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Hagen et al.

(54) **IMPLANTABLE ELECTRODE ASSEMBLY HAVING REVERSE ELECTRODE CONFIGURATION**

(75) Inventors: **Jeffrey J. Hagen**, Plymouth, MN (US); **Mary L. Cole**, St. Paul, MN (US); **Martin A. Rossing**, Coon Rapids, MN (US)

Correspondence Address:
TOWNSEND AND TOWNSEND AND CREW, LLP
TWO EMBARCADERO CENTER, EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

(73) Assignee: **CVRx, Inc.**, Minneapolis, MN (US)

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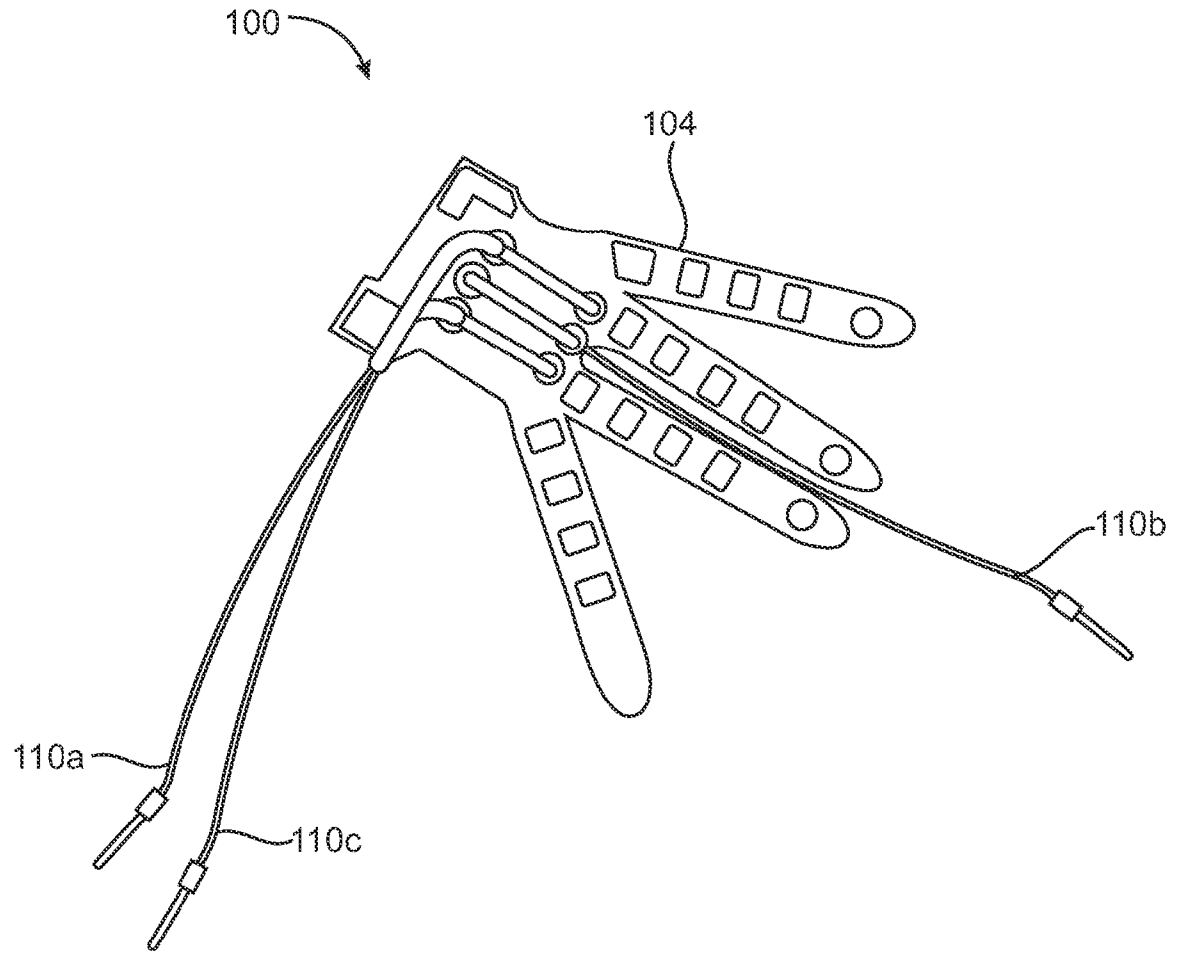
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(57) **ABSTRACT**

Methods and apparatus for generating an electric field inside a patient include at least a first electrode and a second electrode on a common implantable substrate. Each of the electrodes has a respective proximal end and a respective distal end. Electrical energy can be applied that causes electrical current to flow simultaneously through the first and second electrodes preferentially from the proximal end of one electrode to the distal end of the other electrode.



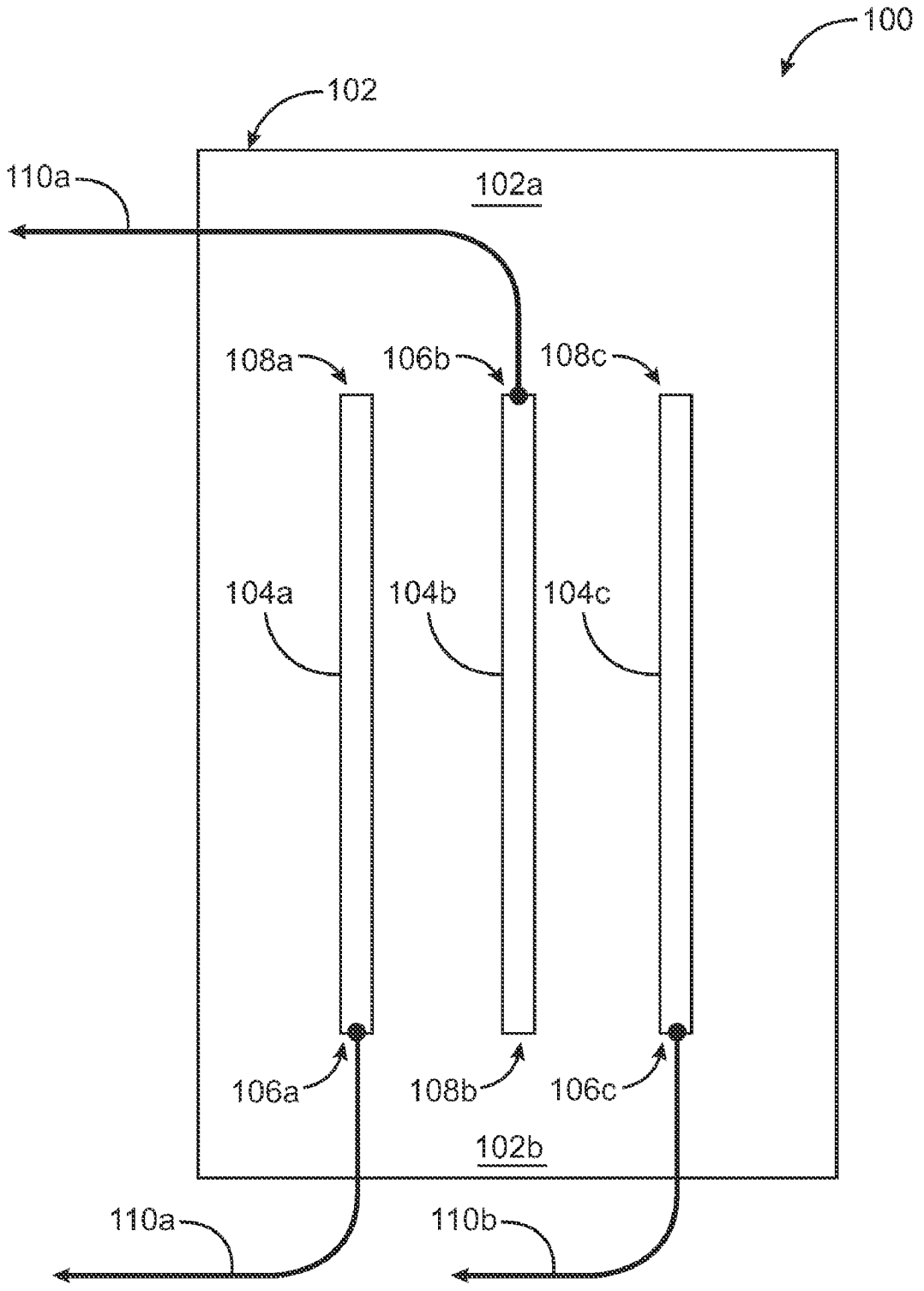

100
102
110a
102a
108a
106b
108c
104a
104b
104c
106a
108b
106c
102b
110a
110b

FIG. 1A

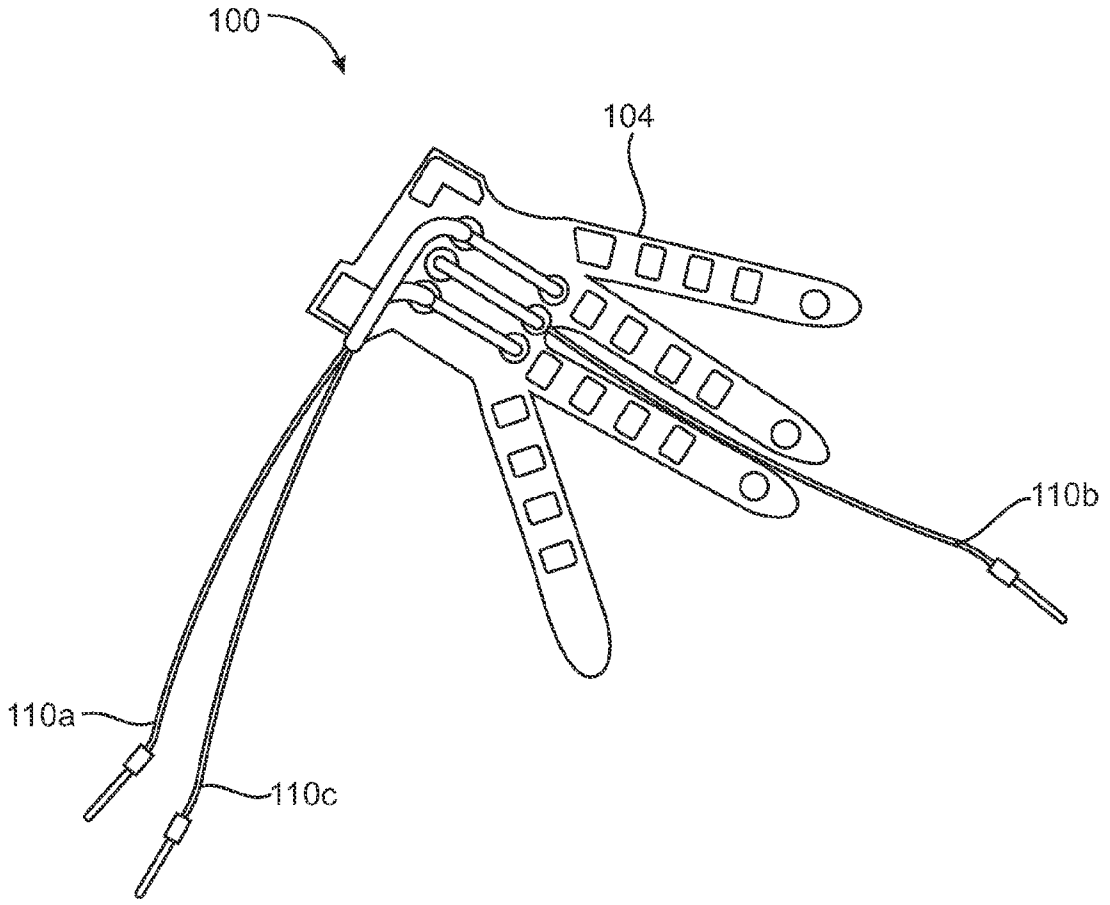


FIG. 1B

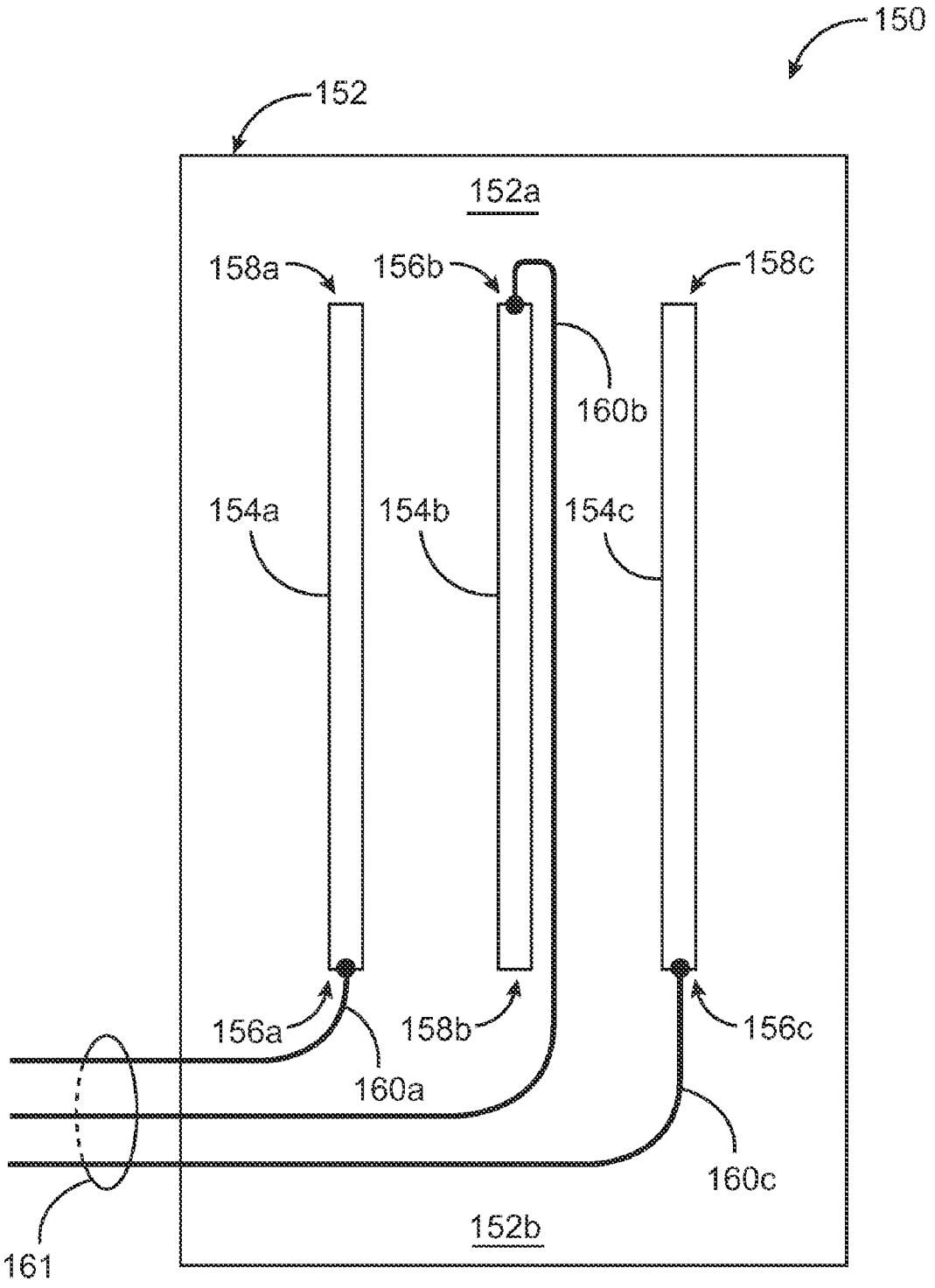

150
152
152a
158a
156b
158c
160b
154a
154b
154c
156a
158b
156c
160a
160c
152b
161

FIG. 1C

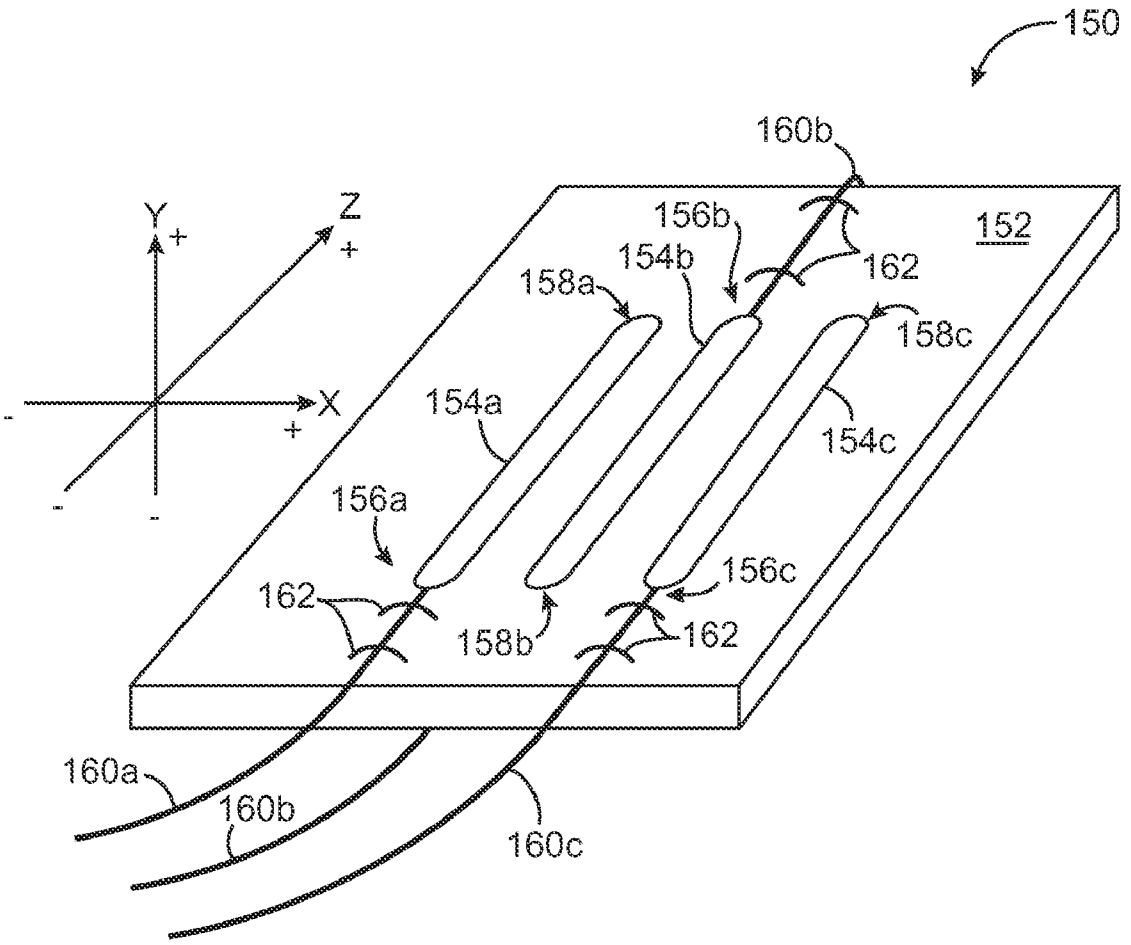

150
160b
Y
+
Z
+
156b
152
154b
158a
162
158c
X
+
154a
154c
156a
156c
162
158b
162
160a
160b
160c

FIG. 1D

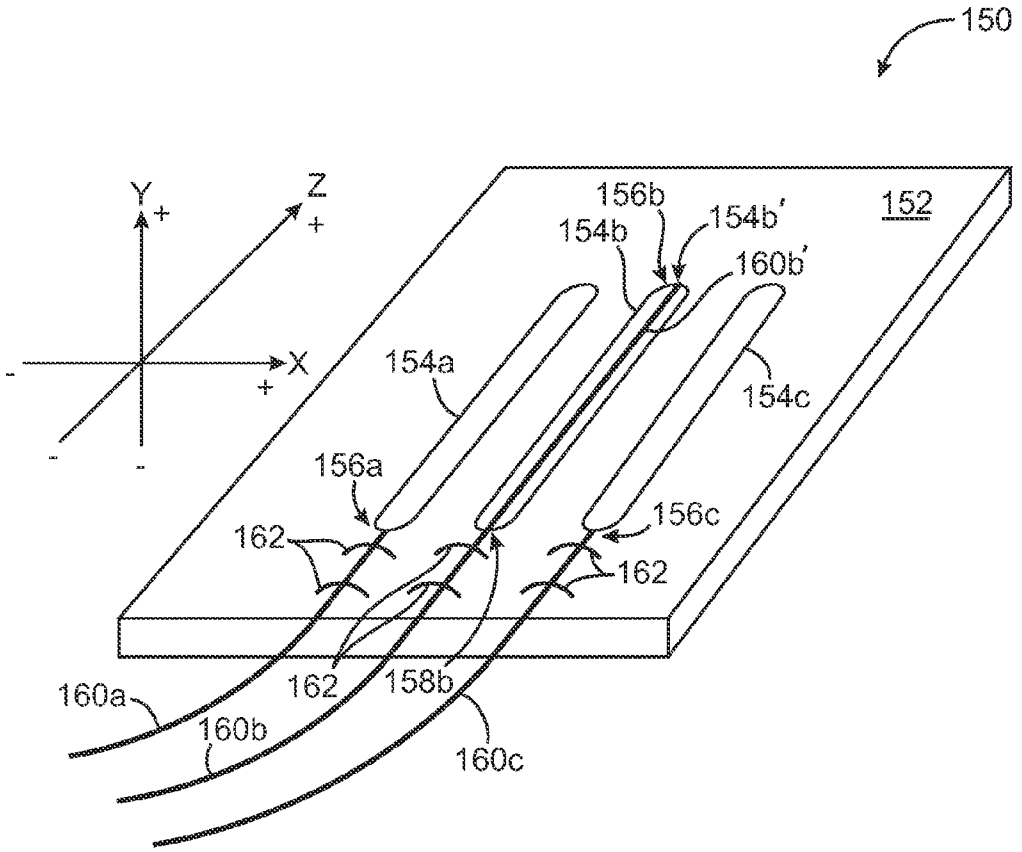

150
Y
+
Z
+
X
+
-
-
-
152
156b
154b'
154b
160b'
154a
154c
156a
156c
162
162
162
158b
160a
160b
160c

FIG. 1E

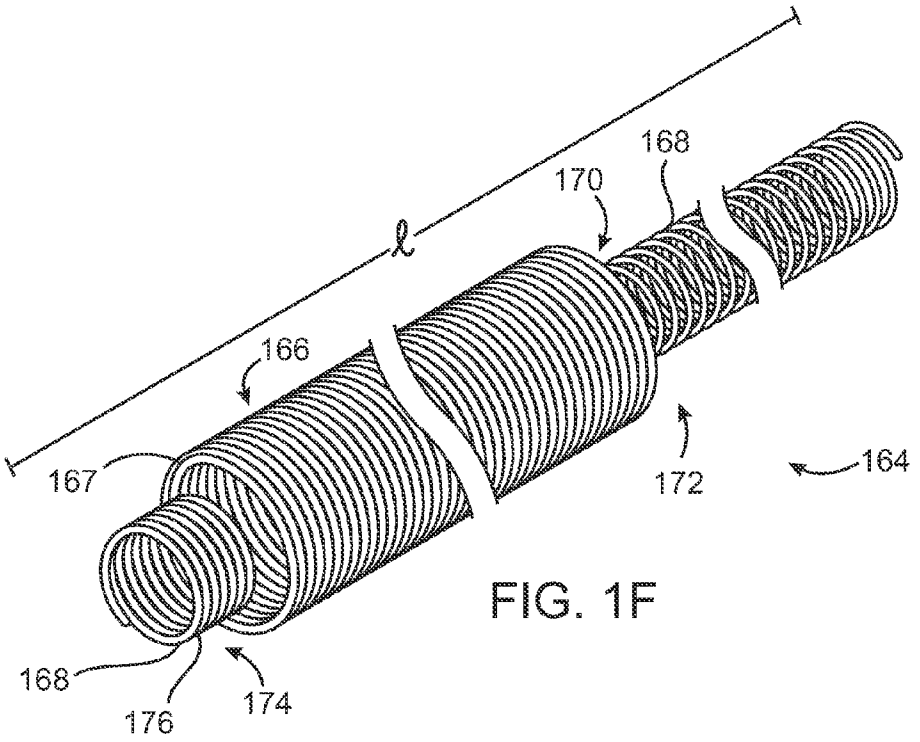


FIG. 1F

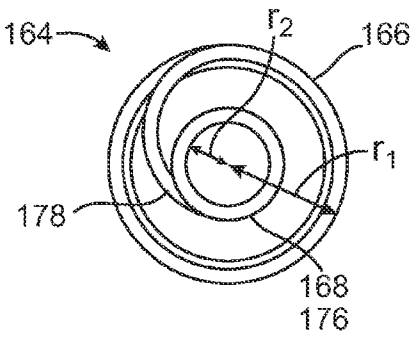


FIG. 1G

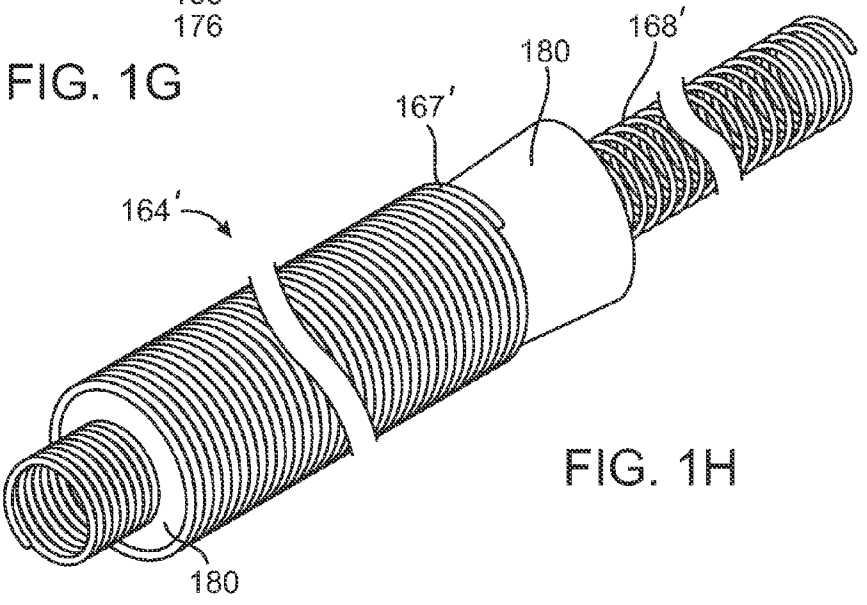


FIG. 1H

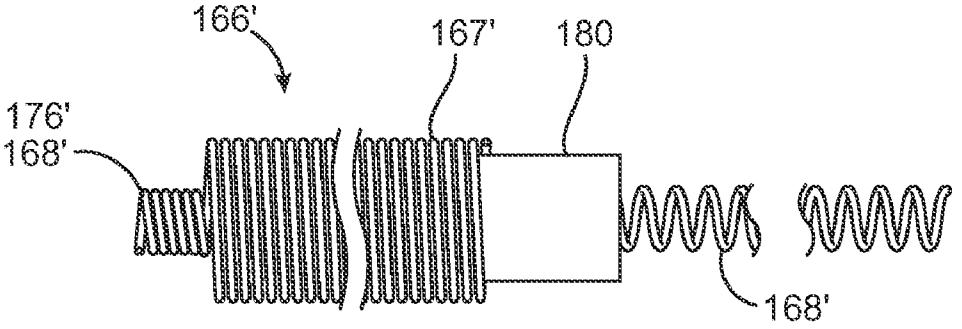


FIG. 1I

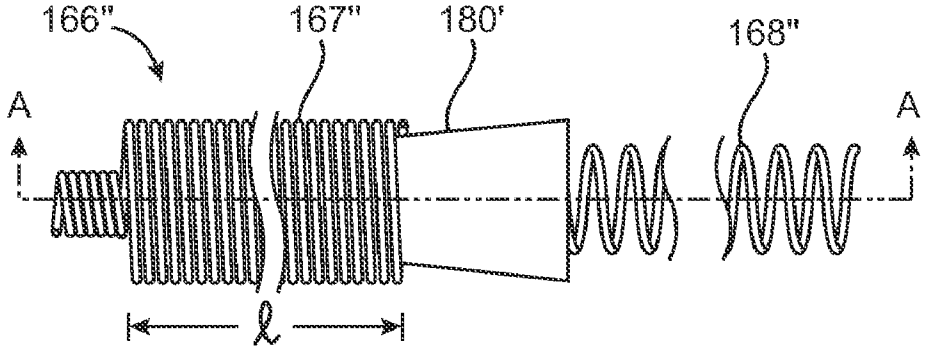


FIG. 1J

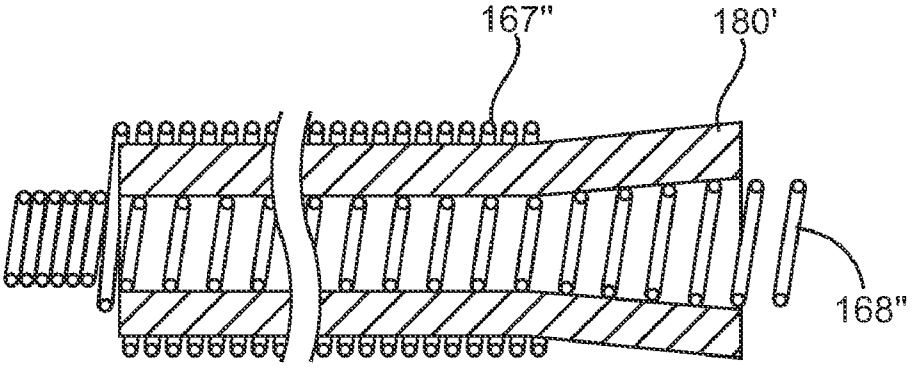


FIG. 1K

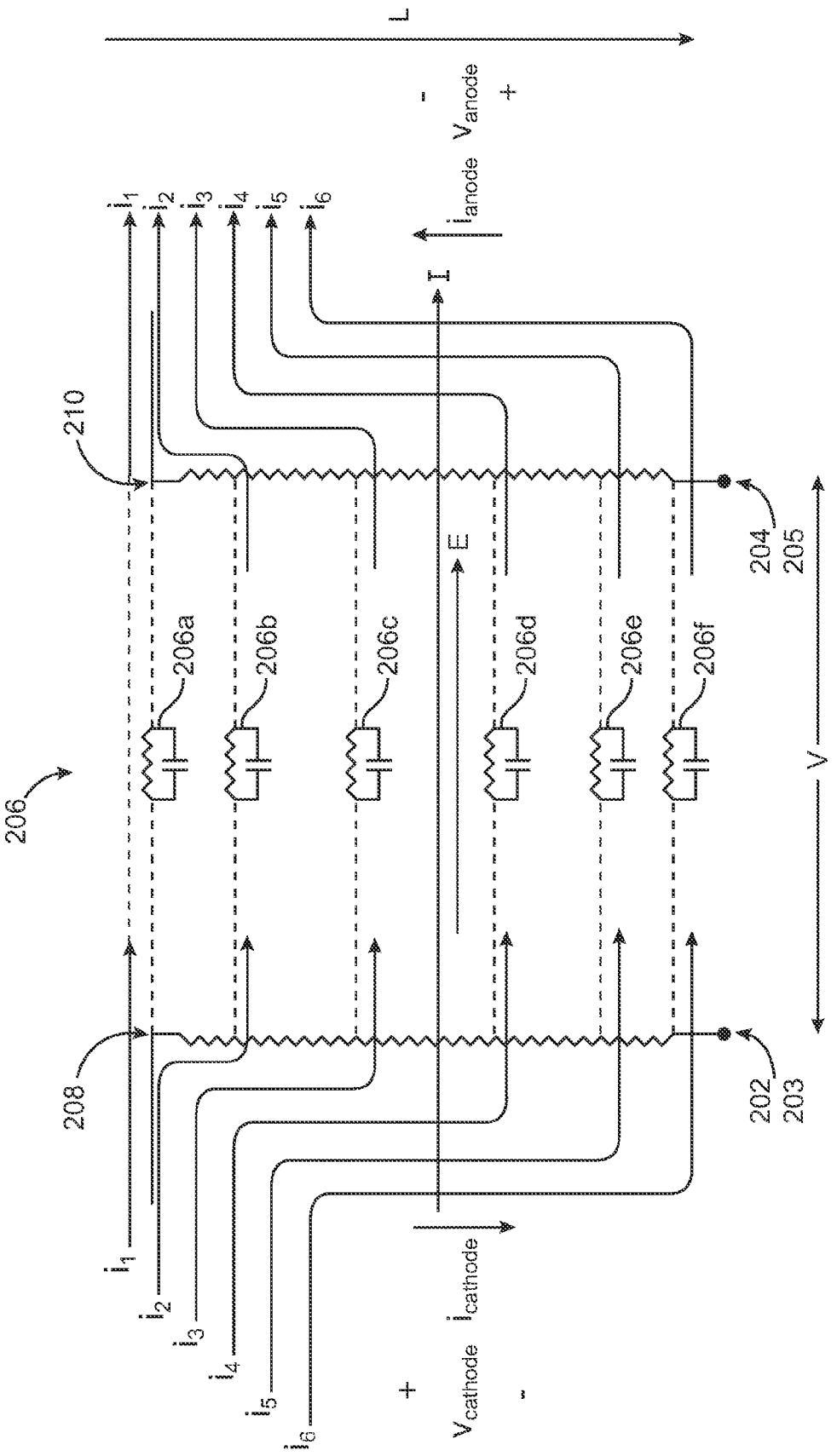


FIG. 2
(Prior Art)

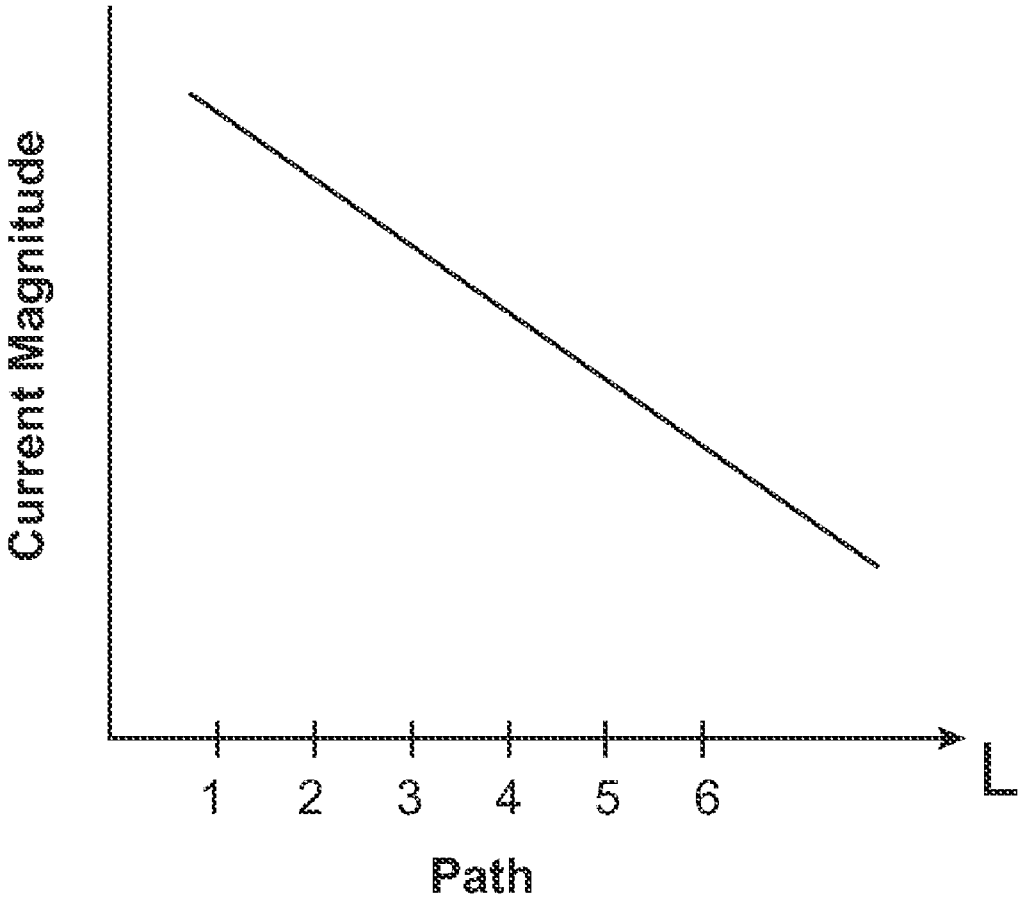


FIG. 3
(Prior Art)

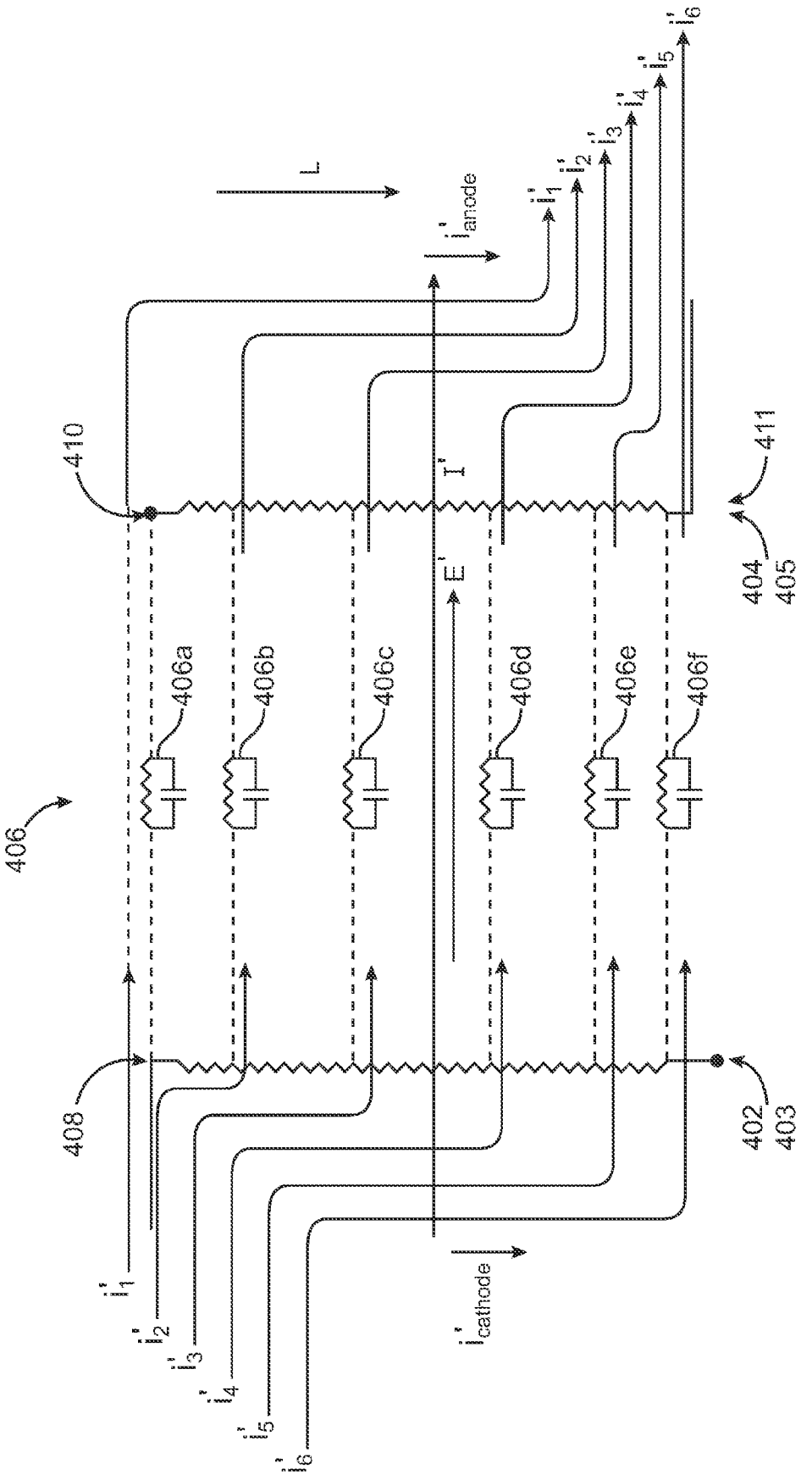

L
i'anode
i'1
i'2
i'3
i'4
i'5
i'6
410
I'
411
404
405
E'
406a
406b
406c
406d
406e
406f
406
408
402
403
i'1
i'2
i'3
i'4
i'5
i'6
i'cathode

FIG. 4

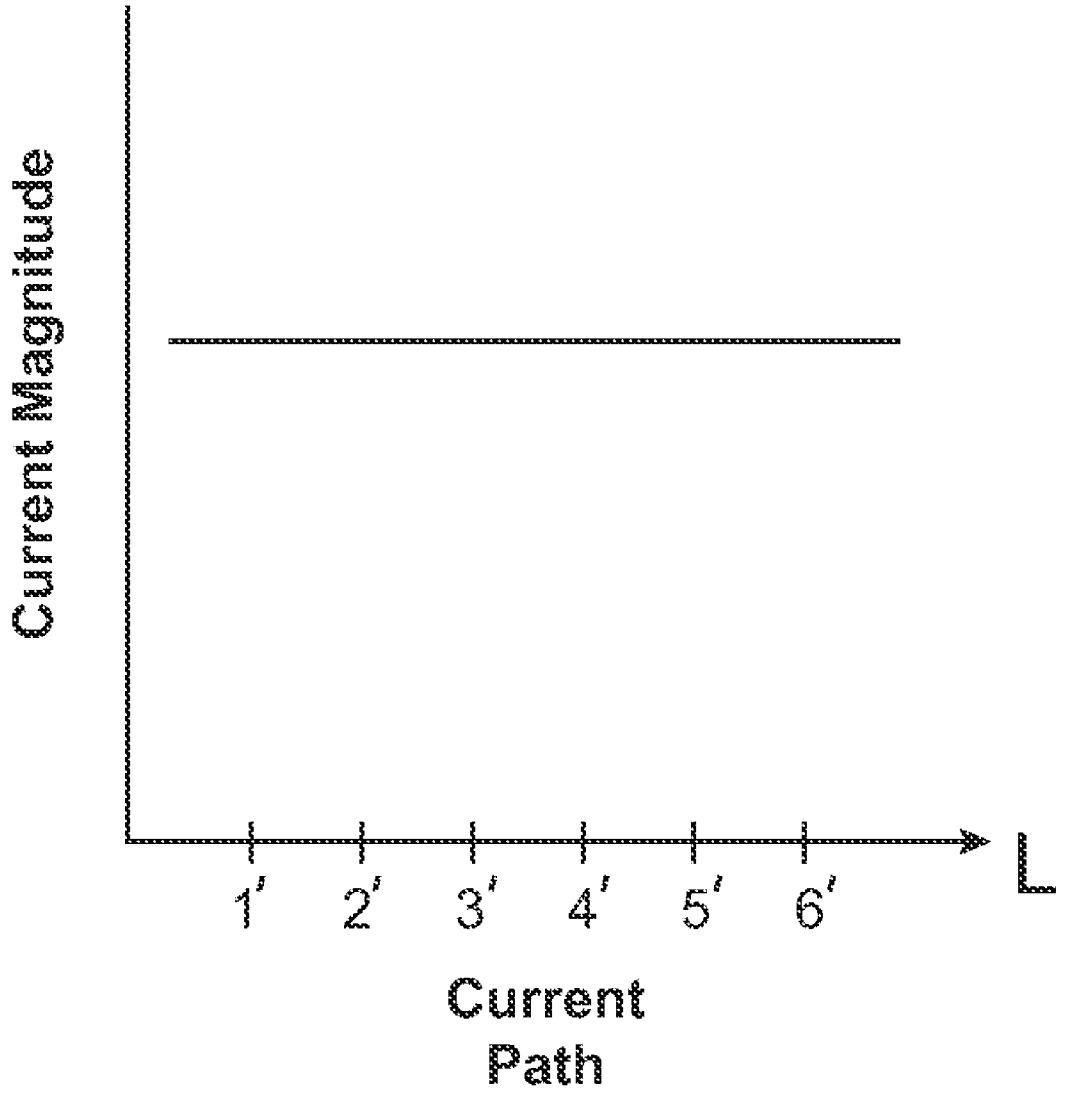


FIG. 5

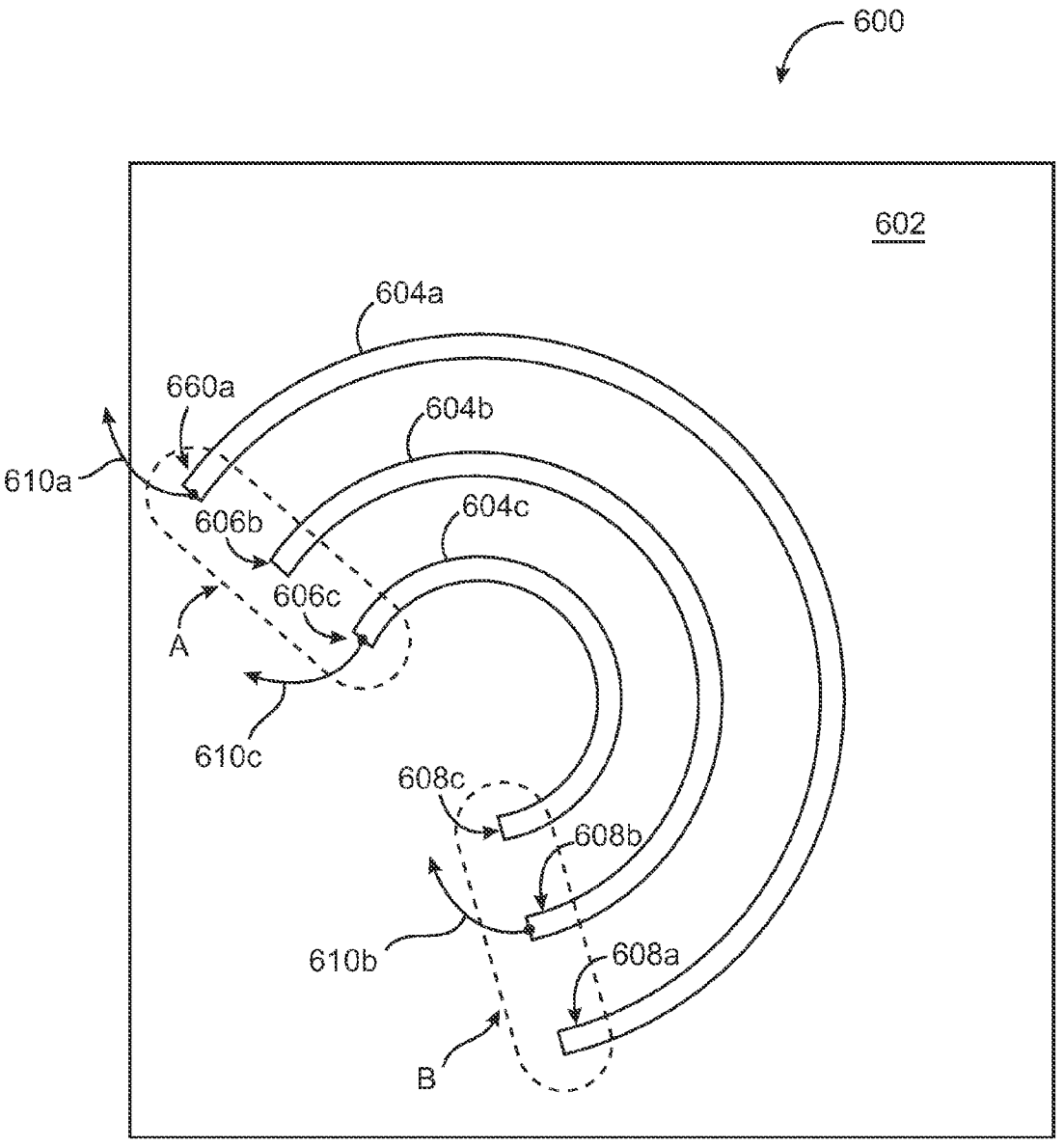

600
602
604a
660a
604b
610a
606b
604c
606c
A
610c
608c
608b
610b
608a
B

FIG. 6

IMPLANTABLE ELECTRODE ASSEMBLY HAVING REVERSE ELECTRODE CONFIGURATION

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] The present application is a continuation of U.S. application Ser. No. 11/122,741 (Attorney Docket No. 021433-001700US) filed May 19, 2005, the full disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The invention relates generally to medical devices and methods, and more particularly, to implantable electrodes for applying electrotherapy/electrostimulation that utilizes at least a pair of electrodes employing a reverse electrode configuration.

[0003] Implantable electrode assemblies for electrotherapy or electrostimulation are well-known in the art. For example, various configurations of implantable electrodes are described in U.S. Patent Publication No. U.S. 2004/0010303, which is incorporated herein by reference in its entirety. One type of electrode assembly described therein is a surface-type stimulation electrode that generally includes a set of generally parallel elongate electrodes secured to, or formed on, a common substrate or base. Prior to implantation in a patient, the electrodes are generally electrically isolated from one another. Once the electrode assembly is implanted, one or more of the electrodes are utilized as a cathode(s), while one or more of the remaining electrodes are utilized as an anode (s). The implanted cathode(s) and anode(s) are electrically coupled via the target region of tissue to be treated or stimulated.

[0004] One example of an application for this type of electrode assembly is for implantation onto a surface of tissue to be the target for electrotherapy or electrostimulation. The target tissue may have an irregular or complex shape, such as the outer surface of a blood vessel. The base or substrate and the electrodes of the electrode assembly can be sufficiently flexible to conform to the shape of the target tissue while maintaining a particular relative positioning of the electrodes. The geometry of the electrode assembly can be especially adapted for implantation at a particular site. For example, an electrode assembly can be sized and shaped to be implanted around the outside of the vascular wall such that the electrotherapy or electrostimulation can be focused on a particular target region.

[0005] One known problem associated with state of the art implantable electrode arrangements of certain geometries is their tendency to produce non-uniform electric fields or currents in the target region under certain conditions. An example of such a condition is when the implantation site has a low enough impedance to approach that of the electrode materials. In such cases, the internal resistance of the implanted electrodes becomes a significant parameter in the electrical/electromagnetic model of the implanted electrode arrangements. This problem can become pronounced in electrode arrangements in which the size of the electrodes approaches or exceeds the general size of the target region, or in arrangements in which the electrodes have structural geometries other than merely point electrodes.

[0006] Non-uniformity of electric field in the target region can result in sub-optimal electrotherapy or electrostimulation. Another consequence that occurs when the surface regions of implanted electrodes operate with disparate charge densities is an increased susceptibility of the electrodes to corrosion. Because corrosion is a charge density based phenomenon, increased concentrations of charge carriers in certain regions of the electrodes tends to focus faradaic processes responsible for corrosion at those regions.

[0007] In U.S. Pat. No. 5,265,623, a defibrillation catheter is described having generally linear electrode geometries (elongate helical or spiral coils) that, when implanted, are both situated generally longitudinally in the heart. The electrodes of the defibrillation catheter are connected to the defibrillation energy source from a center point of each electrode, rather than at the ends thereof. This arrangement is intended to provide an improved field distribution around the catheter electrode and avoid high current densities at the electrode ends. The arrangement nevertheless operates with a charge density gradient in each electrode due to the construction and relative positioning of the electrodes. Thus, the applied electric signaling is not likely to be uniform along the length of the electrodes. Furthermore, the multi-layer or multi-axial construction of the disclosed catheter requires a complex and relatively expensive fabrication process. Moreover, the catheter electrode assembly is not suitable for the surface-type of implantation applications described above.

[0008] While techniques have been developed to improve the distribution of electric field densities with respect to axial defibrillation electrode leads, it would be desirable to provide designs for implantable electrodes that improve the distribution of electrical field densities with respect to surface-type implantable electrodes.

BRIEF SUMMARY OF THE INVENTION

[0009] The present invention provides methods and apparatus for generating an electric field inside a patient that enhances the effective distribution of the density of the electric field. In one embodiment, at least a first and a second electrode are arranged on a common implantable substrate such that a proximal end of the first electrode is closer to a distal end of the second electrode and vice-versa. The electrodes are arranged and electrically connected to an energy source via the proximal ends such that when electrical energy is applied across the first and second electrodes, electrical current preferentially flows simultaneously through the first and second electrodes from the proximal end of one electrode to the distal end of the other electrode. In one aspect of the invention, the first and second electrodes are situated proximate a surface of tissue to be stimulated such that the electrodes are generally uniformly electrically coupled along their lengths via the tissue.

[0010] A method of evenly distributing an electric field between at least a pair of implanted electrodes according to another aspect of the invention includes providing an implantable electrode assembly that includes at least two electrodes on a common substrate, wherein each electrode has an elongate shape and is situated generally equidistantly along its length from at least one of the other electrodes in a configuration where the proximal and distal ends of the electrodes are reversed between an anode and a cathode. Electrical energy is applied through the at least two electrodes such that a generally uniform current density is established between the anode and the cathode.

[0011] An electrode assembly according to another aspect of the invention includes a generally flexible base and at least three generally parallel elongate electrode structures secured over a surface of the base, each electrode structure having a proximal end and a distal end. An outer pair of the electrode structures is electrically isolated from an inner electrode structure, and the proximal end of each electrode structure is electrically coupled to a conductive lead adapted to carry electrical energy. The proximal ends of the outer electrode structures and the distal end of the inner electrode structure are proximately situated at a first surface region of the base, and the distal ends of the outer electrode structures and the proximal end of the inner electrode structure are proximately situated at a second surface region of the base that is separate from the first surface region.

[0012] Another aspect of the invention is directed to an electrode assembly implanted at an electrotherapy site in a patient, the electrode assembly comprising a substrate; at least two elongate electrodes secured to the substrate and electrically coupled to the electrotherapy site, each electrode having opposing ends proximally and distally situated; and an electrotherapy signal generator circuit electrically coupled with the at least two electrodes and supplying electrotherapy signaling to the electrotherapy site via the at least two electrodes. The electrical coupling facilitates a generally uniform charge density in the at least two electrodes.

[0013] An electrotherapy arrangement implanted at an electrotherapy site according to another aspect of the invention comprises an electrode assembly that includes a substrate; and at least two elongate electrodes secured to the substrate and electrically coupled to the electrotherapy site, wherein each electrode is situated such that its proximal ends are longitudinally opposing. The electrotherapy arrangement further comprises an electrotherapy signal generator circuit electrically coupled with the at least two electrodes and applying electrotherapy signaling to the electrotherapy site via the at least two electrodes. The electrotherapy signaling generates an electric field through the electrotherapy site that is generally uniformly distributed along a longitudinal reference axis located in the electrotherapy site between the anode and cathode of the at least two electrodes.

[0014] According to another aspect of the invention, an implantable electrode assembly includes an implantable substrate and three elongate electrodes secured to the substrate. Each electrode has respective proximal and distal opposing ends, and the electrodes are relatively situated such that each electrode is generally uniformly spaced along its length with respect to its adjacent electrode(s). The electrodes are also relatively spaced such that an inner electrode is flanked on two sides by a pair of outer electrodes. A first lead is connected to the inner electrode at the inner electrode's proximal end positioned on one side of the substrate, and second and third leads are connected to the outer electrodes at the respective proximal ends positioned on an opposite side of the substrate. In one embodiment, each of the leads for the outer electrodes are positioned on one side and the lead for the inner electrode is positioned on the opposite side.

[0015] In an alternate embodiment, all of the leads are arranged on one side and a portion of the lead to the inner electrode is routed across the substrate within an insulator for the distal end of the lead to connect to the proximal end of the electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The invention may be more completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

[0017] FIG. **1**A is a top-view diagram illustrating an electrode assembly according to one embodiment of the present invention.

[0018] FIG. **1**B is a diagram illustrating one physical embodiment of the electrode assembly of FIG. **1**A.

[0019] FIG. **1**C is a top-view diagram illustrating an electrode assembly having a particular wiring arrangement according to one embodiment of the invention.

[0020] FIG. **1**D is a perspective view diagram illustrating an example physical layout of the electrode assembly of FIG. **1**C in which the lead connecting one of the electrodes to the signal generator runs along the bottom surface of the substrate.

[0021] FIG. **1**E is a perspective view diagram illustrating another example physical layout of the electrode assembly of FIG. **1**C in which at least one of the electrodes is formed around a portion of the lead connected with the electrode.

[0022] FIG. **1**F is a perspective view diagram illustrating one example physical embodiment of a coiled outer electrode structure formed around an inner coiled lead portion that is connected to the electrode at a proximal end.

[0023] FIG. **1**G is an end-view diagram of the electrode structure of FIG. **1**F.

[0024] FIG. **1**H is a perspective view diagram illustrating another example physical embodiment of a coiled outer electrode structure formed around an inner coiled lead portion that is connected to the electrode at a proximal end, in which an insulator is positioned between the outer electrode and inner conductor portion.

[0025] FIG. **1***i* is a side-view diagram illustrating an example coiled electrode structure of the type illustrated in FIG. **1**H, in which the outer and inner coils are generally helical in geometry and in which the insulator is generally cylindrical in geometry.

[0026] FIG. **1**J is a side view diagram illustrating an example coiled electrode structure of the type illustrated in FIG. **1**H, in which the inner coil has a spiral geometry wherein coil radius decreases towards the proximal end, and in which the insulator has a geometry wherein the walls have a profile of decreasing radius that corresponds to the decreasing radius profile of the inner coil.

[0027] FIG. **1**K is a cross-sectional view diagram of the electrode structure of FIG. **1**J.

[0028] FIG. **2** is a schematic diagram illustrating functional aspects of electrode assemblies known in the art.

[0029] FIG. **3** is a chart illustrating the current distribution through target tissue during operation of the electrodes represented in the schematic of FIG. **2**.

[0030] FIG. **4** is a schematic diagram illustrating functional aspects of an electrode assembly according to one embodiment of the present invention.

[0031] FIG. **5** is a chart illustrating the current distribution through target tissue during operation of the electrodes represented in the schematic of FIG. **4**.

[0032] FIG. **6** is a diagram illustrating an electrode assembly according to one embodiment of the present invention in which the electrodes are non-linear.

[0033] While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

[0034] FIG. **1**A is a diagram illustrating an implantable electrode assembly **100** according to one example embodiment of the invention. Electrode assembly **100** can be utilized in a variety of applications including, but not limited to, electrotherapy or stimulation of the patient. Tissue regions that are potential targets of electrotherapy/electrostimulation include the patient's nervous system (including nerve cells and synapses, and sensory receptors such as baroreceptors), muscle tissue, organs, and blood vessels. Electrode assembly **100** includes a base structure or substrate **102** that includes a flexible and electrically insulating material suitable for implantation, such as silicone, optionally reinforced with a flexible material such as polyester fabric. Base structure or substrate **102** can be sized and shaped according to the implantation site for the target tissue region (e.g., targeted blood vessels, muscles, nerves, skin, bone, organs, cells, etc.), and can have flexible and/or elastic properties. Thus, for example, base structure or substrate **102** can have a length suitable to wrap around all (360 degrees) or a portion (i.e., less than 360 degrees) of the circumference of one or more blood vessels.

[0035] In one embodiment, electrode assembly **100** includes elongate electrodes **104***a*-**104***c* for making contact with the target tissue region into which electrotherapy or electrostimulation is to be applied. The electrodes can be un-insulated portions of larger electrical conductors, dedicated un-insulated conductive structures, or a combination thereof. While the elongate electrodes **104***a*-**104***c* generally extend along a longitudinal axis, it will be recognized that embodiments of the elongate electrodes can include nonlinear geometries such as serpentine, curved or zig-zag, for example, and that in some embodiments not all of an electrode structure need be considered as part of the elongate electrode geometry. In one example embodiment, as illustrated in FIG. **1**A, elongate electrodes **104***a*-**104***c* are each about the same length, and are situated generally parallel to one another such that proximal ends **106***a* and **106***c* of outer electrodes **104***a* and **104***c* are positioned on the same side **102***a* of base **102** as distal end **108***b* of center electrode **104***b*. On the other side **102***b* of base **102**, distal ends **108***a* and **108***c* of outer electrodes **104***a* and **104***c* are positioned proximate to proximal end **106***b* of center electrode **104***b* on side **102***b*. For purposes of the present invention it will be understood that proximal is used to reference a region proximate an end of a structure that is electrically closer to the pulse generator and that distal references a region proximate an end of a structure that is further away electrically from the pulse generator as compared to the proximal portion.

[0036] In a related type of embodiment, the electrodes are generally co-extensive. Among electrode assemblies of this type, the extent of co-extensiveness can vary according to the geometry of the implantation site. For example, in one example embodiment, the electrodes are co-extensive to within +/−25%. In another embodiment, the electrodes are co-extensive to within +/−5%. While this embodiment features one arrangement of three electrodes **104***a*-**104***c* in accordance with the present invention, other arrangements and configurations of electrodes **104** as described hereinafter may also be utilized to enhance the uniform distribution of the electric field delivered through the electrodes to the target tissue region.

[0037] Electrodes **104***a*-**104***c* are made from a suitable implantable material, and are preferably adapted to have flexible and/or elastic properties. Electrodes **104***a*-**104***c* can comprise round wire, rectangular ribbon or foil formed of an electrically conductive and radiopaque material such as platinum. In one embodiment, the base structure **102** substantially encapsulates the conductive material, leaving only exposed electrode **104***a*-**104***c* portions for electrical connection to the target tissue. For example, each conductive structure can be partially recessed in the base **102** and can have one side exposed along all or a portion of its length for electrical connection to target tissue. The exposed portions constitute electrodes **104***a*-**104***c*. In another embodiment, the electrodes **104***a*-**104***c* are made from conductive structures that can be adhesively attached to the base **102** or can be physically connected by straps, moldings or other forms of operably securing them to the base **102**. Electrical paths through the target tissue are defined by anode-cathode pairs of the elongate electrodes **104***a*-**104***c*. For example, in one embodiment, center electrode **104***b* is a cathode, and outer electrodes **104***a* and **104***c* are both anodes, or vice-versa. Thus, electrons of the electrotherapy or electrostimulus signaling will flow through the target region either into, or out of, electrode **104***b*.

[0038] Each electrode **104***a*-**104***c* is connected at the corresponding proximal end **106***a*-**106***c* to an electrotherapy/electrostimulus source, such as an implantable pulse generator (not shown) via a corresponding lead **110***a*-**110***c*. In one example embodiment, leads **110***a*-**110***c* are each an insulated wire formed with, welded to, or suitably interconnected with each corresponding electrode **104***a*-**104***c*. Persons skilled in the art will appreciate that leads **110***a*-**110***c* can be made of any suitable materials or geometries. Furthermore, leads **110***a*-**110***c* can each include a combination of conductor types. Thus, for example, leads **110***a*-**110***c* can each include an insulated stranded wire portion, an un-insulated solid wire portion, and/or a coiled wire portion having helical, spiral, or other such coiled geometry.

[0039] FIG. **1**B illustrates a physical embodiment of the example electrode assembly **100** of FIG. **1**A. The shape of base structure or substrate **102** includes finger-type extensions **112**, and reinforced portions **114** for facilitating wrapping and securing the electrode assembly **100** to the implantation site during implantation. Because leads **110***a* and **110***c* are connected at opposite electrode ends from lead **110***b*, leads **110***a* and **110***c* naturally extend in a different direction away from the electrodes **104** than the direction of lead **110***b*. In certain applications, it may be desirable for the leads to extend in the same direction away from the electrodes **104**.

[0040] FIG. **1**C is a diagram illustrating example electrode assembly **150** according to a related embodiment. Electrode assembly **150** includes a flexible and stretchable implantable substrate **152**, to which elongate electrodes **154***a*-**154***c* are secured. Electrodes **154***a* and **154***c* are connected respec-

tively to leads **160***a* and **160***c* at proximal ends **156***a* and **156***c* located on side **152***a* of substrate **152**. Electrode **154***b* is connected to lead **160***b* at proximal end **156***b* located on side **152***b* of substrate **152**. Distal ends **158***a* and **158***c* of electrodes **154***a* and **154***c*, respectively, are located on side **152***b* and are not connected to any leads. Distal end **158***b* of electrode **154***b* is located on side **152***a* and is not connected to any lead. Lead **160***b* extends along the length of electrode **154***b* towards distal end **156***b*, and further extends in the same direction as leads **160***a* and **160***c*, as illustrated in FIG. **1**C. The leads **160***a*-**160***c* are optionally bundled and secured together by wire tie **161**.

[0041] FIG. **1**D illustrates a physical embodiment of example electrode assembly **150**. Electrodes **154***a*-**154***c* are secured to substrate **152**, and are oriented along the reference z-axis. Insulated leads **160***a*-**160***c* are attached to their respective electrodes as shown. Leads **160***a* and **160***b* are connected to respective electrodes **154***a* and **154***c* at respective proximal ends **156***a* and **156***c*. Lead **160***b* is connected to electrode **154***b* at proximal end **156***b*. Leads **160***a* and **160***c* extend in the −z direction away from their corresponding electrodes **154***a* and **154***c*, and proceed in the −x direction. Lead **160***b* extends away from electrode **154***b* in the +z direction, then loops around substrate **152**, and further proceeds in the −z along the underside of substrate **152**. Leads **160***a*-**160***c* are secured to substrate at various points by anchors **162** as shown. Lead **162***b* is also secured at points along the underside surface of substrate **152** by anchors **162** (not shown).

[0042] FIG. **1**E illustrates another example physical layout of the electrode assembly **150**. In this embodiment, electrode **154***b* is formed from an elongate structure having a hollow core **154***b*'. Lead **160***b* enters core **154***b*' at an opening at distal end **158***b* and passes through core **154***b*' of the elongate structure to proximal end **156***b*, at which point lead **160***b* connects with electrode **154***b*. In one example embodiment, lead **160***b* includes a portion **160***b*' that is specially adapted to be situated within core **154***b*'. Optionally, electrodes **154***a* and **154***c* are adapted to be pliably compatible with the structure of electrode **154***b* having a portion of lead **160***b* in its core **154***b*'.

[0043] FIGS. **1**F-**1**H illustrate various example electrode structures that each include an elongate electrode portion in the shape of a coil formed around a portion of a lead that is connected to the electrode portion at the proximal end. Structure **164** of FIG. **1**F is an elongate structure having a length l. Structure **164** has an outer coiled portion **166** made of non-insulated wire and generally helical in its geometry. At least a portion of structure **164** can operate as an electrode when in contact with target tissue. Structure **164** further includes a generally helical inner coiled portion **168** passing through the core **170** defined by the wire of outer coiled portion **166**. Inner coiled portion **168** is thus circumscribed along at least a portion of its length by outer coil portion **166**. One type of wire material that can be suitable for certain implantable applications is 80/20 Pt/Ir. However, persons skilled in the art will recognize that other suitable materials may be used. Inner coiled portion **168** enters core **170** at distal end **172**, and helically extends through core **170** towards proximal end **174**, at which point inner coiled portion **168** makes contact with outer coiled portion **166**.

[0044] In one example embodiment, near proximal end **174**, one or more windings of outer coiled portion **166** have a progressively reducing radius as they approach proximal end **174** such that, at proximal end **174**, windings of outer coiled portion **166** have approximately the same radius as the windings of inner coiled portion **168**. This embodiment is illustrated in FIG. **1**F. Outer coiled portion **166** includes windings **167** having a relatively larger radius, and windings **176** having a relatively smaller radius. Reduced radius windings **176** are situated in a bifilar arrangement at proximal end **174** with the windings of inner coiled portion **168**. FIG. **1**G is an end view of structure **164** illustrating this embodiment. Outer coiled portion **166** includes windings **167** having larger radius r_1, and windings **176** near the proximal end **174** having smaller radius r_2. Winding **178** of outer coiled portion **166** integrally bridges the larger radius windings **167** with the smaller radius windings **176**. In one embodiment, at proximal end **174**, the wire forming outer coiled portion **166** is welded to the wire forming inner coiled portion **168**. Persons skilled in the art will appreciate that other suitable mechanisms of creating an electrical contact between these wires, including, but not limited to, soldering, crimping, twisting, or conductively adhesively bonding, may be utilized.

[0045] In one embodiment, inner coiled portion **168** is positioned relative to larger outer coiled portion **166**'s windings **167** such that, in operation, the inner coiled portion **168** and outer coiled portion **166** do not make contact at any point other than at the proximal end **174**. In one embodiment, inner coiled portion **168** is formed from insulated wire. In another embodiment, inner coiled portion **168** is formed from uninsulated wire, but inner surfaces of windings **167** are insulated. In another embodiment, the radius of the inner coiled portion's windings R_2 is sized relatively to the outer coiled portion's windings **167** having larger radius r_1 such that undesired contact points are not created when the structure **164** is elastically flexed to a maximum limit.

[0046] In another type of embodiment, as illustrated in FIG. **1**H, structure **164'** includes an insulating material **180** that is coaxially situated between inner coiled portion **168'** and large-radius coils **167'** of outer coiled portion **166'**. According to one example of this type of embodiment, as illustrated in the side view diagram of FIG. **1**I, the radii of inner coiled portion **168'** and of outer coiled portion **167'** remain generally constant over the length of the structure (disregarding the change in radius of the outer portion near the proximal end). Insulator **180** has a generally cylindrical outer wall that is adjacent to outer coiled portion coils **167'**, and a generally cylindrical inner wall adjacent to inner coiled portion **168'**.

[0047] FIGS. **1**J and **1**K illustrate an example of a variation of the embodiment of FIG. **1**I. FIGS. **1**J and **1**K are, respectively, side view diagrams of a structure in which large-radius coils **167"** of outer coiled portion **166"** have a constant radius over length l, but inner portion **168"** has a spiral geometry in which the coil radius decreases towards the proximal end. The radii of outer and inner walls of insulator **180'** also have a profile of decreasing radius that corresponds to the decreasing radius profile of inner coils **168"**. According to one aspect of this embodiment, the geometry of the structure of FIGS. **1**J and **1**K provides a benefit of securing in place the insulator **180'** by preventing it from sliding towards either end of the structure.

[0048] In the configuration of electrodes **104***a*-**104***c* (FIGS. **1**A and **1**B) and **154***a*-**154***c* (FIGS. **1**C, **1**D, and **1**E), having the electrode/lead connections at opposite ends for electrodes of opposite polarity provides improved electric field uniformity and improved corrosion resistance as compared against equivalent configurations having the connections at the same end. FIGS. **2**-**5**, described in detail below, illustrate these principles.

[0049] FIG. **2** is a diagram illustrating an electrical circuit model of a state-of-the-art implanted electrode assembly. Distributed resistance **202** represents one or more cathodes **203** connected to the electrotherapy/electrostimulus signal generator. Likewise, distributed resistance **204** represents one or more anodes **205** connected to the opposite pole of the electrotherapy/electrostimulus generator. Distributed resistances **202** and **204** are each distributed over the length L and quantity of their corresponding electrode(s), and are not necessarily equal in magnitude. Target tissue impedance **206** represents the electrical properties of the target tissue interconnecting the electrodes. Target tissue impedance **206** is modeled as a set of parallel resistor-capacitor pairs **206***a*-**206***f* distributed over the aggregate volume V that separates the cathode(s) from the anode(s). The resistance of each electrode's distributed resistance **202** and **204** is generally evenly distributed over length L. With increasing length L, the resistance component of impedance **206** decreases, whereas the capacitance component increases.

[0050] Cathode **203** is connected to the signal generator at top end **208**; anode **205** is connected to the opposite pole of the signal generator at top end **210**. When the electrotherapy/electrostimulus signal is applied across electrodes **203** and **205**, an aggregate current I generally passes through the resistive component of the target tissue having impedance **206**. Also, an aggregate electric field E generally exists across the electrodes **203** and **205** due to the capacitive component of impedance **206**. However, due to the distributed resistances of the electrodes **203** and **205**, as well as the distributed target tissue impedance **206**, the current I and electric field E are also distributed over the length L and volume V. The distribution of current I and electric field E depends on the distribution of tissue impedance **206**, and on the charge distribution over the length L of each electrode **203** and **205**.

[0051] Within each of the distributed electrode resistances **202** and **204**, there exist a cathode current $i_{cathode}$ and i_{anode}, and corresponding voltage drops $V_{cathode}$ and V_{anode}. These currents and voltages occur within each elongate electrode because the electrode resistances **202** and **204** create voltage and current divisions with respect to signal paths through the target tissue. Because the signal generator connections are located at the top ends **208** and **210** of electrodes **203** and **205**, respectively, the cathode and anode currents and voltages have opposite directions and polarities, as illustrated in FIG. **2**.

[0052] As a result, the distributed current I and electric field E through the target tissue region are not evenly distributed. By way of example, discrete current components i_1-i_6 located successively at greater distances from the top ends **208** and **210** are successively lower in amplitude such that i_1 has the greatest amplitude while i_6 has the lowest amplitude. FIG. **3** illustrates an example current distribution through volume V over length L. The axis labeled L corresponds to the L dimension of FIG. **2**, and the paths **1**-**6** correspond to the paths taken by example current components i_1-i_6.

[0053] FIG. **4** illustrates an electrical diagram of an example implanted electrotherapy/electrostimulation electrode assembly according to one embodiment of the present invention. Distributed resistances **402** and **404** represent aggregate elongate electrodes **403** and **405**, respectively. Electrodes **403** and **405**, and the target tissue having impedance **406** are all correspondingly similar to their respective analogues described above with reference to FIG. **2**. The only difference in the arrangement between the example of FIG. **2** and the example of FIG. **4** is the connection of the signal generator to the cathode and anode. Cathode **403** is connected to the signal generator at top end **408**; whereas anode **405** is connected at bottom end **411**. As a result of this reversal, the bottom end **411** is more negatively charged than the top end **410** of the anode **405**. This causes the charge density of the electrodes **403** and **405** to be evenly distributed along the length L, which results in an even distribution of aggregate current I' and aggregate electric field E'. Thus, example discrete current components i_1'-i_6' each pass through an equivalent impedance. For instance, current component i_2' passes through a smaller portion of cathode impedance **402**, through target tissue impedance component **406***b*, and through a larger portion of anode impedance **404**; whereas current component i_5' passes through a larger portion of cathode impedance **402**, an equivalent target tissue impedance component **406***e*, and through a smaller portion of anode impedance **404**.

[0054] Another result of the electrode arrangement of FIG. **4** is that the cathode current $i_{cathode}$' is directed along the same direction as the anode current i_{anode}'. FIG. **5** illustrates the uniform distribution of aggregate current I' over length L for the example electrode assembly configuration of this embodiment.

[0055] By distributing the charge density evenly over each of the electrodes **403** and **405**, any faradaic processes are also distributed over the surfaces of the electrodes. This effect results in an increased corrosion threshold because electrode corrosion is based on the charge density. Another effect is an increase in capacitance seen by the electrotherapy or electrostimulation signaling. Because the charge density is evenly distributed along length L, the signaling sees a greater overall target tissue capacitance. With an increased overall capacitance created by the charge balancing, more of the activation current is used to charge the electrode double layer and less is available for faradaic processes. The charging of the electrode double layer results in an induced current in the target tissue resulting in the desired stimulation or therapeutic effect.

[0056] The present invention contemplates a variety of electrode forms or shapes, not necessarily limited to straight linear segments. FIG. **6** is a diagram illustrating an example electrode assembly **600** according to another embodiment of the present invention. Electrode assembly **600** includes a flexible substrate **602** to which arcing elongate electrodes **604***a*-**604***c* are secured. Arcing elongate electrodes **604***a*-**604***c* each have a first end in a first region A and a second end in a second region B such that the electrodes **604***a*-**604***c* arcuately extend between regions A and B. Electrode **604***a* has a lead **610***a* electrically connected to its first end **606***a*. Electrode **604***b* has a lead **610***b* electrically connected to its second end **608***b*. Electrode **604***c* has a lead **610***c* electrically connected to its first end **606***c*. For electrodes **604***a* and **604***c*, respective second ends **608***a* and **608***c* have no leads connected thereto. Conversely, for electrode **604***b*, first end **606***b* is free of any lead connection. When implanted in a patient, electrodes **604***a*-**604***c* are electrically interconnected by the target tissue. In operation, the charge distribution in each of the electrodes is approximately uniform, resulting in electric fields and currents approximately uniformly distributed through the interconnecting target tissue.

[0057] The invention may be embodied in other specific forms without departing from the essential attributes thereof, therefore, the illustrated embodiments should be considered in all respects as illustrative and not restrictive.

What is claimed is:

1. A method of generating an electric filed inside a patient, the method comprising:

providing at least a first electrode and a second electrode on a common implantable substrate, wherein each of the first and second electrodes has a respective proximal end and a respective distal end, wherein the proximal end of the first electrode is positioned closer to the distal end of the second electrode than to the proximal end of the second electrode, wherein the proximal end of the second electrode is positioned closer to the distal end of the first electrode than to the proximal end of the first electrode;

implanting the implantable substrate inside the patient; and

applying electrical energy across the first and second electrodes to cause electrical current to flow simultaneously through the first and second electrodes preferentially from the proximal end of one electrode to the distal end of the other electrode.

2. The method of claim **1**, and further comprising:

implanting the implantable electrode assembly such that each cathode electrode is coupled to at least one anode electrode via electrically conductive target tissue.

3. The method claim **2**, wherein the target tissue provides a generally uniform coupling along the lengths of the coupled electrodes.

4. The method of claim **1**, and further comprising:

establishing a generally uniform current density substantially through the length of each electrode.

5. The method of claim **1**, wherein the step of applying electrical energy causes electrical current to flow preferentially from the proximal end of the first electrode to the distal end of the second electrode and preferentially from the distal end of the first electrode to the proximal end of the second electrode.

6. An electrode assembly comprising:

a generally flexible base having a first surface region and an axially spaced-apart second surface region; and

at least three generally parallel elongate electrode structures secured and axially aligned over a surface of the base, each electrode structure having a proximal end and a distal end;

wherein an outer pair of the electrode structures is electrically isolated from an inner electrode structure;

wherein the proximal ends of the outer pair of electrode structures and the distal end of the inner electrode structure are disposed on the first surface region of the vase, and the distal ends of the outer electrode structures and the proximal end of the inner electrode structure are disposed on the second surface region of the base that is separate from the surface region.

7. The electrode assembly of claim **6**, wherein the conductive lends electrically coupled to the outer electrode structures are electrically coupled to a first pole of an electrical signal generator, and the conductive lead electrically coupled to the inner electrode structure is electrically coupled to a second pole of the electrical generator.

8. The electrode assembly of claim **6**, wherein the base is adapted to be attachable to an outside surface of a blood vessel.

9. The electrode assembly of claim **6**, wherein the base includes a plurality of finger-type extensions for facilitating securing the base to target tissue.

10. The electrode assembly of claim **6**, wherein each electrode structure has a generally uniformly distributed impedance along its length.

11. The electrode assembly of claim **6**, wherein each electrode structure includes a coiled portion adapted to make contact with target tissue.

12. The electrode assembly of claim **6**, wherein the electrode structures are aligned to facilitate transmission of a generally uniformly distributed electric field through target tissue situated between the electrode structures.

13. An electrode assembly adapted for implantation at an electrotherapy site in a patient, the electrode assembly comprising:

a substrate; and

at least three elongate electrodes secured to the substrate and electrically coupled to the electrotherapy site, each electrode having a proximal end connected to an electrically conductive lead and a distal end not connected to a lead or other electrode;

wherein a generally uniform charge density is generated between an outer pair of the at least three electrodes and an inner electrode when an electrical current is applied to the electrodes.

14. The electrode assembly of claim **13**, wherein the proximal ends of the outer electrode structures and the distal end of the inner electrode structure are disposed on the first surface region of the base, and the distal ends of the outer electrode structures and the proximal end of the inner electrode structure are disposed on the second surface region of the base that is separate from the first surface region.

15. The electrode assembly of claim **14**, and further comprising:

a remote electrotherapy signal generator circuit electrically coupled with the at least three electrodes and supplying electrotherapy signaling to the electrotherapy site via the at least three electrodes; and

wherein at least the outer pair of the electrodes is electrically coupled at the proximately situated region with a lead to s first pole of the electrotherapy signal generator, and an inner one of the electrodes is electrically coupled at the distally situated region with a lead to a second pole of the electrotherapy signal generator.

16. The electrode assembly of claim **14**, wherein the at least three electrodes include at least one anode and at least one cathode; and

wherein the at least one cathode is electrically coupled with at least one corresponding lead at the proximally situated region, and the at least one anode is electrically coupled with at least one corresponding lead at the distally situated region.

17. The electrode assembly of claim **13**, wherein the at least three electrodes are situated generally coextensively.

18. An electrotherapy arrangement implanted at an electrotherapy site, the electrotherapy arrangement comprising:

an electrode assembly, including:

a substrate; and

at least three adjacent elongate electrodes secured to the substrate and electrically coupled to the electrotherapy site, wherein each electrode is situated such that proximal and distal ends of each successive adjacent electrode's ends are longitudinally opposing; and

an electrotherapy signal generator circuit electrically coupled with the at least three electrodes and applying electrotherapy signaling to the electrotherapy site via the at least two electrodes;

wherein the electrotherapy signaling generates an electric field through the electrotherapy site that is generally uniformly distributed along a longitudinal reference axis located in the electrotherapy site between an anode and a cathode of the at least three electrodes.

19. The electrotherapy arrangement of clam **18**, wherein the electrotherapy signaling is adapted to stimulate baroreceptors.

20. The electrotherapy arrangement of claim **18**, wherein the electrotherapy signaling is adapted to stimulate at least one nerve.

21. The electrotherapy arrangement of claim **18**, wherein the electrotherapy signaling is adapted to stimulate muscle tissue.

22. A method of generating an electric field inside a patient, the method comprising:

providing at least a first electrode, a second electrode and a third electrode on a common implantable substrate, wherein each of the first, second and third electrodes has a respective proximal end and a respective distal end, wherein the proximal end of the first electrode is positioned closer to the distal end of the second electrode than to the distal end of the second electrode than to the proximal end of the second electrode, wherein the proximal end of the second electrode is positioned closer to the distal end of the first electrode than to the proximal end of the first electrode;

implanting the implantable substrate inside the patient; and

applying electrical energy across the first, second and third electrodes to cause electrical current to flow simultaneously through the first and second electrodes preferentially from the proximal end of one electrode to the distal end of the other electrode and across the third electrode preferentially from the proximal end of the third electrode to the distal end of the second electrode and from the distal end of the third electrode to the proximal end of the second electrode.

23. The method of claim **22**, and further comprising:

implanting the implantable electrode assembly such that each cathode electrode is coupled to at least one anode electrode via electrically conductive target tissue.

24. The method of claim **23**, wherein the target tissue provides a generally uniform coupling along the lengths of the coupled electrodes.

25. The method of claim **22**, and further comprising:

establishing a generally uniform current density substantially through the length of each electrode.

26. An electrode assembly comprising:

a first electrode having a first arcuate shape; and

a second electrode having a second arcuate shape; and

wherein the second electrode at least partially encircles the first electrode.

27. The electrode assembly of claim **26**, further comprising:

a third electrode having a third arcuate shape; and

wherein the third electrode at least partially encircles the first and second electrodes.

28. The electrode assembly of claim **27**, wherein the second electrode is electrically insulated from the first and third electrodes.

29. The electrode assembly of claim **26**, wherein the first and third electrodes are electrically connected to one another.

30. The electrode assembly of claim **26**, wherein each electrode comprises a coil.

31. The electrode assembly of claim **26**, wherein each electrode is disposed on a common implantable substrate.

32. The electrode assembly of claim **26**, wherein one of the electrodes is electrically insulated from the other two electrodes.

33. The electrode assembly of claim **26**, wherein one of the electrodes is electrically connected to one of the other two electrodes.

34. The electrode assembly of claim **26**, wherein each electrode has a first end and a second end.

35. The electrode assembly of claim **26**, further comprising a lead electrically connected to a first end of the first electrode.

36. The electrode assembly of claim **26**, further comprising a lead electrically connected to a second end of the second electrode.

37. The electrode assembly of claim **26**, further comprising a lead electrically connected to a first end of the third electrode.

38. The electrode assembly of claim **26**, further comprising an electrotherapy signal generator electrically connected to at least the first electrode and the second electrode, and delivering an electrotherapy signal thereto.

39. The electrode assembly of claim **38**, wherein a generally uniform electric field is generated between the electrodes when the electrotherapy signal is delivered thereto.

40. The electrode assembly of claim **38**, wherein a generally uniform current density is generated in a tissue when the electrodes are placed in contact with the tissue and the electrotherapy signal is delivered to the electrodes.

41. A method of generating an electric field inside a patient, the method comprising:

electrically contacting a target tissue of the patient with a first electrode;

electrically contacting the target tissue along an arcuate path of a second electrode that least partially encircles the first electrode; and

applying electrical energy across the first and second electrodes to establish a generally uniform current density between the first and second electrodes.

42. The method of claim **41**, further comprising electrically connecting the first electrode and the second electrode to a signal source.

43. The method of claim **41**, wherein contacting the target tissue with the first electrode comprises contacting an exterior surface of a wall of a blood vessel with the first electrode.

44. The method of claim **41**, wherein the first electrode is fixed to a flexible substrate and the method comprises conforming the flexible substrate to the exterior surface of the wall of the blood vessel.

45. The method of claim **41**, further comprising delivering a signal to the wall of the blood vessel to cause a change in the patient.

46. The method of claim **45**, wherein the change comprises a change in blood pressure.

47. The method of claim **46**, wherein the change comprises a reduction in blood pressure.

48. The method of claim **45**, wherein the change comprises an increase in parasympathetic nervous system activity.

49. The method of claim **45**, wherein the change comprises a decrease in sympathetic system activity.

50. The method of claim **45**, wherein the change comprises a change in a radio of sympathetic nervous system activity to parasympathetic nervous system activity.

51. The method of claim **45**, wherein the change occurs in cells in the wall of the blood vessel.

52. The method of claim **45**, wherein the change occurs in nerve fibers in the wall of the blood vessel.

53. The method of claim **45**, wherein the change comprises a change in receptors in the wall of the blood vessel.

54. The method of claim **53**, wherein the change comprises a change in baroreceptors in the wall of the blood vessel.

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