisch mit dem ersten Mäanderteil verbunden ist;
>> wobei das erste Medium eine erste relative dielektrische Konstante hat und das zweite Medium eine unterschiedliche zweite relative dielektrische Konstante hat;
>> wobei die zweite elektrische Länge in dem zweiten Medium kürzer als eine physische Länge der Antenne ist aufgrund zumindest teilweise einer kapazitiven Kopplung des ersten Mäandersegments und des zweiten Mäandersegments in dem zweiten Medium; und
>> wobei der erste Operationsfrequenzbereich unter Verwendung der ersten elektrischen Länge bestimmt wird und der zweite Ope-

rationsfrequenzbereich unter Verwendung der zweiten elektrischen Länge bestimmt wird.

9. Verfahren nach Anspruch 8, bei dem der erste Operationsfrequenzbereich im Wesentlichen gleich dem zweiten Operationsfrequenzbereich ist.

10. Verfahren nach einem der Ansprüche 8 oder 9, bei dem das erste mäanderfreie Segment angenähert parallel zu einer ersten Achse positioniert ist;
wobei das erste und das zweite Mäandersegment, die den ersten Mäanderteil aufweisen, angenähert parallel zu einer zweiten Achse sind; und
wobei das zweite mäanderfreie Segment angenähert parallel zu der ersten Achse ist.

Revendications

1. Système (100) comprenant :

un circuit de télémétrie implantable (115) destiné à être implanté à l'intérieur du corps d'un être humain ou d'un animal ;
une antenne à multiples longueurs implantable (120) destinée à être implantée à l'intérieur du corps d'un être humain ou d'un animal, l'antenne à multiples longueurs implantable étant connectée électriquement au circuit de télémétrie implantable et étant configurée de manière à transférer sans fil une information électromagnétiquement selon une première plage de fréquences de fonctionnement spécifiée dans un premier milieu et selon une seconde plage de fréquences de fonctionnement spécifiée dans un second milieu différent, dans lequel le premier milieu présente une première constante diélectrique relative et le second milieu présente une seconde constante diélectrique relative différente, l'antenne à multiples longueurs implantable incluant :

un premier segment de non retour (522B) ;
un premier retour (523A), connecté électriquement au premier segment de non retour, le premier retour comprenant des premier et second segments de retour (519A, 519B), dans lequel les premier et second segments de retour sont connectés en utilisant un segment de transition (521) ;
un second segment de non retour (823A) connecté électriquement au premier retour, dans lequel
l'antenne à multiples longueurs implantable est configurée de manière à apparaître électriquement en tant que première longueur électrique dans le premier milieu et en tant que seconde longueur électrique différente dans le second milieu, dans lequel la seconde longueur électrique dans le second milieu est inférieure à une longueur physique de l'antenne du fait au moins en partie d'un couplage capacitif du premier segment de retour et du second segment de retour dans le second milieu ; et dans lequel
la première plage de fréquences de fonctionnement est spécifiée par la première longueur électrique et la seconde plage de fréquences de fonctionnement est spécifiée par la seconde longueur électrique.

2. Système selon la revendication 1, dans lequel la première plage de fréquences de fonctionnement est sensiblement égale à la seconde plage de fréquences de fonctionnement.

3. Système selon l'une quelconque des revendications 1 et 2, dans lequel au moins l'un des premier et second segments de retour comprend un segment en forme d'arc présentant un rayon constant par rapport à une position spécifiée.

4. Système selon l'une quelconque des revendications 1 à 3, dans lequel le premier segment de non retour est positionné approximativement parallèlement à un premier axe, dans lequel :

les premier et second segments de retour constituant le premier retour sont approximativement parallèles à un second axe ; et dans lequel
le second segment de non retour est approximativement parallèle au premier axe.

5. Système selon la revendication 4, dans lequel le second axe est sensiblement perpendiculaire au premier axe ; et dans lequel :

l'antenne à multiples longueurs implantable inclut un second retour connecté électriquement au second segment de non retour, dans lequel le premier retour est positionné dans un plan défini par le premier axe et le second axe, dans lequel le second retour est positionné dans un plan défini par le premier axe et un troisième axe et dans lequel le troisième axe est sensiblement perpendiculaire au premier axe et différent du second axe.

6. Système selon l'une quelconque des revendications 1 à 4, dans lequel l'antenne à multiples longueurs implantable inclut :

un second retour connecté électriquement au second segment de non retour, le second retour

étant situé à une première distance du premier retour ;
un troisième segment de non retour connecté électriquement au second retour, le troisième segment de non retour étant approximativement parallèle au premier axe ; et
un troisième retour connecté électriquement au troisième segment de non retour, le troisième retour étant situé à une seconde distance différente du second retour.

7. Système selon la revendication 6, dans lequel l'antenne à multiples longueurs implantable est configurée de manière à transférer sans fil une information électromagnétiquement selon une troisième plage de fréquences de fonctionnement spécifiée dans le premier milieu et selon une quatrième plage de fréquences de fonctionnement spécifiée dans le second milieu, dans lequel :

la troisième plage de fréquences de fonctionnement est différente de la première plage de fréquences de fonctionnement et la quatrième plage de fréquences de fonctionnement est différente de la seconde plage de fréquences de fonctionnement, dans lequel
la première plage de fréquences de fonctionnement et la seconde plage de fréquences de fonctionnement sont spécifiées en utilisant la première distance entre le premier retour et le second retour ; et dans lequel
la troisième plage de fréquences de fonctionnement et la quatrième plage de fréquences de fonctionnement sont spécifiées en utilisant la seconde distance entre le second retour et le troisième retour.

8. Procédé comprenant :

le transfert sans fil d'une information électromagnétiquement selon une première plage de fréquences de fonctionnement spécifiée dans un premier milieu et selon une seconde plage de fréquences de fonctionnement spécifiée dans un second milieu différent en utilisant un circuit de télémétrie implantable couplé à une antenne à multiples longueurs implantable, dans lequel le circuit de télémétrie implantable et l'antenne à multiples longueurs implantable sont destinés à être implantés à l'intérieur du corps d'un être humain ou d'un animal, dans lequel :

l'antenne à multiples longueurs implantable est configurée de manière à apparaître électriquement en tant que première longueur électrique dans le premier milieu et en tant que seconde longueur électrique différente dans le second milieu, l'antenne à multiples longueurs implantable incluant :
un premier segment de non retour ;
un premier retour, connecté électriquement au premier segment de non retour, le premier retour comprenant des premier et second segments de retour, dans lequel les premier et second segments de retour sont connectés en utilisant un segment de transition ;
un second segment de non retour connecté électriquement au premier retour, dans lequel
le premier milieu présente une première constante diélectrique relative et le second milieu présente une seconde constante diélectrique différente, dans lequel
la seconde longueur électrique dans le second milieu est inférieure à une longueur physique de l'antenne du fait au moins en partie d'un couplage capacitif du premier segment de retour et du second segment de retour dans le second milieu ; et dans lequel
la première plage de fréquences de fonctionnement est spécifiée en utilisant la première longueur électrique et la seconde plage de fréquences de fonctionnement est spécifiée en utilisant la seconde longueur électrique.

9. Procédé selon la revendication 8, dans lequel la première plage de fréquences de fonctionnement est sensiblement égale à la seconde plage de fréquences de fonctionnement.

10. Procédé selon l'une quelconque des revendications 8 et 9, dans lequel le premier segment de non retour est positionné approximativement parallèlement au premier axe, dans lequel :

les premier et second segments de retour constituant le premier retour sont approximativement parallèles à un second axe ; et dans lequel
le second segment de non retour est approximativement parallèle au premier axe.

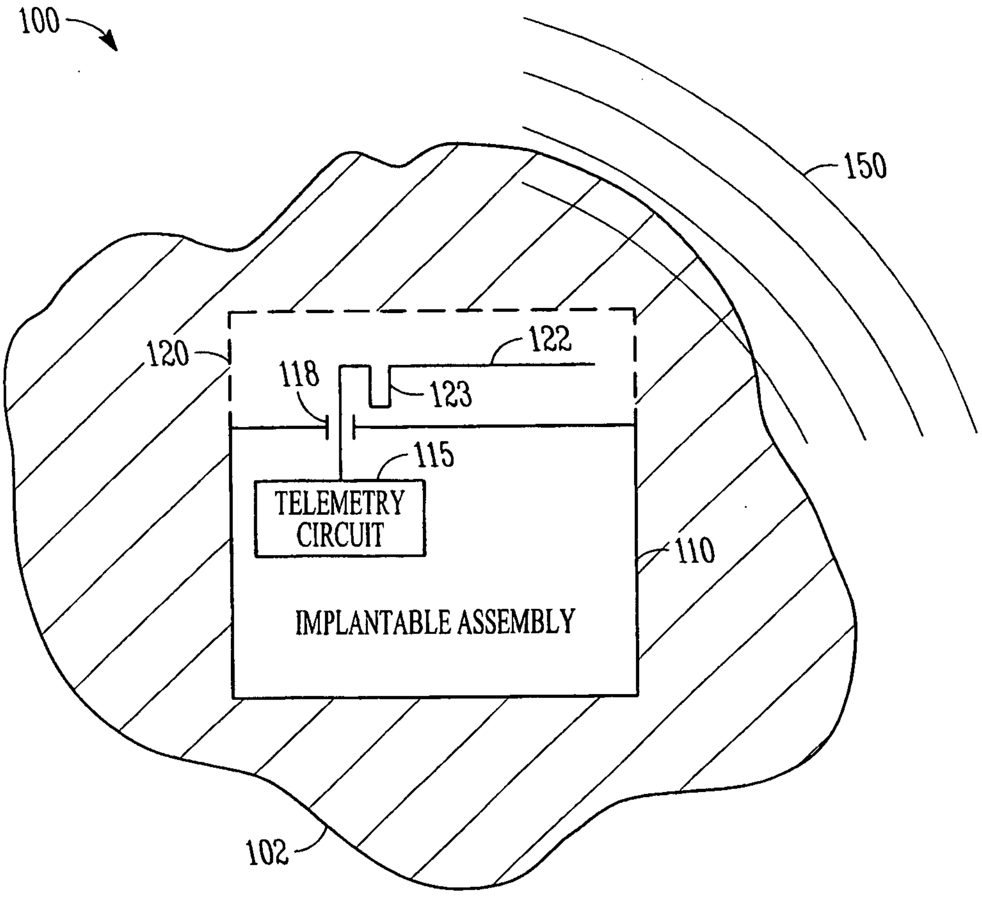
100
150
120
122
118
123
115
TELEMETRY CIRCUIT
110
IMPLANTABLE ASSEMBLY
102

FIG. 1

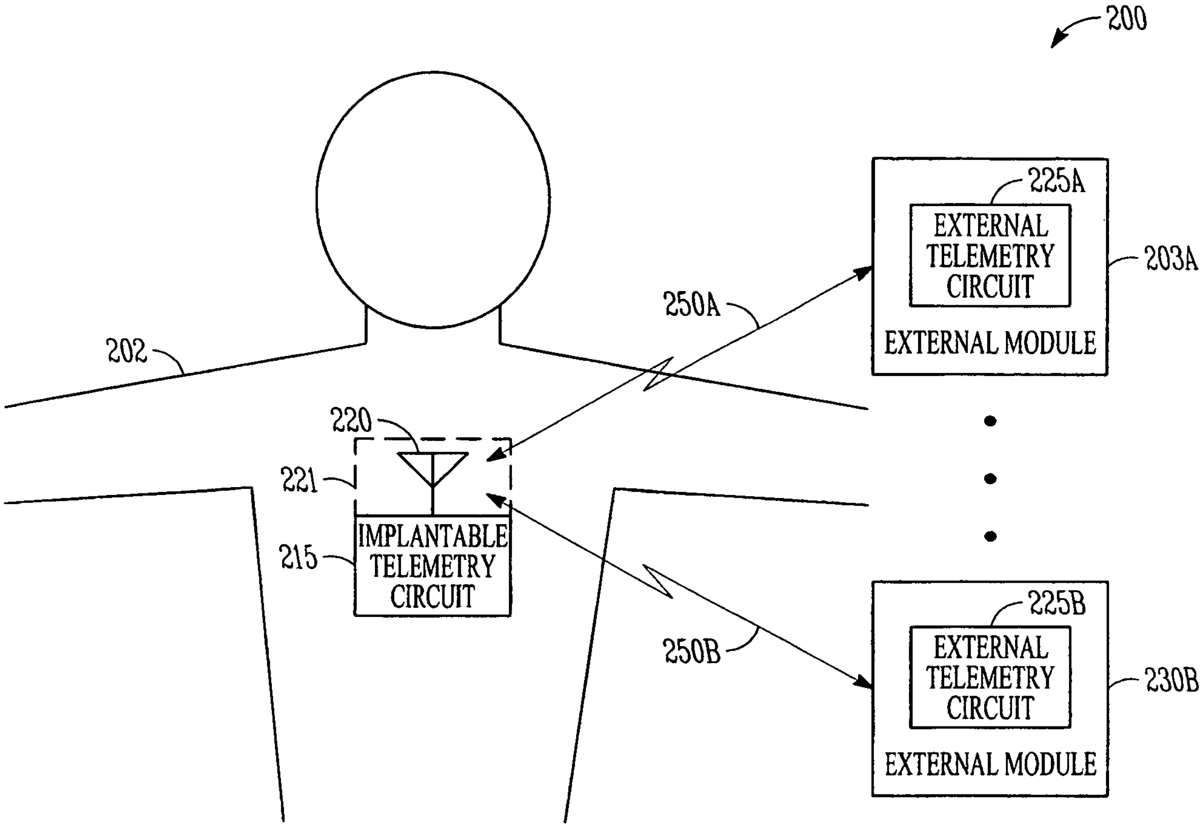
200
202
220
221
215
IMPLANTABLE TELEMETRY CIRCUIT
250A
250B
225A
EXTERNAL TELEMETRY CIRCUIT
203A
EXTERNAL MODULE
225B
EXTERNAL TELEMETRY CIRCUIT
230B
EXTERNAL MODULE

FIG. 2

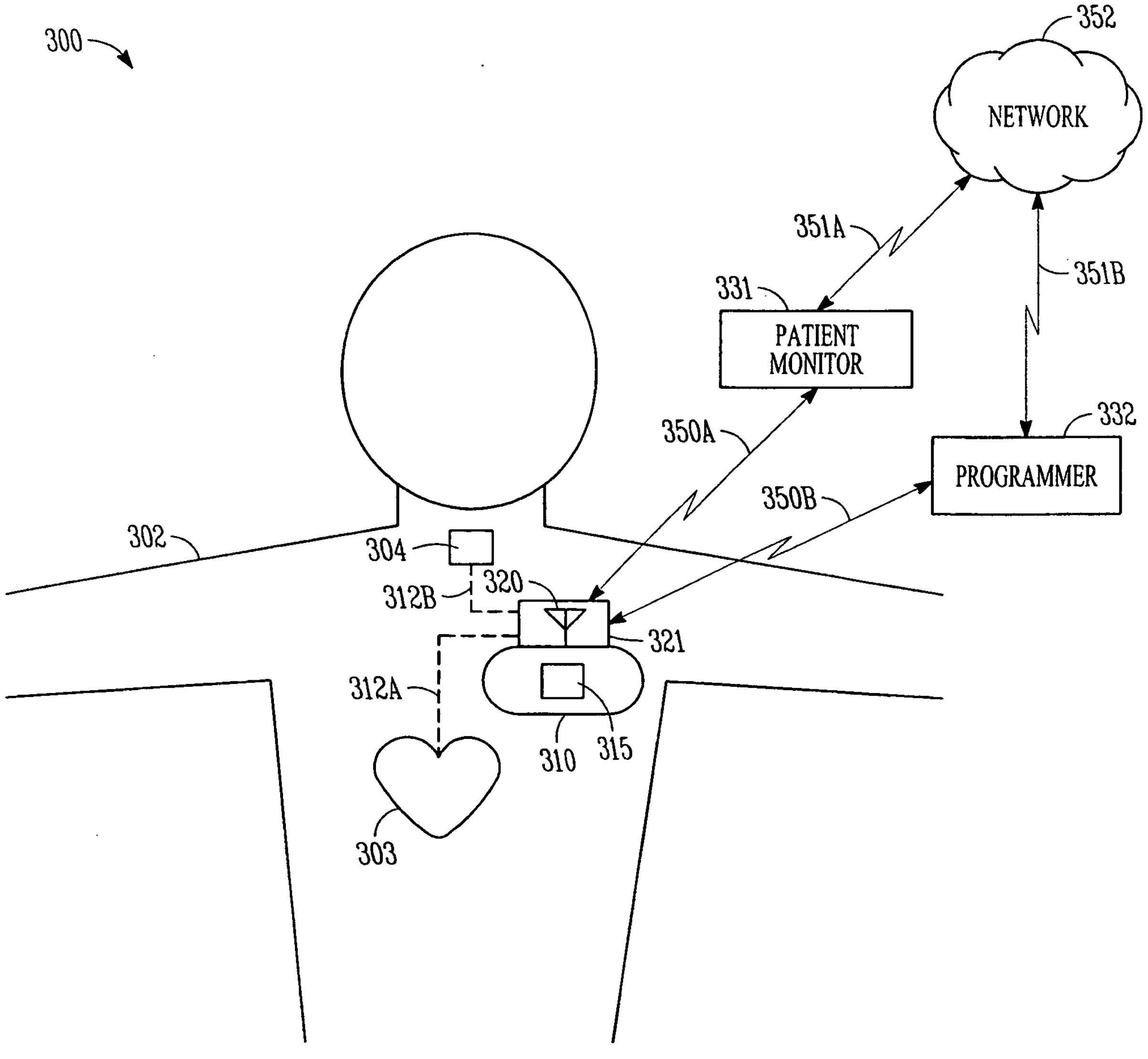
300
352
NETWORK
351A
351B
331
PATIENT MONITOR
350A
332
PROGRAMMER
350B
302
304
320
312B
321
312A
310
315
303

FIG. 3

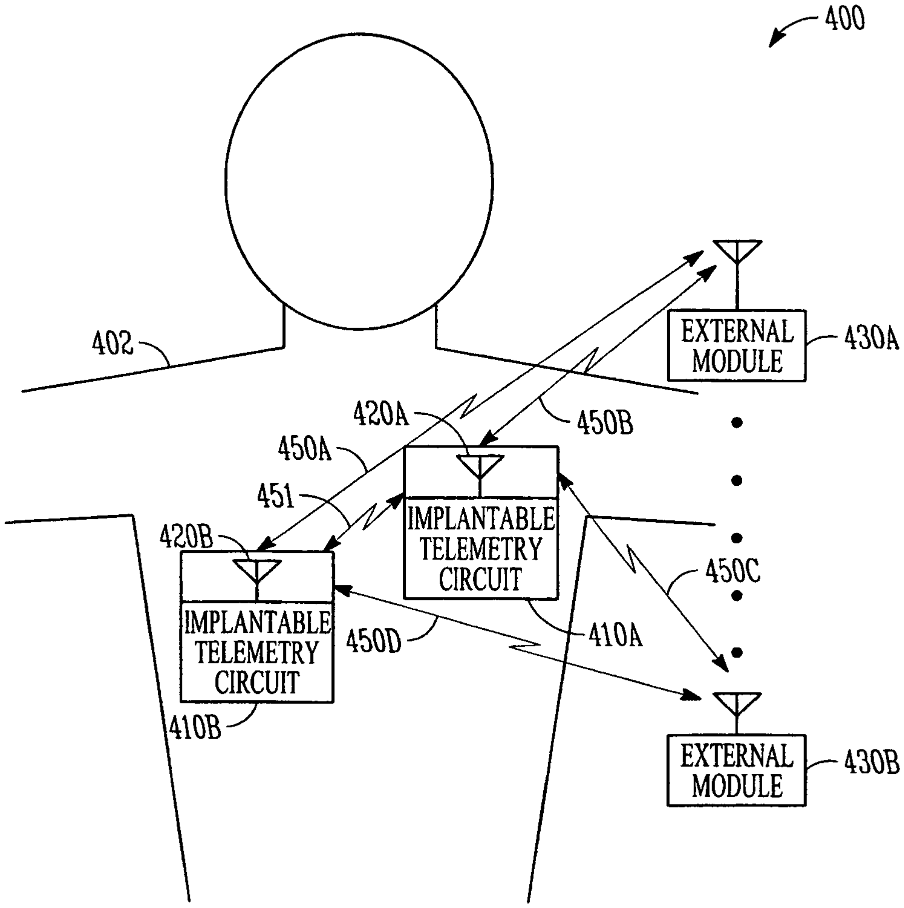
400
402
EXTERNAL MODULE
430A
420A
450B
450A
451
420B
IMPLANTABLE TELEMETRY CIRCUIT
IMPLANTABLE TELEMETRY CIRCUIT
450C
450D
410A
410B
EXTERNAL MODULE
430B

FIG. 4

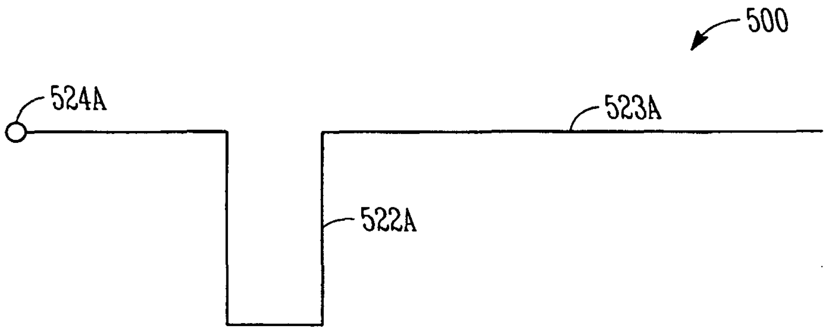

FIG. 5A

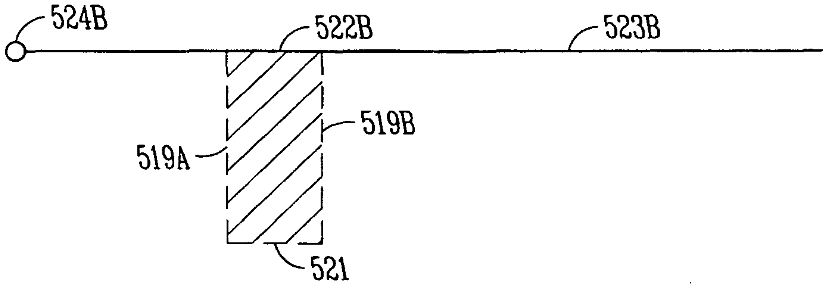

FIG. 5B

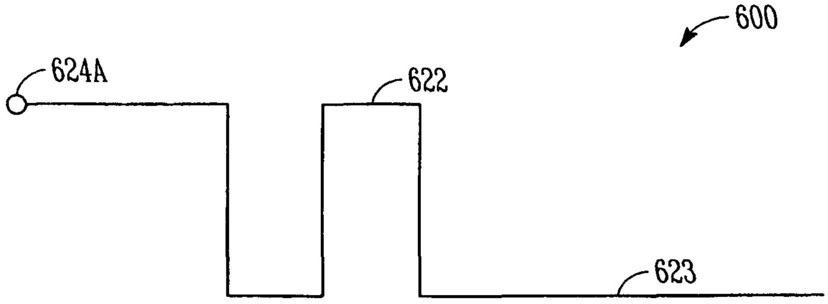

FIG. 6A

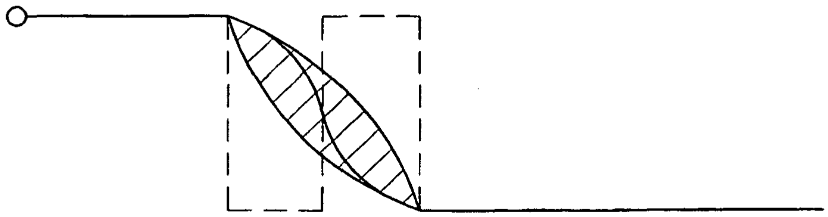

FIG. 6B

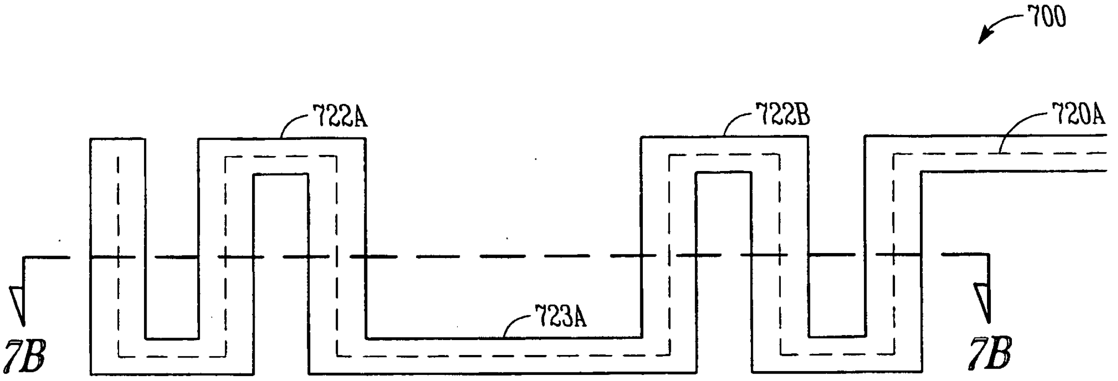

FIG. 7A

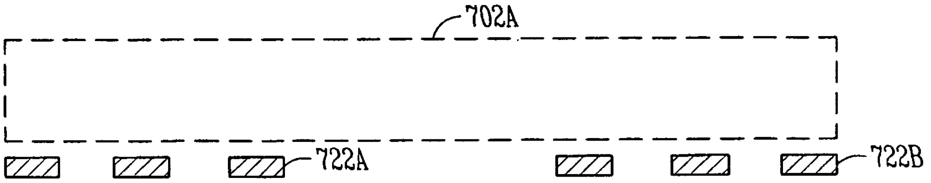

FIG. 7B

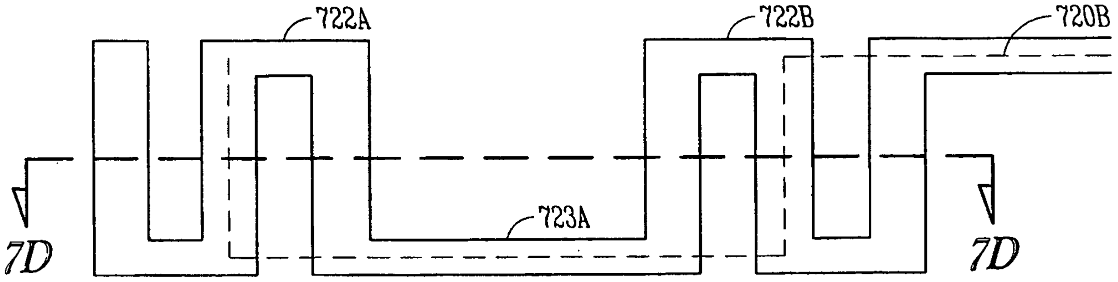

FIG. 7C

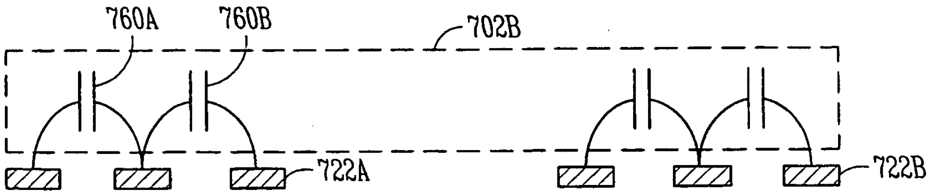

FIG. 7D

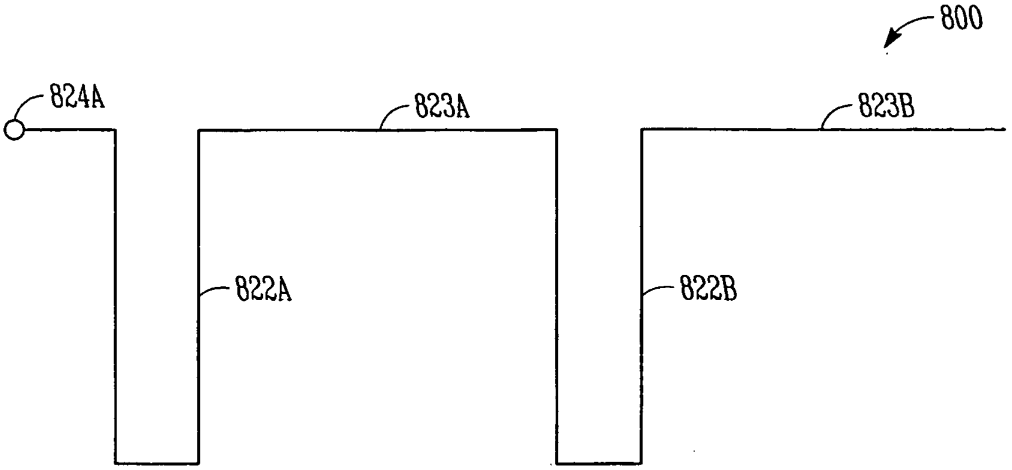

FIG. 8A

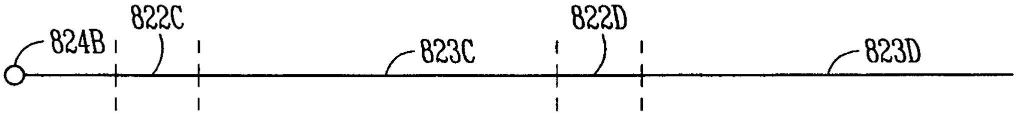

FIG. 8B

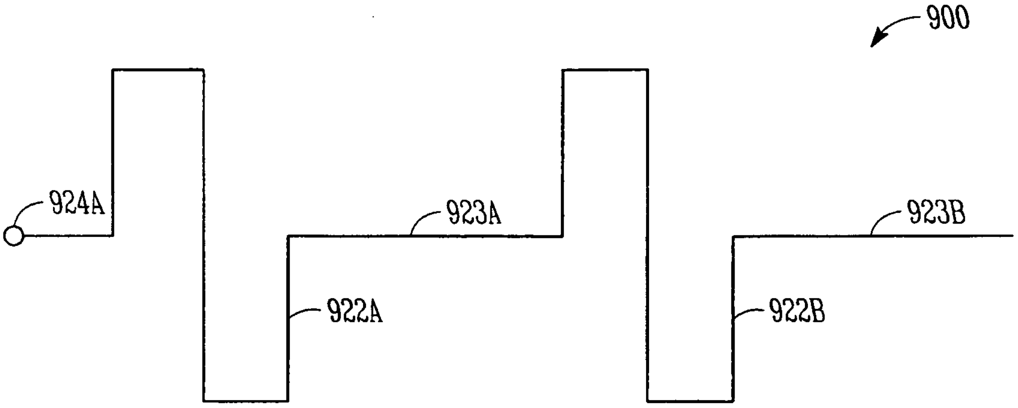

FIG. 9A

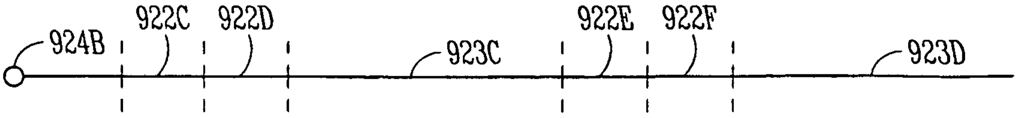

FIG. 9B

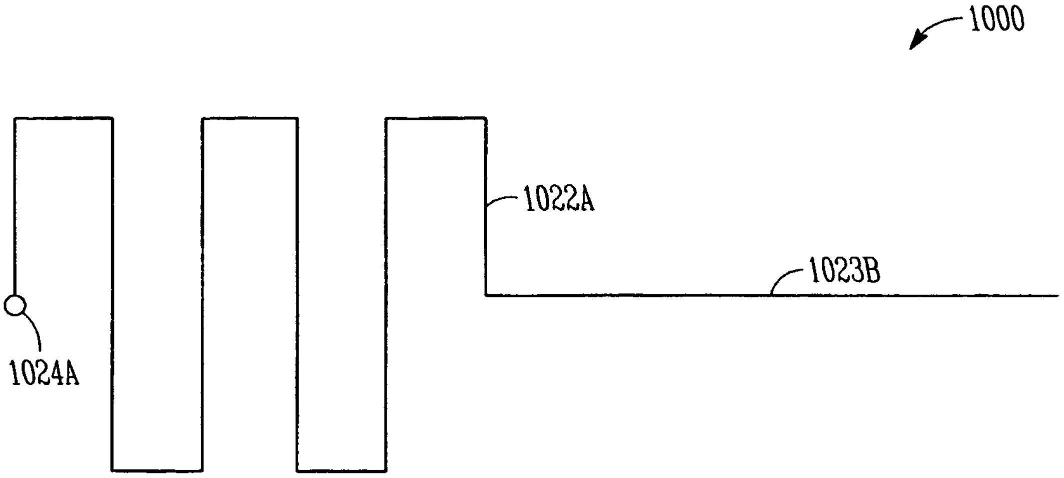

FIG. 10A

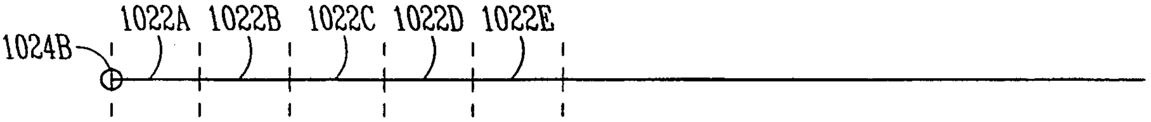

FIG. 10B

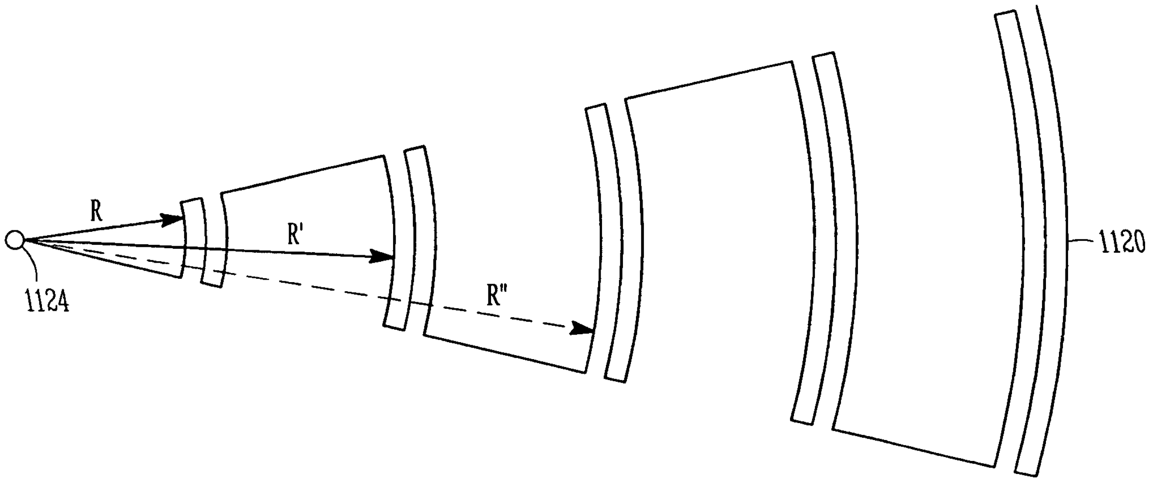

FIG. 11

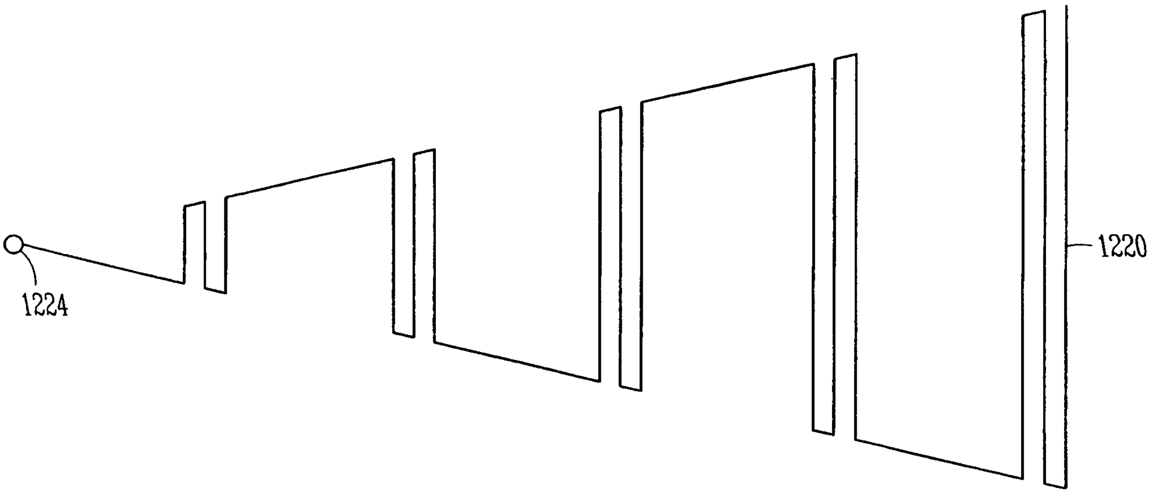

FIG. 12

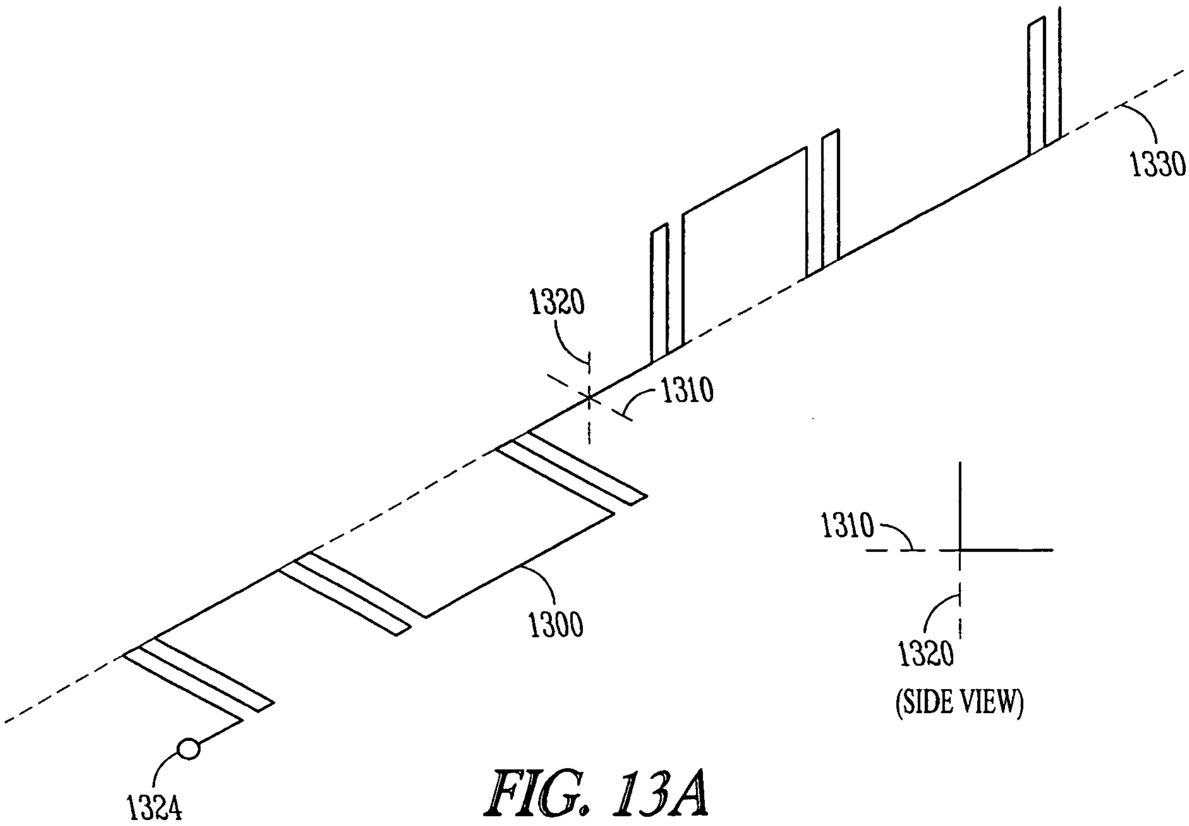

FIG. 13A

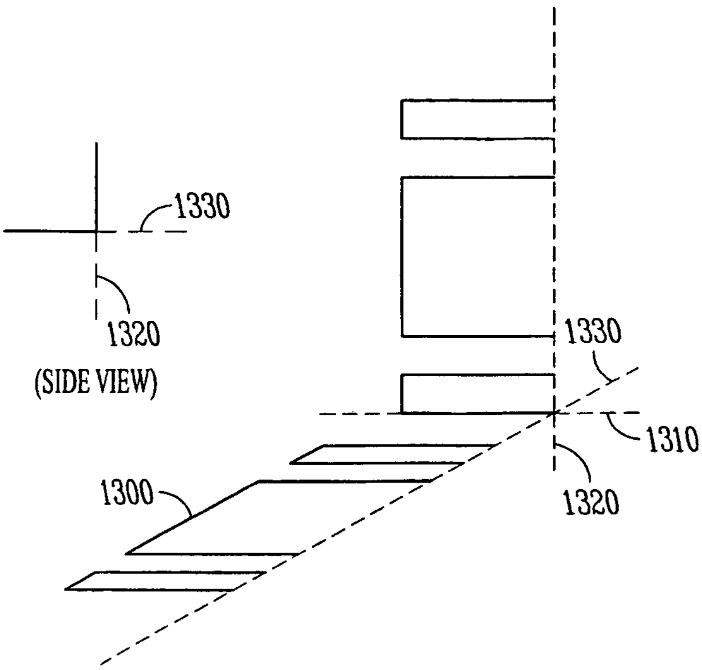

FIG. 13B

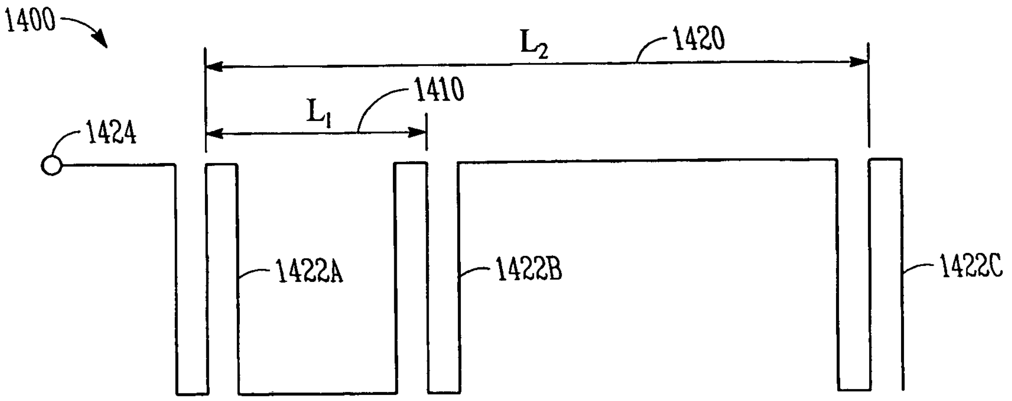

FIG. 14

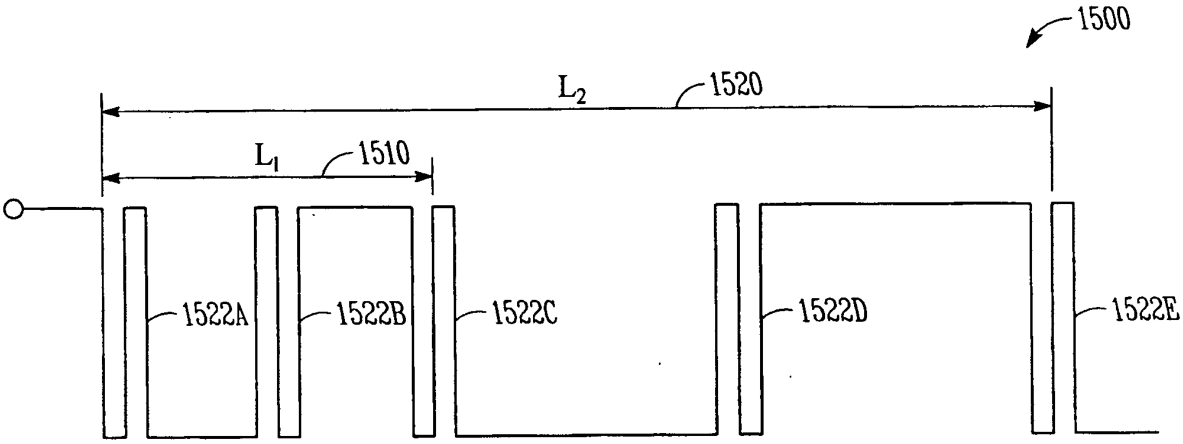

FIG. 15A

FIG. 15B

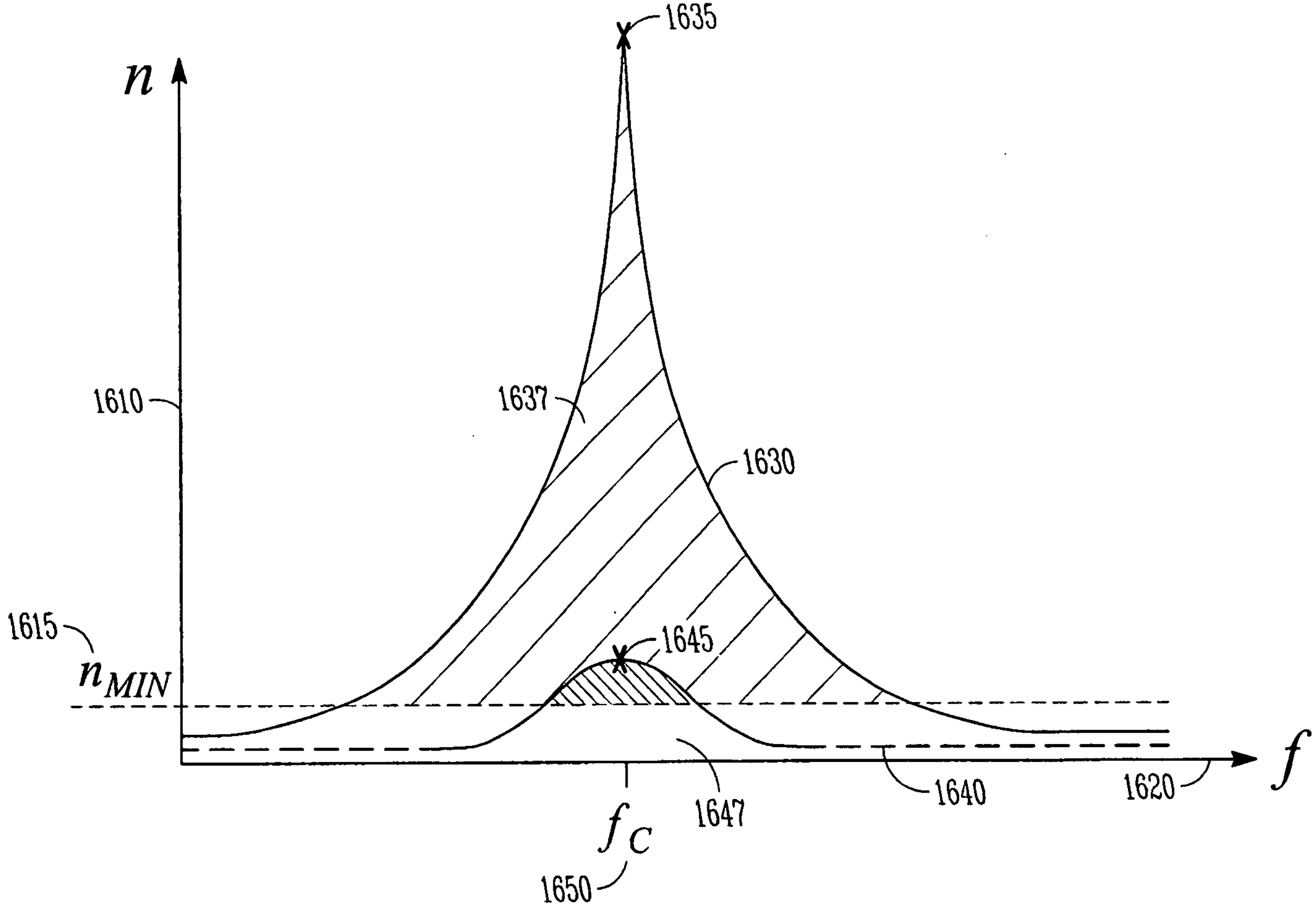

FIG. 16

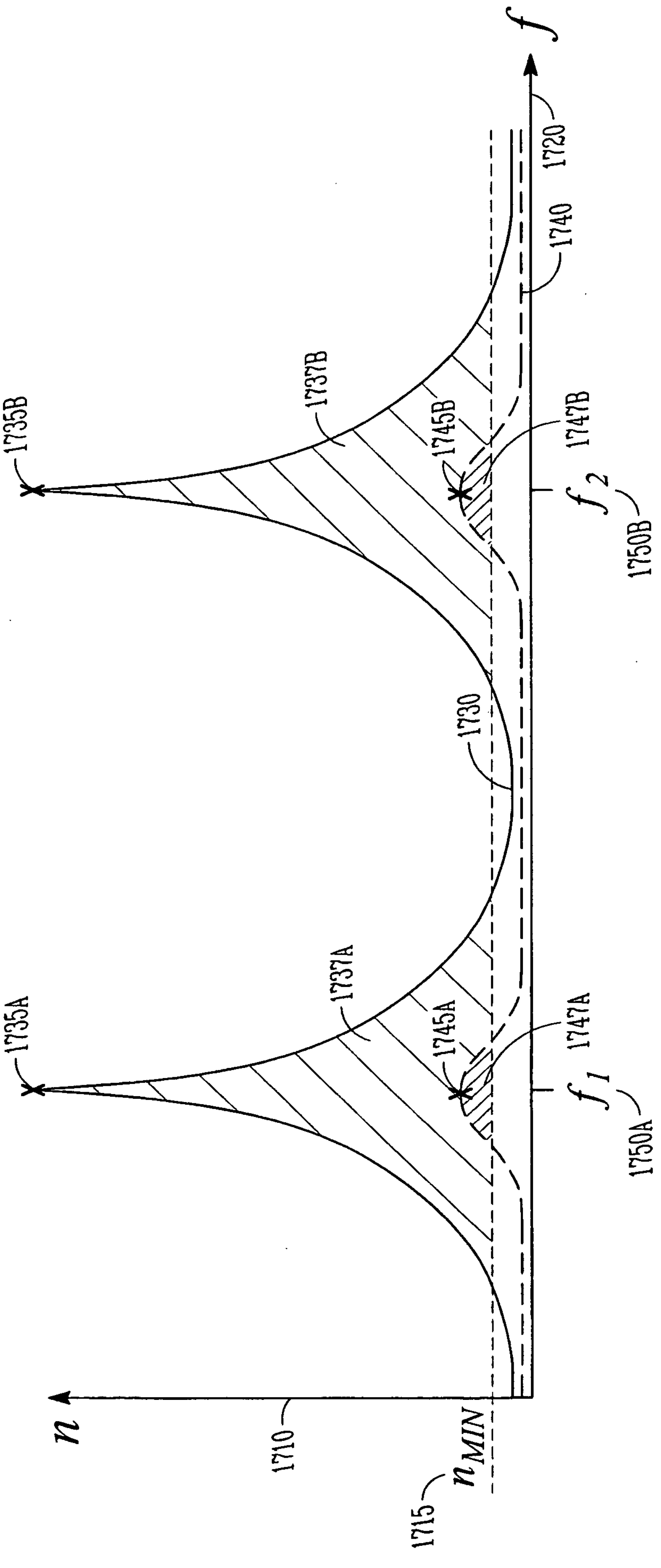
n
1710
n_{MIN}
1715
1735A
1737A
1745A
1747A
f_1
1750A
1730
1735B
1737B
1745B
1747B
f_2
1750B
1740
1720
f

FIG. 17

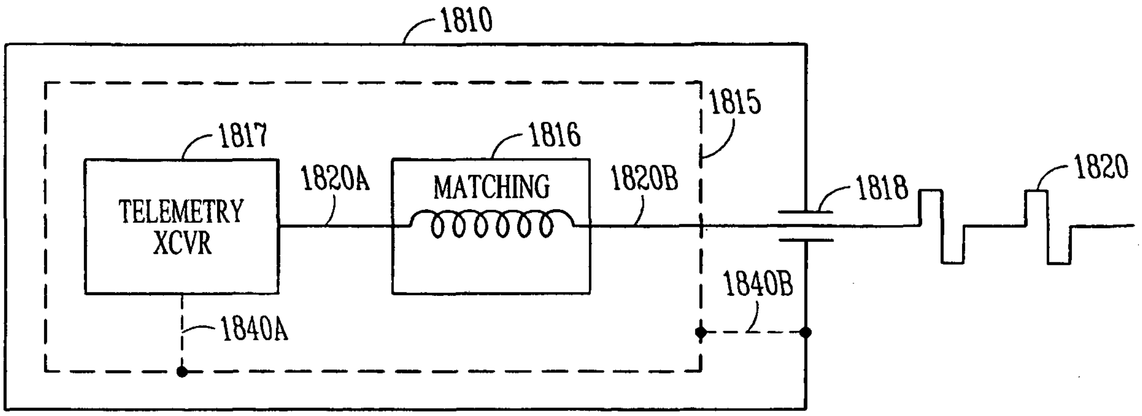

FIG. 18

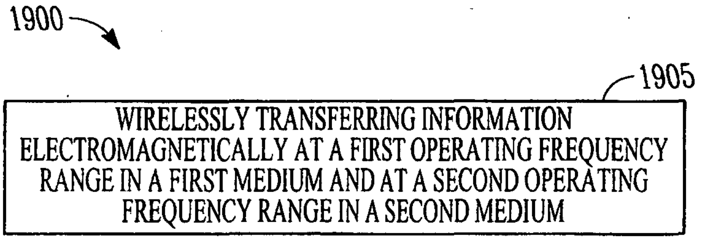

FIG. 19

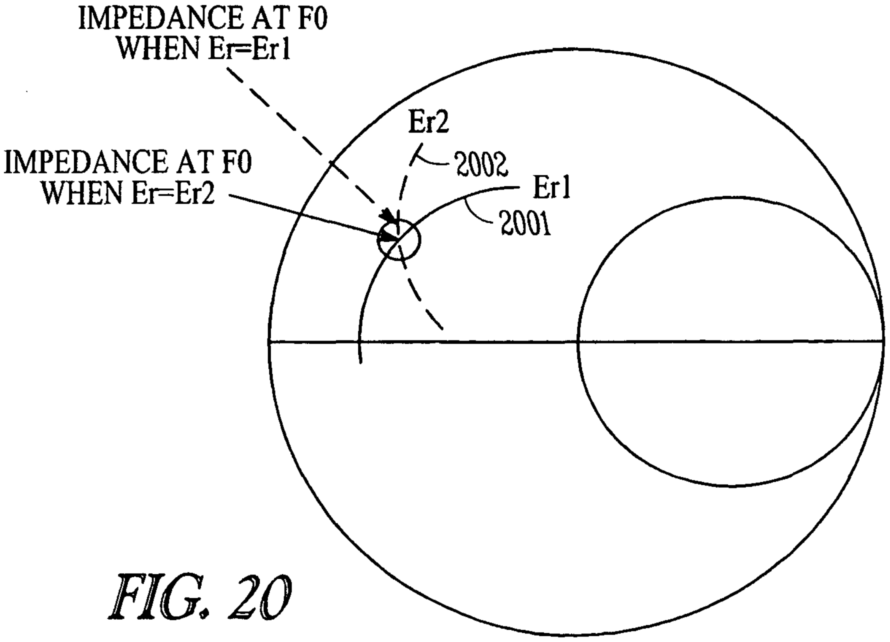

FIG. 20

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 61033535 A **[0001]**
- US 61087476 A **[0002]**
- US 2005203583 A1 **[0006]**

专利名称(译)	可植入的多长度RF天线		
公开(公告)号	EP2266164B1	公开(公告)日	2014-05-28
申请号	EP2009716210	申请日	2009-03-03
[标]申请(专利权)人(译)	心脏起搏器股份公司		
申请(专利权)人(译)	心脏起搏器，INC.		
当前申请(专利权)人(译)	心脏起搏器，INC.		
[标]发明人	AMERI MASOUD		
发明人	AMERI, MASOUD		
IPC分类号	H01Q1/27 H01Q1/36 H01Q1/40 H01Q5/00 A61B5/00 A61N1/372 H01Q5/10 H01Q5/321		
CPC分类号	A61B5/0031 A61N1/37229 H01Q1/273 H01Q1/36 H01Q1/40 H01Q5/321		
优先权	61/033535 2008-03-04 US 61/087476 2008-08-08 US		
其他公开文献	EP2266164A1		
外部链接	Espacenet		

摘要(译)

该文件尤其讨论了使用可植入多长度天线（120）在第二介质中在第一介质和指定第二工作频率范围内以指定的第一工作频率范围电磁地无线传输信息的系统和方法。 。在某些示例中，可植入多长度天线（120）可以被配置为在第一介质中作为第一电长度电出现并且在第二介质中作为不同的第二电长度出现。在某些示例中，可以使用第一电长度指定第一操作频率范围，并且可以使用第二电长度指定第二操作频率范围。

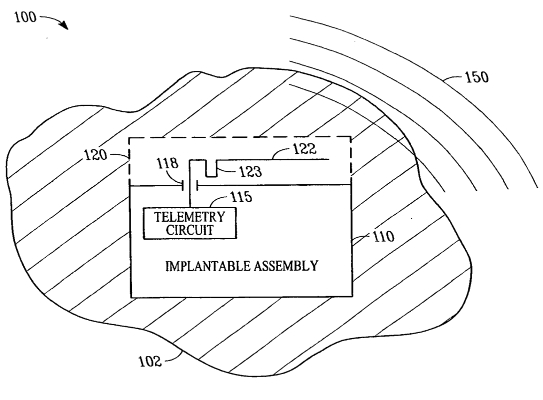

FIG. 1