(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 581 125 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
18.12.2019 Bulletin 2019/51

(21) Application number: **19189835.2**

(22) Date of filing: **24.06.2016**

(51) Int Cl.:
A61B 17/32 *(2006.01)* ***A61B 18/14*** *(2006.01)*
A61B 17/00 *(2006.01)* ***A61B 18/00*** *(2006.01)*
A61B 90/00 *(2016.01)*

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **30.06.2015 US 201562186984 P**
30.09.2015 US 201562235368 P
30.09.2015 US 201562235466 P
30.09.2015 US 201562235260 P
15.01.2016 US 201662279635 P
02.05.2016 US 201662330669 P
09.06.2016 US 201615177439

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
16739613.4 / 3 316 812

(71) Applicant: **Ethicon LLC**
Guaynabo 00969 (PR)

(72) Inventors:
- **STULEN,, Foster B.**
  Cincinnati, OH Ohio 45242 (US)
- **MADAN,, Ashvani K.**
  Cincinnati, OH Ohio 45242 (US)
- **HOUSER,, Kevin L**
  Cincinnati, OH Ohio 45242 (US)

(74) Representative: **Bettridge, Paul Sebastian**
Carpmaels & Ransford LLP
One Southampton Row
London WC1B 5HA (GB)

Remarks:
This application was filed on 02.08.2019 as a divisional application to the application mentioned under INID code 62.

(54) SURGICAL SYSTEM WITH USER ADAPTABLE TECHNIQUES BASED ON TISSUE TYPE

(57) Various forms are directed to systems and methods for coagulation and dissection of tissue. A surgical instrument includes an end effector configured to seal and dissect tissue at a distal end thereof and a generator circuit that is configured to deliver energy to the end effector. A force sensor is in communication with the end effector and is configured to measure a force being applied to the tissue by the end effector. The energy delivered to the end effector is dynamic based on a determination of the type of tissue interacting with the end effector. The tissue type is determined based on a tissue coefficient that is calculated based on the measured force applied to the tissue by the end effector, the ultrasonic motion of the end effector, and a rate of heat generated by the end effector.

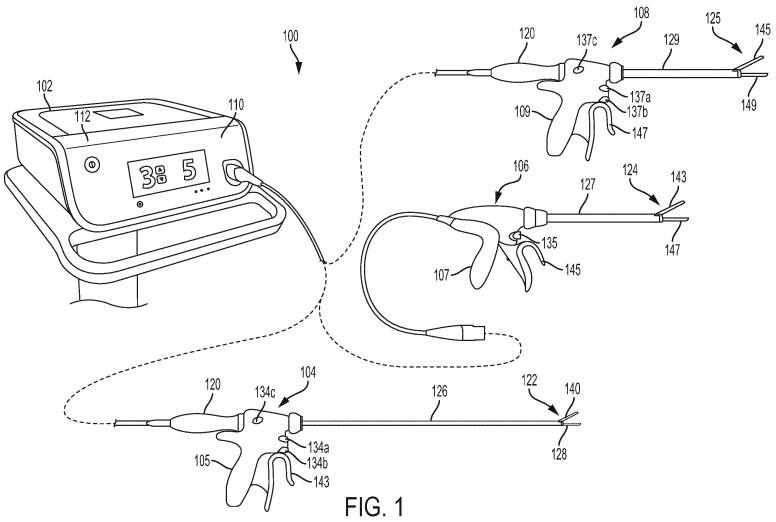

FIG. 1

EP 3 581 125 A1

Description

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 62/186,984 filed June 30, 2015, U.S. Provisional Application Serial No. 62/235,260, filed September 30, 2015, U.S. Provisional Application Serial No. 62/235,368, filed September 30, 2015, U.S. Provisional Application Serial No. 62/235,466, filed September 30, 2015, U.S. Provisional Application Serial No. 62/279,635, filed January 15, 2016, and U.S. Provisional Application Serial No. 62/330,669, filed May 2, 2016, the contents of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

[0002] The present disclosure generally relates to ultrasonic surgical systems and, more particularly, to ultrasonic and electrosurgical systems that allows surgeons to perform cutting and coagulation and adapt and customize techniques for performing such procedures based on the type of tissue being treated.

BACKGROUND

[0003] Ultrasonic surgical instruments are finding increasingly widespread applications in surgical procedures by virtue of the unique performance characteristics of such instruments. Depending upon specific instrument configurations and operational parameters, ultrasonic surgical instruments can provide substantially simultaneous cutting of tissue and hemostasis by coagulation, desirably minimizing patient trauma. The cutting action is typically realized by an-end effector, or blade tip, at the distal end of the instrument, which transmits ultrasonic energy to tissue brought into contact with the end effector. Ultrasonic instruments of this nature can be configured for open surgical use, laparoscopic, or endoscopic surgical procedures including robotic-assisted procedures.

[0004] Some surgical instruments utilize ultrasonic energy for both precise cutting and controlled coagulation. Ultrasonic energy cuts and coagulates by vibrating a blade in contact with tissue. Vibrating at high frequencies (*e.g.*, 55,500 times per second), the ultrasonic blade denatures protein in the tissue to form a sticky coagulum. Pressure exerted on tissue with the blade surface collapses blood vessels and allows the coagulum to form a hemostatic seal. The precision of cutting and coagulation is controlled by the surgeon's technique and adjusting the power level, blade edge, tissue traction, and blade pressure.

[0005] Electrosurgical devices for applying electrical energy to tissue in order to treat and/or destroy the tissue are also finding increasingly widespread applications in surgical procedures. An electrosurgical device typically includes a hand piece, an instrument having a distally-mounted end effector (*e.g.*, one or more electrodes). The end effector can be positioned against the tissue such that electrical current is introduced into the tissue. Electrosurgical devices can be configured for bipolar or monopolar operation. During bipolar operation, current is introduced into and returned from the tissue by active and return electrodes, respectively, of the end effector. During monopolar operation, current is introduced into the tissue by an active electrode of the end effector and returned through a return electrode (*e.g.*, a grounding pad) separately located on a patient's body. Heat generated by the current flowing through the tissue may form hemostatic seals within the tissue and/or between tissues and thus may be particularly useful for sealing blood vessels, for example. The end effector of an electrosurgical device also may include a cutting member that is movable relative to the tissue and the electrodes to transect the tissue.

[0006] Electrical energy applied by an electrosurgical device can be transmitted to the instrument by a generator in communication with the hand piece. The electrical energy may be in the form of radio frequency ("RF") energy. RF energy is a form of electrical energy that may be in the frequency range of 200 kilohertz (kHz) to 1 megahertz (MHz). In application, an electrosurgical device can transmit low frequency RF energy through tissue, which causes ionic agitation, or friction, in effect resistive heating, thereby increasing the temperature of the tissue. Because a sharp boundary is created between the affected tissue and the surrounding tissue, surgeons can operate with a high level of precision and control, without sacrificing un-targeted adjacent tissue. The low operating temperatures of RF energy is useful for removing, shrinking, or sculpting soft tissue while simultaneously sealing blood vessels. RF energy works particularly well on connective tissue, which is primarily comprised of collagen and shrinks when contacted by heat.

[0007] The RF energy may be in a frequency range described in EN 60601-2-2:2009+A11:2011, Definition 201.3.218 - HIGH FREQUENCY. For example, the frequency in monopolar RF applications may be typically restricted to less than 5MHz. However, in bipolar RF applications, the frequency can be almost anything. Frequencies above 200 kHz can be typically used for monopolar applications in order to avoid the unwanted stimulation of nerves and muscles that would result from the use of low frequency current. Lower frequencies may be used for bipolar applications if the risk analysis shows the possibility of neuromuscular stimulation has been mitigated to an acceptable level. Normally, frequencies above 5 MHz are not used in order to minimize the problems associated with high frequency leakage currents. Higher frequencies may, however, be used in the case of bipolar applications. It is generally recognized that 10 mA is the lower threshold of thermal effects on tissue.

[0008] A challenge of using these medical devices is the inability to control and customize the power output depending on the type of tissue being treated by the devices. It would be desirable to provide a surgical instrument that overcomes some of the deficiencies of current instruments. The surgical system described herein overcomes those deficiencies.

SUMMARY

[0009] In one aspect, a surgical instrument for coagulating and dissecting tissue is provided. The surgical instrument comprising a processor; an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising: a clamp arm; an ultrasonic blade; a force sensor in communication with the processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade; and a temperature sensor in communication with the processor; an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive a drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver energy to the ultrasonic blade; wherein the processor is configured to: determine a type of tissue interacting with the end effector based on a tissue coefficient of friction, wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector; and dynamically control the drive signal delivered to the ultrasonic transducer based on the type of tissue interacting with the end effector.

[0010] In addition to the foregoing, various other method and/or system and/or program product aspects are set forth and described in the teachings such as text (e.g., claims and/or detailed description) and/or drawings of the present disclosure.

[0011] The foregoing is a summary and thus may contain simplifications, generalizations, inclusions, and/or omissions of detail; consequently, those skilled in the art will appreciate that the summary is illustrative only and is NOT intended to be in any way limiting. Other aspects, features, and advantages of the devices and/or processes and/or other subject matter described herein will become apparent in the teachings set forth herein.

[0012] In one or more various aspects, related systems include but are not limited to circuitry and/or programming for effecting herein-referenced method aspects; the circuitry and/or programming can be virtually any combination of hardware, software, and/or firmware configured to affect the herein-referenced method aspects depending upon the design choices of the system designer. In addition to the foregoing, various other method and/or system aspects are set forth and described in the teachings such as text (e.g., claims and/or detailed description) and/or drawings of the present disclosure.

[0013] Further, it is understood that any one or more of the following-described forms, expressions of forms, examples, can be combined with any one or more of the other following-described forms, expressions of forms, and examples.

[0014] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

FIGURES

[0015] The novel features of the described forms are set forth with particularity in the appended claims. The described forms, however, both as to organization and methods of operation, may be best understood by reference to the following description, taken in conjunction with the accompanying drawings in which:

FIG. 1 illustrates one aspect of a surgical system comprising a generator and various surgical instruments usable therewith;
FIG. 2 is a diagram of one aspect of the ultrasonic surgical instrument of FIG. 16;
FIG. 3 is a diagram of one aspect of the surgical system of FIG. 16;
FIG. 4 is a model illustrating one aspect of a motional branch current;
FIG. 5 is a structural view of one aspect of a generator architecture;
FIG. 6 illustrates one aspect of a drive system of a generator, which creates the ultrasonic electrical signal for driving an ultrasonic transducer;
FIG. 7 illustrates one aspect of a drive system of a generator comprising a tissue impedance module;
FIG. 8 illustrates one aspect of a generator for delivering multiple energy modalities to a surgical instrument;
FIG. 9 is an example graph of two waveforms of energy from one aspect of a generator;
FIG. 10 is an example graph of the sum of the waveforms of FIG. 9;
FIG. 11 is an example graph of sum of the waveforms of FIG. 9 with the RF waveform dependent on the ultrasonic waveform;
FIG. 12 is an example graph of the sum of the waveforms of FIG. 9 with the RF waveform being a function of the ultrasonic waveform;

FIG. 13 is an example graph of a complex RF waveform;
FIG. 14 illustrates one aspect of an end effector comprising RF data sensors located on the clamp arm;
FIG. 15 illustrates one aspect of the flexible circuit shown in FIG. 14 in which the sensors may be mounted to or formed integrally therewith;
FIG. 16 is a cross-sectional view of the flexible circuit shown in FIG. 15;
FIG. 17 illustrates one aspect of a segmented flexible circuit configured to fixedly attach to a clamp arm of an end effector;
FIG. 18 illustrates one aspect of a segmented flexible circuit configured to mount to a clamp arm of an end effector;
FIG. 19 illustrates one aspect of an end effector configured to measure a tissue gap G_T;
FIG. 20 illustrates one aspect of a left-right segmented flexible circuit;
FIG. 21 illustrates one aspect of an end effector comprising segmented flexible circuit as shown in FIG. 20;
FIG. 22 illustrates the end effector shown in FIG. 21 with the clamp arm clamping tissue between the clamp arm and the ultrasonic blade;
FIG. 23 illustrates graphs of energy applied by the right and left side of an end effector based on locally sensed tissue parameters;
FIG. 24 illustrates a graph depicting one aspect of adjustment of threshold due to the measurement of a secondary tissue parameter such as continuity, temperature, pressure, and the like;
FIG. 25 is a cross-sectional view of one aspect of a flexible circuit comprising RF electrodes and data sensors embedded therein;
FIG. 26 is a cross-sectional view of one aspect of an end effector configured to sense force or pressure applied to tissue located between a clamp arm and an ultrasonic blade;
FIG. 27 is a schematic diagram of one aspect of a signal layer of a flexible circuit;
FIG. 28 is a schematic diagram of sensor wiring for the flexible circuit shown in FIG. 27;
FIG. 29 is a schematic diagram of one aspect of an RF energy drive circuit;
FIG. 30 is a graphical representation of measuring tissue gap at a preset time;
FIG. 31 is a time to preset force versus time graph for thin, medium, and thick tissue types;
FIG. 32 is a graphical depiction of a graph of three curves, where the first curve represents power (P), voltage(V_{RF}), and current (I_{RF}) versus tissue impedance (Z), the second curve and third curve represent tissue impedance (Z) versus time (t);
FIG. 33 is a plan view of one aspect of an end effector;
FIG. 34 is a side view of the end effector shown in FIG. 33 with a partial cut away view to expose the underlying structure of the clamp arm and an ultrasonic blade;
FIG. 35 is partial sectional view of the end effector shown in FIGS. 33, 34 to expose the ultrasonic blade and right and left electrodes, respectively;
FIG. 36 is a cross-sectional view taken at section 36--36 of the end effector shown in FIG. 33;
FIG. 37 is cross-sectional view taken at section 37--37 of the end effector shown in FIG. 33;
FIG. 38 is a cross-sectional view taken at section 36--36 of the end effector shown in FIG. 33, except that the ultrasonic blade has a different geometric configuration;
FIG. 39 is cross-sectional view taken at section 37--37 of the end effector shown in FIG. 33, except that the ultrasonic blade has a different geometric configuration;
FIG. 40 is a cross-sectional view taken at section 36--36 of the end effector shown in FIG. 33, except that the ultrasonic blade has a different geometric configuration;
FIG. 41 is cross-sectional view taken at section 37--37 of the end effector shown in FIG. 33, except that the ultrasonic blade has a different geometric configuration;
FIG. 42A is a graphical representation of one aspect of a medical device surrounding tissue;
FIG. 42B is a graphical representation of one aspect of a medical device compressing tissue;
FIG. 43A is a graphical representation of one aspect of a medical device compressing tissue;
FIG. 43B also depicts example forces exerted by one aspect of an end-effector of a medical device compressing tissue;
FIG. 44 illustrates a logic diagram of one aspect of a feedback system;
FIG. 45 is a graph of power versus force as measured with a plurality of plot points for various tissue types;
FIG. 46 is another graph of power versus force as measured with a plurality of plot points for various tissue types;
FIG. 47 is a logic flow diagram of one aspect of dynamically changing the energy delivered to a surgical instrument based on a determination of tissue type being treated by the instrument;
FIG. 48 is a logic flow diagram of one aspect of dynamically changing the energy delivered to a surgical instrument based on a determination of tissue type being treated by the instrument;
FIG. 49 is a logic flow diagram of one aspect of a method of dynamically changing the energy delivered to a surgical instrument based on a determination of the hydration level of tissue being treated by a surgical instrument;

FIG. 50 is a logic flow diagram of one aspect of a method of dynamically changing energy being delivered from a generator based on the type of tissue being treated by a surgical instrument and various characteristics of the tissue;
FIG. 51 is a logic flow diagram of one aspect of a technique for dynamically changing the energy delivered from a generator based on aperture defined by the end effector and energy parameters;
FIG. 52 is a logic flow diagram of one aspect of a technique for dynamically changing the energy delivered from a generator based on aperture defined by the end effector and energy parameters; and
FIG. 53 is a logic flow diagram of one aspect of a dynamic tissue sensing technique.

DESCRIPTION

[0016] Before explaining various forms of surgical instruments in detail, it should be noted that the illustrative forms are not limited in application or use to the details of construction and arrangement of parts illustrated in the accompanying drawings and description. The illustrative forms may be implemented or incorporated in other forms, variations and modifications, and may be practiced or carried out in various ways. Further, unless otherwise indicated, the terms and expressions employed herein have been chosen for the purpose of describing the illustrative forms for the convenience of the reader and are not for the purpose of limitation thereof.

[0017] Further, it is understood that any one or more of the following-described forms, expressions of forms, examples, can be combined with any one or more of the other following-described forms, expressions of forms, and examples.

[0018] Various forms are directed to improved ultrasonic and/or electrosurgical (RF) instruments configured for effecting tissue dissecting, cutting, and/or coagulation during surgical procedures. In one form, a combined ultrasonic and electrosurgical instrument may be configured for use in open surgical procedures, but has applications in other types of surgery, such as laparoscopic, endoscopic, and robotic-assisted procedures. Versatile use is facilitated by selective use of ultrasonic and RF energy.

[0019] The various forms will be described in combination with an ultrasonic instrument as described herein. Such description is provided by way of example, and not limitation, and is not intended to limit the scope and applications thereof. For example, any one of the described forms is useful in combination with a multitude of ultrasonic instruments including those described in, for example, U.S. Patent Nos. 5,938,633; 5,935,144; 5,944,737; 5,322,055; 5,630,420; and 5,449,370.

[0020] As will become apparent from the following description, it is contemplated that forms of the surgical instruments described herein may be used in association with an oscillator unit of a surgical system, whereby ultrasonic energy from the oscillator unit provides the desired ultrasonic actuation for the present surgical instrument. It is also contemplated that forms of the surgical instrument described herein may be used in association with a signal generator unit of a surgical system, whereby electrical energy in the form of radio frequencies (RF), for example, is used to provide feedback to the user regarding the surgical instrument. The ultrasonic oscillator and/or the signal generator unit may be non-detachably integrated with the surgical instrument or may be provided as separate components, which can be electrically attachable to the surgical instrument.

[0021] One form of the present surgical apparatus is particularly configured for disposable use by virtue of its straightforward construction. However, it is also contemplated that other forms of the present surgical instrument can be configured for non-disposable or multiple uses. Detachable connection of the present surgical instrument with an associated oscillator and signal generator unit is presently disclosed for single-patient use for illustrative purposes only. However, non-detachable integrated connection of the present surgical instrument with an associated oscillator and/or signal generator unit is also contemplated. Accordingly, various forms of the presently described surgical instruments may be configured for single use and/or multiple use with either detachable and/or non-detachable integral oscillator and/or signal generator unit, without limitation, and all combinations of such configurations are contemplated to be within the scope of the present disclosure.

[0022] The surgical instruments disclosed herein are related to surgical instruments described in the following commonly owned applications and filed concurrently herewith: END7747USNP titled "Surgical System With User Adaptable Techniques" by Yates et al., END7747USNP2 titled "Surgical System With User Adaptable Techniques Employing Multiple Energy Modalities Based On Tissue Parameters" by Wiener et al., END7747USNP3 titled "Surgical System With User Adaptable Techniques Based On Tissue Impedance" by Yates et al., and END7747USNP4 titled "Surgical System With User Adaptable Techniques Employing Simultaneous Energy Modalities Based On Tissue Parameters" by Yates et al., each of which is incorporated herein by reference in its entirety.

[0023] With reference to FIGS. 1-5, one form of a surgical system 10 including an ultrasonic surgical instrument is illustrated. FIG. 1 illustrates one form of a surgical system 100 comprising a generator 102 and various surgical instruments 104, 106, 108 usable therewith. FIG. 2 is a diagram of the ultrasonic surgical instrument 104 of FIG. 1.

[0024] FIG. 1 illustrates a generator 102 configured to drive multiple surgical instruments 104, 106, 108. The first surgical instrument 104 comprises a handpiece 105, an ultrasonic transducer 120, a shaft 126, and an end effector 122. The end effector 122 comprises an ultrasonic blade 128 acoustically coupled to the transducer 120 and a clamp arm

140. The handpiece 105 comprises a trigger 143 to operate the clamp arm 140 and a combination of the toggle buttons 134a, 134b, 134c to energize and drive the ultrasonic blade 128 or other function. The toggle buttons 134a, 134b, 134c can be configured to energize the ultrasonic transducer 120 with the generator 102.

[0025] Still with reference to FIG. 1, the generator 102 also is configured to drive a second surgical instrument 106. The second surgical instrument 106 is an RF electrosurgical instrument and comprises a handpiece 107, a shaft 127, and an end effector 124. The end effector 124 comprises electrodes in the clamp arms143 and return through the ultrasonic blade 149. The electrodes are coupled to and energized by a bipolar energy source within the generator 102. The handpiece 107 comprises a trigger 147 to operate the clamp arm 145 and an energy button 135 to actuate an energy switch to energize the electrodes in the end effector 124.

[0026] Still with reference to FIG. 1, the generator 102 also is configures to drive a combination electrosurgical and ultrasonic instrument 108. The combination electrosurgical and ultrasonic multifunction surgical instrument 108 comprises a handpiece 109, a shaft 129, and an end effector 125. The end effector comprises an ultrasonic blade 149 and a clamp arm 145. The ultrasonic blade 149 is acoustically coupled to the ultrasonic transducer 120. The handpiece 109 comprises a trigger 147 to operate the clamp arm 145 and a combination of the toggle buttons 137a, 137b, 137c to energize and drive the ultrasonic blade 149 or other function. The toggle buttons 137a, 137b, 137c can be configured to energize the ultrasonic transducer 120 with the generator 102 and energize the ultrasonic blade 149 with a bipolar energy source also contained within the generator 102.

[0027] With reference to both FIGS. 1 and 2, the generator 102 is configurable for use with a variety of surgical devices. According to various forms, the generator 102 may be configurable for use with different surgical devices of different types including, for example, the ultrasonic surgical instrument 104, the electrosurgical or RF surgical devices, such as, the RF electrosurgical instrument 106, and the multifunction surgical instrument 108 that integrate electrosurgical RF and ultrasonic energies delivered simultaneously from the generator 102. Although in the form of FIG. 1, the generator 102 is shown separate from the surgical instruments 104, 106, 108, in one form, the generator 102 may be formed integrally with either of the surgical instrument 104, 106, 108 to form a unitary surgical system. The generator 102 comprises an input device 110 located on a front panel of the generator 102 console. The input device 110 may comprise any suitable device that generates signals suitable for programming the operation of the generator 102. The generator 102 also may comprise one or more output devices 112.

[0028] The generator 102 is coupled to an ultrasonic transducer 120 via a cable 144. The ultrasonic transducer 120 and a waveguide extending through a shaft 126 (waveguide not shown in FIG. 2) may collectively form an ultrasonic drive system driving an ultrasonic blade 128 of an end effector 122. The end effector 122 further may comprise a clamp arm 140 to clamp tissue between the clamp arm 140 and the ultrasonic blade 128. In one form, the generator 102 may be configured to produce a drive signal of a particular voltage, current, and/or frequency output signal that can be stepped or otherwise modified with high resolution, accuracy, and repeatability.

[0029] Still with reference to FIG. 2, It will be appreciated that a surgical instrument 104 may comprise any combination of the toggle buttons 134a, 134b, 134c. For example, the surgical instrument 104 could be configured to have only two toggle buttons: a toggle button 134a for producing maximum ultrasonic energy output and a toggle button 134c for producing a pulsed output at either the maximum or less than maximum power level. In this way, the drive signal output configuration of the generator 102 could be 5 continuous signals and 5 or 4 or 3 or 2 or 1 pulsed signals. In certain forms, the specific drive signal configuration may be controlled based upon, for example, EEPROM settings in the generator 102 and/or user power level selection(s).

[0030] In certain forms, a two-position switch may be provided as an alternative to a toggle button 134c. For example, a surgical instrument 104 may include a toggle button 134a for producing a continuous output at a maximum power level and a two-position toggle button 134b. In a first detented position, toggle button 134b may produce a continuous output at a less than maximum power level, and in a second detented position the toggle button 134b may produce a pulsed output (*e.g.*, at either a maximum or less than maximum power level, depending upon the EEPROM settings).

[0031] Still with reference to FIG. 2, forms of the generator 102 may enable communication with instrument-based data circuits. For example, the generator 102 may be configured to communicate with a first data circuit 136 and/or a second data circuit 138. For example, the first data circuit 136 may indicate a burn-in frequency slope, as described herein. Additionally or alternatively, any type of information may be communicated to second data circuit for storage therein via a data circuit interface (*e.g.*, using a logic device). Such information may comprise, for example, an updated number of operations in which the instrument has been used and/or dates and/or times of its usage. In certain forms, the second data circuit may transmit data acquired by one or more sensors (*e.g.*, an instrument-based temperature sensor). In certain forms, the second data circuit may receive data from the generator 102 and provide an indication to a user (*e.g.*, an LED indication or other visible indication) based on the received data. The second data circuit 138 contained in the multifunction surgical instrument 108 of a surgical device. In some forms, the second data circuit 138 may be implemented in a many similar to that of the first data circuit 136 described herein. An instrument interface circuit may comprise a second data circuit interface to enable this communication. In one form, the second data circuit interface may comprise a tri-state digital interface, although other interfaces also may be used. In certain forms, the second data

circuit may generally be any circuit for transmitting and/or receiving data. In one form, for example, the second data circuit may store information pertaining to the particular surgical instrument with which it is associated. Such information may include, for example, a model number, a serial number, a number of operations in which the surgical instrument has been used, and/or any other type of information. In some forms, the second data circuit 138 may store information about the electrical and/or ultrasonic properties of an associated transducer 120, end effector 122, or ultrasonic drive system. Various processes and techniques described herein may be executed by a generator. It will be appreciated, however, that in certain example forms, all or a part of these processes and techniques may be performed by internal logic 139 of the multifunction surgical instrument 108.

[0032] FIG. 3 is a diagram of the surgical system 100 of FIG. 1. In various forms, the generator 102 may comprise several separate functional elements, such as modules and/or blocks. Different functional elements or modules may be configured for driving the different kinds of surgical instruments 104, 106, 108. For example, an ultrasonic generator drive circuit 114 may drive ultrasonic devices such as the ultrasonic surgical instrument 104 via a cable 142. An electrosurgery/RF generator drive circuit 116 may drive the electrosurgical instrument 106 via a cable 144. For example, the respective drive circuits 114, 116 may generate respective drive signals for driving the surgical instruments 104, 106, 108. In various forms, the ultrasonic generator drive circuit 114 (e.g., ultrasonic drive circuit) and/or the electrosurgery/RF generator drive circuit 116 (e.g., RF drive circuit) each may be formed integrally with the generator 102. Alternatively, one or more of the drive circuits 114, 116 may be provided as a separate circuit module electrically coupled to the generator 102. (The drive circuits 114 and 116 are shown in phantom to illustrate this option.) Also, in some forms, the electrosurgery/RF generator drive circuit 116 may be formed integrally with the ultrasonic generator drive circuit 114, or vice versa. Also, in some forms, the generator 102 may be omitted entirely and the drive circuits 114, 116 may be executed by processors or other hardware within the respective surgical instruments 104, 106, 108.

[0033] In other forms, the electrical outputs of the ultrasonic generator drive circuit 114 and the electrosurgery/RF generator drive circuit 116 may be combined into a single drive circuit to provide a single electrical signal capable of driving the multifunction surgical instrument 108 simultaneously with electrosurgical RF and ultrasonic energies via a cable 146. The multifunction surgical instrument 108 comprises an ultrasonic transducer 120 coupled to an ultrasonic blade 149 and one or more electrodes in the end effector 124 to receive electrosurgical RF energy. In such implementations, the combined RF/ultrasonic signal is coupled to the multifunction surgical instrument 108. The multifunction surgical instrument 108 comprises signal processing components to split the combined RF/ultrasonic signal such that the RF signal can be delivered to the electrodes in the end effector 124 and the ultrasonic signal can be delivered to the ultrasonic transducer 120.

[0034] In accordance with the described forms, the ultrasonic generator drive circuit 114 may produce a drive signal or signals of particular voltages, currents, and frequencies, e.g., 55,500 cycles per second (Hz). The drive signal or signals may be provided to the ultrasonic surgical instrument 104, and specifically to the transducer 120, which may operate, for example, as described herein. The transducer 120 and a waveguide extending through the shaft 126 (waveguide not shown in FIG. 2) may collectively form an ultrasonic drive system driving an ultrasonic blade 128 of an end effector 122. In one form, the generator 102 may be configured to produce a drive signal of a particular voltage, current, and/or frequency output signal that can be stepped or otherwise modified with high resolution, accuracy, and repeatability.

[0035] The generator 102 may be activated to provide the drive signal to the transducer 120 in any suitable manner. For example, the generator 102 may comprise a foot switch 130 coupled to the generator 102 via a foot switch cable 132. A clinician may activate the transducer 120 by depressing the foot switch 130. In addition, or instead of the foot switch 130 some forms of the ultrasonic surgical instrument 104 may utilize one or more switches positioned on the hand piece that, when activated, may cause the generator 102 to activate the transducer 120. In one form, for example, the one or more switches may comprise a pair of toggle buttons 134a, 134b (FIG. 2), for example, to determine an operating mode of the surgical instrument 104. When the toggle button 134a is depressed, for example, the ultrasonic generator 102 may provide a maximum drive signal to the transducer 120, causing it to produce maximum ultrasonic energy output. Depressing toggle button 134b may cause the ultrasonic generator 102 to provide a user-selectable drive signal to the transducer 120, causing it to produce less than the maximum ultrasonic energy output. The surgical instrument 104 additionally or alternatively may comprise a second switch (not shown) to, for example, indicate a position of a jaw closure trigger for operating jaws of the end effector 122. Also, in some forms, the ultrasonic generator 102 may be activated based on the position of the jaw closure trigger, (*e.g.*, as the clinician depresses the jaw closure trigger to close the jaws, ultrasonic energy may be applied).

[0036] Additionally or alternatively, the one or more switches may comprises a toggle button 134c that, when depressed, causes the generator 102 to provide a pulsed output. The pulses may be provided at any suitable frequency and grouping, for example. In certain forms, the power level of the pulses may be the power levels associated with toggle buttons 134a, 134b (maximum, less than maximum), for example.

[0037] In accordance with the described forms, the electrosurgery/RF generator drive circuit 116 may generate a drive signal or signals with output power sufficient to perform bipolar electrosurgery using radio frequency (RF) energy. In

bipolar electrosurgery applications, the drive signal may be provided, for example, to electrodes of the electrosurgical instrument 106, for example. Accordingly, the generator 102 may be configured for therapeutic purposes by applying electrical energy to the tissue sufficient for treating the tissue (*e.g.*, coagulation, cauterization, tissue welding).

[0038] The generator 102 may comprise an input device 110 (FIG. 1) located, for example, on a front panel of the generator 102 console. The input device 110 may comprise any suitable device that generates signals suitable for programming the operation of the generator 102. In operation, the user can program or otherwise control operation of the generator 102 using the input device 110. The input device 110 may comprise any suitable device that generates signals that can be used by the generator (*e.g.*, by one or more processors contained in the generator) to control the operation of the generator 102 (*e.g.*, operation of the ultrasonic generator drive circuit 114 and/or electrosurgery/RF generator drive circuit 116). In various forms, the input device 110 includes one or more of buttons, switches, thumbwheels, keyboard, keypad, touch screen monitor, pointing device, remote connection to a general purpose or dedicated computer. In other forms, the input device 110 may comprise a suitable user interface, such as one or more user interface screens displayed on a touch screen monitor, for example. Accordingly, by way of the input device 110, the user can set or program various operating parameters of the generator, such as, for example, current (I), voltage (V), frequency (f), and/or period (T) of a drive signal or signals generated by the ultrasonic generator drive circuit 114 and/or electrosurgery/RF generator drive circuit 116.

[0039] The generator 102 also may comprise an output device 112 (FIGS. 1, 3), such as an output indicator, located, for example, on a front panel of the generator 102 console. The output device 112 includes one or more devices for providing a sensory feedback to a user. Such devices may comprise, for example, visual feedback devices (*e.g.*, a visual feedback device may comprise incandescent lamps, light emitting diodes (LEDs), graphical user interface, display, analog indicator, digital indicator, bar graph display, digital alphanumeric display, LCD display screen, LED indicators), audio feedback devices (*e.g.*, an audio feedback device may comprise speaker, buzzer, audible, computer generated tone, computerized speech, voice user interface (VUI) to interact with computers through a voice/speech platform), or tactile feedback devices (*e.g.*, a tactile feedback device comprises any type of vibratory feedback, haptic actuator).

[0040] Although certain modules, circuits, and/or blocks of the generator 102 may be described by way of example, it can be appreciated that a greater or lesser number of modules, circuits, and/or blocks may be used and still fall within the scope of the forms. Further, although various forms may be described in terms of modules, circuits, and/or blocks to facilitate description, such modules, circuits, and/or blocks may be implemented by one or more hardware components, *e.g.*, processors, Digital Signal Processors (DSPs), Programmable Logic Devices (PLDs), Application Specific Integrated Circuits (ASICs), circuits, registers and/or software components, *e.g.*, programs, subroutines, logic and/or combinations of hardware and software components. Also, in some forms, the various modules described herein may be implemented utilizing similar hardware positioned within the surgical instruments 104, 106, 108 (*i.e.*, the generator 102 may be omitted).

[0041] In one form, the ultrasonic generator drive circuit 114 and electrosurgery/RF drive circuit 116 may comprise one or more embedded applications implemented as firmware, software, hardware, or any combination thereof. The drive circuits 114, 116 may comprise various executable modules such as software, programs, data, drivers, application program interfaces (APIs), and so forth. The firmware may be stored in nonvolatile memory (NVM), such as in bit-masked read-only memory (ROM) or flash memory. In various implementations, storing the firmware in ROM may preserve flash memory. The NVM may comprise other types of memory including, for example, programmable ROM (PROM), erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), or battery backed random-access memory (RAM) such as dynamic RAM (DRAM), Double-Data-Rate DRAM (DDRAM), and/or synchronous DRAM (SDRAM).

[0042] In one form, the drive circuits 114, 116 comprise a hardware component implemented as a processor for executing program instructions for monitoring various measurable characteristics of the surgical instruments 104, 106, 108 and generating a corresponding output control signals for operating the surgical instruments 104, 106, 108. In forms in which the generator 102 is used in conjunction with the surgical instrument 104, the output control signal may drive the ultrasonic transducer 120 in cutting and/or coagulation operating modes. Electrical characteristics of the surgical instrument 104 and/or tissue may be measured and used to control operational aspects of the generator 102 and/or provided as feedback to the user. In forms in which the generator 102 is used in conjunction with the electrosurgical instrument 106, the output control signal may supply electrical energy (*e.g.*, RF energy) to the end effector 124 in cutting, coagulation and/or desiccation modes. Electrical characteristics of the electrosurgical instrument 106 and/or tissue may be measured and used to control operational aspects of the generator 102 and/or provide feedback to the user. In various forms, as previously discussed, the hardware component may be implemented as a DSP, PLD, ASIC, circuits, and/or registers. In one form, the processor may be configured to store and execute computer software program instructions to generate the output signal functions for driving various components of the surgical instruments 104, 106, 108, such as the ultrasonic transducer 120 and the end effectors 122, 124.

[0043] FIG. 4 illustrates an equivalent circuit 150 of an ultrasonic transducer, such as the ultrasonic transducer 120 shown in FIGS. 1-3, according to one form. The circuit 150 comprises a first "motional" branch having a serially connected inductance L_s, resistance R_s and capacitance C_s that define the electromechanical properties of the resonator, and a

second capacitive branch having a static capacitance C_o. Drive current I_g may be received from a generator at a drive voltage V_g, with motional current I_m flowing through the first branch and current I_g - I_m flowing through the capacitive branch. Control of the electromechanical properties of the ultrasonic transducer may be achieved by suitably controlling I_g and V_g. As explained above, conventional generator architectures may include a tuning inductor L_t (shown in phantom in FIG. 4) for tuning out in a parallel resonance circuit the static capacitance Co at a resonant frequency so that substantially all of generator's current output I_g flows through the motional branch. In this way, control of the motional branch current I_m is achieved by controlling the generator current output I_g. The tuning inductor L_t is specific to the static capacitance C_o of an ultrasonic transducer, however, and a different ultrasonic transducer having a different static capacitance requires a different tuning inductor L_t. Moreover, because the tuning inductor L_t is matched to the nominal value of the static capacitance Co at a resonant frequency, accurate control of the motional branch current I_m is assured only at that frequency, and as frequency shifts down with transducer temperature, accurate control of the motional branch current is compromised.

[0044] Forms of the generator 102 shown in FIGS. 1-3 do not rely on a tuning inductor L_t to monitor the motional branch current I_m. Instead, the generator 102 may use the measured value of the static capacitance C_o in between applications of power for a specific ultrasonic surgical instrument 104 (along with drive signal voltage and current feedback data) to determine values of the motional branch current I_m on a dynamic and ongoing basis (*e.g.*, in real-time). Such forms of the generator 102 are therefore able to provide virtual tuning to simulate a system that is tuned or resonant with any value of static capacitance C_o at any frequency, and not just at the resonant frequency dictated by a nominal value of the static capacitance C_o.

[0045] FIG. 5 is a simplified block diagram of a generator 200 which is one form of the generator 102 shown in FIGS. 1-3 for proving inductorless tuning as described herein, among other benefits. Additional details of the generator 102 are described in commonly assigned and contemporaneously filed U.S. Patent Application Serial No. 12/896,360, titled "Surgical Generator For Ultrasonic And Electrosurgical Devices," Attorney Docket Number END6673USNP/100558, the disclosure of which is incorporated herein by reference in its entirety. With reference to FIG. 5, the generator 200 may comprise a patient isolated stage 202 in communication with a non-isolated stage 204 via a power transformer 206. A secondary winding 208 of the power transformer 206 is contained in the isolated stage 202 and may comprise a tapped configuration (*e.g.*, a center-tapped or a non-center-tapped configuration) to define drive signal outputs 210a, 210b, 210c for outputting drive signals to different surgical devices, such as, for example, an ultrasonic surgical instrument 104 and an electrosurgical instrument 106 (as shown in FIGS. 1-3). In particular, the drive signal outputs 210a, 210c may output an ultrasonic drive signal (*e.g.*, a 420V RMS drive signal) to an ultrasonic surgical instrument 104, and the drive signal outputs 210b, 210c may output an electrosurgical RF drive signal (*e.g.*, a 100V RMS drive signal) to an electrosurgical instrument 106, with the output 210b corresponding to the center tap of the power transformer 206.

[0046] In certain forms, the ultrasonic and electrosurgical drive signals may be provided simultaneously to distinct surgical instruments and/or to a single surgical instrument having the capability to deliver both ultrasonic and electrosurgical energy to tissue, such as multifunction surgical instrument 108 (FIGS. 1 and 3). It will be appreciated that the electrosurgical signal, provided either to a dedicated electrosurgical instrument and/or to a combined multifunction ultrasonic/electrosurgical instrument may be either a therapeutic or sub-therapeutic level signal. For example, the ultrasonic and radio frequency signals can be delivered separately or simultaneously from a generator with a single output port in order to provide the desired output signal to the surgical instrument, as will be discussed in more detail below. Accordingly, the generator can combine the ultrasonic and electrosurgical RF energies and deliver the combined energies to the multifunction ultrasonic/electrosurgical instrument. Bipolar electrodes can be placed on one or both jaws of the end effector. One jaw may be driven by ultrasonic energy in addition to electrosurgical RF energy, working simultaneously. The ultrasonic energy may be employed to dissect tissue while the electrosurgical RF energy may be employed for vessel sealing.

[0047] The non-isolated stage 204 may comprise a power amplifier 212 having an output connected to a primary winding 214 of the power transformer 206. In certain forms the power amplifier 212 may be comprise a push-pull amplifier. For example, the non-isolated stage 204 may further comprise a logic device 216 for supplying a digital output to a digital-to-analog converter (DAC) 218, which in turn supplies a corresponding analog signal to an input of the power amplifier 212. In certain forms the logic device 216 may comprise a programmable gate array (PGA), a field-programmable gate array (FPGA), programmable logic device (PLD), among other logic circuits, for example. The logic device 216, by virtue of controlling the input of the power amplifier 212 via the DAC 218, may therefore control any of a number of parameters (*e.g.*, frequency, waveform shape, waveform amplitude) of drive signals appearing at the drive signal outputs 210a, 210b, 210c. In certain forms and as discussed below, the logic device 216, in conjunction with a processor (*e.g.*, a digital signal processor discussed below), may implement a number of digital signal processing (DSP)-based and/or other control techniques to control parameters of the drive signals output by the generator 200.

[0048] Power may be supplied to a power rail of the power amplifier 212 by a switch-mode regulator 220. In certain forms the switch-mode regulator 220 may comprise an adjustable buck regulator, for example. The non-isolated stage 204 may further comprise a first processor such as DSP processor 222, which in one form may comprise a DSP processor

such as an Analog Devices ADSP-21469 SHARC DSP, available from Analog Devices, Norwood, MA, for example, although in various forms any suitable processor may be employed. In certain forms the DSP processor 222 may control operation of the switch-mode power converter 220 responsive to voltage feedback data received from the power amplifier 212 by the DSP processor 222 via an analog-to-digital converter (ADC) 224. In one form, for example, the DSP processor 222 may receive as input, via the ADC 224, the waveform envelope of a signal (*e.g.*, an RF signal) being amplified by the power amplifier 212. The DSP processor 222 may then control the switch-mode regulator 220 (*e.g.*, via a pulse-width modulated (PWM) output) such that the rail voltage supplied to the power amplifier 212 tracks the waveform envelope of the amplified signal. By dynamically modulating the rail voltage of the power amplifier 212 based on the waveform envelope, the efficiency of the power amplifier 212 may be significantly improved relative to a fixed rail voltage amplifier schemes.

[0049] In certain forms, the logic device 216, in conjunction with the DSP processor 222, may implement a direct digital synthesizer (DDS) control scheme to control the waveform shape, frequency and/or amplitude of drive signals output by the generator 200. In one form, for example, the logic device 216 may implement a DDS control technique by recalling waveform samples stored in a dynamically-updated look-up table (LUT), such as a RAM LUT, which may be embedded in an FPGA. This control technique is particularly useful for ultrasonic applications in which an ultrasonic transducer, such as the ultrasonic transducer 120 (FIGS. 1-3), may be driven by a clean sinusoidal current at its resonant frequency. Because other frequencies may excite parasitic resonances, minimizing or reducing the total distortion of the motional branch current may correspondingly minimize or reduce undesirable resonance effects. Because the waveform shape of a drive signal output by the generator 200 is impacted by various sources of distortion present in the output drive circuit (*e.g.*, the power transformer 206, the power amplifier 212), voltage and current feedback data based on the drive signal may be input into a technique, such as an error control technique implemented by the DSP processor 222, which compensates for distortion by suitably pre-distorting or modifying the waveform samples stored in the LUT on a dynamic, ongoing basis (*e.g.*, in real-time). In one form, the amount or degree of pre-distortion applied to the LUT samples may be based on the error between a computed motional branch current and a desired current waveform shape, with the error being determined on a sample-by-sample basis. In this way, the pre-distorted LUT samples, when processed through the drive circuit, may result in a motional branch drive signal having the desired waveform shape (*e.g.*, sinusoidal) for optimally driving the ultrasonic transducer. In such forms, the LUT waveform samples will therefore not represent the desired waveform shape of the drive signal, but rather the waveform shape that is required to ultimately produce the desired waveform shape of the motional branch drive signal when distortion effects are taken into account.

[0050] The non-isolated stage 204 may further comprise an ADC 226 and an ADC 228 coupled to the output of the power transformer 206 via respective isolation transformers 230, 232 for respectively sampling the voltage and current of drive signals output by the generator 200. In certain forms, the ADCs 226, 228 may be configured to sample at high speeds (*e.g.*, 80 MSPS) to enable oversampling of the drive signals. In one form, for example, the sampling speed of the ADCs 226, 228 may enable approximately 200x (depending on frequency) oversampling of the drive signals. In certain forms, the sampling operations of the ADC 226, 228 may be performed by a singe ADC receiving input voltage and current signals via a two-way multiplexer. The use of high-speed sampling in forms of the generator 200 may enable, among other things, calculation of the complex current flowing through the motional branch (which may be used in certain forms to implement DDS-based waveform shape control described herein), accurate digital filtering of the sampled signals, and calculation of real power consumption with a high degree of precision. Voltage and current feedback data output by the ADCs 226, 228 may be received and processed (*e.g.*, FIFO buffering, multiplexing) by the logic device 216 and stored in data memory for subsequent retrieval by, for example, the DSP processor 222. As noted above, voltage and current feedback data may be used as input to a technique for pre-distorting or modifying LUT waveform samples on a dynamic and ongoing basis. In certain forms, this may require each stored voltage and current feedback data pair to be indexed based on, or otherwise associated with, a corresponding LUT sample that was output by the logic device 216 when the voltage and current feedback data pair was acquired. Synchronization of the LUT samples and the voltage and current feedback data in this manner contributes to the correct timing and stability of the pre-distortion technique.

[0051] In certain forms, the voltage and current feedback data may be used to control the frequency and/or amplitude (*e.g.*, current amplitude) of the drive signals. In one form, for example, voltage and current feedback data may be used to determine impedance phase. The frequency of the drive signal may then be controlled to minimize or reduce the difference between the determined impedance phase and an impedance phase setpoint (*e.g.*, 0°), thereby minimizing or reducing the effects of ultrasonic distortion and correspondingly enhancing impedance phase measurement accuracy. The determination of phase impedance and a frequency control signal may be implemented in the DSP processor 222, for example, with the frequency control signal being supplied as input to a DDS control technique implemented by the logic device 216.

[0052] In another form, for example, the current feedback data may be monitored in order to maintain the current amplitude of the drive signal at a current amplitude setpoint. The current amplitude setpoint may be specified directly or determined indirectly based on specified voltage amplitude and power setpoints. In certain forms, control of the current

amplitude may be implemented by control technique, such as, for example, a PID control technique, in the DSP processor 222. Variables controlled by the control technique to suitably control the current amplitude of the drive signal may include, for example, the scaling of the LUT waveform samples stored in the logic device 216 and/or the full-scale output voltage of the DAC 218 (which supplies the input to the power amplifier 212) via a DAC 234.

[0053] The non-isolated stage 204 may further comprise a second processor such as UI processor 236 for providing, among other things user interface (UI) functionality. In one form, the UI processor 236 may comprise an Atmel AT91SAM9263 processor having an ARM 926EJ-S core, available from Atmel Corporation, San Jose, CA, for example. Examples of UI functionality supported by the UI processor 236 may include audible and visual user feedback, communication with peripheral devices (e.g., via a Universal Serial Bus (USB) interface), communication with the foot switch 130, communication with an input device 118 (e.g., a touch screen display) and communication with an output device 112 (e.g., a speaker), as shown in FIG. 3, for example. The UI processor 236 may communicate with the DSP processor 222 and the logic device 216 (e.g., via serial peripheral interface (SPI) buses). Although the UI processor 236 may primarily support UI functionality, it also may coordinate with the DSP processor 222 to implement hazard mitigation in certain forms. For example, the UI processor 236 may be programmed to monitor various aspects of user input and/or other inputs (e.g., touch screen inputs, foot switch 130 inputs (FIG. 3), temperature sensor inputs) and may disable the drive output of the generator 200 when an erroneous condition is detected.

[0054] In certain forms, both the DSP processor 222 and the UI processor 236, for example, may determine and monitor the operating state of the generator 200. For the DSP processor 222, the operating state of the generator 200 may dictate, for example, which control and/or diagnostic processes are implemented by the DSP processor 222. For the UI processor 236, the operating state of the generator 200 may dictate, for example, which elements of a user interface (*e.g.*, display screens, sounds) are presented to a user. The respective DSP and UI processors 222, 236 may independently maintain the current operating state of the generator 200 and recognize and evaluate possible transitions out of the current operating state. The DSP processor 222 may function as the master in this relationship and determine when transitions between operating states are to occur. The UI processor 236 may be aware of valid transitions between operating states and may confirm if a particular transition is appropriate. For example, when the DSP processor 222 instructs the UI processor 236 to transition to a specific state, the UI processor 236 may verify that requested transition is valid. In the event that a requested transition between states is determined to be invalid by the UI processor 236, the UI processor 236 may cause the generator 200 to enter a failure mode.

[0055] The non-isolated stage 204 may further comprise a controller 238 for monitoring input devices 110 (e.g., a capacitive touch sensor used for turning the generator 200 on and off, a capacitive touch screen, e.g., as shown in FIGS. 1 and 3). In certain forms, the controller 238 may comprise at least one processor and/or other controller device in communication with the UI processor 236. In one form, for example, the controller 238 may comprise a processor (*e.g.*, a Mega168 8-bit controller available from Atmel) configured to monitor user input provided via one or more capacitive touch sensors. In one form, the controller 238 may comprise a touch screen controller (*e.g.*, a QT5480 touch screen controller available from Atmel) to control and manage the acquisition of touch data from a capacitive touch screen.

[0056] In certain forms, when the generator 200 is in a "power off' state, the controller 238 may continue to receive operating power (*e.g.*, via a line from a power supply of the generator 200. In this way, the controller 238 may continue to monitor an input device 110 (*e.g.*, a capacitive touch sensor located on a front panel of the generator 200) for turning the generator 200 on and off. When the generator 200 is in the power off state, the controller 238 may wake the power supply (*e.g.*, enable operation of one or more DC/DC voltage converters of the power supply) if activation of the "on/off" input device 110 by a user is detected. The controller 238 may therefore initiate a sequence for transitioning the generator 200 to a "power on" state. Conversely, the controller 238 may initiate a sequence for transitioning the generator 200 to the power off state if activation of the "on/off" input device 110 is detected when the generator 200 is in the power on state. In certain forms, for example, the controller 238 may report activation of the "on/off" input device 110 to the UI processor 236, which in turn implements the necessary process sequence for transitioning the generator 200 to the power off state. In such forms, the controller 238 may have no independent ability for causing the removal of power from the generator 200 after its power on state has been established.

[0057] In certain forms, the controller 238 may cause the generator 200 to provide audible or other sensory feedback for alerting the user that a power on or power off sequence has been initiated. Such an alert may be provided at the beginning of a power on or power off sequence and prior to the commencement of other processes associated with the sequence.

[0058] In certain forms, the isolated stage 202 may comprise an instrument interface circuit 240 to, for example, provide a communication interface between a control circuit of a surgical device (*e.g.*, a control circuit comprising hand piece switches) and components of the non-isolated stage 204, such as, for example, the programmable logic device 216, the DSP processor 222 and/or the UI processor 236. The instrument interface circuit 240 may exchange information with components of the non-isolated stage 204 via a communication link that maintains a suitable degree of electrical isolation between the stages 202, 204, such as, for example, an infrared (IR)-based communication link. Power may be supplied to the instrument interface circuit 240 using, for example, a low-dropout voltage regulator powered by an isolation

transformer driven from the non-isolated stage 204.

[0059] In one form, the instrument interface circuit 240 may comprise a logic device 242 (e.g., logic circuit, programmable logic circuit, PGA, FPGA, PLD) in communication with a signal conditioning circuit 242. The signal conditioning circuit 244 may be configured to receive a periodic signal from the logic circuit 242 (e.g., a 2 kHz square wave) to generate a bipolar interrogation signal having an identical frequency. The interrogation signal may be generated, for example, using a bipolar current source fed by a differential amplifier. The interrogation signal may be communicated to a surgical device control circuit (*e.g.*, by using a conductive pair in a cable that connects the generator 200 to the surgical device) and monitored to determine a state or configuration of the control circuit. The control circuit may comprise a number of switches, resistors and/or diodes to modify one or more characteristics (*e.g.*, amplitude, rectification) of the interrogation signal such that a state or configuration of the control circuit is uniquely discernable based on the one or more characteristics. In one form, for example, the signal conditioning circuit 244 may comprises an ADC for generating samples of a voltage signal appearing across inputs of the control circuit resulting from passage of interrogation signal therethrough. The logic device 242 (or a component of the non-isolated stage 204) may then determine the state or configuration of the control circuit based on the ADC samples.

[0060] In one form, the instrument interface circuit 240 may comprise a first data circuit interface 246 to enable information exchange between the logic circuit 242 (or other element of the instrument interface circuit 240) and a first data circuit disposed in or otherwise associated with a surgical device. In certain forms, for example, a first data circuit 136 (FIG. 2) may be disposed in a cable integrally attached to a surgical device hand piece, or in an adaptor for interfacing a specific surgical device type or model with the generator 200. The first data circuit 136 may be implemented in any suitable manner and may communicate with the generator according to any suitable protocol including, for example, as described herein with respect to the first circuit 136. In certain forms, the first data circuit may comprise a non-volatile storage device, such as an electrically erasable programmable read-only memory (EEPROM) device. In certain forms and referring again to FIG. 5, the first data circuit interface 246 may be implemented separately from the logic device 242 and comprise suitable circuitry (e.g., discrete logic devices, a processor) to enable communication between the programmable logic device 242 and the first data circuit. In other forms, the first data circuit interface 246 may be integral with the logic device 242.

[0061] In certain forms, the first data circuit 136 (FIG. 2) may store information pertaining to the particular surgical device with which it is associated. Such information may include, for example, a model number, a serial number, a number of operations in which the surgical device has been used, and/or any other type of information. This information may be read by the instrument interface circuit 1098 (*e.g.*, by the logic device 242), transferred to a component of the non-isolated stage 204 (*e.g.*, to logic device 216, DSP processor 222 and/or UI processor 236) for presentation to a user via an output device 112 (FIGS. 1 and 3) and/or for controlling a function or operation of the generator 200. Additionally, any type of information may be communicated to first data circuit 136 for storage therein via the first data circuit interface 246 (*e.g.*, using the logic device 242). Such information may comprise, for example, an updated number of operations in which the surgical device has been used and/or dates and/or times of its usage.

[0062] As discussed previously, a surgical instrument may be detachable from a hand piece (*e.g.*, as shown in FIGS. 1 and 2, the transducer 120 and the shaft 126 is detachable from the handpiece 105 of the ultrasonic surgical instrument 104) to promote instrument interchangeability and/or disposability. In such cases, conventional generators may be limited in their ability to recognize particular instrument configurations being used and to optimize control and diagnostic processes accordingly. The addition of readable data circuits to surgical device instruments to address this issue is problematic from a compatibility standpoint, however. For example, designing a surgical device to remain backwardly compatible with generators that lack the requisite data reading functionality may be impractical due to, for example, differing signal schemes, design complexity, and cost. Forms of instruments discussed herein address these concerns by using data circuits that may be implemented in existing surgical instruments economically and with minimal design changes to preserve compatibility of the surgical devices with current generator platforms.

[0063] With reference to FIGS. 1-3 and 5, additionally, forms of the generator 200 may enable communication with instrument-based data circuits. For example, the generator 200 may be configured to communicate with a second data circuit 138 contained in the ultrasonic surgical instrument 104 (*e.g.*, and/or the other surgical instruments 106, 108). In some forms, the second data circuit 138 may be implemented in a many similar to that of the first data circuit 136 described herein. The instrument interface circuit 240 may comprise a second data circuit interface 248 to enable this communication. In one form, the second data circuit interface 248 may comprise a tri-state digital interface, although other interfaces also may be used. In certain forms, the second data circuit may generally be any circuit for transmitting and/or receiving data. In one form, for example, the second data circuit may store information pertaining to the particular surgical instrument with which it is associated. Such information may include, for example, a model number, a serial number, a number of operations in which the surgical instrument has been used, and/or any other type of information. In some forms, the second data circuit 138 may store information about the electrical and/or ultrasonic properties of an associated transducer 120, end effector 122, or ultrasonic drive system. For example, the first data circuit 136 may indicate a burn-in frequency slope, as described herein. Additionally or alternatively, any type of information may be

communicated to second data circuit for storage therein via the second data circuit interface 248 (*e.g.*, using the logic device 242). Such information may comprise, for example, an updated number of operations in which the instrument has been used and/or dates and/or times of its usage. In certain forms, the second data circuit may transmit data acquired by one or more sensors (*e.g.*, an instrument-based temperature sensor). In certain forms, the second data circuit may receive data from the generator 200 and provide an indication to a user (*e.g.*, an LED indication or other visible indication) based on the received data.

[0064] In certain forms, the second data circuit and the second data circuit interface 248 may be configured such that communication between the logic device 242 and the second data circuit can be effected without the need to provide additional conductors for this purpose (*e.g.*, dedicated conductors of a cable connecting a hand piece to the generator 200). In one form, for example, information may be communicated to and from the second data circuit using a 1-wire bus communication scheme implemented on existing cabling, such as one of the conductors used transmit interrogation signals from the signal conditioning circuit 244 to a control circuit in a hand piece. In this way, design changes or modifications to the surgical device that might otherwise be necessary are minimized or reduced. Moreover, because different types of communications implemented over a common physical channel can be frequency-band separated, the presence of a second data circuit may be "invisible" to generators that do not have the requisite data reading functionality, thus enabling backward compatibility of the surgical device instrument.

[0065] In certain forms, the isolated stage 202 may comprise at least one blocking capacitor 250-1 connected to the drive signal output 210b to prevent passage of DC current to a patient. A single blocking capacitor may be required to comply with medical regulations or standards, for example. While failure in single-capacitor designs is relatively uncommon, such failure may nonetheless have negative consequences. In one form, a second blocking capacitor 250-2 may be provided in series with the blocking capacitor 250-1, with current leakage from a point between the blocking capacitors 250-1, 250-2 being monitored by, for example, an ADC 252 for sampling a voltage induced by leakage current. The samples may be received by the logic device 242, for example. Based changes in the leakage current (as indicated by the voltage samples in the form of FIG. 5), the generator 200 may determine when at least one of the blocking capacitors 250-1, 250-2 has failed. Accordingly, the form of FIG. 5 provides a benefit over single-capacitor designs having a single point of failure.

[0066] In certain forms, the non-isolated stage 204 may comprise a power supply 254 for outputting DC power at a suitable voltage and current. The power supply may comprise, for example, a 400 W power supply for outputting a 48 VDC system voltage. The power supply 254 may further comprise one or more DC/DC voltage converters 256 for receiving the output of the power supply to generate DC outputs at the voltages and currents required by the various components of the generator 200. As discussed above in connection with the controller 238, one or more of the DC/DC voltage converters 256 may receive an input from the controller 238 when activation of the "on/off" input device 110 (FIG. 3) by a user is detected by the controller 238 to enable operation of, or wake, the DC/DC voltage converters 256.

[0067] With reference back to FIG. 1, having described operational details of various forms of the surgical system 100 operations for the above surgical system 100 may be further described generally in terms of a process for cutting and coagulating tissue employing a surgical instrument comprising an input device 110 and the generator 102. Although a particular process is described in connection with the operational details, it can be appreciated that the process merely provides an example of how the general functionality described herein can be implemented by the surgical system 100. Further, the given process does not necessarily have to be executed in the order presented herein unless otherwise indicated. As previously discussed, the input devices 110 may be employed to program the output (e.g., impedance, current, voltage, frequency) of the surgical instruments 104, 106, 108.

[0068] FIG. 6 illustrates a generator 300 comprising one form of drive system 302, according to one aspect of the present disclosure. The generator 300 is similar to the generators 102, 200 described in connection with in FIGS. 1 and 5. The generator 300 produces an ultrasonic electrical signal for driving an ultrasonic transducer, also referred to as a drive signal. The drive system 302 is flexible and can create an ultrasonic electrical output drive signal 304 at a desired frequency and power level setting for driving an ultrasonic transducer 306. In various forms, the generator 300 may comprise several separate functional elements, such as modules and/or blocks. Although certain modules, circuits, and/or blocks may be described by way of example, it can be appreciated that a greater or lesser number of modules, circuits, and/or blocks may be used and still fall within the scope of the forms. Further, although various forms may be described in terms of modules, circuits, and/or blocks to facilitate description, such modules, circuits, and/or blocks may be implemented by one or more hardware components, e.g., processors, Digital Signal Processors (DSPs), Programmable Logic Devices (PLDs), Application Specific Integrated Circuits (ASICs), circuits, registers and/or software components, e.g., programs, subroutines, logic and/or combinations of hardware and software components.

[0069] In one form, the drive system 302 of the generator 300 may comprise one or more embedded applications implemented as firmware, software, hardware, or any combination thereof. The drive system 302 may comprise various executable modules such as software, programs, data, drivers, application program interfaces (APIs), and so forth. The firmware may be stored in nonvolatile memory (NVM), such as in bit-masked read-only memory (ROM) or flash memory. In various implementations, storing the firmware in ROM may preserve flash memory. The NVM may comprise other

types of memory including, for example, programmable ROM (PROM), erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), or battery backed random-access memory (RAM) such as dynamic RAM (DRAM), Double-Data-Rate DRAM (DDRAM), and/or synchronous DRAM (SDRAM).

[0070] In one form, the drive system 302 comprises a hardware component implemented as a processor 308 for executing program instructions for monitoring various measurable characteristics of the ultrasonic surgical instrument 104 (FIG. 1) and generating various functions as an output signal for driving the ultrasonic transducer 306 in cutting and/or coagulation operating modes. It will be appreciated by those skilled in the art that the generator 300 and the drive system 302 may comprise additional or fewer components and only a simplified version of the generator 300 and the drive system 302 are described herein for conciseness and clarity. In various forms, as previously discussed, the hardware component may be implemented as a DSP, PLD, ASIC, circuits, and/or registers. In one form, the processor 308 may be configured to store and execute computer software program instructions to generate the output signal functions for driving various components of the ultrasonic surgical instrument 104 (FIG. 1), such as an ultrasonic transducer 306, an end effector, and/or a blade 340.

[0071] In one form, under control of one or more software program routines, the processor 308 executes the methods in accordance with the described forms to generate a function formed by a stepwise waveform of drive signals comprising current (I), voltage (V), and/or frequency (f) for various time intervals or periods (T). The stepwise waveforms of the drive signals may be generated by forming a piecewise linear combination of constant functions over a plurality of time intervals created by varying the generator 300 drive signals, e.g., output drive current (I), voltage (V), and/or frequency (f). The time intervals or periods (T) may be predetermined (e.g., fixed and/or programmed by the user) or may be variable. Variable time intervals may be defined by setting the drive signal to a first value and maintaining the drive signal at that value until a change is detected in a monitored characteristic. Examples of monitored characteristics may comprise, for example, transducer impedance, tissue impedance, tissue heating, tissue transection, tissue coagulation, and the like. The ultrasonic drive signals generated by the generator 300 include, without limitation, ultrasonic drive signals capable of exciting the ultrasonic transducer 306 in various vibratory modes such as, for example, the primary longitudinal mode and harmonics thereof as well flexural and torsional vibratory modes.

[0072] In one form, the executable modules comprise one or more technique(s) 310 stored in memory that when executed causes the processor 308 to generate a function formed by a stepwise waveform of drive signals comprising current (I), voltage (V), and/or frequency (f) for various time intervals or periods (T). The stepwise waveforms of the drive signals may be generated by forming a piecewise linear combination of constant functions over two or more time intervals created by varying the generator 300 output drive current (I), voltage (V), and/or frequency (f). The drive signals may be generated either for predetermined fixed time intervals or periods (T) of time or variable time intervals or periods of time in accordance with the one or more technique(s) 310. Under control of the processor 308, the generator 300 varies (*e.g.*, increment or decrement over time) the current (I), voltage (V), and/or frequency (f) up or down at a particular resolution for a predetermined period (T) or until a predetermined condition is detected, such as a change in a monitored characteristic (*e.g.*, transducer impedance, tissue impedance). The steps can change in programmed increments or decrements. If other steps are desired, the generator 300 can increase or decrease the step adaptively based on measured system characteristics.

[0073] In operation, the user can program the operation of the generator 300 using the input device 312 located on the front panel of the generator 300 console. The input device 312 may comprise any suitable device that generates signals 314 that can be applied to the processor 308 to control the operation of the generator 300. In various forms, the input device 312 includes buttons, switches, thumbwheels, keyboard, keypad, touch screen monitor, pointing device, remote connection to a general purpose or dedicated computer. In other forms, the input device 312 may comprise a suitable user interface. Accordingly, by way of the input device 312, the user can set or program the current (I), voltage (V), frequency (f), and/or period (T) for programming the output function of the generator 300. The processor 308 then displays the selected power level by sending a signal on line 316 to an output indicator 318.

[0074] In various forms, the output indicator 318 may provide visual, audible, and/or tactile feedback to the surgeon to indicate the status of a surgical procedure, such as, for example, when tissue cutting and coagulating is complete based on a measured characteristic of the ultrasonic surgical instrument 104 (FIG. 1), *e.g.*, transducer impedance, tissue impedance, or other measurements as subsequently described. By way of example, and not limitation, visual feedback comprises any type of visual indication device including incandescent lamps or light emitting diodes (LEDs), graphical user interface, display, analog indicator, digital indicator, bar graph display, digital alphanumeric display. By way of example, and not limitation, audible feedback comprises any type of buzzer, computer generated tone, computerized speech, voice user interface (VUI) to interact with computers through a voice/speech platform. By way of example, and not limitation, tactile feedback comprises any type of vibratory feedback provided through an instrument housing handle assembly.

[0075] In one form, the processor 308 may be configured or programmed to generate a digital current drive signal 320 and a digital frequency signal 322. These drive signals 320, 322 are applied to a direct digital synthesizer (DDS) circuit 324 to adjust the amplitude and the frequency (f) of the output drive signal 304 to the ultrasonic transducer 306. The

output of the DDS circuit 324 is applied to an amplifier 326 whose output is applied to a transformer 328. The output of the transformer 328 is the output drive signal 304 applied to the ultrasonic transducer 306, which is coupled to the blade 340 by way of a waveguide.

[0076] In one form, the generator 300 comprises one or more measurement modules or components that may be configured to monitor measurable characteristics of the ultrasonic surgical instrument 104 (FIG. 1). In the illustrated form, the processor 308 may be employed to monitor and calculate system characteristics. As shown, the processor 308 measures the impedance Z of the ultrasonic transducer 306 by monitoring the current supplied to the transducer 306 and the voltage applied to the ultrasonic transducer 306. In one form, a current sense circuit 330 is employed to sense the current supplied to the ultrasonic transducer 306 and a voltage sense circuit 332 is employed to sense the output voltage applied to the ultrasonic transducer 306. These signals may be applied to the analog-to-digital converter 336 (ADC) via an analog multiplexer 334 circuit or switching circuit arrangement. The analog multiplexer 334 routes the appropriate analog signal to the ADC 336 for conversion. In other forms, multiple ADCs 336 may be employed for each measured characteristic instead of the multiplexer 334 circuit. The processor 308 receives the digital output 338 of the ADC 336 and calculates the transducer impedance Z based on the measured values of current and voltage. The processor 308 adjusts the output drive signal 304 such that it can generate a desired power versus load curve. In accordance with programmed techniques 310, the processor 308 can vary the drive signal 320, e.g., the current or frequency, in any suitable increment or decrement in response to the transducer impedance Z.

[0077] Having described operational details of various forms of the surgical system 100 shown in FIG. 1, operations for the above surgical system 100 may be further described in terms of a process for cutting and coagulating a blood vessel employing a surgical instrument comprising the input device 110 and the transducer impedance measurement capabilities of the drive system 302 described with reference to FIG. 6. Although a particular process is described in connection with the operational details, it can be appreciated that the process merely provides an example of how the general functionality described herein can be implemented by the surgical system 100. Further, the given process does not necessarily have to be executed in the order presented herein unless otherwise indicated.

[0078] FIG. 7 illustrates one aspect of a drive system of a generator 400 comprising a tissue impedance module 442. The drive system 402 generates the ultrasonic electrical drive signal 404 to drive the ultrasonic transducer 406. In one aspect, the tissue impedance module 442 may be configured to measure the impedance Zt of tissue grasped between the blade 440 and the clamp arm assembly 444. The tissue impedance module 442 comprises an RF oscillator 446, a voltage sensing circuit 448, and a current sensing circuit 450. The voltage and current sensing circuits 448, 450 respond to the RF voltage Vrf applied to the blade 440 electrode and the RF current irf flowing through the blade 440 electrode, the tissue, and the conductive portion of the clamp arm assembly 444. The sensed current Irf and the sensed voltage Vrf from the current sense circuit 430 and the voltage sense circuit 432 are converted to digital form by the ADC 436 via the analog multiplexer 434. The processor 408 receives the digitized output 438 of the ADC 436 and determines the tissue impedance Zt by calculating the ratio of the RF voltage Vrf to current Irf measured by the voltage sensing circuit 448 and the current sense circuit 450.

[0079] In one form, the processor 408 may be configured or programmed to generate a digital current signal 420 and a digital frequency signal 422. These signals 420, 422 are applied to a direct digital synthesizer (DDS) circuit 424 to adjust the amplitude and the frequency (f) of the current output signal 404 to the transducer 406. The output of the DDS circuit 424 is applied to an amplifier 426 whose output is applied to a transformer 428. The output of the transformer 428 is the signal 404 applied to the ultrasonic transducer 406, which is coupled to the blade 440 by way of a waveguide.

[0080] In one aspect, the transection of the inner muscle layer and the tissue may be detected by sensing the tissue impedance Zt. Accordingly, detection of the tissue impedance Zt may be integrated with an automated process for separating the inner muscle layer from the outer adventitia layer prior to transecting the tissue without causing a significant amount of heating, which normally occurs at resonance.

[0081] In one form, the RF voltage Vrf applied to the blade 440 electrode and the RF current Irf flowing through the blade 440 electrode, the tissue, and the conductive portion of the clamp arm assembly 444 are suitable for vessel sealing and//or dissecting. Thus, the RF power output of the generator 400 can be selected for non-therapeutic functions such as tissue impedance measurements as well as therapeutic functions such as vessel sealing and/or dissection. It will be appreciated, that in the context of the present disclosure, the ultrasonic and the RF electrosurgical energies can be supplied by the generator either individually or simultaneously.

[0082] In operation, the user can program the operation of the generator 400 using the input device 412 located on the front panel of the generator 400 console. The input device 412 may comprise any suitable device that generates signals 414 that can be applied to the processor 408 to control the operation of the generator 400. In various forms, the input device 412 includes buttons, switches, thumbwheels, keyboard, keypad, touch screen monitor, pointing device, remote connection to a general purpose or dedicated computer. In other forms, the input device 412 may comprise a suitable user interface. Accordingly, by way of the input device 412, the user can set or program the current (I), voltage (V), frequency (f), and/or period (T) for programming the function output of the generator 400. The processor 408 then displays the selected power level by sending a signal on line 416 to an output indicator 418.

[0083] In various forms, feedback is provided by the output indicator 418. The output indicator 418 is particularly useful in applications where the tissue being manipulated by the end effector is out of the user's field of view and the user cannot see when a change of state occurs in the tissue. The output indicator 418 communicates to the user that a change in tissue state has occurred. As previously discussed, the output indicator 418 may be configured to provide various types of feedback to the user including, without limitation, visual, audible, and/or tactile feedback to indicate to the user (*e.g.*, surgeon, clinician) that the tissue has undergone a change of state or condition of the tissue. By way of example, and not limitation, as previously discussed, visual feedback comprises any type of visual indication device including incandescent lamps or LEDs, graphical user interface, display, analog indicator, digital indicator, bar graph display, digital alphanumeric display. By way of example, and not limitation, audible feedback comprises any type of buzzer, computer generated tone, computerized speech, VUI to interact with computers through a voice/speech platform. By way of example, and not limitation, tactile feedback comprises any type of vibratory feedback provided through the instrument housing handle assembly. The change of state of the tissue may be determined based on transducer and tissue impedance measurements as previously described, or based on voltage, current, and frequency measurements.

[0084] In one form, the various executable modules (*e.g.*, algorithms 410) comprising computer readable instructions can be executed by the processor 408 portion of the generator 400. In various forms, the operations described with respect to the techniques may be implemented as one or more software components, *e.g.*, programs, subroutines, logic; one or more hardware components, *e.g.*, processors, DSPs, PLDs, ASICs, circuits, registers; and/or combinations of software and hardware. In one form, the executable instructions to perform the techniques may be stored in memory. When executed, the instructions cause the processor 408 to determine a change in tissue state provide feedback to the user by way of the output indicator 418. In accordance with such executable instructions, the processor 408 monitors and evaluates the voltage, current, and/or frequency signal samples available from the generator 400 and according to the evaluation of such signal samples determines whether a change in tissue state has occurred. As further described below, a change in tissue state may be determined based on the type of ultrasonic instrument and the power level that the instrument is energized at. In response to the feedback, the operational mode of the ultrasonic surgical instrument may be controlled by the user or may be automatically or semi-automatically controlled.

[0085] As noted above, a single output generator can deliver both RF and ultrasonic energy through a single port and these signals can be delivered separately or simultaneously to the end effector to treat tissue. A single output port generator can include a single output transformer with multiple taps to provide power, either RF or ultrasonic energy, to the end effector depending on the type of treatment of tissue being performed. For example, the generator can deliver energy with higher voltage and lower current to drive an ultrasonic transducer, with lower voltage and higher current as required to drive electrodes for sealing tissue, or with a coagulation waveform for spot coagulation using either monopolar or bipolar electrosurgical electrodes. The output waveform from the generator can be steered, switched, or filtered to provide the desired frequency to the end effector of the surgical instrument.

[0086] FIG. 8 illustrates an example of a generator 500 for delivering multiple energy modalities to a surgical instrument. The generator 500 is similar to the generator 102 described in connection with FIG. 1 and includes functionalities of the generators 200, 300, 400 shown in FIGS. 5-7. For conciseness and clarity of disclosure, hereinbelow, the various logic flow diagrams are described in connection with the generator 500, which is a high level block diagram representation. Accordingly, the reader is directed to the description of the functional blocks of the generators 200, 300, 400 in FIGS. 5-7 for additional details that may be necessary to understand and practice the logic flow diagrams described hereinbelow in connection with the generator 500.

[0087] Turning back to FIG. 8, the generator 500 provides radio frequency and ultrasonic signals for delivering energy to a surgical instrument. The radio frequency and ultrasonic signals may be provided alone or in combination and may be provided simultaneously. As noted above, at least one generator output can deliver multiple energy modalities (e.g., ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others) through a single port and these signals can be delivered separately or simultaneously to the end effector to treat tissue. The generator 500 comprises a processor 502 coupled to a waveform generator 504. The processor 502 and waveform generator 504 are configured to generate a variety of signal waveforms based on information stored in a memory coupled to the processor 502, not shown for clarity of disclosure. The digital information associated with a waveform is provided to the waveform generator 504 which includes one or more digital-to-analog (DAC) converters to convert the digital input into an analog output. The analog output is fed to an amplifier 1106 for signal conditioning and amplification. The conditioned and amplified output of the amplifier 506 is coupled to a power transformer 508. The signals are coupled across the power transformer 508 to the secondary side, which is in the patient isolation side. A first signal of a first energy modality is provided to the surgical instrument between the terminals labeled ENERGY1 and RETURN. A second signal of a second energy modality is coupled across a capacitor 510 and is provided to the surgical instrument between the terminals labeled ENERGY2 and RETURN. It will be appreciated that more than two energy modalities may be output and thus the subscript "n" may be used to designate that up to n ENERGYn terminals may be provided, where n is a positive integer greater than 1. It also will be appreciated that up to "n" return paths RETURNn may be provided without departing from the scope of the present disclosure.

[0088] A first voltage sensing circuit 512 is coupled across the terminals labeled ENERGY1 and the RETURN path to measure the output voltage therebetween. A second voltage sensing circuit 524 is coupled across the terminals labeled ENERGY2 and the RETURN path to measure the output voltage therebetween. A current sensing circuit 514 is disposed in series with the RETURN leg of the secondary side of the power transformer 508 as shown to measure the output current for either energy modality. If different return paths are provided for each energy modality, then a separate current sensing circuit should be provided in each return leg. The outputs of the first and second voltage sensing circuits 512, 524 are provided to respective isolation transformers 516, 522 and the output of the current sensing circuit 514 is provided to another isolation transformer 518. The outputs of the isolation transformers 516, 518, 522 in the on the primary side of the power transformer 508 (non-patient-isolated side) are provided to a one or more analog-to-digital converters 526 (ADC). The digitized output of the ADC 526 is provided to the processor 502 for further processing and computation. The output voltages and output current feedback information can be employed to adjust the output voltage and current provided to the surgical instrument and to compute output impedance, among other parameters. Input/output communications between the processor 502 and patient isolated circuits is provided through an interface circuit 520. Sensors also may be in electrical communication with the processor 502 by way of the interface 520.

[0089] In one aspect, the impedance may be determined by the processor 502 by dividing the output of either the first voltage sensing circuit 512 coupled across the terminals labeled ENERGY1/RETURN or the second voltage sensing circuit 524 coupled across the terminals labeled ENERGY2/RETURN by the output of the current sensing circuit 514 disposed in series with the RETURN leg of the secondary side of the power transformer 508. The outputs of the first and second voltage sensing circuits 512, 524 are provided to separate isolations transformers 516, 522 and the output of the current sensing circuit 514 is provided to another isolation transformer 516. The digitized voltage and current sensing measurements from the ADC 526 are provided the processor 502 for computing impedance. As an example, the first energy modality ENERGY1 may be ultrasonic energy and the second energy modality ENERGY2 may be RF energy. Nevertheless, in addition to ultrasonic and bipolar or monopolar RF energy modalities, other energy modalities include irreversible and/or reversible electroporation and/or microwave energy, among others. Also, although the example illustrated in FIG. 8 shows a single return path RETURN may be provided for two or more energy modalities, in other aspects multiple return paths RETURNn may be provided for each energy modality ENERGYn. Thus, as described herein, the ultrasonic transducer impedance may be measured by dividing the output of the first voltage sensing circuit 512 by the current sensing circuit 514 and the tissue impedance may be measured by dividing the output of the second voltage sensing circuit 524 by the current sensing circuit 514.

[0090] As shown in FIG. 8, the generator 500 comprising at least one output port can include a power transformer 508 with a single output and with multiple taps to provide power in the form of one or more energy modalities, such as ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others, for example, to the end effector depending on the type of treatment of tissue being performed. For example, the generator 500 can deliver energy with higher voltage and lower current to drive an ultrasonic transducer, with lower voltage and higher current to drive RF electrodes for sealing tissue, or with a coagulation waveform for spot coagulation using either monopolar or bipolar RF electrosurgical electrodes. The output waveform from the generator 500 can be steered, switched, or filtered to provide the frequency to the end effector of the surgical instrument. The connection of an ultrasonic transducer to the generator 500 output would be preferably located between the output labeled ENERGY1 and RETURN as shown in FIG. 8. An In one example, a connection of RF bipolar electrodes to the generator 500 output would be preferably located between the output labeled ENERGY2 and RETURN. In the case of monopolar output, the preferred connections would be active electrode (e.g., pencil or other probe) to the ENERGY2 output and a suitable return pad connected to the RETURN output.

[0091] In other aspects, the generators 102, 200, 300, 400, 500 described in connection with FIGS. 1-3 and 5-8, the ultrasonic generator drive circuit 114, and/or electrosurgery/RF drive circuit 116 as described in connection with FIG. 3 may be formed integrally with any one of the surgical instruments 104, 106, 108 described in connection with FIGS. 1 and 2. Accordingly, any of the processors, digital signal processors, circuits, controllers, logic devices, ADCs, DACs, amplifiers, converters, transformers, signal conditioners, data interface circuits, current and voltage sensing circuits, direct digital synthesis circuits, multiplexer (analog or digital), waveform generators, RF generators, memory, and the like, described in connection with any one of the generators 102, 200, 300, 400, 500 can be located within the surgical instruments 104, 106, 108 or may be located remotely from the surgical instruments 104, 106, 108 and coupled to the surgical instruments via wired and/or wireless electrical connections.

[0092] Examples of waveforms representing energy for delivery from a generator are illustrated in FIGS. 9-13. FIG. 9 illustrates an example graph 600 showing first and second individual waveforms representing an RF output signal 602 and an ultrasonic output signal 604 superimposed on the same time and voltage scale for comparison purposes. These output signals 602, 604 are provided at the ENERGY output of the generator 500 shown in FIG. 8. Time (t) is shown along the horizontal axis and voltage (V) is shown along the vertical axis. The RF output signal 602 has a frequency of about 330kHz RF and a peak-to-peak voltage of $\pm$1V. The ultrasonic output signal 604 has a frequency of about 55kHz and a peak-to-peak voltage of $\pm$1V. It will be appreciated that the time (t) scale along the horizontal axis and the voltage

(V) scale along the vertical axis are normalized for comparison purposes and may be different actual implementations, or represent other electrical parameters such as current.

[0093] FIG. 10 illustrates an example graph 610 showing the sum of the two output signals 602, 604 shown in FIG. 9. Time (t) is shown along the horizontal axis and voltage (V) is shown along the vertical axis. The sum of the RF output signal 602 and the ultrasonic output signal 604 shown in FIG. 9 produces a combined output signal 612 having a 2V peak-to-peak voltage, which is twice the amplitude of the original RF and ultrasonic signals shown (1V peak-to-peak) shown in FIG. 9. An amplitude of twice the original amplitude can cause problems with the output section of the generator, such as distortion, saturation, clipping of the output, or stresses on the output components. Thus, the management of a single combined output signal 612 that has multiple treatment components is an important aspect of the generator 500 shown in FIG. 8. There are a variety of ways to achieve this management. In one form, one of the two RF or ultrasonic output signals 602, 604 can be dependent on the peaks of the other output signal.

[0094] For example, FIG. 11 illustrates an example graph 620 showing a combined output signal 622 representative of a dependent sum of the output signals 602, 604 shown in FIG. 9. Time (t) is shown along the horizontal axis and voltage (V) is shown along the vertical axis. As shown in FIG. 11, the RF output signal 602 component of FIG. 9 depends on the peaks of the ultrasonic output signal 604 component of FIG. 9 such that the amplitude of the RF output signal component of the dependent sum combined output signal 622 is reduced when an ultrasonic peak is anticipated. As shown in the example graph 620 in FIG. 11, the peaks have been reduced from 2 to 1.5. In another form, one of the output signals is a function of the other output signal.

[0095] For example, FIG. 11 illustrates an example graph 630 showing an output signal 632 representative of a dependent sum of the output signals 602, 604 shown in FIG. 9. Time (t) is shown along the horizontal axis and voltage (V) is shown along the vertical axis. As shown in FIG. 12, the RF output signal is a function of the ultrasonic output signal. This provides a hard limit on the amplitude of the output. As shown in FIG. 12, the ultrasonic output signal is extractable as a sine wave while the RF output signal has distortion but not in a way to affect the coagulation performance of the RF output signal.

[0096] A variety of other techniques can be used for compressing and/or limiting the waveforms of the output signals. It should be noted that the integrity of the ultrasonic output signal 604 (FIG. 9) can be more important than the integrity of the RF output signal 602 (FIG. 9) as long as the RF output signal 602 has low frequency components for safe patient levels so as to avoid neuro-muscular stimulation. In another form, the frequency of an RF waveform can be changed on a continuous basis in order to manage the peaks of the waveform. Waveform control is important as more complex RF waveforms, such as a coagulation-type waveform 644, as illustrated in the graph 640 shown in FIG. 13, are implemented with the system. Again, time (t) is shown along the horizontal axis and voltage (V) is shown along the vertical axis.

[0097] FIGS. 14-42 (26-54) illustrate various configurations of sensors, circuits, and techniques for measuring tissue parameters to facilitate executing the various adaptive tissue identification and treatment technique described herein. FIG. 14 illustrates one aspect of an end effector 700 comprising RF data sensors 706, 708a, 708b located on the clamp arm 702. The end effector 700 comprises a clamp arm 702 and an ultrasonic blade 704. The clamp arm 702 is shown clamping tissue 710 located between the clamp arm 702 and the ultrasonic blade 704. A first sensor 706 is located in a center portion of the clamp arm 702. Second and third sensors 708a, 708b are located on lateral portions of the clamp arm 702. The sensors 706, 708a, 708b are mounted or formed integrally with on a flexible circuit 712 (shown more particularly in FIG. 15 and more particularly segmented flexible circuits 800, 900 shown in FIGS. 17 and 18) configured to be fixedly mounted to the clamp arm 702.

[0098] The end effector 700 is an example end effector for the multifunction surgical instrument 108 shown in FIGS. 1 and 2. The sensors 706, 708a, 708b are electrically connected to an energy source, such as for example, the generator 500 shown in FIG. 8. The sensors 706, 708a, 708b are powered by suitable sources within the generator and the signals generated by the sensors 706, 708a, 708b are provided to analog and/or digital processing circuits of the generator 500.

[0099] In one aspect, the first sensor 706 is a force sensor to measure a normal force F_3 applied to the tissue 710 by the clamp arm 702. The second and third sensors 708a, 708b include one or more elements to apply RF energy to the tissue 710, measure tissue impedance, down force F_1, transverse forces F_2, and temperature, among other parameters. Electrodes 709a, 709b are electrically coupled to the generator and apply RF energy to the tissue 710. In one aspect, the first sensor 706 and the second and third sensors 708a, 708b are strain gauges to measure force or force per unit area. It will be appreciated that the measurements of the down force F_1, the lateral forces F_2, and the normal force F_3 may be readily converted to pressure by determining the surface area upon which the force sensors 706, 708a, 708b are acting upon. Additionally, as described with particularity herein, the flexible circuit 712 may comprise temperature sensors embedded in one or more layers of the flexible circuit 712. The one or more temperature sensors may be arranged symmetrically or asymmetrically and provide tissue 710 temperature feedback to control circuits of the generator.

[0100] FIG. 15 illustrates one aspect of the flexible circuit 712 shown in FIG. 14 in which the sensors 706, 708a, 708b may be mounted to or formed integrally therewith. The flexible circuit 712 is configured to fixedly attach to the clamp arm 702. As shown particularly in FIG. 15, asymmetric temperature sensors 714a, 714b are mounted to the flexible

circuit 712 to enable measuring the temperature of the tissue 710 (FIG. 14).

[0101] FIG. 16 is a cross-sectional view of the flexible circuit 712 shown in FIG. 15. The flexible circuit 712 comprises multiple layers and is fixedly attached to the clamp arm 702. A top layer of the flexible circuit 712 is an electrode 709a, which is electrically coupled to an energy source, such as the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), to apply RF energy to the tissue 710 (FIG. 14). A layer of electrical insulation 718 is provided below the electrode 709a layer to electrically isolate the sensors 714a, 706, 708a from the electrode 709a. The temperature sensors 714a are disposed below the layer of electrical insulation 718. The first force (pressure) sensor 706 is located below the layer containing the temperature sensors 714a and above a compressive layer 720. The second force (pressure) sensor 708a is located below the compressive layer 720 and above the clamp arm 702 frame.

[0102] FIG. 17 illustrates one aspect of a segmented flexible circuit 800 configured to fixedly attach to a clamp arm 804 of an end effector. The segmented flexible circuit 800 comprises a distal segment 802a and lateral segments 802b, 802c that include individually addressable sensors to provide local tissue control, as described herein in connection with FIGS. 14-16, for example. The segments 802a, 802b, 802c are individually addressable to treat tissue and to measure tissue parameters based on individual sensors located within each of the segments 802a, 802b, 802c. The segments 802a, 802b, 802c of the segmented flexible circuit 800 are mounted to the clamp arm 804 and are electrically coupled to an energy source, such as the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), via electrical conductive elements 806. A Hall effect sensor 808, or any suitable magnetic sensor, is located on a distal end of the clamp arm 804. The Hall effect sensor 808 operates in conjunction with a magnet to provide a measurement of an aperture defined by the clamp arm 804, which otherwise may be referred to as a tissue gap, as shown with particularity in FIG. 19.

[0103] FIG. 18 illustrates one aspect of a segmented flexible circuit 900 configured to mount to a clamp arm 904 of an end effector. The segmented flexible circuit 1900 comprises a distal segment 902a and lateral segments 902b, 902c that include individually addressable sensors for tissue control, as described herein in connection with FIGS. 14-17, for example. The segments 902a, 902b, 902c are individually addressable to treat tissue and to read individual sensors located within each of the segments 902a, 902b, 902c. The segments 902a, 902b, 902c of the segmented flexible circuit 900 are mounted to the clamp arm 904 and are electrically coupled to an energy source, such as the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), via electrical conductive elements 906. A Hall effect sensor 908, or other suitable magnetic sensor, is provided on a distal end of the clamp arm 904. The Hall effect sensor 908 operates in conjunction with a magnet to provide a measurement of an aperture defined by the clamp arm 904 of the end effector or tissue gap as shown with particularity in FIG. 19. In addition, a plurality of lateral asymmetric temperature sensors 910a, 910b are mounted on or formally integrally with the segmented flexible circuit 900 to provide tissue temperature feedback to control circuits in the generator.

[0104] FIG. 19 illustrates one aspect of an end effector 1000 configured to measure a tissue gap G_T. The end effector 1000 comprises a jaw member 1002 and a clamp arm 904. The flexible circuit 900 as described in FIG. 18, is mounted to the clamp arm 904. The flexible circuit 900 comprises a Hall effect sensor 908 that operates with a magnet 1004 mounted to the jaw member 1002 to measure the tissue gap G_T. This technique can be employed to measure the aperture defined between the clamp arm 904 and the jaw member 1002. The jaw member 1002 may be an ultrasonic blade.

[0105] FIG. 20 illustrates one aspect of a left-right segmented flexible circuit 1100. The left-right segmented flexible circuit 1100 comprises a plurality of segments L1-L5 on the left side of the left-right segmented flexible circuit 1100 and a plurality of segments R1-R5 on the right side of the left-right segmented flexible circuit 1100. Each of the segments L1-L5 and R1-R5 comprise temperature sensors and force sensors to sense tissue parameters locally within each segment L1-L5 and R1-R5. The left-right segmented flexible circuit 1100 are configured to influence the RF treatment energy based on tissue parameters sensed locally within each of the segments L1-L5 and R1-R5.

[0106] FIG. 21 illustrates one aspect of an end effector 1200 comprising segmented flexible circuit 1100 as shown in FIG. 20. The end effector 1200 comprises a clamp arm 1202 and an ultrasonic blade 1204. The segmented flexible circuit 1100 is mounted to the clamp arm 1202. Each of the sensors disposed within the segments 1-5 are configured to detect the presence of tissue positioned between the clamp arm 1202 and the ultrasonic blade 1204 and represent tissue zones 1-5. In the configuration shown in FIG. 21, the end effector 1200 is shown in an open position ready to receive or grasp tissue between the clamp arm 1202 and the ultrasonic blade 1204.

[0107] FIG. 22 illustrates the end effector 1200 shown in FIG. 21 with the clamp arm 1202 clamping tissue 1206 between the clamp arm 1202 and the ultrasonic blade 1204. As shown in FIG. 22, the tissue 1206 is positioned between segments 1-3 and represents tissue zones 1-3. Accordingly, tissue 1206 is detected by the sensors in segments 1-3 and the absence of tissue (empty) is detected in section 1208 by segments 4-5. The information regarding the presence and absence of tissue 1206 positioned within certain segments 1-3 and 4-5, respectively, is communicated to a control circuit of the generator, such as the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8). The generator 500 is configured to energize only the segments 1-3 where tissue 1206 is detected and does not energize the segments 4-5 where tissue is not detected. It will be appreciated that the segments 1-5 may contain any suitable temperature, force/pressure, and/or Hall effect magnetic sensors to measure tissue parameters of tissue located within certain segments 1-5 and electrodes to deliver RF energy to tissue located in certain segments 1-5.

[0108] FIG. 23 illustrates graphs 1300 of energy applied by the right and left side of an end effector based on locally sensed tissue parameters. As discussed herein, the clamp arm of an end effector may comprise temperature sensors, force/pressure sensors, Hall effector sensors, among others, along the right and left sides of the clamp arm as shown, for example, in FIGS. 14-22. Thus, RF energy can be selectively applied to tissue positioned between the clam jaw and the ultrasonic blade. The top graph 1302 depicts power P_R applied to a right side segment of the clamp arm versus time (t) based on locally sensed tissue parameters. Thus, the generator, such as the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), is configured to measure the sensed tissue parameters and to apply power P_R to a right side segment of the clamp arm. The generator 500 delivers an initial power level P_1 to the tissue via the right side segment and then decreases the power level to P_2 based on local sensing of tissue parameters (e.g., temperature, force/pressure, thickness) in one or more segments. The bottom graph 1304 depicts power P_L applied to a left side segment of the clamp arm versus time (t) based on locally sensed tissue parameters. The generator 500 delivers an initial power level of P_1 to the tissue via the left side segment and then increases the power level to P_3 based local sensing of tissue parameters (e.g., temperature, force/pressure, thickness). As depicted in the bottom graph 1304, the generator is configured to re-adjust the energy delivered P_3 based on sensing of tissue parameters (e.g., temperature, force/pressure, thickness).

[0109] FIG. 24 illustrates a graph 1400 depicting one aspect of adjustment of threshold due to the measurement of a secondary tissue parameter such as continuity, temperature, pressure, and the like. The horizontal axis of the graph 1400 is time (t) and the vertical axis is tissue impedance (Z). The curve 1412 represents the change of tissue impedance (Z) over time (t) as different energy modalities are applied to the tissue. With reference also to FIGS. 20-22, the original threshold 1402 is applied when tissue is detected in all five segments 1-5 (tissue zones 1-5) and the adjusted threshold 1404 is applied when the tissue is detected in tissue segments 1-3 (tissue zones 1-3). Accordingly, once the tissue is located in particulars segments (zones) the control circuit in the generator adjusts the threshold accordingly.

[0110] As shown in FIG. 24, the curve 1412 includes three separate sections 1406, 1408, 1410. The first section 1406 of the curve 1412 represents the time when RF energy is applied to the tissue in tissue zones 1-3 until the tissue impedance drops below the adjusted threshold 1404. At that point 1414, which may indicate that a tissue seal is completed, the energy modality applied to tissue zones 1-3 is changed from RF energy to ultrasonic energy. The ultrasonic energy is then applied in the second and third sections 1408, 1410 and the impedance rises exponentially until the tissue is severed or cut.

[0111] FIG. 25 is a cross-sectional view of one aspect of a flexible circuit 1500 comprising RF electrodes and data sensors embedded therein. The flexible circuit 1500 can be mounted to the right or left portion of an RF clamp arm 1502, which is made of electrically conductive material such as metal. Below the RF clamp arm 1502 down force/pressure sensors 1506a, 1506b are embedded below a laminate layer 1504. A transverse force/pressure sensor 1508 is located below the down force/pressure sensor 1506a, 1506b layer and a temperature sensor is 1510 is located below the transverse force/pressure sensor 1508. An electrode 1512 electrically coupled to the generator and configured to apply RF energy to the tissue 1514 is located below the temperature sensor 1510.

[0112] FIG. 26 is a cross-sectional view of one aspect of an end effector 1600 configured to sense force or pressure applied to tissue located between a clamp arm and an ultrasonic blade. The end effector 1600 comprises a clamp jaw 1602 and a flexible circuit 1604 fixedly mounted to the clamp arm 1602. The clamp arm 1602 applies forces F_1 and F_2 to the tissue 1606 of variable density and thickness, which can be measure by first and second force/pressure sensors 1608, 1610 located in different layers of the flexible circuit 1604. A compressive layer 1612 is sandwiched between the first and second force/pressure sensors 1608, 1610. An electrode 1614 is located on outer portion of the flexible circuit 1604 which contacts the tissue. As described herein, other layers of the flexible circuit 1604 may comprise additional sensors such temperature sensors, thickness sensors, and the like.

[0113] FIGS. 27-29 illustrate various schematic diagrams of flexible circuits of the signal layer, sensor wiring, and an RF energy drive circuit. FIG. 27 is a schematic diagram of one aspect of a signal layer of a flexible circuit 1700. The flexible circuit 1700 comprises multiple layers (~4 to ~6, for example). One layer will supply the integrated circuits with power and another layer with ground. Two additional layers will carry the RF power RF1 and RF2 separately. An analog multiplexer switch 1702 has eight bidirectional translating switches that can be controlled through the I^2C bus. The SCL/SDA upstream pair fans out to eight downstream pairs, or channels. Any individual SCn/SDn channel or combination of channels can be selected, determined by the contents of a programmable control register. The upstream pairs SCL/SDA are connected to a control circuit in the generator. There are six down stream sensors, three on each side of the clamp arm. A first side 1704a comprises a first thermocouple 1706a, a first pressure sensor 1708a, and a first Hall effect sensor 1710a. A second side 1704b comprises a second thermocouple 1706b, a second pressure sensor 1708b, and a second Hall effect sensor 1710b. FIG. 28 is a schematic diagram 1750 of sensor wiring for the flexible circuit 1700 shown in FIG. 27.

[0114] FIG. 29 is a schematic diagram of one aspect of an RF energy drive circuit 1800. The RF energy drive circuit 1800 comprises an analog multiplexer 1702 described in connection with FIG. 27. The analog multiplexer multiplexes various signals from the upstream channels SCL/SDA. A current sensor 1802 is coupled in series with the return or ground leg of the power supply circuit to measure the current supplied by the power supply. An FET temperature sensor

1804 provided the ambient temperature. A pulse width modulation (PWM) watchdog timer 1808 automatically generates a system reset if the main program neglects to periodically service it. It is provided to automatically reset the RF energy drive circuit 1800 when it hangs because of a software or hardware fault.

[0115] A drive circuit 1806 provides left and right RF energy outputs. The digital signal is provided to the SCL/SDA inputs of the analog multiplexer 1702 from a control circuit of the generator. A digital-to-analog converter (DAC) converts the digital input to an analog output to drive a pulse width modulation (PWM) circuit 1812 coupled to an oscillator 1814. The PWM circuit 1812 provides a first gate drive signal 1816a to a first transistor output stage 1818a to drive a first RF (Left) energy output. The PWM circuit 1812 also provides a second gate drive signal 1816b to a second transistor output stage 1818 to drive a second RF (Right) energy output.

[0116] The circuits 1700, 1750, 1800 described in connection with FIGS. 27-29 are electrically coupled to the generators 200, 300, 400, 500 shown in FIGS. 5-7. For example, the circuits 1700, 1750, 1800 may be coupled to the generator 200 via the signal conditioning circuit 244 and may be coupled to the generator 500 through the interface circuit 520.

[0117] FIG. 30 is a graphical representation 1900 of measuring tissue gap at a preset time. A first graph 1902 represents tissue impedance Z versus time (t) where the horizontal axis represents time (t) and the vertical axis represents tissue impedance Z. A second graph 1904 represents change in tissue gap Δ_{gap} versus time(t) where the horizontal axis represents time (t) and the vertical axis represents change in tissue gap Δ_{gap}. A third graph 1906 represents force F versus time (t) where the horizontal axis represents time (t) and the vertical axis represents force F. With a constant force F applied to tissue and impedance Z interrogation to define a wait period, energy modality (e.g., RF and ultrasonic) and motor control parameters, displacement at a time provides velocity. With reference to the three graphs 1902, 1904, 1906, impedance sensing energy is applied during a first period 1908 to determine the tissue type such as thin mesentery tissue (solid line), intermediate thickness vessel tissue (dashed line), or thick uterus/bowel tissue (dash-dot line).

[0118] As shown in the third graph 1906, the clamp arm initially applies a force which ramps up from zero exponentially until it reaches a constant force 1924. The preset time t_1 is selected such that it occurs some time after the clamp arm force reaches a constant force 1924. As shown in the first and second graphs 1902, 1904, from the time the clamp force is applied to the mesentery tissue until the preset time t_1 is reached, the change in tissue gap Δ_{gap} curve 1912 decreases exponentially and the tissue impedance curve 1918 also decreases until the preset time t_1 is reached. From the preset time t_1, a short delay 1928 is applied before treatment energy is applied to the mesentery tissue at t_{E1}.

[0119] As shown in the first and second graphs 1902, 1904, from the time the clamp force is applied to the vessel tissue until the preset time t_1 is reached, the change in tissue gap Δ_{gap} curve 1916 also decrease exponentially and the tissue impedance curve 1920 also decreases until the preset time t_1 is reached. From the preset time t_1, a medium delay 1930 is applied before treatment energy is applied to the vessel tissue at t_{E2}.

[0120] As shown in the first and second graphs 1902, 1904, from the time the clamp force is applied to the uterus/bowel tissue until the preset time t_1 is reached, the change in tissue gap Δ_{gap} curve 1914 drops exponentially and the tissue impedance curve 1914 also drops until the preset time t_1 is reached. From the preset time t_1, a short delay 1928 is applied before treatment energy is applied to the mesentery tissue at t_{E1}.

[0121] FIG. 31 is a time to preset force 2008 versus time graph 2000 for thin, medium, and thick tissue types. The horizontal axis represents time (t) and the vertical axis represents force (F) applied by the clamp arm to the tissue. The graph 2000 depicts three curves, one for thin tissue 2002 shown in solid line, one for medium thickness tissue 2004 shown in dash-dot line, and thick tissue 2006 in dashed line. The graph 2000 depicts measuring time at a preset force as an alternative to tissue gap to control delayed energy mode and other control parameters. Accordingly, the time to preset force 2008 for thick tissue 2006 is t_{1a}, the time to preset force 2008 for medium thickness tissue 2004 is t_{1b}, and the time to preset force 2008 for thin tissue 2002 is t_{1c}.

[0122] Once the force reaches the preset force 2008, energy is applied to the tissue. For thin tissue 2002 the time to preset $t_{1c} > 0.5$ seconds and then RF energy is applied for an energizing period t_e of about 1-3 seconds. For thick tissue 2006 the time to preset $t_{1a} < 0.5$ seconds and then RF energy is applied for an energizing period t_e of about 5-9 seconds. For medium thickness tissue 2004 the time to preset t_{1b} is about 0.5 seconds and then RF energy is applied for an energizing period t_e of about 3 to 5 seconds.

[0123] FIG. 32 is a graphical depiction of a graph 2100 of three curves 2102, 2104, 2106, where the first curve 2102 represents power (P), voltage(V_{RF}), and current (I_{RF}) versus tissue impedance (Z), the second curve 2104 and third curve 2106 represent tissue impedance (Z) versus time (t). The first curve 2102 illustrates the application of power (P) for thick tissue impedance range 2110 and thin tissue impedance range 2112. As the tissue impedance Z increases, the current I_{RF} decrease and the voltage V_{RF} increases. The power curve P increases until it reaches a maximum power output 2108 which coincides with the intersection 2114 of the current I_{RF} and voltage V_{RF} curves.

[0124] The second curve 2104 represents the measured tissue impedance Z versus time (t). The tissue impedance threshold limit 2120 is the cross over limit for switching between the RF and ultrasonic energy modalities. For example, as shown in FIG. 32, RF energy is applied while the tissue impedance is above the tissue impedance threshold limit 2120 and ultrasonic energy 2124 is applied while the tissue impedance is below the tissue impedance threshold limit 2120. Accordingly, with reference back to the second curve 2104, the tissue impedance of the thin tissue curve 2116

remains above the tissue impedance threshold limit 2120, thus only RF energy modality is applied to the tissue. On the other hand, RF energy modality is applied to the tick tissue while the impedance is above the tissue impedance threshold limit 2120 and ultrasonic energy is applied to the tissue when the impedance is below the tissue impedance threshold limit 2120. Accordingly, the energy modality switches from RF to ultrasonic when the tissue impedance falls below the tissue impedance threshold limit 2120 and the energy modality switches from ultrasonic to RF when the tissue impedance rises above the tissue impedance threshold limit 2120.

[0125] FIG. 33 is a plan view of one aspect of an end effector 2200. The end effector 2200 comprises a clamp arm 2202 and a shaft 2204. The clamp arm 2202 pivots about pivot point 2206 and defines a pivot angle. FIG. 34 is a side view of the end effector 2200 shown in FIG. 33 with a partial cut away view to expose the underlying structure of the clamp arm 2202 and an ultrasonic blade 2208. An electrode 2210 is fixedly mounted to the clamp arm 2202. The electrode 2210 is electrically coupled to the generator and is configured to apply RF energy to tissue located between the clamp arm 2202 and the ultrasonic blade 2208. FIG. 35 is partial sectional view of the end effector shown in FIGS. 33, 34 to expose the ultrasonic blade and right and left electrodes 2210a, 2210b, respectively.

[0126] FIG. 36 is a cross-sectional view taken at section 36--36 of the end effector 2200 shown in FIG. 33. The end effector 2200 comprises an ultrasonic blade 2208 acoustically coupled to an ultrasonic transducer which is electrically driven by the generator. The clamp arm 2202 comprises an electrode 2210a on the right side and an electrode 2210b on the left side (from the perspective of the operator). The right side electrode 2210a defines a first width W_1 and defines a first gap G_1 between the electrode 2210a and the ultrasonic blade 2208. The left side electrode 2210b defines a second width W_2 and defines a second gap G_2 between the electrode 2210b and the ultrasonic blade 2208. In one aspect the first width W_1 is less than the second width W_2 and the first gap G_1 is less than the second gap G_2. With reference also to FIG. 35, a soft polymeric pad 2212 is located between the ultrasonic blade 2208 and the clamp arm 2202. A high density polymeric pad 2214 is located adjacent the soft polymeric pad 2212 to prevent the ultrasonic blade 2208 from shorting the electrodes 2210a, 2210b. In one aspect, the soft polymeric pads 2212, 2214 can be made of polymers known under the tradename TEFLON (polytetrafluoroethylene polymers and copolymers), for example.

[0127] FIG. 37 is cross-sectional view taken at section 37--37 of the end effector 2200 shown in FIG. 33. At the plane where section 37--37 the end effector 2200 is thinner and has more curvature than section 36--36. The right side electrode 2210a defines a third width W_3 and defines a third gap G_3 between the electrode 2210a and the ultrasonic blade 2208. The left side electrode 2210b defines a fourth width W_4 and defines a fourth gap G_4 between the electrode 2210b and the ultrasonic blade 2208. In one aspect the third width W_3 is less than the fourth width W_4 and the third gap G_3 is less than the fourth gap G_4.

[0128] FIG. 38 is a cross-sectional view taken at section 36--36 of the end effector 2200 shown in FIG. 33, except that the ultrasonic blade 2208' has a different geometric configuration. The end effector 2200' comprises an ultrasonic blade 2208'cacoustically coupled to an ultrasonic transducer which is electrically driven by the generator. The clamp arm 2202' comprises an electrode 2210a' on the right side and an electrode 2210b' on the left side (from the perspective of the operator). The right side electrode 2210a' defines a first width W_1 and defines a first gap G_1 between the electrode 2210a' and the ultrasonic blade 2208'. The left side electrode 2210b' defines a second width W_2 and defines a second gap G_2 between the electrode 2210b' and the ultrasonic blade 2208'. In one aspect the first width W_1 is less than the second width W_2 and the first gap G_1 is less than the second gap G_2. A high density polymeric pad 2214' is located adjacent the soft polymeric pad 2212' to prevent the ultrasonic blade 2208' from shorting the electrodes 2210a', 2210b'. In one aspect, the soft polymeric pads 2212', 2214' can be made of polymers known under the tradename TEFLON (polytetrafluoroethylene polymers and copolymers), for example.

[0129] FIG. 39 is cross-sectional view taken at section 37--37 of the end effector 2200 shown in FIG. 33, except that the ultrasonic blade 2208' has a different geometric configuration. At the plane where section 37--37 the end effector 2200' is thinner and has more curvature than the end effector 2200' at section 36--36. The right side electrode 2210a' defines a third width W_3 and defines a third gap G_3 between the electrode 2210a' and the ultrasonic blade 2208'. The left side electrode 2210b' defines a fourth width W_4 and defines a fourth gap G_4 between the electrode 2210b' and the ultrasonic blade 2208'. In one aspect the third width W_3 is less than the fourth width W_4 and the third gap G_3 is less than the fourth gap G_4.

[0130] FIG. 40 is a cross-sectional view taken at section 36--36 of the end effector 2200 shown in FIG. 33, except that the ultrasonic blade 2208" has a different geometric configuration. The end effector 2200" comprises an ultrasonic blade 2208"cacoustically coupled to an ultrasonic transducer which is electrically driven by the generator. The clamp arm 2202" comprises an electrode 2210a" on the right side and an electrode 2210b" on the left side (from the perspective of the operator). The right side electrode 2210a" defines a first width W_1 and defines a first gap G_1 between the electrode 2210a" and the ultrasonic blade 2208". The left side electrode 2210b" defines a second width W_2 and defines a second gap G_2 between the electrode 2210b" and the ultrasonic blade 2208". In one aspect the first width W_1 is less than the second width W_2 and the first gap G_1 is less than the second gap G_2. A high density polymeric pad 2214" is located adjacent the soft polymeric pad 2212" to prevent the ultrasonic blade 2208" from shorting the electrodes 2210a", 2210b". In one aspect, the polymeric pads 2212", 2214" can be made of polymers known under the tradename TEFLON (poly-

tetrafluoroethylene polymers and copolymers), for example.

[0131] FIG. 41 is cross-sectional view taken at section 37--37 of the end effector 2200 shown in FIG. 33, except that the ultrasonic blade 2208" has a different geometric configuration. At the plane where section 37--37 the end effector 2200" is thinner and has more curvature than the end effector 2200" at section 36--36. The right side electrode 2210a" defines a third width W_3 and defines a third gap G_3 between the electrode 2210a" and the ultrasonic blade 2208". The left side electrode 2210b" defines a fourth width W_4 and defines a fourth gap G_4 between the electrode 2210b" and the ultrasonic blade 2208". In one aspect the third width W_3 is less than the fourth width W_4 and the third gap G_3 is less than the fourth gap G_4.

[0132] The surgical instruments described herein also can include features to allow the energy being delivered by the generator to be dynamically changed based on the type of tissue being treated by an end effector of a surgical instrument and various characteristics of the tissue. In one aspect, a technique for controlling the power output from a generator, such as the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), that is delivered to the end effector of the surgical instrument can include an input that represents the tissue type to allow the energy profile from the generator to be dynamically changed during the procedure based on the type of tissue being effected by the end effector of the surgical instrument.

[0133] As disclosed herein, techniques for controlling a generator based on the tissue type may be provided. Various techniques can be used to select a power profile to allow the energy being delivered from the generator to dynamically change based on the tissue type being treated by the surgical instrument.

[0134] FIG. 42A illustrates an end effector 2300 comprising a clamp arm 2302 and an ultrasonic blade 2304, where the clamp arm 2302 includes electrodes 2306. The end effector 2300 can be employed in one of the surgical instruments 104, 106, 108 referred to in FIGS. 1-3. In addition to the end effector 122, 124, 125, the surgical instruments 104, 106, 108 include a handpiece 105, 107, 109 and a shaft 126, 127, 129, respectively. The end effectors 122, 124, 125 may be used to compress, cut, and/or seal tissue. Referring to FIG. 42A, the end effector 2300, similar to the end effectors 122, 124, 125 shown in FIGS. 1-3, may be positioned by a physician to surround tissue 2308 prior to compression, cutting, or stapling. As shown in FIG. 42A, no compression may be applied to the tissue while preparing to use the end effector 2300. As shown in FIG. 42A, the tissue 2308 is not under compression between the clamp arm 2302 and the ultrasonic blade 2304.

[0135] Referring now to FIG. 42B, by engaging the trigger on the handle of a surgical instrument, the physician may use the end effector 2300 to compress the tissue 2308. In one aspect, the tissue 2308 may be compressed to its maximum threshold, as shown in FIG. 42B. As shown in FIG. 42A, the tissue 2308 is under maximum compression between the clamp arm 2302 and the ultrasonic blade 2304.

[0136] Referring to FIG. 43A, various forces may be applied to the tissue 2308 by the end effector 2300. For example, vertical forces F1 and F2 may be applied by the clamp arm 2302 and the ultrasonic blade 2304 of the end effector 2300 as tissue 2308 is compressed between the two. Referring now to FIG. 43B, various diagonal and/or lateral forces also may be applied to the tissue 2308 when compressed by the end effector 2300. For example, a force F3 may be applied. For the purposes of operating a medical device such as the surgical instruments 104, 106, 108 it may be desirable to sense or calculate the various forms of compression being applied to the tissue by the end effector. For example, knowledge of vertical or lateral compression may allow the end effector to more precisely or accurately apply a staple operation or may inform the operator of the surgical instrument such that the surgical instrument can be used more properly or safely.

[0137] In one form, a strain gauge can be used to measure the force applied to the tissue 2308 by the end effector shown in FIGS. 42A-B and 43A-B. A strain gauge can be coupled to the end effector 2300 to measure the force on the tissue 2308 being treated by the end effector 2300. With reference now also to FIG. 44, in the aspect illustrated in FIG. 44, a system 2400 for measuring forces applied to the tissue 2308 comprises a strain gauge sensor 2402, such as, for example, a micro-strain gauge, is configured to measure one or more parameters of the end effector 2300 such as, for example, the amplitude of the strain exerted on a clamp arm of an end effector, such as the clamp arm 2302 of FIGS. 43A-B, during a clamping operation, which can be indicative of the tissue compression. The measured strain is converted to a digital signal and provided to a processor 2410 of a microcontroller 2408. A load sensor 2404 can measure the force to operate the ultrasonic blade 2304 to cut the tissue 2308 captured between the clamp arm 2302 and the ultrasonic blade 2304 of the end effector 2300. A magnetic field sensor 2406 can be employed to measure the thickness of the captured tissue 2308. The measurement of the magnetic field sensor 2406 also may be converted to a digital signal and provided to the processor 2410.

[0138] Further to the above, a feedback indicator 2414 also can be configured to communicate with the microcontroller 2408. In one aspect, the feedback indicator 2414 can be disposed in the handle of a surgical instrument, such as those shown in FIGS. 1-3. Alternatively, the feedback indicator 2414 can be disposed in a shaft assembly of a surgical instrument, for example. In any event, the microcontroller 2408 may employ the feedback indicator 2414 to provide feedback to an operator of the surgical instrument with regard to the adequacy of a manual input such as, for example, a selected position of a firing trigger that is used to cause the end effector to clamp down on tissue. To do so, the microcontroller

2408 may assess the selected position of the clamp arm 2302 and/or firing trigger. The measurements of the tissue 2308 compression, the tissue 2308 thickness, and/or the force required to close the end effector 2300 on the tissue, as respectively measured by the sensors 2402, 2404, 2406, can be used by the microcontroller 2408 to characterize the selected position of the firing trigger and/or the corresponding value of the speed of end effector. In one instance, a memory 2412 may store a technique, an equation, and/or a look-up table which can be employed by the microcontroller 2408 in the assessment.

[0139] The generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), surgical instruments 104, 106, 108 (FIGS. 1-3), and end effectors 122, 124, 125, 700, 800, 900, 1000, 1100, 1200, 2200, 2200', 2200", 2300 (FIGS. 1-3, 14-22, 33-43B) described herein may be employed alone or in combination to perform surgical procedures in accordance with the techniques and processes described hereinbelow. Nevertheless, for conciseness and clarity, the surgical procedures are described with reference to the multifunction surgical instrument 108 and the generator 500. The multifunction surgical instrument 108 comprises an end effector 125 which includes a clamp arm 145 and an ultrasonic blade 149. The end effector 125 may be configured with any of the structural or functional features of any one of the end effectors 122, 124, 125, 700, 800, 900, 1000, 1100, 1200, 2200, 2200', 2200", 2300 to provide electrodes to apply RF energy to tissue, temperature sensors, force/pressure sensors, and gap measurement sensors, as described hereinabove.

Techniques For Determining Tissue Coefficient Of Friction/Tissue Coefficient of Coagulation

[0140] In one aspect, the present disclosure provides a technique for determining a tissue coefficient of friction/tissue coefficient of coagulation to control the power output from a generator, such as any one of the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), or a surgical instrument, such as the surgical instrument 108 (FIGS. 1-3). The power delivered to an end effector of a surgical instrument can vary based on a tissue coefficient of friction. The energy profile from the generator can be adjusted based on the tissue coefficient of friction and dynamically switched during the procedure between RF and ultrasonic energy modalities based on the tissue impedance to treat the tissue clamped between a clamp arm and an ultrasonic blade of the end effector of the surgical instrument. For conciseness and clarity of disclosure, the techniques for determining a tissue coefficient of friction will be described with reference to the multi-function surgical instrument 108 of FIG. 2 coupled to the generator 500 of FIG. 8, although it will be appreciated that other configurations of instruments, generators, and end effectors described herein may be readily substituted without departing from the scope of the present disclosure.

[0141] The following description provides techniques for determining a tissue coefficient of friction μ. In order to accurately calculate the tissue coefficient of friction μ of the tissue 2308, the force applied to the tissue 2308 must be in a certain range to ensure that there is sufficient contact between the tissue 2308 and the end effector 2300 and that therapeutic amounts of energy are being delivered to the end effector 2300. For example, in one aspect, a minimum load on the tissue 2308 can be 1.5 lbs. to ensure that there is enough contact between the tissue 2308 and the end effector 2300, and a maximum load on the tissue 2308 can be 2.2 lbs. to ensure that a therapeutic amount of energy is being used. These values can be used with a power level 1. In addition, the force is measured using any of the above measurement components and techniques at various loads on the tissue 2308. At least two measurements can be taken at two different loads. For example, power can be measured at 1.76 lbs. (800 grams) and 2.2 lbs. (1000 grams) in order to graph power versus force. It can be more accurate, however, to take measurements at a plurality of loads and store the values in a buffer. In one form, a buffer can be filled with values for each incremental gram between 2400 grams and 1000 grams and can use various rules, such as the first in first out rule, to store the values until the slope value is maximized. A new regression can be performed each time a new value is added to the buffer and a value is dropped from the buffer. Various other methods can be used as well to calculate the slope value.

[0142] A functional model for heating of tissue can be represented in a simple frictional model:

$$\dot{Q} = \mu \cdot v \cdot N \qquad \textit{Equation 1}$$

where $\dot{Q}$ is the rate of heat generation, v is the rms velocity of the ultrasonic motion at the tip of the blade, and N is the normal force driving tissue against the ultrasonic blade. The tissue coefficient of friction, μ, is the proportionality constant that makes the statement true and it relates to tissue properties. It is therefore referred to as the tissue coefficient of friction μ and may be referred to interchangeably as the tissue coefficient of coagulation. As is known in the art, friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.

[0143] In practice, $\dot{Q}$ is the measured amount power equal to the product of the rms values of current and voltage when driven at zero phase. The velocity is the product of the rms displacement, *d,* times the radian frequency or $v = 2\pi f \cdot d$. In the case of an ultrasonic surgical system this is the frequency at resonance which equals 55.5 kHz for the ultrasonic system. Furthermore *d* is proportional to the current driving the system, which is set by the level on the generator. The factor *v* is readily calculated. *N* is the normal force which is either set by the instrument design at full

trigger closure or can be measured with a force gage/strain gage. Since *Q, v*, and *N* are calculable from known parameters, then can be estimated by rearranging Equation 1:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

[0144] Note that removing the quiescent power from $\dot{Q}$ and updating the frequency *f* as the resonance drifts lower, will increase the repeatability and accuracy of the estimated tissue coefficient of friction μ. In order to determine the type of tissue being treated by the end effector of the surgical instrument, a tissue coefficient of friction μ can be calculated. The calculated tissue coefficient of friction is compared to a database of tissue coefficients of friction that correlates each tissue coefficient of friction with a tissue type, as will be discussed in more detail below. The calculated tissue coefficient of friction and its related tissue type are used by a technique to control the energy being delivered from the generator to the surgical instrument. In one form, the tissue coefficient of friction μ is described by the above where $\dot{Q}$ is the rate of heat generation, v is the velocity of the ultrasonic motion of the end effector, and *N* is the force applied to the tissue by the end effector. The velocity v of the ultrasonic motion is a known value from the settings of the generator. Since the value v is a known value, the tissue coefficient of friction μ can be calculated using the slope of a graph of heat generation versus force on the tissue.

[0145] The force applied to the tissue by the end effector can be measured in a variety of ways using different type of components to measure force. This force measurement can be used, for example in the equation above, to determine the tissue coefficient of friction of the tissue being treated to determine its tissue type.

[0146] Looking at the equation $\dot{Q} = \mu \cdot v \cdot N$ the product of the tissue coefficient of friction and velocity, $\mu \cdot v$, is the slope of the relation of heat generation and normal load. Because *v* is known, μ can be determined by the slope of a graph of heat generation versus normal load. An example of a graph 2500 of power (Watts) shown along the vertical axis versus force (g) shown along the horizontal axis as measured with a plurality of plotted data points is illustrated in FIGS. 45-46. FIG. 45 illustrates graphs 2500 for a porcine carotid curves 2502, 2504 at two different power levels, porcine bowel curve 2506, and dry chamois curve 2508. The data for a carotid artery at Level 3 is also shown. These are single measurements and there are no means and standard deviations to test for differences. While ideally the values of the tissue coefficient of friction μ at Levels 1 and 3 should be the same, the values at 0.30 and 0.35 are sufficiently close to believe that μ is an intrinsic property of the tissue.

[0147] FIG. 46 illustrates the same graphs 2500' as FIG. 45, but only the sections of each graph that are substantially linear. The linear sections 2502', 2504', 2506', 2508' of each curve 2502, 2504, 2506, 2508 (FIG. 45) are located in the region of the curve where the force was greater than the initial low level of force used. Each of the linear sections 2502', 2504', 2506', 2508' can be modeled as a regression line in the form of:

$$y = mx + b \qquad \textit{Equation 2}$$

where *y* is the dependent variable (Power [Watts]), *x* is the independent variable (Force [g]), m is the slope of the line, and *b* is the y-intercept.

[0148] Each of the linear sections 2502', 2504', 2506', 2508' also are characterized by R-squared (R^2), where R^2 is a statistical measure of how close the data are to the fitted regression line *y*. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression. The definition of R^2 is the percentage of the response variable variation that is explained by the linear model *y*. In other words:

$$R^2 = \text{Explained variation/Total variation}$$

[0149] R^2 is always between 0 and 100% where 0% indicates that the model explains none of the variability of the response data around its mean and 100% indicates that the model explains all the variability of the response data around its mean. In general, the higher the R^2, the better the model fits the data.

[0150] In the example illustrated in FIG. 46, the regression line and R^2 for the linear section 2502' representing porcine carotid tissue at power level 1 are:

$$y = 0.0137x + 0.2768$$

$$R^2 = 0.9902$$

[0151] The regression line and R^2 for the linear section 2504' representing porcine carotid tissue at power level 3 are:

$$y = 0.0237x + 8.9847$$

$$R^2 = 0.978$$

[0152] The regression line and R^2 for the linear section 906' representing bowel tissue at power level 1 are:

$$y = 0.0085x + 10.587$$

$$R^2 = 0.9147$$

[0153] The regression line and R^2 for the linear section 2508' representing chamois tissue at power level 1 are:

$$y = 0.034x + 0.0735$$

$$R^2 = 0.9949$$

[0154] The calculated tissue coefficient of friction μ is compared to a database of tissue coefficients of friction that correlated each coefficient with a tissue type. For example, Table 1 includes example tissue coefficients of friction μ as calculated from the plots of power and force illustrated in FIGS. 45-46 for each of the porcine carotid curves 2502, 2504 at two different power levels, porcine bowel curve 2506, and dry chamois curve 2508.

Table 1

Tissue Type	Power Level	Coefficient of Friction μ
Porcine carotid	1	0.30
Porcine carotid	3	0.35
Porcine bowel	1	0.19
Dry chamois	1	0.75

Assumptions: Ultrasonic bade amplitude is nominally 75μm p-p at level 5 and the frequency *f* is 55.5kHz. It will be appreciated that the power levels referenced above are specific to the LCS product and level 5 of the GEN11 generator available from Ethicon Endo-Surgery, Inc. that is compatible with devices known under the tradename HARMONIC and ENSEAL, also available from Ethicon Endo-Surgery, Inc.

[0155] It should be noted that the tissue coefficient of friction μ for the porcine carotid tissue at various power levels should be the same as the tissue coefficient of friction μ is a value intrinsic to the tissue. The values of 0.30 and 0.35 for the calculated tissue coefficients of friction μ are substantially close enough to show that the tissue coefficient of friction μ is intrinsic to the tissue itself.

[0156] One technique for determining the slope is to measure power delivered at two loads. Assuming Level 1 is used for this calculation, then the power could be measured at nominally 800 grams (1.76 lbs) and 1000 grams (2.2 lbs). However just using the two points can be inaccurate. It is better to fill a buffer of approximately 201 points for every gram in the 800 to 1000 gram range inclusive. The buffer could be slide advanced using a first-in-first-out (FIFO) rule until the R^2 value is maximized. A new regression would be performed each time a new point is added and an old point is dropped. Other schemes can be envisioned as well. The calculated slope is then compared with known values for specific tissue types. For example if the calculated slope is in the region of 0.30 to 0.35, then an artery is determined to be in the jaws. If the values are in the range of 0.15 to 0.20 then a section of bowel is determined to be in the jaws. In one technique,

the R^2 value may be used as an indication of specificity. For example if R^2 is less than 0.90, for example, then an indication is given that a determination cannot be made. R^2 values in the range of 0.60 to 1.00 may be used to indicate that a determination of tissue type can be made and preferably tis threshold may be about 0.90.

[0157] In practice, sampling would be done on a time basis and both power and force would be sampled. These configurations are captured in the logic flow diagram of FIG. 47. The technique can be implemented in the generator software and/or the surgical instrument software.

[0158] It will be appreciated that using the averages for power and force at two positions can improve the accuracy of a two-point slope calculation. For accuracy it may be necessary to measure closure force (and moment) in addition to power.

[0159] The benefits of using the tissue coefficient of friction μ as a means to characterize tissue is discussed hereinbelow in connection with FIG. 48. Accordingly, the tissue coefficient of friction μ can be used to discriminate tissues and can be calculated using a technique for including steps to determine that a selection cannot be made.

[0160] FIG. 47 illustrates a logic flow diagram 2600 of one form of a method for dynamically changing the energy delivered to a surgical instrument based on a determination of tissue type being treated by the instrument. As described herein, the logic flow diagram 2600 may be implemented in the generator 500, the multifunction surgical instrument 108, or a combination thereof. With reference now to the logic flow diagram 2600 shown in FIG. 47, a characterization mode of the system is started by the processor 502 in which the type of tissue being treated by the surgical instrument is determined 2602 by the processor 502. The end effector 125 is positioned such that tissue is positioned within the clamp arm 145 and the ultrasonic blade 149 of the end effector 125. The clamp arm 145 is used to apply a force to the tissue. The force of the end effector 125 on the tissue is measured and compared 2604 by the processor 502 to a threshold minimum force. If the force applied to the tissue is below a minimum threshold force, the force applied to the tissue is increased 2606 and is again measured and compared 2604 by the processor 502 to the threshold minimum force.

[0161] Once the force on the tissue has reached the minimum threshold force, the processor 502 samples 2608 the force applied to the tissue and the power delivered to the end effector 125 by the generator 500 and saves 2612 the samples in a buffer. The processor 502 determines 2610 whether the buffer is full. Samples are saved 2612 in the buffer until the buffer is full, and then the processor 502 utilizes the samples to plot 2614 points on a graph of force versus power. This information is used by the processor 502 to calculate and store 2616 the slope and R^2 values in a database. See FIG. 46, for example, for a graphical representation of the linear sections of power versus force plots including the coefficient of determination R^2. Once stored in the database, the processor 502 compares the force values to a maximum force threshold and determines 2618 when the force reaches a maximum threshold value. Until the force reaches the maximum threshold value, the processor 502 continues along the NO branch and continues sampling 2608 the next samples of power and force. The processor 502 repeats until the force reaches the maximum threshold.

[0162] Once the force has reached the maximum threshold, the samples are no longer taken and stored and the processor 502 continues along the YES branch to select 2620 the slope with the highest R^2 value and to calculate the tissue coefficient of friction μ. Next, the processor 502 determines 2622 if the maximum slope value R^2 is greater than a predetermined threshold. If R^2 is less than the predetermined threshold, then the confidence level is low and the slope value cannot be used to calculate the tissue coefficient of friction μ and identify the tissue type and the processor 502 continues along the YES branch to display 2624 a message indicating that the tissue type has not been identified. In one aspect, the threshold may be selected in the range of 0.6 to 1.00 and may preferably be set to about 0.90, for example. In other aspects, the threshold may be selected using more sophisticated, statistical tests applied to determine the level confidence R^2. If R^2 is greater than or equal to the predetermined threshold, the calculated tissue coefficient of friction μ can be used to identify the tissue and the processor 502 continues along the NO branch where the processor 502 compares 2626 the calculated tissue coefficient of friction μ to a database 2628 of stored tissue coefficients of friction μ which the stored tissue coefficients of friction μ correspond to tissue types. The tissue type is selected 2630 and displayed and used to specify 2632 the power delivery profile for delivering energy from the generator 500 to the end effector 125 of the surgical instrument 108. Normal operation mode is entered 2634 such that the tissue type and related power delivery profile are used to control the end effector 125 for treating the tissue.

[0163] In one aspect, the tissue coefficient of friction μ and its rate may be employed to determine tissue type and power delivery profile. For example, It has been shown in preliminary work that μ is significantly different between porcine bowel, artery and chamois. Furthermore the μ values were initial flat but did change as time progressed presumably because of the temperature rise as heat was added. From these observations, μ can be used as a tissue differentiator and can be done at lower current to avoid rapid changes in μ when the purpose is to characterize the tissue. Also, another parameter of interest would be the rate of change of the tissue coefficient of friction μ for fixed conditions of $\dot{Q}$, v, and N. It will be appreciated that $\dot{\mu}$ is not simply differentiating the equation $\mu = \frac{\dot{Q}}{v \cdot N}$ with respect time, because the change is due to changes in the tissue itself. For example the μ for chamois rapidly rises when heat is delivered compare with carotid arteries or bowel, because it is dry. The rate of change is likely dependent on the percentage of water content

in the tissue. In one aspect, the present disclosure provides a technique to estimate both the tissue coefficient of friction μ and the rate of change of the tissue coefficient of friction μ and compare them with table of know values stored in a database, for example. The tissue selection can be based on the values closet to the estimated values. The power delivery profile could then be optimize for that tissue and delivered to the surgical instrument 108. Estimating the tissue coefficient of friction μ and the rate of change of the tissue coefficient of friction μ may be able to further differentiate tissue types. Another aspect of the present disclosure includes tracking the tissue coefficient of friction μ as the seal/transection progresses. Key changes in this parameter may signal a need to modify the power delivery profile.

[0164] FIG. 48 illustrates a logic flow diagram 2700 of another form of a method for dynamically changing the energy delivered to a surgical instrument 108 based on a determination of tissue type being treated by the surgical instrument 108. As described herein, the logic flow diagram 2700 may be implemented in the generator 500, the multifunction surgical instrument 108, or a combination thereof. With reference now to the logic flow diagram 2700 shown in FIG. 48 and the surgical system 100 of FIG. 1, the processor 502 initiates a power evaluation mode of the system to determine 2702 the power profile for the generator 500. The end effector 125 of the surgical instrument 108 is then engaged with the tissue to be treated and the end effector 125 of the surgical instrument 108 is activated 2704 with energy delivered from the generator 500. The tissue coefficient of friction μ and the processor 502 measures 2706 the rate of change (e.g., rate of rise) of the tissue coefficient of friction μ over a short period of time. The processor 502 compares 2708 the measured tissue coefficient of friction μ and the rate of change of the tissue coefficient of friction μ to values stored in a tissue information database 2714.

[0165] If the system is in learning mode, in which the tissue information database 2714 information regarding tissue type and tissue coefficients of friction μ are being updated, the tissue type can be visually identified 2710. The processor 502 updates 2712 the tissue information database 2714 of tissue coefficient of friction μ and tissue type information to increase the accuracy of the tissue information database 2714.

[0166] If the system is not in learning mode, then the processor 502 selects 2716 a power delivery profile based on the determined tissue and surgical instrument type 2718 being used. During the treatment of the tissue, the processor 502 continues to calculate and monitor 2720 the tissue coefficient of friction μ and the rate of change of the tissue coefficient of friction μ to allow the processor 502 to dynamically update the power delivery profile. If an error is found, the power delivery profile is modified 2724. The processor 502 then determines 2722 if the correct pattern of power and delivery profile is being used. If no error is found, the current power delivery profile continues 2726. Otherwise, the processor 502 modifies 2724 the power and delivery profile. The processor 502 continues the process of verification and correction of the power delivery profile during the entire surgical procedure to optimize the energy being delivered to the surgical instrument 108 based on the type of tissue being treated.

Techniques For Controlling A Generator Based On The Hydration Level Of Tissue

[0167] In one aspect, the present disclosure provides a technique for controlling the power output from a generator, such as any one of the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), or a surgical instrument, such as the surgical instrument 108 (FIGS. 1-3). The power delivered to the end effector of the surgical instrument can be controlled based on the hydration level of the tissue to allow the energy profile from the generator to be dynamically changed based on the hydration level of the tissue being treated by the end effector of the surgical instrument. For conciseness and clarity of disclosure, the techniques for controlling the power output from a generator based on the hydration level of tissue will be described with reference to the multifunction surgical instrument 108 of FIG. 2 coupled to the generator 500 of FIG. 8, although it will be appreciated that other configurations of instruments, generators, and end effectors described herein may be readily substituted without departing from the scope of the present disclosure.

[0168] In order to determine the hydration level of the tissue being treated by the end effector 125 of the surgical instrument 108, the tissue coefficient of friction μ as described herein can be used. As explained above, a force measurement is taken using any of the methods described herein to calculate the tissue coefficient of friction μ to determine the hydration level of the tissue. The calculated tissue coefficient of friction μ is compared to a database of tissue coefficients of friction μ that correlate each tissue coefficient with a hydration level of the tissue. The calculated tissue coefficient of friction μ and its related tissue hydration level are used by the technique to control the energy being delivered from the generator 500 to the surgical instrument 108.

[0169] The hydration level of the tissue can be indicative of a variety of conditions within the tissue. During a coagulation cycle in which RF energy is being used to coagulate the tissue, a decrease in the tissue hydration level can indicate that the tissue is nearing the end of the coagulation cycle. In addition, the hydration level of the tissue can vary during the coagulation cycle such that the RF energy being delivered from the generator 500 can dynamically change during the coagulation cycle based on the calculated hydration levels during the cycle. For example, as a coagulation cycle progresses, the hydration level of the tissue will decrease such that the technique used to control the energy delivered from the generator 500 can decrease the power as the cycle progresses. Thus, the hydration level of the tissue can be an indicator of the progress through a coagulation cycle of the tissue by the end effector of the surgical instrument 108.

[0170] FIG. 49 illustrates a logic flow diagram 2800 of one form of a method for dynamically changing the energy delivered to a surgical instrument 108 based on a determination of the hydration level of tissue being treated by the surgical instrument 108. As described herein, the logic flow diagram 2800 may be implemented in the generator 500, the multifunction surgical instrument 108, or a combination thereof. With reference now to the logic flow diagram 2800 shown in FIG. 49, the processor 502 determines the hydration level of the tissue by measuring the tissue coefficient of friction μ as described herein. Initially, the end effector 125 of the surgical instrument 108 is closed on tissue and the end effector 125 is activated 2802 with energy from the generator 500. The processor 502 measures 2804 the tissue coefficient of friction μ, as described herein. The processor 502 compares 2806 the tissue coefficient of friction μ and the rate of change of the tissue coefficient of friction μ to values stored in a database to determine the hydration level of the tissue. The processor 502 selects 2808 a power delivery profile based on the hydration level of the tissue. The processor 502 monitors 2810 the tissue coefficient of friction μ and the rate of change of the tissue coefficient of friction μ during treatment of the tissue to monitor the changes in the tissue hydration level. This allows the processor 502 to dynamically change 2812 the power delivery profile, such that power delivered from the generator 500 can dynamically change during tissue treatment.

Techniques For Switching Between RF And Ultrasonic Energy Based On Tissue Type

[0171] In another aspect, the present disclosure provides a technique for controlling energy delivered by a generator and/or a surgical instrument by dynamically switching between RF and ultrasonic energy. The technique includes controlling the power output from a generator, such as any one of the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), or a surgical instrument, such as the surgical instrument 108 (FIGS. 1-3). In one aspect, RF and ultrasonic energy can be dynamically switched based on the type of tissue being treated by an end effector of a surgical instrument and various characteristics of the tissue. The power delivered to the end effector of the surgical instrument can include an input that represents the tissue type to allow the energy profile from the generator to be dynamically changed between RF and ultrasonic energy during the procedure based on the type of tissue being effected by the end effector of the surgical instrument. For conciseness and clarity of disclosure, techniques for dynamically switching between different energy modalities, such as, for example RF energy and ultrasonic energy, will be described with reference to the multifunction surgical instrument 108 of FIG. 2 coupled to the generator 500 of FIG. 8, although it will be appreciated that other configurations of instruments, generators, and end effectors described herein may be readily substituted without departing from the scope of the present disclosure.

[0172] In order to determine the type of tissue being treated by the end effector 125 of the surgical instrument 108, a tissue coefficient of friction μ and/or the rate of change of the tissue coefficient of friction μ can be calculated and compared to a database of tissue coefficient of friction μ that correlates each tissue coefficient of friction μ with a tissue type, as explained above. The calculated tissue coefficient of friction μ and its related tissue type are used by a technique to control the type (RF or ultrasonic) and power level of energy being delivered from the generator 500 to the surgical instrument 108. Tissue types include, without limitation, tissue with a muscular structure, tissue with a vascular structure, tissue with a thin mesentery structure.

[0173] FIG. 50 illustrates a logic flow diagram 2900 of one aspect of a method of dynamically changing the between RF energy delivered from the ENERGY2/RETURN output of the generator 500 and ultrasonic energy delivered from the ENERGY1/RETURN output of the generator 500 to the surgical instrument 108 based on a determination of tissue type being treated by the surgical instrument 108. As described herein, the logic flow diagram 2900 may be implemented in the generator 500, the multifunction surgical instrument 108, or a combination thereof. With reference now to the logic flow diagram 2900 shown in FIG. 50, the processor 502 initiates a characterization mode of the generator 500 to determine 2902 the type of tissue being treated by the surgical instrument 108. The end effector 125 is positioned such that tissue is positioned between the clamp arm 145 and the ultrasonic blade 149 of the end effector 125. The end effector 1255 applies a force to the tissue. The force applied to the tissue by the end effector 125 is measured and compared 2904 by the processor 502 to a threshold minimum force. If the processor 502 determines that the force applied to the tissue is below a minimum threshold force, the force applied to the tissue is increased 2906. Once the force on the tissue has reached the minimum threshold force, the processor 502 samples 2908 the force applied to the tissue and the power delivered to the end effector 125 by the generator 500 and stores the samples in a buffer.

[0174] The processor 502 determines 2901 if the buffer is full. If the buffer is not full, the processor 502 enters 2912 the most recent samples into the buffer. If the buffer is full, the processor 502 enters the most recent samples into the buffer and drops 2914 the first point (e.g., FIFO method for organizing and manipulating a data buffer). The processor 502 calculates and stores 2916 the slope and R^2 values and the force is tested to determine 2918 if the force applied to the tissue is greater than a maximum force threshold. If the force applied to the tissue is not greater than the maximum threshold, the processor 502 samples 2908 the force applied to the tissue and the power delivered to the end effector 125 by the generator 500 and saves the samples in a buffer. The processor 502 repeats until the force applied to the tissue is greater than the maximum threshold. The processor 502 selects the slope with the highest R^2 and calculates

2920 the tissue coefficient of friction μ. If the processor 502 determines 2922 that R^2 is less than a predetermined threshold, the processor 502 continues along the YES branch and the system displays 2924 that the tissue type was not identified. If R^2 is greaten than or equal to the threshold, the processor 502 continues along the NO branch and compares 2926 the calculated tissue coefficient of friction μ to values stored in a tissue information database 2928.

[0175] In one aspect, the threshold may be selected in the range of 0.6 to 1.00 and may preferably be set to about 0.90, for example. In other aspects, the threshold may be selected using more sophisticated, statistical tests applied to determine the level confidence R^2. In one aspect, the threshold may be selected between 0.6 to 1.00 and may preferably be set to about 0.90. In other aspects, the threshold may be selected using more sophisticated, statistical tests applied to determine the level confidence R^2. The processor 502 then selects 2930 and displays the tissue type and specifies 2932 the power delivery profile for delivering either ultrasonic energy (ENERGY1/RETURN) or RF energy (ENERGY2/RETURN) from the generator 500 to the end effector 125 of the surgical instrument 108. Normal operation mode is entered 2934 such that the tissue type and related power delivery profile are used to control the end effector for treating the tissue. Using the tissue type determined in accordance with the logic flow diagram 2900, the processor 502 can provide optimized energy delivery for that particular tissue. Tissue types that are determined to be more vascular or muscular would require more RF energy at the beginning of the cycle to provide more sealing energy either before the application of the ultrasonic energy or at a higher ratio of RF vs. ultrasonic energy. And tissue types that are less vascular would require less RF energy at the beginning of the cycle and the system would change the energy delivery toward a cutting profile using ultrasonic energy. Energy may be applied to the tissue until the tissue meets or exceeds a predetermined threshold impedance, which may be referred to as the termination impedance, and which is the tissue impedance that corresponds to the impedance of tissue when the tissue seal is complete.

Techniques For Dynamically Changing The Energy Delivered From A Generator Based On Aperture Defined By The End Effector And Energy Parameters

[0176] In one aspect, the present disclosure provides a technique for dynamically changing the energy delivered from a generator based on an aperture defined by an end effector. According to one aspect, the techniques for dynamically changing the energy delivered from a generator, such as any one of the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), or a surgical instrument, such as the surgical instrument 108 (FIGS. 1-3). For conciseness and clarity of disclosure, techniques for dynamically changing energy delivered from a generator based on an aperture defined by an end effector and energy parameters will be described with reference to the multifunction surgical instrument 108 of FIG. 2 coupled to the generator 500 of FIG. 8, although it will be appreciated that other configurations of instruments, generators, and end effectors described herein may be readily substituted without departing from the scope of the present disclosure.

[0177] The energy profile from the generator 500 can be dynamically changed during the procedure between RF and ultrasonic energy based on the aperture defined by the end effector 125 that is clamping on a tissue. This allows the generator 500 to switch from RF energy to ultrasonic energy based on the amount of clamping force exerted by the end effector 125 on the tissue being treated by the surgical instrument 108. The aperture defined by the clamp arm 145 is related to the creation of a proper coagulation seal, for example, when RF energy is being delivered from the generator 500 to the end effector 125 of the surgical instrument 108, such that RF energy should be used when there is a sufficient closure of the end effector 108 on the tissue. Thus, when the aperture defined by the end effector 108 is too large and there is not a sufficient clamping force exerted on the tissue for proper coagulation, only ultrasonic energy is delivered to the ultrasonic blade 149 of the end effector 125 through the ENERGY1/RETURN output of the generator 500.

[0178] For example, misleading information regarding various tissue measurements and/or characteristics can be transmitted to the generator 500 for use in the techniques for controlling the energy delivered depending on the aperture defined by the end effector 125. One such measurement that can be affected by the aperture defined by the end effector 125 is tissue impedance. Tissue impedance measured by an instrument as described herein will depend on several factors including the clamping force or pressure applied by the end effector 125 and the distance between electrodes in the case of RF energy or the clamp arm 145 aperture in the case of ultrasonic energy. Many techniques that determine the end of the coagulation cycle depend on the tissue impedance. A clamp arm 145 that is not fully closed on the ultrasonic blade 149 can lead to a tissue impedance determination that may not properly represent the condition of the tissue. An incorrect tissue impedance determination can lead to early termination of a coagulation cycle as the generator 500 may switch from RF to ultrasonic energy before a proper coagulation seal has been achieved. In one aspect, the tissue impedance may be determined by the processor 502 by dividing the output of the second voltage sensing circuit 524 coupled across the terminals labeled ENERGY2/RETURN by the output of the current sensing circuit 514 is disposed in series with the RETURN leg of the secondary side of the power transformer 508 as shown in FIG. 8. The outputs of the voltage sensing circuit 512 are provided to an isolation transformer and ADC 516 and the output of the current sensing circuit 514 is provided to another isolation transformer and ADC 518 to provide the voltage and current measurement is digital form to the processor 502.

[0179] The aperture defined by the end effector 125 can be determined using a variety of techniques. In various aspects, the aperture defined by the end effector 125 may be determined by detecting the pivot angle of the end effector 125. This can be accomplished using a potentiometer, a Hall effect sensor (in a manner described in connection with FIG. 19), an optical encoder, an optical IR sensor, an inductance sensor, or combinations thereof. In another aspect, the proximity of first and second components of an end effector is measured to determine the aperture defined by the end effector using, for example, the Hall effect sensor, an optical encoder, an optical IR sensor, an inductance sensor, or combinations thereof. In another aspect, the surgical instrument 108 may be configured to detect the aperture defined by the end effector 125 by measuring a change in a tissue impedance of the tissue interacting with the end effector. In another aspect, the surgical instrument 108 may be configured to detect the aperture defined by the end effector 125 by measuring a load applied by the end effector 125 on the tissue as ultrasonic energy is pulsed to the end effector 125. In another aspect, the surgical instrument 108 includes a switch or other mechanism for closing the end effector 125 that can detect the aperture defined by the end effector 125. In another aspect, the aperture defined by the end effector 125 may be determined based on linear displacement or stroke of the closure mechanism located either in the shaft 129 or the handle 109 of the surgical instrument 108. In another form, the aperture defined by the end effector 125 may be determined by the angular displacement of the trigger mechanism located in the handle 109 of the surgical instrument 108.

[0180] FIG. 51 is a logic flow diagram 3000 of one aspect of a technique for dynamically changing the energy delivered from a generator based on aperture defined by the end effector and energy parameters. As described herein, the logic flow diagram 3000 may be implemented in the generator 500, the surgical instrument 108, or a combination thereof. With reference now to the logic flow diagram 3000 shown in FIG. 51 and the surgical system 100 of FIG. 1 with the combination electrosurgical and ultrasonic multifunction surgical instrument 108 and the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), the aperture defined by the end effector 125 is determined as described herein. Initially, the end effector 125 of the surgical instrument 108 is closed on tissue, as shown in FIGS. 42A-B, 43A-B, and the end effector 125 is activated 3002 with energy from the generator 500, for example. The aperture defined by the end effector 125 is determined 3004 by the processor 502 using any of the techniques described herein. Once the aperture defined by the end effector 125 is determined 3004, the processor 502 signals the waveform generator 504 to delivery energy from the generator 500 and controls switching the output of the generator 500 between RF energy ENERGY2 and ultrasonic energy (ENERGY1/RETURN) based on the determined aperture defined by the end effector 125. Accordingly, the processor 502 selects 3006 a power delivery profile based on the aperture defined by the end effector 125. The processor 502 continues to monitor 3008 the aperture defined by the end effector 125 during the tissue treatment process and dynamically changes 3010 the energy delivered from the generator 500 based on the changing aperture defined by the end effector 125.

[0181] In another aspect, a technique for controlling the power output from the generator, such as the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), or the surgical instrument 108, such as the surgical instrument 108 (FIGS. 1-3) that is delivered to the end effector 125 of the surgical instrument 108 can include an input that includes energy parameters based on an aperture defined by the end effector 125 of the surgical instrument 108. The energy profile from the generator 500 can be dynamically changed during the procedure between RF and ultrasonic energy using the energy parameters based on the aperture defined by the end effector 125 that is clamping on tissue as shown in FIGS. 42A-B, 43A-B. This allows the generator 500 to switch from RF energy ENERGY2 to ultrasonic energy (ENERGY1/RETURN) based on the clamping force applied by the end effector 125 to the tissue being treated by the surgical instrument 108. As explained above, the aperture defined by the clamp arm 145 is related to creating a proper coagulation seal, for example, when RF energy is being delivered from the generator 500 to the end effector 125 of the surgical instrument 108, such that RF energy should be used when there is a sufficient closure of the end effector 125 on the tissue. Thus, when the aperture defined by the end effector 125 is too large and the clamping force applied to the tissue is insufficient for proper coagulation, only ultrasonic energy is delivered to the end effector 125 by the generator 500.

[0182] The aperture defined by the end effector 125 can be determined using any of the methods described herein. For example, the surgical instrument 108 can include an aperture defined by a sensor located in the end effector 125 that can be fed through a connector to the ASIC in the handle 109 of the surgical instrument 108. The surgical instrument 108 also can include a sensor in the handle 109 of the surgical instrument 108 that is configured to detect the aperture defined by the end effector 125.

[0183] Energy parameters are configured to be loaded into the generator 500, and can include a plurality of different parameters, including but not limited to voltage, current, power, and one or more techniques for use in treating tissue. These parameters can be related to the RF energy and ultrasonic energy that can be delivered from the generator 500. The energy parameters can include information such as maximum and/or minimum values to be used to control the energy delivered from the generator 500. The energy parameters can be stored in a variety of locations, including an EEPROM on the surgical instrument or some other non-volatile memory. In addition, there can be multiple sets of energy parameters. For example, there can be a first set of energy parameters that are used to optimize tissue transection, and a second set of energy parameters that are used to optimize tissue spot coagulation. It will be understood that there can

be any number of set of energy parameters that correspond to various types of tissue treatments to allow the generator to switch between the various sets of energy parameters based on the necessary tissue treatments.

[0184] When the end effector 125 of the surgical instrument 108 is activated, one or more of the various techniques described herein are used to detect the aperture defined by the end effector 108. In one aspect, when the end effector 125 is closed around the tissue, the generator 500 can utilize the energy parameters for optimizing tissue transection. When the end effector 125 has a larger aperture and is not clamped on the tissue, the generator 500 can utilize the energy parameters for optimizing spot coagulation of the tissue.

[0185] FIG. 52 is a logic flow diagram 3200 of one aspect of a technique for dynamically changing the energy delivered from a generator based on aperture defined by the end effector and energy parameters. As described herein, the logic flow diagram 3200 may be implemented in the generator 500, the multifunction surgical instrument 108, or a combination thereof. With reference now to the logic flow diagram 3100 shown in FIG. 52, with the combination electrosurgical and ultrasonic instrument 108 and the generator 500, initially the aperture defined by the end effector 125 is determined by the processor 502 as described herein. The end effector 125 of the surgical instrument 108 is closed on tissue, as shown in FIGS. 42A-B, 43A-B, and the end effector 125 is activated with energy from the generator 500. The aperture defined by the end effector 125 is determined 3104 using any of the techniques described herein. The processor 502 signals the waveform generator 504 to deliver energy from the generator 500 to the end effector 125 and switch the generator 500 output between to switch between RF and ultrasonic energy based on the aperture defined by the end effector 125 by using one of the sets of energy parameters that was previously loaded into the generator 500. Accordingly, energy parameters are communicated 3106 to the generator 500 based on the previously determined 3104 aperture defined by the end effector 125. The processor 502 monitors 3108 the aperture defined by the end effector 125 during the tissue treatment process such that the energy delivered from the generator 500 can be dynamically communicated 3110 by the processor 502 during the tissue treatment process based on the changing aperture defined by the end effector 125. This allows the generator 500 to dynamically switch between the various sets of energy parameters based on the changing aperture defined by the end effector 125.

[0186] It will be understood that various combinations of information can be used to determine which set of energy parameters are to be used during tissue treatment. For example, the aperture defined by the end effector and calculated tissue impedance can be used to determine which set of energy parameters are needed to control the energy being delivered from the generator.

Techniques For Dynamic Sensing Of Tissue

[0187] In one aspect, the present disclosure provides dynamic tissue sensing techniques. In one aspect, the dynamic tissue sensing techniques may be implemented with a generator, such as any one of the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), or a surgical instrument, such as the surgical instrument 108 (FIGS. 1-3). For conciseness and clarity of disclosure, the dynamic tissue sensing techniques will be described with reference to the multifunction surgical instrument 108 of FIG. 2 coupled to the generator 500 of FIG. 8, although it will be appreciated that other configurations of instruments, generators, and end effectors described herein may be readily substituted without departing from the scope of the present disclosure.

[0188] Upon measuring the tissue thickness and the normal force on the ultrasonic blade as shown in and described in connection with FIGS. 42A-B, 43A-B, and measuring the tissue coefficient of friction μ, in one aspect a technique is provided that pulses to measure the tissue coefficient of friction μ at set time intervals and based on the measured coefficient μ over time, adjusts the power delivered by any one of and the generators 102, 200, 300, 400, 500 (FIGS. 1-3 and 4-8), or the surgical instrument (FIGS. 1-3), in order to transect or "cut" tissue efficiently and with good hemostasis. In one aspect, a sensing technique is configured to monitor tissue friction and determine the tissue coefficient of friction μ, as described herein, throughout a cut and modulates energy delivered during the cut based on change in the tissue coefficient of friction μ over time.

[0189] FIG. 53 is a logic flow diagram 3200 of one aspect of a dynamic tissue sensing technique. As described herein, the logic flow diagram 3200 may be implemented in the generator 500, the multifunction surgical instrument 108, or a combination thereof. With reference now to the logic flow diagram 3200 shown in FIG. 53, case specific details for knowledge of tissue type are input 322 into the generator 500. The end effector 125 of the surgical instrument 108 is closed on the tissue, as shown in FIGS. 42A-B, 43A-B, and the tissue coefficient of friction μ is checked 3204 by the processor 502 and power is delivered 3206 to the tissue according to known normal force N, tissue coefficient of friction μ, and tissue thickness as determined by processor 502 as described herein. The processor 502 compares 3208 the rate of change of $\mu/|\mu|$ to known values of μ. In one aspect, a look-up table for predefined μ/Power Delivery Ratios may be utilized by the processor 502. The processor 502 adjusts 3210 the power delivered by the generator 500 higher or lower based on $\Delta\mu$. When μ reaches 3212 a known or predetermined threshold, the processor 502 checks 3214 the clamp arm 145 of the end effector 125 for closure against the ultrasonic blade 149. In one aspect, this can be determined based on known normal force N and known production normal force N_p that represents a closed end effector jaw. When

the jaw closure is complete, the processor 502 control the delivery 3216 of short bursts of power to complete the tissue transection or cut until the cut is completed 3218.

[0190] Accordingly, by measuring the tissue coefficient of friction μ, the processor 502 pulses to measure the tissue coefficient of friction μ at set time intervals and based on the measured coefficient μ over time, and adjusts the power delivered by generator 500 to the tissue in order to transect or "cut" tissue efficiently and with good hemostasis. In one aspect, the sensing technique monitors and periodically determines the tissue coefficient of friction μ, as described herein, while making the cut and modulates the energy delivered by the generator during the cut based on change in the tissue coefficient of friction $\Delta\mu$ over time.

[0191] While various details have been set forth in the foregoing description, it will be appreciated that the various aspects of the surgical system with user adaptable techniques based on tissue type may be practiced without these specific details. For example, for conciseness and clarity selected aspects have been shown in block diagram form rather than in detail. Some portions of the detailed descriptions provided herein may be presented in terms of instructions that operate on data that is stored in a computer memory. Such descriptions and representations are used by those skilled in the art to describe and convey the substance of their work to others skilled in the art. In general, a technique refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities which may, though need not necessarily, take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It is common usage to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. These and similar terms may be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities.

[0192] Unless specifically stated otherwise as apparent from the foregoing discussion, it is appreciated that, throughout the foregoing description, discussions using terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

[0193] It is worthy to note that any reference to "one aspect," "an aspect," "one form," or "an form" means that a particular feature, structure, or characteristic described in connection with the aspect is included in at least one aspect. Thus, appearances of the phrases "in one aspect," "in an aspect," "in one form," or "in an form" in various places throughout the specification are not necessarily all referring to the same aspect. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner in one or more aspects.

[0194] Some aspects may be described using the expression "coupled" and "connected" along with their derivatives. It should be understood that these terms are not intended as synonyms for each other. For example, some aspects may be described using the term "connected" to indicate that two or more elements are in direct physical or electrical contact with each other. In another example, some aspects may be described using the term "coupled" to indicate that two or more elements are in direct physical or electrical contact. The term "coupled," however, also may mean that two or more elements are not in direct contact with each other, but yet still cooperate or interact with each other.

[0195] Although various forms have been described herein, many modifications, variations, substitutions, changes, and equivalents to those forms may be implemented and will occur to those skilled in the art. Also, where materials are disclosed for certain components, other materials may be used. It is therefore to be understood that the foregoing description and the appended claims are intended to cover all such modifications and variations as falling within the scope of the disclosed forms. The following claims are intended to cover all such modification and variations.

[0196] In a general sense, those skilled in the art will recognize that the various aspects described herein which can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or any combination thereof can be viewed as being composed of various types of "electrical circuitry." Consequently, as used herein "electrical circuitry" includes, but is not limited to, electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit, electrical circuitry forming a general purpose computing device configured by a computer program (e.g., a general purpose computer configured by a computer program which at least partially carries out processes and/or devices described herein, or a microprocessor configured by a computer program which at least partially carries out processes and/or devices described herein), electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). Those having skill in the art will recognize that the subject matter described herein may be implemented in an analog or digital fashion or some combination thereof.

[0197] The foregoing detailed description has set forth various forms of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In one form, several portions of the subject

matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), or other integrated formats. However, those skilled in the art will recognize that some aspects of the forms disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as a program product in a variety of forms, and that an illustrative form of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include, but are not limited to, the following: a recordable type medium such as a floppy disk, a hard disk drive, a Compact Disc (CD), a Digital Video Disk (DVD), a digital tape, a computer memory, etc.; and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link (e.g., transmitter, receiver, transmission logic, reception logic, etc.), etc.).

[0198] All of the above-mentioned U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications, non-patent publications referred to in this specification and/or listed in any Application Data Sheet, or any other disclosure material are incorporated herein by reference, to the extent not inconsistent herewith. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

[0199] One skilled in the art will recognize that the herein described components (e.g., operations), devices, objects, and the discussion accompanying them are used as examples for the sake of conceptual clarity and that various configuration modifications are contemplated. Consequently, as used herein, the specific exemplars set forth and the accompanying discussion are intended to be representative of their more general classes. In general, use of any specific exemplar is intended to be representative of its class, and the non-inclusion of specific components (e.g., operations), devices, and objects should not be taken limiting.

[0200] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations are not expressly set forth herein for sake of clarity.

[0201] The herein described subject matter sometimes illustrates different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely example, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated also can be viewed as being "operably connected," or "operably coupled," to each other to achieve the desired functionality, and any two components capable of being so associated also can be viewed as being "operably couplable," to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components, and/or wirelessly interactable, and/or wirelessly interacting components, and/or logically interacting, and/or logically interactable components.

[0202] In some instances, one or more components may be referred to herein as "configured to," "configurable to," "operable/operative to," "adapted/adaptable," "able to," "conformable/conformed to," etc. Those skilled in the art will recognize that "configured to" can generally encompass active-state components and/or inactive-state components and/or standby-state components, unless context requires otherwise.

[0203] While particular aspects of the present subject matter described herein have been shown and described, it will be apparent to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from the subject matter described herein and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of the subject matter described herein. It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and

"one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations.

[0204] In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms unless context dictates otherwise. For example, the phrase "A or B" will be typically understood to include the possibilities of "A" or "B" or "A and B."

[0205] With respect to the appended claims, those skilled in the art will appreciate that recited operations therein may generally be performed in any order. Also, although various operational flows are presented in a sequence(s), it should be understood that the various operations may be performed in other orders than those which are illustrated, or may be performed concurrently. Examples of such alternate orderings may include overlapping, interleaved, interrupted, reordered, incremental, preparatory, supplemental, simultaneous, reverse, or other variant orderings, unless context dictates otherwise. Furthermore, terms like "responsive to," "related to," or other past-tense adjectives are generally not intended to exclude such variants, unless context dictates otherwise.

[0206] Although various forms have been described herein, many modifications, variations, substitutions, changes, and equivalents to those forms may be implemented and will occur to those skilled in the art. Also, where materials are disclosed for certain components, other materials may be used. It is therefore to be understood that the foregoing description and the appended claims are intended to cover all such modifications and variations as falling within the scope of the disclosed forms. The following claims are intended to cover all such modification and variations.

[0207] In summary, numerous benefits have been described which result from employing the concepts described herein. The foregoing description of the one or more forms has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The one or more forms were chosen and described in order to illustrate principles and practical application to thereby enable one of ordinary skill in the art to utilize the various forms and with various modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

[0208] The following list of embodiments forms part of the description:

1. A surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising:

    a processor;
    an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising:

        a clamp arm;
        an ultrasonic blade;
        a force sensor in communication with the processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade; and
        a temperature sensor in communication with the processor;

    an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive a drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver energy to the ultrasonic blade;
    wherein the processor is configured to:

determine a type of tissue interacting with the end effector based on a tissue coefficient of friction, wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector; and
dynamically control the drive signal delivered to the ultrasonic transducer based on the type of tissue interacting with the end effector.

2. The surgical instrument of embodiment 1, wherein the tissue coefficient of friction is determined based on the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the ultrasonic blade, and N is force applied to the tissue by the end effector.

3. The surgical instrument of embodiment 1, wherein the force sensor comprises a strain gauge coupled to the end effector.

4. The surgical instrument of embodiment 3, wherein the force measurement is communicated from the strain gauge to the processor.

5. The surgical instrument of embodiment 1, wherein the processor is configured to:

store two data points of the measured force and power delivered to the end effector in a buffer;
determine a slope value of the power versus force based on the two data points;
determine a statistical measure R^2 of the slope value relative to a fitted regression line; and
determine the tissue coefficient of friction based on the slope value.

6. The surgical instrument of embodiment 5, wherein the processor is configured to:

compare R^2 to a threshold value; and
select a slope value associated with an R^2 value that is greater than or equal to the threshold value to determine the tissue coefficient of friction.

7. The surgical instrument of embodiment 1, wherein the processor is configured to control power of the drive signal delivered to the ultrasonic transducer based on the tissue coefficient of friction.

8. The surgical instrument of embodiment 1, wherein the processor is configured to:

compare the tissue coefficient of friction to tissue coefficients of friction stored in a tissue information database;
determine the type of tissue based on the tissue coefficient of friction; and
deliver the drive signal to the ultrasonic transducer based on the tissue coefficient of friction.

9. The surgical instrument of embodiment 1, further comprising a generator configured to deliver the drive signal to the ultrasonic transducer.

10. A generator for delivering energy to a surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising an end effector at a distal end thereof, the end effector configured to interact with tissue, the end effector comprising a clamp arm, an ultrasonic blade, a force sensor in communication with the processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade, and a temperature sensor in communication with a processor, an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive a drive signal from the generator to cause ultrasonic motion of the ultrasonic blade and deliver energy to the ultrasonic blade, the generator comprising:

a drive circuit configured to deliver a drive signal to an ultrasonic transducer; and
a processor configured to control energy delivered by the drive circuit to the ultrasonic transducer based on a type of tissue interacting with the end effector;

wherein the processor is configured to:

receive a measurement of force applied to tissue by the end effector, ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector;
determine the type of tissue interacting with the end effector based on a tissue coefficient of friction, wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector; and
dynamically control the drive signal delivered to the ultrasonic transducer based on the type of tissue interacting with the end effector.

11. The generator of embodiment 10, wherein the tissue coefficient of friction is determined based on the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the ultrasonic blade, and N is force applied to the tissue by the end effector.

12. The generator of embodiment 10, wherein the processor is configured to:

store two data points of the measured force and power delivered to the ultrasonic transducer in a buffer;
determine a slope value of the power versus force based on the two data points;
determine a statistical measure R^2 of the slope value relative to a fitted regression line; and
determine the tissue coefficient of friction based on the slope value.

13. The generator of embodiment 12, wherein the processor is configured to:

compare R^2 to a threshold value; and
select a slope value associated with an R^2 value that is greater than or equal to the threshold value to determine the tissue coefficient of friction.

14. The generator of embodiment 10, wherein the processor is configured to control power of the drive signal delivered to the ultrasonic transducer based on the tissue coefficient of friction.

15. The generator of embodiment 10, wherein the processor is configured to:

compare the tissue coefficient of friction to tissue coefficients of friction stored in a tissue information database;
determine the tissue type based on the tissue coefficient of friction; and
deliver the drive signal to the end effector based on the tissue coefficient of friction.

16. A method of coagulating and dissecting tissue, the method comprising:

measuring, by a force sensor, a force being applied to a tissue by an end effector disposed on a distal end of a surgical instrument configured to interact with the tissue, the end effector comprising a clamp arm, an ultrasonic blade acoustically coupled to an ultrasonic transducer, a force sensor in communication with a processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade, and a temperature sensor;
determining, by the processor, a tissue coefficient of friction based on the measured force applied to the tissue by the end effector, ultrasonic motion of the end effector caused by energy delivered thereto from a generator, and a rate of heat generated by the end effector;
determining, by the processor, a type of tissue interacting with the end effector based on the tissue coefficient of friction; and
delivering, by a drive circuit, a drive signal to the ultrasonic transducer to interact the ultrasonic blade with the tissue based on the determined type of tissue.

17. The method of embodiment 16, wherein measuring the force comprises:

measuring, by the force sensor, at least two data points of the force and power delivered to the end effector;
storing, by the processor, the data points in a buffer;
determining, by the processor, a slope value of the force versus the power; and
determining, by the processor, the tissue coefficient of friction.

18. The method of embodiment 16, comprising determining, by the processor, the tissue coefficient of friction based on the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the end effector, and N is force applied to the tissue by the end effector.

19. The method of embodiment 18, further comprising:

storing, by the processor, two data points of the measured force and power delivered to the ultrasonic transducer in a buffer;
determining, by the processor, a slope value of the power versus force based on the two data points;
determining, by the processor, a statistical measure R^2 of the slope value relative to a fitted regression line;
determining, by the processor, the tissue coefficient of friction based on the slope value;
comparing, by the processor, R^2 to a threshold value;
selecting, by the processor, a slope value associated with an R^2 value that is greater than or equal to the threshold value; and
determining, by the processor, the tissue coefficient of friction based on the slope value.

20. The method of embodiment 16, further comprising:

comparing, by the processor, the tissue coefficient of friction to tissue coefficients of friction stored in a tissue information database;
determining, by the processor, the tissue type based on the tissue coefficient of friction;
determining, by the processor, power delivered to the ultrasonic transducer based the tissue type; and
delivering, by the drive circuit, the drive signal to the ultrasonic transducer based on the tissue type.

21. A surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising:

a processor;
an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising:

a clamp arm comprising an electrode;
an ultrasonic blade;
a force sensor in communication with the processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade; and
a temperature sensor in communication with the processor;

an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive a drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver energy to the ultrasonic blade;
wherein the processor is configured to:

determine a hydration level of the tissue based on a tissue coefficient of friction, wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector; and
dynamically control the drive signal delivered to the ultrasonic transducer based on the hydration level of the tissue interacting with the end effector.

22. The surgical instrument of embodiment 21, wherein the processor is configured to control power of the drive

signal delivered to the ultrasonic transducer based on the hydration level of the tissue.

23. The surgical instrument of embodiment 22, wherein the power of the drive signal delivered to the ultrasonic transducer is decreased as the hydration level of the tissue decreases.

24. The surgical instrument of embodiment 21, wherein the tissue coefficient of friction is determined in accordance with the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the end effector, and N is force applied to the tissue by the end effector.

25. The surgical instrument of embodiment 21, wherein the force sensor comprises a strain gauge coupled to the end effector, and wherein the force measurement is transmitted from the strain gauge to the processor.

26. The surgical instrument of embodiment 21, wherein the processor is configured to:

store two data points of the measured force and power delivered to the end effector in a buffer;
determine a slope value of the power versus force based on the two data points;
determine a statistical measure R^2 of the slope value relative to a fitted regression line; and
determine the tissue coefficient of friction based on the slope value.

27. The surgical instrument embodiment 26, wherein the processor is configured to:

compare R^2 to a threshold value; and
select a slope value associated with an R^2 value that is greater than or equal to the threshold value to determine the tissue coefficient of friction.

28. The surgical instrument of embodiment 21, wherein the processor is configured to:

compare the tissue coefficient of friction to tissue coefficients of friction stored in a tissue information database;
determine a type of tissue based on the tissue coefficient of friction; and
deliver the drive signal to the ultrasonic transducer based on the tissue coefficient of friction.

29. The surgical instrument of embodiment 21, further comprising a generator configured to deliver radio frequency (RF) energy to the electrode and the drive signal to the ultrasonic transducer.

30. A generator for delivering energy to a surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising an end effector at a distal end thereof, the end effector configured to interact with tissue, the end effector comprising a clamp arm comprising an electrode, an ultrasonic blade, a force sensor in communication with a processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade, and a temperature sensor in communication with the processor, an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive a drive signal from the generator to cause ultrasonic motion of the ultrasonic blade and deliver energy to the ultrasonic blade, the generator comprising:

a first drive circuit configured to deliver a drive signal to an ultrasonic transducer; and
a processor configured to control energy delivered by the drive circuit to the ultrasonic transducer based on a type of tissue interacting with the end effector;
wherein the processor is configured to:

receive a measurement of force applied to tissue by the end effector, ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector;
determine a hydration level of the tissue, wherein the hydration level of the tissue is determined based on a tissue coefficient of friction and wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade, and a rate of heat

generated by the end effector; and
dynamically control the drive signal delivered to the ultrasonic transducer based on the type of tissue interacting with the end effector.

31. The generator of embodiment 30, wherein the processor is configured to control power of the drive signal delivered to the ultrasonic transducer based on the hydration level of the tissue.

32. The generator of embodiment 31, wherein the processor is configured to decrease the power of the drive signal delivered to the ultrasonic transducer as the hydration level of the tissue decreases.

33. The generator of embodiment 30, wherein the tissue coefficient of friction is determined based on the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the ultrasonic blade, and N is force applied to the tissue by the end effector.

34. The generator of embodiment 30, wherein the processor is configured to:

store two data points of the measured force and power delivered to the ultrasonic transducer in a buffer;
determine a slope value of the power versus force based on the two data points;
determine a statistical measure R^2 of the slope value relative to a fitted regression line; and
determine the tissue coefficient of friction based on the slope value.

35. The generator of embodiment 34, wherein the processor is configured to:

compare R^2 to a threshold value; and
select a slope value associated with an R^2 value that is greater than or equal to the threshold value to determine the tissue coefficient of friction.

36. The generator of embodiment 30, wherein the processor is configured to:

compare the tissue coefficient of friction to tissue coefficients of friction stored in a tissue information database;
determine the tissue type based on the tissue coefficient of friction; and
deliver the drive signal to the end effector based on the tissue coefficient of friction.

37. The generator of embodiment 30, further comprising a second drive circuit configured to deliver radio frequency (RF) energy to the electrode.

38. A method of coagulating and dissecting tissue, the method comprising:

measuring, by a force sensor, a force being applied to a tissue by an end effector disposed on a distal end of a surgical instrument configured to interact with the tissue, the end effector comprising a clamp arm, an ultrasonic blade acoustically coupled to an ultrasonic transducer, a force sensor in communication with a processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade, and a temperature sensor;
determining, by the processor, a tissue coefficient of friction based on the measured force applied to the tissue by the end effector, ultrasonic motion of the end effector caused by energy delivered thereto from a generator, and a rate of heat generated by the end effector;
determining, by the processor, a hydration level of the tissue interacting with the end effector based on the tissue coefficient of friction; and
delivering, by a drive circuit, a drive signal to the ultrasonic transducer to cause the end effector to interact with the tissue based on a determined hydration level of the tissue.

39. The method of embodiment 38, wherein measuring the force comprises:

measuring, by the processor, at least two data points of the force and the power delivered to the end effector;
storing, by the processor, the data points in a buffer;
determining, by the processor, a slope value of the force versus the power;
determining, by the processor, the tissue coefficient of friction;
storing, by the processor, two data points of the measured force and power delivered to the ultrasonic transducer in a buffer;
determining, by the processor, a slope value of the power versus force based on the two data points;
determining, by the processor, a statistical measure R^2 of the slope value relative to a fitted regression line;
determining, by the processor, the tissue coefficient of friction based on the slope value;
comparing, by the processor, R^2 to a threshold value;
selecting a slope value associated with an R^2 value that is greater than or equal to the threshold value; and
determining, by the processor, the tissue the tissue coefficient of friction based on the slope value.

40. The method of embodiment 38, comprising determining, by the processor, the tissue coefficient of friction based on the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the end effector, and N is force applied to the tissue by the end effector.

41. A surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising:

a processor;
an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising:

a clamp arm comprising an electrode;
an ultrasonic blade;
a force sensor in communication with the processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade; and
a temperature sensor in communication with the processor;

an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive an ultrasonic drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver energy to the ultrasonic blade;
wherein the processor is configured to:

determine a type of tissue interacting with the end effector based on a tissue coefficient of friction, wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade in response to an ultrasonic drive signal, and a rate of heat generated by the end effector;
dynamically control delivery of radio frequency (RF) energy to the electrode and the drive signal to the ultrasonic transducer based on the type of tissue interacting with the end effector; and
switch between delivery of the RF energy and the ultrasonic drive signal based on the type of tissue interacting with the end effector.

42. The surgical instrument of embodiment 41, wherein the tissue coefficient of friction is determined in accordance with the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the end effector, and N is force applied to the tissue by the end effector.

43. The surgical instrument of embodiment 41, wherein the force sensor comprises a strain gauge coupled to the end effector, and wherein the force measurement is transmitted from the strain gauge to the processor.

44. The surgical instrument of embodiment 41, wherein the processor is configured to:

store two data points of the measured force and power delivered to the end effector in a buffer;
determine a slope value of the power versus force based on the two data points;
determine a statistical measure R^2 of the slope value relative to a fitted regression line; and
determine the tissue coefficient of friction based on the slope value.

45. The surgical instrument embodiment 44, wherein the processor is configured to:

compare R^2 to a threshold value; and
select a slope value associated with an R^2 value that is greater than or equal to the threshold value to determine the tissue coefficient of friction.

46. The surgical instrument of embodiment 41, wherein the processor is configured to:

compare the tissue coefficient of friction to tissue coefficients of friction stored in a tissue information database;
determine the tissue type based on the tissue coefficient of friction; and
deliver the drive signal to the ultrasonic transducer based on the tissue coefficient of friction.

47. The surgical instrument of embodiment 41, further comprising a generator configured to deliver radio frequency (RF) energy to the electrode and the drive signal to the ultrasonic transducer.

48. The surgical instrument of embodiment 41, wherein the processor is configured to control delivery of the ultrasonic drive signal to the ultrasonic transducer if the tissue type is one having a muscular structure.

49. The surgical instrument of embodiment 41, wherein the processor is configured to control delivery of the RF energy to the electrode if the tissue type is one having a vascular structure.

50. The surgical instrument of embodiment 41, wherein the processor is configured to control delivery of a drive signal to the ultrasonic transducer corresponding to a rapid cutting motion if the tissue type is one having a thin mesentery structure.

51. A generator for delivering energy to a surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising an end effector at a distal end thereof, the end effector configured to interact with tissue, the end effector comprising a clamp arm comprising an electrode, an ultrasonic blade, a force sensor in communication with a processor and configured to measure a force applied to tissue located between the clamp arm and the ultrasonic blade, and a temperature sensor in communication with the processor, an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive a drive signal from the generator to cause ultrasonic motion of the ultrasonic blade and deliver energy to the ultrasonic blade, the generator comprising:

a first drive circuit configured to deliver a drive signal to an ultrasonic transducer;
a second drive circuit configured to deliver radio frequency (RF) energy to the electrode; and
a processor configured to control energy delivered by the first drive circuit to the ultrasonic transducer and the second drive circuit to the electrode based on a type of tissue interacting with the end effector;
wherein the processor is configured to:

receive a measurement of force applied to tissue by the end effector, ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector;
determine a type of tissue interacting with the end effector based on a tissue coefficient of friction, wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector;
dynamically control delivery of RF energy to the electrode and the drive signal to the ultrasonic transducer based on the type of tissue interacting with the end effector; and
switch between delivery of the RF energy and the ultrasonic drive signal based on the type of tissue interacting with the end effector.

52. The generator of embodiment 51, wherein the processor is configured to control delivery of the ultrasonic drive signal to the ultrasonic transducer if the tissue type is one having a muscular structure.

53. The generator of embodiment 51, wherein the processor is configured to control delivery of the RF energy to the electrode if the tissue type is one having a vascular structure.

54. The generator of embodiment 51, wherein the processor is configured to control delivery of a drive signal to the ultrasonic transducer corresponding to a rapid cutting motion if the tissue type is one having a thin mesentery structure.

55. A method of dissecting and coagulating tissue, the method comprising:

delivering, by a first drive circuit, a drive signal to an ultrasonic transducer;
delivering, by a second drive circuit, radio frequency (RF) energy to an electrode;
controlling, by a processor, energy delivered by the first drive circuit to the ultrasonic transducer and the second drive circuit to the electrode based on a type of tissue interacting with an end effector;
wherein controlling by the processor further comprises:

receiving a measurement of force applied to tissue by the end effector, ultrasonic motion of an ultrasonic blade, and a rate of heat generated by the end effector;
determining a type of tissue interacting with the end effector based on a tissue coefficient of friction, wherein the tissue coefficient of friction is determined based on the force applied to the tissue by the end effector, the ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector;
dynamically controlling delivery of RF energy to the electrode and the drive signal to the ultrasonic transducer based on the type of tissue interacting with the end effector; and
switching between delivery of the RF energy and the ultrasonic drive signal based on the type of tissue interacting with the end effector.

56. The method of embodiment 55, further comprising controlling, by the processor, delivery of RF energy to the electrode and the drive signal to the ultrasonic transducer.

57. The method of embodiment 55, further comprising controlling, by the processor, delivery of the ultrasonic drive signal to the ultrasonic transducer if the tissue type is one having a muscular structure.

58. The method of embodiment 55, further comprising controlling, by the processor, delivery of the RF energy to the electrode if the tissue type is one having a vascular structure.

59. The method of embodiment 55, further comprising controlling, by the processor, delivery of a drive signal to the ultrasonic transducer corresponding to a rapid cutting motion if the tissue type is one having a thin mesentery structure.

60. The method of embodiment 55, comprising determining, by the processor, the tissue coefficient of friction based on the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the end effector, and N is force applied to the tissue by the end effector.

61. A surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising:

a processor;
an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising:

a clamp arm comprising an electrode;
an ultrasonic blade;

an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive an ultrasonic drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver ultrasonic energy to the ultrasonic blade;
wherein the processor is configured to:

determine a tissue impedance of a tissue interacting with the end effector;
dynamically control delivery of radio frequency (RF) energy to the electrode and the drive signal to the ultrasonic transducer based on the tissue impedance interacting with the end effector; and
switch between delivery of the RF energy and the ultrasonic drive signal based on the tissue impedance of the tissue interacting with the end effector.

62. The surgical instrument of embodiment 61, wherein the processor is configured to switch between delivery of RF energy and ultrasonic energy when the tissue impedance reaches a threshold level.

63. The surgical instrument of embodiment 61, wherein the impedance of the tissue is defined by dividing RF voltage applied to the tissue by RF current through the tissue.

64. The surgical instrument of embodiment 61, wherein a threshold level of the impedance of the tissue is a termination impedance at which a seal is complete during coagulation of the tissue using RF energy.

65. The surgical instrument of embodiment 64, wherein the processor is configured to switch from RF energy to ultrasonic energy upon the tissue impedance exceeding the termination impedance, wherein the ultrasonic energy is employed to cut the tissue following completion of sealing the tissue employing RF energy.

66. The surgical instrument of embodiment 61, wherein the processor is configured to utilize the RF energy to coagulate vessels in the tissue and the ultrasonic energy is utilized to cut through the tissue.

67. The surgical instrument of embodiment 61, wherein the processor is configured to utilize a process for controlling power delivered to the end effector, the process utilizing the tissue impedance as an input to determine a type of energy to utilize to interact with the tissue by the end effector.

68. The surgical instrument of embodiment 61, wherein the processor is configured to compare the tissue impedance to a threshold impedance value stored in a tissue information database.

69. A method of coagulating and dissecting tissue, the method comprising:

determining, by a processor, a tissue impedance of a tissue interacting with an end effector of a surgical instrument;
comparing, by the processor, the determined tissue impedance with a threshold termination impedance;
delivering, by an RF drive circuit, radio frequency (RF) energy to the end effector when the determined tissue impedance is less than the threshold termination impedance to interact with the tissue based on the determined tissue impedance; and
delivering, by an ultrasonic drive circuit, ultrasonic energy to the end effector when the determined tissue impedance is greater than or equal to the threshold termination impedance

70. The method of embodiment 69, wherein the RF energy and ultrasonic energy are delivered to the end effector through a single output port of a generator electrically coupled to the surgical instrument.

71. The method of embodiment 69, wherein tissue impedance is defined by dividing RF voltage applied to the tissue by RF current through the tissue.

72. The method of embodiment 69, further comprising:

controlling, by the processor, power delivered from a generator to the end effector, the process including the tissue impedance as an input;
determining, by the processor, a type of energy delivered to interact with the tissue by the end effector based on the tissue impedance; and
determining, by the processor, properties of the type of energy delivered to the end effector corresponding to

a type of interaction between the end effector and the tissue.

73. The method of embodiment 69, wherein the threshold termination impedance of the tissue is a termination impedance at which a seal is complete during coagulation of the tissue using RF energy delivered from a generator to the end effector.

74. A method of coagulating and dissecting tissue, the method comprising:

delivering, by an RF drive circuit, RF energy to an end effector of a surgical instrument interacting with a tissue to create a seal;
determining, by a processor, a tissue impedance of the tissue interacting with the end effector during tissue coagulation;
comparing, by the processor, the determined tissue impedance with a threshold termination impedance; and
delivering, by an ultrasonic drive circuit, ultrasonic energy to the end effector when the determined tissue impedance is greater than or equal to the threshold termination impedance, wherein the end effector uses the ultrasonic energy to cut through the tissue.

75. The method of embodiment 74, further comprising, calculating, by the processor, tissue impedance defined by dividing RF voltage applied to the tissue by the RF current through the tissue.

76. The method of embodiment 74, further comprising:

controlling, by the processor, power delivered from a generator to the end effector based on the tissue impedance as an input; and
determining, by the processor, a type of energy being delivered to interact with the tissue by the end effector, wherein properties of the type of energy delivered corresponds to a type of interaction between the end effector and the tissue.

77. The method of embodiment 74, wherein the threshold termination impedance is the tissue impedance at which a seal is complete during coagulation of the tissue using RF energy delivered from a generator to the end effector.

78. A surgical instrument for coagulating and dissecting tissue, comprising:

a processor;
an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising:

a clamp arm comprising an electrode;
an ultrasonic blade; and
an aperture sensor;

an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive an ultrasonic drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver ultrasonic energy to the ultrasonic blade;
wherein the processor is configured to:

determine a tissue impedance of a tissue interacting with the end effector;
dynamically control delivery of radio frequency (RF) energy to the electrode and the drive signal to the ultrasonic transducer based on the tissue impedance interacting with the end effector; and
switch between delivery of the RF energy and the ultrasonic drive signal based on the aperture defined by the end effector to dynamically switch between RF energy for tissue sealing and ultrasonic energy for tissue cutting.

79. The surgical instrument of embodiment 78, wherein the aperture sensor is configured to measure the aperture defined by the end effector by detecting a pivot angle of the clamp arm or by detecting a measurement of a stroke of a closure mechanism of the clamp arm.

80. The surgical instrument of embodiment 79, wherein the aperture sensor comprises an optical encoder to detect

the pivot angle of the clamp arm.

81. The surgical instrument of embodiment 79, wherein the aperture sensor comprises an inductance sensor to detect the pivot angle of the clamp arm.

82. The surgical instrument of embodiment 79, wherein the aperture sensor comprises a potentiometer to detect the pivot angle of the clamp arm.

83. The surgical instrument of embodiment 79, wherein the aperture sensor comprises a Hall effect sensor to detect the pivot angle of the clamp arm.

84. The surgical instrument of embodiment 79, wherein the aperture sensor is configured to detect the aperture of the clamp arm based on the proximity of first and second components of the end effector.

85. The surgical instrument of embodiment 84, wherein the aperture sensor comprises a Hall effect sensor to detect proximity of the first and second components of the end effector.

86. The surgical instrument of embodiment 84, wherein the aperture sensor comprises an optical encoder to detect proximity of the first and second components of the end effector.

87. The surgical instrument of embodiment 84, wherein the aperture sensor comprises an inductance sensor to detect the proximity of the first and second components of the end effector.

88. The surgical instrument of embodiment 78, wherein the processor is configured to detect the aperture of the clamp arm based on a change in tissue impedance of the tissue interacting with the end effector.

89. The surgical instrument of embodiment 78, wherein the processor is configured to detect the aperture of the clamp arm based on a load of the end effector on the tissue as ultrasonic energy is pulsed to the end effector.

90. The surgical instrument of embodiment 78, wherein the processor utilizes a process to control power delivered to the end effector, wherein the process utilizes the aperture of the clamp arm as an input to determine power level and energy type to utilize to interact with the tissue by the end effector.

91. A method of coagulating and dissecting tissue, the method comprising:

determining, by an aperture sensor, an aperture of a clamp arm of an end effector of a surgical instrument configured to interact with a tissue; and
delivering, by a drive circuit, either RF energy or ultrasonic energy to the end effector to interact with the tissue based on the determined aperture of the clamp arm.

92. The method of embodiment 91, wherein determining, by the aperture sensor, the aperture of the clamp arm comprises detecting, by the aperture sensor, a pivot angle of the clamp arm.

93. The method of embodiment 91, wherein determining, by the aperture sensor, the aperture of the clamp arm comprises detecting, by the aperture sensor, a proximity of first and second components of the end effector.

94. The method of embodiment 91, wherein determining, by the aperture sensor, the aperture of the clamp arm comprises measuring, by the processor sensor, a change in tissue impedance of the tissue interacting with the end effector.

95. The method of embodiment 91, wherein determining, by the aperture sensor, the aperture of the clamp arm comprises measuring, by the processor, a load of the end effector on the tissue as ultrasonic energy is pulsed to the end effector.

96. A method of dissecting tissue, the method comprising:

measuring a force applied to tissue disposed in an end effector configured to interact with the tissue, wherein the end effector comprises:

an ultrasonic blade;
a clamp arm configured to clamp tissue between the clamp arm and the ultrasonic blade;
an electrode;
a temperature sensor;
an aperture sensor; and
a force sensor configured to measure the force applied to the tissue disposed between the clamp arm and the ultrasonic blade;

measuring, by a processor, a thickness of the tissue;
determining, by the processor, a tissue coefficient of friction based on the measured force applied to the tissue by the end effector, ultrasonic motion of the ultrasonic blade, and a rate of heat generated by the end effector;
delivering, by an ultrasonic drive circuit, a first quantity of energy to the ultrasonic blade to interact with the tissue based on the measured force applied to the tissue, the measured thickness of the tissue, and the determined tissue coefficient of friction;
comparing, by the processor, a rate of change of the tissue coefficient of friction to a predetermined value of the tissue coefficient of friction;
adjusting, by the processor, the quantity of energy delivered o the ultrasonic blade based on the rate of change of the tissue coefficient;
determining, by the processor, whether the tissue coefficient of friction matches a predetermined threshold value of the tissue coefficient of friction;
upon determining, by the processor, that the tissue coefficient of friction matches a predetermined threshold value of the tissue coefficient of friction, determining, by the processor, whether the clamp arm and the ultrasonic blade are in a closed position; and
upon determining, by the processor, that the clamp arm and the ultrasonic blade are in the closed position, delivering, by the ultrasonic drive circuit, a second quantity of energy to the ultrasonic blade to interact with the tissue.

97. The method of embodiment 96, further comprising determining, by the processor, the tissue coefficient of friction according to the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the end effector, and N is force applied to the tissue by the end effector.

98. The method of embodiment 96, further comprising receiving, by the processor, an input associated with a predetermined tissue type.

99. The method of embodiment 96, wherein measuring a thickness of the tissue comprises measuring, by the aperture sensor, a distance between the clamp arm and the ultrasonic blade.

100. The method of embodiment 96, further comprising upon determining, by the aperture sensor, that the clamp arm and the ultrasonic blade are in the closed position, delivering, by a radio frequency (RF) drive circuit, RF energy to the electrode of the end effector to coagulate tissue locate din the end effector.

101. The method of embodiment 96, wherein measuring the force comprises:

measuring, by the processor, two data points of the force and the energy delivered to the end effector; and
storing, by the processor, the two data points in a buffer to calculate a slope value of the force versus power to calculate the tissue coefficient of friction.

102. The method of embodiment 96, wherein the first quantity of energy and the second quantity of energy are different.

103. The method of embodiment 96, wherein delivering the first quantity of energy to the end effector comprises delivering ultrasonic energy by an ultrasonic drive circuit, RF energy by an RF drive circuit, or a combination thereof

to the tissue.

104. The method of embodiment 96, wherein delivering the second quantity of energy to the end effector comprises delivering ultrasonic energy by an ultrasonic drive circuit, RF energy by an RF drive circuit, or a combination thereof to the tissue.

105. A method of dissecting tissue comprising:

measuring, by a force sensor, a force being applied to a tissue by an end effector disposed on a distal end of a surgical instrument configured to interact with the tissue, wherein the end effector comprises a clamp arm and an ultrasonic blade;
measuring, by an aperture sensor, a thickness of the tissue;
determining, by a processor, a tissue coefficient of friction at a predetermined time interval, wherein the tissue coefficient of friction is based on a measured force applied to the tissue by the end effector, ultrasonic motion of the end effector caused by energy delivered thereto from a generator, and a rate of heat generated by the end effector;
adjusting, by the processor, a quantity of energy delivered to the end effector to interact with the tissue, wherein the quantity of energy applied is adjusted based on the determined tissue coefficient of friction.

106. The method of embodiment 105, further comprising determining, by the processor, the tissue coefficient of friction according to the following expression:

$$\mu = \frac{\dot{Q}}{v \cdot N}$$

wherein Q is rate of heat generation, v is velocity of the ultrasonic motion of the end effector, and N is force applied to the tissue by the end effector.

107. The method of embodiment 105, further comprising receiving, by the processor, an input associated with a predetermined tissue type.

108. The method of embodiment 105, wherein measuring, by the aperture sensor, a thickness of the tissue comprises measuring a distance between the clamp arm and the ultrasonic blade.

109. The method of embodiment 105, further comprising delivering, by an RF drive circuit, RF energy to an electrode positioned on the electrode to seal the tissue.

110. The method of embodiment 105, further comprising delivering, by a drive circuit, energy to the end effector through a single output port of a generator that is electrically coupled to the surgical instrument.

111. The method of embodiment 105, wherein measuring the force, by the force sensor, comprises:

measuring, by the force sensor, two data points of the force and the energy delivered to the end effector; and storing the data points in a buffer to calculate a slope value of the force versus the power to calculate the tissue coefficient of friction.

112. The method of embodiment 105, wherein the quantity of energy delivered is adjusted based on the force, measured by the force sensor, applied to the tissue and the thickness, measured by the aperture sensor, of the tissue.

113. The method of embodiment 105, wherein the quantity of energy delivered to the end effector is a first quantity of energy, the method further comprising:

determining, by the processor, whether the tissue coefficient of friction matches a predetermined threshold value of the tissue coefficient of friction;
upon determining, by the processor, that the tissue coefficient of friction matches a predetermined threshold value of the tissue coefficient of friction, determining, by the processor, whether the clamp arm and the ultrasonic blade are in a closed position;

upon determining, by the processor, that the clamp arm and the ultrasonic blade are in the closed position, delivering, by a drive circuit, a second quantity of energy to the end effector to interact with the tissue.

114. The method of embodiment 105, wherein delivering, by a drive circuit, the quantity of energy to the end effector comprises, delivering, by an RF drive circuit, RF energy and delivering, by an ultrasonic drive circuit, ultrasonic energy, or a combination thereof, to the tissue.

Claims

1. A surgical instrument for coagulating and dissecting tissue, comprising:

a processor;
an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising:

a clamp arm comprising an electrode;
an ultrasonic blade; and
an aperture sensor;

an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive an ultrasonic drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver ultrasonic energy to the ultrasonic blade;
wherein the processor is configured to:

determine a tissue impedance of a tissue interacting with the end effector;
dynamically control delivery of radio frequency (RF) energy to the electrode and the drive signal to the ultrasonic transducer based on the tissue impedance interacting with the end effector; and
switch between delivery of the RF energy and the ultrasonic drive signal based on the aperture defined by the end effector to dynamically switch between RF energy for tissue sealing and ultrasonic energy for tissue cutting.

2. The surgical instrument of claim 1, wherein the aperture sensor is configured to measure the aperture defined by the end effector by detecting a pivot angle of the clamp arm or by detecting a measurement of a stroke of a closure mechanism of the clamp arm.

3. The surgical instrument of claim 2, wherein the aperture sensor comprises either:

an optical encoder to detect the pivot angle of the clamp arm; or
an inductance sensor to detect the pivot angle of the clamp arm; or
a potentiometer to detect the pivot angle of the clamp arm; or
a Hall effect sensor to detect the pivot angle of the clamp arm.

4. The surgical instrument of claim 2, wherein the aperture sensor is configured to detect the aperture of the clamp arm based on the proximity of first and second components of the end effector.

5. The surgical instrument of claim 4, wherein the aperture sensor comprises either:

a Hall effect sensor to detect proximity of the first and second components of the end effector; or
an optical encoder to detect proximity of the first and second components of the end effector; or
an inductance sensor to detect the proximity of the first and second components of the end effector.

6. The surgical instrument of claim 1, wherein the processor is configured to detect the aperture of the clamp arm based on a change in tissue impedance of the tissue interacting with the end effector.

7. The surgical instrument of claim 1, wherein the processor is configured to detect the aperture of the clamp arm based on a load of the end effector on the tissue as ultrasonic energy is pulsed to the end effector.

8. The surgical instrument of claim 1, wherein the processor utilizes a process to control power delivered to the end effector, wherein the process utilizes the aperture of the clamp arm as an input to determine power level and energy type to utilize to interact with the tissue by the end effector.

9. A surgical instrument for coagulating and dissecting tissue, the surgical instrument comprising:

a processor;
an end effector at a distal end of the surgical instrument, the end effector configured to interact with tissue, the end effector comprising:

a clamp arm comprising an electrode;
an ultrasonic blade;

an ultrasonic transducer acoustically coupled to the ultrasonic blade and configured to receive an ultrasonic drive signal from a generator to cause ultrasonic motion of the ultrasonic blade and deliver ultrasonic energy to the ultrasonic blade;
wherein the processor is configured to:

determine a tissue impedance of a tissue interacting with the end effector;
dynamically control delivery of radio frequency (RF) energy to the electrode and the drive signal to the ultrasonic transducer based on the tissue impedance interacting with the end effector; and
switch between delivery of the RF energy and the ultrasonic drive signal based on the tissue impedance of the tissue interacting with the end effector.

10. The surgical instrument of claim 9, wherein the processor is configured to switch between delivery of RF energy and ultrasonic energy when the tissue impedance reaches a threshold level.

11. The surgical instrument of claim 9, wherein the impedance of the tissue is defined by dividing RF voltage applied to the tissue by RF current through the tissue.

12. The surgical instrument of claim 9, wherein a threshold level of the impedance of the tissue is a termination impedance at which a seal is complete during coagulation of the tissue using RF energy, optionally wherein the processor is configured to switch from RF energy to ultrasonic energy upon the tissue impedance exceeding the termination impedance, wherein the ultrasonic energy is employed to cut the tissue following completion of sealing the tissue employing RF energy.

13. The surgical instrument of claim 9, wherein the processor is configured to utilize the RF energy to coagulate vessels in the tissue and the ultrasonic energy is utilized to cut through the tissue.

14. The surgical instrument of claim 9, wherein the processor is configured to utilize a process for controlling power delivered to the end effector, the process utilizing the tissue impedance as an input to determine a type of energy to utilize to interact with the tissue by the end effector.

15. The surgical instrument of claim 9, wherein the processor is configured to compare the tissue impedance to a threshold impedance value stored in a tissue information database.

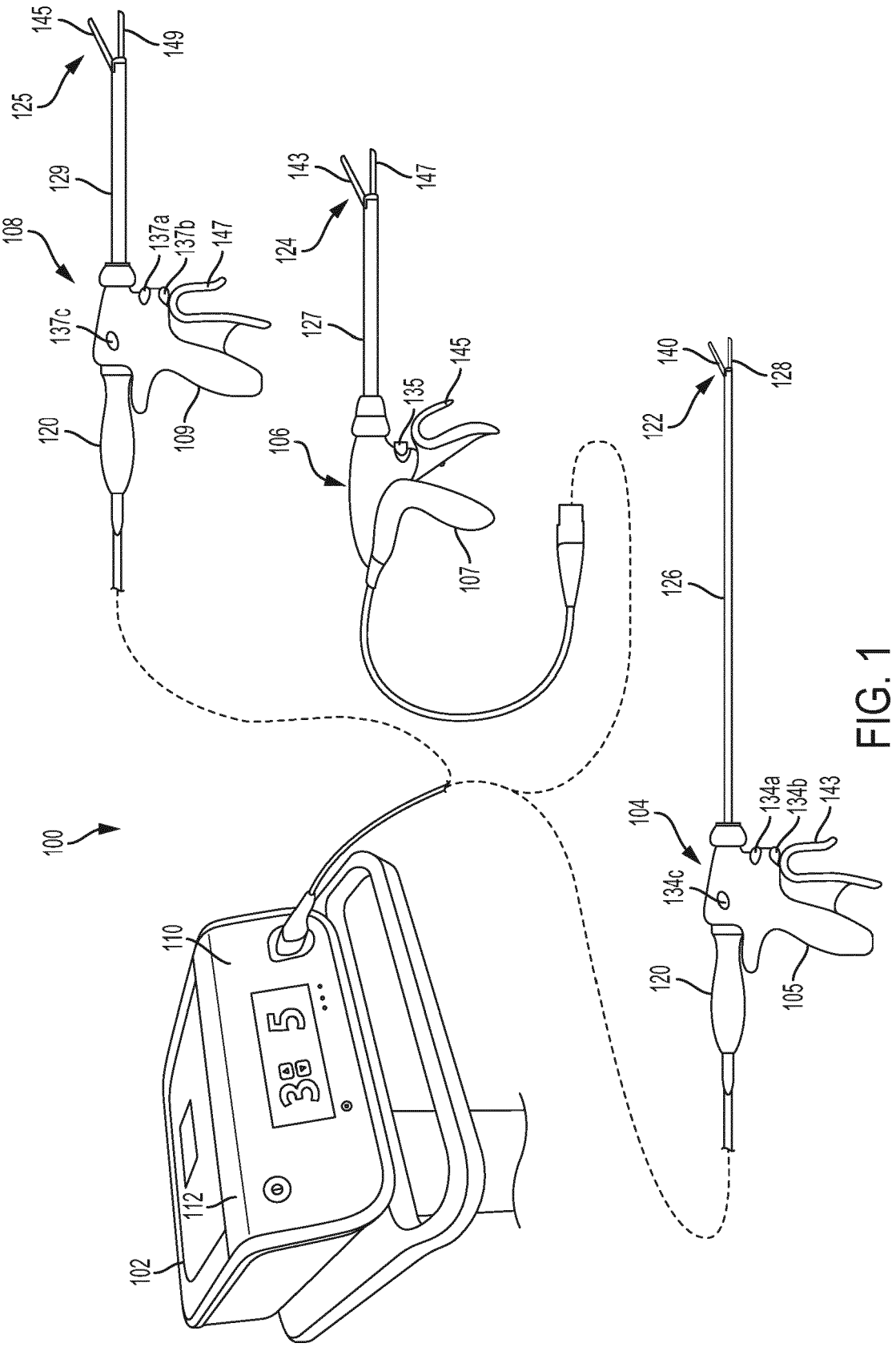
100
102
104
105
106
107
108
109
110
112
120
122
124
125
126
127
128
129
134a
134b
134c
135
137a
137b
137c
140
143
145
147
149

FIG. 1

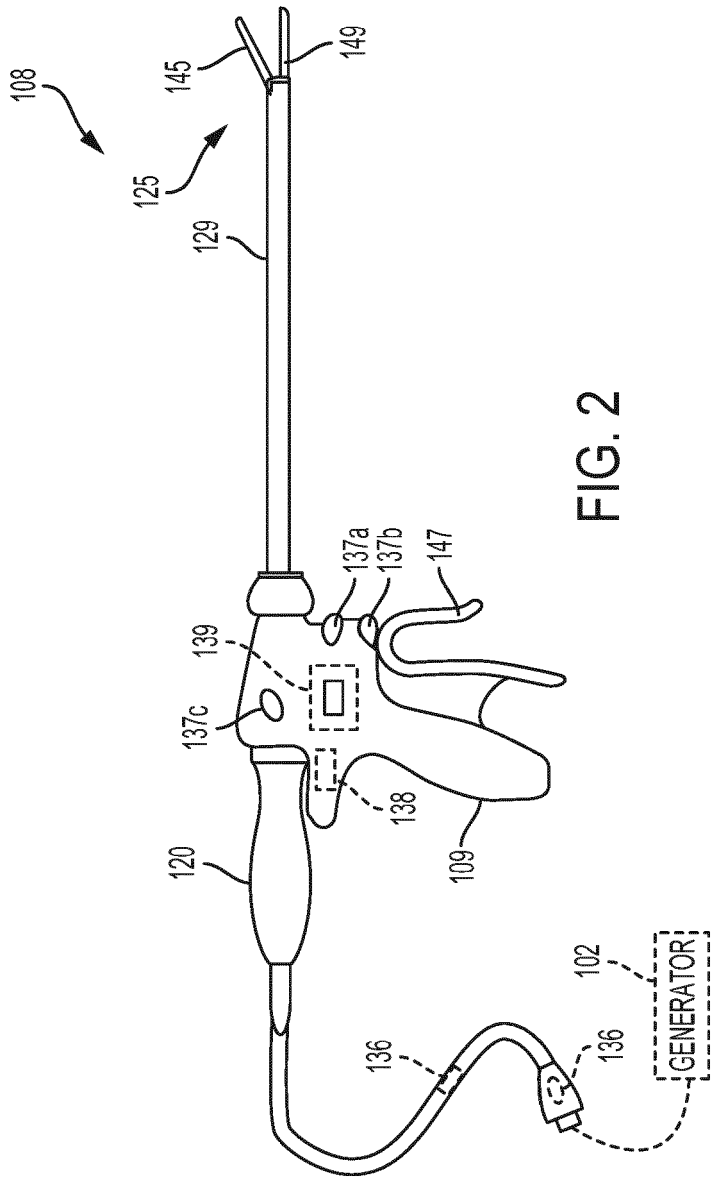
108
145
149
125
129
137a
137b
147
139
137c
138
109
120
102
GENERATOR
136
136

FIG. 2

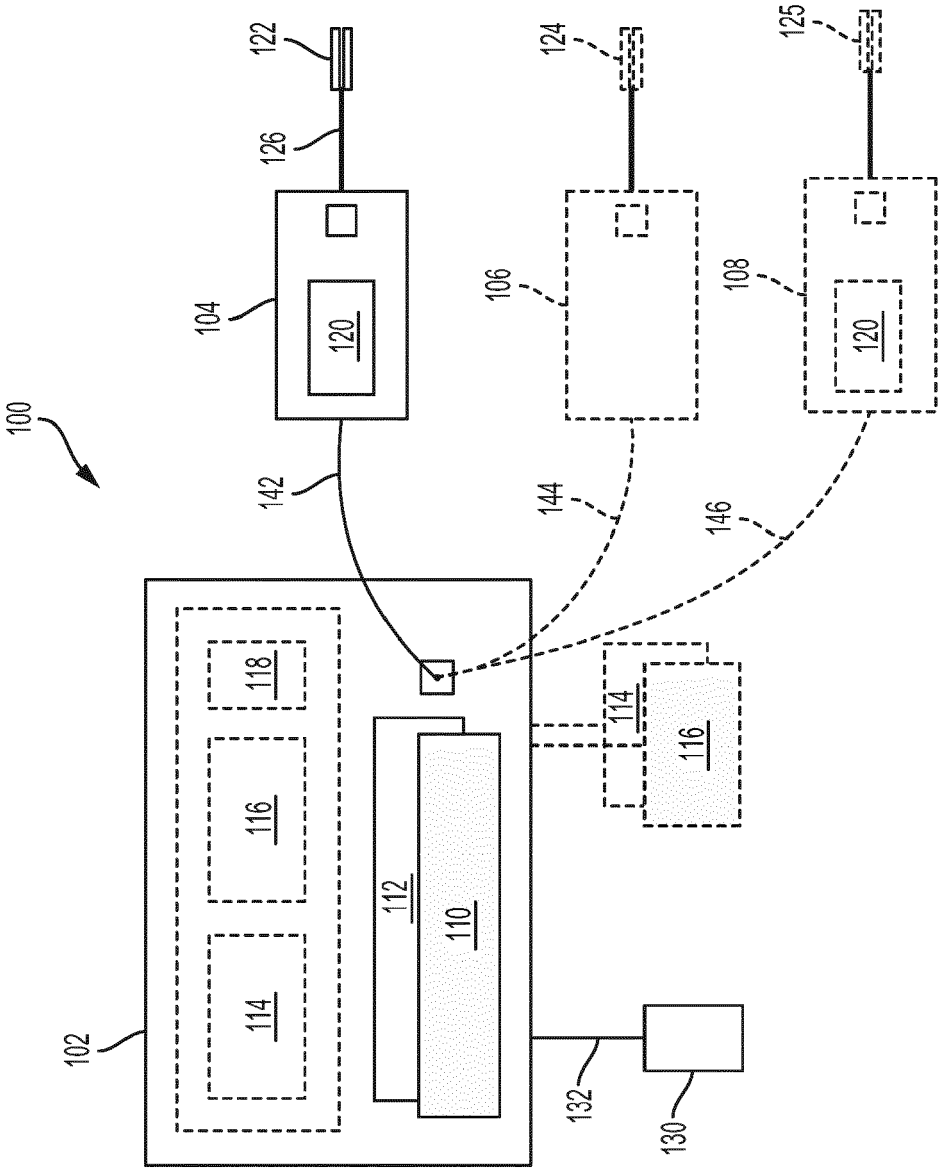
100
102
104
106
108
110
112
114
116
118
120
122
124
125
126
130
132
142
144
146

FIG. 3

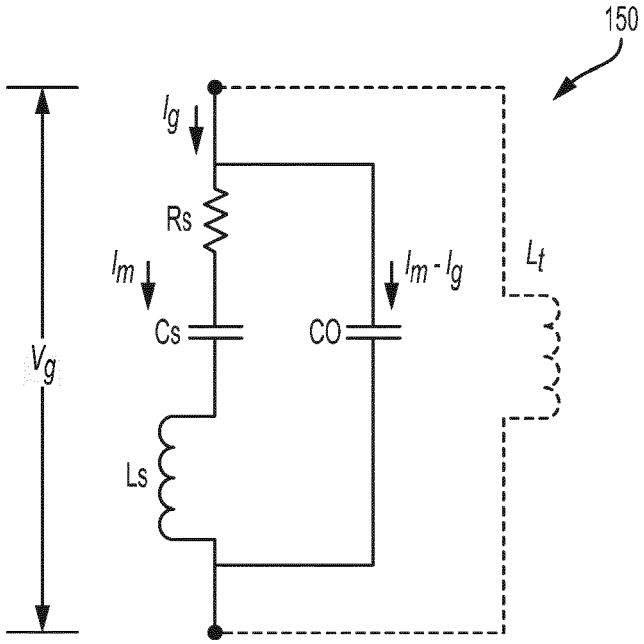

FIG. 4

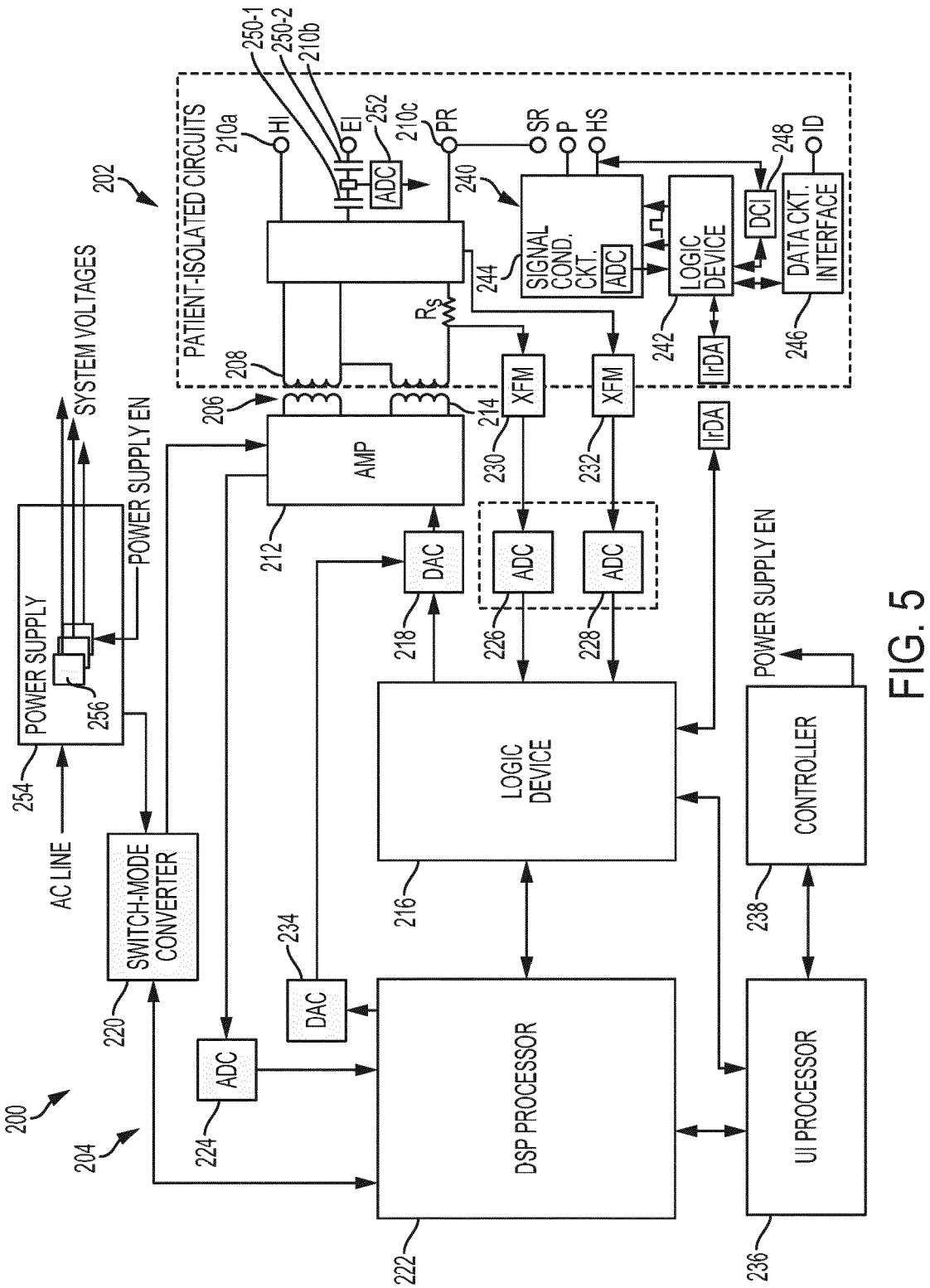
200
202
204
PATIENT-ISOLATED CIRCUITS
210a
HI
250-1
250-2
210b
EI
252
ADC
210c
PR
SR
P
HS
240
SIGNAL COND. CKT.
ADC
LOGIC DEVICE
DCI
248
ID
DATA CKT. INTERFACE
242
246
IrDA
244
R_S
208
206
214
XFM
XFM
AMP
212
230
232
IrDA
SYSTEM VOLTAGES
POWER SUPPLY EN
POWER SUPPLY
256
254
AC LINE
SWITCH-MODE CONVERTER
220
DAC
218
ADC
226
ADC
228
POWER SUPPLY EN
LOGIC DEVICE
216
CONTROLLER
238
234
DAC
ADC
224
DSP PROCESSOR
222
UI PROCESSOR
236

FIG. 5

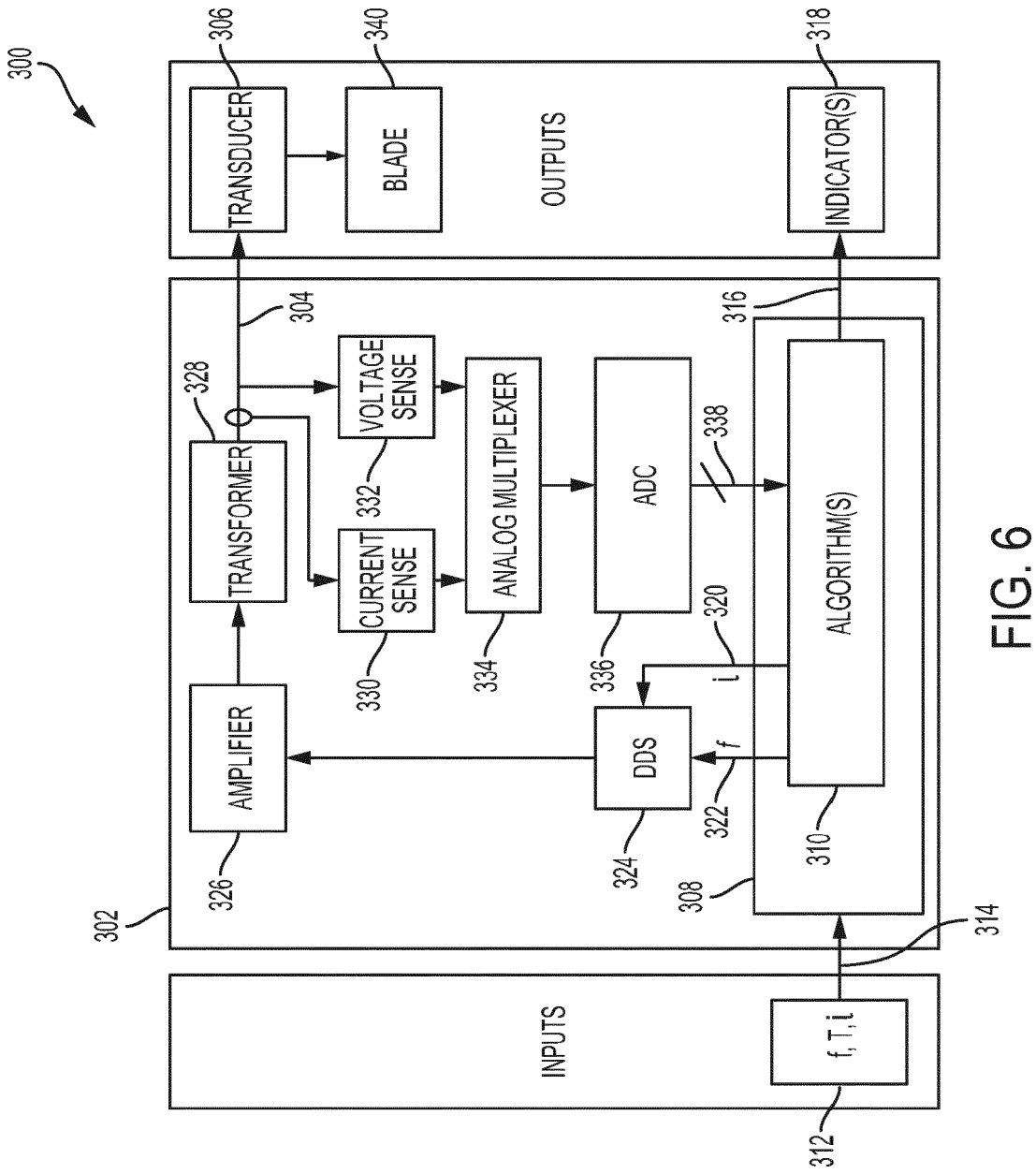
300
306
340
318
TRANSDUCER
BLADE
OUTPUTS
INDICATOR(S)
304
316
328
VOLTAGE SENSE
TRANSFORMER
332
CURRENT SENSE
330
ANALOG MULTIPLEXER
334
ADC
336
338
320
i
ALGORITHM(S)
AMPLIFIER
326
DDS
324
f
322
310
308
302
314
INPUTS
f, T, i
312

FIG. 6

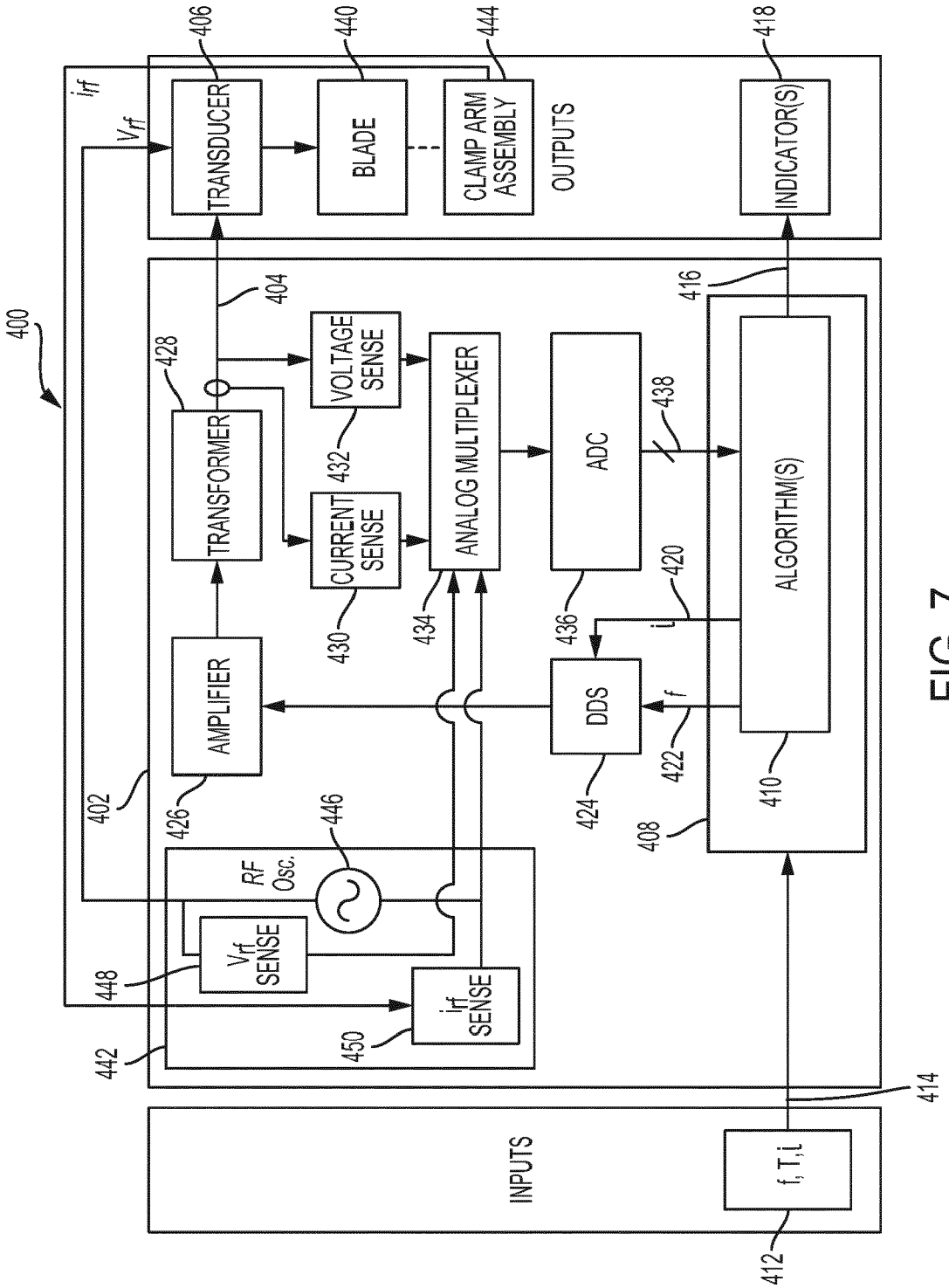
400
402
404
406
408
410
412
414
416
418
420
422
424
426
428
430
432
434
436
438
440
442
444
446
448
450
i_{rf}
V_{rf}
TRANSDUCER
BLADE
CLAMP ARM ASSEMBLY
OUTPUTS
INDICATOR(S)
TRANSFORMER
VOLTAGE SENSE
CURRENT SENSE
ANALOG MULTIPLEXER
ADC
ALGORITHM(S)
AMPLIFIER
DDS
RF Osc.
V_{rf} SENSE
i_{rf} SENSE
INPUTS
f, T, i
i
f

FIG. 7

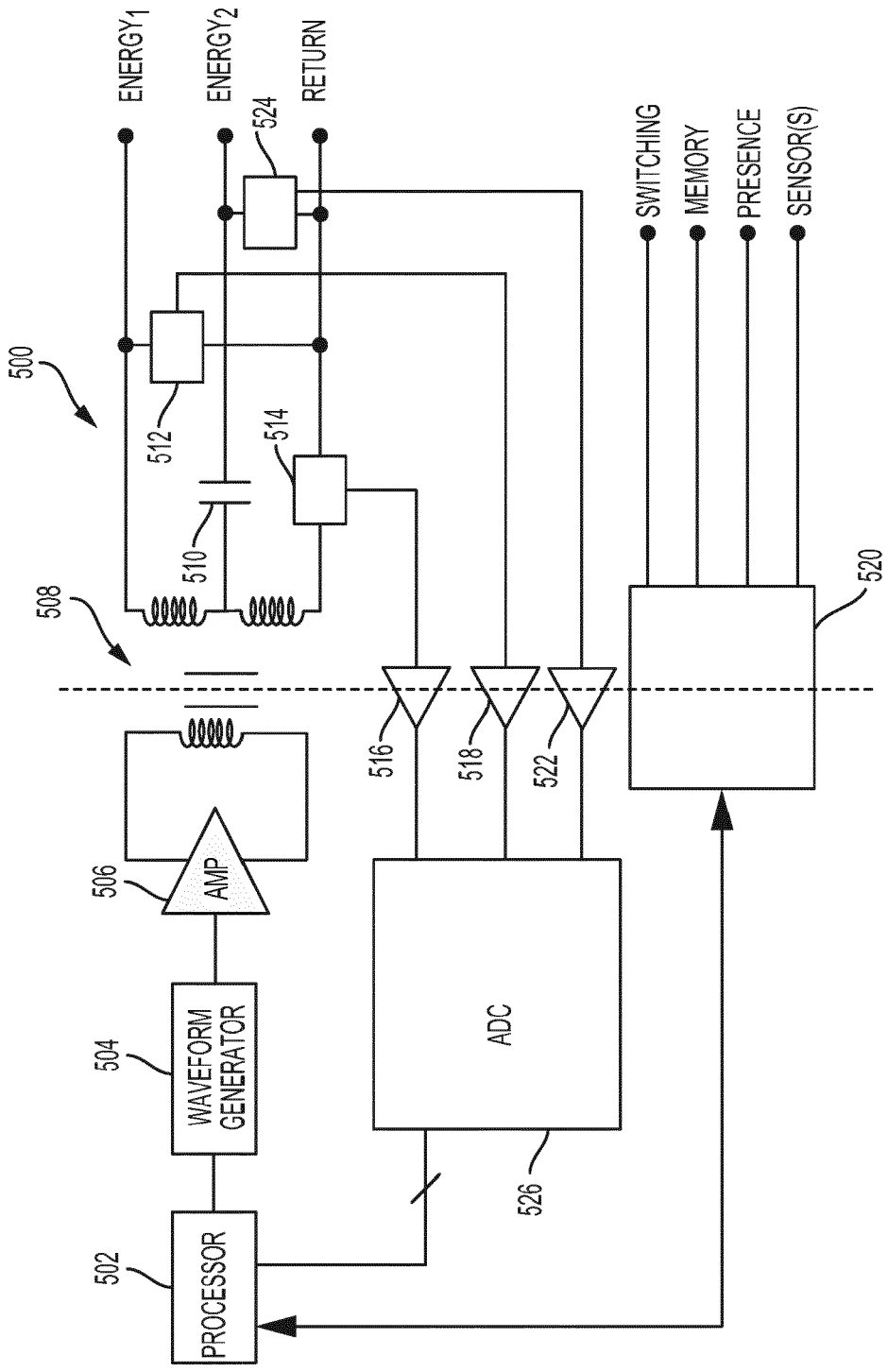
ENERGY1
ENERGY2
RETURN
524
SWITCHING
MEMORY
PRESENCE
SENSOR(S)
500
512
514
510
508
520
516
518
522
AMP
506
WAVEFORM GENERATOR
504
ADC
526
PROCESSOR
502

FIG. 8

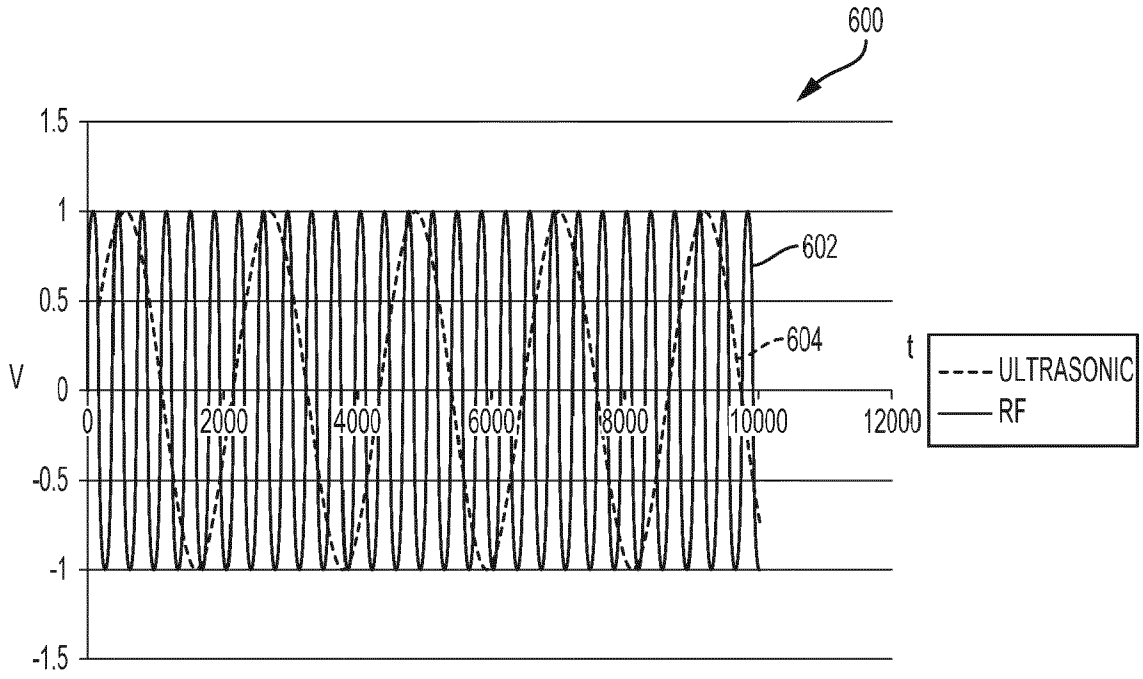
600
1.5
1
0.5
0
-0.5
-1
-1.5
V
0
2000
4000
6000
8000
10000
12000
t
602
604
ULTRASONIC
RF

FIG. 9

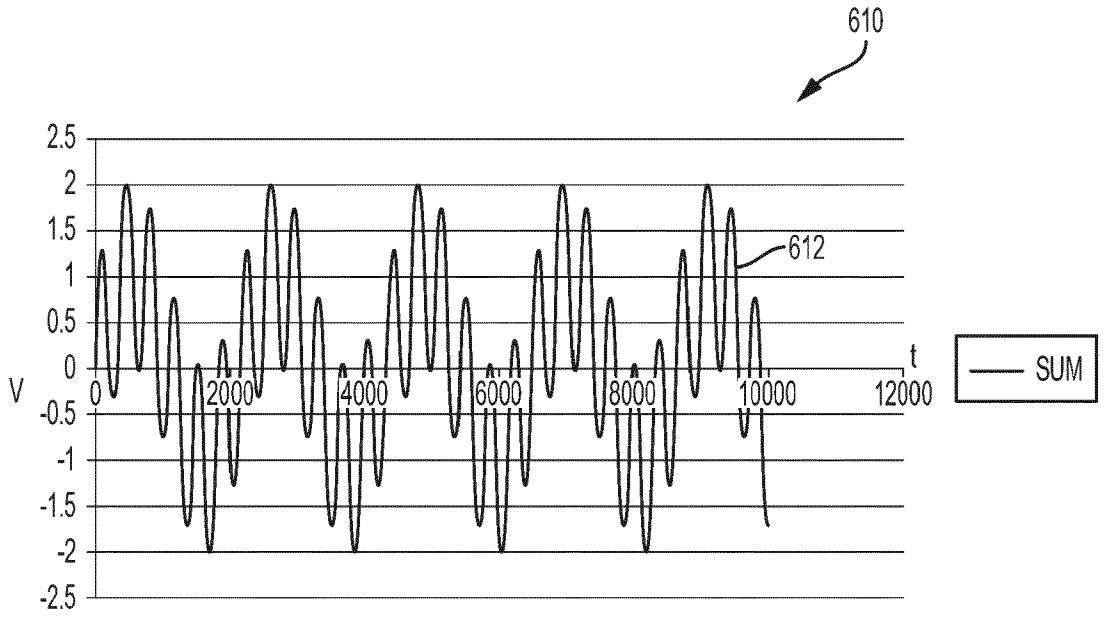
610
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
V
0
2000
4000
6000
8000
10000
12000
t
612
SUM

FIG. 10

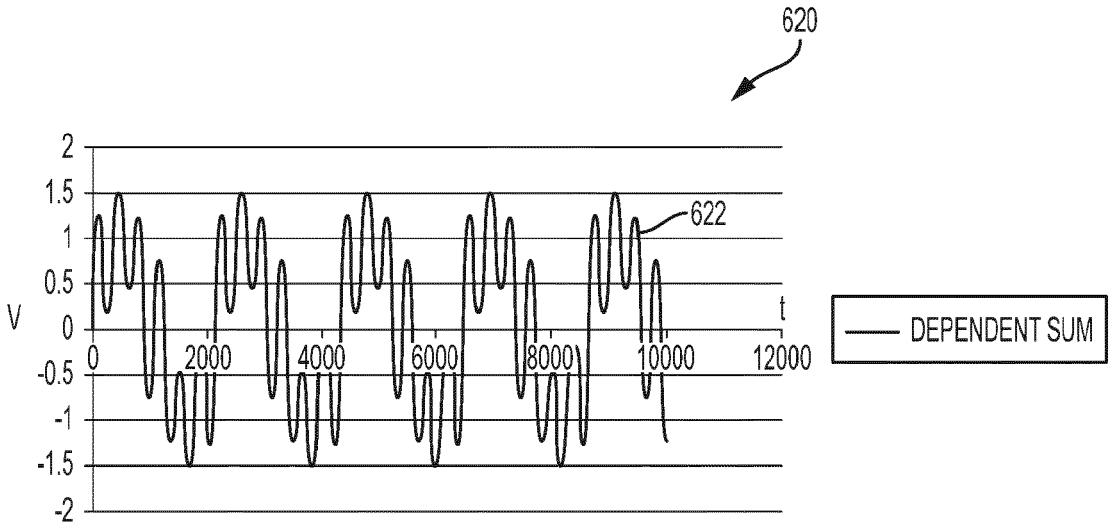
620
622
V
t
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
2000
4000
6000
8000
10000
12000
DEPENDENT SUM

FIG. 11

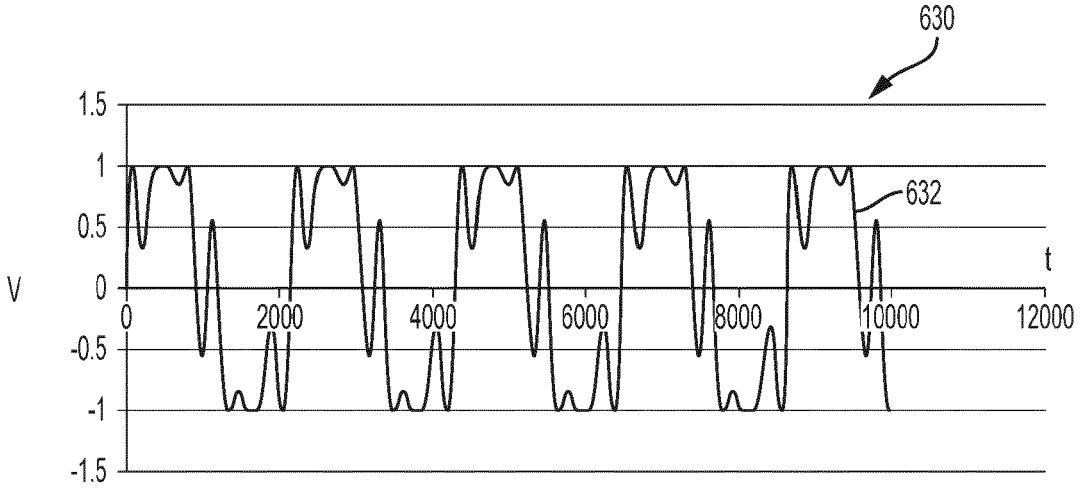
630
632
V
t
1.5
1
0.5
0
-0.5
-1
-1.5
0
2000
4000
6000
8000
10000
12000

FIG. 12

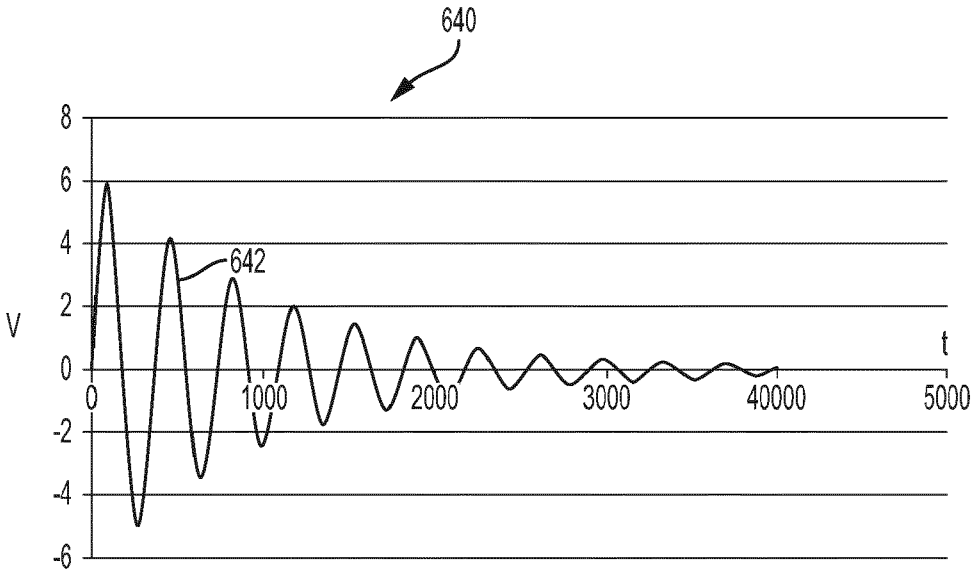

FIG. 13

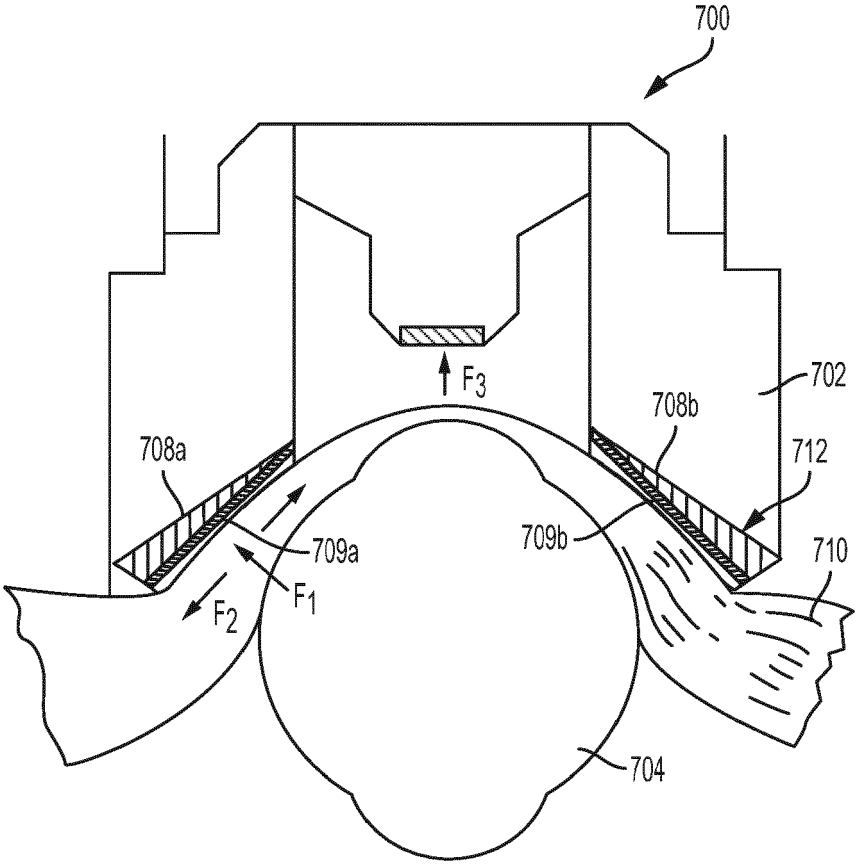
700
F3
702
708b
712
708a
709a
709b
710
F1
F2
704

FIG. 14

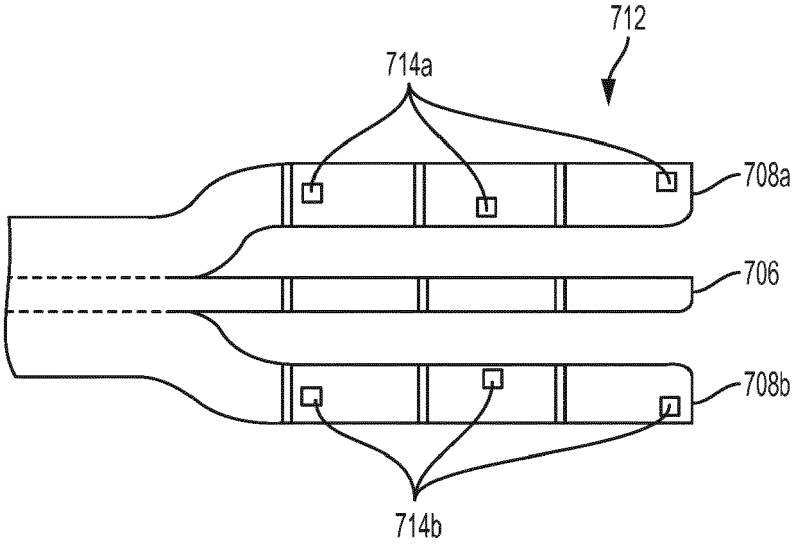
712
714a
708a
706
708b
714b

FIG. 15

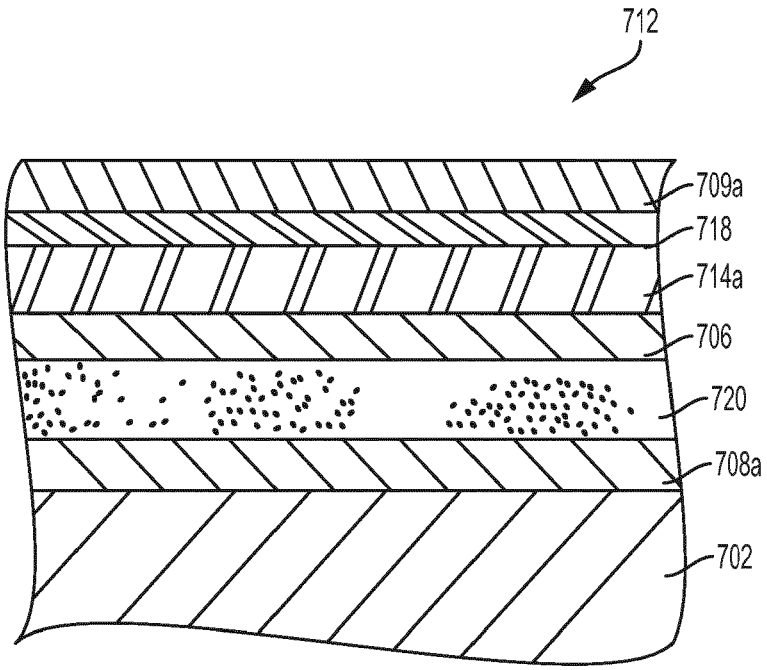
712
709a
718
714a
706
720
708a
702

FIG. 16

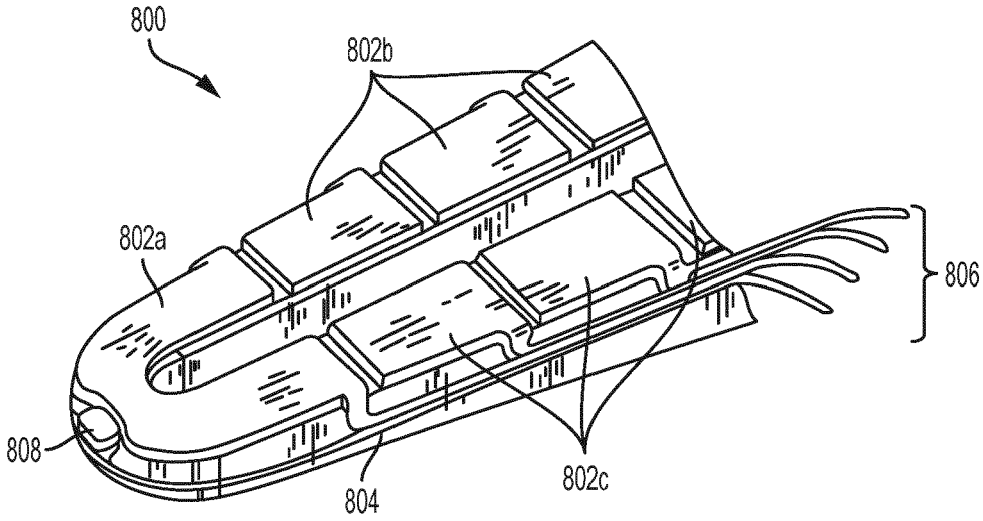
800
802b
802a
806
808
804
802c

FIG. 17

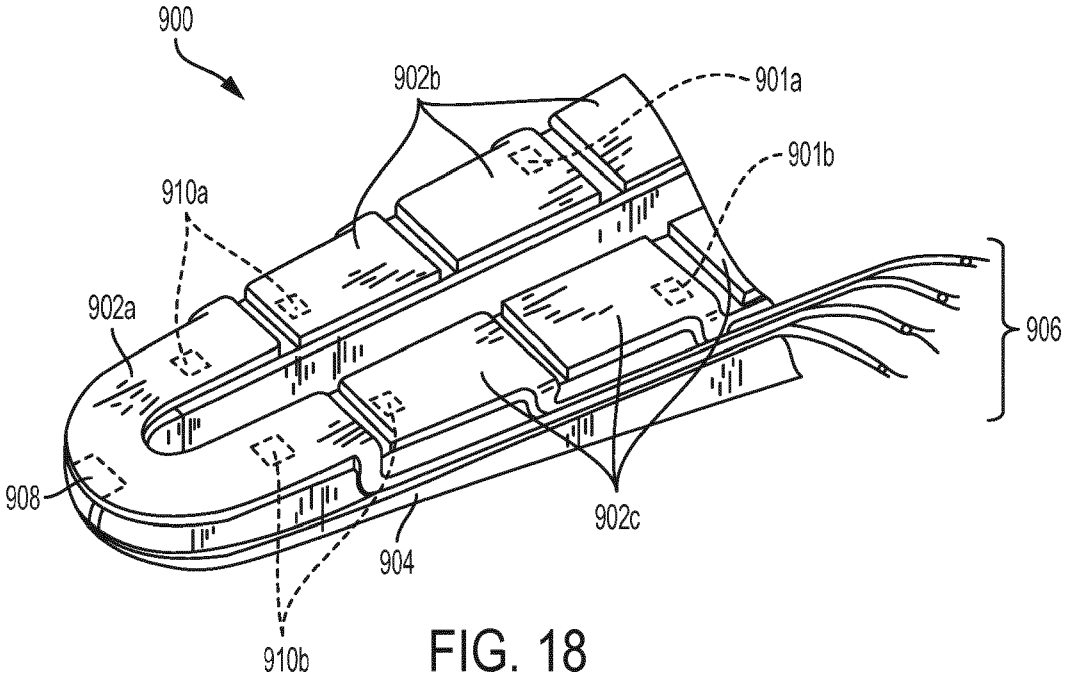
900
902b
901a
901b
910a
902a
906
908
902c
904
910b

FIG. 18

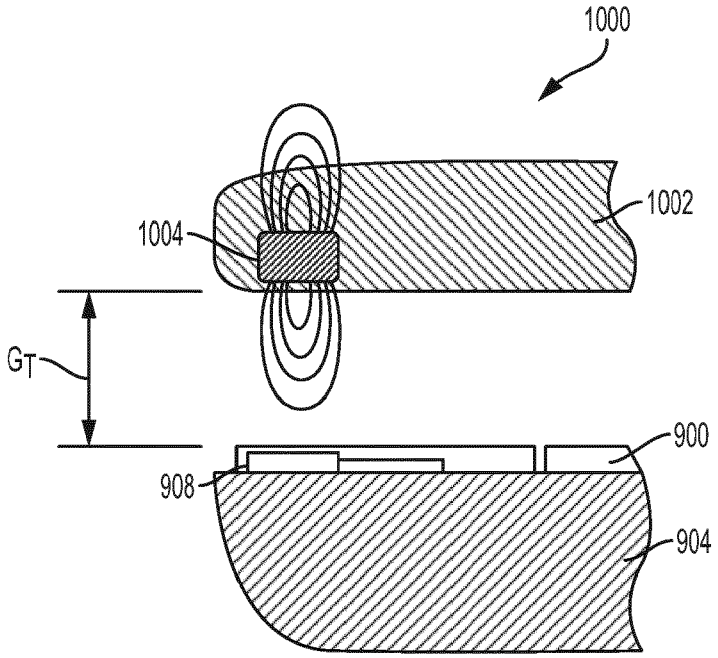
1000
1002
1004
GT
900
908
904

FIG. 19

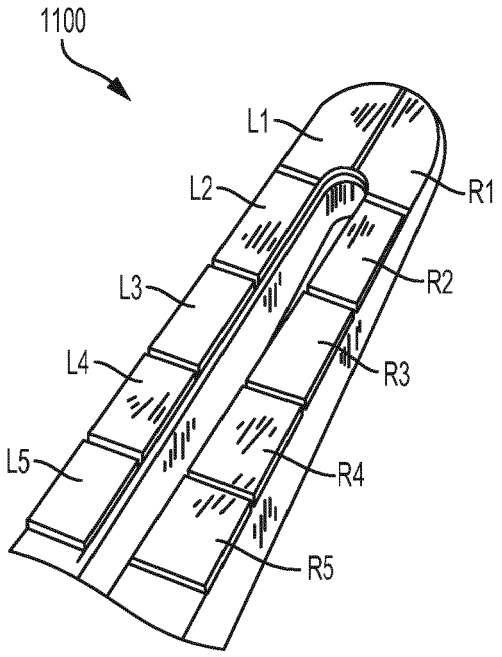

FIG. 20

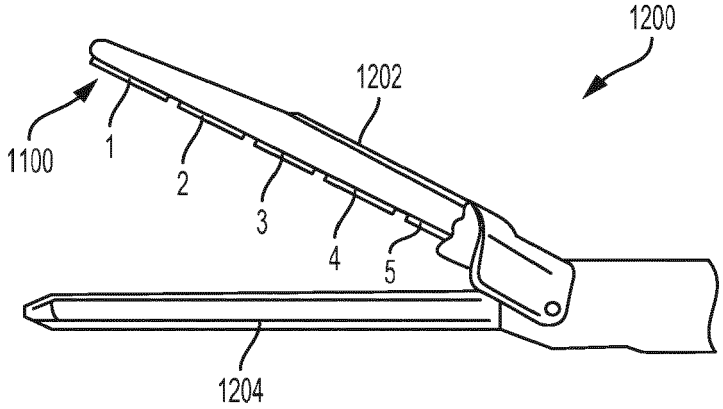

FIG. 21

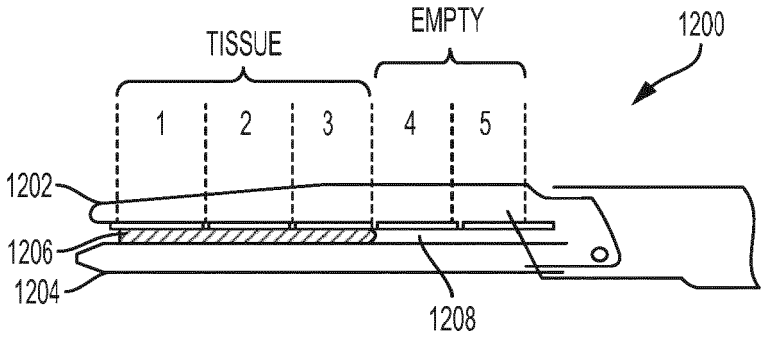

FIG. 22

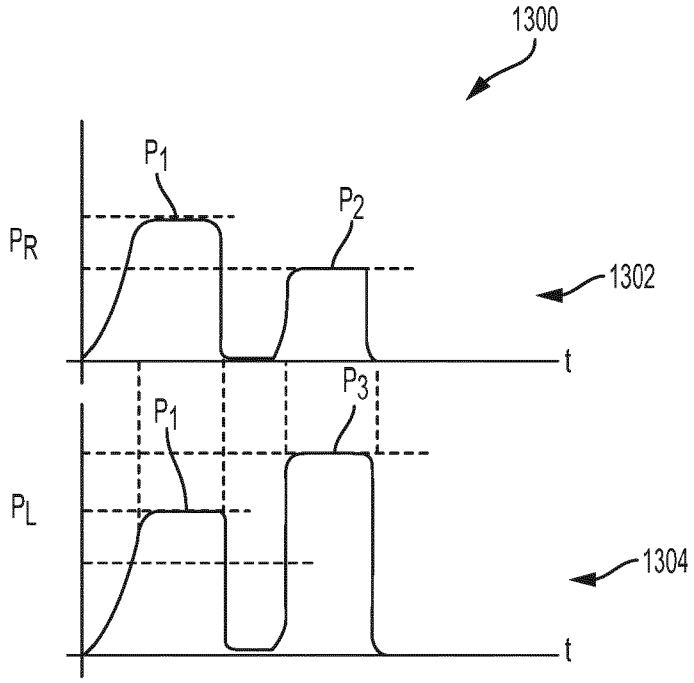
1300
P1
P2
PR
1302
t
P3
P1
PL
1304
t

FIG. 23

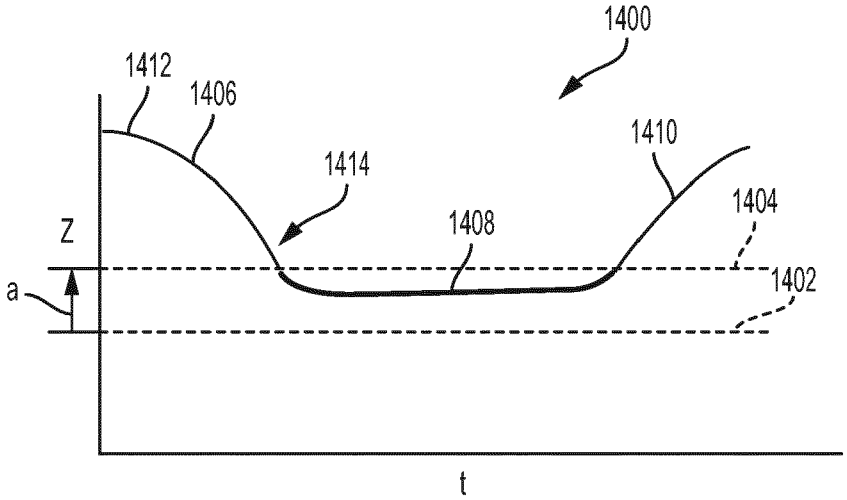
1400
1412
1406
1414
1410
1404
Z
1408
a
1402
t

FIG. 24

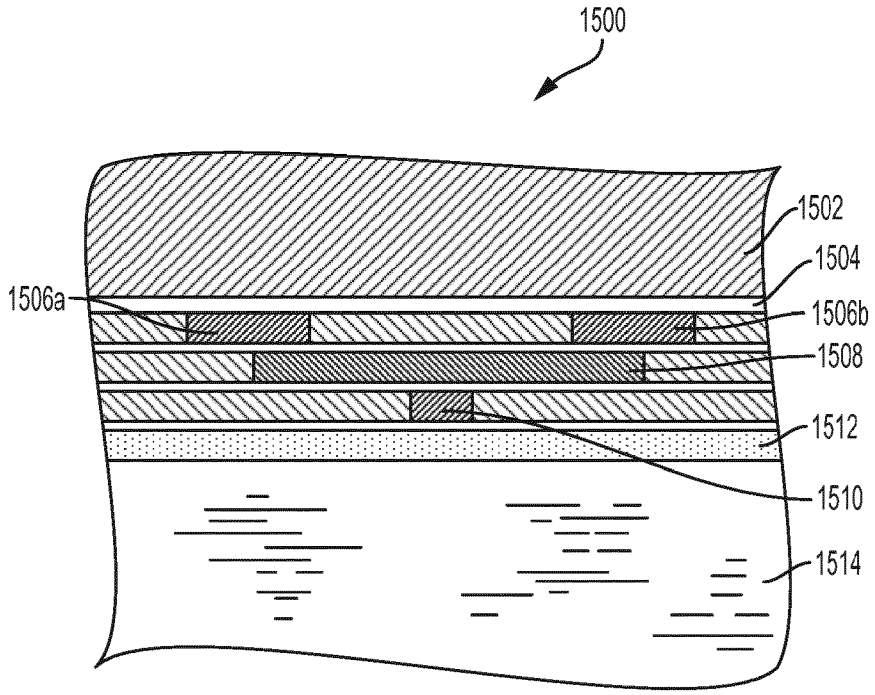
1500
1502
1504
1506a
1506b
1508
1512
1510
1514

FIG. 25

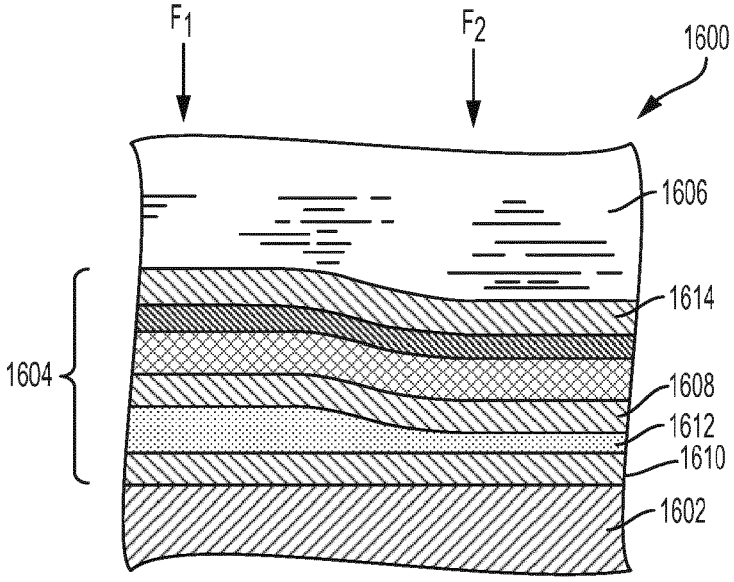
F1
F2
1600
1606
1614
1604
1608
1612
1610
1602

FIG. 26

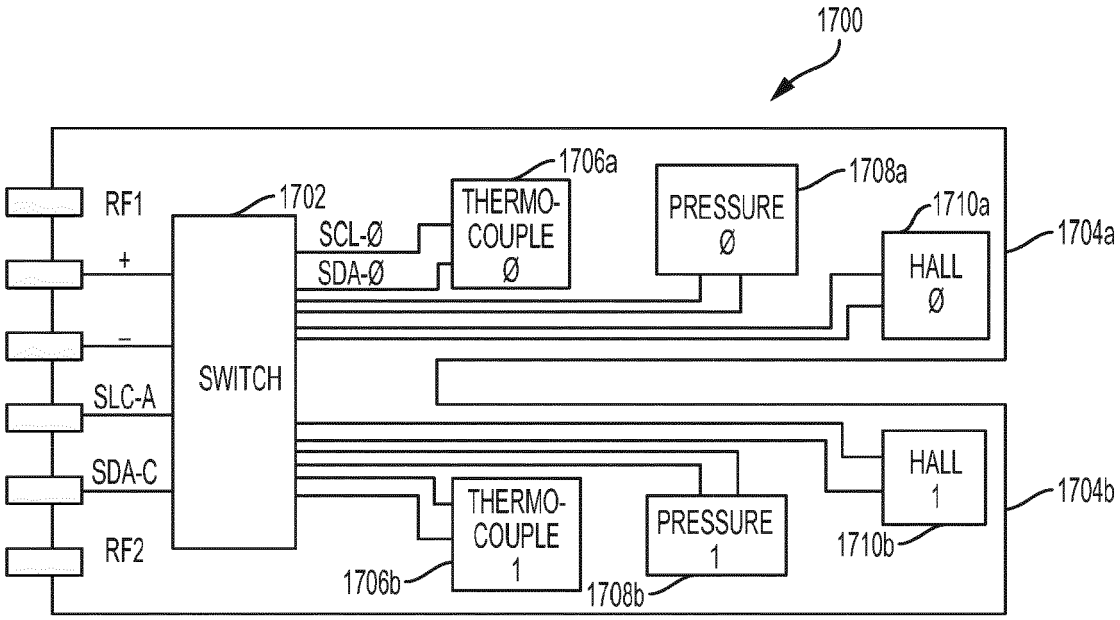
1700
RF1
+
–
SLC-A
SDA-C
RF2
1702
SWITCH
SCL-Ø
SDA-Ø
1706a
THERMO-COUPLE Ø
1708a
PRESSURE Ø
1710a
HALL Ø
1704a
1706b
THERMO-COUPLE 1
1708b
PRESSURE 1
1710b
HALL 1
1704b

FIG. 27

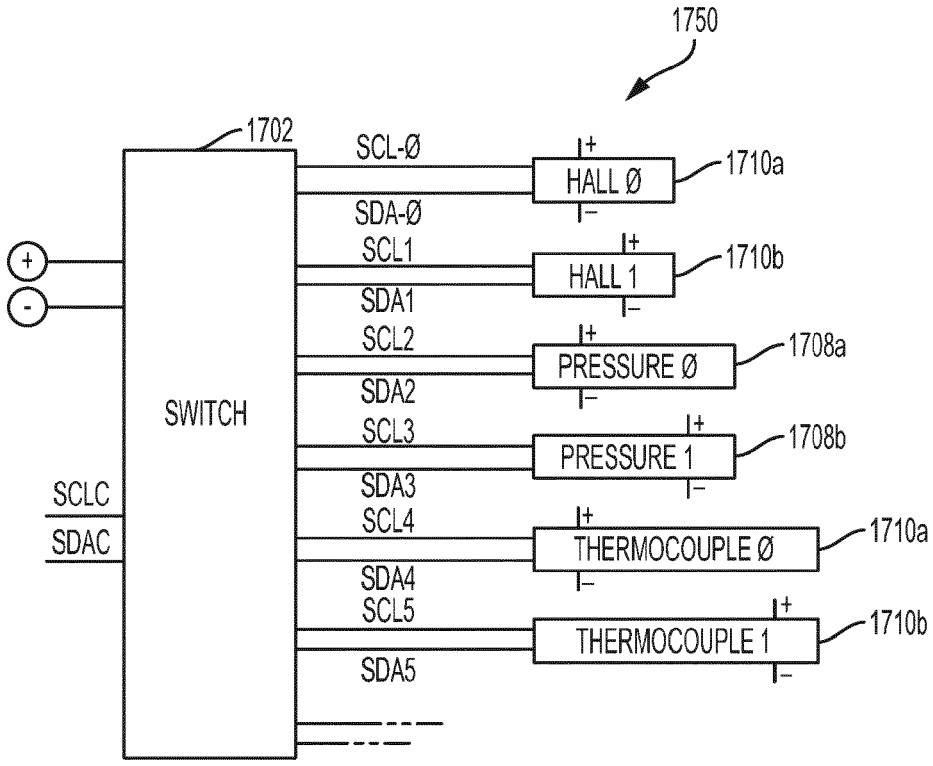
1750
1702
SWITCH
+
-
SCLC
SDAC
SCL-Ø
SDA-Ø
HALL Ø
1710a
SCL1
SDA1
HALL 1
1710b
SCL2
SDA2
PRESSURE Ø
1708a
SCL3
SDA3
PRESSURE 1
1708b
SCL4
SDA4
THERMOCOUPLE Ø
1710a
SCL5
SDA5
THERMOCOUPLE 1
1710b

FIG. 28

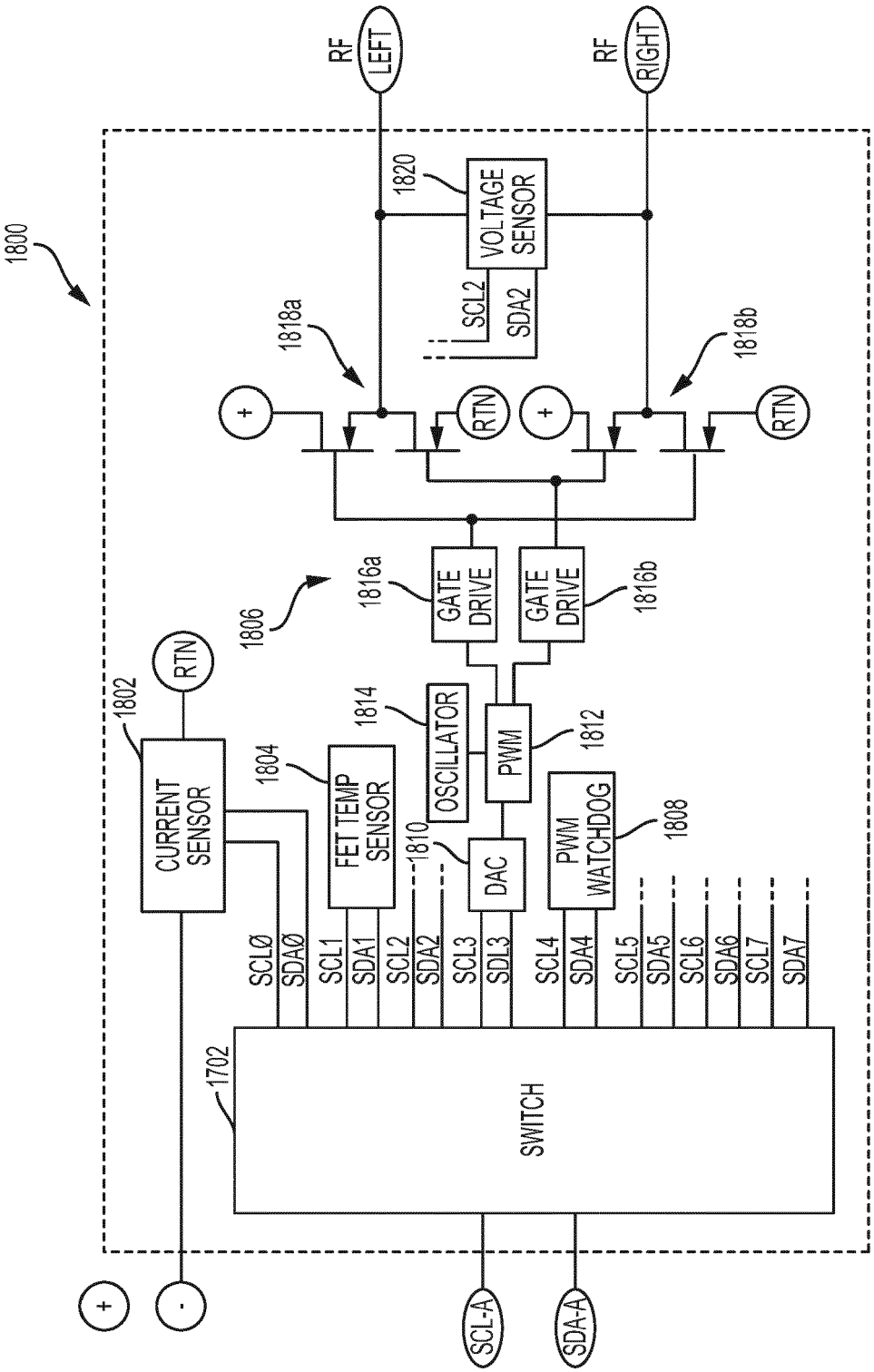
1800
RF LEFT
RF RIGHT
1820
VOLTAGE SENSOR
SCL2
SDA2
1818a
1818b
+
RTN
+
RTN
1806
1816a
GATE DRIVE
GATE DRIVE
1816b
RTN
1802
1814
OSCILLATOR
PWM
1812
CURRENT SENSOR
1804
FET TEMP SENSOR
1810
DAC
PWM WATCHDOG
1808
SCLØ
SDAØ
SCL1
SDA1
SCL2
SDA2
SCL3
SDL3
SCL4
SDA4
SCL5
SDA5
SCL6
SDA6
SCL7
SDA7
1702
SWITCH
+
-
SCL-A
SDA-A

FIG. 29

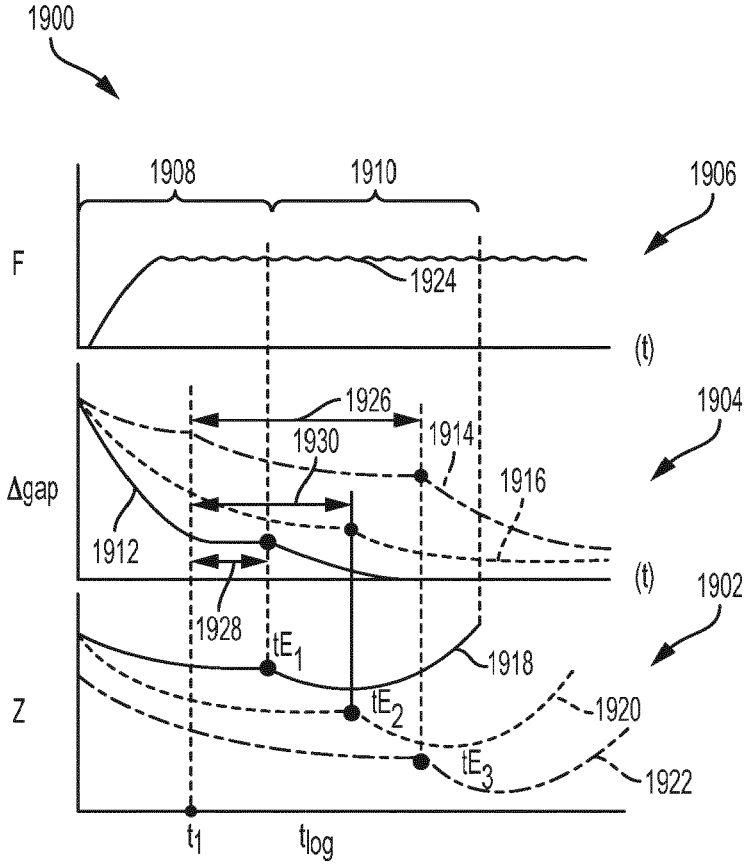
1900
1908
1910
1906
F
1924
(t)
1926
1904
1930
1914
Δgap
1916
1912
(t)
1928
1902
tE1
1918
Z
tE2
1920
tE3
1922
t1
tlog

FIG. 30

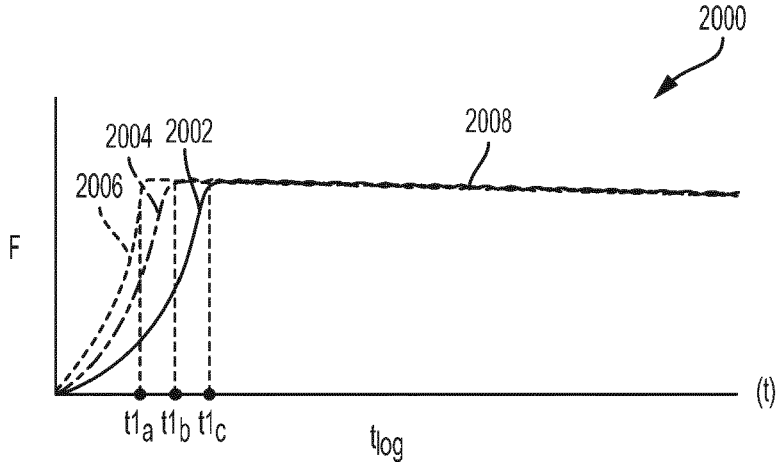
2000
2004
2002
2008
2006
F
(t)
t1a t1b t1c
tlog

FIG. 31

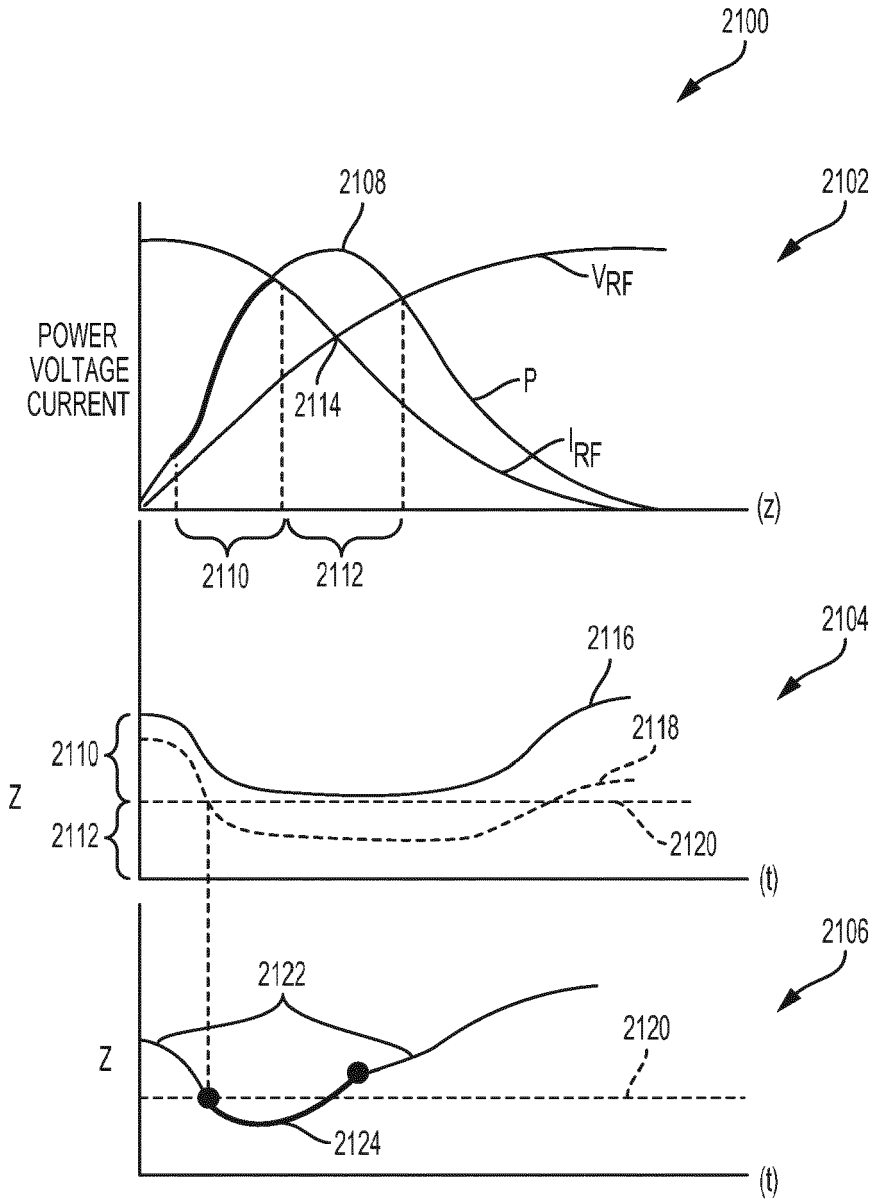
2100
2102
2108
POWER
VOLTAGE
CURRENT
V_{RF}
P
I_{RF}
2114
(z)
2110
2112
2104
2116
2118
2110
Z
2112
2120
(t)
2106
2122
2120
Z
2124
(t)

FIG. 32

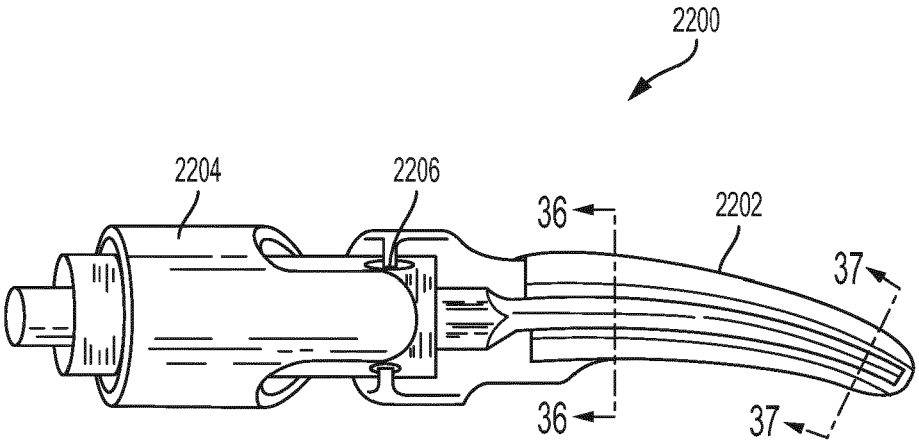

FIG. 33

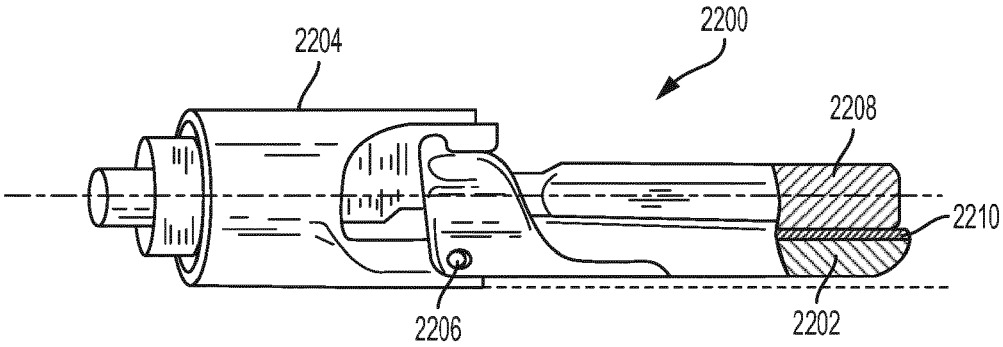

FIG. 34

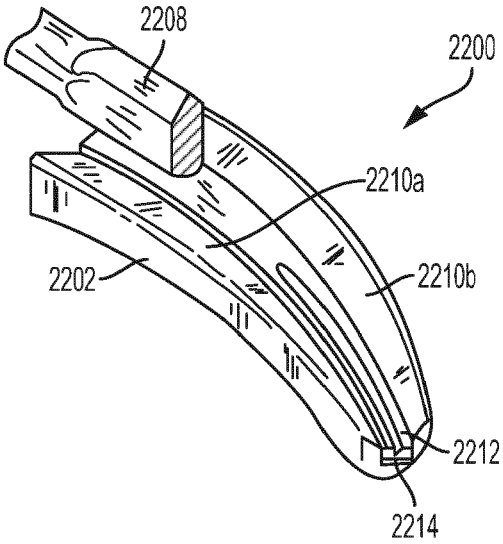

FIG. 35

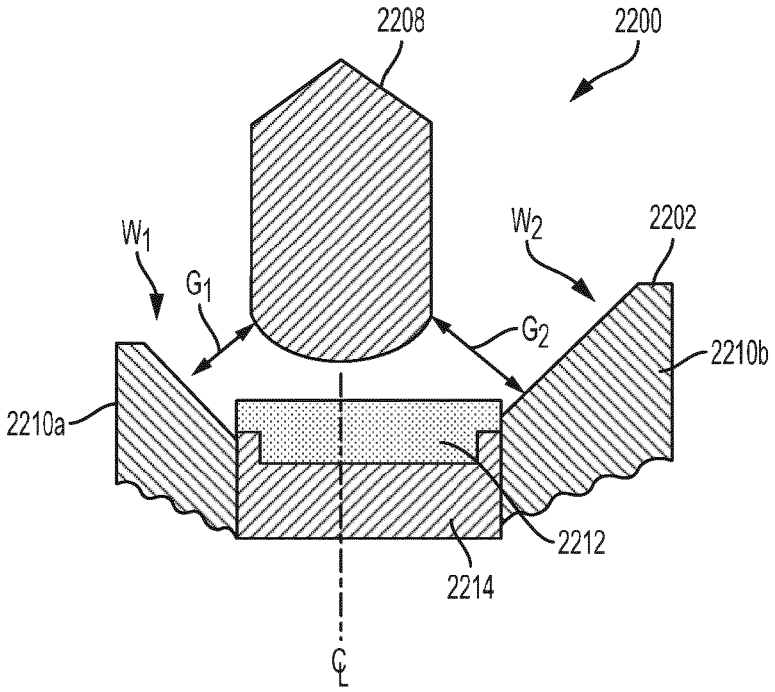
2208
2200
W1
G1
W2
2202
G2
2210b
2210a
2212
2214
CL

FIG. 36

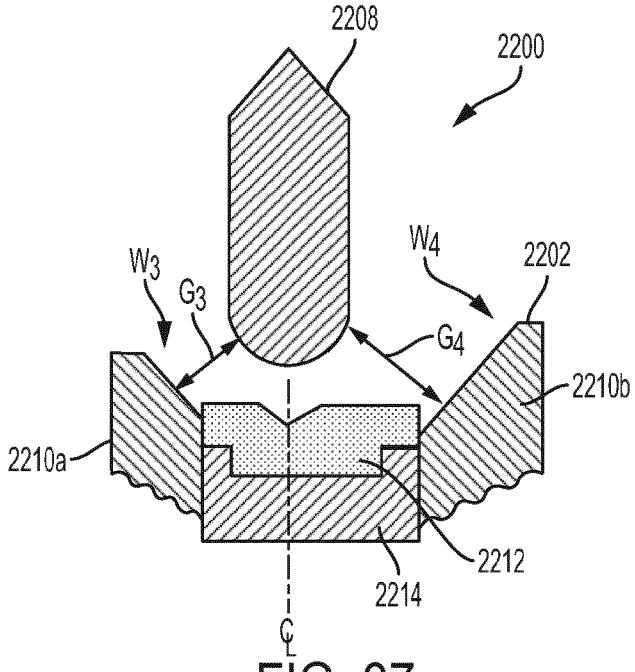
2208
2200
W3
G3
W4
2202
G4
2210b
2210a
2212
2214
CL

FIG. 37

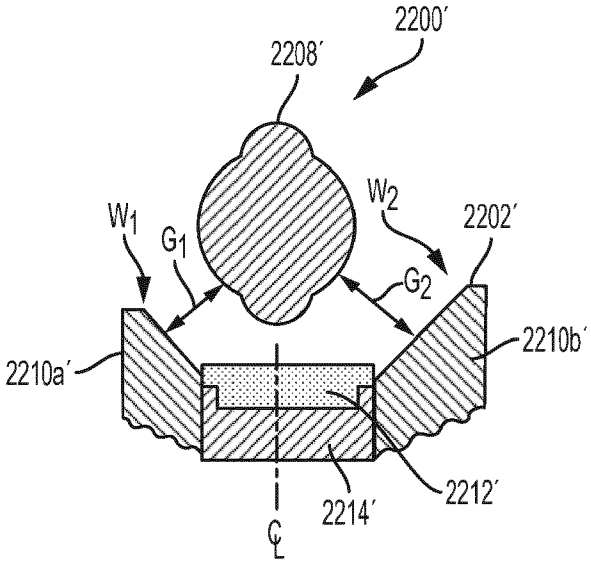

FIG. 38

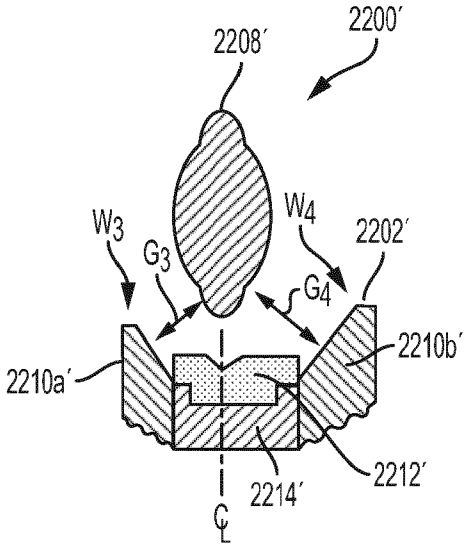

FIG. 39

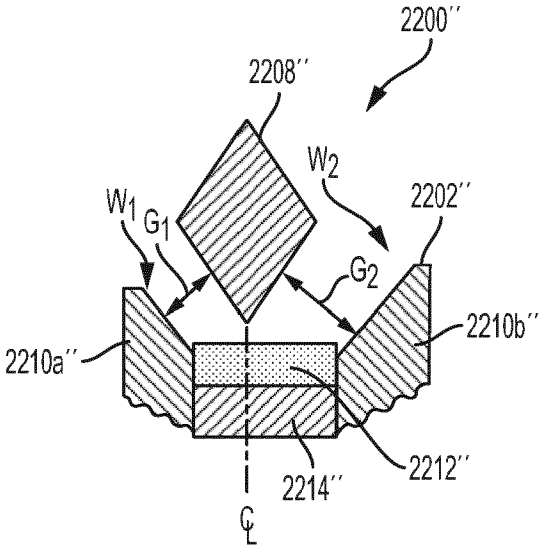

FIG. 40

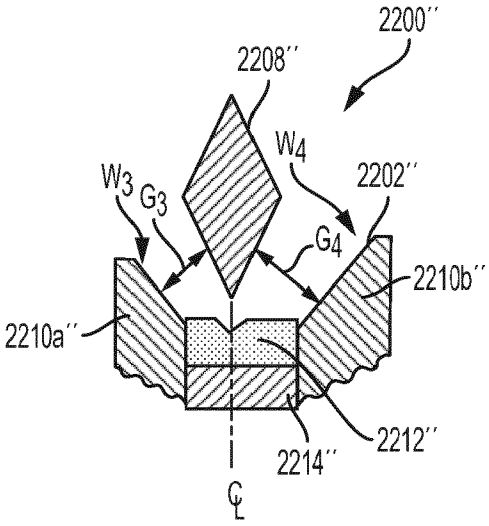

FIG. 41

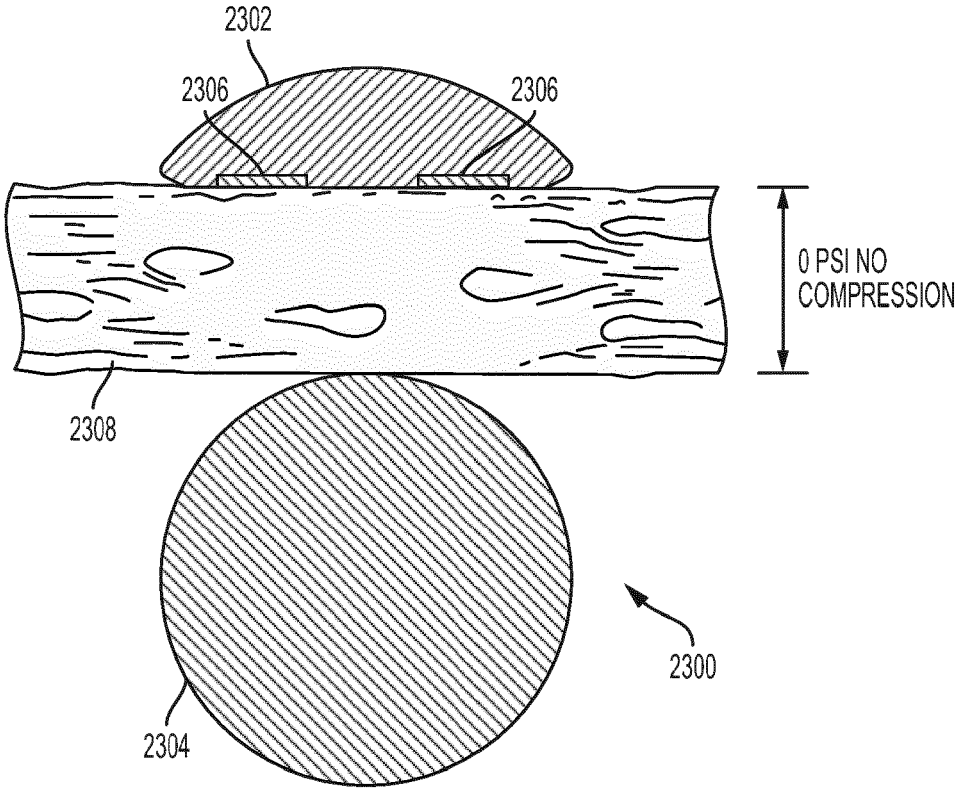

FIG. 42A

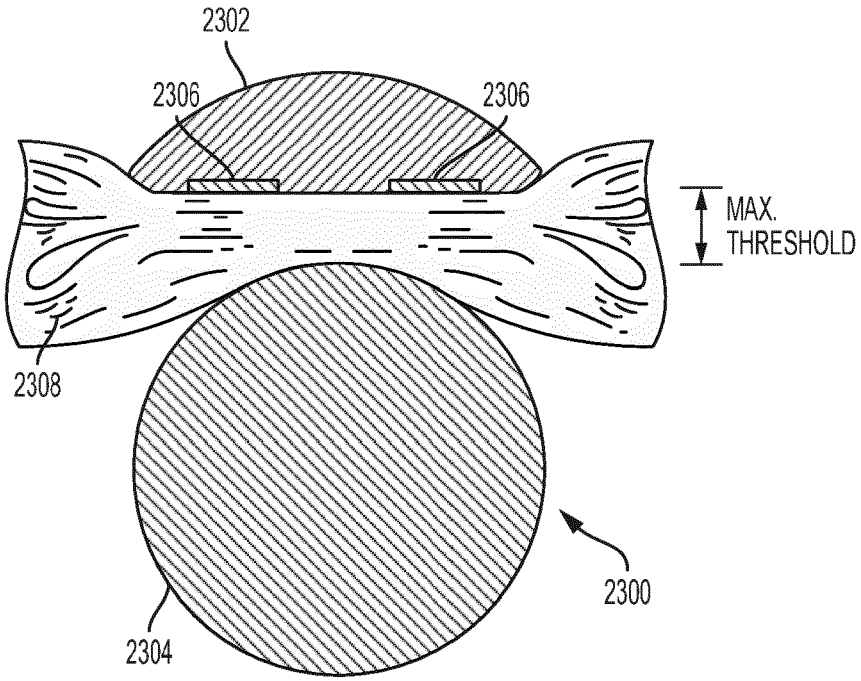

FIG. 42B

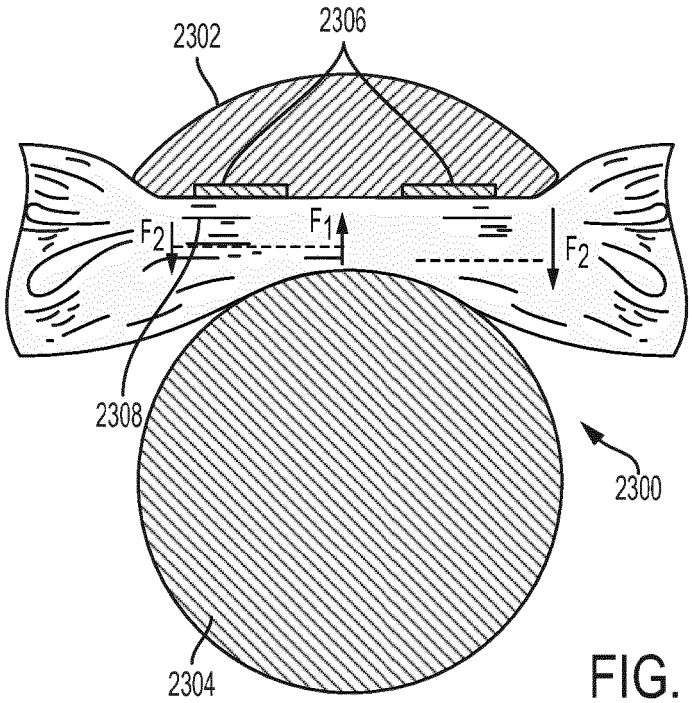

FIG. 43A

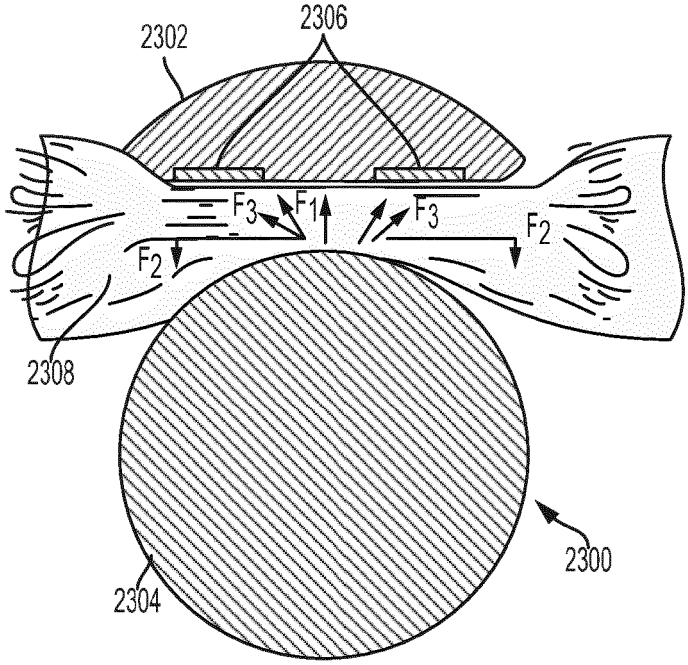

FIG. 43B

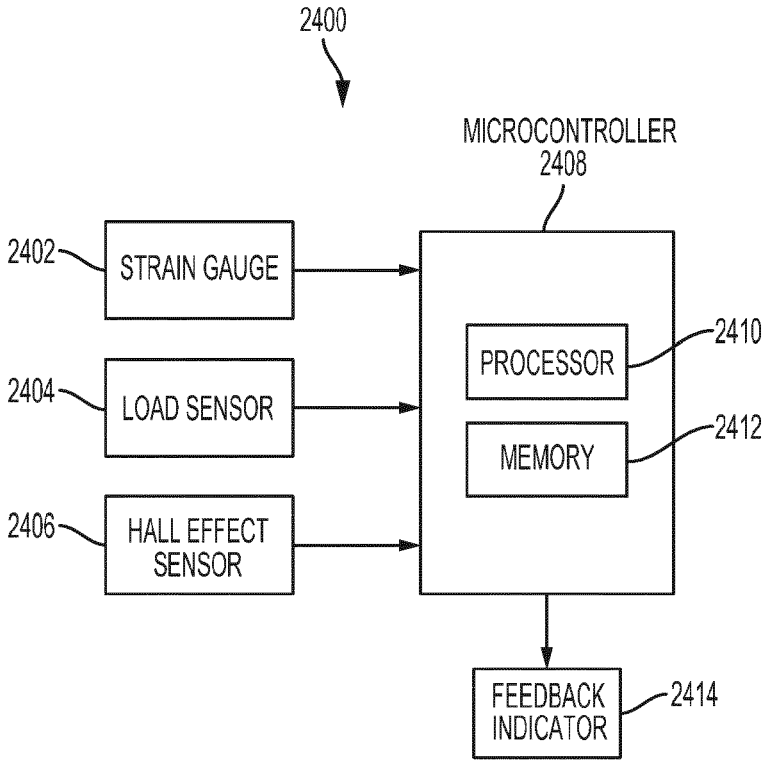
2400
MICROCONTROLLER
2408
2402
STRAIN GAUGE
2404
LOAD SENSOR
2406
HALL EFFECT SENSOR
PROCESSOR
2410
MEMORY
2412
FEEDBACK INDICATOR
2414

FIG. 44

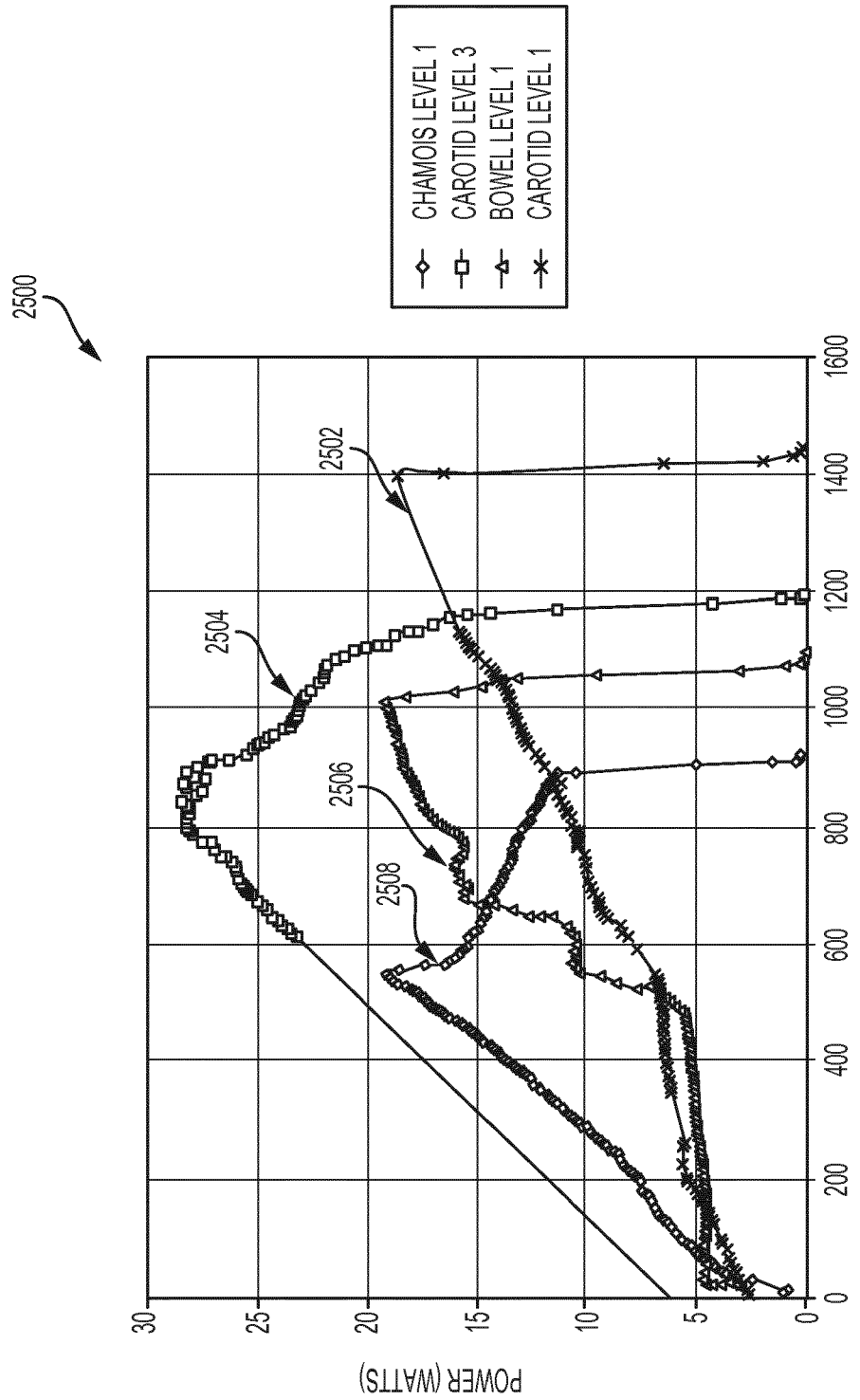
2500
CHAMOIS LEVEL 1
CAROTID LEVEL 3
BOWEL LEVEL 1
CAROTID LEVEL 1
2502
2504
2506
2508
POWER (WATTS)
FORCE (g)
0
5
10
15
20
25
30
200
400
600
800
1000
1200
1400
1600

FIG. 45

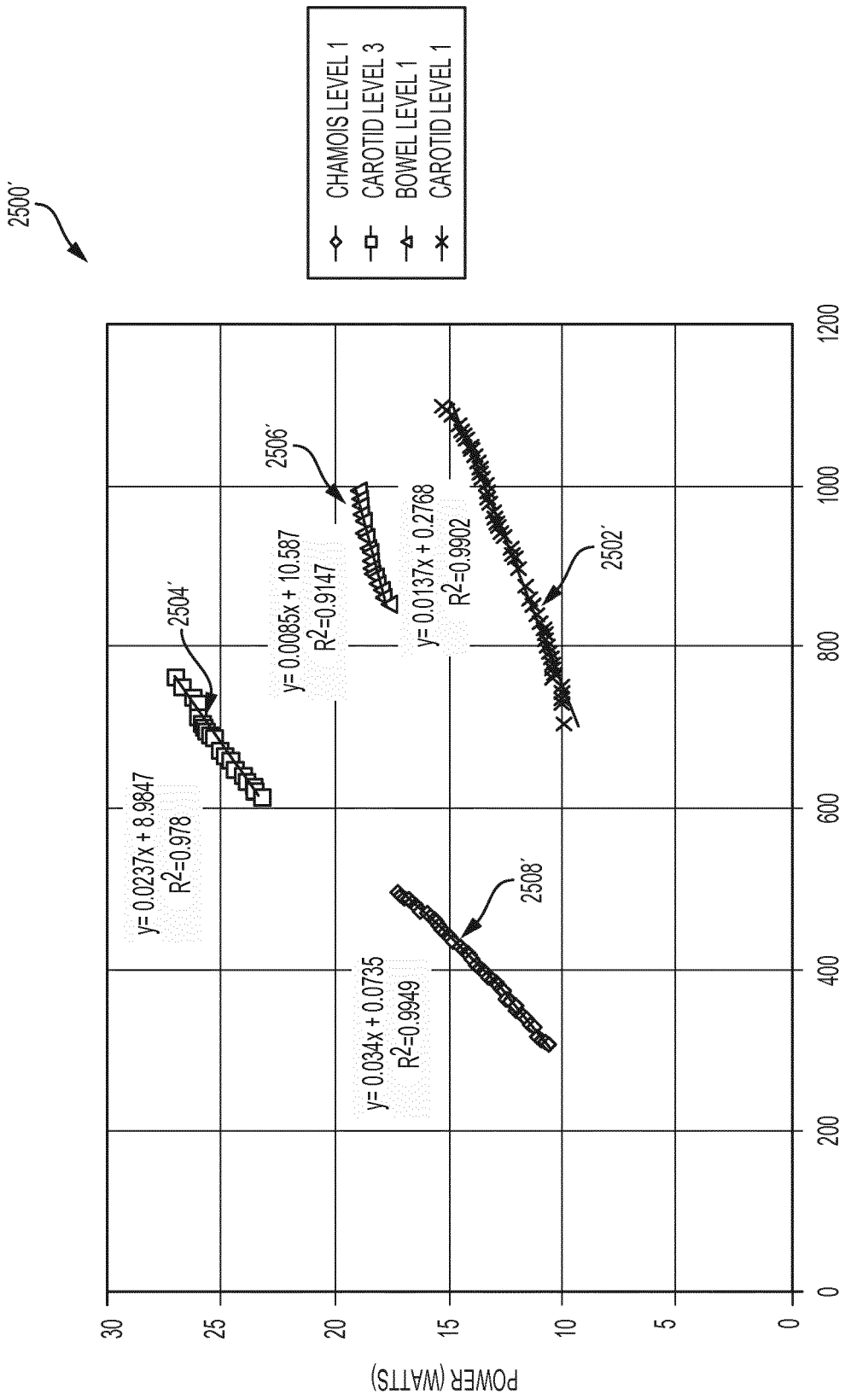
2500´
CHAMOIS LEVEL 1
CAROTID LEVEL 3
BOWEL LEVEL 1
CAROTID LEVEL 1
2504´
2506´
2502´
2508´
y= 0.0237x + 8.9847
R2=0.978
y= 0.0085x + 10.587
R2=0.9147
y= 0.0137x + 0.2768
R2=0.9902
y= 0.034x + 0.0735
R2=0.9949
POWER (WATTS)
FORCE (g)
0
5
10
15
20
25
30
0
200
400
600
800
1000
1200

FIG. 46

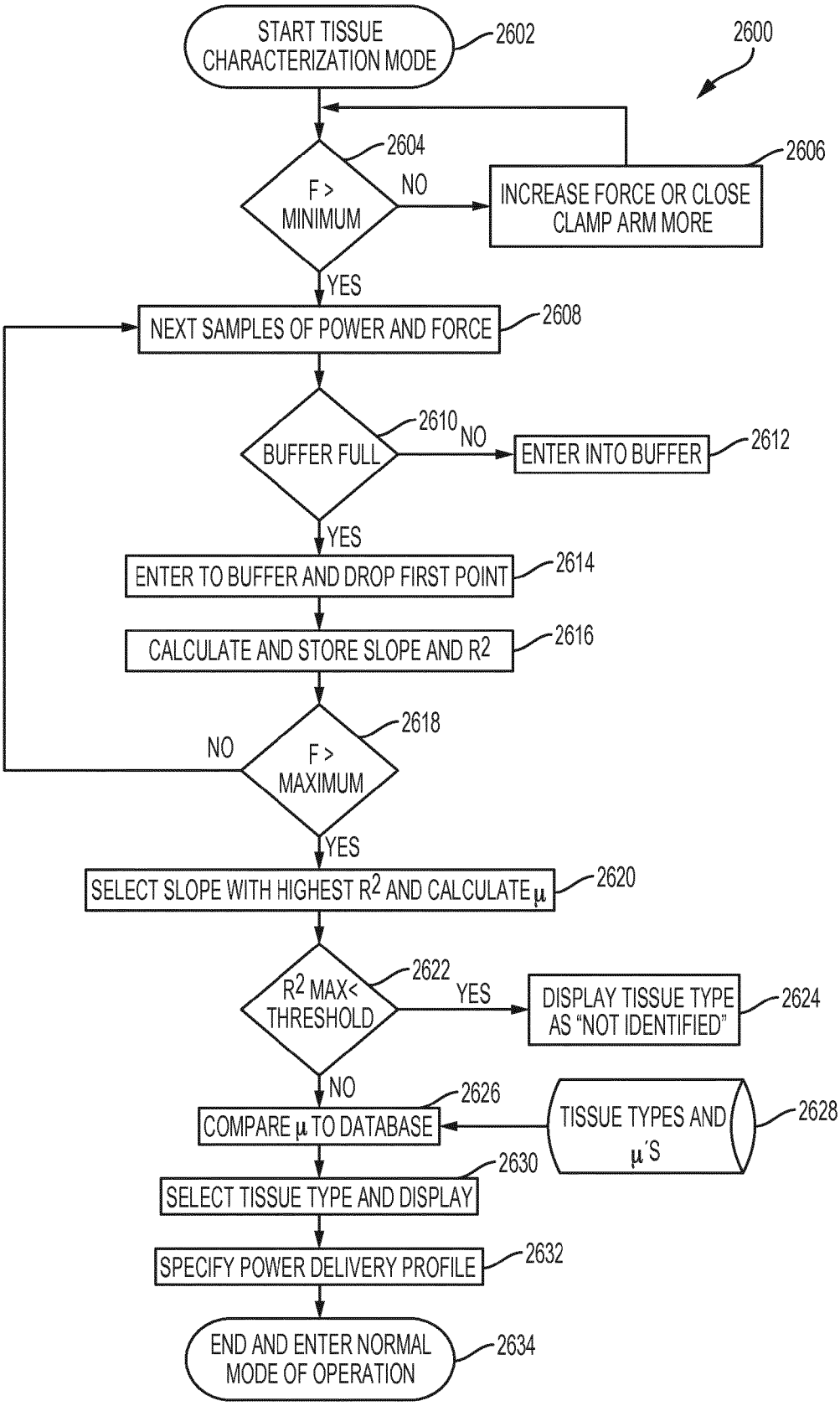
START TISSUE CHARACTERIZATION MODE
2602
2600
2604
F > MINIMUM
NO
INCREASE FORCE OR CLOSE CLAMP ARM MORE
2606
YES
NEXT SAMPLES OF POWER AND FORCE
2608
BUFFER FULL
2610
NO
ENTER INTO BUFFER
2612
YES
ENTER TO BUFFER AND DROP FIRST POINT
2614
CALCULATE AND STORE SLOPE AND R2
2616
F > MAXIMUM
2618
NO
YES
SELECT SLOPE WITH HIGHEST R2 AND CALCULATE μ
2620
R2 MAX< THRESHOLD
2622
YES
DISPLAY TISSUE TYPE AS "NOT IDENTIFIED"
2624
NO
COMPARE μ TO DATABASE
2626
TISSUE TYPES AND μ´S
2628
SELECT TISSUE TYPE AND DISPLAY
2630
SPECIFY POWER DELIVERY PROFILE
2632
END AND ENTER NORMAL MODE OF OPERATION
2634

FIG. 47

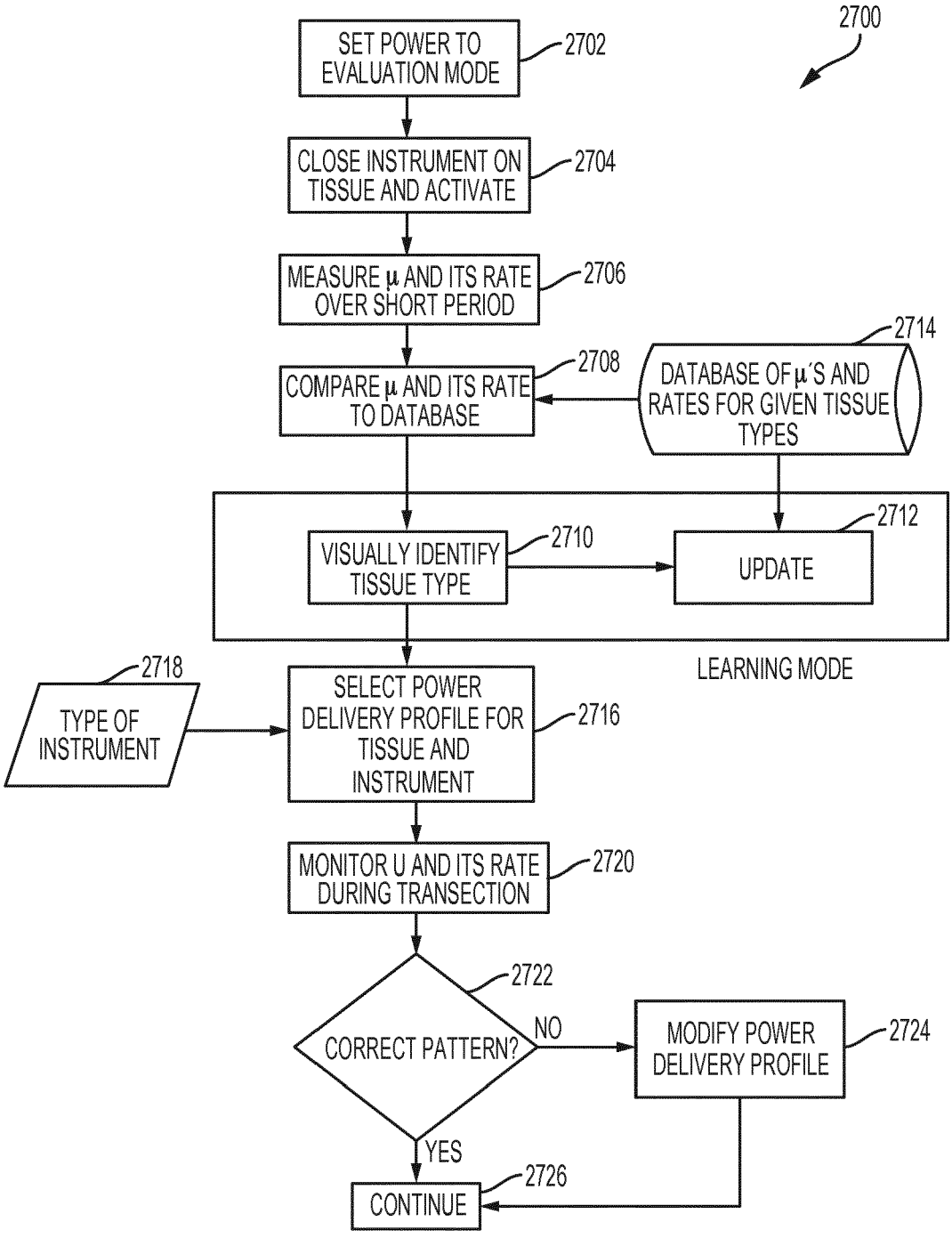
2700
SET POWER TO EVALUATION MODE
2702
CLOSE INSTRUMENT ON TISSUE AND ACTIVATE
2704
MEASURE μ AND ITS RATE OVER SHORT PERIOD
2706
COMPARE μ AND ITS RATE TO DATABASE
2708
DATABASE OF μ´S AND RATES FOR GIVEN TISSUE TYPES
2714
VISUALLY IDENTIFY TISSUE TYPE
2710
UPDATE
2712
LEARNING MODE
TYPE OF INSTRUMENT
2718
SELECT POWER DELIVERY PROFILE FOR TISSUE AND INSTRUMENT
2716
MONITOR U AND ITS RATE DURING TRANSECTION
2720
CORRECT PATTERN?
2722
NO
MODIFY POWER DELIVERY PROFILE
2724
YES
CONTINUE
2726

FIG. 48

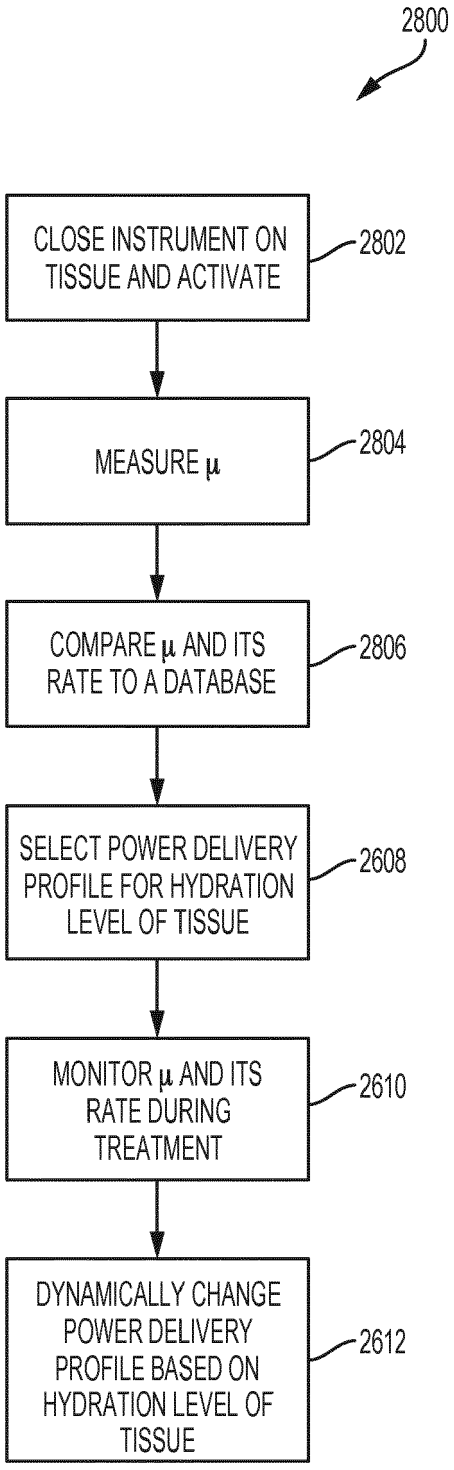
2800
CLOSE INSTRUMENT ON TISSUE AND ACTIVATE
2802
MEASURE μ
2804
COMPARE μ AND ITS RATE TO A DATABASE
2806
SELECT POWER DELIVERY PROFILE FOR HYDRATION LEVEL OF TISSUE
2608
MONITOR μ AND ITS RATE DURING TREATMENT
2610
DYNAMICALLY CHANGE POWER DELIVERY PROFILE BASED ON HYDRATION LEVEL OF TISSUE
2612

FIG. 49

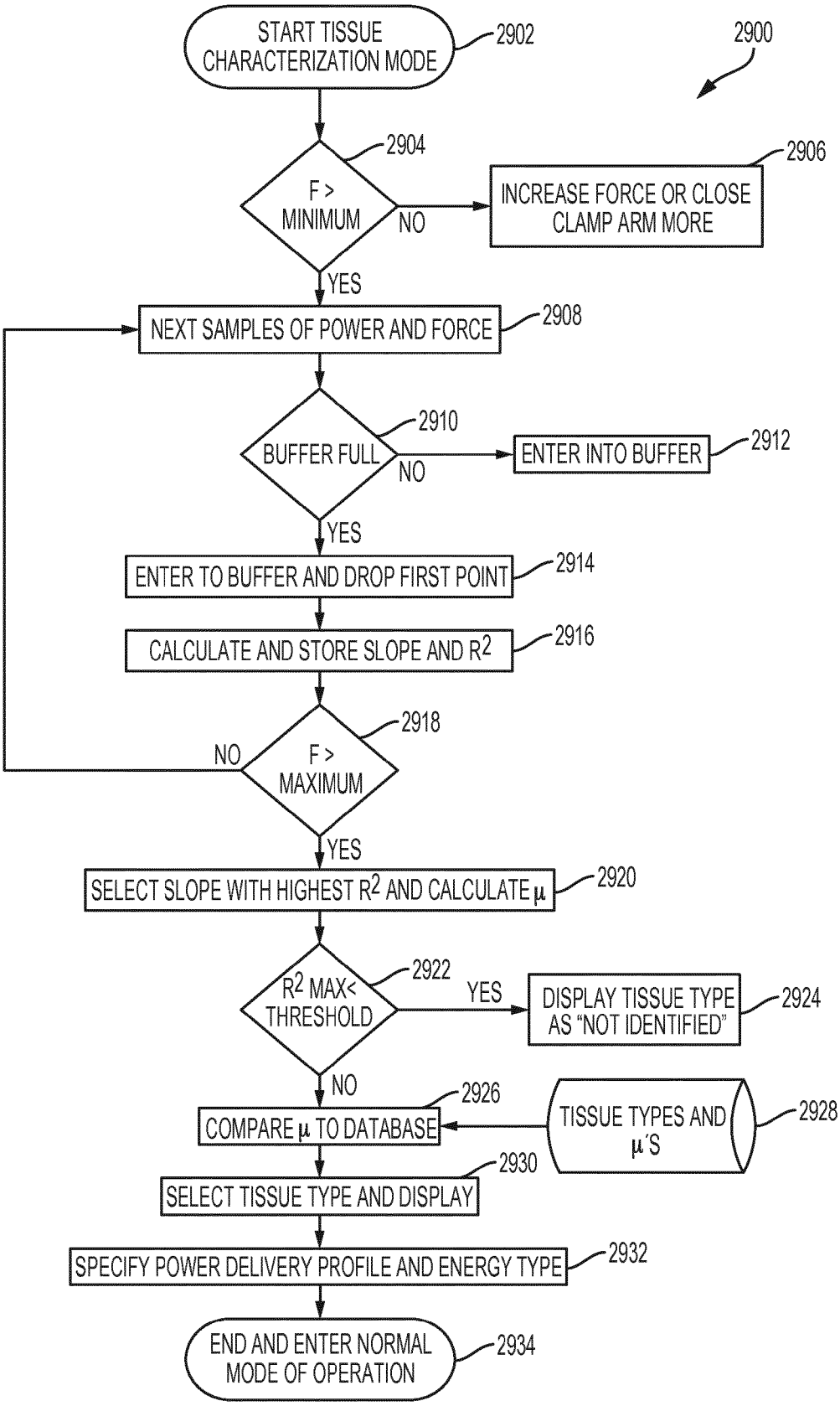
START TISSUE CHARACTERIZATION MODE
2902
2900
2904
F > MINIMUM
NO
2906
INCREASE FORCE OR CLOSE CLAMP ARM MORE
YES
NEXT SAMPLES OF POWER AND FORCE
2908
2910
BUFFER FULL
NO
ENTER INTO BUFFER
2912
YES
ENTER TO BUFFER AND DROP FIRST POINT
2914
CALCULATE AND STORE SLOPE AND R2
2916
2918
NO
F > MAXIMUM
YES
SELECT SLOPE WITH HIGHEST R2 AND CALCULATE μ
2920
2922
R2 MAX< THRESHOLD
YES
DISPLAY TISSUE TYPE AS "NOT IDENTIFIED"
2924
NO
2926
COMPARE μ TO DATABASE
TISSUE TYPES AND μ´S
2928
2930
SELECT TISSUE TYPE AND DISPLAY
SPECIFY POWER DELIVERY PROFILE AND ENERGY TYPE
2932
END AND ENTER NORMAL MODE OF OPERATION
2934

FIG. 50

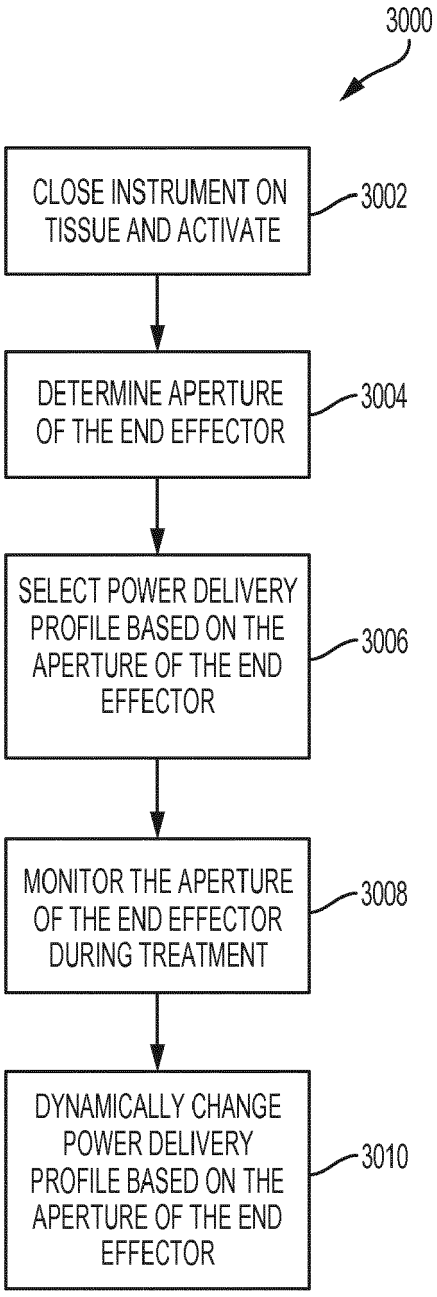
3000
CLOSE INSTRUMENT ON TISSUE AND ACTIVATE
3002
DETERMINE APERTURE OF THE END EFFECTOR
3004
SELECT POWER DELIVERY PROFILE BASED ON THE APERTURE OF THE END EFFECTOR
3006
MONITOR THE APERTURE OF THE END EFFECTOR DURING TREATMENT
3008
DYNAMICALLY CHANGE POWER DELIVERY PROFILE BASED ON THE APERTURE OF THE END EFFECTOR
3010

FIG. 51

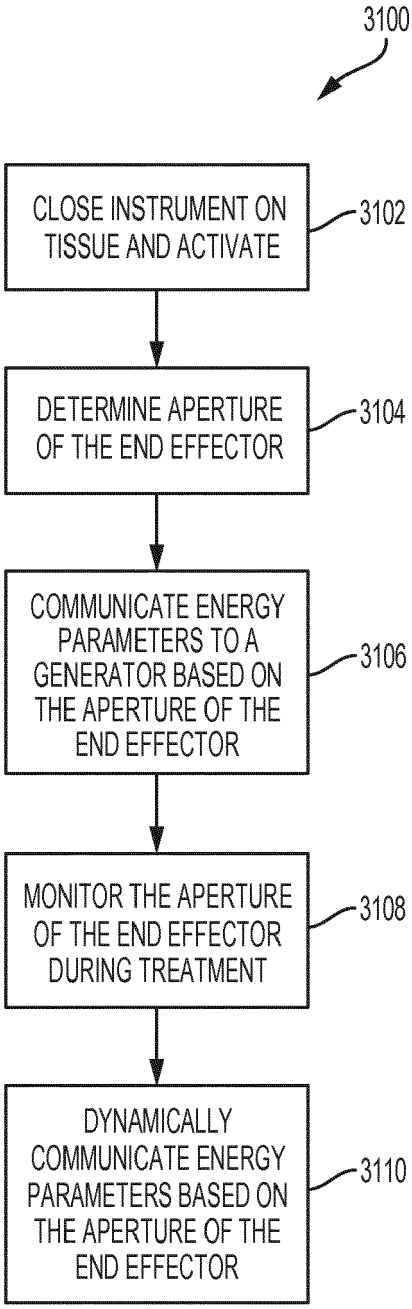
3100
CLOSE INSTRUMENT ON TISSUE AND ACTIVATE
3102
DETERMINE APERTURE OF THE END EFFECTOR
3104
COMMUNICATE ENERGY PARAMETERS TO A GENERATOR BASED ON THE APERTURE OF THE END EFFECTOR
3106
MONITOR THE APERTURE OF THE END EFFECTOR DURING TREATMENT
3108
DYNAMICALLY COMMUNICATE ENERGY PARAMETERS BASED ON THE APERTURE OF THE END EFFECTOR
3110

FIG. 52

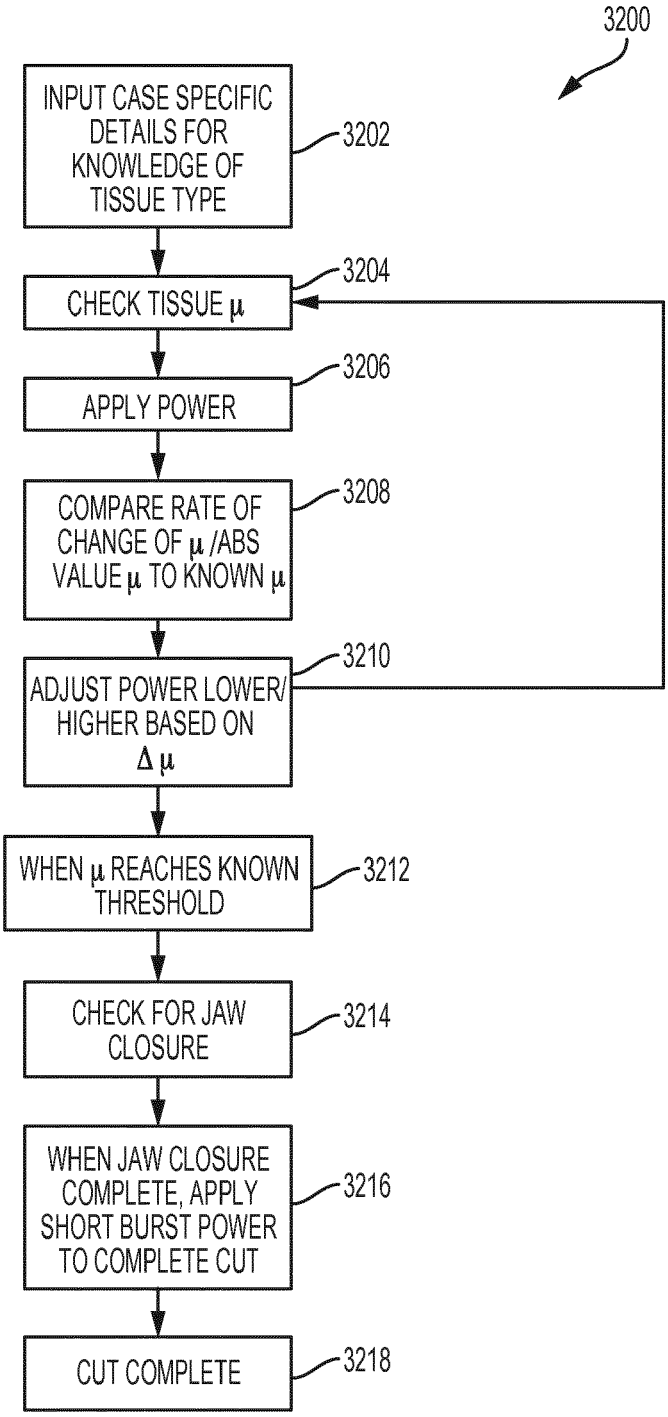
3200
INPUT CASE SPECIFIC DETAILS FOR KNOWLEDGE OF TISSUE TYPE
3202
CHECK TISSUE μ
3204
APPLY POWER
3206
COMPARE RATE OF CHANGE OF μ /ABS VALUE μ TO KNOWN μ
3208
ADJUST POWER LOWER/ HIGHER BASED ON Δ μ
3210
WHEN μ REACHES KNOWN THRESHOLD
3212
CHECK FOR JAW CLOSURE
3214
WHEN JAW CLOSURE COMPLETE, APPLY SHORT BURST POWER TO COMPLETE CUT
3216
CUT COMPLETE
3218

FIG. 53

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 19 18 9835

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y A	US 2009/254080 A1 (HONDA SATOSHI [JP]) 8 October 2009 (2009-10-08) * figure 5 * -----	9-14 15 1-8	INV. A61B17/32 A61B18/14 A61B17/00 A61B18/00
X A	US 2015/141981 A1 (PRICE DANIEL W [US] ET AL) 21 May 2015 (2015-05-21) * paragraph [0045] * -----	9-11,13 1-8	A61B90/00
A	WO 2012/135705 A1 (TYCO HEALTHCARE [US]; STODDARD ROBERT B [US] ET AL.) 4 October 2012 (2012-10-04) * paragraphs [0007], [0009], [0030], [0034] * -----	1-8	
A	US 2009/204114 A1 (ODOM DARREN [US]) 13 August 2009 (2009-08-13) * paragraph [0075]; figure 1c * -----	1-8	
A	EP 2 111 813 A1 (TYCO HEALTHCARE [US]) 28 October 2009 (2009-10-28) * paragraphs [0016], [0017], [0022] * -----	1-8	TECHNICAL FIELDS SEARCHED (IPC) A61B
Y	US 2013/066238 A1 (IRISAWA TAKASHI [JP] ET AL) 14 March 2013 (2013-03-14) * paragraph [0175] * -----	15	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	7 November 2019	Cornelissen, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

Europäisches Patentamt
European Patent Office
Office européen des brevets

Application Number
EP 19 18 9835

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☒ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

Europäisches Patentamt
European Patent Office
Office européen des brevets

LACK OF UNITY OF INVENTION
SHEET B

Application Number
EP 19 18 9835

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-15

A combined Rf and ultrasound forceps

1.1. claims: 1-8

A combined RF/ultrasound surgical forceps system measuring impedance and aperature and switching between RF and ultrasound based on the measured jaw aperture

1.2. claims: 9-15

A combined RF/ultrasound surgical forceps system measuring impedance switching between RF and ultrasound based on the measured tissue impedance

---

Please note that all inventions mentioned under item 1, although not necessarily linked by a common inventive concept, could be searched without effort justifying an additional fee.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 19 18 9835

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

07-11-2019

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009254080 A1	08-10-2009	JP 5178559 B2	10-04-2013
		JP 2009247887 A	29-10-2009
		US 2009254080 A1	08-10-2009
US 2015141981 A1	21-05-2015	CN 105764435 A	13-07-2016
		EP 3071129 A1	28-09-2016
		JP 6523281 B2	29-05-2019
		JP 2016537129 A	01-12-2016
		US 2015141981 A1	21-05-2015
		US 2018256245 A1	13-09-2018
		WO 2015077119 A1	28-05-2015
WO 2012135705 A1	04-10-2012	EP 2691037 A1	05-02-2014
		US 2014012299 A1	09-01-2014
		WO 2012135705 A1	04-10-2012
US 2009204114 A1	13-08-2009	NONE	
EP 2111813 A1	28-10-2009	AU 2009201567 A1	05-11-2009
		CA 2664199 A1	22-10-2009
		EP 2111813 A1	28-10-2009
		JP 2009261943 A	12-11-2009
		US 2009261804 A1	22-10-2009
		US 2013123780 A1	16-05-2013
		US 2014288549 A1	25-09-2014
		US 2017035494 A1	09-02-2017
		US 2019223942 A1	25-07-2019
US 2013066238 A1	14-03-2013	CN 103260539 A	21-08-2013
		EP 2662045 A1	13-11-2013
		JP 5259883 B2	07-08-2013
		JP WO2012108295 A1	03-07-2014
		US 2013066238 A1	14-03-2013
		US 2014336646 A1	13-11-2014
		WO 2012108295 A1	16-08-2012

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 62186984 B **[0001]**
- US 62235260 A **[0001]**
- US 62235368 A **[0001]**
- US 62235466 A **[0001]**
- US 62279635 A **[0001]**
- US 62330669 A **[0001]**
- US 5938633 A **[0019]**
- US 5935144 A **[0019]**
- US 5944737 A **[0019]**
- US 5322055 A **[0019]**
- US 5630420 A **[0019]**
- US 5449370 A **[0019]**
- US 896360 A **[0045]**

Non-patent literature cited in the description

- **YATES.** Surgical System With User Adaptable Techniques. *END7747USNP* **[0022]**
- **WIENER.** Surgical System With User Adaptable Techniques Employing Multiple Energy Modalities Based On Tissue Parameters. *END7747USNP2* **[0022]**
- **YATES.** Surgical System With User Adaptable Techniques Based On Tissue Impedance. *END7747USNP3* **[0022]**
- **YATES.** Surgical System With User Adaptable Techniques Employing Simultaneous Energy Modalities Based On Tissue Parameters. *END7747USNP4* **[0022]**

专利名称(译)	基于组织类型的可定制方法的外科手术系统		
公开(公告)号	EP3581125A1	公开(公告)日	2019-12-18
申请号	EP2019189835	申请日	2016-06-24
[标]申请(专利权)人(译)	ETHICON，LLC		
申请(专利权)人(译)	ETHICON LLC		
当前申请(专利权)人(译)	ETHICON LLC		
发明人	STULEN,, FOSTER B. MADAN,, ASHVANI K. HOUSER,, KEVIN L		
IPC分类号	A61B17/32 A61B18/14 A61B17/00 A61B18/00 A61B90/00		
CPC分类号	A61B17/320092 A61B18/1445 A61B2017/00017 A61B2017/00039 A61B2017/00075 A61B2017/00084 A61B2017/320094 A61B2017/320095 A61B2017/320097 A61B2018/00642 A61B2018/00648 A61B2018/00702 A61B2018/00791 A61B2018/00875 A61B2018/0088 A61B2018/00994 A61B2090/064 A61B2018/00589 A61B2018/00601 A61B2018/0063 A61B2560/0475 A61B2562/0261		
优先权	62/186984 2015-06-30 US 62/235368 2015-09-30 US 62/235466 2015-09-30 US 62/235260 2015-09-30 US 62/279635 2016-01-15 US 62/330669 2016-05-02 US 15/177439 2016-06-09 US PCT/US2016/039218 2016-06-24 WO		
外部链接	Espacenet		

摘要(译)

各种形式涉及用于组织的凝固和解剖的系统和方法。 外科器械包括配置成在其远端密封和解剖组织的端部执行器和配置成将能量传递到端部执行器的发生器电路。 力传感器与末端执行器连通并且被配置为测量由末端执行器施加到组织的力。 基于确定与末端执行器相互作用的组织的类型，传递到末端执行器的能量是动态的。 基于组织系数来确定组织类型，该组织系数是基于由末端执行器施加到组织上的测得力，末端执行器的超声运动以及末端执行器产生的热量计算得出的。

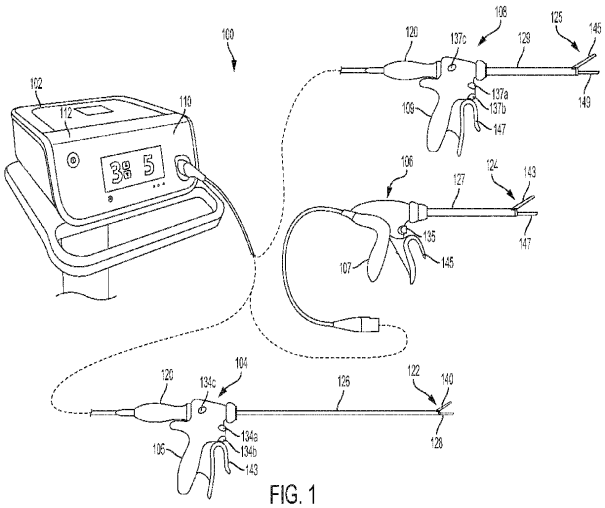

FIG. 1