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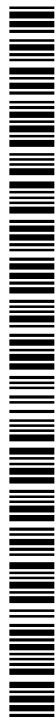


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(54) **Title:** VASCULAR FILTER WITH SENSING CAPABILITY

(57) **Abstract:** An implantable vessel filter having an integrated sensing capability for monitoring the condition of the vessel filter. In one variation, the vessel filter includes a plurality of legs that would themselves perform as a sensor device for detecting distention, which would indicate the presence of a clot or thrombus therein. A passive electrical circuit may be implemented on the vessel filter to receive electromagnetic energy and transmit signals indicative of the condition of the implanted vessel filter. In another variation, a miniaturized sensor is adapted for measuring the strain and/or other physical parameters of the filter legs.

**VASCULAR FILTER WITH SENSING CAPABILITY****PRIORITY**

**[0001]** This application claims the benefit of priority to United States Application No. 11/051,101, filed February 4, 2005, which is incorporated by reference into this application as if fully set forth herein.

**BACKGROUND OF THE INVENTION**

**[0002]** A vena cava filter is a device inserted into a blood vessel to capture particles in the blood flow. Typically the device is inserted into a major vein to prevent a blood clot from reaching the lungs. Patients who have recently suffered from trauma, have had a heart attack (myocardial infarction), or who have experienced a major surgical procedure (e.g., surgical repair of a fractured hip, etc.) may have thrombosis in a deep vein. When the thrombus clot loosens from the site of formation and travels to the lung it may cause pulmonary embolism, a life-threatening condition. A vena cava filter may be placed in the circulatory system to intercept the thrombi and prevent them from entering the lungs.

**[0003]** Examples of various blood vessel filters are disclosed in U.S. Patent Application, Publication No. 2001/0000799 A1, titled "BODY VESSEL FILTER" by Wessman *et al.*, published May 3, 2001; U.S. Patent Application, Publication No. 2002/0038097 A1, titled "ATRAUMATIC ANCHORING AND DISENGAGEMENT MECHANISM FOR PERMANENT IMPLANT DEVICE" by Ostrovsky *et al.*, published September 26, 2002; U.S. Patent Application, Publication No. 2002/0193828 A1, titled "ENDOVASCULAR FILTER" by Griffin *et al.*, published December 19, 2002; U.S. Patent Application, Publication No. 2003/0199918 A1, titled "CONVERTIBLE BLOOD CLOT FILTER" by Patel *et al.*, published October 23, 2003; U.S. Patent Application, Publication No. 2003/0208227 A1, titled "TEMPORARY VASCULAR FILTERS AND METHODS" by Thomas, published November 6, 2003; U.S. Patent Application, Publication No. 2003/0208253 A1, titled "BLOOD CLOT FILTER" by Beyer *et al.*, published Nov. 6, 2003; U.S. Patent No. 4,425,908, titled "BLOOD CLOT FILTER" issued to Simon, dated January 17, 1984; U.S. Patent No. 4,643,184, titled "EMBOLUS. TRAP" issued to Mobin-Uddin, dated February 17, 1987; U.S. Patent No. 4,817,600, titled "IMPLANTABLE FILTER" issued to Herms *et al.*, dated April 4, 1989; U.S. Patent No. 5,059,205, titled "PERCUTANEOUS. ANTI-MIGRATION VENA CAVA FILTER" issued to El-Nounou *et al.*, dated October 22, 1991; U.S. Patent No. 5,344,427, entitled "FILTER WITH TRIANGULAR FINGERS" issued to Cottenceau *et al.*, dated Sep. 6, 1994; U.S. Patent No.

5,626,605, entitled "THROMBOSIS FILTER" issued to Irie *et al.*, dated May 6, 1997; U.S. Patent No. 5,755,790, titled "INTRALUMINAL MEDICAL DEVICE" issued to Chevillon *et al.*, dated May 26, 1998; U.S. Patent No. 6,258,026 B1, titled "REMOVABLE EMBOLUS. BLOOD CLOT FILTER AND FILTER DELIVERY UNIT" issued to Ravenscroft *et al.*, dated July 10, 2001; U.S. Patent No. 6,443,972 B1, titled "VASCULAR FILTER" issued to Bosman *et al.*, dated Sep. 3, 2002; U.S. Patent No. 6,497,709 B1, titled "METAL MEDICAL DEVICE" issued to Heath, dated December 24, 2002; U.S. Patent No. 6,506,205 B2, titled "BLOOD CLOT FILTERING SYSTEM" issued to Goldberg *et al.*, dated January 14, 2003; and U.S. Patent No. 6,517,559 B1, titled "BLOOD FILTER AND METHOD FOR TREATING VASCULAR DISEASE" issued to O'Connell, dated February 11, 2003; U.S. Patent No. 6,540,767 B1, titled "RECOILABLE THROMBOSIS FILTERING DEVICE AND METHOD" issued to Walak *et al.*, dated April 1, 2003; U.S. Patent No. 6,620,183 B2, titled "THROMBUS. FILTER WITH BREAK-AWAY ANCHOR MEMBERS" issued to DiMatteo, dated September 16, 2003; each of which is incorporated herein by reference in its entirety.

**[0004]** Typically the vessel filter includes a plurality of radially expandable legs that supports one or more filter baskets which are conical in configuration. The device is adapted for compression into a small size to facilitate delivery into a vascular passageway and is subsequently expandable into contact with the inner wall of the vessel. The device may later be retrieved from the deployed site by compressing the radially expanded legs and the associated baskets back into a small size for retrieval. Alternatively, the vessel filter may be configured for permanent implantation. The radially expandable leg may further include engagements for anchoring the filter in position within a blood vessel (e.g., vena cava). For example, the expandable legs may have hooks that can penetrate into the vessel wall and positively prevent migration of the filter in either direction along the length of the vessel. The body of the filter may include various biocompatible materials including compressible spring metals and shape memory materials to allow easy expansion and compression of the filter within the vessel. The hooks on the radially expandable legs may further include materials more elastic than the legs to permit the hooks to straighten in response to withdrawal forces to facilitate withdrawal from the endothelium layer without risk of significant injury to the vessel wall. In one variation, the hooks are formed on the ends of a portion of the radially expandable legs, but not on others.

**[0005]** For treatment of recurrent pulmonary embolism, a vessel filter may be permanently implanted in the patient's vena cava. Alternatively, the vessel filter may be

implanted in the patient's vena cava for a few weeks, after which the vessel filter is removed. However, during the implanted period, it is generally difficult to monitor the condition of the vessel filter. For example, to verify that the vessel filter has not migrated along the length of the blood vessel or become misaligned post-implantation, complex imaging systems such as MRI, CT Scan or X-ray may be needed to determine the condition of the vessel filter. In addition, the hooks on the implanted vessel filter may penetrate and/or perforate the blood vessel wall. Perforation of the blood vessel may require immediate intervention by the physician. Furthermore, a possible contraindication associated with the implantation of vessel filter is the build-up of significant amount of trapped thrombus either within the implanted filter or directly upstream from the vessel filter. The built of thrombus may result in complications that require intervention by the physician. For example, when too much thrombus has been trapped inside and/or behind the vessel filter, the build-up may impede blood flow in the blood vessel. The pressure build-up due to the partial blockage of the blood flow may also lead to expansion of the blood vessel, which may cause tilting and/or migration of the vessel filter. In addition, for retrievable filter application, too much thrombus build-up may also make it difficult to compress the vessel filter and thus hinder the vessel filter removal process. In some medical condition, it may also be desirable to wait till the captured thrombus has lysed before the physician proceed with the removal of the vessel filter. Thus, it may be desirable to monitor the position/orientation of the implanted vessel filter and/or the condition/parameter of the implanted vessel filter.

[0006] Various vascular devices with built-in sensors have been previously disclosed. Examples of some of these filters are described in U.S. Patent Application, Publication No. 2003/0171803 A1, titled "ENDOVASCULAR DEVICE FOR ENTRAPMENT OF PARTICULATE MATTER AND METHOD FOR U.S.E" by Shimon, published September 11, 2003; U.S. Patent Application, Publication No. 2002/0165575 A1, titled "VASCULAR FILTRATION DEVICE" by Saleh, published November 7, 2002; U.S. Patent Application, Publication No. 2004/0082867 A1, titled "VASCULAR GRAFT WITH INTEGRATED SENSOR" by Esch et al., published April 29, 2004; U.S. Patent No. 6,652,556, titled "FILTER APPARATUS FOR OSTIUM OF LEFT ATRIAL APPENDAGE" issued to VanTassel et al., dated November 25, 2003; U.S. Patent No. 5,053,008, titled "INTRACARDIAC CATHETER" issued to Bajaj, dated October 1, 1991; U.S. Patent No. 6,623,507 titled "VASCULAR FILTRATION DEVICE" issued to Saleh, dated September 23, 2003; U.S. Patent No. 6,702,847 titled "ENDOLUMINAL DEVICE WITH INDICATOR MEMBER FOR REMOTE DETECTION OF ENDOLEAKS AND/OR CHANGES IN

DEVICE MORPHOLOGY” issued to DiCarlo, dated March 9, 2004; U.S. Patent No. 6,053,873 titled “PRESSURE-SENSING STENT” issued to Govari et al., dated April 25, 2000; U.S. Patent No. 6,092,530 titled “REMOTELY INTERROGATED IMPLANT DEVICE WITH SENSOR FOR DETECTING ACCRETION OF BIOLOGICAL MATTER” issued to Weissman et al., dated July 25, 2000; U.S. Patent No. 6,206,835 titled “REMOTELY INTERROGATED DIAGNOSTIC IMPLANT DEVICE WITH ELECTRICALLY PASSIVE SENSOR” issued to Spillman et al., dated March 27, 2001; U.S. Patent No. 6,726,703 titled “DISTAL PROTECTION DEVICE AND METHOD” issued to Broome et al., dated April 27, 2004; each of which is incorporated herein by reference in its entirety. Most of these devices utilize sensors to monitor the physiological condition of the surrounding environment (e.g., blood pressure, temperature, blood chemistry, etc.), and the sensors are not designed to monitor the condition of the device itself.

[0007] Applicants recognize the desirability of an improved filter with a mechanism and/or a sensor for monitoring the condition of the implanted vessel filter, for example, an electronic circuit that is capable of monitoring a physical parameter of the vessel filter, and thereby notifying the user of the condition of the vessel filter. Applicants also recognize the desirability of a device that can provide efficient and cost-effective verification of the condition of the implanted vessel filter, which may improve the physicians confidence in the implanted device and allow the physician to intervene when the vessel becomes dislodged through migration or when too much thrombus has been captured within the vessel filter. In particular, applicants recognize a device that allows regular monitoring of the vessel filter while the patient is away from the hospital or the treatment facility may be especially useful in preventing occurrences of serious complications while the vessel filter is implanted.

#### BRIEF SUMMARY OF THE INVENTION

[0008] Accordingly, described herein is an implantable vessel filter having an integrated sensing capability for monitoring the conditions that are associated with the filter. For example, an electronic circuit may be implemented on the vessel filter to measure a physical parameter (e.g., strain, position of the filter legs, pressure on the filter body, etc.) that corresponds to the condition of the vessel filter. This improved vessel filter may detect the capturing and/or build-up of thrombus within the implanted vessel filter. In one variation, a vessel filter includes one or more legs or other members that would themselves perform as a sensor device for detecting distention, which would indicate the presence of a clot or thrombus therein. In one design, a passive inductive circuit is connected to one or more of the filter legs to measure the strain on the filter legs. In another design, technologies similar

to the ones implemented on a passive RFID system may be implemented on the vessel filter to direct energy to and receive information from micro-electronics connected to or attached on the legs or members of the filter.

**[0009]** A miniaturized sensor (e.g., pressure sensors, piezoresistive sensors, optical sensors, strain gauge, etc.) may also be positioned on or integrated within the vessel filter body. The miniaturized sensor may be adapted for measuring the strain or other physical parameters on the filter legs. Alternatively, the miniaturized sensor may be configured for measuring the amount of blood clots that are captured within the vessel filter. An external device may be utilized periodically to provide energy to the micro-electronics on the vessel filter, which would then relay information regarding the desired measurements (e.g., distention or migration of the device, increased strain on the vessel filter legs, increase shear stress on the vessel filter legs, etc.). Other electromagnetic and/or inductive mechanisms, that are well known to one of ordinary skill in the art, may also be implanted to provide energy to, and/or establish communication with, the micro-electronics embedded on the vessel filter.

**[0010]** The vessel filter monitor may be utilized by the physician to assess the condition of the implanted vessel filter during post-implantation follow-up visits. In another variation, the vessel filter monitoring system may be implemented in the form of a device carried by the patient following implantation of the vessel filter to monitor the condition of the implanted vessel filters. The external device would query the embedded micro-electronics, perhaps, once or twice a day, and should a problem be detected (e.g., distention, migration, uneven distribution of strain or stress, etc.), the device would notify the patient and/or the physician. Although in the preferred design, an electrically passive circuit is implemented to measure the condition of the vessel filter, one of ordinary skill in the art, having the benefit of this disclosure, would appreciate that an active circuit may also be utilized to measure the condition of the vessel filter. For example, an active circuit with an on-board battery may be implemented to measure the strain on the legs of the vessel filter and then transmit the measured data to a remote device. Alternatively, the circuit may be provided with a rechargeable battery that can be energized through electromagnetic waves.

**[0011]** The improved implantable vessel filter may provide one or more of the various advantages described herein, including, for example, early notification of significant thrombus build-up (e.g., detection of distension or increased strain in the vessel filter legs, etc.), early notification of filter migration, displacement, and/or perforation, etc. In the case that the vessel filter provides notification of excessive thrombus build-up, the physician may then remove the filter and the captured thrombus. Alternatively, the physician may clear the

captured thrombus from the filter, for example, by introducing a catheter to remove the captured thrombus through suction or by injecting the patient with an anticoagulation medication. In the case that the vessel filter provides notification of migration and/or displaced alignment thereof (e.g., uneven distribution of strain in the various vessel legs may indicate that the vessel filter has moved or has become misaligned with the blood vessel), the physician may remove the migrated and/or misaligned vessel filter.

**[0012]** Detection of uneven strain, stress, and/or pressure distribution on the filter appendages or body structure may suggest that possible complication has occurred with the implanted vessel filter. This would prompt the physician to order additional tests (e.g., X-ray, MRI, etc.) to further verify the condition of the implanted vessel filter. In the event that complications have occurred, the physician may then provide necessary intervention. For example, the detection by the remote monitor of uneven strain distribution on the implanted vessel filter may prompt the physician to order an MRI. The MRI may show that the vessel filter has perforated the blood vessel and blood is leaking out of the blood vessel into the abdomen of the patient. Surgical intervention may then be provided to repair the damage vessel and/or removed the dislodged vessel filter.

**[0013]** In one embodiment, a vessel filter includes a plurality of elongated appendages, wherein each of said appendages has a distal end and a proximal end, said plurality of appendages being coupled together at the proximal ends thereof, said appendages being configured to extend radially from said proximal end in a distal direction and away from a central longitudinal axis of said vessel filter, wherein said plurality of elongated appendages is collapsible toward said central longitudinal axis, and an electronic circuit connected to at least one of said appendages, said electronic circuit being configured to measure a physical parameter of the vessel filter.

**[0014]** In another embodiment, a vessel filter for implantation in a hollow body organ in a human includes a plurality of elongated appendages, wherein each of said appendages has a distal end and a proximal end, wherein said plurality of appendages are coupled together at the proximal ends thereof, said appendages being configured to extend radially from said proximal end in a distal direction and away from a central longitudinal axis of said vessel filter, wherein said plurality of elongated appendages is collapsible toward said central longitudinal axis, a sensor coupled to at least one of said plurality of elongated appendages, wherein said sensor is adapted to monitor the condition of said vessel filter, and an electronic circuit connected to said sensor, wherein said electronic circuit is adapted to detect an electrical signal from said sensor.

[0015] In yet another embodiment, an implantable particle capturing device, includes a compressible vessel filter adapted for implantation into a body vessel, and an electronic circuit attached to the vessel filter, said electronic circuit being adapted to determine a distension of said vessel filter. In still another embodiment, an implantable particle capturing device includes a vessel filter adapted for implantation into a body vessel, and an electronic circuit attached to the vessel filter, said electronic circuit being adapted to measure a parameter on at least a portion of said vessel filter.

[0016] In one embodiment, a method for monitoring the condition of an implanted vessel filter includes remotely energizing a passive circuit which is coupled to said implanted vessel filter, and interrogating said passive circuit to determine a physical parameter of said vessel filter.

[0017] These and other embodiments, features and advantages of the present invention will become more apparent to those skilled in the art when taken with reference to the following more detailed description of the invention in conjunction with the accompanying drawings that are first briefly described.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1A illustrates a variation of an implantable vessel filter with an integrated electronic circuit for measuring the strain on the radially expandable legs.

[0019] FIG. 1B illustrates the particular electronic circuit connection for measuring the strain on the vessel filter legs which are implemented in the vessel filter of FIG. 1A. In this variation, conductive bridges are provided between the legs.

[0020] FIG. 1C illustrates another variation where the conductive bridge between the two legs includes a strain gauge which is highly sensitive to extension due to pressure and/or stress that is exerted on it.

[0021] FIG. 1D illustrates yet another variation where the structure of the legs is configured with materials/profile that are highly sensitive to increase in strain due to distension of the filter structure.

[0022] FIG. 2 is a circuit representation illustrating the variable resistive characteristics due to strain exerted on each of the legs and the corresponding conductive bridge.

[0023] FIG. 3A illustrates one configuration where the electronic circuit is designed to measure the change in strain on the two filter legs.



[0024] FIG. 3B illustrates another configuration where the conductive bridge is configured with a strain gauge material with resistive characteristics that are highly sensitive to changes in strain.

[0025] FIG. 3C illustrates another configuration where the electronic circuit for strain measurement is configured to measure the strain on selective pairs of filter legs independent of the other legs.

[0026] FIG. 3D illustrates another configuration where the electronic circuit for strain measurement is configured to measure the strain on each of the conductive bridges independently.

[0027] FIG. 3E illustrates another configuration where the filter legs are electrically connected in a parallel manner such that an electronic measurement circuit may be utilized to measure the strain on all the legs in the vessel filter as a single consolidated parameter.

[0028] FIG. 4 illustrates another variation where the vessel filter includes two filter cones.

[0029] FIG. 5A illustrates the physical connections in the distal legs of the vessel filter shown in FIG. 4. The three pairs of filter legs are measured independently with corresponding electronic measurement circuits embedded within the filter sleeve. The vessel filter is shown without its proximal legs.

[0030] FIG. 5B is an electrical circuit diagram representing the electrical connections of the vessel filter shown in FIG. 5A.

[0031] FIG. 6 illustrates another design, where pairs of strain gauge are implemented between the adjacent legs to measure the distention of the vessel filter due to trapping of thrombus within the vessel filter.

[0032] FIG. 7A illustrates another variation of the vessel filter where the conductive bridge includes interlinks.

[0033] FIG. 7B is a frontal view of an expanded vessel filter implementing the interlinked bridge design shown in FIG. 7A. The vessel filter is viewed from the proximal end (i.e., head end) down the longitudinal axis of the filter toward the distal end of the vessel filter.

[0034] FIG. 8A illustrates one variation of a passive circuit system for measuring the strain on the vessel filter legs by remotely energizing a passive measurement circuit and detecting changes in the passive measurement circuit due to resistive changes on the vessel legs as a result of change in strain.

[0035] FIG. 8B illustrates another representation of a passive circuit measurement system showing the inductive elements of the circuit.

[0036] FIG. 9A illustrates one variation where the inductive circuit loop is provided on the circumferential surface of the filter sleeve.

[0037] FIG. 9B illustrates another design where the inductive circuit loop is provided on a surface on the vessel filter sleeve.

[0038] FIG. 10 illustrates another design variation where sensors are connected to the legs of the vessel filter to measure strain and/or strain on the vessel filter legs. In the configuration shown in FIG. 10, a passive circuit is utilized to measure changes in the sensors and transmit data to a remote device.

[0039] FIG. 11A illustrates a design variation where a strain gauge is wrapped around a filter leg on the vessel filter in a helical manner for measuring the distension of the leg due to pressure exerted on the filter leg. The figure also illustrates a corresponding passive circuit for measuring the strain gauge.

[0040] FIG. 11B is a circuit diagram representing the electrical connection of the strain gauge measurement circuit shown in FIG. 11A. The strain gauge is represented by a variable resistor in the diagram.

[0041] FIG. 11C illustrates a variation where multiple sensors are implemented on the vessel filter to determine the condition of the filter.

[0042] FIG. 12 is another design variation where sensors are provided on the vessel filter to detect the presence of thrombus within the vessel filter.

[0043] FIG. 13 is yet another design where the vessel filter is configured with a center post with embedded sensors to detect the presence of thrombus within the vessel filter. The center post may be further configured with slots or grooves to prevent the entanglement of the filter legs when the filter legs are collapsed onto the center post in the compressed configuration. The rod may also serve as an antenna for transmission of electrical signals.

[0044] FIG. 14A illustrates another variation where sensing members extending from the sleeve (i.e., head portion) of the vessel filter are provided to detect the presence of blood clots within the vessel filter.

[0045] FIG. 14B illustrates one particular design where the proximal portion of the sensing members are connected to strain gauges for detecting or distension of the sensing members. A passive circuit may be implemented to measure the variable resistance of the strain gauges.

[0046] FIG. 14C illustrates another configuration of the sensing members where an electronic circuit is provided to measure the strain on the sensing members by directing current through the sensing members and measuring the changes in the strain of the sensing members.

[0047] FIG. 14D illustrates another variation where a strain gauge is provided between a pair of sensing members to measure the displacement and/or distension of the sensing members due to the presence of a blood clot in the vessel filter. The figure is shown within a blood clot engaging the sensing members.

[0048] FIG. 15A illustrates another variation of a vessel filter with integrated sensing members where the presence of blood clots can cause the displacement of the sensing members.

[0049] FIG. 15B illustrates a design where a strain gauge positioned parallel to a spring, which supports the sensing members, is implemented to measure the displacement of the sensing members.

[0050] FIG. 16 illustrates another variation where the sensing members are connected to sensors placed within the sleeve of the vessel filter. The sensors are configured to measure stress and/or displacement of the sensing members.

[0051] FIG. 17 illustrates another implementation where a reference beacon is utilized to determine the position of the vessel filter within the body of the patient.

#### DETAILED DESCRIPTION OF THE INVENTION

[0052] The following detailed description should be read with reference to the drawings, in which identical reference numbers refer to like elements throughout the different figures. The drawings, which are not necessarily to scale, depict selective embodiments and are not intended to limit the scope of the invention. The detailed description illustrates by way of example, not by way of limitation, the principles of the invention. This description will clearly enable one skilled in the art to make and use the invention, and describes several embodiments, adaptations, variations, alternatives and uses of the invention, including what is presently believed to be the best mode of carrying out the invention.

[0053] Before describing the present invention, it is to be understood that unless otherwise indicated this invention need not be limited to applications in humans. As one of ordinary skill in the art would appreciate, variations of the invention may be applied to other mammals as well. Moreover, it should be understood that embodiments of the present invention may be applied in combination with various catheters, tubing introducers or other

filter deployment devices for implantation and/or retrieval of the filter in a vessel within a patient's body.

[0054] A vena cava filter is used herein as an example application of the filter device to illustrate the various aspects of the invention disclosed herein. In light of the disclosure herein, one of ordinary skill in the art would appreciate that variations of the filter device may be applicable for placement in various hollow body organs and elongated cavities in a human body for capturing particles in a fluid stream. It is also contemplated that the filter device described herein may be implemented for capturing particles other than blood clots.

[0055] It must also be noted that, as used in this specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, the term "a hook" is intended to mean a single hook or a combination of hooks, "a fluid" is intended to mean one or more fluids, or a mixture thereof.

[0056] In one aspect of the invention, the implantable vessel filter 2 includes a plurality of legs 4 (e.g., flexible or semi-flexible wiring, etc.) extending from a sleeve 6 in the radial direction towards the distal end 8 of the device. In this variation, an electronic circuit connected to a leg 4 is provided to measure the strain in the leg 4. It is well known to one of ordinary skill in the art that the electric resistance of a wire increases with increasing strain and decreases with decreasing strain. By measuring the changes in resistance in the deployed metallic legs of a vessel filter, one may determine the increase or decrease in strain experienced by the filter leg. When a thrombus is trapped within a deployed filter, the blood flow pushes the thrombus against the filter legs, thus increasing strain experienced by the filter legs. By measuring the strain on the filter legs one may be able to determine the presence of a thrombus.

[0057] An electronic measurement circuit may be connected to the proximal portion of the legs and placed within the sleeve of the vessel filter. The legs are configured with materials such that they may be collapsed toward a central axis along the length of the device for insertion and/or retrieval from a patient's vascular system. A hook is provided on the distal end of each of the legs, such that when the vessel filter is deployed inside a blood vessel, the hooks engage the blood vessel wall and anchor the filter in the blood vessel. Each of the filter legs may include various metals or metal alloys (e.g., nitinol) that are well known to one of ordinary skill in the art for implantation within a blood vessel. In one variation, each of the filter legs includes a conductive alloy which increases the sensitivity factor of the resistive characteristics of the filter leg in response to strain exerted on the filter leg. Various

metals and metal alloys that are well known to one of ordinary skill in the art to have high sensitivity to strain (e.g., platinum, platinum-iridium, platinum-tungsten, isoelastic alloy, constantan alloy, Nichrome V, Karma, etc.) may be incorporated during the manufacturing of the vessel filter legs.

**[0058]** The plurality of legs 4 may be configured for deployment into one or more cone shaped filters. FIG. 1A illustrates an example implementing a single cone filter design where six legs 10, 12, 14, 16, 18, 20 expand to form a conical-shaped filter basket 22 centered around the longitudinal axis 24 of the device. In this particular design, electric conductive bridges 26 connect each of the filter legs 10, 12, 14, 16, 18, 20 with adjacent filter legs. An electronic measurement circuit 28 may be configured, as shown in FIG. 1B, to measure the changes in strain in the pairs of corresponding legs 4. Each pair of legs 4 may be configured with a corresponding electronic measurement circuit. Alternatively, a single electric measurement circuit may be adapted to measure the strain on different pairs of filter legs 4 either serially or simultaneously. The electronic measurement circuit may include an integrated circuit implemented on a silicon-based chip. Alternatively, the electronic measurement circuit may be implemented on a thin polymeric film. The electronic measurement circuit may include various active or passive circuits that are well known to one of ordinary skill in the art for measuring resistance and/or impedance.

**[0059]** The conductive bridge 26 may include material with low sensitivity to strain and serves the primary purpose of conducting electricity between the filter legs, such that the resistance changes detected by the electronic measurement circuit are primarily dependent on the strain exerted on the filter legs 4. Alternatively, the conductive bridge 26 may be sensitive to strain, whereby the variation in resistance detected by the electronic measurement circuit 28 represents the combined change in resistance in the leg portions and the conductive bridge. In another design, as shown in FIG. 1C, the filter legs 4 include material with low sensitivity to strain while the conductive bridge 26 includes a strain gauge material or other materials that are sensitive to strain, such that when a trapped thrombus pushes on the filter legs 4 and/or the conductive bridge 26, an increase in strain in the conductive bridge occurs. In yet another design, as shown in FIG. 1D, portions 28 of the filter legs 4 include strain gauge material. The strain gauge portion 28 of the filter leg 4 may also have structure or pattern that increases its sensitivity factor. When a thrombus is trapped between the filter legs 4, the blood flow pushes on the thrombus which in turn applies pressure on the filter legs 4 and forces them to divert from each other. As a result, the strain gauge portion 28 of the filter leg 4 will experience increase in strain.

**[0060]** Referring to FIG. 2, a circuit model illustrating the variable resistive characteristic of a pair of filter legs 30, 32 within a deployed filter 2 is shown. In this model each segment of the leg 30, 32 and each segment of the conductive bridge 34, 36 within the electric circuit loop is represented by a variable resistor 38. Increase in strain in any of the segments will result in change in overall resistance and/or impedance of the circuit loop which is measured by the electronic measurement circuit 28 connected to the filter legs 30, 32. As one of ordinary skill in the art having the benefit of this disclosure would appreciate, various circuit configurations may be applicable for measuring the strain in the plurality of legs in a vessel filter. Selective examples of connections between the electronic measurement circuit and the filter legs are illustrated below.

**[0061]** In one variation, as shown in FIG. 3A, the strain in the filter legs is measured in pairs. R1 and R2 represent the variable resistive characteristics in a corresponding pair of filter legs. For each pair of filter legs that needs to be monitored, an electronic measurement circuit 28 is provided. In one configuration, each pair of adjacent filter legs is connected to a measurement circuit 28 such that for a six leg filter, five measurement circuits are provided. Each of the measurement circuits may transmit information regarding the strain experienced by its corresponding pair of legs to a receiving device at a different transmission frequency. A control circuit in the receiving device may poll the different measurement circuits to collect the data and then determine the strain distribution in the filter legs. Uneven strain distribution in the filter legs may suggest that the filter is misaligned with the blood vessel, or that the vessel filter has penetrated through or perforated the blood vessel wall. Alternatively, a control circuit may be implemented to collect strain information on the different pairs of filter legs and then transmit the data as a group to a remote receiving device.

**[0062]** FIG. 3B illustrates a variation where the conductive bridge has two segments and each segment is sensitive to changes in strain. The variable resistive characteristics of the two conductive bridge segments are represented as r1 and r2. A thrombus may apply pressure directly on the conductive bridge and cause an increase in strain. The thrombus may also force the filter legs apart and indirectly extend the conductive bridge laterally and cause an increase in strain. Similar to the above configuration, each pair of filter legs R1, R2 and its corresponding bridge r1, r2 may be connected to a separate measurement circuit 28.

**[0063]** In FIG. 3C, a variation utilizing a single measurement circuit 28 to measure the strain in the various filter legs 4 is shown. A switch 40 is provided such that different electric loops may be established to measure the resistance R1, R2, R3, R4 in the different filter legs. The switch may include electronic gates implemented on an integrated circuit.

FIG. 3D illustrates another variation where a pair of switches 42, 44 are implemented to measure strain in the different pairs of filter legs 46, 48, 50, 52 selectively. FIG. 3E illustrates yet another variation where the electric connection between the legs are configured such that the strain in the various filter legs is measured simultaneously to determine the overall strain on the vessel filter. The overall strain on the vessel filter may correspond to the distension of the filter structure. In the example shown in FIG. 3E, the filter has six legs and their corresponding variable resistive characteristics in response to strain are represented by R1–R6. As one of ordinary skill in the art having the benefit of this disclosure would appreciate, electric measurement circuits 28 may be configured to support measurement of strain in filters with any number of legs, including those of configurations described herein.

**[0064]** Referring now to FIG. 4, another variation of a vessel filter 2 implementing a dual cone filter 54, 56 structure is shown. An electronic circuit 28 may be provided to measure the strain in one or more of the filter legs. Strain in both the distal 56 and proximal filters 54 may be measured. However, in this particular design, passive circuits are implemented to measure the strain on only the six distal filter legs 58, 60, 62, 64, 66, 68. The six distal legs are configured as three separate pairs for measurement. A simplified drawing illustrating the connections in the six distal legs 58, 60, 62, 64, 66, 68 is shown in FIG. 5A. The passive electronic circuits 70, 72, 74 are connected to the three pairs of distal legs 58, 60, 62, 64, 66, 68 as shown in FIG. 5B. Each of the passive circuits 70, 72, 74 may be configured with a different resonance frequency such that a remote device with an interrogation circuit may utilize the different resonance frequency to query each of the three passive electronic circuits 70, 72, 74 independently of each other. The data collected from the three passive electronic circuits 70, 72, 74 may be utilized by a control circuit in the remote device to determine whether there are changes in the overall strain experienced by the filter legs and the strain distribution between the different pairs of filter legs.

**[0065]** Although in the example discussed above, the plurality of legs forms two filter baskets along the longitudinal length of the device, one may configure the device with only one filter basket, or alternatively with three or more filter baskets. In addition, the device may be configured with three or more legs forming each basket and is not limited to the six-legged basket as shown above. Also discussed earlier, hooks 76 may be provided on the distal end of each leg. As one of ordinary skill in the art would appreciate, the precise length and angle of the hooks 76 may be designed to provide secure attachment to the vessel wall without causing perforation or tearing. Moreover, hooks may be provided on all the distal legs or only on some of the distal legs. Hooks may also be provided on the proximal legs if

desired. Furthermore, secondary struts, which may also serve as a conductive bridge, may be provided for interconnecting two or more of the radially expandable legs. The secondary struts may increase wiring density for each filter basket, which may in turn increase the filters capability to capture smaller particles.

**[0066]** In addition, two or more conductive bridges may also be implemented. For example, as shown in FIG. 6, a pair of conductive bridges 78, 80 is implemented between each pair of adjacent filter legs 4. Each segment of the conductive bridges may also be configured as a strain gauge. FIG. 7A illustrates another variation where the conductive bridges are configured as interlinks 82. FIG. 7B shows a six-legged filter 84 utilizing interlined 82 connections between the filter legs 4.

**[0067]** As discussed above, various passive sensing circuits may be implemented to measure the strain in the filter legs. Passive circuits, such as those described in U.S. Patent No. 5,581,248, U.S. Patent No. 6,206,835 B1, U.S. Patent No. 6,682,490, and U.S. Patent Application No. 2004/0082867 A1, each of which is incorporated by reference in its entirety, may be used to measure the strain in the vessel filters described herein. An example of a passive circuit implemented to measure the strain in the filter legs is shown in FIG. 8A. The exciter/interrogator unit 88 includes an exciter/interrogator coil 90, a voltage controlled oscillator 92, and a load sensing resistor 94. The oscillator 92 provides an excitation signal to the exciter/interrogator coil 90 and the load sensing resistor 92 which are coupled in series. The exciter/interrogator unit 88 is coupled via the cable 96 to the main circuitry 98 which includes signal conditioning electronics 100 and a data processing and control section 102. The data processing and control section 102 produces a control signal on line 105 for controlling the frequency and the magnitude of the excitation signal that the oscillator 92 applies to the exciter/interrogator coil 90. The exciter/interrogator coil 90, sensing resistor 94 and oscillator 92 provide a resonant exciter/interrogator circuit that is used to induce currents in a coil 104 within the implant device 106 in order to perform interrogation.

**[0068]** The electronic measurement circuit 108 embedded in the vessel filter is connected to two of the filter legs. The variable resistive characteristics of the filter legs are represented as R11 and R12. The electronic measurement circuit 108 includes a sense coil 104 for receiving electromagnetic energy from the exciter/interrogator unit 88. The sense coil 104 may be integrally secured to a surface on the sleeve of the vessel filter. The sense coil 104 is part of a passive resonant sensing circuit 110 which includes, for example, a capacitor 112 and the strain gauges (i.e., the filter legs to be measured) 114, 116 in electrical series with the sense coil 104. In applications where sensors are applied on the vessel filter to



measure strain or distension of the vessel filter, the electronic measurement circuit 108 may be connected to the sensor instead of the vessel filter legs. The sensor can be any sensor which produces a variable impedance (e.g., resistance, capacitance or inductance), or which produces an output that can be converted into a variable impedance that can change or modulate the impedance of one or more of the resonant circuit components. The sensor can be any of a variety of known types of sensors which may be used to sense the condition of the vessel filter. Such parameters to be measured may include, but are not limited to, strain on the sensor legs, force or pressure on the filter legs, shear stress on the filter legs, displacement of the filter legs, distension of the vessel filter, presences of a blood clot in the vessel filter. Exemplary sensor types include electrical sensors, piezoelectric sensors, sonic sensors, optical sensors, microfluidic sensors, chemical sensor, membrane, strain gauge, thermal sensors, pressure sensors, magnetohydrodynamic sensor, magnetic sensors, magnetostrictive sensors, biological sensors, microelectromechanical sensors (MEMs), etc. The sensor itself may be characterized as an impedance-based sensor whose resistance, capacitance and/or inductance varies directly with respect to frequency as a function of the sensed parameter, or another type of sensor whose output can be converted into a variable impedance.

[0069] As shown in FIG. 8A, the sensors 114, 116 (i.e., the filter legs) are represented by a variable resistance R11, R12, which varies based on the strain exerted on the filter legs. In an alternative variation, the sensor may provide a capacitance, inductance and/or resistance which varies based on a sensed parameter. When a sensor is combined with the sense coil 104 alone or together with one or more elements (e.g., capacitor 112), a resonant sensing circuit 110 (e.g., LC or LRC) may be obtained.

[0070] The sensing circuit 110 exhibits a resonant frequency which is defined as the frequency which is the point of maximum sensitivity to changes in the excitation current  $I_p$  for a given change in the impedance of the filter legs R11, R12. The resonant frequency  $f_s$  is determined by the sum total of the reactive elements of the circuit, which includes the inductance 118 of the sense coil 104, and the inductance 120 of the exciter/interrogator coil 90, as well as the capacitance 112 and parasitic capacitances  $C_{p1}$  and  $C_{p2}$ , shown in FIG. 8B, and the value of a coupling constant K. The amplitude of the current through the coil 104 is also a function of the sensors 114, 116, particularly at the resonant frequency of the sensing circuit 110. When the exciter/interrogator coil 90 has an AC signal applied, current in the primary or exciter/interrogator coil 90 induces current in the secondary or sense coil 104, as in an air gap transformer. This current in the sense coil 104, however, is reflected back to the

exciter/interrogator coil 90 by the mutual coupling of the two coils. The sensing resistor 94 is used to detect the current in the exciter/interrogator coil 90.

[0071] When the excitation frequency is approximately at the resonant frequency of the sensing circuit 110, the current in the exciter/interrogator coil 90 changes maximally in relation to the value of the filter legs 114, 116. Thus, the condition of the filter legs can be determined as a function of the detected current in the exciter/interrogator coil 90. Using an amplifier 122, the signal conditioning electronics 100 amplify the voltage developed across the sensing resistor 94 by the exciter/interrogator circuit current  $I_p$ . This amplified voltage is then rectified and low pass filtered via a rectifier and low pass filter circuit 124 to provide a DC voltage output  $V_{dc}$ . The control circuit 102 then uses the DC value to determine the state or output of the filter legs 114, 116.

[0072] FIG. 8B provides a more detailed circuit model of an exciter/interrogator unit 88 and the implant device 106. As shown, the exciter/interrogator unit 88 includes the exciter/interrogator coil 90 that has a determinable inductance  $L_p$ . The coil 90 and associated components of the exciter/interrogator unit 88 also will exhibit an overall parasitic capacitance,  $C_{p1}$ , that appears in parallel with the coil inductance. The exciter/interrogator unit 88 further includes the variable frequency oscillator 92 and the sensing resistor 94 used to sense the primary or excitation current  $I_p$ . Thus, all components in the exciter/interrogator unit 88 are known quantities for each application.

[0073] The resonant sensing circuit 110 includes the sense coil 104 which has a determinable inductance,  $L_s$ , in one embodiment; or in another embodiment an inductance which varies in relation to the sensed parameter. In such an embodiment, the sense coil 104 itself forms part of the sensing element. The sense coil 104 also has an associated parasitic capacitance, which parasitic capacitance is in effect part of the capacitance  $C_{p2}$  which is a discrete capacitor selected to optimize the sensitivity of the device 106 to changes in the value of the sensing elements 114, 116. In other words, the value of  $C_{p2}$  can be selected, such as based on experimental data for specific circuits, to maximize the current  $I_p$  induced in the exciter/interrogator unit 88 as a function of changes in the resistance of the sensing element 114, 116. The sensing circuit 110 also includes the additional discrete capacitor 112 which is selected to adjust the frequency at which the change in current versus change in sensing element resistance ratio is optimized. The basic operation of a passive circuit system 30 is explained more fully in U.S. Patent No. 5,581,248, which is incorporated herein by reference in its entirety.

[0074] The sense coil may be integrated with the vessel filter through various methods well known to one of ordinary skill in the art. An example of sense coil integration is shown in FIG. 9A where the sense coil 104 is wrapped around the sleeve 6 of the filter head. The coil 104 may be also be placed on the inner surface of the sleeve or be embedded within the sleeve. In another variation, the sense coil 104 is printed on a surface on the filter sleeve 6 as shown in FIG. 9B.

[0075] In another aspect of the invention, a sensor is placed on the vessel filter to determine the condition of the vessel filter. For example, a strain gauge may be placed on the vessel legs to detect the strain and/or distension of the legs. Although both passive and active electronic circuit may be implemented to measure changes detected by the sensor, a passive circuit is used in the preferred design. For example, a passive circuit 130 shown in FIG. 10 may be utilized to measure the two sensors 132, 134 which are placed on the vessel filter.

[0076] In one variation, the sensor includes a strain gauge 136 wrapped around a vessel leg 138 in a helical manner, as shown in FIG. 11A. A pressure applied on the filter leg that causes distension or bending of the filter leg can lead to the strain on the strain gauge 136 to increase. This change in strain may be measured with an exciter/interrogator circuit interacting with the passive electronic measurement circuit 140 that is connected to the strain gauge 136 on the filter leg 138. FIG. 11B illustrates the complete passive circuit loop 142, with the strain gauge 136 being repressed as a variable resistor 144 that changes resistance in response to strain exerted on the strain gauge 136.

[0077] A strain gauge may be implemented on one or more of the filter legs to detect distension of the vessel filter. The strain gauge may be placed on the filter legs in various patterns and configurations well known to one of ordinary skill in the art. For example, the strain gauge material may be deposited on the filter legs through plasma deposition. The strain gauge material may also be embedded on or within a polymer coating placed on the surface of the vessel filter. In addition, two or more strain gauges 136 may be placed on different portions of a given leg to monitor strain distribution along the length of the filter 2, as shown in FIG. 11C. Furthermore, other sensors that are well known to one of ordinary skill in the art may also be implemented on the vessel filter to monitor the condition of the filter legs. For example, pressure sensors may be distributed along the vessel filter body to detect pressure distribution on the body of the vessel filter. In another design, wire mounted pressure sensors may be implemented on the vessel filter legs. In yet another design, a sensor similar to the PressureWire® Sensor (RADI Medical Systems) may be integrated within the vessel filter.

[0078] In another aspect of the invention, a sensor 146 is provided on the vessel filter to detect the presence of a thrombus or other objects that have been captured within a deployed filter. For example, as shown in FIG. 12, pressure sensors 146 are placed on the legs of the vessel filter to detect the presence of blood clots. A passive or active circuit 148 may be implemented to drive the sensor and detect signals provided by the sensor 146. Other sensors 146 that are well known to one of ordinary skill in the art may also be implemented on the vessel filter to detect thrombus.

[0079] In another variation, the vessel filter includes a center post 150 extending along the longitudinal axis of the vessel filter 2, as shown in FIG. 13. Sensors 146 placed on the center post 150 may be used to detect the presence of thrombus. An electronic circuit may be provided either within the center post 150 or embedded in the sleeve of the vessel filter for detecting signals from the sensors. The center post 150 may be configured with slots 152 for receiving the hooks 76 on the filter legs 4 when the filter legs 4 are compressed onto the center post. The slots on the center post may be adapted to prevent the filter legs 4 hooks from entanglement while the filter 2 is in the compressed position, as described more fully in pending US patent application Serial No. 10/912,601, which is incorporated herein by reference in its entirety.

[0080] In yet another variation, sensing members 154, (which may be whisker-like extension elements) extending from the sleeve 6 of the vessel filter 2 are utilized to detect the presence of thrombus in the deployed filter. An example, illustrated in FIG. 14A, shows the sensing members 154 extending from the base of the sleeve 6 towards the distal end of the filter 2. When a blood clot is captured by the vessel filter 2 it will glide towards the sleeve 6 and engage the sensing members 154. FIG. 14B illustrates one variation of a circuitry for detecting the presence of the blood clot. In this variation, the proximal end of the sensing member is connected to a strain gauge 156. The blood clot applies pressure on the sensing member and a force is transmitted through the sensing element to the strain gauge 156. An electronic measurement circuit 158 is used to measure the strain gauge. The electronic circuit 158 may be either a passive or an active circuit.

[0081] In another variation, the sensing member 154 includes a strain gauge material itself. An electronic measurement circuit 158 is connected to the sensing member 154 in a serial manner to detect changes in the sensing member as shown in FIG. 14C. In yet another design, a strain gauge 160 is placed between the two sensing members 154 as shown in FIG. 14D. The blood flow forces the blood clot 162 onto the sensing members 154, which in turn extend the strain gauge 160. An electronic measurement circuit 158 is connected to the

proximal end of the sensing members 154. The electronic circuit 158 is configured to measure the strain experienced by the strain gauge 160.

**[0082]** In yet another design variation, the sensing members 154 are connected to a hub 156 that can be moveably displaced within the sleeve 6 of the vessel filter 2, as shown in FIG. 15A. A spring 166 or other elastic material positioned between the hub 164 and the top surface 168 of the sleeve keeps the tip of the hub 164 from contacting the top surface 168 of the sleeve 6. A trapped blood clot can force the hub 164 to compress the string 166 and displaces the hub 164 toward the proximal direction of the filter 2. A sensor may be implemented to measure this displacement. FIG. 15B illustrates one variation where a strain gauge 170 is placed at the proximal end of the hub 164 to measure the displacement of the hub.

**[0083]** In another variation, illustrated in FIG. 16, each of the sensing members 154 is connected to a microelectromechanical sensor 172 positioned within the sleeve 6 of the vessel filter. The microelectromechanical sensor 172 is configured to detect the movement of the sensing member 154 in the longitudinal direction and in the horizontal direction. Objects trapped within the vessel filter 2 will force the sensing members 154 to move, and such movement can be detected by the microelectromechanical sensor 172. As discussed above, an active or passive measurement electronic circuit may be utilized to receive signals from the microelectromechanical sensor. Although in the above examples two sensing elements are illustrated, one of ordinary skill in the art would appreciate that one, three or more sensing elements may be implemented in these devices.

**[0084]** In another aspect of the invention, shown in FIG. 17, a remote monitor 180 is utilized to detect the position of the vessel filter 2 within the patient's body 182 to determine whether the implanted vessel filter has migrated from its original implant location. An electronic circuit embedded in the vessel filter 2 is configured to transmit electromagnetic signals to a monitor 180, such that the monitor can determine the position of the vessel filter 2. Although active transmission circuits may be used, preferably a passive circuit is used. In a passive circuit configuration, the monitor 180 is configured to transmit an electromagnetic energy to the passive circuit through methods well known to one of ordinary skill in the art. The signals directed back to the monitor from the passive circuit allows the monitor 180 to determine the location of the vessel filter. A reference beacon 184 is provided so the monitor 180 can determine a reference position and calculate the position of the vessel filter 2 relative to the reference beacon 184. Preferably, the reference beacon 184 has an active circuit that transmits electronic signals to the monitor 180. The reference beacon 184 may be placed at a

position on the patient's body that is in a relatively fixed position. For example, when the patient 186 is lying flat on a flat surface 188, the reference beacon 184 may be placed at the heel of the foot 190, next to the tip of the toe 196 and vertically aligned with the heel of the foot 190, next to the tip of the tail bone 192, or be secured between teeth 194.

**[0085]** In one variation, when there are no obstructions between the monitor 180 and the reference beacon 184, infrared light, laser or ultrasound may be implemented to emit from the reference beacon for identifying its position. Alternatively, the monitor 180 may emit a radio, light or ultrasound energy towards the reference beacon 184 and/or the vessel filter 2, and relying on the reflected energy to determine the distance and/or location of the reference beacon 184 and/or the vessel filter 2. In another design, the monitor 180 sent out an interrogating signal towards the reference beacon 184 and/or the vessel filter 2. In response to the interrogating signal the reference beacon 184 or the vessel filter 2 may send back a responding signal. The monitor 180 may then calculate the time between sending of the interrogating signal and receiving of the responding signal, taking into account the delays in electronic circuit response time, and determine the distance between the monitor 180 and the reference beacon 184 or the vessel filter 2. The interrogating signal may be transmitted in various form of energy (e.g., light, electromagnetic wave, sound, etc.). The responding signal may also be transmitted in various form of energy (e.g., light, electromagnetic wave, sound, etc.).

**[0086]** In one variation, the monitor 180 is configured to determine the relative position between the reference beacon 184 and the implanted vessel filter 2 through electromagnetic signals transmitted from both the reference beacon and the vessel filter. In another variation, the monitor 180 is configured to detect the implanted vessel filter 2, and as the monitor 180 is moved about the surface of the patient's body the monitor 180 indicates its closeness to the vessel filter. Once the monitor 180 (positioned on the frontal surface of the patient) is directly on top of the filter, it may then calculate its position relative to the reference beacon 184. A measurement is made immediately after the implantation of the vessel filter, and a subsequent measurement may be compared with the data collected post-implantation to determine if the filter has migrated within the blood vessel. The monitor may further include memory to record and compare measurements to determine whether the vessel filter has migrated. One of ordinary skill in the art having the benefit of this disclosure herein would appreciate the device location detection monitor describe above may be adapted to monitor the position other devices which are configured for implantation inside a patients body.

[0087] One of ordinary skill in the art having the benefit of this disclosure would appreciate that the electronic measurement circuit may be implemented on various vessel filter designs. Examples of vessel filters that may be adapted with electronic measurement circuits are illustrated in FIG. 18A, 18B, 18C, and 18D. In FIG. 18A, the vessel filter 2 includes two sleeves 6, where each sleeve 6 is configured to couple a plurality of appendages 4. The appendages 4 are interlinked to form an expendable filter. An electronic measurement circuit may be positioned in one or both of the sleeves to measure the strain on one or more of the appendages. Portion of the interconnecting links of the vessel filter appendages may include non-conductive material such that electric conductive loops may be formed to measure the strain on one or more of the appendages. Alternatively, sensors, which are connected to an electronic measurement circuit, may be attached to one or more of the appendages to measure a parameter on the appendages. FIG. 18B shows a vessel filter 2 with jagged leg 4 configuration. An electronic measurement circuit may be positioned in the sleeve 6 to measure a parameter of one or more of said legs 4. Alternatively, the electronic measurement circuit may be attached to one or more of the legs. FIG. 18C illustrates another variation of a vessel filter 2 with multiple interlinks 202. A measurement circuit may be implemented either in the sleeve 6, attached to the sleeve 6, or attached to one or more of the legs. The electronic measurement circuit may be adapted to measure the strain on the legs 4 and/or interlinks 202. In yet another design, the vessel filter 2 is configured with a reverse loop 26 extending from each pair of legs 4 as show in FIG. 18D. Each pair of legs 4 and their corresponding reverse loop 26 may form a complete circuit loop, and an electronic measurement circuit positioned on or within the sleeve of the vessel filter may be connected to the pair of legs to measure the strain in each pair of legs. One of ordinary skill in the art having the benefit of this disclosure would appreciate that the electronic measurement circuit may be implemented on these filters with other electronic configurations.

[0088] In addition, one of ordinary skill in the art having the benefit of this disclosure would also appreciate that the electronic measurement circuit is not limited to implementation for measuring strain on the legs of a vessel filter. The electronic measurement circuit, which may be a passive circuit, may be adapted to measure strain and/or other parameters on various portions or structures on a vessel filter.

[0089] This invention has been described and specific examples of the invention have been portrayed. While the invention has been described in terms of particular variations and illustrative figures, those of ordinary skill in the art will recognize that the invention is not limited to the variations or figures described. In addition, where methods and steps described

above indicate certain events occurring in certain order, those of ordinary skill in the art will recognize that the ordering of certain steps may be modified and that such modifications are in accordance with the variations of the invention. Additionally, certain of the steps may be performed concurrently in a parallel process when possible, as well as performed sequentially as described above. Therefore, to the extent there are variations of the invention, which are within the spirit of the disclosure or equivalent to the inventions found in the claims, it is the intent that this patent will cover those variations as well. Finally, all publications and patent applications cited in this specification are herein incorporated by reference in their entirety as if each individual publication or patent application were specifically and individually put forth herein.



## CLAIMS

What is claimed as new and desired to be protected by Letters Patent of the United States is:

1. A vessel filter comprising:
  - a plurality of elongated appendages, wherein each of said appendages has a distal end and a proximal end, said plurality of appendages being coupled together at the proximal ends thereof, said appendages being configured to extend radially from said proximal end in a distal direction and away from a central longitudinal axis of said vessel filter, wherein said plurality of elongated appendages is collapsible toward said central longitudinal axis; and
  - an electronic circuit connected to at least one of said appendages, said electronic circuit being configured to measure a physical parameter of the vessel filter.
2. The vessel filter according to claim 1, wherein the distal ends of at least three of said plurality of elongated appendages being configured with hooks such that when said appendages are expanded in a body vessel the hooks engage an inner wall of the body vessel.
3. The vessel filter according to claim 2, wherein said electronic circuit is adapted to measure a strain on at least one of said appendages.
4. The vessel filter according to claim 2, wherein said electronic circuit is a passive electrical circuit.
5. The vessel filter according to claim 3, wherein said electronic circuit is a passive electrical circuit.
6. The vessel filter according to claim 3, wherein said electronic circuit directs current flow through at least a portion of one of said appendages to measure the strain in said appendages.
7. The vessel filter according to claim 4, further comprising a remote unit having an electronic component configured for energizing said passive electrical circuit

and interrogating said passive electrical circuit to determine said physical parameter of the vessel filter.

8. The vessel filter according to claim 7, wherein said remote unit is further configured to determine whether said vessel filter is distended based on said physical parameter.

9. The vessel filter according to claim 5, further comprising a remote unit having an electronic component configured for energizing said passive electrical circuit and interrogating said passive electrical circuit to determine said physical parameter of the vessel filter.

10. The vessel filter according to claim 9, wherein said remote unit is further configured to determine whether said vessel filter is distended based on said physical parameter.

11. The vessel filter according to claim 4, wherein said passive electrical circuit produces a signal that is a function of the strain in at least one of said appendages.

12. The vessel filter according to claim 4, wherein a first of said passive electrical circuit produces a first signal that is a function of the strain in a first of said appendages, and a second of said passive electrical circuit produces a second signal that is a function of the strain in a second of said appendages.

13. The vessel filter according to claim 4, wherein said passive electrical circuit produces a signal that is a function of said physical parameter.

14. The vessel filter according to claim 5, wherein said passive electrical circuit comprises an inductive element and a capacitive element.

15. The vessel filter according to claim 1, further comprising a conductive bridge providing an electrical connection between a first of said appendages to a second of said appendages.

16. The vessel filter according to claim 15, wherein said conductive bridge comprises a strain gauge material.

17. A vessel filter for implantation in a hollow body organ in a human, comprising:

a plurality of elongated appendages, wherein each of said appendages has a distal end and a proximal end, wherein said plurality of appendages are coupled together at the proximal ends thereof, said appendages being configured to extend radially from said proximal end in a distal direction and away from a central longitudinal axis of said vessel filter, wherein said plurality of elongated appendages is collapsible toward said central longitudinal axis;

a sensor coupled to at least one of said plurality of elongated appendages, wherein said sensor is adapted to monitor the condition of said vessel filter; and

an electronic circuit connected to said sensor, wherein said electronic circuit is adapted to detect an electrical signal from said sensor.

18. The vessel filter according to claim 17, wherein the distal ends of at least three of said plurality of elongated appendages being configured with hooks such that when said appendages are expanded in a body vessel the hooks engage an inner wall of the body vessel.

19. The vessel filter according to claim 18, wherein said electronic circuit is further configured to transmit said electrical signal to a remote receiving unit.

20. The vessel filter according to claim 19, wherein said electronic circuit is a passive electrical circuit.

21. The vessel filter according to claim 18, wherein said sensor is a pressure sensor adapted to measure the pressure being exerted on said vessel filter.

22. The vessel filter according to claim 21, wherein said pressure sensor is adapted to measure the pressure being exerted on at least one of said appendages.

23. The vessel filter according to claim 18, wherein said sensor is a strain gauge.

24. The vessel filter according to claim 23, wherein said strain gauge is adapted to measure the strain in at least one of said appendages.

25. The vessel filter according to claim 18, wherein said sensor is configured to detect distension of said vessel filter.

26. The vessel filter according to claim 18, wherein said sensor is configured to detect displacement of said appendages.

27. The vessel filter according to claim 18, wherein said sensor is configured to detect strain distribution between said plurality of appendages.

28. The vessel filter according to claim 18, wherein said sensor is configured to detect pressure distribution between said plurality of appendages for pressure being exerted on said plurality of appendages.

29. The vessel filter according to claim 20, further comprising a remote unit having an electronic component configured for energizing said passive electrical circuit and interrogating said passive electrical circuit to receive said electrical signal.

30. The vessel filter according to claim 29, wherein said remote unit is further configured to determine whether said vessel filter is distended based on said electrical signal.

31. The vessel filter according to claim 29, wherein said electrical signal is a function of a strain in at least one of said appendages.

32. The vessel filter according to claim 29, wherein said electrical signal is a function of a pressure being exerted on at least one of said appendages.

33. An implantable particle capturing device, comprising:  
a compressible vessel filter adapted for implantation into a body vessel; and  
an electronic circuit attached to the vessel filter, said electronic circuit being adapted to determine a distension of said vessel filter.

34. The implantable particle capturing device according to claim 33, further comprising a sensor connected to said vessel filter and said electronic circuit for detecting the distension of said vessel filter.

35. The implantable particle capturing device according to claim 33, wherein said vessel filter comprises a plurality of legs, and said sensor is configured to measure a strain in at least one of said legs.

36. The implantable particle capturing device according to claim 34, wherein said vessel filter comprises a plurality of legs, and said electronic circuit is configured to measure a strain in at least one of said legs.

37. The implantable particle capturing device according to claim 33, wherein said electronic circuit is a passive electrical circuit.

38. The implantable particle capturing device according to claim 37, further comprising a remote unit capable of energizing said passive electrical circuit and interrogating said passive electrical circuit to determine said distension of said vessel filter.

39. An implantable particle capturing device, comprising:  
a vessel filter adapted for implantation into a body vessel; and  
an electronic circuit attached to the vessel filter, said electronic circuit being adapted to measure a parameter on at least a portion of said vessel filter.

40. The implantable particle capturing device according to claim 39, wherein said parameter comprises a strain.

41. The implantable particle capturing device according to claim 40, wherein said electronic circuit is configured to transmit information regarding said strain to a remote monitor.

42. The implantable particle capturing device according to claim 40, wherein said electronic circuit is configured to transmit information regarding a distribution of said strain on said vessel filter to a remote monitor.

43. The implantable particle capturing device according to claim 39, wherein said parameter comprises a stress.

44. The implantable particle capturing device according to claim 39, wherein said parameter comprises a pressure.

45. The implantable particle capturing device according to claim 39, wherein said electronic circuit is configured to transmit information regarding said parameter to a remote monitor.

46. The implantable particle capturing device according to claim 45, wherein said electronic circuit comprises a passive electronic circuit.

47. A method for monitoring the condition of an implanted vessel filter, comprising:

remotely energizing a passive circuit which is coupled to said implanted vessel filter; and

interrogating said passive circuit to determine a physical parameter of said vessel filter.

48. The method according to claim 47, wherein said implanted vessel filter comprises a plurality of elongated appendages, wherein each of said appendages has a distal end and a proximal end, said plurality of appendages being coupled together at the proximal ends of said appendages, said appendages being configured to extend radially from said proximal end in a distal direction and away from a central longitudinal axis of said vessel filter, the distal ends of at least three of said plurality of elongated appendages being configured with hooks such that when said appendages are expanded in a body vessel the hooks engage an inner wall of the body vessel, wherein said plurality of elongated appendages is collapsible toward said central longitudinal axis.

49. The method according to claim 48, wherein said physical parameter comprises a strain in at least one of said plurality of appendages.

50. The method of claim 47, further comprising the step of determining whether the implanted vessel filter has distended based on said physical parameter.

51. The method of claim 49, further comprising the step of determining the distribution of strain between two or more of said plurality of appendages.

52. The method according to claim 47, wherein said physical parameter comprises a strain on at least a portion of said vessel filter.

53. The method according to claim 47, wherein said physical parameter comprises a stress on at least a portion of said vessel filter.

54. The method according to claim 47, wherein said physical parameter comprises a pressure on at least a portion of said vessel filter.

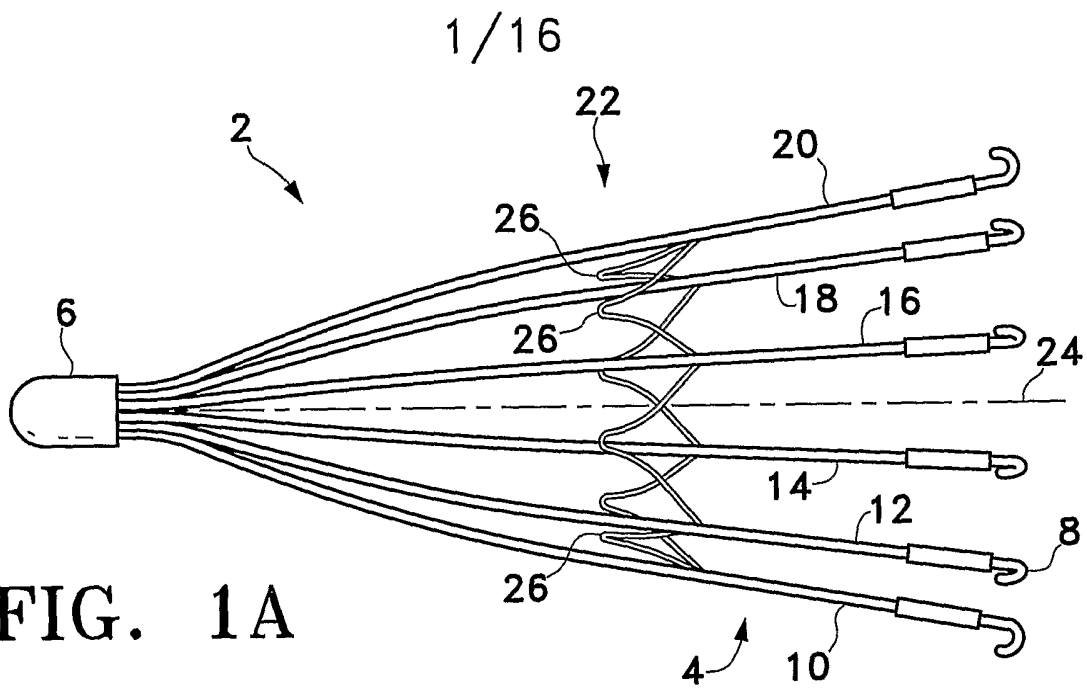


FIG. 1A

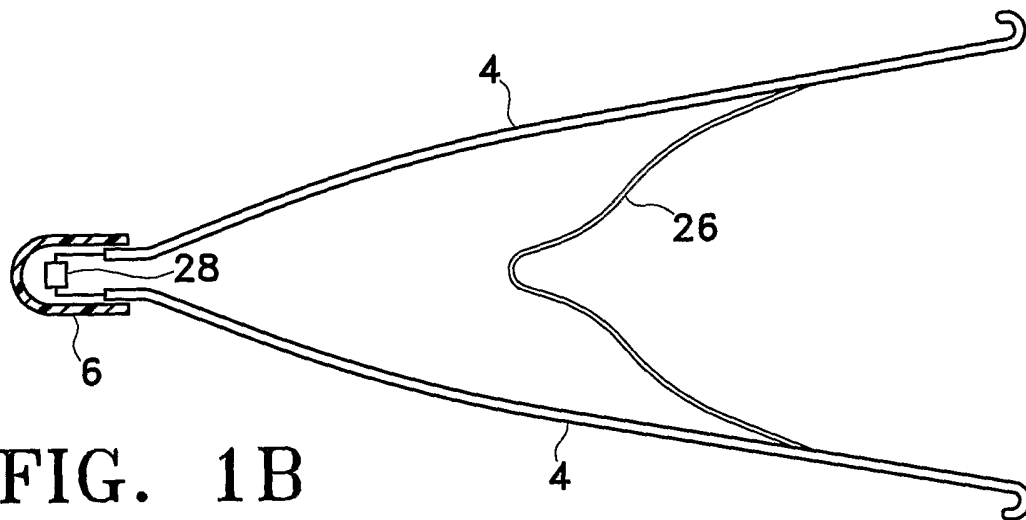


FIG. 1B

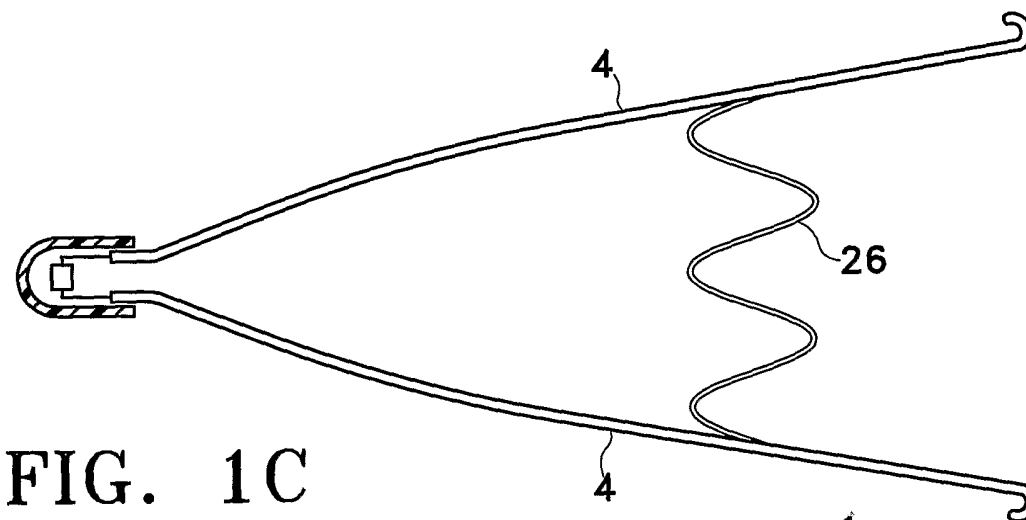


FIG. 1C





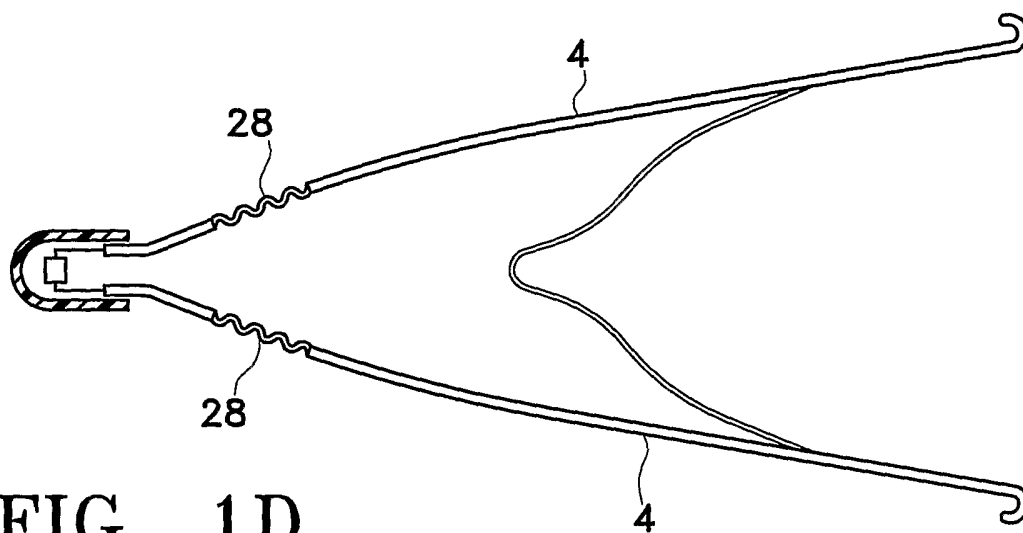


FIG. 1D

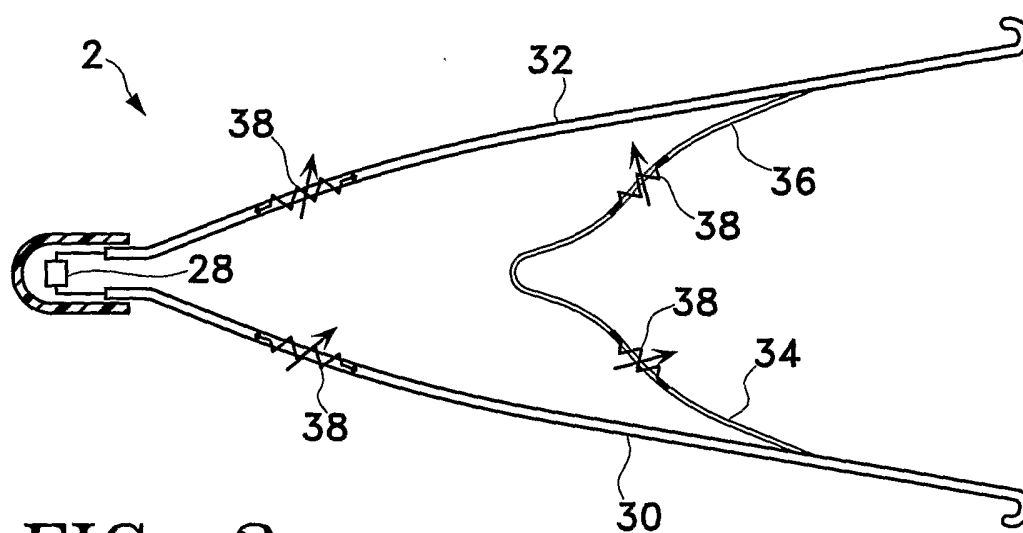


FIG. 2

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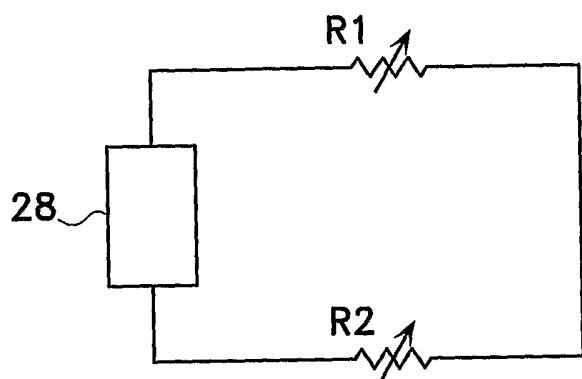


FIG. 3A

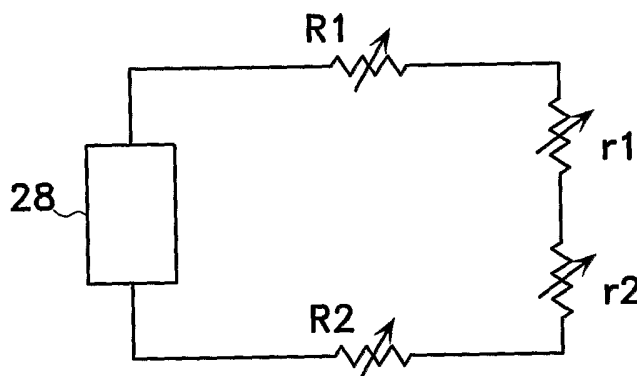


FIG. 3B

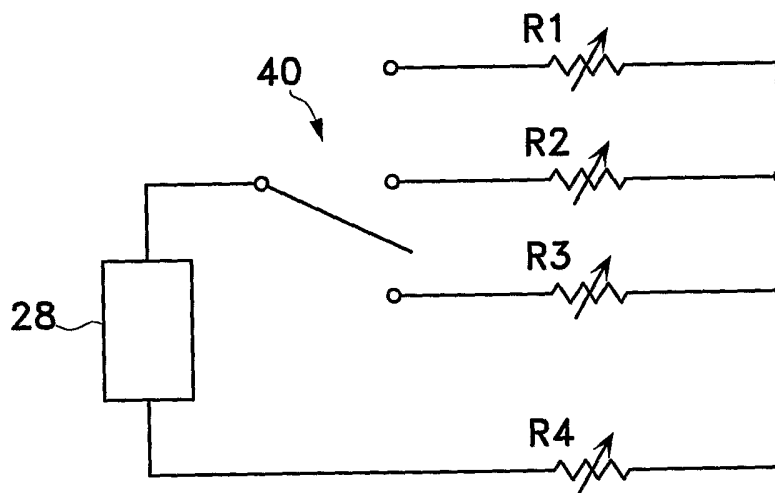


FIG. 3C

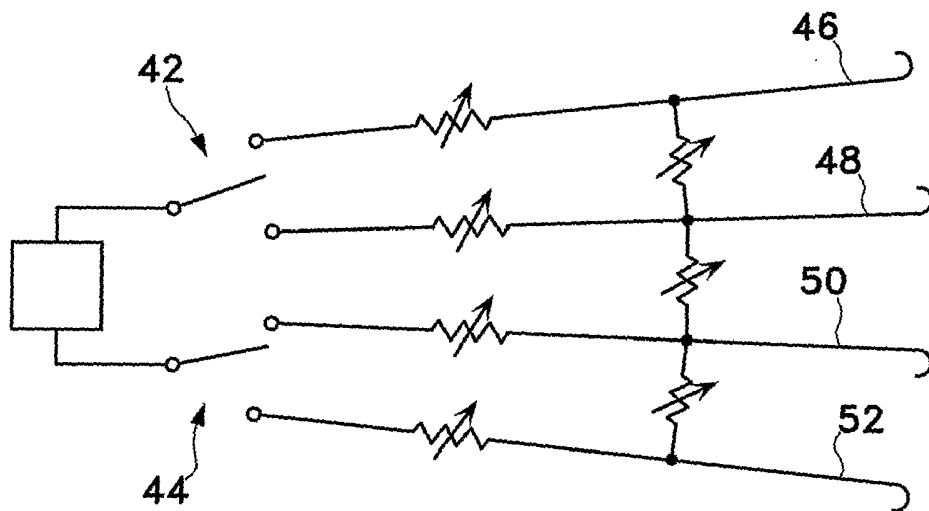


FIG. 3D

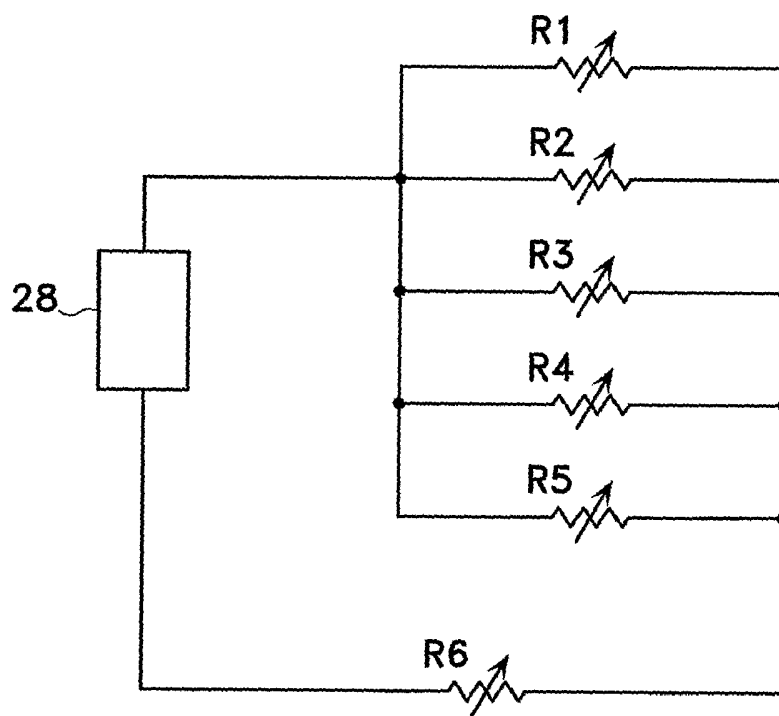


FIG. 3E



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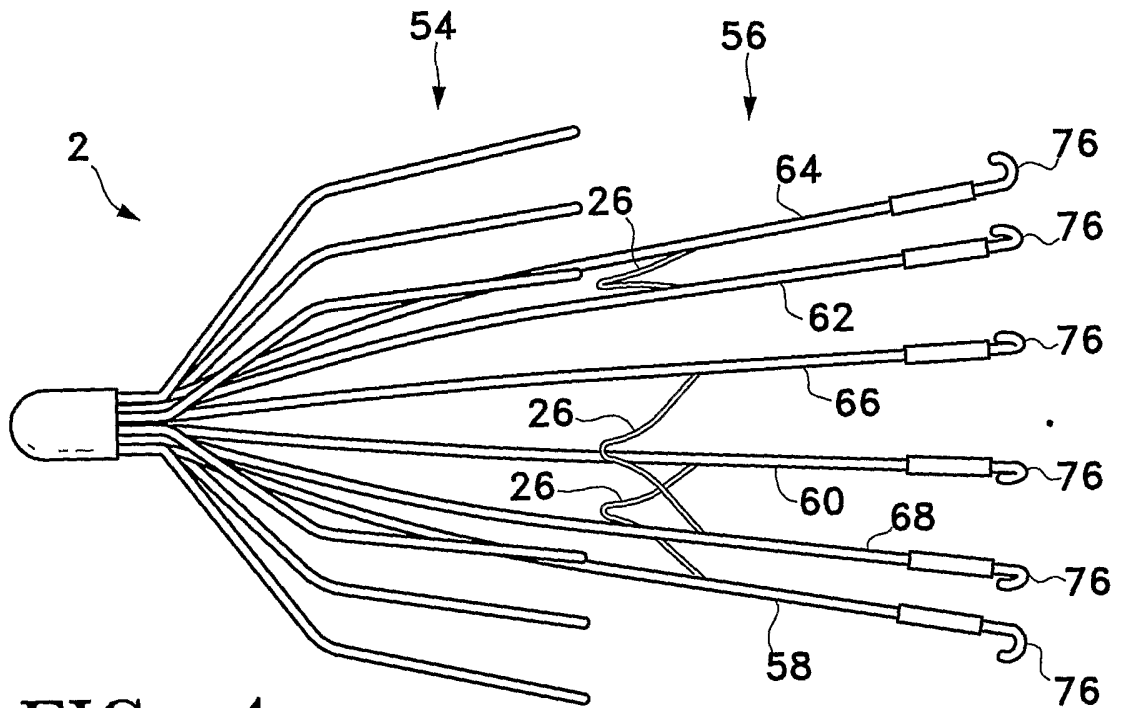


FIG. 4

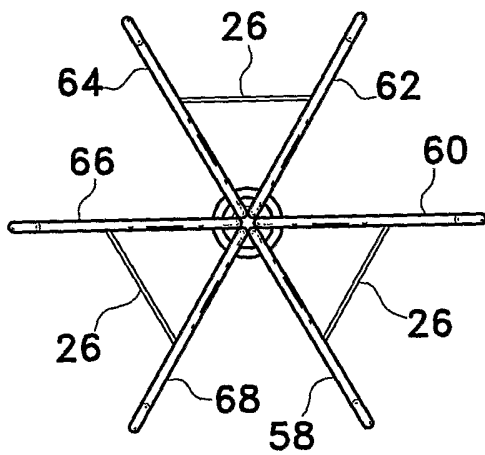


FIG. 5A

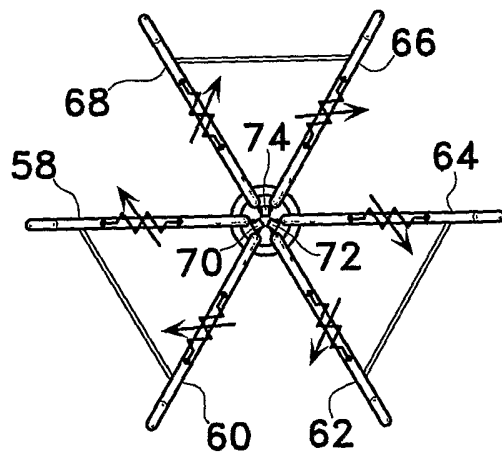
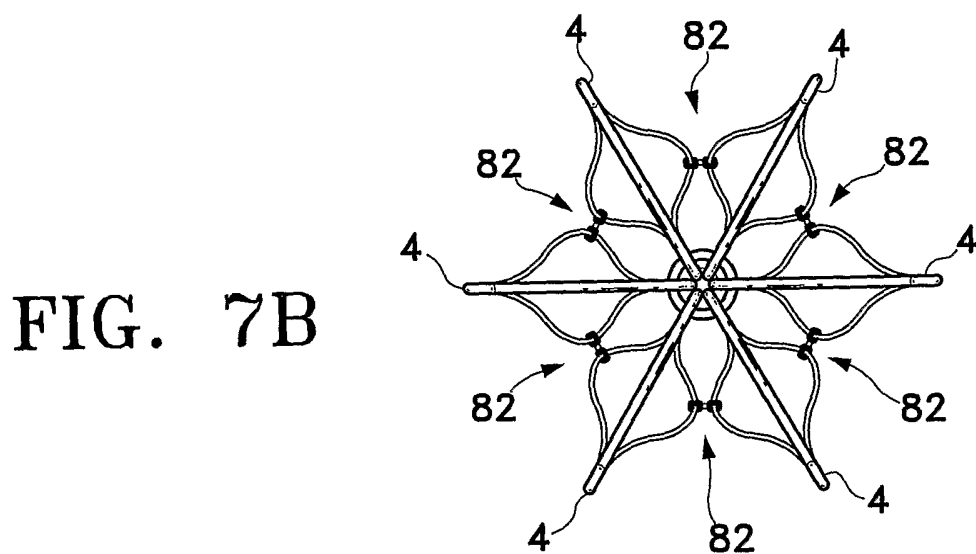
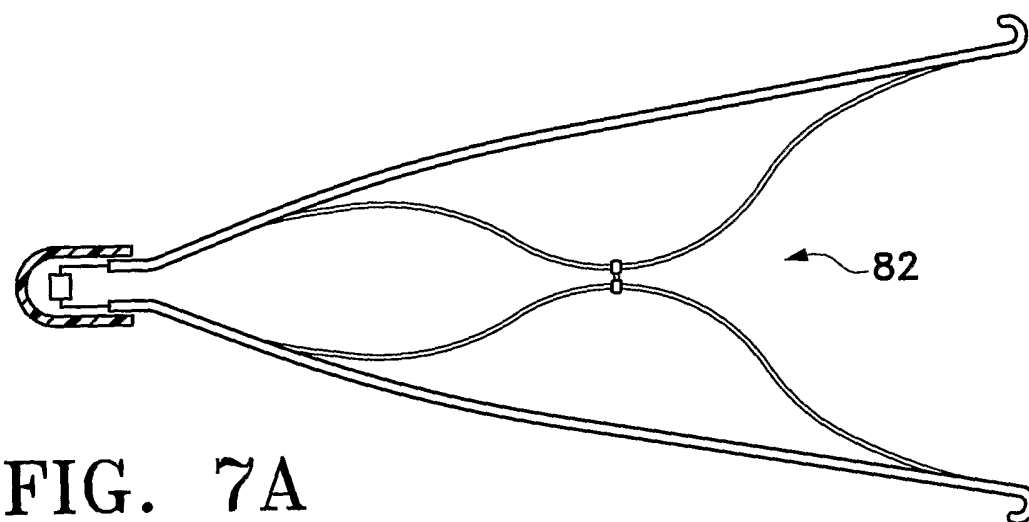
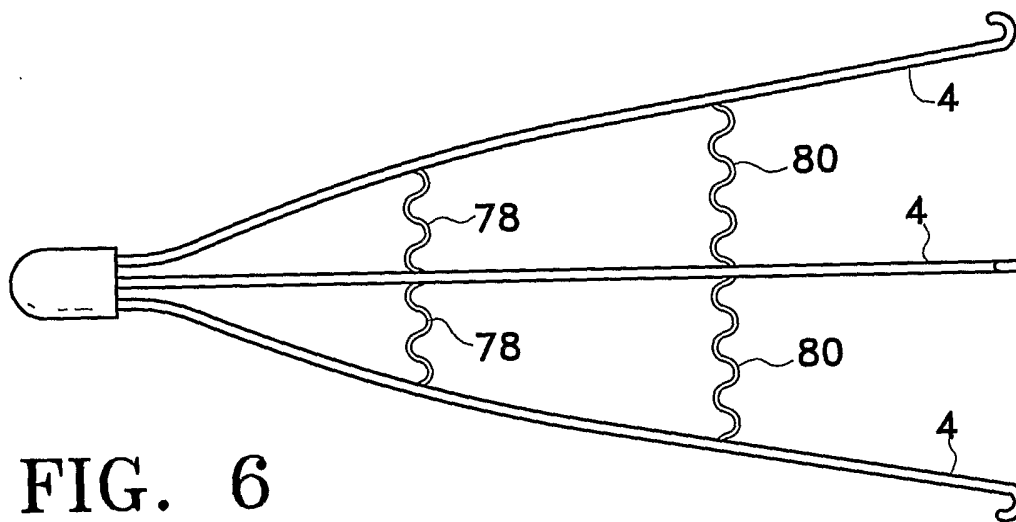
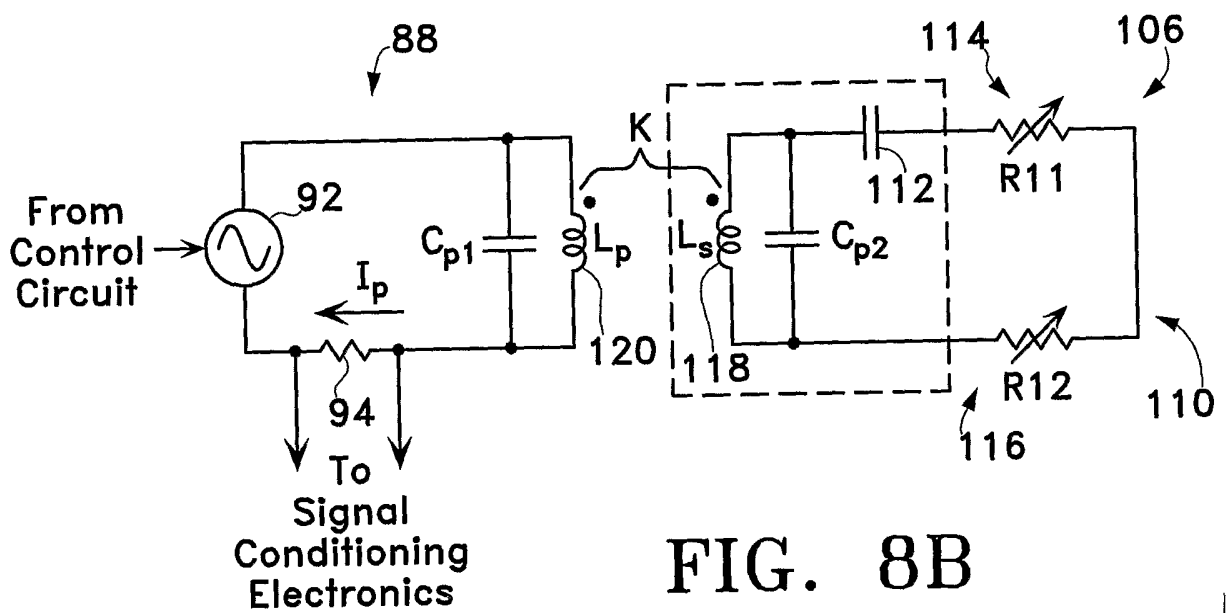
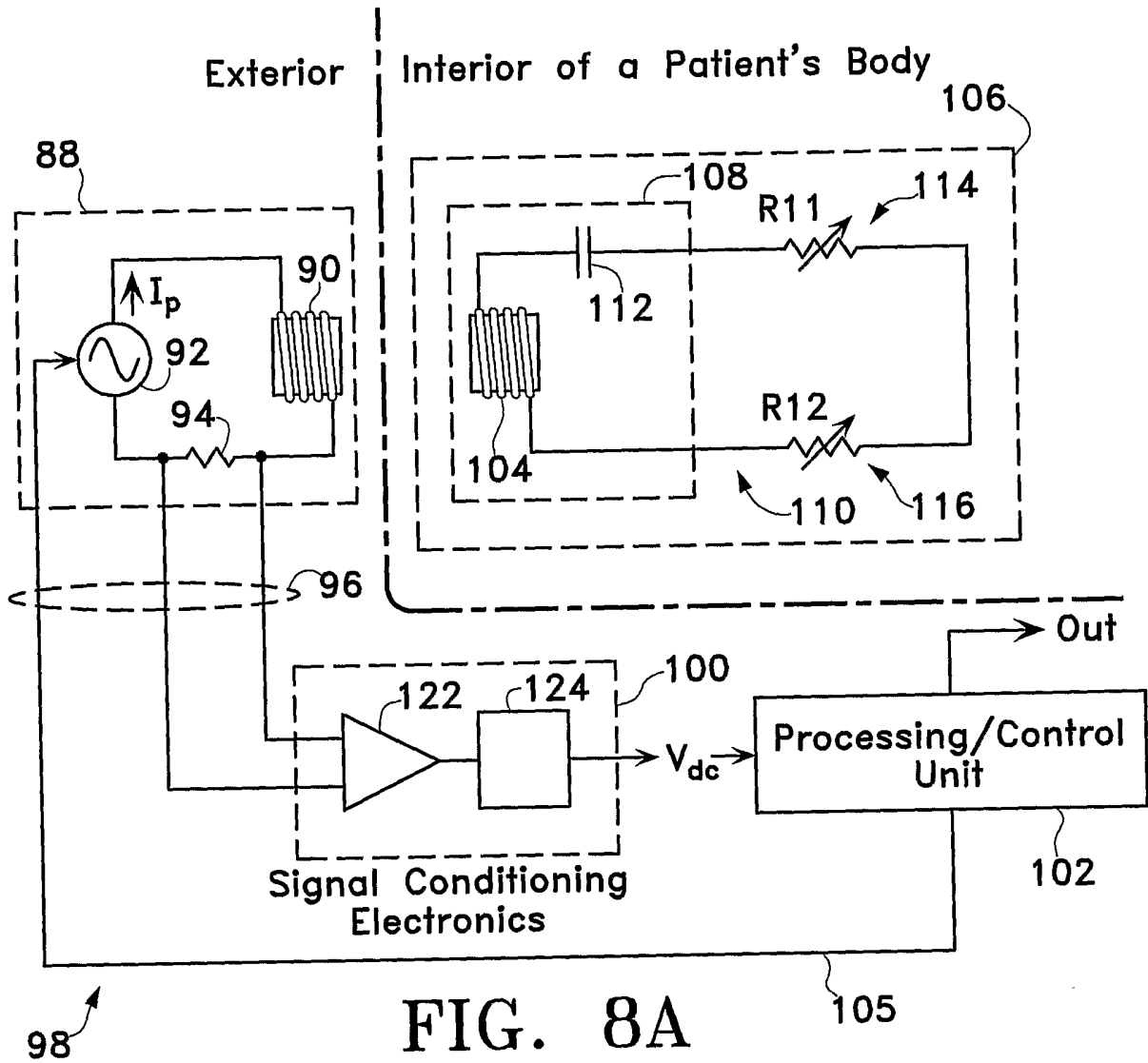


FIG. 5B



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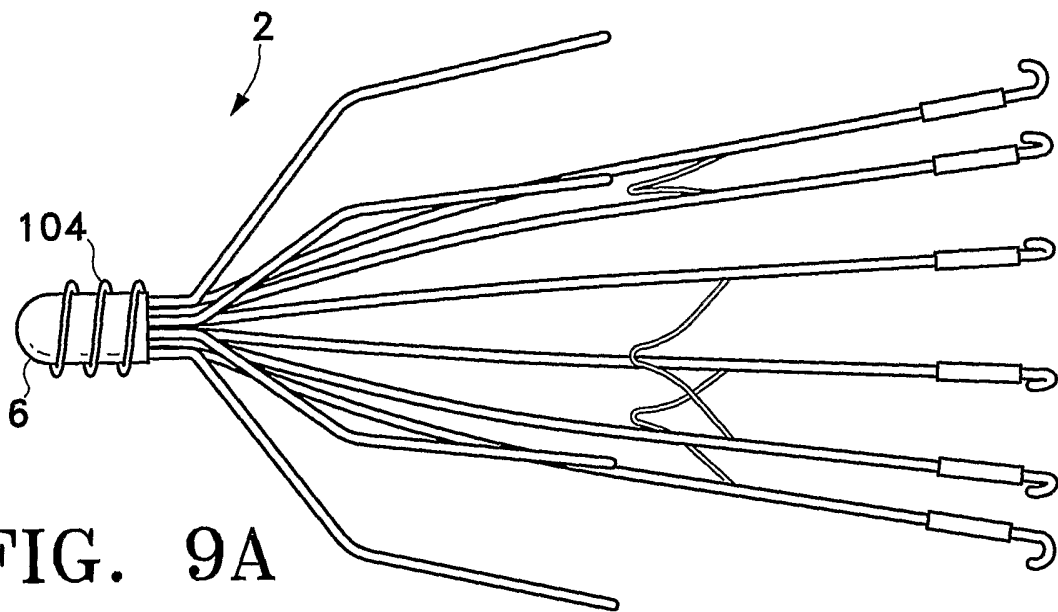


FIG. 9A

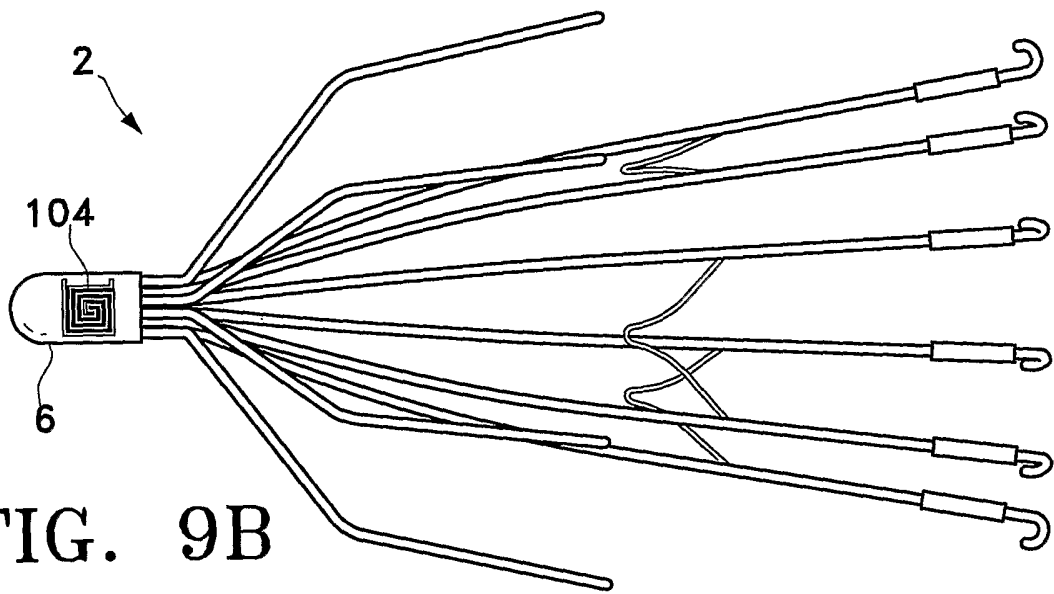
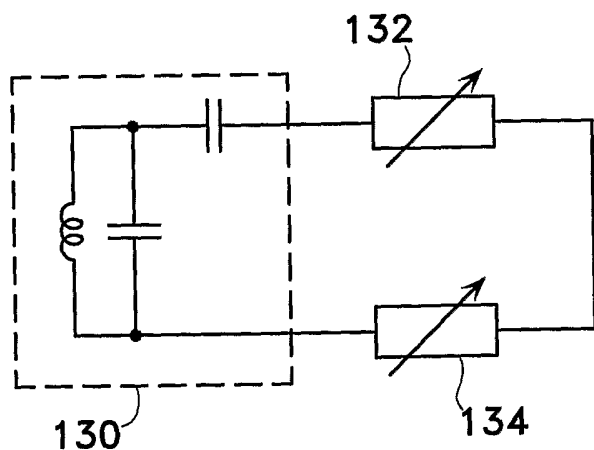


FIG. 9B

FIG. 10



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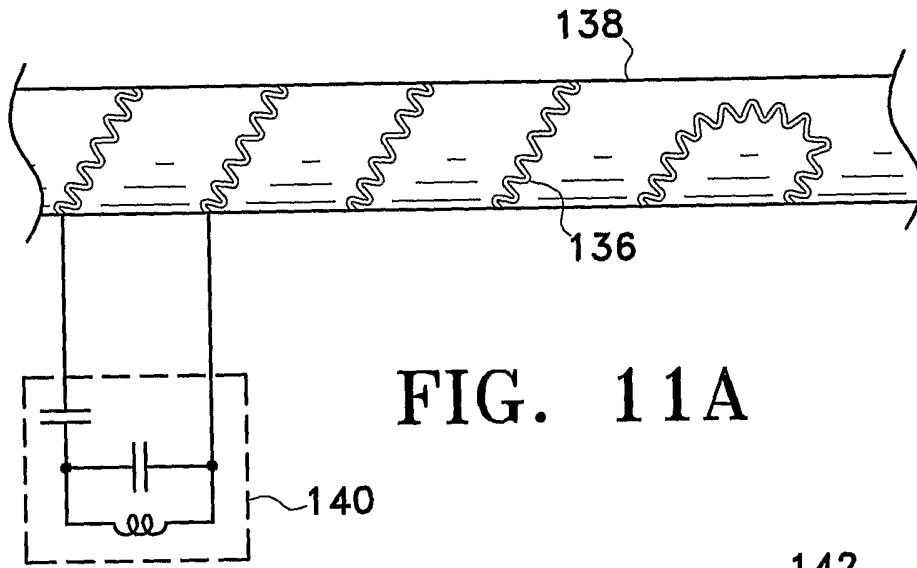


FIG. 11A

FIG. 11B

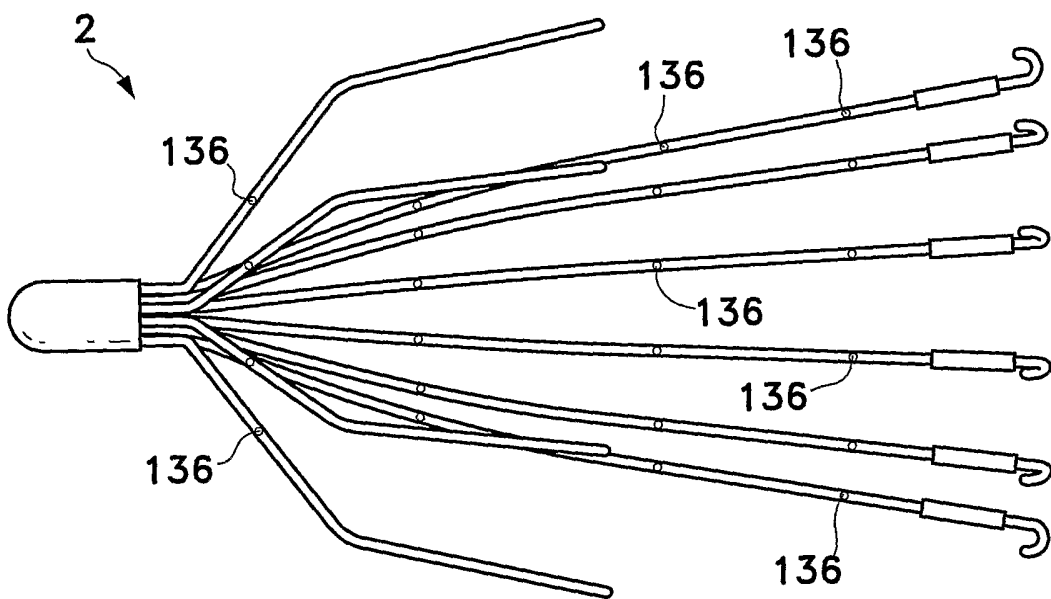
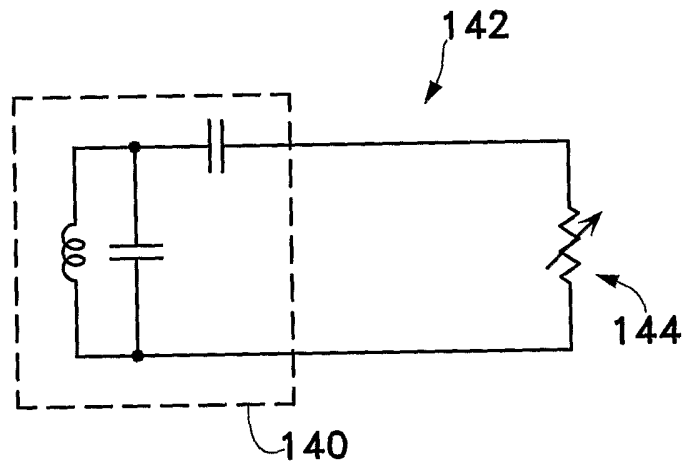


FIG. 11C



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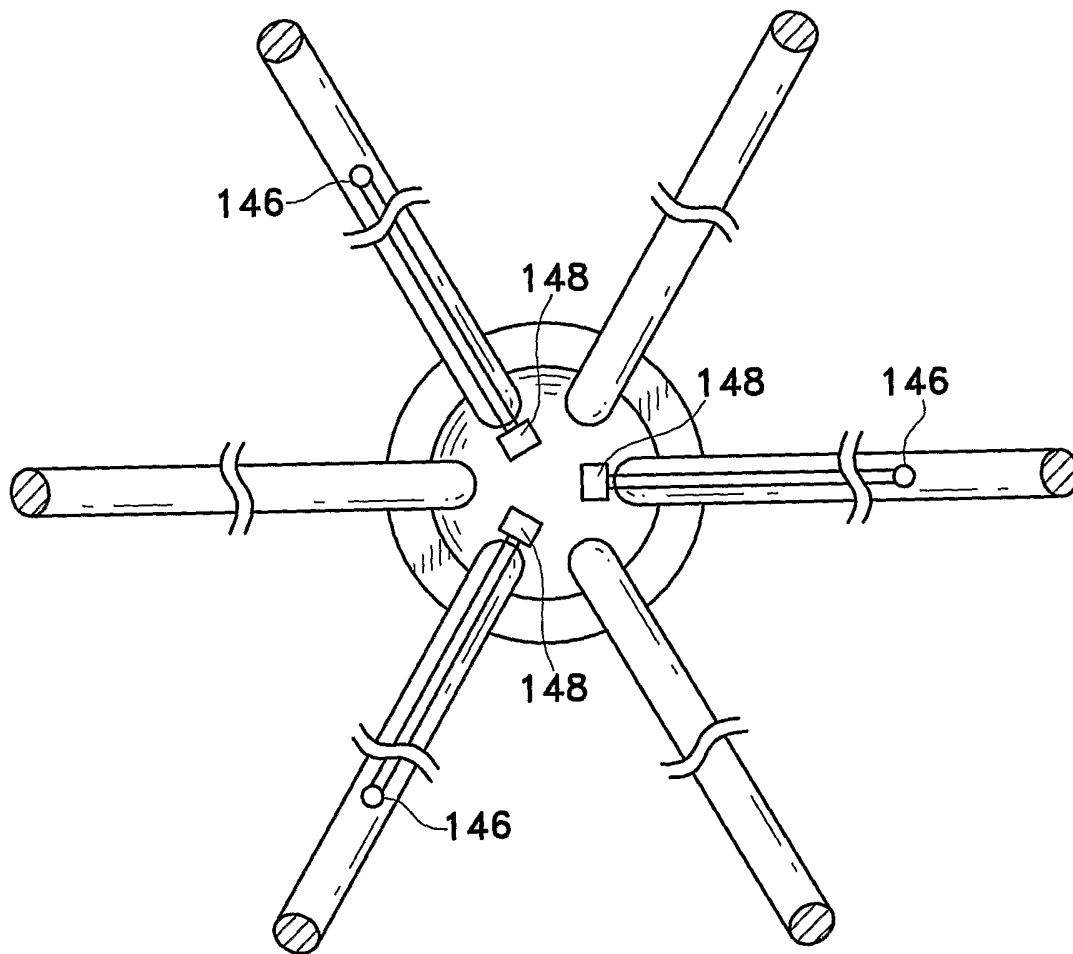


FIG. 12

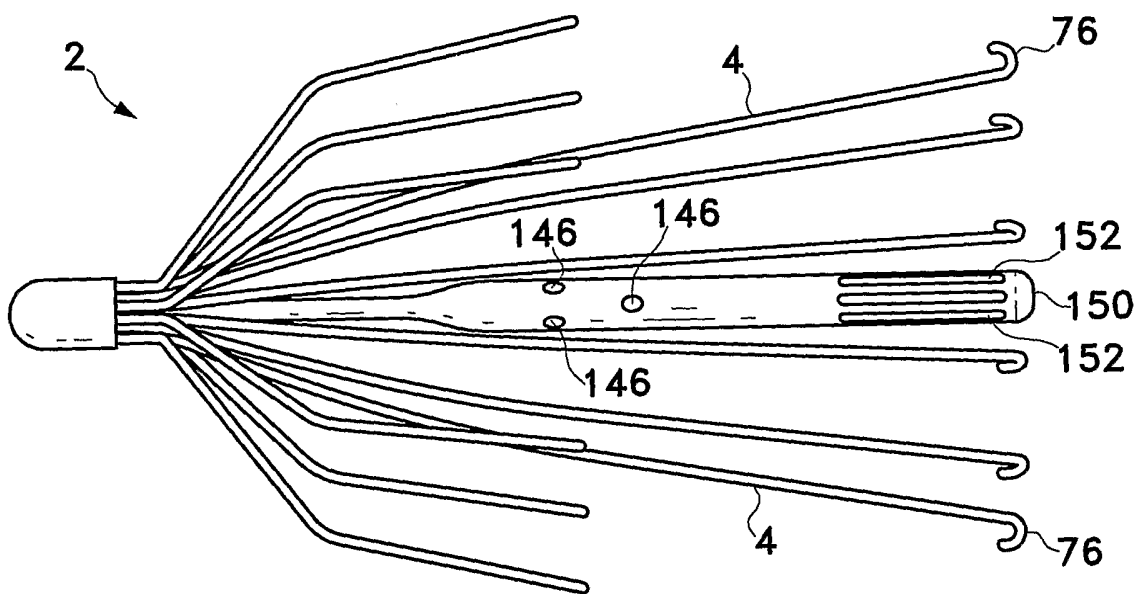


FIG. 13

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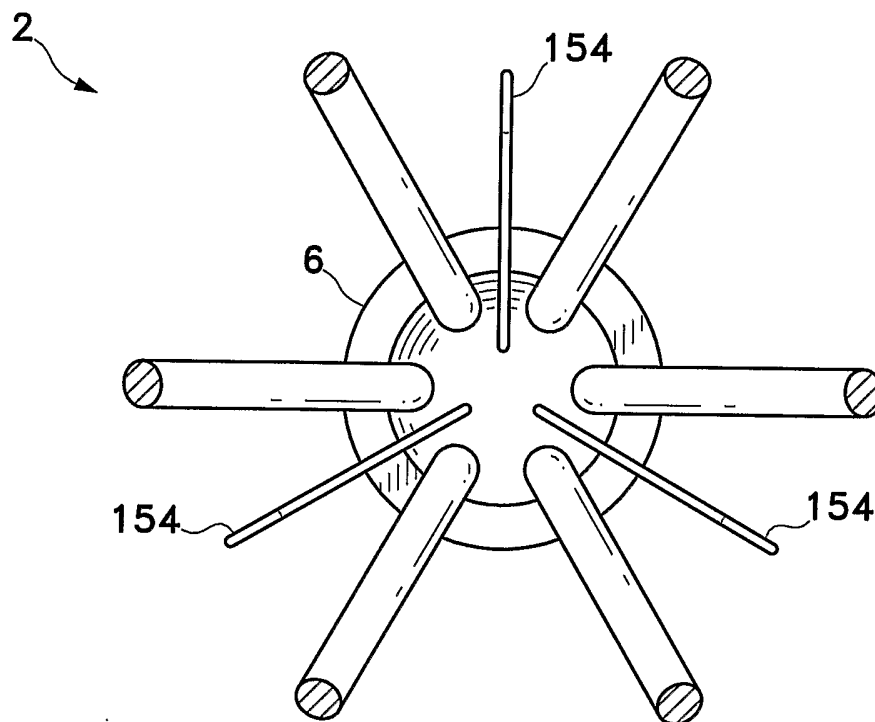


FIG. 14A

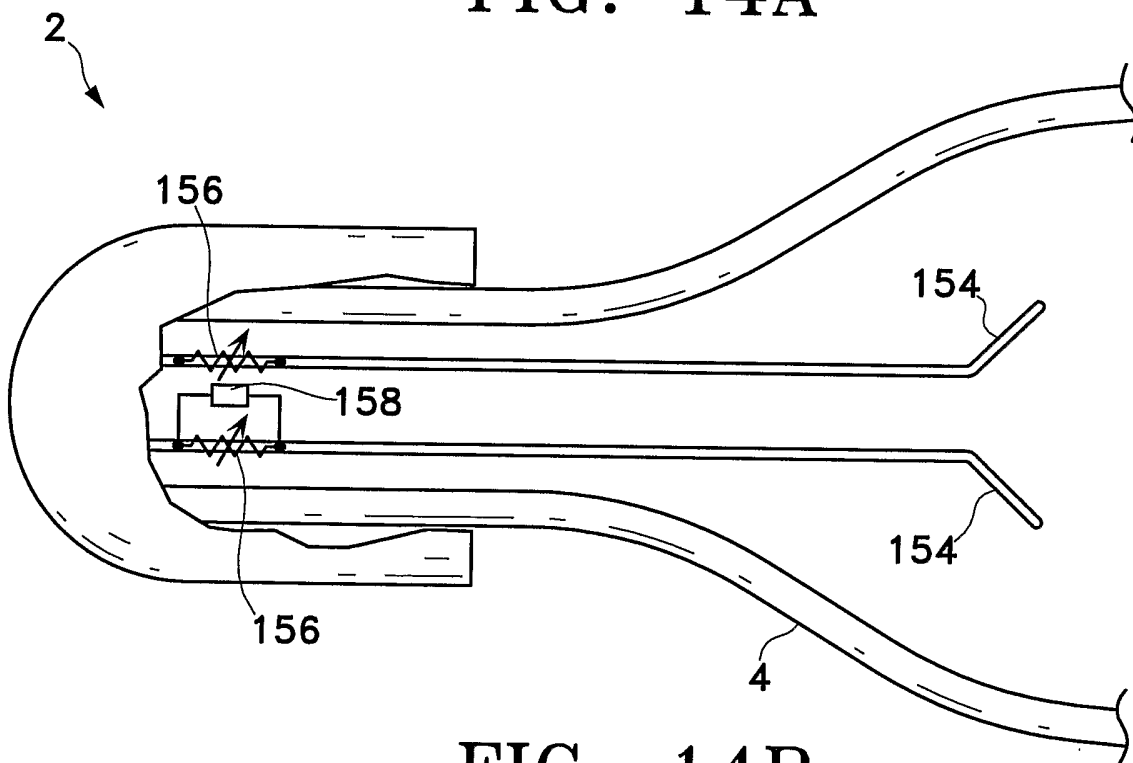


FIG. 14B

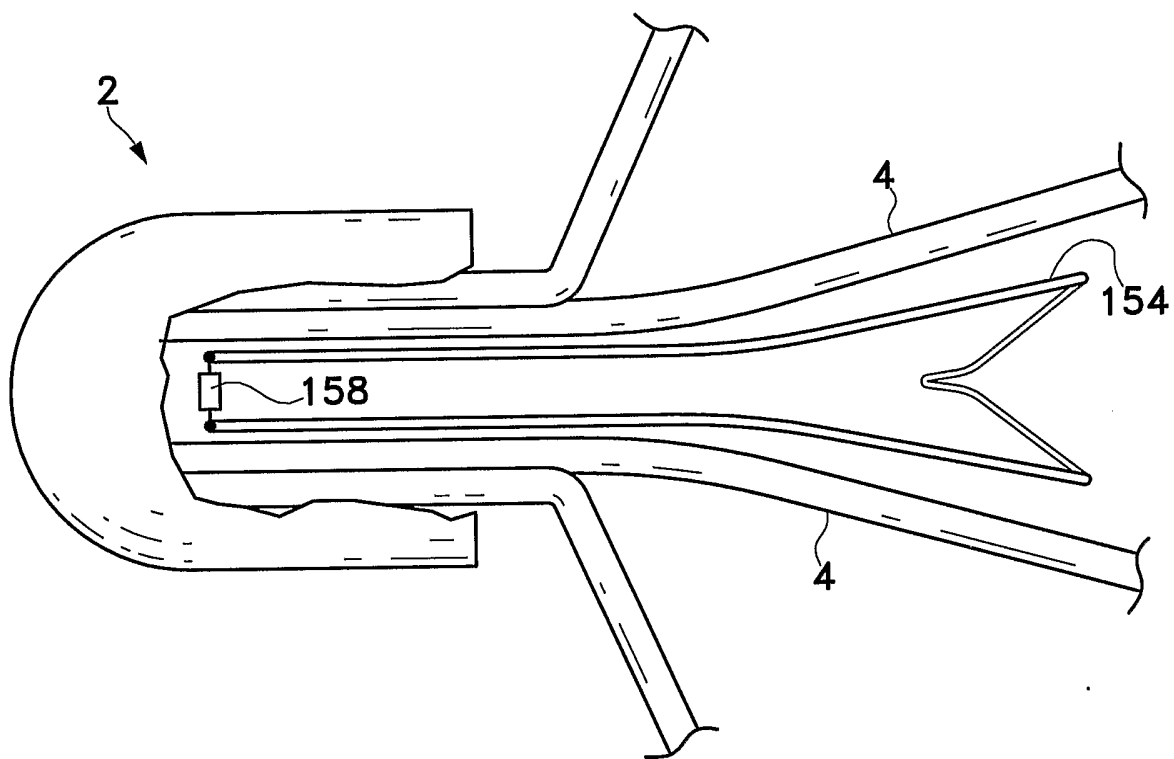


FIG. 14C

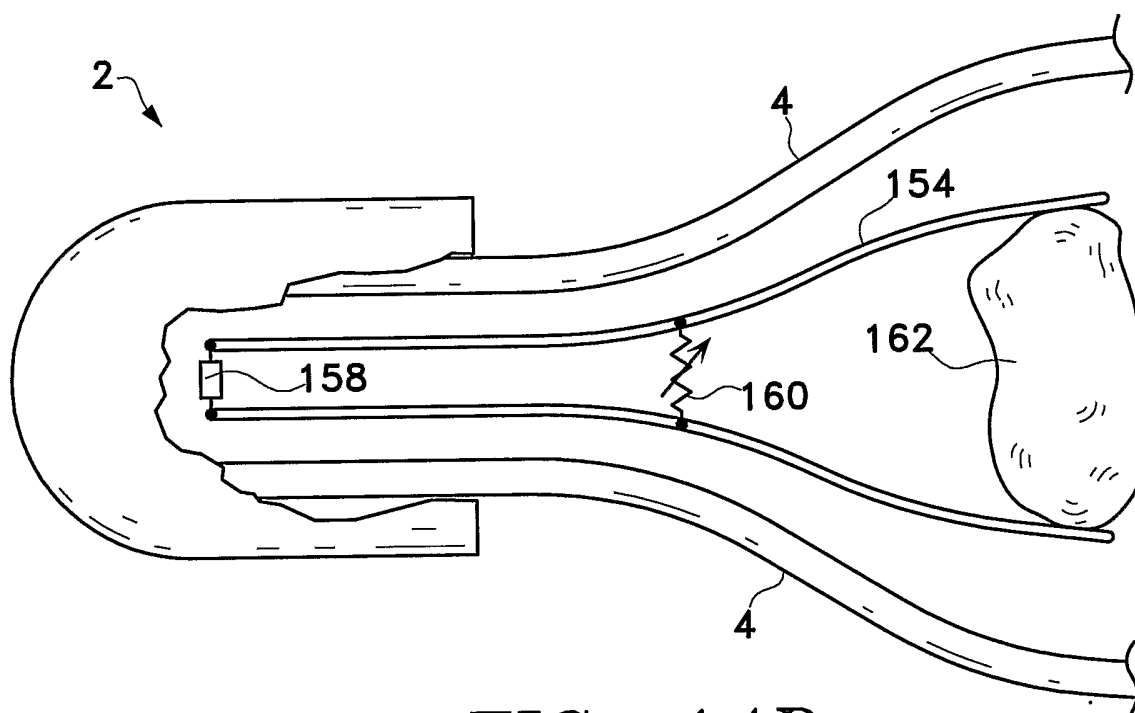


FIG. 14D

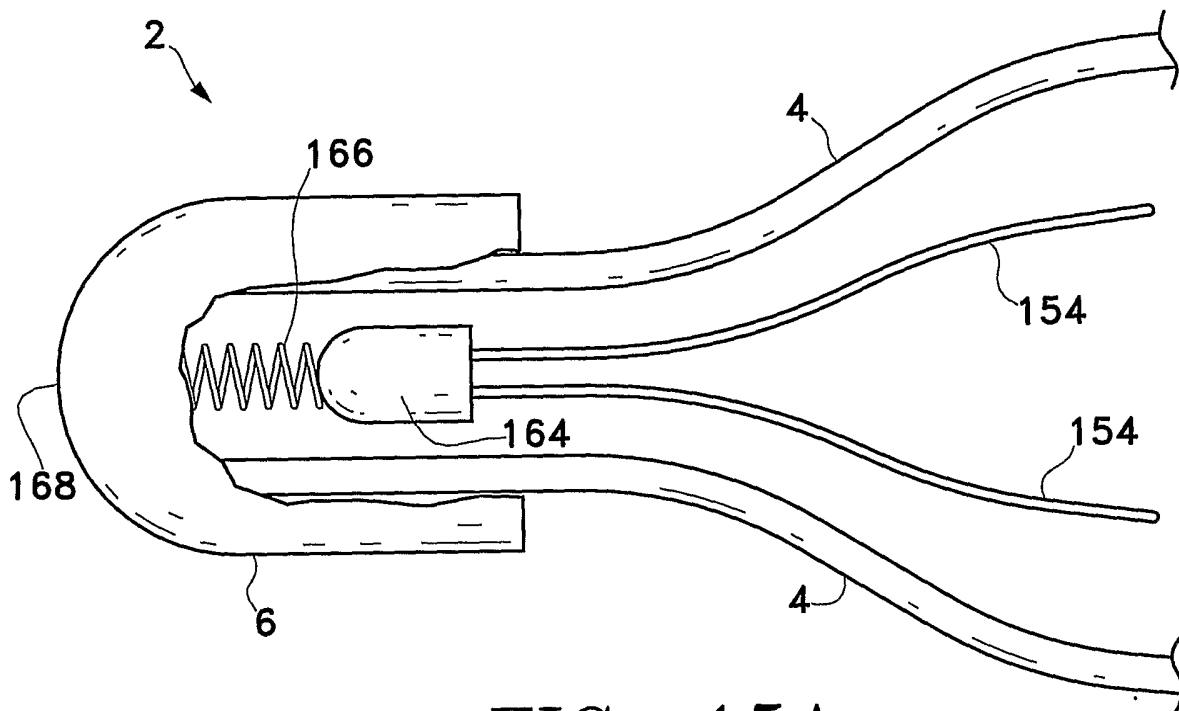


FIG. 15A

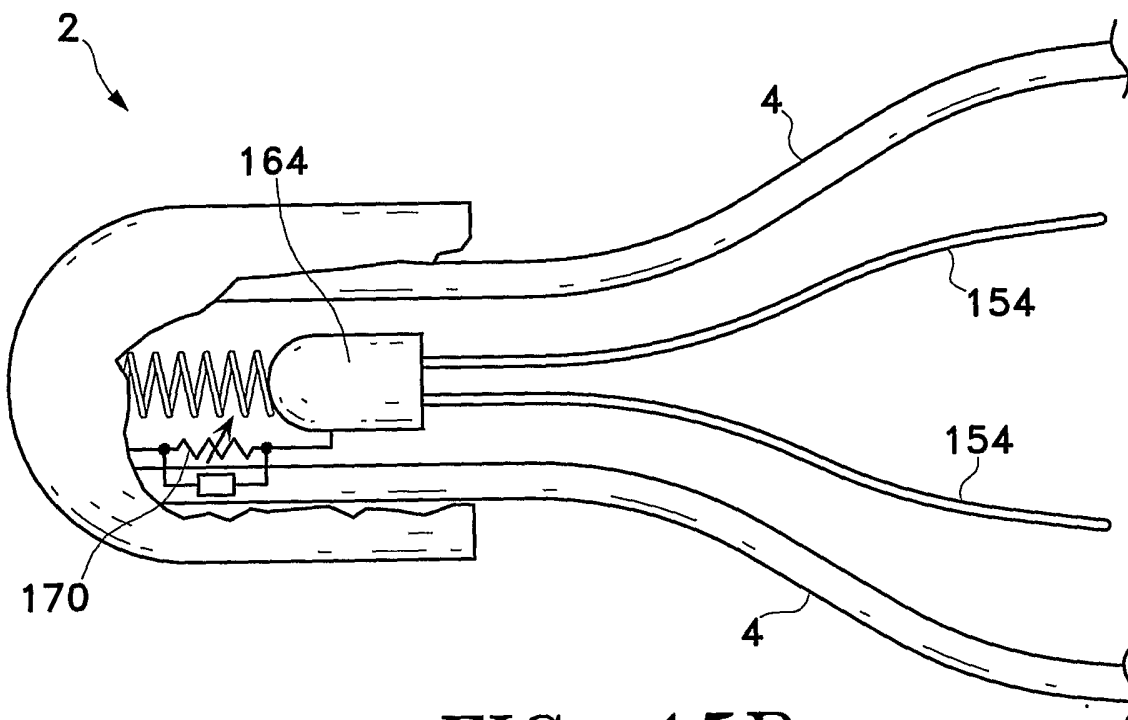


FIG. 15B

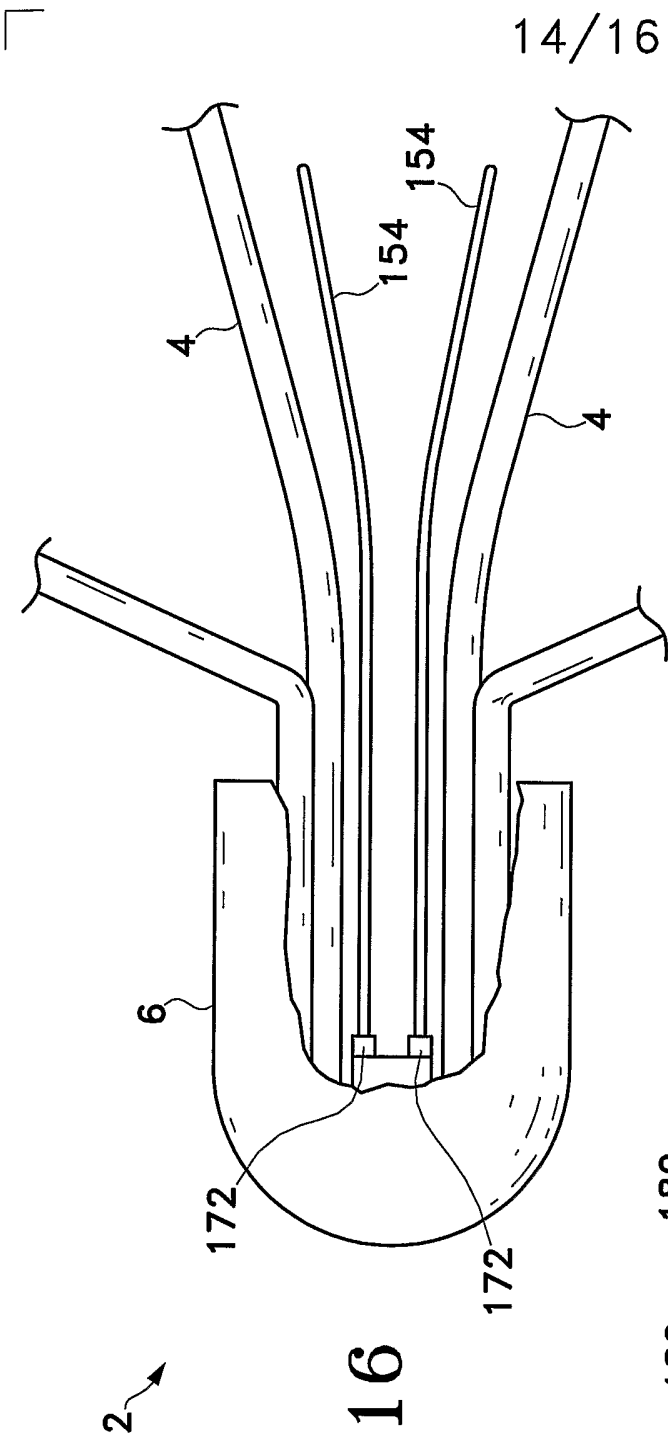


FIG. 16

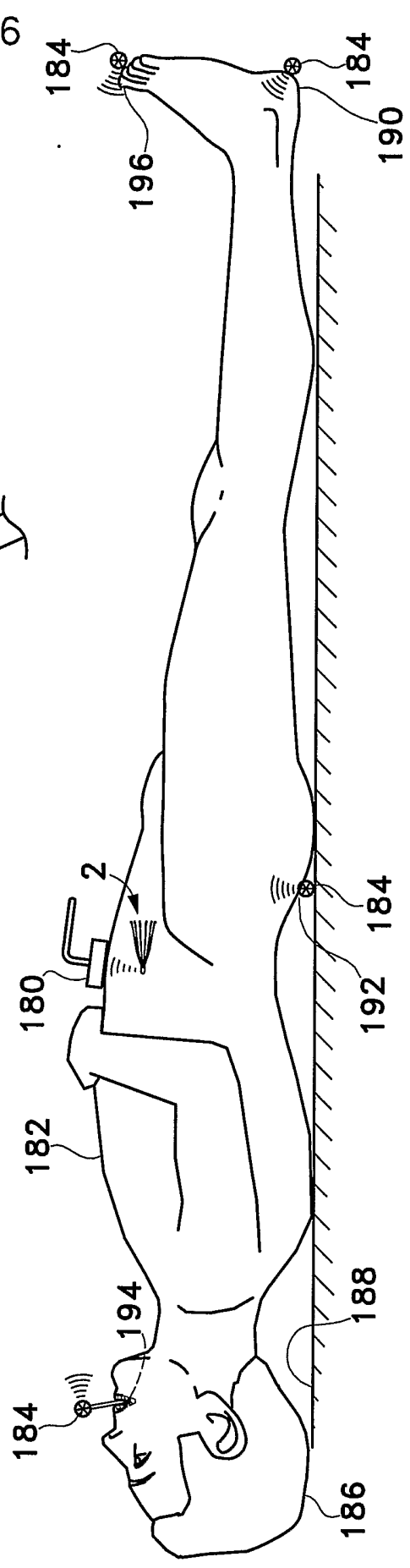


FIG. 17

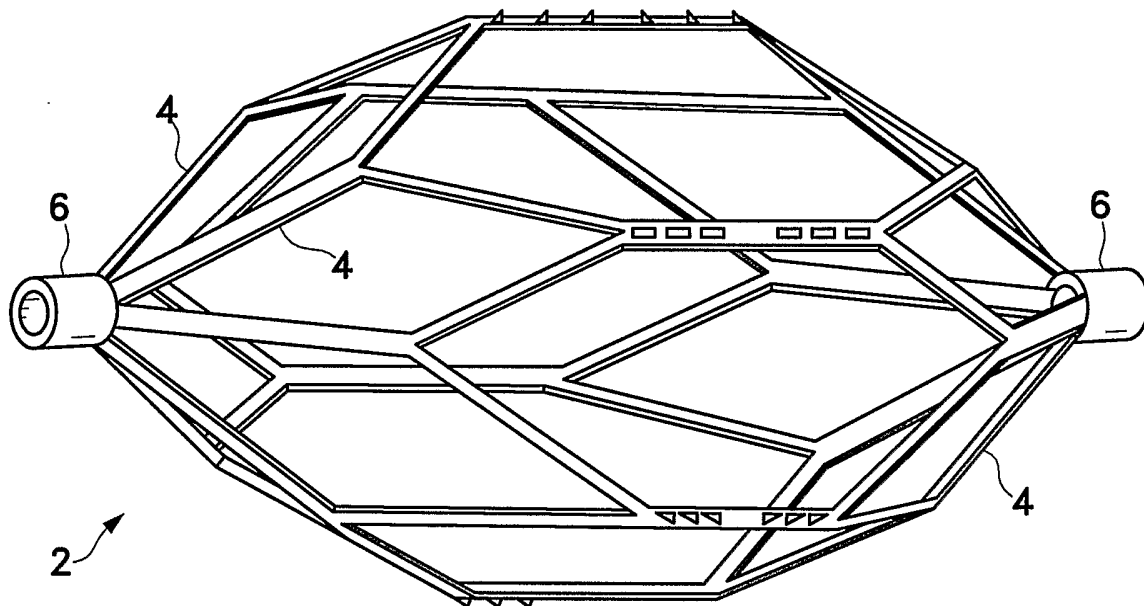


FIG. 18A

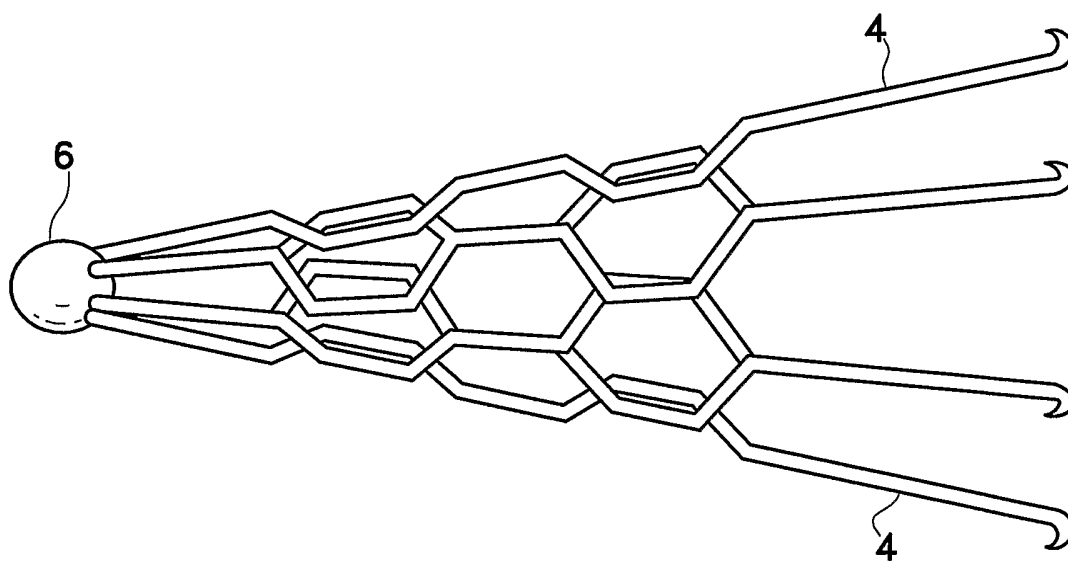


FIG. 18B

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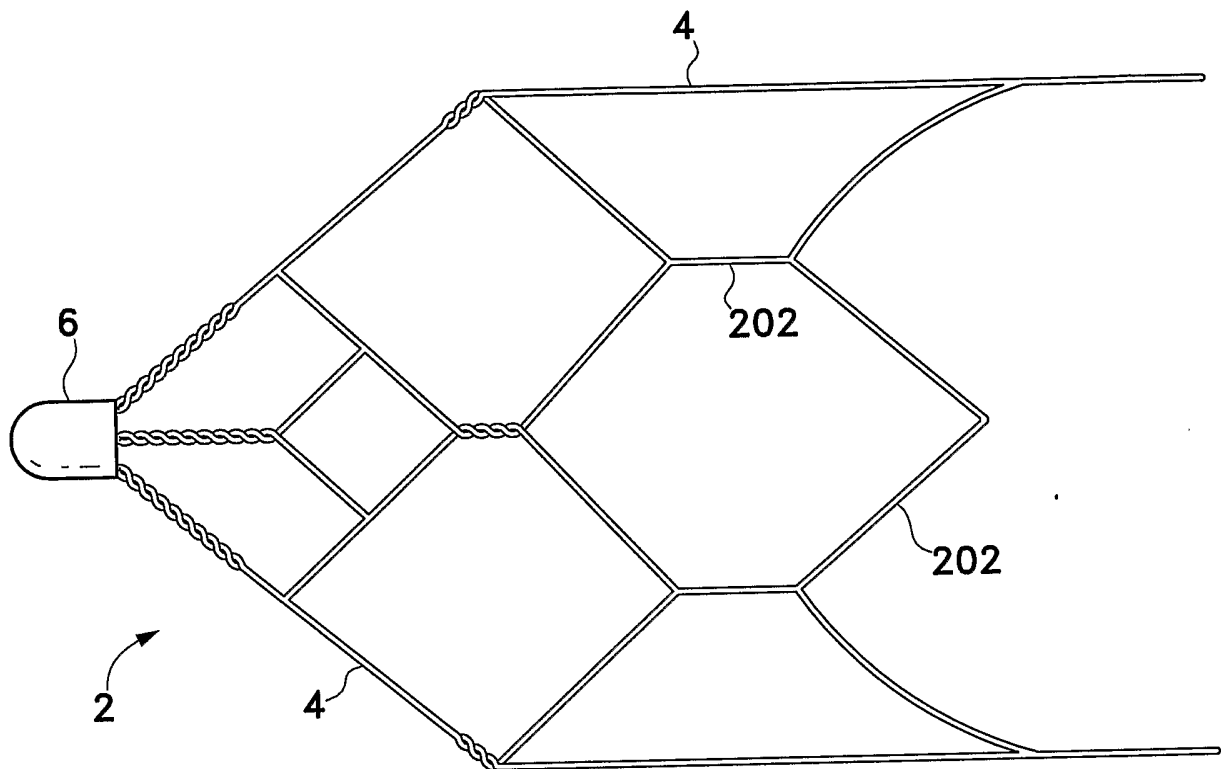


FIG. 18C

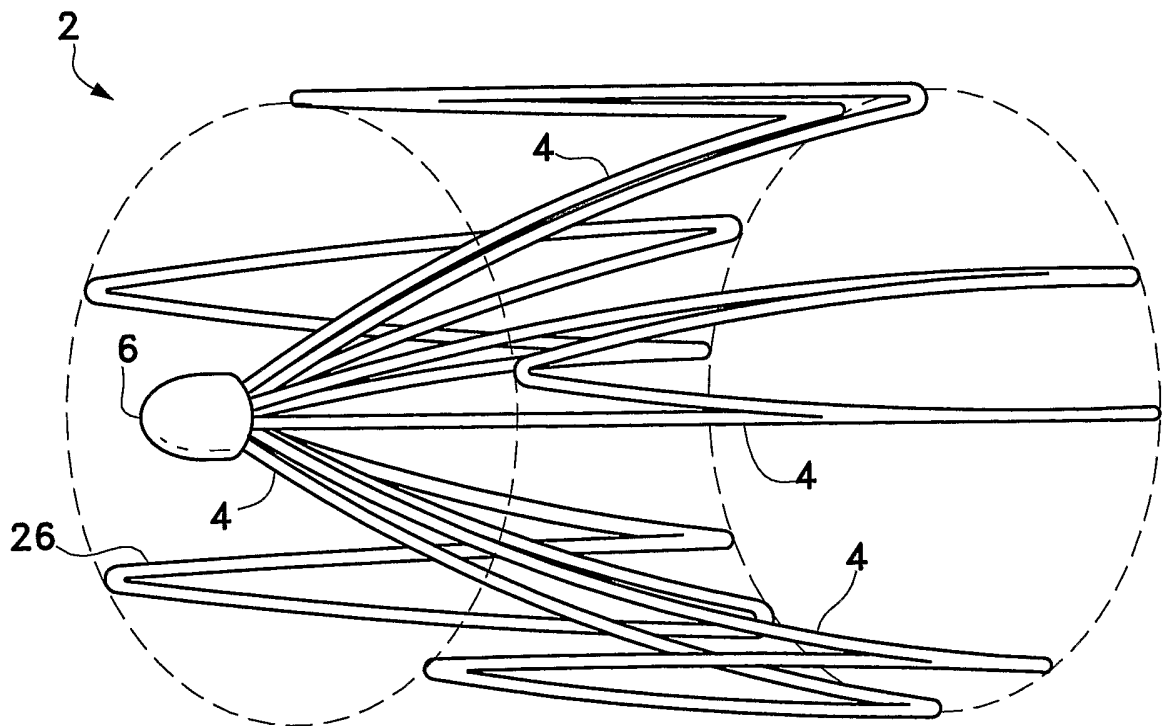


FIG. 18D